

Understanding Satellite Broadband Quality of Experience – Final Report

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1 INTRODUCTION

The UK government recently published "Britain's Superfast Broadband Future" [Ref 1] that sets out its vision for the UK's future broadband infrastructure with virtually all homes having access to at least a 2Mbps broadband service by 2015. It envisions world class connectivity using various communications networks: fixed, fixed-wireless, mobile and satellite so that as many people as possible can be reached. The document recognises that satellite is a viable option for the most remote users and for those in some other 'not-spots'.

However, there is an inevitable delay when communicating over geostationary satellites which can have a detrimental impact on the user experience, especially for bidirectional real-time or quasi real-time applications such as voice and gaming. Therefore alongside the policy document, Ofcom have commissioned this study which investigates the Quality of Experience (QoE) and user satisfaction when using broadband satellite communication services for applications such as online gaming, VPN, video/audio streaming and VoIP [Ref 2].

This study investigates the Quality of Experience (which is a subjective measure) of satellite broadband by placing a number of volunteers in front of representative test systems to compare their performance. The subjective testing is carried out using industry-standard methodologies and analysis techniques involving a wide range of demographic profiles, including underlying statistical tests for bias, significance and secondary effects.

This study controls each of the experiments so that they are consistent and repeatable for each volunteer whilst still capturing the fundamental properties of a number of everyday online activities. These activities are performed over three different network access models so that the impact of the network (or satellite) on QoE can be understood. The three network access models are: terrestrial ADSL broadband; an emulated satellite link¹; and a real satellite link².

Finally the study report concludes by extracting the key messages of the QoE assessment along with the consequences and next steps for Ofcom.

The details of this study are divided into five main sections:

- **Section 2: Current and Future Broadband Satellite Systems:** This section details the technical aspects of satellite broadband delivery technologies and systems. It covers a historical perspective and the state-of-the-art of what is currently commercially available; operational issues of delivering broadband via satellite; major design considerations when developing satellite systems; issues to do with delivering TCP over satellite links; an estimation of realistic satellite networking performance parameters; and future developments and trends in satellite broadband over the next 10 years.
- **Section 3: Quality of Experience Experimental Framework:** This section details the practical aspects regarding formulating and setting up the user trial environment. It details the physical arrangements; an explanation of what the volunteers were

¹ In order to be able to precisely control its network characteristics

² To fairly capture the full range of end-to-end technologies and systems used on a current satellite broadband ISP.

asked to do; how the experimental framework was designed to be fair, consistent and realistic; and technical details of the systems that were being evaluated.

- **Section 4: Quality of Experience Assessment:** This section details the performance measures and metrics obtained from the volunteers during the trials. It outlines the methodology and objectives behind the questions and assessment; the procedures that were followed and demographics used; statistical processing and tests performed on the data; and the processed empirical results of the trials along with discussions and observations.
- **Section 5: Conclusions:** This section highlights the key findings and conclusions of the user trials including observations, lessons learnt and the consequences for Ofcom.

The main body of the report is supported by a number of appendices which provide more details of some of the more significant topics; reference material; a bibliography; and a glossary.

2 CURRENT AND FUTURE BROADBAND SATELLITE SYSTEMS

2.1 CURRENT SATELLITE BROADBAND SYSTEMS

2.1.1 INTRODUCTION

2.1.1.1 What is Broadband?

The term broadband is commonly used to describe recent Internet connections that are significantly faster than earlier dial-up technologies. For example, Recommendation I.113 of the ITU Standardisation Sector defines broadband as “a transmission capacity that is faster than primary rate Integrated Services Digital Network (ISDN) at 1.5 or 2.0 Mbit/s” [Ref 3]. However, not all bodies follow this definition. The Organisation for Economic Co-operation and Development (OECD) [Ref 4], for example, considers broadband to correspond to transmission speeds equal to or greater than 256 kbit/s.

Broadband technologies are changing and the definition of broadband also continues to evolve. For the purposes of this report, 256 kbit/s is taken as the lower limit of broadband, but it is clear that, as technology improves with, for example, fibre connections to the home, we will soon reach a day when even ITU’s recommended speeds are considered too slow. Broadband services may involve more than one information type. For example, videotelephony will include audio, video and possibly some form of data; other information types may be text and graphics. These services are termed multimedia services. ITU-T has defined these in Recommendation ITU-T I.374. ETSI have reviewed standardisation issues with respect to services and architectures for broadband satellite multimedia [Ref 5].

The ETSI model divides the global IP network into three parts: core network, distribution network, and access network. ETSI describe the distribution network as an intermediate IP sub-network that is used to connect an access network into the core network.

2.1.1.2 Background

The European Digital Agenda makes the case for universal broadband provision on the basis that it will engender growth and future sustainability and thus avoid financial difficulties such as bail-outs for countries as we have seen in the recent recession. The digital agenda and the provision of broadband is thus an enabler which has emerged as an essential part of the infrastructure of business, without which economies cannot be sustained or grow.

Studies conducted in Europe and the US have substantiated the link between broadband and growth as follows:

- Europe ⇒ 6.6-7.3% growth in GDP with BB and 0.9-3% increase in jobs.
- US ⇒ 3.5% growth in GDP with BB and 0.6 to 1.4% increase in jobs.

These are powerful indicators and have led to both European wide and individual country Digital Plans.

The European Digital Agenda plan [Ref 6] is for;

- 2013—100% coverage of broadband at a basic rate. Each country has their own digital plan but the basic rates are within the 2-4Mb/s range.
- 2020—100% coverage at 30Mb/s of households and with greater than 50% at 100Mb/s.

Current provision is variable across Europe but 41m households do not have ADSL connection and 50% of the population have less than 2Mb/s service. There is much work still to do in order to meet the 2013 targets. Line systems such as ADSL can provide basic services up to 2Mb/s for around 80% of the population but thereafter the bit rate depends on the customer distance from the exchange and could fall to 40% of the population for up to 10 Mb/s. Terrestrial connections for the higher rates rely on Fibre To The Home (FTTH) provision. Estimates are that €15bn is needed to achieve 80% coverage by (FTTH) and the time to roll out could be 20 years. Complete coverage would cost more than double this sum and thus is uneconomic. Studies have shown that beyond the 80% coverage, radio (WiMax or B3G) can extend the coverage to 90-95% depending on the availability and cost of spectrum, but beyond this satellite is the cheapest option for the last 5-10% of customers (Figure 1). Current satellite connection costs are circa €300 with less than €30/ month charges as compared to 5000€ connection for rural fibre with similar monthly charges.

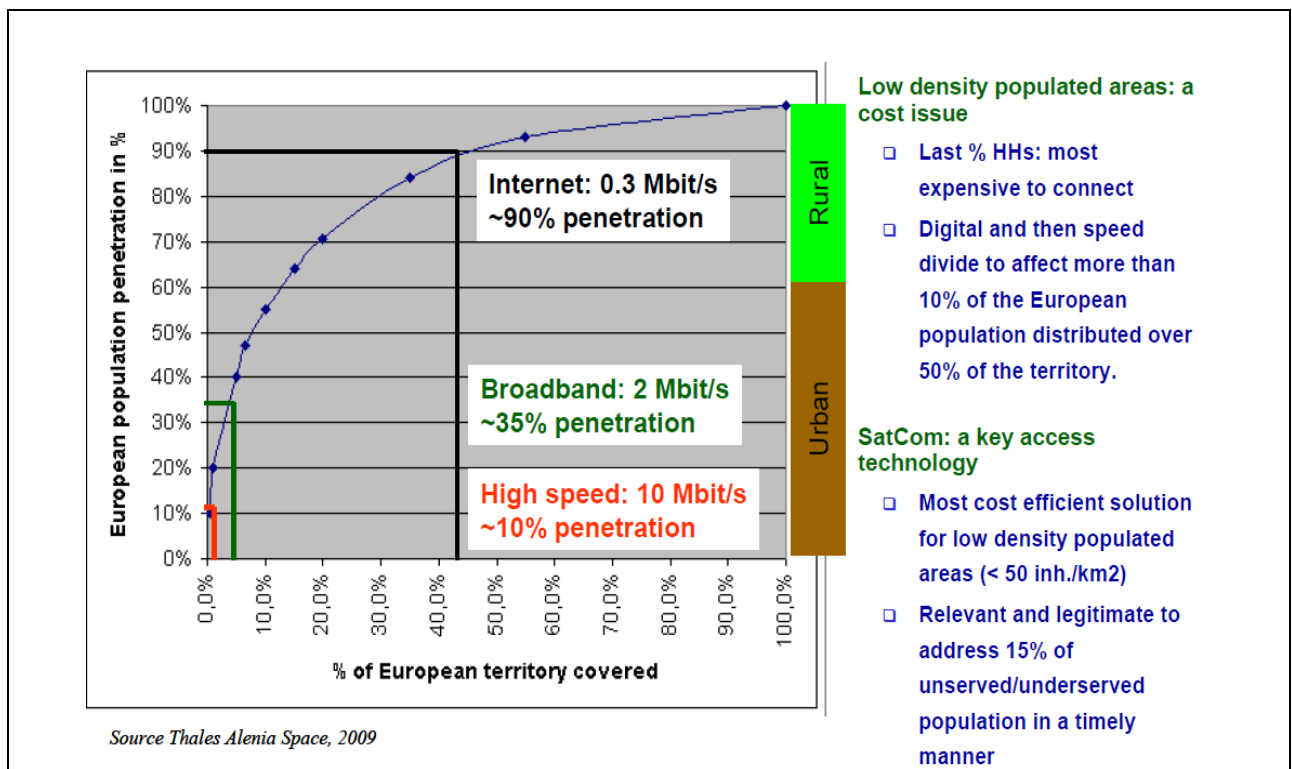


Figure 1 - BB Satellite; the missing link

Satellite is thus the delivery mechanism of choice for the last 10% to 5% of the population scattered around the rural areas for which terrestrial xDSL and FTTH cannot economically reach. The issues to be addressed are the cost of satellite services and the quality of experience (QoE) on this delivery mechanism. The cost is related to the satellite itself and to the ground infrastructure and user terminals (Figure 2). In this section we will not concentrate on the cost issue as a primary task except in stating that the satellite cost relates to its capacity, and as we move from Ku band to Ka bands the number of beams and the frequency reuse factor increases, and thus the cost per bit decreases. However the cost of the terminals will increase until the market generates sufficient numbers.

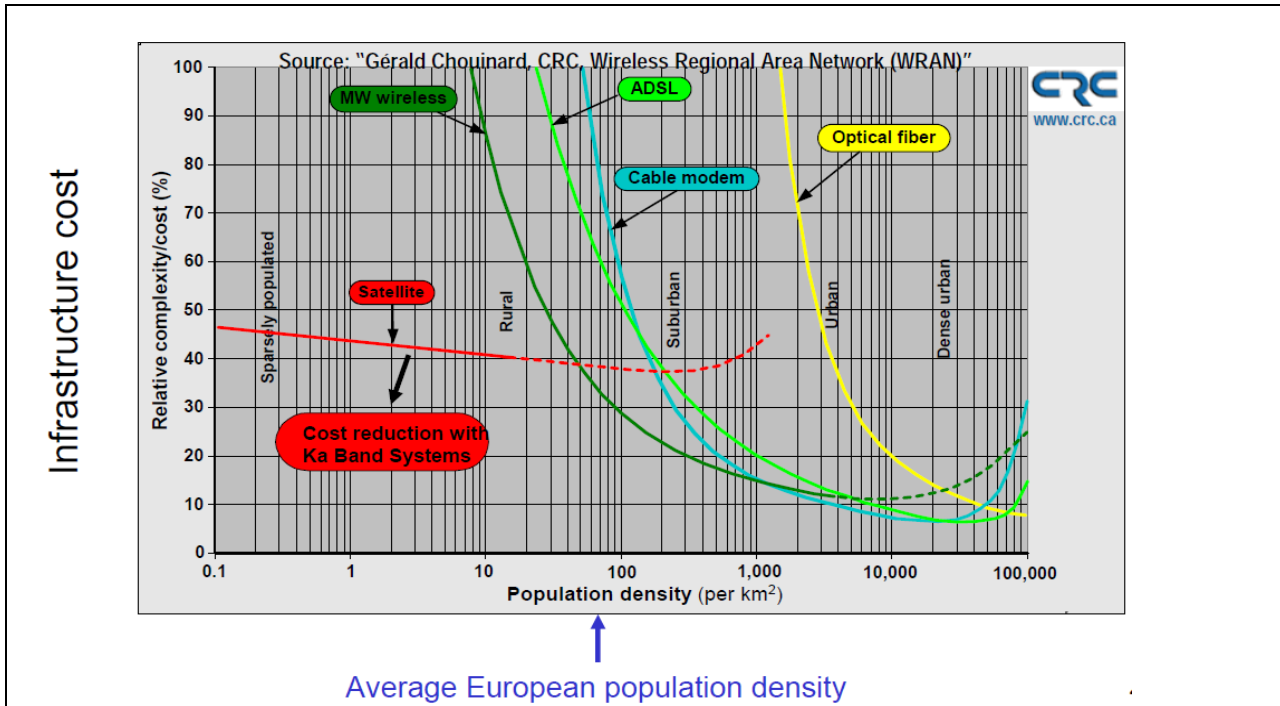


Figure 2 - Mix of Access Technologies to Achieve Broadband for All Users

The QoE of IP-delivered services may be different on satellite from that on terrestrial xDSL due to the latency of the links (for GEO especially) and the channel performance. These issues can be overcome for some services (see later sections) and it is expected that for most low rate services satellite delivery will be similar to terrestrial. However for other services such as video delivery, due to the bandwidth restrictions on the satellite they may be different. The issue is whether they are acceptable or not to the rural customer whose only alternative might only be a dial up service. In addition it must be recognised that delivery via satellite involves additional considerations over and above those for xDSL. For example there is the setting up of the satellite links themselves via a link budget which is properly dimensioned to account for the channel variations and the dynamics of the satellite. There is also the dimensioning and loading of the satellite transponders which brings into play, not only the user contention ratio but also the non-linear performance of the satellite amplifiers. These are issues that are dealt with by the satellite Internet provider (Virtual Network Operator (VNO)) of which there are large numbers operating in Europe (see for example: www.sat-sig.net for a listing). The eventual service quality will depend upon these providers and how they balance the various design issues of which there are many more than for xDSL provision (see section 2.2).

Satellites have provided 'network' extension data access since the 1980's. The technology has evolved through two generations of data network access capability since then and is currently evolving into a third generation in 2010/11. Each succeeding generation has improved the performance and reduced costs. The first generation (C band satellites) provided connectivity to the telephone network in remote, unwired areas and was based on analogue technology and pre Internet Protocol (IP) technology that was subject to bandwidth limitations and quality limitations due to such artefacts as echo and excessive delay (Latency). This started the unfair trend of condemning satellite for poorer performance, but with properly set up echo cancellation in the terrestrial networks this was quickly resolved. By combining the increased bandwidth available on second generation satellites (Ku) in the 2000's, with advanced processing surrounding the transmission of IP data (slow start and Performance Enhancing Protocols (PEPs) these artefacts have been

largely removed and throughput and quality have been increased, and costs reduced [Ref 7].

At the same time standards have been introduced for terminals- e.g. DVB-S-RCS (an ETSI standard that was produced by the Digital Video Broadcast group with a Return Channel by Satellite). Although the outbound DVB-S standard was designed for video broadcast it is packet based and thus IP packets can be incorporated into the delivery system. Today satellite TV providers additionally offer Internet and phone services ("Triple Play") where the return link is either over the fixed telephone system or uses the RCS part of the standard in Ka band (e.g. DStar) which constitutes the more expensive part of the technology. DVB-S-RCS terminals have been available for some time but were generally used by professional users (VSATs) due to the cost. However now, with the DVB-S standard being replaced by a new DVB-S2 standard to allow increased capacity via higher order modulation and coding schemes, their use has extended to domestic use with terminals costing around €3k. The DVB-S2 standard can also be operated in an Adaptive Coding and Modulation (ACME) mode to overcome the increased rain attenuation at Ku and higher frequency bands.

In the US, a cable modem standard, DOCSIS-S for satellite, which is similar in that it implements ACM and MAC layer schemes for MF-TDMA, has been adopted. There is a third standard IPoS which is based on a Hughes proprietary system and is similar on the forward link to both of the other standards but differs on the return link. As the RCS link uses a multi frequency TDMA resource allocation scheme this will also add delay to the satellite connection. VSAT terminals include PEPs, slow start up mechanisms and the RCS resource allocation.

The two most popular satellite broadband Internet offerings currently in use in Europe are Astra2Connect and Tooway. Astra2Connect employs a stripped down version of the DVB-RCS standard with DVB-S2 in the forward direction and in the return direction simplified modulation and coding, that was developed by ESA SATLABS group and is called SATMODE together with the MF-TDMA resource allocation scheme of RCS. The resulting equipment is cheaper than the full DVB-RCS standard as used in professional VSATs and is aimed at the domestic market.

2.1.2 FIRST GENERATION SATELLITES

Before going on to review the current second generation and future third generation satellite broadband VSAT systems we briefly review the first generation which started in the 1980's. These systems were primarily business networks for corporate users with dispersed operations, e.g. Point of sale transaction verification for retail companies or corporate LAN extensions to all locations. User throughput rates were in the 56-256 kbps range and the traffic was very bursty with limited need for continuous real time circuits. These systems were deployed before general availability of the Internet and designed with proprietary, non-IP based standards based upon Aloha, slotted Aloha or slotted Reject Aloha resource allocation schemes. Typically they used a portion of a satellite transponder which was shared among many users and different applications. The satellite terminal equipment including RF and modem's was developed by companies such as Hughes Network Systems, Viasat, iDirect, Gilat etc with Newtec and STM being the main European suppliers. Terminals originally cost around 10k€ but have now reduced to around 3k€.

2.1.3 CURRENT SECOND GENERATION KU/KA BAND SATELLITES FOR EUROPE AND THE US

Satellite systems launched in the 2000's use mainly Ku band, 11/12GHz in the down link and 14 GHz in the uplink. Some satellites have a mix of Ku and C band (4/6GHz) transponders on board and all satellites have global, regional and spot beams connected to

selected transponders. Thus some satellites may not have Ku band coverage over a specific region. Furthermore in some satellites it is possible to cross strap between C and Ku bands on the up and down links. This is useful for instance in allocating C band to high rainfall areas such as parts of Africa and Ku band for the downlink in Europe where rain attenuation is less severe.

Each satellite comprises a number of transponders which are usually around 36MHz in bandwidth but can also go up to 72 MHz. The power levels from the transponders are all around 50-54dBW with the higher powers on the more recent satellites. In general the satellites have a 10-15 year lifetime and so some operational satellites are quite old. The number of transponders varies, but is some 20 to 40 per satellite and with typically 50Mbps per transponder the satellite capacities are a few Gbps each. Each transponder can support around 10,000 users at 256kbps with a contention ratio of 50:1. Apart from the cross strapping and the ability to reconnect transponders to specific antennas on the satellite there is no processing in the satellites—they are so called 'bent pipe' satellites.

The major satellite operators covering Europe and the US are INTELSAT, and SES with EUTELSAT covering Europe and Africa. These operators have excellent websites which show all of their satellites positions, their coverage patterns and the details of the satellites e.g. power and numbers of transponders. They are as follows:

- <http://www.intelsat.com/network/satellite/>
- <http://www.eutelsat.com/satellites/satellite-fleet.html>
- <http://www.ses.com/ses/footerPages/Pop-ups/SatelliteFleet.php>

Figure 3, Figure 4 and Figure 5 show examples of the three major operators' interactive websites which allow any satellite to be selected and the coverage patterns and satellite details to be displayed. Intelsat currently has 9 Ku band satellites covering the US from 127 W to 74 W with 50-53dBW eirp. Covering Europe INTELSAT have 13 satellites from 302 E to 359 E. Eutelsat have 24 Ku band satellites from 12.5 W to 75 E covering Europe and SES ASTRA have 16 satellites covering Europe and via SES Americas 21 satellites covering the US. All of the major satellite operator fleets are of the same type differing only marginally in eirp, numbers of transponders and coverage patterns.

There are also a number of smaller satellite operators.

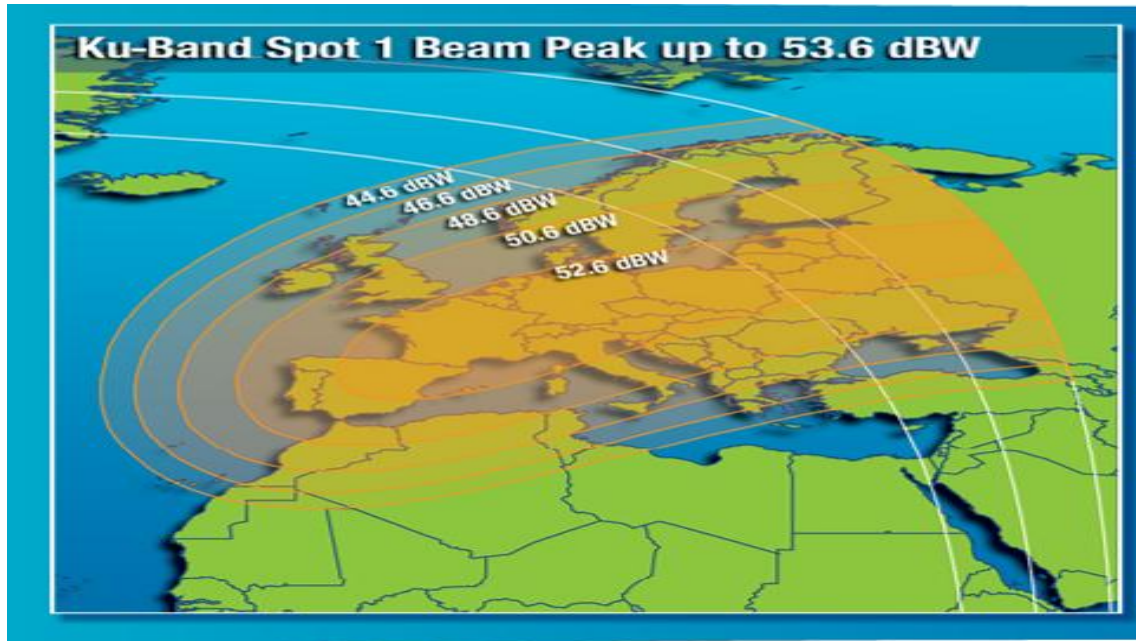
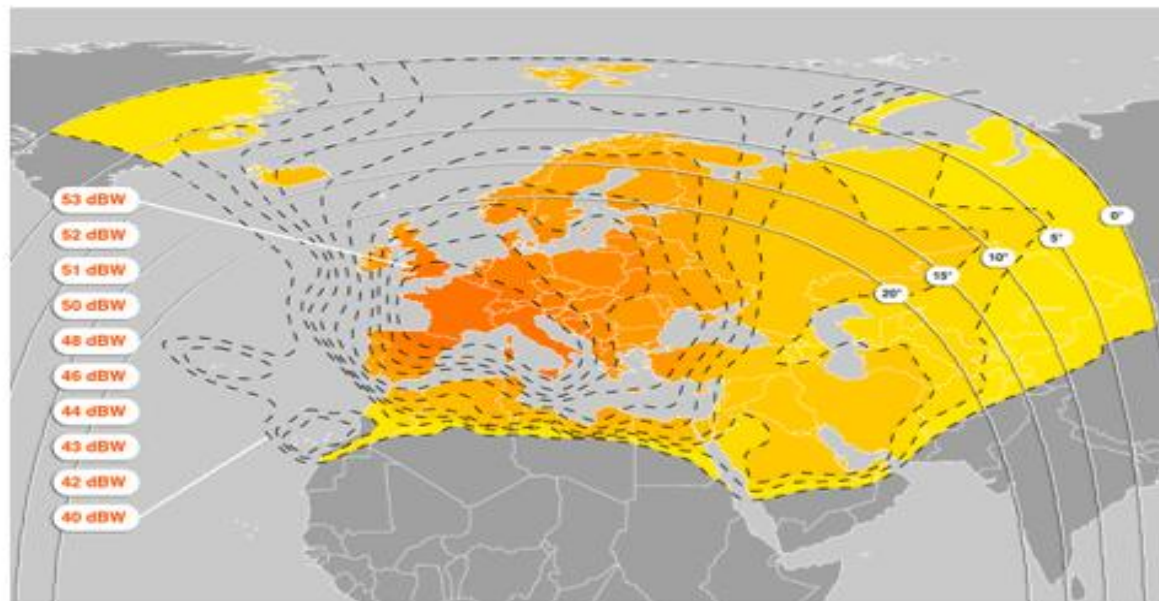


Figure 3 - Intelsat IS-903 at 325.5 E-Ku spot beams.

HOT BIRD™ 8 :: 13° EAST :: DOWNLINK COVERAGE



Launch date: 05/08/06
 Launch details: Proton M Breeze M
 Satellite construction: EADS Astrium

Figure 4 - Eutelsat Ku band spot beam example.

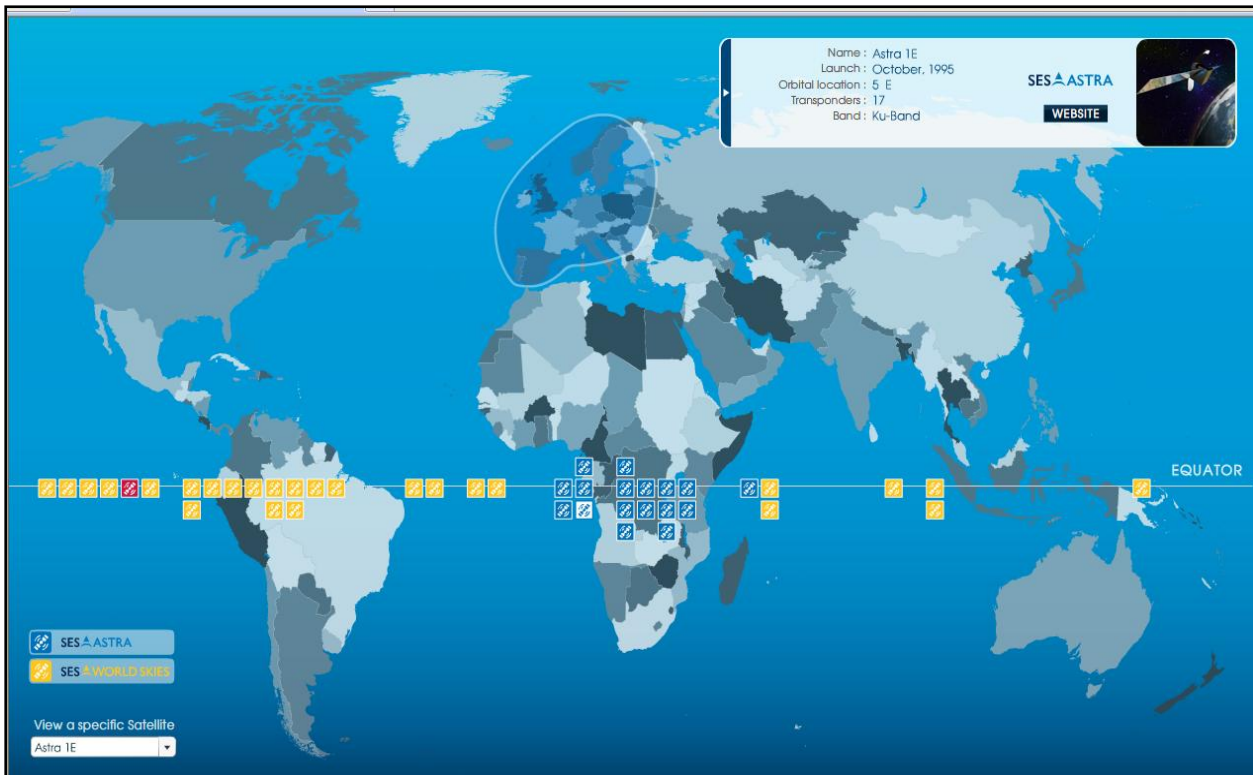


Figure 5 - SES Satellite Fleet and Astra 1E Ku band spot beam

The orbital position of the chosen satellite is important as it dictates the elevation angle of the user terminals which should be as high as possible to avoid additional clear air and rain propagation degradations.

The data base for each operator allows the service provider to select the exact satellite EIRP and on the receive side the G/T of the satellite for each earth terminal location. These can then be used in the link budget calculations which will also involve an assessment of the rain margin to be included at the particular site (this depends on the availability selected but for example can vary in Europe for an availability of 99.9% from 3 to 12dB depending on the location of the terminal) and the power level to be transmitted given a particular terminal antenna size and receiver noise performance (usually fixed by the terminal manufacturer). The latter will be performed for both forward and return directions to provide a desired QoS. However, this does not account for the loading on the transponder and the back off that has to be used due to the transponder amplifier's non linearity. This is a complex design issue and one that is open to misunderstandings between the players involved in the delivery chain. Further details of the design considerations are given in section 2.3.

The current generation of domestic broadband equipment in addition to those in professional VSATs are used to extend the Internet connectivity and feature rich applications to underserved users and thus customers are small businesses and domestic consumers in rural and suburban areas not well served by xDSL. Terminal equipment uses antennas of just below 1m in diameter with the RF equipment located along with it, outdoors, with connection at IF to the indoor modem/codecs. Systems are enabled with integration of IP routing technology and IP QoS management with software defined modems and use advanced modulation and coding as in DVB-S2. Together with the higher power satellites this all results in smaller, more capable 'consumer grade' VSAT terminals costing down to €500. The systems have latency management technology which:

- Compensate for latency-sensitive TCP/IP protocols via PEPs to allow TCP/IP transmission over the satellite at higher data rates.
- Accelerate latency-sensitive applications via pre-fetching of subsequently requested and commonly requested information to reduce response time.
- Prioritise traffic to meet timing and jitter requirements
- Compress IP headers and payloads to reduce transmission time.

A comparison of the service provided by three operators: one in Asia and two in Europe is given in Table 1 - note that the most popular offerings in Europe are ASTRA2Connect [Ref 8] and Tooway [Ref 9]. Astra2Connect is operated via SES and its operational subsidiary Astra Broadband Services and uses NETEC equipment. Tooway is operated by Eutelsat and its operational subsidiary Skylogic and uses Viasat terminals. Professional VSATs employ full DVB-S2-RCS and are available from most equipment suppliers. A range of VNOs offer customer service packages and interface with the operator organisations for provision of the space segment.

Characteristic	IPSTAR	SES ASTRA2Connect	Eutelsat TooWay
Service Area	Southeast Asia — 14 nations	Europe	Europe
Launch Date	August 2005	March 2007	August 2007
Satellite and Orbital Location	IPSTAR @ 120 EL	Astra 1E @ 23.5 EL	Hotbird 6 @ 13 EL for Ka service; Eurobird 3 @ 33 EL for Ku service
Band	Ku-band to users; Ka-band feeder links	Ku-band	Ku-band and Ka-band
Number Spot Beams	84 user beams; 14 feeder link beams	Europe regional beam	4 Ka-band transponders with Europe regional beam; Ku regional beam
Satellite Payload Type	Bent Pipe	Bent Pipe	Bent Pipe
User Terminal Antenna Size	120 cm – 180 cm	80 cm	96 cm Ku; 67 cm Ka
Maximum Throughput per User	256 kbps up (consumer); 256 kbps – 2 Mbps down (consumer)	128 kbps up; 1 Mbps down	156 kbps (Ku); 384 kbps (Ka) (up); 2 Mbps (Ku and Ka) (down)
System Capacity (throughput)	20 Gbps	~50 Mbps per transponder	~50 Mbps per transponder
Maximum Number of Users	5 million	~20,000 per transponder	~20,000 per transponder 2 million on Ka-Sat
Subscribers Realized	146,810 in 2Q 08	30,000 YE 2008	2,800 terminals with 11,000 equivalent customers

Table 1 - Comparison of Existing Generation 2 Satellite Systems

Broadband delivery has in the second generation used Fixed Satellite Service (FSS) satellites in Ku band. These standard satellites are general purpose and are designed to support a diversity of applications; TV direct broadcast and delivery to cable hubs has dominated the traffic, along with point to point backhaul for the core network. Such general purpose satellites are designed to interoperate with a variety of ground equipment serving different needs. Consequently these FSS satellites can be efficiently procured in isolation from the ground equipment but still achieve reasonable performance and cost across the breadth of ground equipment and applications employed. Broadband access is just one of these applications and thus the satellites are not specifically designed for this purpose and have limitations in their performance. Specifically these limitations are in the bit rate and QoS for the service and relate to the bandwidth/capacity and the power of the satellites which are

both low. This has limited the service rates to around 2Mbps maximum and often only to 256kbps. This is quite adequate for web browsing and lower rate video streaming, and even for VOIP and some gaming applications. However as we have seen the demands for Internet speeds are increasing rapidly driven by video applications. Take for example a capacity of 10Mbps to be delivered by satellite to say 250,000 rural users with a contention ratio of 50:1 (typical of that used today for domestic users). The total outbound traffic required would be 50Gbps. Current satellites with 40 x 36MHz transponders would have a capacity of 2Gbps and thus we would require 25 such Ku band FSS satellites to provide the service. This is clearly uneconomic and thus we have to look towards the next (third generation) of satellites to address this market—the Ka band satellites.

2.1.4 INTERMEDIATE GENERATION OF KA BAND SATELLITES

The US realised in 2005/7 the potential of moving to higher capacity satellites specifically designed and aimed at the broadband market, thus Space Systems Loral and Boeing Space Systems launched Wildblue 1, Spaceway 3 (Hughes) and for Canadian coverage Anik F2 (operated by Telesat). A review of these satellites is given in Table 2. They all use Ka band at 20GHz and 30GHz which provides more capacity, and more spot (65-110) beams. This allows the power to be concentrated into a smaller coverage, increasing the eirp and frequency reuse between beams (3 or 4 colours). It thus increases the effective spectrum available (by a further factor of 3 or 4) allowing 5-10Gbps capacity per satellite. Asia's iPSTAR (also shown in Table 1) uses the Ka band and has a capacity of 20Gbps.

These satellites were early entrants in a sort of 'generation 2.5' and there has been experience in both the US and Asia in broadband service delivery over the last five years. However Europe has lagged behind and didn't enter this field until 2011.

Characteristic	WildBlue	Telesat	Spaceway
Service Area	United States	Canada	United States
Launch Date	December 2006	July 2005	August 2007
Satellite and Orbital Location	WildBlue 1 @ 111.1 WL	Anik F2 @ 111.1 WL Anik F3 @ 118.7 WL	Spaceway 3 @ 95 WL
Band	Ka-band	Ka-band	Ka-band
Number Spot Beams	65 (30 on F2 + 35 on WB-1)	16 (15 on F2 + 1 on F3)	-110 hopping beams 68 transponders
Satellite Payload Type	Bent Pipe	Bent Pipe	Processing
User Terminal Antenna Size	66 cm	66 cm	75 cm
Maximum Throughput per User	256 kbps up; 1.5 Mbps down	500 kbps up; 2 Mbps down	128 kbps – 500 kbps up; 750 kbps – 3 Mbps down
System Capacity (throughput)		~1 Gbps	10 Gbps
Maximum Number of Users	750,000	150,000	600K to 1 million
Subscribers Realized	390,000 in March 2009	~50,000	455,000 on 3/31/09 with 148,000 on Spaceway;

Table 2 - Generation 2.5 transitional Ka band satellite systems

2.1.5 THIRD GENERATION OF KA BAND EUROPEAN AND US BROADBAND ACCESS SATELLITES

Satellite networks for broadband access need to have satellites that are designed in conjunction with the ground terminals, and achieve a high capacity to provide high data rates to users and hence a 'low cost per bit' so as to be competitive with terrestrial alternatives. The 3rd generation of satellite systems achieve an order of magnitude (x 10) improvement in all three of these metrics by optimising the satellite technology; the ground system and the spectrum. This is a radically different approach to that of the flexible FSS satellite of the 2nd and 2.5 generations. Such an integrated approach has been adopted by Viasat and Hughes in the US and Avanti and Eutelsat in Europe who have the offerings and future plans shown in Table 4

These satellites all use Ka band where increased spectrum is available and up to 100 spot beams achieving frequency reuse of the spectrum to achieve ten fold increases in capacity and thus reduce the 'cost per bit'. Also important to realise is that the capacity per orbit slot is increased and thus achieves a better orbit efficiency.

EUROPE			USA		
	Capacity	Year		Capacity	Year
Hylas 1 (Avanti)	5 Gbps	2010	Viasat 1	140 Gbps	2011
Kasat (Eutelsat)	70 Gbps	2010	JUPITER 1 (Hughes)	120 Gbps	2012
Hylas 2	15 Gbps	2012	CANUK (Telesat)	10 Gbps	2014
KASAT 2			Viasat 2	140 Gbps	2014
			JUPITER 2	120 Gbps	2015

Table 3 - 3RD Generation Satellite Systems

Broadband access leads to a star network configuration with Gateway Earth Stations (GES) interfacing into the ISP networks. Thus on one side of the satellite there are high capacity GES links, e.g. Hylas has one GES (with a diversity partner), whereas KaSAT [Ref 38] has eight which are interconnected by a high capacity fibre network. VIASAT 1 has 16 GES, JUPITER 1 has 9 GES and due to its different architecture SPACEWAY has 112 in the return direction. Apart from SPACEWAY all the other satellites are of the 'bent pipe' variety but HYLAS has an experimental flexible 'bent pipe' payload and SPACEWAY an advanced processing payload which facilitates more flexible routing but at the expense of considerable on board complexity.

Now returning to the traffic issues, we note that the first generation system terminals costing 10k€ were carrying 512kbps, the second generation terminals costing 3k€ carry around 1Mbps but the third generation terminal costs are aimed at 500€ and to carry up to 10Mbps comparable with ADSL2+. These are commensurate with the digital plans mentioned earlier and the series of satellites listed in Table 3 to around 2016. Characteristics of the satellites are presented in Table 4 and coverage in Figure 6 and Figure 7.

	HYLAS 1	KaSAT	VIASAT 1
Operator	Avanti Comms	Eutelsat	Viasat
Satellite	Astrium/ISRO	Astrium	
Launcher	Arianspace (2010)	Proton Breeze (2010)	
Mass (T)	2.3	5.8	
Lifetime (Y)	15	15	
Orbit	33.5 W	9 E	
Payload	200Kg/2KW	?/11KW	18KW
User beams	8	82	72
Eirp/beam	62dBW	?	
Bands	U19.7 – 20.2	19.7 – 20.	
Polarn	Dual Circ	Dual Circ	
Transponders	8 x 250 MHz	57 x 237MHz	56
GES	1 x 1	8	16
BW	2GHz (F) – 1GHz (R)		
Capacity	2.2/0.9 Gbps	70 Gbps	140 Gbps
Terminals	66 cm		

Table 4 - 3rd Generation Ka band Satellites

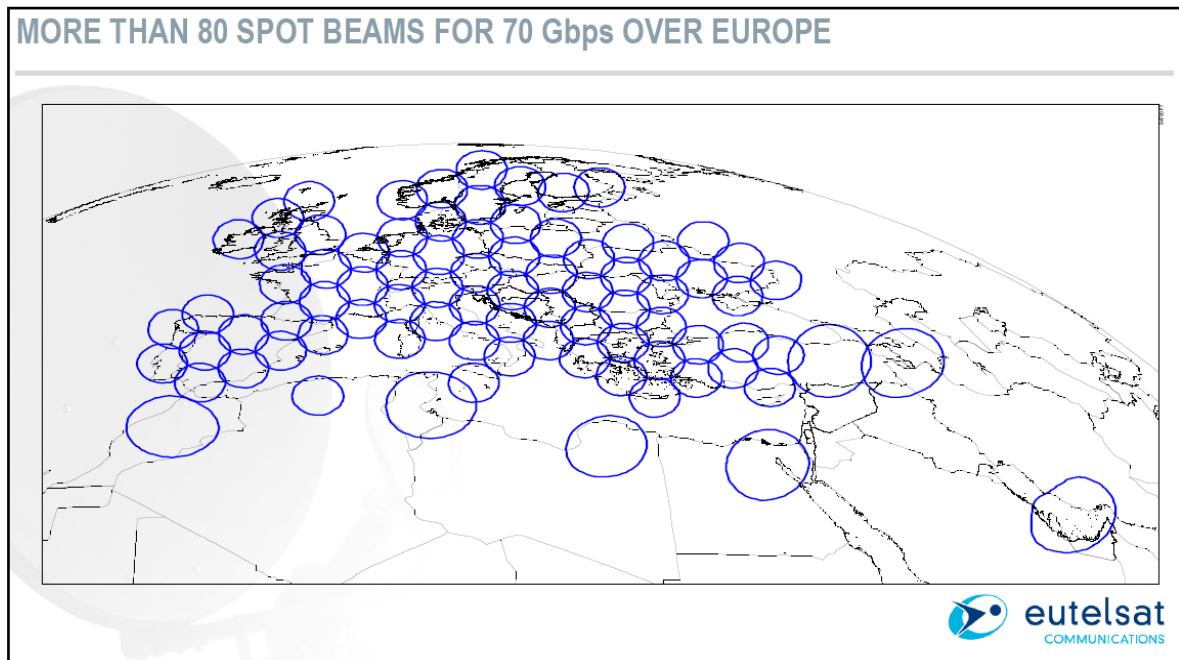


Figure 6 - KaSAT beams over Europe

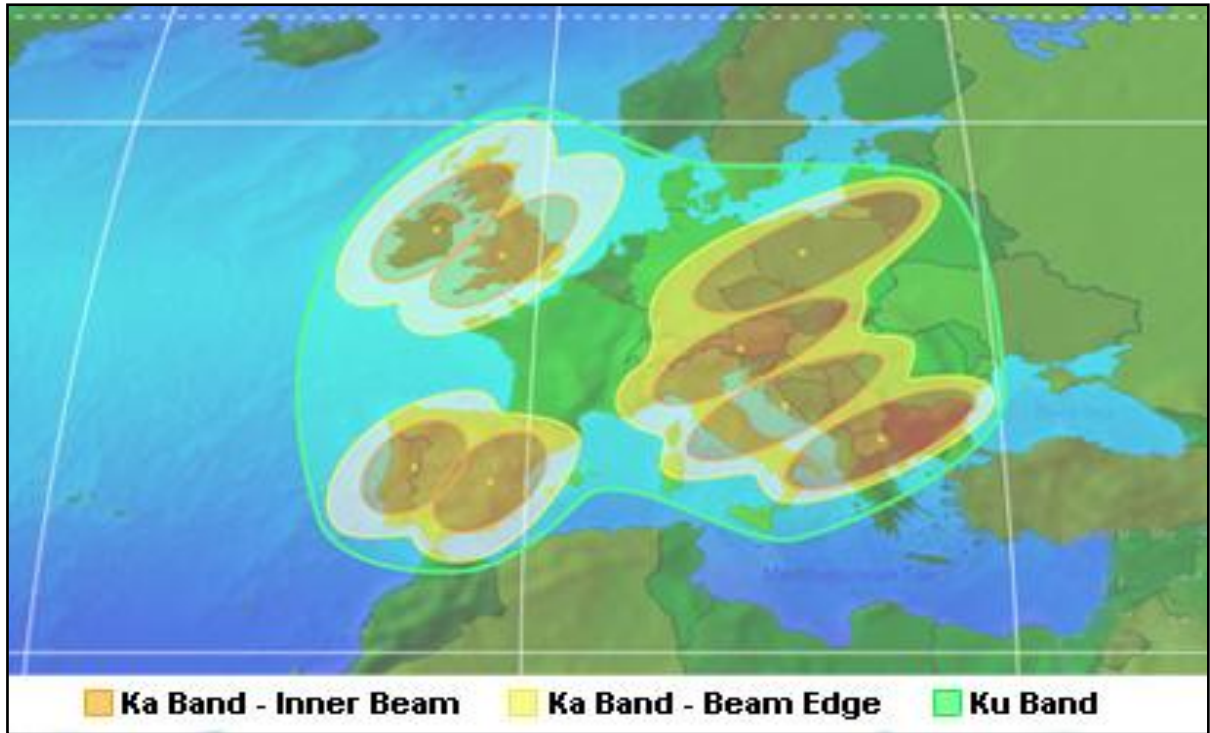


Figure 7 - HYLAS Coverage beams for Europe

These satellites with capacities of 10 -100Gbps can serve up to 2-3 million users each and allow instantaneous throughput per user as high as 100Mbps. The satellites have upwards of 100 spot beams allowing multiple frequency reuses and a bandwidth per spot increasing from 50MHz to 500MHz between the generations. Thus data capacity to the user also increases by a factor of 10 whilst the cost of the terminal reduces by a similar factor. The evolutions between the generations are summarised in Table 5.

Further details of the offerings are provided in Appendix B. At the time of writing the first Hylas 1 offering has just been released and details are included in Appendix E.

<u>Characteristic</u>	<u>First Generation</u>	<u>Second Generation</u>	<u>Third Generation</u>
Timeframe of Operation	1980s to present	mid 2005 to present	2010+
Satellite Capacity	1 Gbps	10 Gbps	100 Gbps
Typical Data Rate per Terminal	56 kbps - 256 kbps	256 kbps - 3 Mbps	2 Mbps - 30 Mbps
Maximum Number of Subscribers per Satellite	100,000 - 500,000	750,000 - 1,000,000	2 million - 3 million
Satellites	All FSS satellites; Example: Hughes leases 126 xpnדרs worldwide	IPStar; SES ASTRA2Connect; Eutelsat TooWay; Wildblue; Telesat; Spaceway	ViaSat-1; KA-SAT; KaComm; SpaceWay 4
Satellite Payload Characteristics	24 Ku-band transponders w/ regional coverage & 36 - 72 MHz bandwidth	Ku-band & Ka-band spot beams w/ 36 - 72 MHz bandwidth	Ka-band spot beams w/ ~500 MHz bandwidth
Major VSAT Terminal Suppliers	Hughes, Gilat, ViaSat, iDirect	Hughes, Gilat, ViaSat, iDirect	Hughes, Gilat, ViaSat, iDirect
Cost of VSAT Terminal	\$5,000 - \$10,000	\$500 - \$1,000	< \$500
Typical Applications	Point-of-sale transactions	Broadband access for enterprise & consumer	Broadband access for enterprise & consumer
Data Protocol	Proprietary and non-IP based	IP based	IP based
Connection Type	Bursty; Non-real-time data	Continuous; VoIP & video streaming capable	Continuous; VoIP & video streaming capable

Table 5 - Evolution of Three Generations of Satellite Broadband Systems

The satellite operator in this 3rd generation is concerned with the overall capacity offered by the satellite over its coverage region. As already mentioned ACM will be employed to mitigate rain fading at Ka band by changing modulation /coding combinations to retain a service. This means that in a rain fade the capacity in the beam will drop for the duration of the fade and this happens across the satellite coverage region. However due to the rain statistics, which across Europe are not generally well spatially correlated, the overall system capacity will vary but not degrade substantially. In the affected beams there could be some throttling back of the service for short periods of time. A new standard, DVB-RCS NG, has just been released in 2011 which makes modifications to the original standard to alleviate some of these issues and will be incorporated into terminals in the near future. These improvements will allow the availability and QoS to be maintained to the user. In order to achieve and maintain the availability on the GESs, diversity can be used as in the Hylas system where replicate GESs separated by greater than 20km are used in order to decorrelate the rain statistics and thus route the traffic via whichever GES is in clear weather. This can be extended to a network of GESs as in KASAT.

On the satellite side the issues are the size of the satellite and its compatibility with the current range of launchers and this dictates the payload power. The multi beam antennas have to be designed to minimise the interference between the beams reusing the same frequency and the complexity increases as the number of beams increases. The large number of beams means that the number of transponders on the satellite increases in order to retain routing. The latter has a limit in the payload power which in turn depends on the size of the satellite which is constrained by launcher space.

It will be noted in European only 2x 500MHz is available in Ka band that is dedicated for satellites. This is used by both current European systems which thus have to be coordinated. Use of other parts of Ka band which are shared with other systems (Terrestrial, Broadcast satellite and military) would need coordination. Thus the spectrum allocations provide a severe limitation to the growth of these systems within Ka band.

2.1.6 CURRENT EXPERIENCES OF SATELLITE BROADBAND

Current experiences of using satellite broadband are difficult to obtain and even typically achieved user rates are not available from the providers. There are numerous comments in blogs on the Internet but caution has to be attached to these as they mostly from dissatisfied users. A trawl of the operators indicates typical service offerings as shown in Table 6 and Table 7.

UP	DOWN	Monthly limit	Monthly price range
64k	256k	2-6GB	£ 30 - 50
128k	512k	2-6GB	£ 40 - 60
256k	1M	3-10GB	£ 70 - 150

Table 6 - Astra2Connect Parameters

UP	DOWN	Monthly limit	Monthly price range
384k	3.6M	2.4GB	£ 25
384k	3.6M	4GB	£ 40
384k	3.6M	6GB	£ 50
384k	3.6M	12GB	£ 100

Table 7 - Tooway Parameters

Similar services are offered by other providers at 384k/3.6M and thus there is a wide variation of services and prices with some special offers going down to £15/month. The cost of professional installation of the equipment is about £200 and the equipment rental is around £5/month. Some manufacturers are now launching equipment that is user installable.

The best single source on experience that we found was in (www.SatSiG.net) where a blog on Astra2Connect and Tooway experience features inputs from a large number of users. We consider that this is fairly representative of similar offerings. In general the experiences are that the equipment is fairly reliable and that the service is an improvement on dial-up. However there are many complaints that the information from providers is misleading and this causes dissatisfaction from users. In particular users confuse interface data rates of 10's Mbps with typical user rates which are 100's kbps. Some VNOs are bad at explaining the offerings and in particular how the complex traffic shaping is likely to affect users. There are a variety of service offerings with the rates and monthly quota increasing with the tariff as shown in the tables. The complaints are mainly from the basic domestic service users and surround congestion with other users on the system and the traffic shaping that is

applied by the satellite Internet providers. Congestion can occur due to under provisioning of the system. Contention ratios are quoted around 50:1 for domestic service and 20:1 for professional services but we believe that these are often exceeded up to 100:1.

On domestic service offerings the providers operate a 'Fair Access Policy' (FAP) (see Appendix C) which aims to give a fair distribution of the available resource of the broadband network to all users. When FAP is used the user can expect a minimum of 50% of peak speed for 90% of the time and 20% of peak speed 95% of the time. The providers adopt a standard traffic model and when a user generates unusually high volume the FAP operates. The user bandwidth is reduced and his rate is throttled back using a sliding window measurement of the traffic. The limits imposed are per hour, 4 hour, day, week and month and vary according to service package.

2.1.6.1 Comments on the experience Blogs

The following are some of the comments made by users about Astra2Connect and Tooway. These are just a sample of the user experience comments but pretty much reflect the overall messages.

It can be seen that the above issues result from a restricted bandwidth on the satellite and over provisioning causing congestion. As we move to Ka band these constraints will be alleviated -Hylas are already suggesting 10Mbps rates being available and Eutelsat are offering 10/4Mbps services. With proper provisioning many of the current artefacts should be removed if the access policies are improved. However this is an area where regulation may be required to ensure that there are proper service level agreements and the providers are adhering to them.

2.1.6.2 Astra2Connect:

- 'The 256/64k basic service is more like 3.8k/500b averaged over a 24hr period'
- 'for the basic service and a single user PC and without extreme usage patterns we get typically 3k/10k as a longer term average'
- 'It appears that the service reduces speed progressively until it resets to full speed at the end of the month—this makes it impossible to use at the end of a month'
- 'the basic service is Ok in the mornings up to early afternoon but is then very slow until around 10pm when it reverts to an acceptable service over night'
- 'We were assured 24Mbps down load but the best we have ever got is around 2Mbps'

2.1.6.3 Tooway:

- 'Speeds vary enormously but best I have got are 1951k degrading to 750k but average around 1.8M. Up link fluctuates much more rapidly 189-29K'
- E-mail and web browsing are fine but for video downloads the FAP kicks in. Average 1.6m and 180k up. Haven't noticed too many issues with rain on the Ka band but it does drop out sometimes.'
- 'There are latency issues and pinging websites is between 1200-2000mS'
- From an installer of Tooway—'notice download averages of 1M and uploads 30-150k, latency is around 1000mS'
- 'Transmitted a 30kB file on 1 min intervals got-1920/1714/2182/1714—Average 1864k on down load'

- 'Get close to 2m on down but the up is variable 65-6k and VoIP is poor'
- There are a number of speed tests summarised in Table 8.

Down (k)	Up (k)	Ping (mS)
1962	32	
1430	189	745
2886	19	1000
3434	224	743
1874	150	1100
1900	150	1200

Table 8 - Results of speed tests

2.2 OPERATIONAL ISSUES OF BROADBAND VIA SATELLITE Cf DSL

2.2.1 DIFFERENCES FROM TERRESTRIAL

First it is worth re-examining the role of broadband access today in order to understand operational issues.

2.2.1.1 Consumer Access to the Internet

Access to the Internet at broadband speeds is a key application for consumers. There is a growing market for asymmetric Internet activities such as Internet surfing and file downloads, but also for symmetric peer to peer usage such as the exchange of music, photographs or video files. Many of these applications and services can be accessed with narrowband (although not streaming), but the user experienced is enhanced by broadband, especially in terms of access time.

Internet applications for consumers are numerous and growing, for example:

- Email
- VoIP
- Web page information gathering / information retrieval
 - Wholesale, retail goods and services information
 - Encyclopaedia
 - News, weather forecast
 - Hobbies
- Interactive applications, including:
 - Home banking
 - Home shopping
 - Booking services, e.g. travel/hotel/theatre
- Streaming services, including :
 - Entertainment, including film and music clips

- Gaming
- Security packages
- Web page hosting

The experience of many of these applications can be enhanced by broadband access, especially those with a video content.

2.2.1.2 SME and SOHO Access to the Internet

Business users (SME / SOHO and Teleworkers) account for a significant proportion of DSL users in the UK today. Comments on file up-load and download speeds for consumers apply equally to business users. Applications include:

- Email
- Information access
- Web page hosting, marketing
- File transfer (FTP)
- Business Television

2.2.1.3 Teleworker Access to the Internet and Intranets

Teleworkers are an important and growing broadband market sector. Teleworkers require always-on availability, fast access to company intranets for applications such as file up-loads, downloads and file sharing. An important issue for Teleworkers is security. Traffic must be able to pass through Firewalls. Applications include:

- Email
- Document access
- File transfer (FTP)
- Application sharing
- Business Television

2.2.1.4 Consumer user application Mix

A typical application mix for a home user both now and in the futures is exemplified in Table 9. We need to bear these applications in mind as we examine the role of terrestrial delivery versus satellite delivery.

Application	Browsing	Audio/Video	Gaming	Messaging	FTP	Mail	Chat
Current Mix	44%	18%	17%	10%	6%	3%	2%
Future Mix	30%	28%	18%	18%	2%	2%	2%

Table 9 - Typical Consumer Application Mix

2.2.1.5 DSL versus Satellite Delivery

In considering the differences between terrestrial (ADSL) delivered broadband and satellite delivered broadband it is useful to divide the comparison into several categories, namely:

-
- Infrastructure aspects;
 - Service aspects;
 - Financial aspects.

In most cases we witness a changing scene as the market evolves and consequently the differences vary with time.

2.2.1.1.1 Infrastructure

The terrestrial infrastructure historically has exploited local loop cables (telephone and TV cables) that have been deployed for alternative services and thus broadband can be considered as a marginal add-on service. This is not the case for satellite delivery where the service requires significant investment in user terminals and hubs.

When considering services in areas that are not currently served by adequate quality cables the cost of provision of these is most likely to exceed the cost of provision by satellite, which can be incremental on an existing satellite platform.

In any wireless-based delivery of services the cost of provision is strongly linked to the radio resources employed to deliver the service (bandwidth and power) and hence there is a strong 'bit rate' dependency in the pricing.

For cable and fibre delivered services the capacity is provided in pre-defined quantum chunks and the resulting 'bit rate' dependency is lower than the wireless case.

2.2.1.1.2 Services

With respect to service aspects wireless delivery mechanisms have defined upper bound to transmission rates that are usually considerably lower than achievable via cable and fibre. Nonetheless, acceptable levels of service can be provided by satellite but the higher the performance required the higher the utilisation of the radio resources which has a commensurate higher price factor. Again this aspect is less dramatic in terrestrial provision.

For satellite services QoS and volume of data transmitted are critical cost determining factors along with activity profiles and contention ratios.

There has been over the last two decades a trend towards delivery of satellite services to the consumer. In the late 1990s and early 2000s satellite access using small antennas (VSATs) was a costly proposition even for remote areas where no alternative existed. The Internet consumer market was not that buoyant in this time frame as the cost of provisioning and installing the user terminals was quite high and the service offerings did not fully match expectations.

As an example of the UK situation, in 2005 offerings from satellite service providers resulted in an average price for downlink rates up to 800 kbps of £198 per month, derived from a database of 73 current service offerings. The average price for CPE and installation for rates up to 800 kbps was £2478. These figures were derived from a database of 46 current service offerings (that match the 73 cases used above).

Such service offerings were taken up by SMEs and similar larger scale organisations but were not very marketable to the home consumer. As a consequence many of the 50 or more satellite ISPs decided not to pursue the consumer market and the industry as a whole decided to look again at the offerings. The resulting evolution of systems suitable for the

home market affects the service offerings, technology and financial aspects of the market place.

2.2.1.1.3 Financial

It is worthwhile at this point examining the constituent breakdown of the cost of provision of a typical VSAT service, as shown in Figure 8.

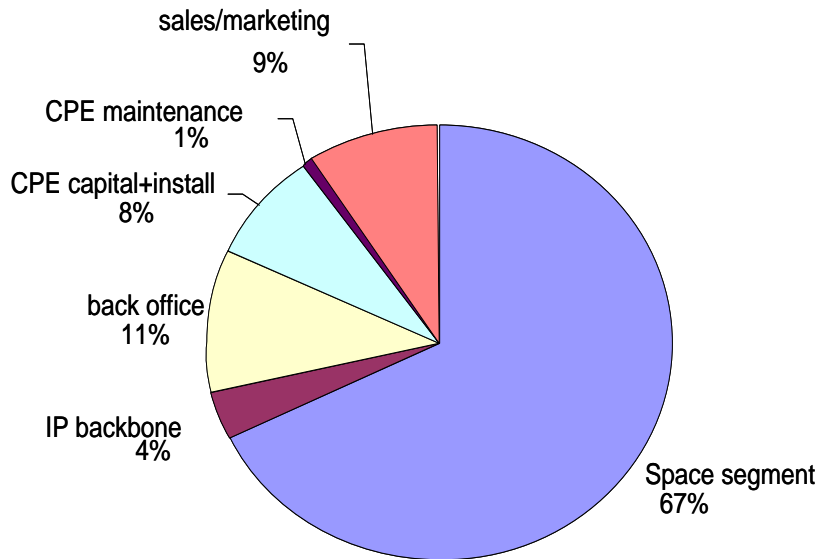


Figure 8 - Breakdown of typical VSAT cost elements

It is evident that some elements of the costs are volume independent. The industry sought to reduce key costs of the overall package with a focus on CPE capital & installation along with the space segment costs.

The CPE costs were reduced by designing terminals that are quick to build, simple to install (using PC Ethernet interfaces with IP transmission protocols) and most importantly by ensuring high volume sales that offset development costs and non-recurring engineering costs. A factor of 10 reduction has been achieved by this means.

Reduction of the space segment costs was also targeted. Clearly cheaper satellites and launches could be of great help here but, this is not achieved quickly or easily. Instead a review of the consumer user requirements led to alternative service offerings that permitted much higher numbers of users per transponder so that the cost per user is greatly reduced. Here a factor of 3 to 5 reduction has been achieved, as indicated in Table 10. The key to this reduction is traffic grooming and high contention ratios by means of Fair Access Policies.

Similar features exist in terrestrial service provision with the segregation of services for residential and business markets where the limiting of throughput and contention ratio of the service is different for the different classes of users. However, in satellite provision such features are quite key to the success of the business.

Thus we see the emergence of three classes of VSAT user, the consumer (home users), The Enterprise & SME users and the specialised high end user who normally has dedicated carrier provision, see Table 10 for further details.

Figure 9 indicates the worldwide annual sale of terminals where it can be seen that the consumer market is relatively recent and growing.

ROLE	UTILISATION
CONSUMER (£ 30-40 PER MONTH) [Astra2Connect, Tooway]	<ul style="list-style-type: none"> - TWO WAY INTERNET ACCESS - LOW COST TERMINALS - USERS NOT SERVED BY TERRESTRIAL BROADBAND - ACCESS MAY BE BUNDLED WITH SATELLITE TV - BROADBAND OPERATED UNDER FAIR ACCESS POLICIES TO REDUCE COSTS
ENTERPRISE & SME (£ 100 – 150 PER MONTH) [Hughes Hx , DVB-RCS]	<ul style="list-style-type: none"> - INTRANET LAN/WAN CONNECTIVITY - INTERNET ACCESS FOR REMOTE LOCATIONS - CORPORATE OR GOVERNMENT - VPN, VoIP, DIGITAL MEDIA DISTRIBUTION
HIGH END SCPC [Dedicated modems e.g. IDR] (£ 1K OR MORE PER MONTH)	<ul style="list-style-type: none"> - IP TRUNKING, ISP BACKBONE, VoIP TERMINATION - CELLULAR BACKHAUL - CORPORATE NETWORKS

Table 10 - Different VSAT Market roles

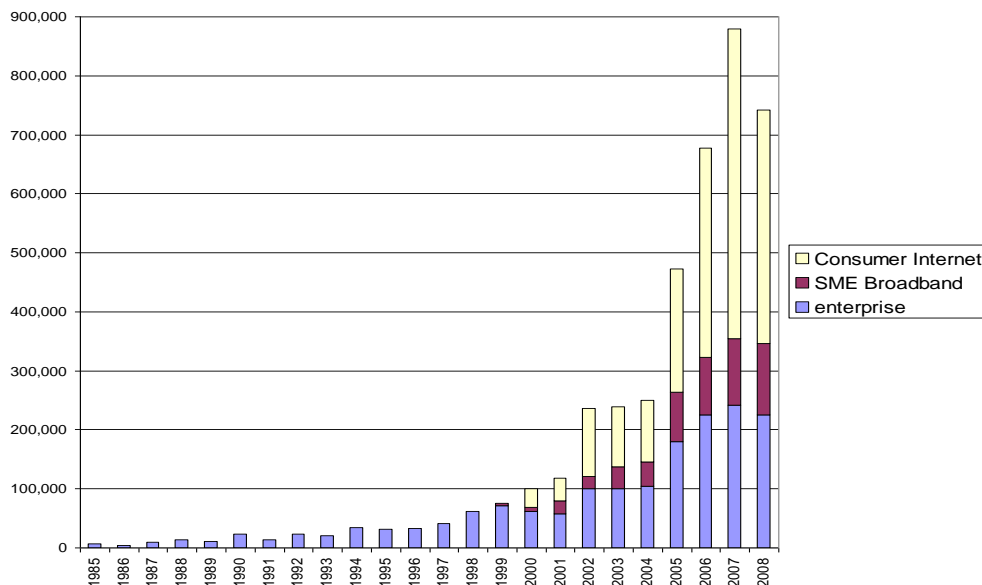


Figure 9 - Growth in Worldwide VSAT services (Courtesy of Comsys)

Another aspect that is different between the ADSL delivery and the satellite delivery is the interoperability of the customer premise equipment. ADSL modems are designed to interface with equipment in the telephone exchange and are usually built to operate to a set standard such that modems built by different suppliers interoperate satisfactorily. This is not the case for satellite customer equipment or the hub earth station. The various standards in use today means that are units not interoperable between networks and the customer will be locked into a given service provider due to the hardware employed.

The second generation DVB-RCS2 was aimed at ensuring interoperability between suppliers who state that they meet this standard. However, the standard has only recently been approved and there are many optional features that may limit interoperability.

2.2.2 THE SATELLITE OPERATOR MODEL

A generic model is considered here that could be simplified for example with the consolidation of the Satellite Capacity Provider, Satellite Service Wholesaler and Hub into one entity (Capacity Wholesaler) and the exclusion of the Channel as an individual entity. The latter may be optionally employed by the Service Provider to retail terminal equipment and elements of the service but is then a sub-set of the Service Providers role and value chain. Nonetheless, the full generic model gives an insight as to how current arrangements work.

An example for satellite broadband delivery is shown in Figure 10 below.

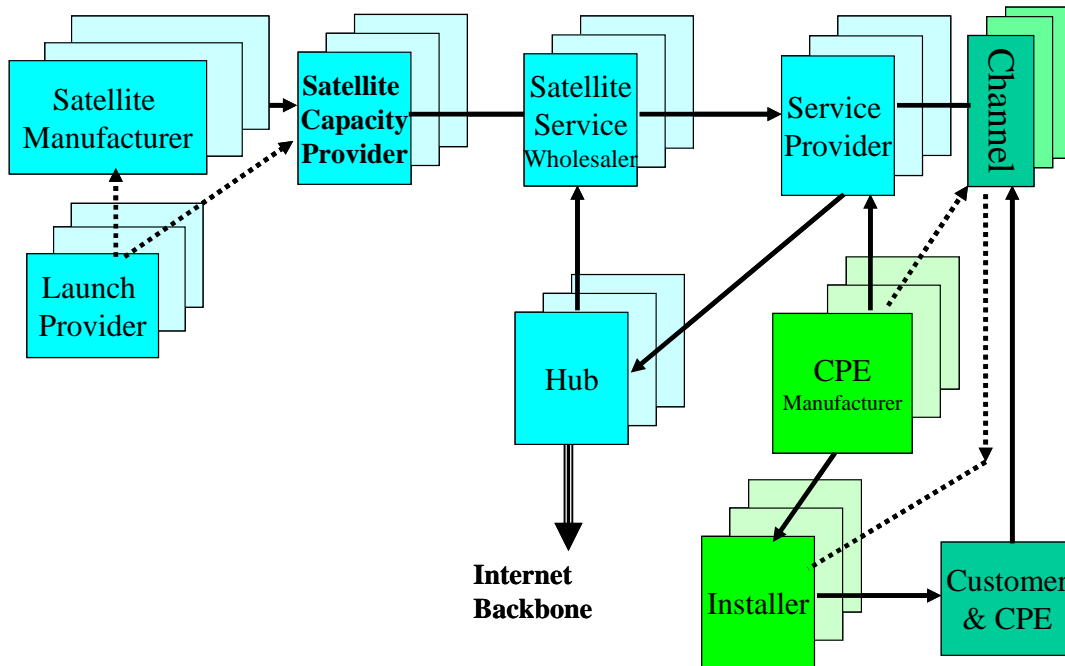


Figure 10 - Satellite Commercial Model

The commercial models within the satellite industry have evolved over the last four decades, with the pace of change increasing in the last twenty years. In this Section we consider the relationship between the various entities required for the provision of satellite services to an end user (customer).

The commercial model for the satellite industry and the value chain associated with broadband service delivery is quite complex and involves a number of inter-twinning relationships between a large number of entities. These entities are illustrated below.

The key entities within the delivery chain considered are:

- Satellite Manufacturer
- Launch provider
- Satellite Capacity Provider
- Satellite Service Wholesaler
- Hub Operator

-
- Service provider
 - CPE manufacturer
 - CPE Installer
 - Channels

In service delivery chains these entities may be mixed and matched in various combinations. Such combinations have often been dictated due to political and financial drivers. The role of the Government Treaty based organisations such as INTELSAT, EUTELSAT and INMARSAT dictated, in the past, certain combinations. In the 1990s the privatisation and de-regulation in the telecommunications arena led to different combinations which were more driven by the financial and competition oriented elements of the organisations involved.

In the period prior to the de-regulation of telecommunications services the operation of telecommunications systems in most countries was strictly regulated by the government of that country. Indeed one of the basic rules of the ITU stipulates that although Administrations should adhere to the ITU regulations it is the sovereign right of each country to determine its own telecommunications policy and its implementation. The main drivers for such sovereignty are, of course, of a political and national security nature. However, with politics in many developed countries turning towards market-led approaches and free market trading, any barriers imposed by national telecommunications regulation became an anathema to the government policy. Consequently, in the 1980s we see these barriers being slowly removed in a carefully planned and controlled manner. This situation is reflected into the satellite communications arm of telecommunications.

The US, followed closely by the UK, were prime movers in deregulation.³ In addition the European Commission (EC) also initiated efforts to ensure proper market operation whilst trying to harmonise European activity⁴. Other countries have followed in the efforts to deregulate. In the UK, access to the space segment operated by the satellite consortia had proved to be difficult for potential non-Signatory users, as highlighted in the evidence given to the House of Lords Select Committee in its Report on Science & Technology, covering the United Kingdom Space Policy 1987⁵. In February 1988 the UK government announced that it intended to issue licences for Specialised Satellite Services which were for operating one-way point-to-multipoint systems within the UK. The UK government announced at the same time its intention to issue 'class licences' for receive-only terminals, not just for Television Receive Only (TVRO) as was previously the case. Work progressed on reviewing access to the satellite consortia space segment⁶.

Thus it can be seen that the commercial model changes structure due to this evolution to a privatised initiative.

³ Jill Hills, Deregulating Telecoms (London 1986, Frances Pinter (Publishers)) pp. 157.

⁴ Paul Lippens de Cerf, "International Satellite Telecommunications and EEC Law", AIAA Paper IISL-87-83, AIAA Space Conference 1987.

⁵ House of Lords Select Committee Report on Science & Technology, covering the United Kingdom Space Policy, 17 December 1987, (HMSO, London), HL Paper 41-I.

⁶ Consultative Document, Office of Telecommunications (London July 1993) paragraph 1.2.

The privatised era also heralded the rise of the 'Channel' as a distribution and sales mechanism.

Turn-key provision of the satellite(s) and associated launch(s) became more prominent with the Satellite manufacturer taking care of all of the interfaces, tests, insurance etc. and delivering to the customer (Satellite Capacity Provider) in orbit. This appears to have been one way of removing some burdens from fledgling Satellite Capacity Providers.

The Satellite Service provider can alternatively be described as a Virtual Network Operator where a Virtual Network Operator (VNO) is defined as a provider of management services and a reseller of network services from other telecommunications suppliers that does not own the telecommunication infrastructure. These network providers are categorised as virtual because they provide network services to customers without owning the underlying network. A VNO typically leases bandwidth at the wholesale rates from various telecom providers in order to provide solutions to their customers. Recently pressure on margins has forced many operators to consider going with the VNO model and cut capital expenditures as well as staffing requirements to maintain and upgrade the infrastructure.

2.3 SATELLITE SYSTEM DESIGN CONSIDERATION

2.3.1 UPLINKING AND DISTRIBUTION

As indicated in the models above the hub earth station and associated equipment, including backbone Internet connectivity may be an independent entity or be integrated with other entities. Considerable cost savings can be achieved by focussing hub operations to specific teleports where service provisions and staff costs can be consolidated. The political requirement for hubs to be located in specific countries now appears to be less of an imperative and more economies are being achieved because of this factor.

In consideration of the user's QoE a key factor with regard to the hub and uplinking is the Internet backbone access. The QoE will depend upon this as well as the satellite link performance and if the backbone is not dimensioned adequately or it has poor access into the Internet core then the QoE will deteriorate.

2.3.2 LINK BUDGETING

In this section a number of issues relating to QoE are addressed that are specifically related to the satellite link and satellite resource utilisation.

2.3.2.1 Transponder Utilisation Model

The following presents a typical methodology used to determine transponder utilisation.

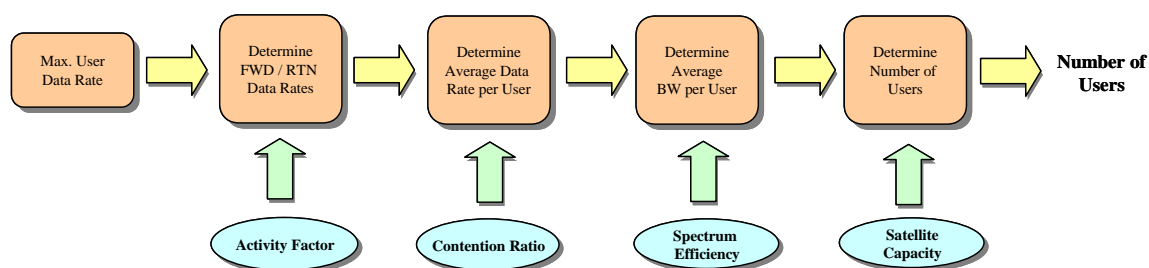


Figure 11 - Transponder Utilisation Methodology

In this process the maximum data rate of the user is estimated and would normally be based on typical data rates used for terrestrial ADSL connections. Next the user data rate is split between forward (FWD) and return (RTN) links based on an activity factor (e.g. 80% FWD / 20% RTN for users). Although this is synonymous with the principle of asymmetry, used in this manner the activity factor is better associated with terrestrial connections where the FWD and RTN links share the same bandwidth; this is not the case in a satellite based solution where FWD and RTN links would have their own dedicated transmission paths and their own access schemes.

Once the FWD and RTN data rates have been established they are then divided by a contention ratio to determine an average data rate requirement, where the contention ratio indicates how many other users share the same connection. Typical values are 50:1 for home users and 20:1 for small businesses. The average data rate is then converted into an average bandwidth by taking into account the spectral efficiency of the modulation process; the spectral efficiency would be dependent on framing, code rate and modulation.

Finally, the number of users is determined by dividing the available FWD link capacity by the average FWD link bandwidth. The number of users is determined by the FWD link parameters, as these would normally be the limiting factor (i.e. the FWD link will have a higher bandwidth requirement). The required RTN link capacity can then be determined by multiplying the number of users by the average RTN link bandwidth.

The next step is to create usage profiles for each user type. The usage profile is directly related to the user's application mix and also contains supplementary information such as contention ratio, level of symmetry, time dependencies (e.g. core usage hours, quiet hours) and composite data rate. Once the user templates and user mix have been defined the total number of users can be calculated; the available FWD link capacity divided by the average FWD link user bandwidth. The required RTN link capacity can then be determined by multiplying the number of users by the average RTN link bandwidth.

By incorporating time dependencies into the user profiles the analysis can be taken a step further. Ignoring time dependencies allows a static transponder utilisation to be calculated. However, if time dependencies are included the transponder utilisation over time can be established by allowing the mix of users accessing transponders to be varied with time. For example, during working hours the percentage of small businesses accessing transponders could be increased and the percentage of home users could be appropriately decreased. Furthermore, the sensitivity to changes in usage profiles could be determined by allowing the application mix to be randomly or pseudo-randomly assigned.

User traffic patterns are used to determine the aggregate capacity required to provide adequate quality of service at peak hours. Figure 13 and Figure 13 indicate one set of measured traffic volumes over typical days for the business and residential users of a satellite broadband offering.

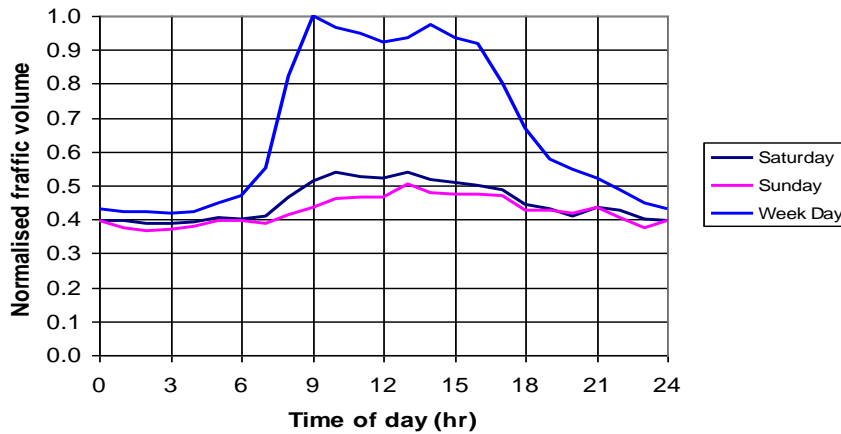


Figure 12 - Typical Diurnal Traffic Profile for Business Users

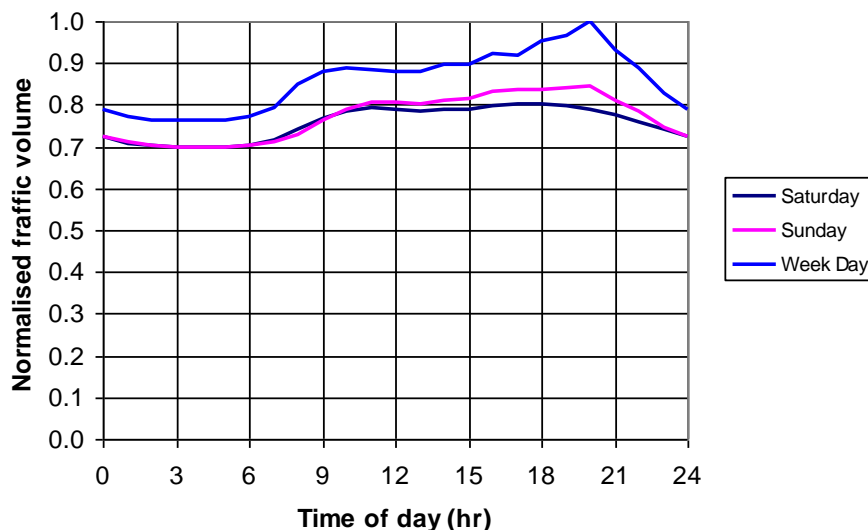


Figure 13 - Typical Diurnal Traffic Profile for Residential Users

Although contention is likely to reduce significantly in future terrestrial broadband services, given satellite bandwidth is comparatively restricted and expensive, it is envisaged contention is likely to remain a more significant satellite broadband planning issue for the foreseeable future. If any premium services (in terms of contention and QoS) are to be offered over a satellite platform, then clearly, they will have to be charged at an increased rate over a contended service, (hence the concept of QoS-based charging is under consideration as is evidence by the different tariffs set. Contention also becomes a more complex issue when broadband satellite “resellers” set up and operate their own hubs (e.g. Satlynx/Gilat, HNSE DIRECWAY) which are independent from the originating suppliers. Because these resellers control their own hubs, they are able to configure bandwidths, contention and pricing to provide differing levels of service to the end user. It should be noted that service levels may vary from the originating suppliers.

As indicated earlier one of the key drivers in reducing the cost of satellite delivered broadband is the ability to have a large volume of users per satellite transponder. Consequently the tariff per user can be reduced as the total income with flat rate tariffs is

adequate to make the business case work. This can be achieved by employing a large contention ratio (such as 100:1) and by limiting the volume of traffic to manageable levels by means of Fair Access Policies. This is a valuable management approach but the throttling of the service, especially at peak periods can rapidly lead to a poor quality of experience for the end user. However, in satellite provision such features are quite key to the success of the business and consequently there is a delicate balance to be made. Furthermore, some form of regulation of guaranteed QoE may be required to avoid excessive exploitation by the service provider.

2.3.2.2 Basic Model of Earth Stations and PEPs

In this section the basic concepts of satellite delivered broadband are outlined.

Most implementations employ a so called Star network that employs a large hub earth station (or gateway) feeding signals from the core IP Internet to and from the user terminal (VSAT) via the satellite as shown in Figure 14.

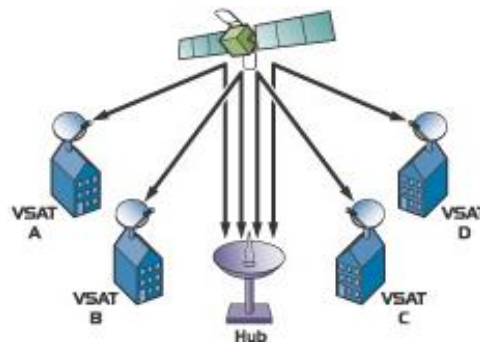


Figure 14 - Star Network Configuration

The user terminal (VSAT) comprises an indoor and an outdoor unit (Figure 15) interconnected by two cables known as the inter facility link (Figure 16).

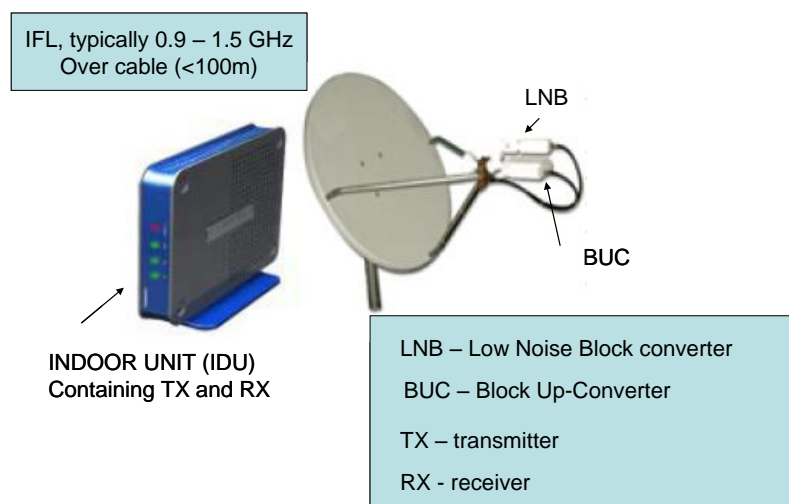


Figure 15 - Consumer terminal equipment (VSAT)

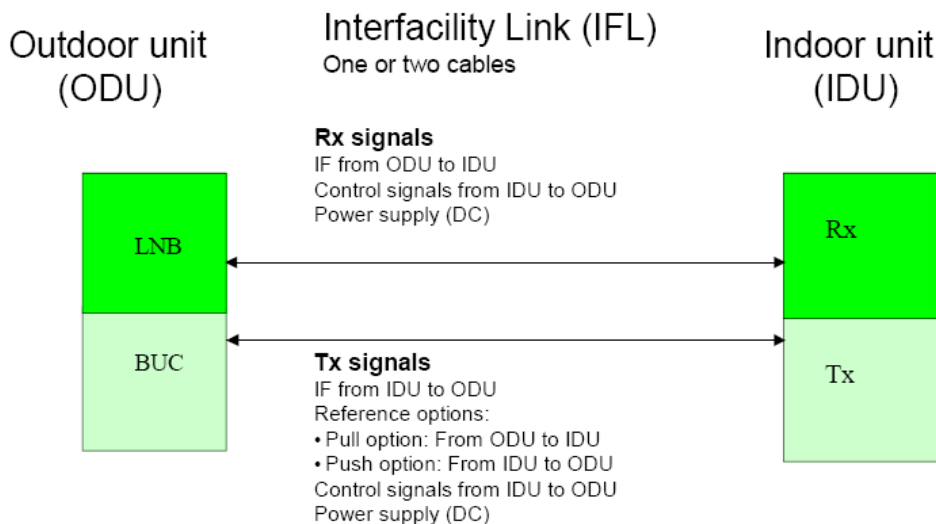


Figure 16 - Customer premises interconnection

All of this hardware is supplied at a one-off cost or by a lease arrangement.

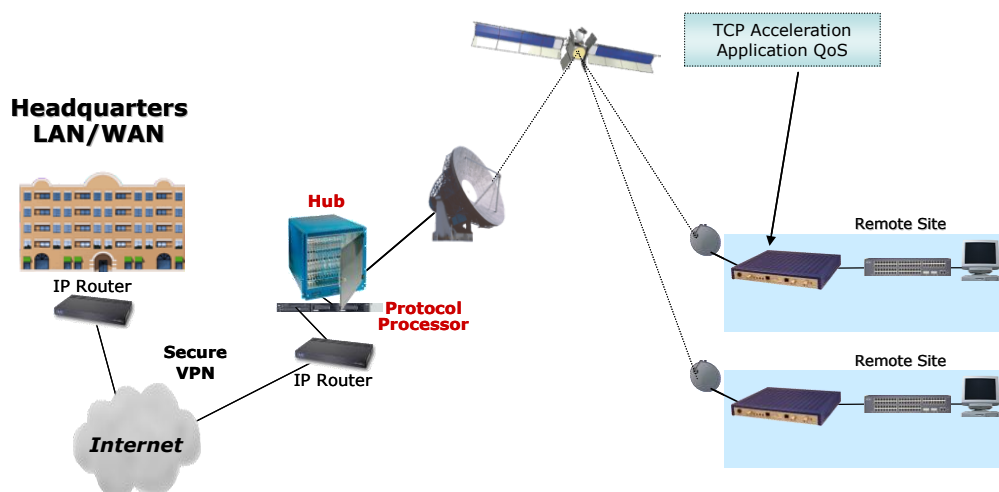


Figure 17 - Network configuration with protocol conversion

TCP/IP consists of TCP - Transmission Control Protocol and IP - Internet Protocol which together forms a protocol stack. TCP/IP was primarily developed mostly for terrestrial based networks, when Satellite Internet access and VSAT systems were yet to be utilized commercially. Despite significant optimisations and enhancements proposed over the many years, TCP/IP operation has not changed significantly since RFC 793, published in 1981. Applying standard TCP/IP to Satellite Internet access circuits leads to the under-utilisation of the link and degraded performance.

There is the issue of round trip latency due to the fact that geostationary satellites are 30,000 km above the earth surface: it takes approximately half a second for the signal to travel from the user to the satellite and back to the hub. Additionally, there is a packet loss possible due to the error rate of the link.

There are a number of solutions available in order to overcome TCP/IP performance degradation. Usually, these solutions are named TCP accelerators and Performance

Enhancing Proxies (PEP). TCP accelerators use various techniques to substitute TCP/IP with a protocol set which is more optimised for Satellite Internet access. Most of solutions use UDP as the primitive IP packets transport while speed and window size negotiations are done inside the TCP accelerator protocol. Most of the TCP accelerators also bundle a number of well known techniques in order to improve the performance of the Satellite Internet circuit. These techniques usually include DNS caching, HTTP pre-fetching and on-the-fly traffic compression.

PEP technology and its implementation is substantially proprietary in nature although attempts have been made to develop a standard called iPEP [Ref 23] and [Ref 24].

Thus, in summary, an alternative protocol is employed over the satellite link itself which is delay tolerant and the TCP/IP interfaces at each interface with the satellite link is spoofed into believing that everything is in order with no perceptible delay.

2.3.2.3 Equivalence of DVB-RCS and Other Offerings

The three key open standards for satellite broadband are:-

- DVB-RCS is the oldest standard for satellite Internet. DVB-RCS is part of the global DVB standards for satellite transmission. The LinkStar system developed by ViaSat supports DVB-RCS as do many European systems.
- IPoS (Internet Protocol over Satellite) is a newer satellite Internet protocol which was developed by Hughes Network Systems (HNS), the developers of Direcway. HNS has attempted to increase adoption of their IPoS protocol by presenting it to ETSI as a standard. ETSI has issued IPoS as ETSI TS 102 354 but IPoS has yet to achieve market acceptance outside of Hughes Network Systems.
- S-DOCSIS is a modification of the DOCSIS cable-modem protocol for transmission over satellite. To work well over satellite links, the DOCSIS protocol was modified to support additional modulation algorithms, such as QPSK. In addition, variable modulation protocols allow support for a wide range of satellite transmission attenuation conditions. S-DOCSIS has been deployed in countries such as the United States, Canada, Saudi Arabia, France, Mexico, Colombia, and Malaysia. The Surfbeam system developed by ViaSat is a DOCSIS-S system.

Some of their characteristics are presented in Table 11.

	DVB-RCS	DOCSIS	IPOS
Original Outbound	DVB-S	DOCSIS 1.1	DVB-S
Current Outbound	DVB-S2	DOCSIS 2.0	DVB-S2
Inbound	MF-TDMA	TDMA	MF-TDMA
Status of standard	Robust / deployed	Used by Viasat in Surfbeam (Tooway)	Used by Hughes
Higher OSI layer support	In development (DVB-RCS2)	Yes	Yes
Higher level support (i.e. management functions)	In development (DVB-RCS2)	Significant	Reasonable amount
Bandwidth efficiency	70 – 85%	Not Known	90% claimed
Observations	Perceived high cost	High volume orders	HNS claim low cost / high performance
Manufacturers	Many US and European	VIASAT using Broadcom Chips	HNS

Table 11 - Comparison of 3 key satellite broadband standards

Another more recent standard is that used by ASTRA2CONNECT and is based upon SATMODE [Ref 39]. The modification of the SATMODE standard is quite extensive and as such it is not feasible to class this as an open standard.

2.3.2.4 Summary

The technical capabilities of the standards adopted for broadband via satellite are all based upon similar concepts that have evolved over many years. They are all capable of supplying a good user experience and only differ in implementation and system management aspects. It is clear to us that the technology is not an issue in determining the quality of experience but the management features that control the technology in terms of contention and traffic volume will have a much greater influence.

2.4 ISSUES WITH TCP OVER SATELLITE

The main issues affecting TCP transmission over satellites are due to the characteristics of satellite link such as the long propagation delay and relatively high transmission bit error ratio. These directly affect the performance of the connection setup as TCP uses three way handshakes to establish a connection before data transfer. These also affect the data transfer speed due to slow start and congestion avoidance algorithms used by the TCP for congestion and flow controls. Some basic background on transmission of messages over the Internet and TCP transmission is included Appendix F. Figure 18 shows the general concept of IP over satellite.

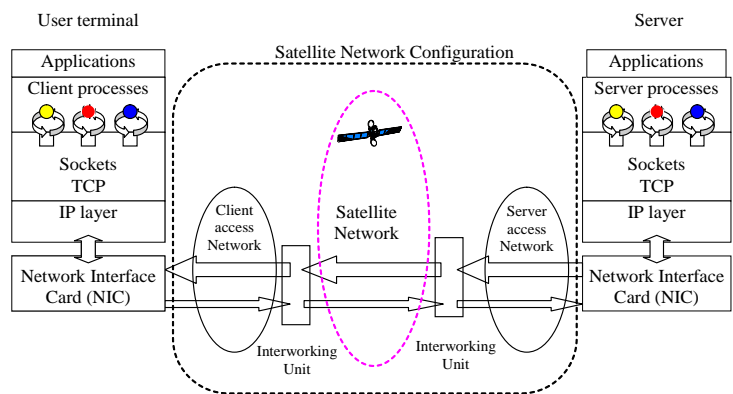


Figure 18 - Satellite in the context of TCP/IP protocol

Long round trip delay (RTT) and relatively high bit error rate are features compared with optical fibre. Long RTT makes the TCP very inefficient to provide reliable service, as it takes a long time for the receiver to acknowledge the received data. This degrades the performance of TCP. Figure 19 shows the data flows and acknowledgement control flow.

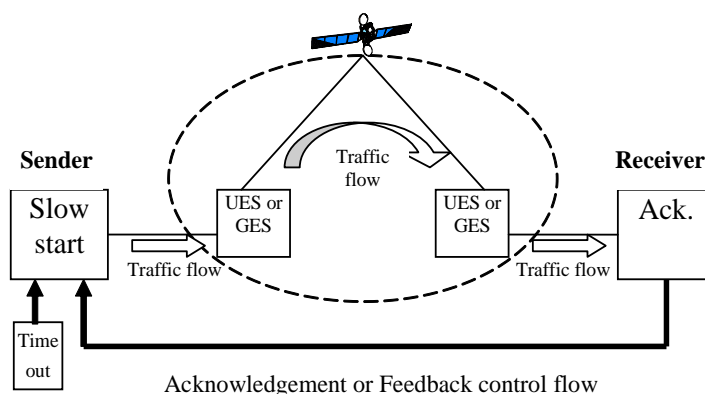


Figure 19 - Data and control flows of TCP over satellite

2.4.1 CONNECTION SET-UP AND DATA TRANSMISSION

The procedures to establish a TCP connection involve an exchange of three control messages. This exchange has been termed a three-way handshake. The connection becomes "established" when sequence numbers have been synchronized in both directions. The clearing of a connection also involves the exchange of segments, in this case carrying the FIN control flag.

The data that flows on the connection may be thought of as a stream of octets. The sending process indicates in each system call SEND that the data in that call (and any preceding calls) should be immediately pushed through to the receiving process by setting of the PUSH flag. The sending TCP is allowed to collect data from the sending process and to send that data in segments at its own convenience, until the push function is signalled, then it must send all unsent data. When a receiving TCP sees the PUSH flag, it must not wait for more data from the sending TCP before passing the data to the receiving process. There is no necessary relationship between push functions and segment boundaries. The data in any particular segment may be the result of a single SEND call, in whole or part, or of multiple SEND calls.

2.4.2 SLOW START AND CONGESTION AVOIDANCE FOR CONGESTION AND FLOW CONTROLS

The TCP has the congestion control and flow control algorithm between the sender and receiver [RFC2581]. This algorithm maintains a congestion window (cwnd) between the sender and receiver, controlling the amount of data in flight at any given point in time. Reducing cwnd reduces the overall bandwidth obtained by the connection; similarly, raising cwnd increases the performance, up to the limit of the available bandwidth.

After connection establishment, the TCP begins with the slow start algorithm to avoid possible congestion across networks, and increases the transmission volume by two for each successful acknowledged packet. Though it starts slow but increases quickly (exponentially). In addition to congestion control, the TCP also deals with flow control to prevent the sender over running the receiver. The congestion avoidance algorithm slows down the increase to one for each round trip (linearly). It goes back to slow start if packet

loss occurs. If no further losses occur, cwnd will ultimately reach the window size advertised by the receiver. Figure 20 illustrates an example of the congestion control and congestion avoidance algorithm.

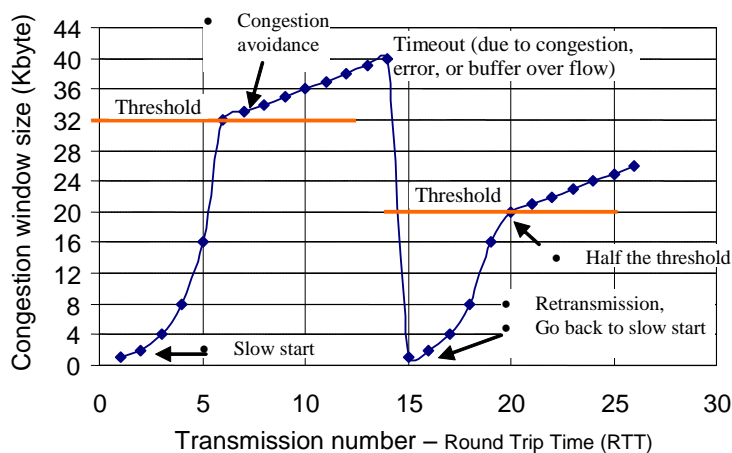


Figure 20 - Congestion Control and Avoidance

One of the functions in the TCP is congestion control between end-hosts over the Internet. This is a critical part of the overall stability of the Internet. In the congestion control algorithms, TCP assumes that, at the most abstract level, the network consists of links for packet transmission and queues in routers for buffering the packets. Queues provide output buffering on links that can be momentarily over subscribed. They smooth instantaneous traffic bursts to fit the link bandwidth.

When demand exceeds link capacity for long enough to cause the queue buffer to overflow, packets are lost. TCP uses sequence numbering and acknowledgements (ACKs) on an end-to-end basis to provide reliable, sequenced, once-only delivery. TCP ACKs are cumulative, i.e., each one implicitly ACKs every segment received so far. If a packet is lost, the cumulative ACK will cease to advance.

Since the most common cause of packet loss is congestion in the traditional wired network technologies, TCP treats packet loss as an indicator of network congestion (but such assumption is not applicable in wireless or satellite networks where packet loss is more likely caused by transmission errors). This happens automatically, and the sub-network need not know anything about IP or TCP. It simply drops packets whenever it must, though some packet-dropping strategies are fairer than others.

TCP recovers from packet losses by using a retransmission timeout. If an ACK fails to arrive after a certain period of time, TCP retransmits the oldest unacknowledged packet. Taking this as a hint that the network is congested, TCP waits for the retransmission to be acknowledged (ACKed) before it continues, and it gradually increases the number of packets in flight as long as a timeout does not occur again.

2.4.3 FAST RETRANSMISSION AND FAST RECOVERY

Performance enhancement mechanisms have been developed to allow TCP fast retransmission and fast recovery. Fast retransmission means to retransmit the packets before timeout; and fast recover means to allow TCP recover from higher level rather than beginning of the slow start for faster recovery from the occasional lost packets in a bulk transfer. These rely on the fact that when a single packet is lost in a bulk transfer, the

receiver continues to return ACKs to subsequent data packets, but they will not actually acknowledge (ACK) any data. These are known as "duplicate acknowledgments" or "dupacks". The sending TCP can use dupacks as a hint that a packet has been lost, and it can retransmit it without waiting for a timeout. Dupacks effectively constitute a negative acknowledgement (NAK) for the packet whose sequence number is equal to the acknowledgement field in the incoming TCP packet. TCP currently waits until a certain number of dupacks (currently 3) are seen prior to assuming a loss has occurred; this helps avoid an unnecessary retransmission in the face of out-of-sequence delivery.

The TCP throughput depends on the window size and RTT and can be estimated as the following [Ref 21], [Ref 22]:

$$U = \frac{W}{RTT}$$

Where W is the receiver window size which changes according to slow start and congestion control algorithms, RTT is the round trip time, and U is throughput.

Therefore, we can calculate the link utilization (E) can be estimated as:

$$E = \frac{W}{(RTT * B) + b}$$

where B is bandwidth capacity and b is the Maximum Segment Size (MSS). It can be seen that large delay band (RTT*B) can make the satellite link very inefficient. The default TCP Maximum Segment Size -MSS is 536 bytes. The maximum window size is $2^{16} = 65536$ bytes by default. This can be set to $2^{30} = 1073$ Mbytes with a window scaling option. Due to slow start, the window size can take a long time to reach the full transmission capacity. Some of the transfers finish long before TCP reaches full capacity.

When the data is corrupted or lost during transmission, it will make it even worse due to the slow start and congestion avoidance algorithm.

2.4.4 PEP - SPOOFING AND SPLIT TCP

In addition to the standard efforts to improve the TCP performance, satellite community has also developed different solutions for IP over satellite but these solutions are not standardised for the Internet and often proprietary solutions of individual companies. However, the only real advantage of standard protocols over a proprietary solution is interoperability with other implementations of the protocol. For those situations where interoperability is not an issue, such as for closed networks or specialized applications, there is no inherent advantage to standardized protocols over proprietary solutions.

Any protocol, even one that is based closely on TCP, UDP, or other standard should be considered proprietary if it does not interoperate with other implementations of the standard. This includes almost all versions of Satellite TCP and Reliable UDP. A standardized protocol can also offer the benefit of a ready-made solution, with implementations available off-the-shelf or possibly even as open source software, reducing the time and cost to develop a solution.

Here we explain the basic concepts of PEPs and highlight two of the current solutions: SCPS-TP and I-PEP.

2.4.4.1 Basic Concepts of TCP Enhancement for Satellite

According to the principle of protocols, each layer of the protocol should only make use of the services provided by the protocol below it to provide services to the protocol above it. TCP is a transport layer protocol providing end to end connection oriented services. Any function between the TCP connection or Internet protocol below it should not disturb or interrupt the TCP data transmission or acknowledgement flows. As the characteristics of satellite networks are known to networking design, there is potential to performance benefit by making use of such knowledge. Two basic concepts have been widely used: TCP spoofing and TCP cascading (also known as split TCP), but they violate the protocol layering principles for network.

Figure 21 illustrates the concept of the mechanisms for solutions to provide satellite friendly TCP.

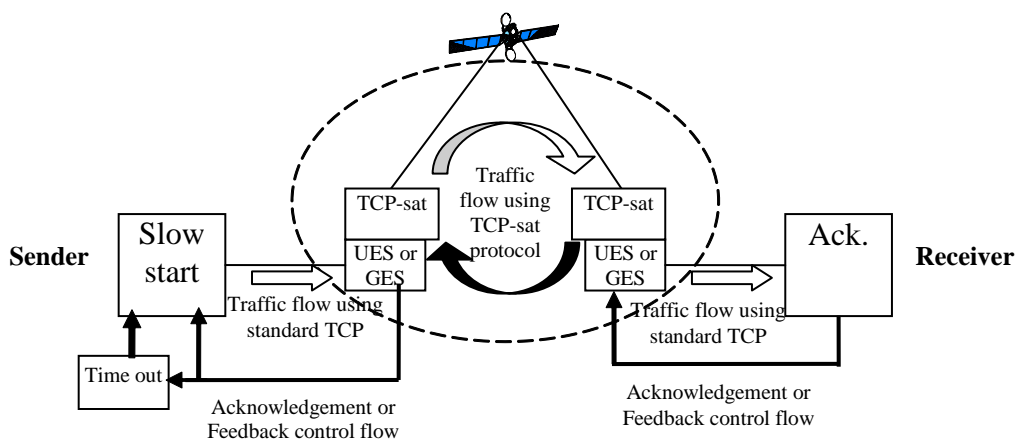


Figure 21 - Illustration of the concept of satellite friendly TCP

2.4.4.2 TCP Spoofing

TCP spoofing is an idea for getting around slow start in a practice known for satellite networks particularly GEO satellite links. The idea calls for a router near the satellite link to send back acknowledgements for the TCP data to give the sender the illusion of a short delay path. The router then suppresses acknowledgements returning from the receiver, and takes responsibility for retransmitting any segments lost downstream of the router.

There are a number of problems with this scheme.

- First, the router must do a considerable amount of work after it sends an acknowledgement. It must buffer the data segment because the original sender is now free to discard its copy (the segment has been acknowledged) and so if the segment gets lost between the router and the receiver, the router has to take full responsibility for retransmitting it. One side effect of this behaviour is that if a queue builds up, it is likely to be a queue of TCP segments that the router is holding for possible retransmission. Unlike IP datagrams, this data cannot be deleted until the router gets the relevant acknowledgements from the receiver.
- Second, spoofing requires symmetric paths: the data and acknowledgements must flow along the same path through the router. However, in much of the Internet, asymmetric paths are quite common.

-
- Third, spoofing is vulnerable to unexpected failures. If a path changes or the router crashes, data may be lost. Data may even be lost after the sender has finished sending and, based on the router's acknowledgements, reported data successfully transferred.
 - Fourth, it does not work if the data in the IP datagram is encrypted because the router will be unable to read the TCP header.

2.4.4.3 Cascading TCP or split TCP

Cascading TCP, also known as split TCP, is an idea where a TCP connection is divided into multiple TCP connections, with a special TCP connection running over the satellite link. The thought behind this idea is that the TCP running over the satellite link can be modified, with knowledge of the satellite's properties, to run faster.

Because each TCP connection is terminated, cascading TCP is not vulnerable to asymmetric paths. And in cases where applications actively participate in TCP connection management (such as Web caching) it works well. But otherwise cascading TCP has the same problems as TCP spoofing.

2.4.4.4 SCPS-TP

Space Communications Protocol Standards (SCPS) is a suite of protocols, covering ISO Layer 3 and above, developed jointly by the U.S. Department of Defense and NASA to fit the needs of ground-to-space communications. The protocols have been created as military specifications and standardised by the ISO under the Consultative Committee for Space Data Systems (CCSDS). The SCPS protocol suite consists of the following specifications:

- Application SCPS-FP (SCPS File Protocol) [Ref 26].
- Transport SCPS-TP (SCPS Transport Protocol) [Ref 27]
- SCPS-SP (SCPS Security Protocol) [Ref 28]
- Network SCPS-NP (SCPS Network Protocol) [Ref 29]

2.4.4.5 I-PEP

Interoperable PEP [I-PEP] is a European initiative to develop specifications by the SatLabs group for the basic procedures applied to and protocol messages exchanged over the air interface between satellite terminal and hub station in general, but focus on DVB-RCS particularly [Ref 24], [Ref 25]. This is to make sure that different PEP implementations are compatible and interoperable. Three scenarios are defined: Single user scenario (client PEP integrated with user PC), Multi-user scenario (client PEP in external box shared by many entities), and PEP server at ISP (rather than satellite service provider). The specification defined part of the SCPS-TP but not fully compatible.

2.5 SATELLITE PACKET SERVICE PARAMETERS FOR THE SIMULATOR

The provisional IP network QoS classes and performance objectives recommended by the ITU are summarised in Table 12. QoS classes and target parameters are discussed further in Appendix G. GEO satellite networks are not able to support Class 0 or Class 2 services due to their latency.

Network performance parameter	Nature of network performance objective	QoS Classes					
		Class 0	Class 1	Class 2	Class 3	Class 4	Class 5 Unspecified
IP packet Transfer Delay (IPTD)	Upper bound on the mean IPTD	100 ms	400 ms	100 ms	400 ms	1 s	U
IP packet Delay Variation (IPDV)	Upper bound on the $1 - 10^{-3}$ quantile of IPTD minus the minimum IPTD	50 ms	50 ms	U	U	U	U
IP packet Error Ratio (IPLR)	Upper bound on the packet loss probability	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	U
IP packet Los Ratio (IPER)	Upper bound	1×10^{-4}					U

Table 12 - Provisional IP Network QoS Class Definitions and Network Performance Objectives (ITU Rec Y.1540)

The proposed parameters for simulation purposes are given in Table 13 to Table 16. The values are end to end user observed performance estimated based on:-

- Real measurement and estimates from users of Tooway and Astra2Connect from the Web (scaled to 2Mbps and 256 kbps where appropriate)
- Measurements made with ESA using Hellasat 2 and included in a conference paper [Ref 37].
- ITU-T specifications.

These parameters are the best ones known to the authors and are based on current Ku band satellite offerings. However, they should be considered as best efforts as current operators who may have better data do not disclose it for commercial reasons. Apart from video streaming delays are round trip delays.

LIGHTLY LOADED NETWORK CONDITIONS

FORWARD LINK						
Service	IP Packet Loss Ratio	Average bit rate (kbps)	Max bit rate (kbps)	Average delay (ms)	Max delay (ms)	Jitter (ms)
Web Browsing	$1.2 * 10^{-3}$	1024	2048	650	1000	20
VoIP	$1.2 * 10^{-3}$	1024	2048	500	750	20
Video Streaming (one way)	$1.2 * 10^{-3}$	1024	2048	270	460	20
File Transfer	$1.2 * 10^{-3}$	1024	2048	550	700	20
Gaming	$1.2 * 10^{-3}$	1024	2048	500	750	20

Table 13 - Light loading, Forward Link

LIGHTLY LOADED NETWORK CONDITIONS

RETURN LINK						
Service	IP Packet Loss Ratio	Average bit rate (kbps)	Max bit rate (kbps)	Average delay (ms)	Max delay (ms)	Jitter (ms)
Web Browsing	$1.2 * 10^{-3}$	150	256	650	1000	20
VoIP	$1.2 * 10^{-3}$	150	256	500	750	20
File Transfer	$1.2 * 10^{-3}$	150	256	550	700	20
Gaming	$1.2 * 10^{-3}$	150	256	500	750	20

Table 14 - Light loading, Return Link

HEAVILY LOADED NETWORK CONDITIONS

FORWARD LINK						
Service	IP Packet Loss Ratio	Average bit rate (kbps)	Max bit rate (kbps)	Average delay (ms)	Max delay (ms)	Jitter (ms)
Web Browsing	$1.2 * 10^{-3}$	1024	2048	1000	1200	50
VoIP	$1.2 * 10^{-3}$	1024	2048	720	850	50
Video Streaming (one way)	$1.2 * 10^{-3}$	1024	2048	450	700	50
File Transfer	$1.2 * 10^{-3}$	1024	2048	600	850	50
Gaming	$1.2 * 10^{-3}$	1024	2048	600	850	50

Table 15 - Heavy loading, Forward Link

HEAVILY LOADED NETWORK CONDITIONS

RETURN LINK						
Service	IP Packet Loss Ratio	Average bit rate (kbps)	Max bit rate (kbps)	Average delay (ms)	Max delay (ms)	Jitter (ms)
Web Browsing	$1.2 * 10^{-3}$	35	65	1000	1200	50
VoIP	$1.2 * 10^{-3}$	35	65	720	850	50
File Transfer	$1.2 * 10^{-3}$	35	65	600	850	50
Gaming	$1.2 * 10^{-3}$	35	65	600	850	50

Table 16 - Heavy loading, Return Link

Note that the above table were based on the reported experiences of users and the return link does seem to be reported as the most critical and is the limiting factor. In the forward link the rate may be subject to slight (but not major) variability, so for the purposes of this report should be considered as static.

2.6 SATELLITE COMMUNICATIONS DEVELOPMENTS OVER THE NEXT 10 YEARS

We have seen that planned 3rd generation satellites (Table 3) will take up to 2016 and will support the next generation of broadband provision. In so doing it will meet the first aims of the European digital agenda and most of the national digital plans to 2015. In a recent study [Ref 34] Analysis Mason have estimated the growth in household broadband traffic demand up to 2016 based on three scenarios as follows:

- Scenario A: Annual growth 28% 2010-2016—limited by cost to customer (similar to mobile BB market) with SDTV steamed video, Skype like video conferencing, web browsing and e-mail.

- Scenario B: Annual growth of 40% with less constrained demand and increased VoD services based on HDTV. More fixed BB model and figures that are similar to the CISCO projections.
- Scenario C: Annual growth of 50% corresponding to more of a retail model with accelerated IP video requirements in HDTV.

The report compares fixed, wireless and satellite provisioning and here we quote only the relevant service requirements:

	A	B	C
2016 Monthly Household demand, GBytes	8	90	180
Peak data rate, (Mb/s)	4.6	19	19

Table 17 - Projected Household Bandwidth Requirements for 2016 under Various Assumptions

The conclusion is that 20Mb/s would be adequate as a peak user rate for the duration of the third generation satellite systems. What this would be in 2020 is a little more speculative. However recent studies in the European Technology Platform Net!works have indicated that by 2020 there will be a 1000 increase in the mobile traffic per user and 1000 times the capacity of HSPA in 2010. This would translate into a much larger requirement per fixed user than 20Mb/s, maybe up to 50-100Mb/s by 2025 which is the mid term market for the next generation of satellites—the fourth generation.

Studies are currently underway for the fourth generation and it is based roughly on achieving another order of magnitude increase in capacity—that is from 100Gb/s to 1 Terabit/s –the so called terabit/s satellite. ESA initiated feasibility studies under SatNEx3 [Ref 35] in 2010 and has a full mission study in 2011 for such a satellite to launch around 2020. The aim is to seek a further factor of ten reductions in the cost per bit and the user terminal whilst increasing the user rates by a similar factor.

There are several issues that have to be addressed and solved if such a satellite is to be realised [Ref 36] and we will briefly discuss each of these.

2.6.1 SPECTRUM

Exclusive bands for satellite are 19.7-20.2 and 29.5 -30 GHz, that is 2x500MHz across Europe and these are used by both Hylas and KASAT necessitating coordination. Under ECC decisions these bands are exempt from individual licensing for low eirp terminals (<55dBW and in some countries 60dBW). All other parts of the Ka band have shared primary frequency allocations and thus would be subject to coordination at particular earth station sites. Thus around 3GHz is available in total for up and down links but with restrictions in the various European countries. In order to operate a Terabit/s satellite we would need to operate user terminals outside of the exclusive band and thus investigate a rapid licensing process.

The capacity of the GESs are very large and to attempt to accommodate these in Ka band as with current third generation systems would not allow the full Terabit/s to be realised and hence the next bands up Q/V bands are suggested for the GES. There are no exclusive satellite bands in Q/V and thus coordination would apply but as the number of GES are

smaller this may not be so much of an issue except for the fact that some Regulators have already auctioned off portions to the terrestrial sector—including the UK. Frequency from 37.5 -42.5 GHz on the down link and 42.5 to 51.4GHz on the uplink are available but with some military restrictions so around 5GHz on the up and 4GHz on the down links is expected but with coordination issues throughout.

The next bands for satellite are at optical frequencies and there has been some study of optical links for the GES but this is probably some way into the future before it becomes realisable. The spectrum issues for satellite are clearly an issue and one that the Regulators must address in greater detail.

2.6.2 FREQUENCY REUSE AND NUMBER OF BEAMS

If we assume that to minimise user terminal costs the Ka band should be used. If we then also consider a system using the current Ka band spectrum with the same spectral efficiency as currently, a Terabit/s satellite would require some 200 to 300 spot beams to cover a continent. This assumes a 3 or 4 colour reuse of the spectrum between the beams. Dual polarisation can halve the numbers of beams but complicates the terminals.

This high number of beams has several implications. Firstly on the stability of the satellite as we could not allow terminals to drift between beams. Secondly on the interference between beams using the same frequency which will mean that the carrier to interference ratio (C/I) rather than carrier to noise ratio (C/N) can dominate the link budgets and may require complex interference management/reduction either at the GES or in the terminal. All of this technology is being studied but will need to be available before 2020.

2.6.3 AIR INTERFACE AND TERMINALS

The air interface standard DVB S2-RCS2 has just been standardised and as already commented has a range of modulations/codings which can be selected according to the terminal link propagation conditions. Thus in clear weather it uses the top set with the largest spectral efficiency (32APSK/9/10 LDPC code) and in rain will drop down the Mod/Cod list to retain communications but sacrifice the spectral efficiency and thus the throughput. For typical continental rain fields there is need to assess the system capacity variability as the traffic requirements will vary in each beam due to their local coverage. Ideally a dynamic resource allocation system is required to maximise the power and bandwidth to each beam. Schemes for adjusting beam characteristics dynamically and even switching between Ka and Q/V could be used but the technology is yet to be prototyped.

2.6.4 RESOURCE ALLOCATION

With several hundred antennas and using a single feed per beam technology we would need several hundred amplifiers on board the satellite and their power requirements would exceed that projected for current payloads—Alphasat extension up to around 25KW. The limitation here is the number of solar paddles that can be folded into current launchers and there is no sign of larger launchers coming onto the scene before 2020. It has been suggested that beam hopping could be used to alleviate this problem and reduce the number of amplifiers in the forward direction. Routing on board the satellite is also an issue and on board equipment could be reduced if full on board processing were used. However for a star configuration the advantages may not be that great and need to be further assessed.

2.6.5 GATEWAYS

We have already mentioned that the GESs would best be operated at Q/V bands to take advantage of the higher capacity available. However at these higher bands the rain fall attenuation is even greater and we still need to provide the availabilities of the order of 99.9%. To do this we have to invoke space diversity. Hylas operates a diversity GES at around 20km distance to achieve a decorrelation of the rain statistics between the sites. If the number of GESs increases to 20-30 per continental coverage this makes the ground segment expensive. An alternative scheme being investigated is called the smart gateway scheme in which all the GES are networked and the traffic is routed around the GES according to the rainfall fields. There are various issues of dimensioning and switching associated with doing this for very large traffic blocks which still need to be solved.

2.6.6 ARCHITECTURES

In all of the above we have assumed that we are operating with a larger and larger GEO satellite and we have seen that there are technical issues to be solved to realise such a satellite. There is also the resilience issue of putting such large capacity through a single satellite which represents a single failure point in the architecture. An alternative solution might be to use a number of smaller GEO satellites connected in a cluster. This would have the advantage of simpler technology and a progressive roll out to cover different geographical areas as the traffic built up. It would also allow the use of different spectrum on different satellites and by cluster connection via inter satellite links an ability to improve routing.

Finally we should mention the use of different orbits. We have seen recently the proposal of O3B's constellation of Medium Earth Orbit (MEO) equatorial orbit Ka band satellites and of the polar orbit constellation of satellites by Constellation. These are aimed at very specific markets of mobile backhauling and peer to peer but one could conceive of a hybrid orbit system to address broadband.

2.6.7 SUMMARY

Above we have listed some of the research issues still to be solved that would make the 4th generation of Terabit/s satellites realisable. Most of the technology is already on the TRL (Technology Readiness Level) scale and will make it through to production in time for the fourth generation. Thus the user speeds will increase up to 100Mbps and the cost should decrease by a factor of 10.

To achieve these projections however, there isn't sufficient bandwidth just in the Ka band and hence Q/V will also be needed. Hence this is something to which Ofcom needs to give consideration, especially as if some of this spectrum is allocated to terrestrial operators it will make the use of these bands by satellite difficult.

3 QUALITY OF EXPERIENCE EXPERIMENTAL FRAMEWORK

3.1 INTRODUCTION

In order to evaluate the quality of experience for users undertaking typical Internet activities over a satellite link, a controlled and structured test environment was created. The details of the experiments and tests that were actually carried out in this environment can be found in section 4. This section focuses on the configuration of the infrastructure and environment.

The goal of the QoE test framework was to provide an environment which was carefully designed to eliminate systematic errors and focus on the difference in experience caused by the satellite link. Equally, great care was taken to ensure that users were unaware of which system they were using at any particular point, so that their impressions were not affected by any preconceived internal bias.

Four different applications / use cases were tested (for reasons behind this selection see section 4.1.3.3.1):

- Remote desktop / VPN
- Online gaming
- Streaming video / web browsing
- Voice over IP

The tasks for the creation of the test environment therefore required that each of the four applications was installed and configured appropriately. Each of these four applications was evaluated over three different candidate systems (see section 4.1.3.3.3):

- A simulation of a "standard" ADSL connection
- Simulated/emulated satellite link
- A real satellite link

The real satellite system was sourced from a commercial provider on the open market (Ethnet). The emulated satellite link and the emulated ADSL broadband connection were both achieved by implementing a bespoke network emulator.

3.2 EXPERIMENTAL SET UP

3.2.1 OVERVIEW

The following diagram illustrates the physical arrangements that were used for the trial.

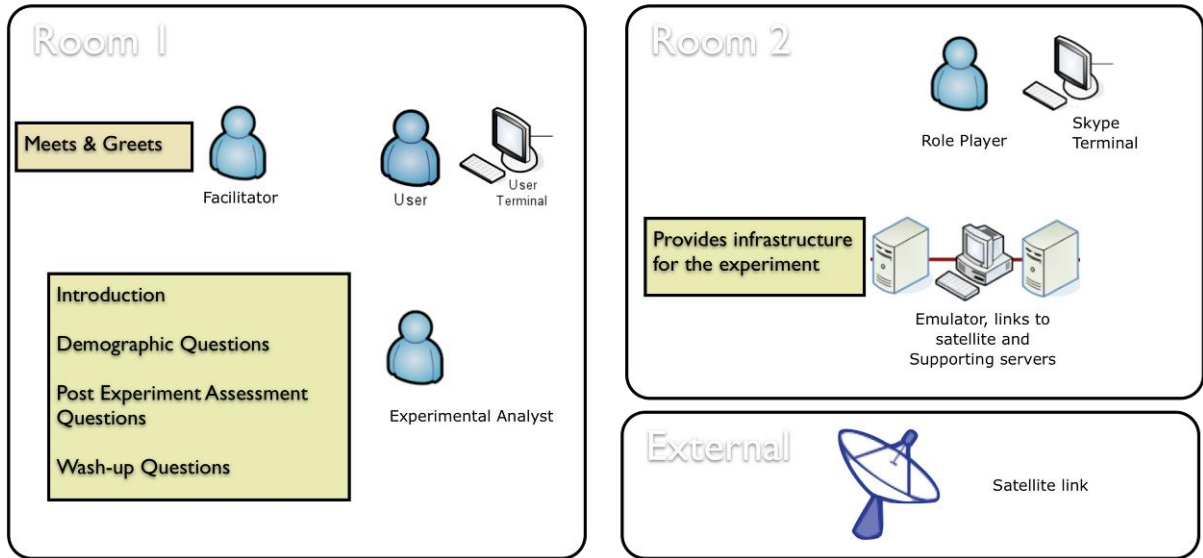


Figure 22 – Physical arrangements schematic

Figure 22 show that the majority of the experiment was carried out in a single room with the participants interacting with a single user terminal guided by the experimental analyst. A secondary room was primarily used for the “VoIP actor”, whose main role was to engage the volunteer in conversation during the VoIP application tests. The satellite dish was external and installed and calibrated by the service providers.



Figure 23 -The installed satellite dish outside Roke’s “Manor House” building where the user trials took place

Figure 23 shows the satellite dish installed outside the Manor house nearby to the room in which the volunteer experiments were taking place. The externals of that room can be seen in this picture (double French windows, ground floor, central).

Figure 24 below shows the user terminal inside the house that the volunteers were presented with, including the microphone headset for the VoIP tests. Various laminated sheets can also be seen which were used for the user to select descriptive words and understand the keys to be used during the online game. It is also possible to make out a group of five icons towards the right of the computer desktop used to initiate each of the test applications. All of the applications were configured to "just start", without the user needing to specify parameters.



Figure 24 - The interface that the trial participants were presented with

Figure 25 below shows the trial equipment in use by a volunteer whilst being monitored by the experimental analyst. Other things that can be seen in this picture are the controls that the experimental analyst used to switch between the various systems. Volunteers were aware that the systems were being switched over, but would be unaware of what system they were using at any particular time. Behind the volunteer's monitor is a push-button KVM switch, which swapped between two identical desktops (satellite and network emulator systems). Behind the experimental analyst a stack of servers (including the network emulator) can be seen as well as two monitors. The experimental analyst used a simple one-line menu interface on this system to switch the network emulator between configurations for the various scenarios. The network emulator monitor was angled in such a way that the volunteer was unable to see what had been selected from the menu interface.



Figure 25 - A female participant carrying out tasks on the trial, whilst being guided and monitored by the Experimental analyst

3.2.2 NETWORK EMULATOR

The purpose of the network emulator was to introduce traffic characteristics similar to those experienced on different types of wide area network communication channels such as satellite and ADSL. To emulate the satellite link some satellite-specific enhancement techniques were also included that are commonly used to reduce the detrimental effect of the inherent communication propagation delays.

The network emulation was implemented on standard Linux machines with the core piece of software being a custom-written Python tool to apply traffic characteristics to each of the individual network interfaces, routes and traffic classes. This tool itself makes heavy use of the “netem” toolkit that is freely available on most Linux systems. Netem is an extremely sophisticated network emulation toolkit capable of manipulating network traffic in a myriad of complex ways in real-time. For this trial, features to control delays, jitters, packet loss and traffic shaping were used to emulate the desired bandwidths/QoS. Usage of netem, however, does require high levels of network engineering expertise and understanding due to the extremely large number of parameters and options available. The Python tool therefore interfaces with netem abstracting away the complexities, to present the experimental analyst with the bespoke customised options in a straightforward control menu. This tool operates in conjunction with another script used to create, load and save configuration files with parameters relevant to each of the scenarios. Representative parameters were selected to model traffic delivery characteristics over the ADSL & satellite

links (dependent on the traffic type and quality of service implementation). For details, see sections 3.4 & 3.5.

In order to mimic things such as rain fading or transient contention ratios, parameter changes would have needed to be made during each test run, greatly increasing the complexity of the network emulator. As each of the volunteers' tasks was only a few minutes in duration it was deemed that to perform parameter variation during the tests would not really have been representative. Furthermore, variation would have added excessive complication to the process of observational analysis. Therefore in order to keep the tests within the scope of this study package, and obtain statistically significant results, traffic characteristics were fixed for the duration of each of the experimental tests⁷.

3.2.2.1 Performance enhancing proxy

Performance enhancing proxies, PEPs, (see section 2.4.4) are widely used on satellite systems to prevent problems associated with using standard terrestrial Internet protocols over high latency satellite links. PEP implementations, however, are entirely proprietary and non-standardised. As these PEPs are highly optimised for their specific satellite systems (and "guarded secrets") it is not possible to emulate their fine grained functionality associated with traffic shaping and QoS. However, this is to some extent accounted for by having different traffic characteristics for each of the different experiments to mimic the action of a QoS PEP to some degree.

For the network emulator a basic PEP was used that improved the performance of TCP over the long latency link. The open source SPCS PEP reference implementation was used and configured to work over the satellite emulator.

The PEP was remotely controlled from the Python script to turn it on and off at the appropriate time. Independent scripts were also created to control the PEP systems in order to take down/bring up interfaces and rebuild routing tables. SPCS aware routing between desired addresses was implemented through the use of configuration files as well as mappings being made between protocol specific names and IP addresses.

The wired and wireless (satellite) components of the link have different link characteristics and these were statically configured in a resource file on the PEPs, some of the basic resource file configurations contain the bandwidth delay product of the link. These parameters allow for optimisation of the TCP protocol, specifically for the reduction of the "slow start" effect of the congestion avoidance algorithm.

3.2.2.2 Testing the emulator

The operation of the emulator was tested with standard network tools to evaluate the latency (packet delay), packet loss ratio and jitter (packet delay variation). The throughput was tested with the 'Jperf' tool and the results, as expected, illustrated the desired throughput constraints applied to the forward and reverse links.

When testing the operation of the PEPs, network packet captures were taken using the 'Wireshark' tool when enforcing a large packet delay (to enable the full effects of the PEP to be visible). Captures were taken with the PEPs activated and deactivated and then the

⁷ Jitter was included, which of course is a variable quantity, however average jitter was maintained at a consistent level during the test

separate packet captures were compared. When looking at round-trip time plots, it could be seen that with the PEPs active, the effects of the slow start congestion avoidance feature of the TCP protocol are mitigated.

When testing the menu script, the correct command line output was validated and a check was made as to whether the correct parameters are loaded for traffic management (i.e. that the operation matched the command line input).

Tests also confirmed that the two PEP systems acted as intermediary systems which either just forward traffic between the endpoints when they are turned off (ADSL mode), or process traffic destined for the endpoint (satellite mode).

3.2.1 TOPOLOGIES AND APPLICATION CONFIGURATION

The following subsections outline the experimental scenarios and network configuration performed for each of the test applications. The network diagrams below show the equipment and data paths used in each scenario. Two identical machines were used to switch between the real satellite link and the network emulator via a KVM switch. A KVM switch means that a single monitor/keyboard/mouse/headset can be plugged into two different PC systems. KVMs can therefore be used to toggle between multiple PCs without requiring multiple I/O devices. For this trial, both of the machines' desktop and applications were configured to appear identical, so that the volunteer would be unable to determine which machine was which.

Part of the experiment framework also included a server (needed for the Remote desktop/VPN case and the gaming case). The server was hosted on the Roke network, separate from the emulated link (the emulated delays included Internet delays). The server was also externally accessible for operation via the real satellite link.

3.2.1.1 Video Streaming / web browsing

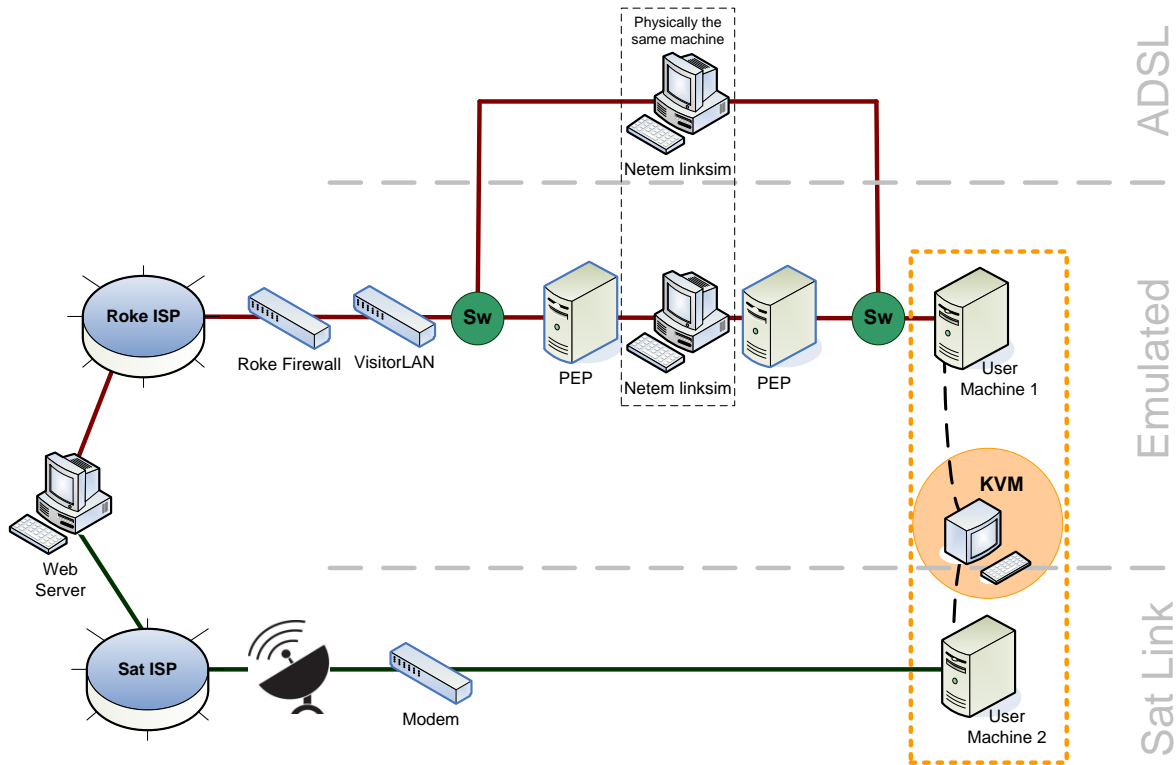


Figure 26 – Configuration for Video Streaming

In configurations terms, this scenario is the most straightforward. The user machines connect directly to the Internet via their respective Internet service providers. The network emulator allows the wired connection to be representative of either the ADSL link or an emulated satellite link.

This scenario required the use of a web browser with built-in flash player (for watching streaming videos). The web browser chosen in this instance was Firefox 4.0 with all the latest patches and Flash player upgrades installed. Firefox was chosen due to its ability to easily configure the caching and history settings. For this trial all download history, cookies, search history, cached files and form entries were cleared every time the browser was shut down (i.e. at the end of each volunteer run). Additionally, the "BetterPrivacy" plug-in was also installed which augmented this process by similarly clearing all the cached data for the embedded Flash player at shut down. These configuration options ensured that every time a volunteer opened Firefox to begin their tasks, they would start from an identical initial setup.

3.2.1.2 Remote Desktop / VPN

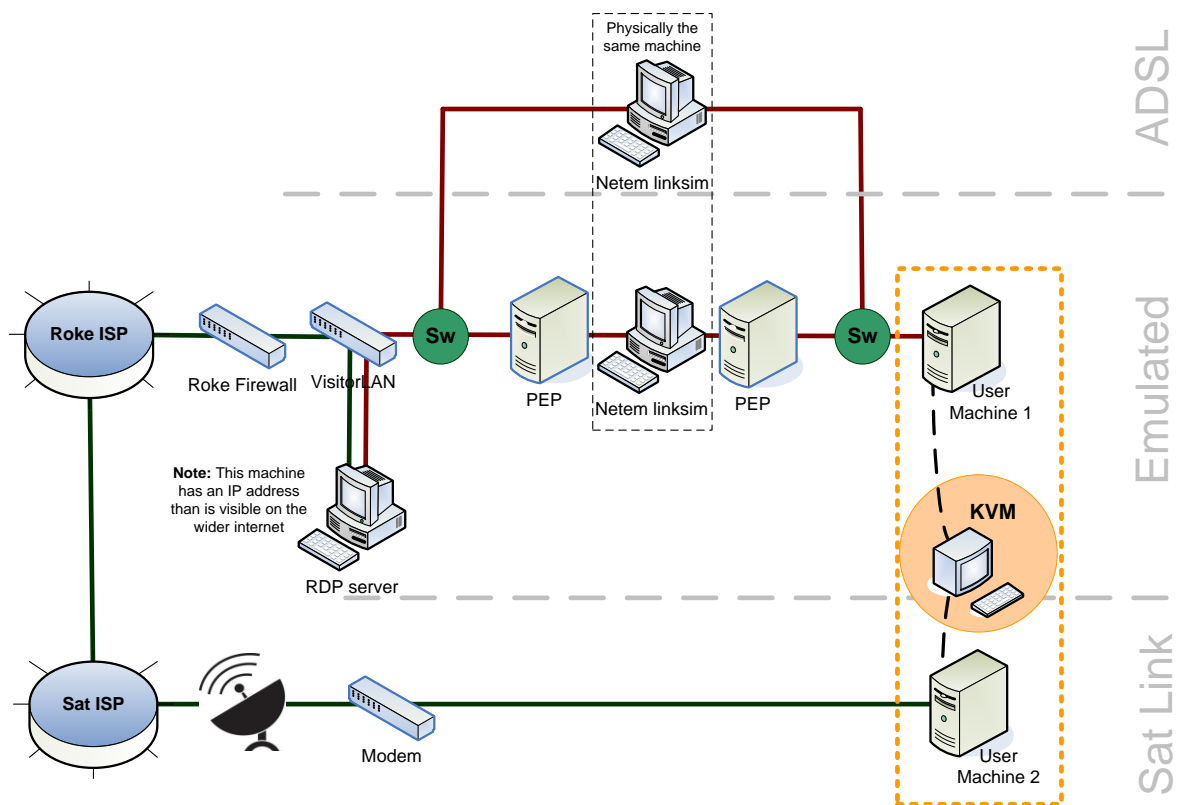


Figure 27 – Configuration for Remote Desktop/VPN

This scenario required users to connect to a server and manipulate files on the server’s desktop remotely. Remote access was achieved using the Windows remote desktop client and server feature that is part of the Windows operating system. An appropriate set of test files was copied across to the server so that the user could perform their simplified VPN tasks (i.e. looking up addresses and copying and pasting between a few documents).

The Windows remote desktop protocol is rarely used over the wider Internet, because of security concerns. Therefore an additional program "OpenVPN" was installed and configured on both the clients and the server so as to encrypt the network traffic between them and provide a more realistic corporate VPN experience.

Both the OpenVPN and Remote Desktop icons on the client machines were set up so that usernames and passwords were not required to be entered by the volunteers, and they could "just click" to establish a remote desktop connection to the server. The process was to double-click the OpenVPN icon, wait for it to finish, and then double-click on remote desktop icon. Termination was by closing of the applications in the reverse order⁸.

⁸ Neither of these applications performed any caching, so there was no requirement to perform any cleanup tasks.

3.2.1.3 Gaming

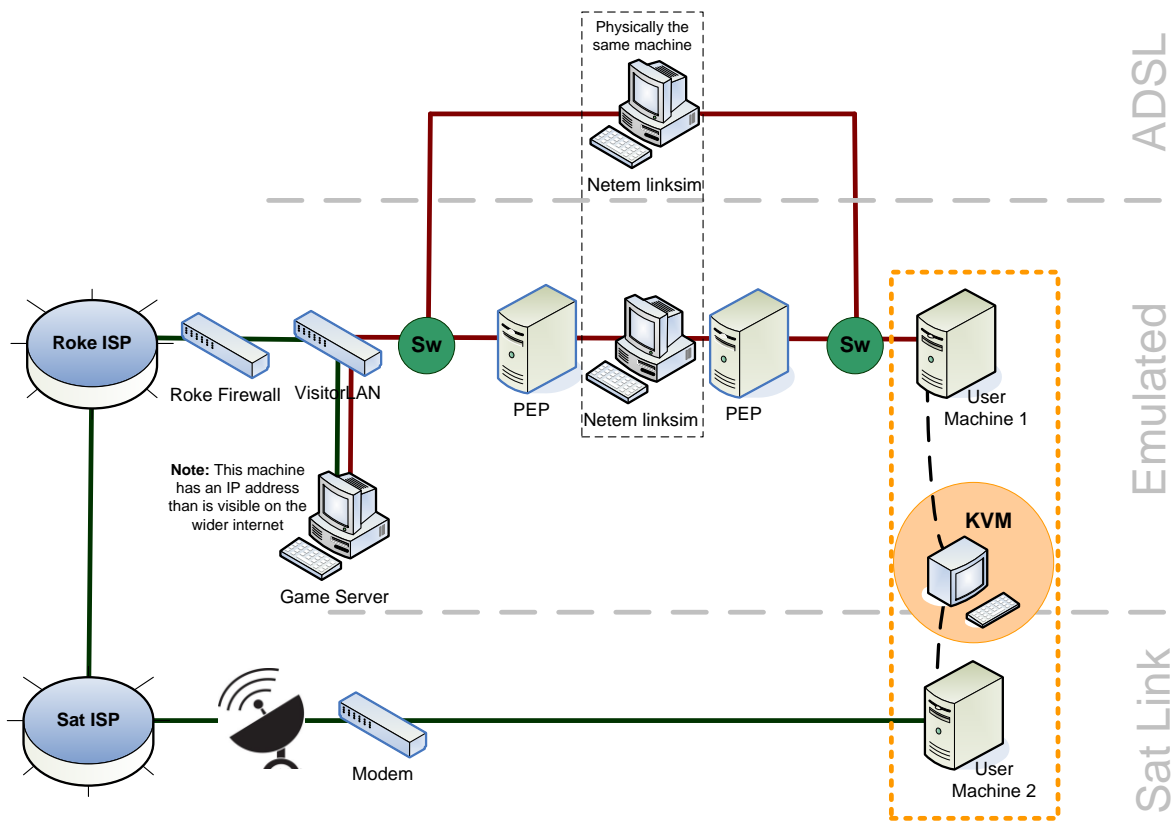


Figure 28 – Configuration for Gaming

This scenario required users to connect to a remote game server and play an online game for a few minutes. So as to maintain control and ensure that the gaming experience would be consistent across all volunteers, a game server was created, rather than use a publicly available game server over the Internet.

The game chosen was "Unreal Tournament 2004", as it allowed games to be configured in a suitable manner for this trial and was representative of the first-person-shooter game genre that was targeted. As it was also a slightly older game, this removed any requirements for high end graphics cards and increased the chances of finding volunteers who had played it previously.

The game server background service was installed on the same machine as was used for the remote desktop connection. It was configured so that games would last for five minutes (with an initial one minute practice). The game server spawned multiple computer-generated bots to play against and shoot at. The game was always played on the same level/area, although the computer-generated players and power ups etc were spawned randomly (to remove any volunteer learning effects). The game always initially started at an identical point, irrespective of previous volunteer's actions or success/failure. It was configured with "resurrection" so that a volunteer would always play for five minutes irrespective of how many times they were killed.

The game was also installed on the two volunteer machines with desktop icons. Although it was not one click to activate, the server address was saved in "favourites" and was simple to navigate to under the guidance of the experimental analyst. Volunteers would therefore

play the game on the local terminal, but it was the server that was running the game over the network.

3.2.1.4 VoIP

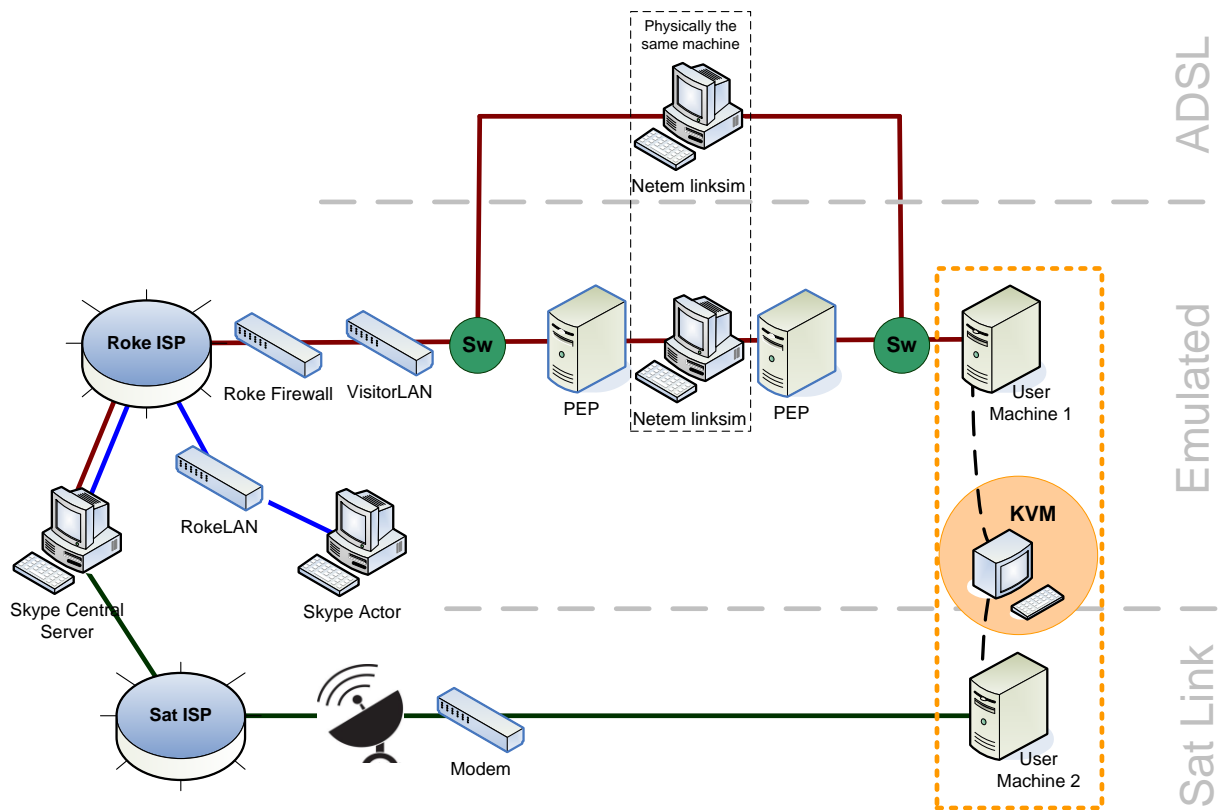


Figure 29 – Configuration for VoIP

In this scenario volunteers had brief (few minutes) conversations with an "actor" over the various network connections. For this scenario the widely used VoIP service, Skype, was selected. Skype was installed on both of the volunteer machines, and a single "Ofcom trial" Skype account was created for them. Skype provides a call quality testing service which was used to confirm the operation of the system and headset over the various networks. The volunteer machines had a Skype desktop icon which lead on to contact list, with a single contact entry for the Actor, which they could click on to initiate a call.

The Skype actor machine was located in another room connected to an entirely separate Roke Manor network. As Skype has sophisticated proxy and firewall detection/traversal mechanisms, connections could be established between the volunteers and the actor automatically and without difficulty.

Skype has proprietary mechanisms for efficient call routing, however the location of the network emulator in the connection tree ensured that it was impossible for Skype to bypass the emulator. Even in the ADSL scenario, with both machines' Skype endpoints within the Roke Manor administrative domain, the emulator ensured ADSL traffic QoS was applied.

3.3 SATELLITE SERVICE

The satellite connection was deliberately sourced from the open market such as would be available to any individual or business within the UK. For this trial Ethnet UK⁹ was used as a supplier who specialise in both long-term installation and also short-term rental for specific events.

The service selected for this trial was the "Business 2000" package that included installation/removal, service provision for the week, and travel costs for the installation engineers. A Ku-band satellite dish was installed and linked to an interior satellite modem, which had an Ethernet cable socket to which the PC was directly connected. The business 2000 package was selected as it was broadly similar to a standard ADSL connection with up to 2Mbps in the downlink and 512kbps in the uplink. There was a pro-rata data volume allowance of 24GB per month.

The supplied Internet service appears to the users PC as a standard broadband connection. There were however a couple of lower-level features of the service that are worth noting:

- The modem also included a PEP (performance enhancing proxy) that improved the TCP connection performance over the satellite.
- The service included a "TurboPage" proxy system that was run at the ISP's NOC (Network Operations Centre, in Germany). Turbo page pre-cached a large proportion of the website traffic at the other end of the satellite link, to try and remove "Internet latency", leaving only the latency of the satellite link itself. In the ideal circumstances therefore (i.e. static webpages) the entire website would be pre-cached at the NOC and then be delivered "all at once" to the user's PC, in an attempt to reduce the large number of small connections, which are inefficient over satellite links, and characteristic of normal HTML traffic.

During the trials, a "Samknows" test unit was plugged directly into the satellite link modem to transparently run quality of service tests in the background (the tests were preempted by any actual traffic to avoid adverse effects to the user). The results of the tests are detailed in Appendix H.

3.4 SATELLITE EMULATOR CHARACTERISTICS

Based on the typical satellite parameters given in Section 2.5, figures were selected for the emulator that represented an average behaviour of a Ku band satellite¹⁰. The figures for delay in those tables are round trip time unless specified otherwise, and thus were halved for configuration on the emulator (which configures each direction of the asymmetric bi-directional link separately).

The global parameters were as follows, and are identical for both forward and reverse link with all types of traffic:

Packet loss:	0.12%
--------------	-------

⁹ <http://www.ethnetuk.com/index.php?pageid=24>

¹⁰ Which amortised components of the observed traffic behaviour resulting from differential QoS treatment as well as all inherent delays and other propagation effects

Jitter: 35ms

(Selected from average jitter at high/low loading)

The bandwidth parameters used were as follows, and are specific for either forward or reverse links or different types of traffic:

Throughput on forward link: 1.024Mb/s

(Selected from average throughput at high/low loading)

Throughput on reverse link: 0.065Mb/s

(Selected from maximum throughput at high loading)

The delay figures were configured for a single direction, and are the average between the high and low loading delays given for each traffic type:

Delay for web browsing: 410ms +/- 35 ms

Delay for VoIP: 305ms +/- 35 ms

Delay for video streaming: 360ms +/- 35 ms

Delay for file transfer: 287ms +/- 35 ms

Delay for video gaming: 275ms +/- 35 ms

3.5 DSL CHARACTERISTICS

The user experience when connected over a typical satellite link is compared with that when using a typical 2Mbit/s DSL connection. Ofcom have published a number of reports providing data on broadband speeds including data on DSL lines. The results are presented in terms of average performance and given that we are concerned with the performance of a typical DSL connection these averages have been used as the basis of the emulated DSL link characteristics.

The data is taken from the most recent Ofcom report into broadband speeds that contains data specific to 2Mbit/s DSL lines (i.e. those using the original standard of ASDL) [Ref 48]. More recent Ofcom reports group 2Mbit/s data with data relating to higher speed lines but the results are generally consistent with the earlier data.

The relevant parameters are summarised below.

Throughput: The downlink throughput of lines with headline speeds of 2Mbit/s is given as being a maximum of 1.8Mbit/s and averaging between 1.6Mbit/s and 1.7Mbit/s depending on time of day and day of the week.

The maximum upload speed is 300kbit/s with an average of 280kbit/s.

Latency: The latency is defined as the time for a packet to be sent to a server and return (i.e. it is the round trip time) and shown as being substantially constant at an average 55ms. There is no indication of whether the delays are the same or different in the two directions of transmission. Here the delay is assumed to be the same.

Jitter is measured as the change in latency and is reported to be less than 2ms on average.

Packet Loss: The packet loss rate is given as averaging between 0.2% and 0.5%.

The parameters used for the emulation of DSL connections are summarised in Table 18.

Parameter	
Downstream Throughput	1.65 Mbit/s
Upstream Throughput	280 kbit/s
Upstream/ Downstream Latency	28 ms
Upstream/ Downstream Jitter	1 ms
Packet Loss	0.4%

Table 18 Emulated DSL Parameters

4 QUALITY OF EXPERIENCE ASSESSMENT

4.1 INTRODUCTION

This user experience experiment investigated aspects of the acceptability of satellite broadband from a usability perspective, to support government initiatives to secure universal access to broadband services, for which satellite broadband might be a cost-effective solution for remote areas.

It is generally recognised that satellite connections have a higher (and more varied) latency, and potentially higher error rates, than terrestrial broadband services, and there is some concern that these factors might lead to low user acceptability. Latency is most intractable in the context of highly interactive (human-to-human) scenarios, and for this reason, the main area of interest in this study is the effect of latency on applications such as gaming, remote desktop/VPN, video/audio streaming and VoIP.

Figure 30 below outlines the methodology to meet the aims of this work. Central to the methodology is the User Experience experiment.

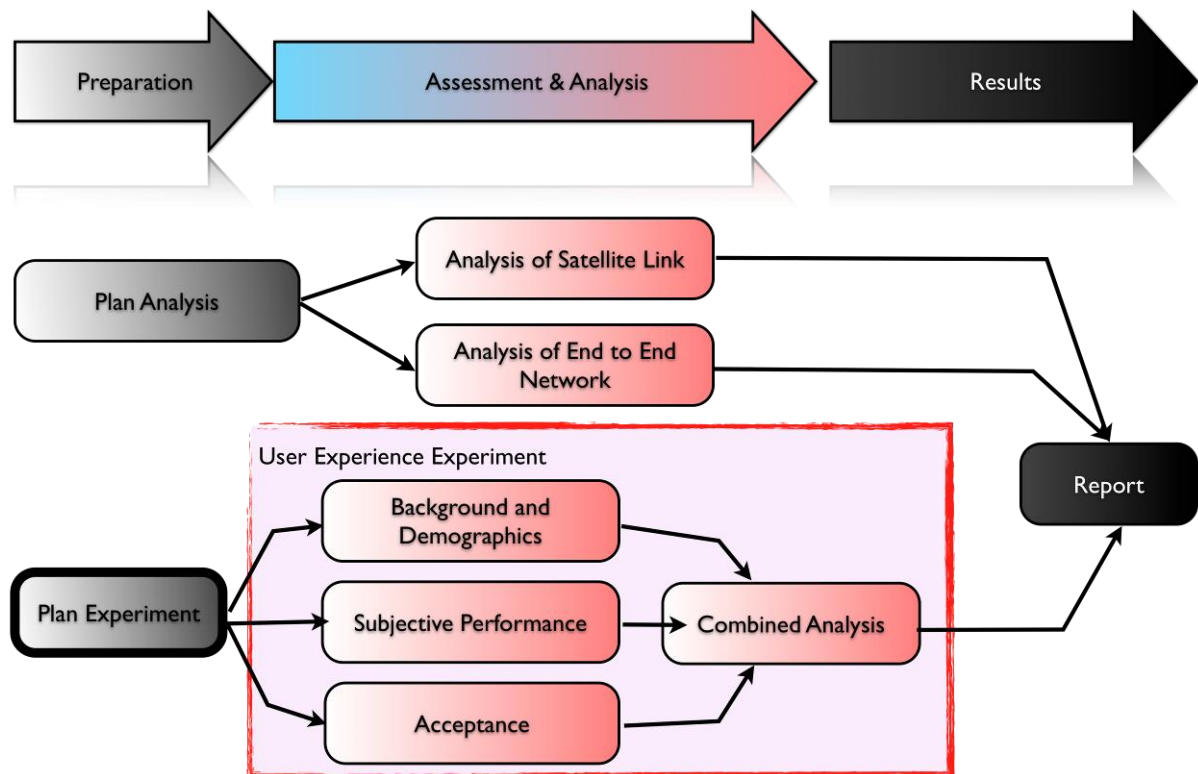


Figure 30 – Overall Methodology

This section of this report discusses the user experience experiment and the combined analysis in regards to the participants' subjective assessments of the systems under test. It considers the participants' backgrounds and what they consider to be the important aspects when using an internet service, as well as their subjective assessment of the services demonstrated during the experiment and their overall assessment of the acceptability of the different systems.

4.1.1 SCOPE

The scope of the experiment is to assess and analyse the subjective opinions of the performance of a satellite link and the acceptability of this performance by a representative sample of the potential user population.

To undertake this user experiment, a number of example applications were utilized to represent typical high-interaction internet usage. These applications covered:

- Remote desktop/VPN
- Gaming
- VoIP
- Video-audio streaming

The experiment took place over five days at Roke Manor Research's site (a rural location near Romsey, Hampshire, UK) and 23 individuals participated.

4.1.2 OBJECTIVES OF ASSESSMENT

The objective of the user experiment was to determine whether there were noticeable differences in the quality of the user experience with the different systems, in order to determine whether satellite broadband would provide an acceptable user experience. Different applications were used in the experiment to be broadly representative of the majority of standard internet usage tasks that rural users might reasonably be interested in.

4.1.3 METHODOLOGY

This section presents an overview of how the experiment and the analysis of the collected results were conducted.

4.1.3.1 Experiment Approach

The model adopted for this experiment was for each participant to experience the emulated satellite system, the live satellite system and the baseline system (an emulated typical ADSL connection) and assess each of them separately immediately after use. The order in which they used each system and each application on that system was randomised: i.e. it was a randomised blind trial. The analysis then gives the comparative results.

Due to time constraints, each participant only experienced three out of the four representative applications. The order in which they did this was randomised across both applications and configurations.

Table 19 below illustrates the randomised order in which the participants used the applications. The full running order is presented in Appendix K.

Participant	System	Gaming	Remote Desktop/VPN	VoIP	Video/audio streaming
User 1	Baseline	1	7	~	4
	Emulator	5	2	~	8
	Satellite	3	6	~	9
User 2	Baseline	~	1	6	5
	Emulator	~	3	7	2
	Satellite	~	4	9	8

Table 19 – Example Running Order

4.1.3.2 Experiment Runs

Each participant was taken through the following activities:

- Briefing: a quick description of the purpose and format of the experiment, to allow the participants to understand what they were about to do.
- Demographic Questionnaire: this questionnaire captured the profile of each individual participant and their experience with the various types of application.
- Experimental Runs: the order of these was randomised across the participants in terms of both the configuration of the system that they were using and the application that they were being asked to use.
- End of Run Questions: these questions captured the participant’s opinion of their experience and their level of adoption.
- Post-trial Debrief: this captured any remaining comments and opinions about the relative experience of the systems.

The relationships between these activities are illustrated in Figure 31 below.

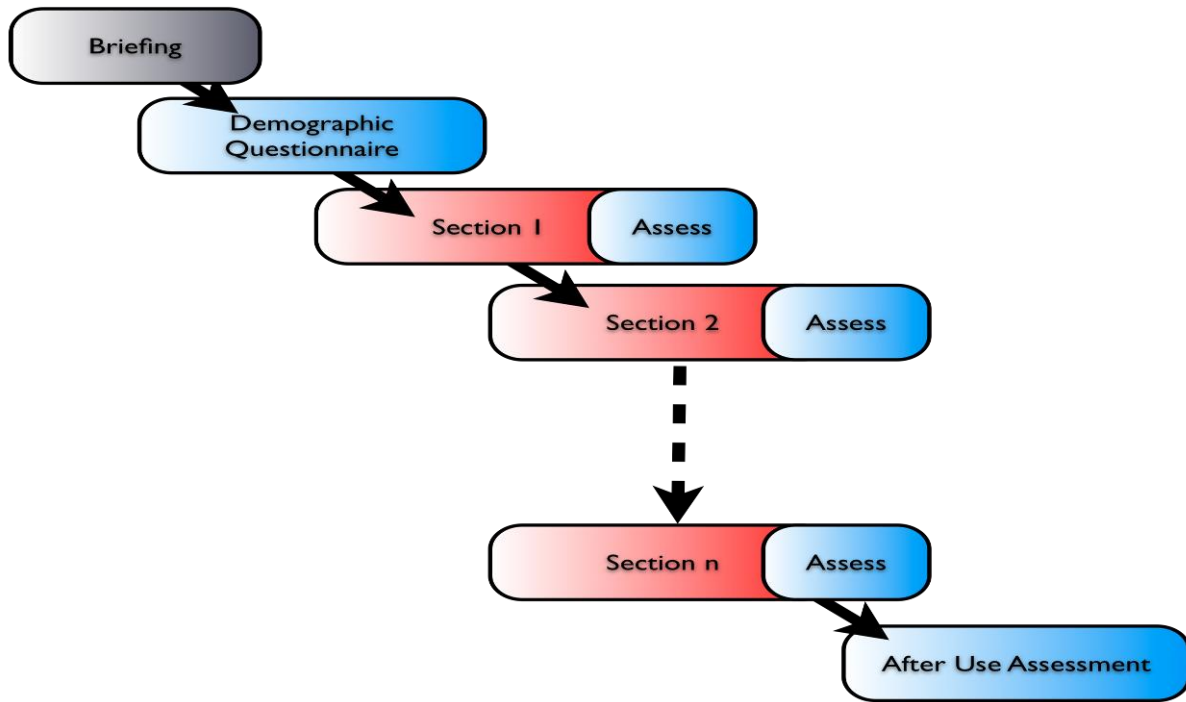


Figure 31 – Relationships between Experimental Activities

4.1.3.3 Experiment Design

The following subsections outline each of the experimental variables.

4.1.3.3.1 Independent Variables - Test applications

The following table presents the selected applications and describes the rationale for their selection.

Application Type	Specific Application Used	Rationale
Remote Desktop/VPN	Windows Standard Remote Desktop over OpenVPN	This application is easily available and is an industry standard application. The freely available OpenVPN is used to encrypt the traffic to provide a simulation of a user connecting to a corporate network and performing tasks on a server.
Gaming	Unreal Tournament 2004	First person shooter games are intensive; they have a constant upload stream and a reasonably constant download stream. 5 minutes of this type of game should be sufficient for the purposes of the experiment. Additionally, first person shooters (in contrast to some other gaming formats) allow you to enter the game at pre-saved points so that the experiment can be sure that each user has a similar experience, without repetition across the different systems.
VoIP	Skype Voice Only	Skype is freely available and is one of the most commonly used VoIP applications.
Video/audio Streaming	BBC news clips	News clips are short (between 3 and 5 minutes) and therefore fit into the flow of the experiment. There is a variety of equivalent news stories available. The content of the selected clips will not be intentionally biased towards interesting any specific participants. The navigation to the clip will also give the user experience with the general response of the internet, thus giving a representation of more general web browsing.

Table 20 – Rationale for Test Applications

4.1.3.3.2 Independent Variables – Demographics

The following tables present the demographic split.

Age	Target percentage of total	Target number of participants	Achieved percentage of total	Actual number of participants (23 in total)
18 - 24	25%	5	17%	4
25 - 44	30%	6	39%	9
45 - 64	30%	6	30%	7
65 - 74	10%	2	13%	3
75+	5%	1	0%	0

Table 21 –Demographic Split for Age

Gender	Target percentage of total	Target number of participants	Achieved percentage of total	Actual number of participants (23 in total)
Male	50%	10	52%	12
Female	50%	10	48%	11

Table 22 –Demographic Split for Gender

Experience with/novice	Target percentage of total	Target number of participants	Achieved percentage of total	Actual number of participants (23 in total)
VOIP	20% experienced 10% novice	4 experienced 2 novice	17% - high 35% - medium 17% - low 30% - none	4 - high 8 - medium 4 - low 7 - none
Streaming Video	20% experienced 10% novice	4 experienced 2 novice	30% - high 57% - medium 4% - low 9% - none	7 - high 13 - medium 1 - low 2 - none
Gaming	20% experienced 10% novice	4 experienced 2 novice	22% - high 4% - medium 26% - low 48% - none	5 - high 1 - medium 6 - low 11 - none

Table 23 –Demographic Split for Experience with Applications

Note: many of the participants had experience in multiple areas. Participants were not asked about their experience with using a remote desktop as the task used to assess this application was general file handling, which was considered to equate to general experience.

Every attempt was made to ensure that there was a spread of experienced/novice users across the age categories, but unsurprisingly the participants in the oldest category (over 65) had generally less experience, including the only participant who had no experience in any of the types of application and the only participant who rated their general internet use as low. The level of experience across the other three age categories was fairly evenly spread and all participants rated their general experience with the internet as “medium” or “high”.

4.1.3.3.3 Independent Variables - Baseline / Simulated Satellite / Live Satellite Link

There are three connection variables, which are:

- Baseline: this configuration represents a “standard” ADSL connection of 2 Mbps.
- Simulated/emulated satellite link: this software simulator emulates the behaviour of a typical satellite link carrying IP packets and includes IP packet delay, jitter, and packet loss as well as a performance enhancing proxy (PEP) to improve the performance of the TCP protocol over satellite links.

-
- Live satellite link: this was a real satellite link from an existing retailer¹¹. It provides a data point for the current off the shelf capability which can be compared with the simulated satellite link. It also included a PEP and a build in "TurboPage" feature. TurboPage is a software solution running at the satellite providers control centre to provide pre-caching of HTTP traffic to improve the apparent responsiveness of web surfing.

4.1.3.4 Measures of User Experience

The following data was captured during the experiment:

- Subject Background: data was gathered on participants':
 - Age
 - Gender
 - Experience with and use of the different application types (VOIP, video streaming and gaming)
 - General experience with and use of the internet
 - What they considered the most important aspect (other than cost) when choosing an internet supply
 - What aspects of an internet supply would cause them most problems or cause them to complain.
- Performance Assessment: after using each application, participants were asked to rate:
 - The speed of response
 - The amount/number of delays
 - How they would rate the general experience (thinking about the internet service rather than the application).
- Acceptance Assessment: after using each application, participants were asked to choose 3 descriptive terms (from the list provided) and state whether these descriptions would make them more or less likely to adopt this internet service.
- Comparative Assessment: participants were then asked to compare their experience with the application with their normal use of the internet for this application. At the end of the experiment participants were asked if they noticed a difference between the three different connection types and, if so, in which application(s) they thought it was most noticeable.

¹¹ Ethnet's "Business 2000" package. <http://www.ethnetuk.com/index.php?pageid=24>

4.1.4 ETHICS

Participants will be informed of their rights during the experiment, including the right to withdraw at any time without recrimination and the right to be non-identifiable in the published report.

Any identifying data about the participants will be removed prior to publication. The raw data which may contain identifying information will be stored securely and destroyed in line with HFE Solutions' quality procedures.

4.1.5 PROCEDURE FOR ASSESSMENT

After using each of the applications, the participants were asked the following questions:

Thinking about the application that you have just been using and using a scale of 1 to 5 where 1 is the worst and 5 is the best:

1. How would you rate the speed of response? (1 – 5)
2. How would you rate the amount/number of delays? (1 – 5)
3. Thinking about the internet service (rather than the application) how would you rate the general experience? (1 – 5)

Can you select three of the following terms that best represent your experience? (the words were shown to the participants on a printed sheet, they were in a random order on the sheet)

- | | | |
|-----------------|-------------------|-----------------|
| A – Exciting | G - Enjoyable | L - Hassle-free |
| B - Boring | H - Acceptable | M - Problematic |
| C - Standard | I - Adequate | N - Simple |
| D - Frustrating | J - Disappointing | O - Easy |
| E - Irritating | K - Stressful | P - Complicated |
| F - Satisfying | | |

4. For each of these terms, would this make you more or less likely to adopt this internet connection?
 - a. Word 1
 - b. Word 2
 - c. Word 3
5. How does it compare with your normal use of the internet for this application? Better/same/worse/don't normally use?
6. Any other comments?

4.1.5.1 Remote Desktop/VPN

The participants were asked to use the Windows remote desktop application to perform a series of simple tasks, representing the sort of thing that you might do over a remote link. A number of folders were put on the desktop containing dummy data, one of these folders (named "contacts") contained a spreadsheet named "address list", containing a list of dummy email addresses. As the participant would use this application on all three systems, they were asked to find a different email address on each use of the application; all the names began with "W" so that the participant would have to scroll down the list.

4.1.5.2 Voice over Network

Participants were asked to use the internet to have a telephone conversation for a few minutes. Their instructions were as follows:

- Please go into the Skype application and find Howard Tripp – he is in the favourites list.
- Once you are connected, Howard will chat to you about your last holiday/your next holiday/last time you went out. You do not have to talk about your real experiences if you do not want to, please feel free to use your imagination if you wish.
- The content of this conversation will not be reported or used in any way, we are just interested in your experience of chatting over the internet.

4.1.5.3 Streaming Video

Participants were asked to watch a video clip. They were asked to go into Firefox and find the BBC News website. They then had to search for the specific video clip, by typing the short phrase provided into the search bar. This took them to a page with links to the video clips; as the search results include more than one clip the participant needed to choose the clip with the specific title given to them. Each clip was about 4 minutes long and was more of a mini-documentary than breaking news: this meant that the same clips could be used for all the participants.

The following list provides the short phrase, followed by the specific title of the video clip: the clips were chosen to be of general interest and were not intended to appeal to any one demographic group.

- Boutique hotels - "Boutique hotels go big in Buenos Aires"
- Pay what you weigh - "Brazil's 'pay what you weigh' restaurants"
- Argentina polo - "Learning to play polo in Argentina"
- WWII bunker - "Berlin's abandoned WWII bunkers"
- Elephant and tiger - "Why an elephant might help you spot a tiger"
- Fastest rollercoaster - "Riding the world's fastest rollercoaster"

4.1.5.4 Gaming

The participants were asked to play an on-line game for a few minutes. The game was Unreal Tournament which is a "first person shooter" game. Their task was to play the game for 4 minutes without getting killed and to kill as many opponents as possible. Should the participant be killed there was a small time delay while their computer character was resurrected so that they could continue to play. Each participant played the game for the same amount of time, regardless of their success.

4.1.5.5 General Interaction with Internet

This aspect was covered by the participants navigating to the BBC News video clip and therefore was not separately assessed, however when assessing the video streaming application several participants provided separate scores for the general internet navigation and the video streaming.

4.1.6 STATISTICAL TESTS ON THE DATA

The data collected was compiled into two primary data tables: one containing the assessment scores and the other containing the participants' opinions on the relative importance and benefit of different aspects of an internet supply.

These data tables were imported into the statistical programme "R" and analysed for any significant relationships within and between the data.

To help with the statistical analysis, some additional fields were added to code the participants' response.

4.1.7 ASSESSMENT OF FINDINGS

For each element that was identified as statistically significant, the data was examined to determine the relationship and the trend of the significance.

In addition, the findings that are meaningful in terms of the differences between the systems were examined to determine the meanings of those differences.

4.1.8 ASSUMPTIONS

No major assumptions were made during the assessment process or subsequent analysis, other than the available participants and selected applications were appropriately representative.

4.2 RESULTS

This section presents the results of the analysis of the data collected.

4.2.1 REVIEW OF OBSERVATIONS FROM EXPERIMENT

Participants were asked to rate the aspects of an internet supply that was most important to them and also those aspects that would cause them most trouble or cause them to complain. The following figures shows that connection speed was considered the most

important aspect, followed by reliability and that an unreliable connection would cause them most problems/cause them to complain, followed by a slow connection.

The specific questions asked were:

When considering an internet supplier and not considering monetary cost, what do you consider the most important features? Choose up to 3.

- Speed
- Bandwidth (number of different users/uses at the same time)
- Response time (delays, latency)
- Reliability (interruptions to service)
- Download limit
- Other – please specify

When considering an internet supply, what would cause you most problems/cause you to complain? Choose up to 3

- Slow speed
- Inconsistent speed
- Limited bandwidth¹²
- Delays in response times (interruptions to download, incomplete webpages, freezing, etc)
- Unreliable service – interruptions to supply
- Inconsistent or unpredictable service – sometimes good, sometimes bad
- Small download limit
- Other – please specify

No participants responded to either of the questions with “other”.

The terms used represent the users’ perception of the internet supply: e.g. “speed” is a subjective assessment of the speed of response that they obtain from the service, it does not refer to the speed of data across the connection.

¹² I.e. are there any monthly data volume limits / caps?

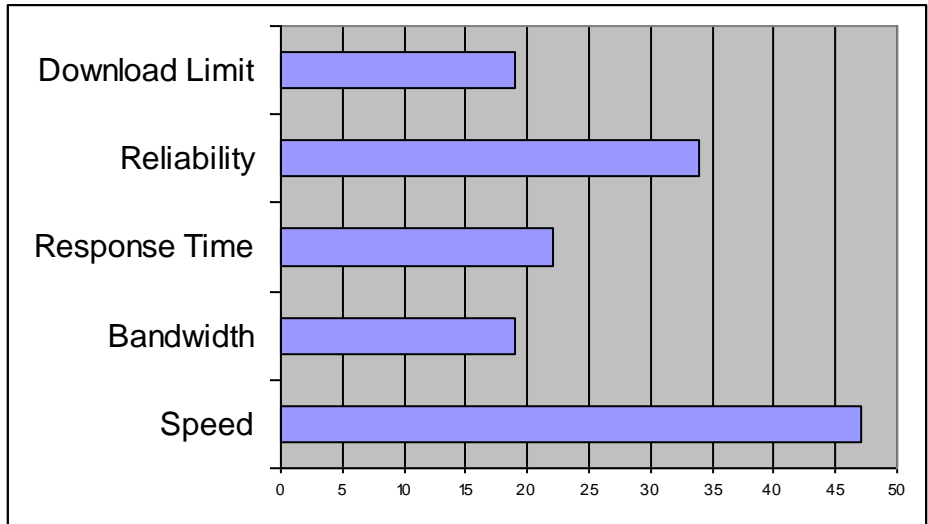


Figure 32 – Important Aspects when Choosing an Internet Supply

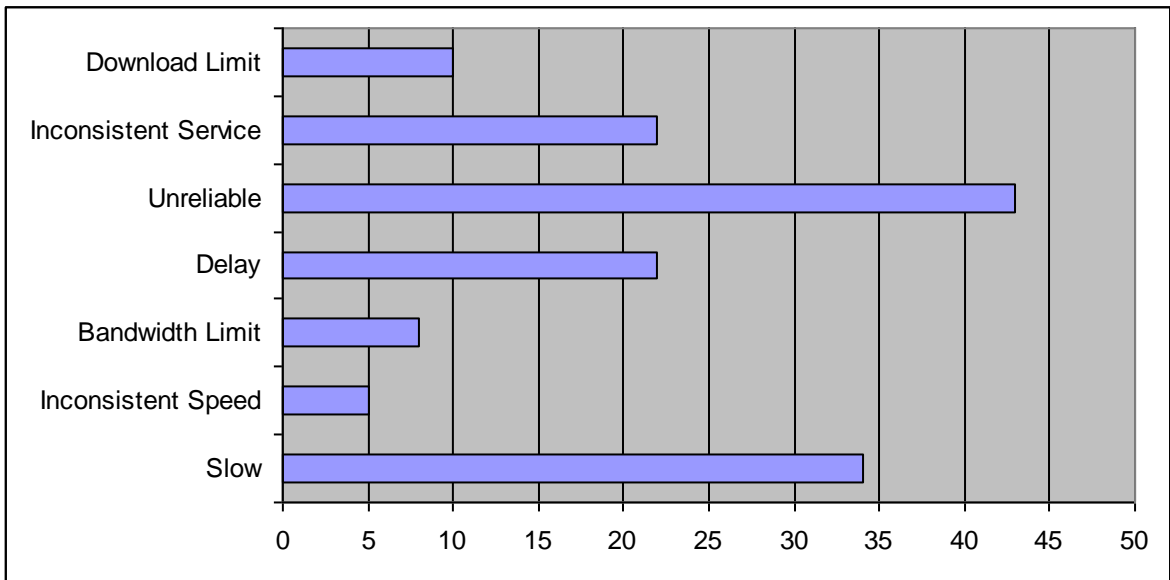


Figure 33 – Aspects of an Internet Supply that would Cause Problems/Complaint

There were very few comments made (other than separating the scores for video streaming and web browsing: these separate assessments are presented in 4.3.1 Observations). Comments made were:

Run	Comment
Video streaming on emulator	System slow, it must be a busy lunchtime
	Failed to start video
	Looks like dial up
	Would have thrown the PC out of the window
	Would have given up
Video streaming on satellite	Generally slow
	Just a bit slow
	Video fine

VOIP on emulator	Faint
Remote desktop/VPN on baseline	I work in graphics over VPN – this connection looks much faster than what I am used to
	Took a bit longer to load
Remote desktop/VPN on emulator	As it was slow, kept clicking, clicks interpreted by system - blamed self for system mis-navigations
	Varied across task
	“Would cry”
	Reassessed speed
	Worse, but not by much
Gaming on emulator	Borderline for adoption

4.2.2 STATISTICAL REVIEW OF THE DATA FROM THE EXPERIMENT

To allow us to look at the overall statistical variation within the collected data, the data was categorised and coded into the following groups:

- Assessment Score: this is the average of the subjective response given for speed, delay and overall service
- Run Type: this is the application being used (video streaming, VOIP, remote desktop or gaming)
- Run Mode: this is the system being used (baseline, emulated satellite or satellite)
- Experience Score: this is calculated from the experience of the participant with the different applications and also their general internet experience
- Word Score: each word was categorised as positive, neutral or negative, a positive word being chosen gave a score of +1, neutral was 0 and negative was -1
- Adoption: this score is calculated based on the participant’s response to the question “would this make you more or less likely to adopt this system?”
- Comparison: this is a subjective score based on a comparison with the participant’s own current system
- Age: there were 4 age categories
- Gender: male or female

Using the statistical analysis package R, a set of tests was conducted to determine the significance of any relationships between the groups of data. All of the data groups were tested against the Assessment Score.

The following table presents the significances found.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Run Type	1	36.930	36.930	93.9487	4.233e-08	***
Run Mode	2	65.991	32.996	83.9390	3.286e-09	***
Experience Score	1	5.773	5.773	14.6868	0.0014690	**

Word Score	1	109.044	109.044	277.4015	1.575e-11	***
Adoption	1	6.858	6.858	17.4453	0.0007123	***
Comparison	1	2.676	2.676	6.8081	0.0189814	*
Age	3	2.517	0.839	2.1341	0.1360011	
Gender	1	2.120	2.120	5.3943	0.0337138	*
Run Type:Word Score	1	2.074	2.074	5.2751	0.0354706	*
Experience Score:Adoption	1	2.879	2.879	7.3238	0.0155714	*
Experience Score:Gender	1	3.130	3.130	7.9616	0.0122806	*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

*** indicates that it is 99.9% likely that the relationship between these groups of data is not random.

The following statements can be concluded from these results:

- The different applications received significantly different scores
- The different systems received significantly different scores
- There were significant differences between the scores given by participants with different levels of experience. Further examination of the data showed that as the participants' experience increases, they are less likely to give extreme scores (either high or low).
- There is a significant relationship between the Word Score and the Assessment Score. Further examination of the data showed a high positive correlation: i.e. participants were consistent in their scoring with the two different question types.
- There is a significant relationship between the Assessment Score and the Adoption rating. Further examination of the data showed a high positive correlation between a low Assessment Score and not adopting and between a high Assessment Score and adopting; however the decision to adopt seems to be a more critical discriminator of the performance as a significant number of high Assessment Scores also indicated neutral adoption. In other words, a high assessment score does not necessarily indicate a sufficiently high performance for the participant to want to adopt the system, although a low assessment score indicates that the participant would not wish to adopt the system. In essence the Adoption rating is a better indicator as it more consistent in situations where users expressed neutral or mild feelings.

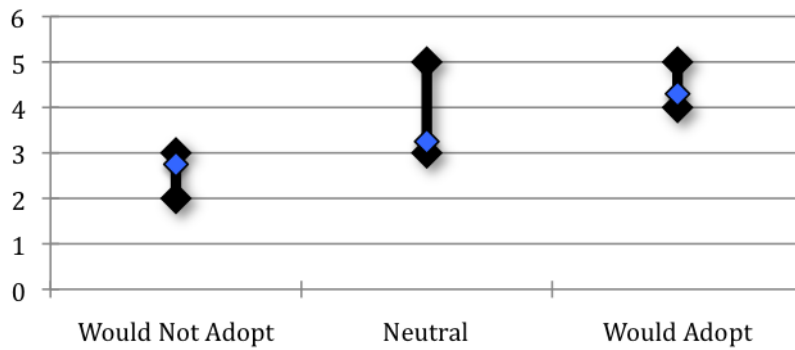


Figure 34 – Relationship between Assessment Score and Adoption Score

- Although there is a positive correlation between the comparison and the Assessment Score, taking into account the spread of data and the number of participants, it is not highly significant: i.e. there is only a 95% likelihood that these results are not random.
- There is no statistical relationship between the age of the participants and their Assessment Score.
- There is a slightly significant relationship between the gender of the participants and their Assessment Score: on further examination of the data it can be seen that women assessed the systems slightly higher than men.

An analysis of variants was also carried out across all of these parameters and the following composite relationships were identified as having a level of significance.

- Assessment Score/Run Type/Word Score: the relationship between the assessment score and the word score had significant differences across the four different run types. However examination of the data showed that the difference is in the gradient of the relationship between the assessment score and the word score: the gradient for the video streaming is significantly steeper than the gradient for gaming: i.e. a bad gaming assessment would score 3 whereas a bad video streaming assessment is more like to have scored 1. This means that the participants were more discriminative of video streaming than gaming. The gradients for VOIP and remote desktop were less extreme.
- Assessment Score/Experience/Adoption: examination of this view of the data provides two separate conclusions:
 - Of those participants who are unsure of adoption, there is significantly more variation in the assessment score: i.e. there is less correlation between adoption and assessment.
 - Of those participants who are unsure of adoption, significantly more are less experienced: i.e. the more experienced participants had clearer views on adoption.
- Assessment Score/Experience/Gender: examination of the data showed that this significance is due to the spread of participants taking part in the experiment: there was a fairly even spread of experience among the male participants, whereas the

female participants tended to have either less or more experience, there were very few female participants with middling experience.

4.2.2.1 Testing for Underlying Bias in the Data

A statistical test was conducted to determine if there was any significant difference in the assessment scores due to the time of day or the order in which the participants used the applications.

No statistical significance was found related either to the order in which the participants undertook the different applications on the different systems or to the time of day when they took part in the experiment.

4.2.3 STATISTICAL ANALYSIS FOR REPRESENTATIVE SYSTEM

This section presents the data gathered during the experiment, both overall and for each application separately.

4.2.3.1 Overall

Figure 35 below presents the assessment of speed of response for each application for each system. As can be seen, the satellite connection was assessed as best for streaming video, whereas the baseline was assessed as best for the other three applications.

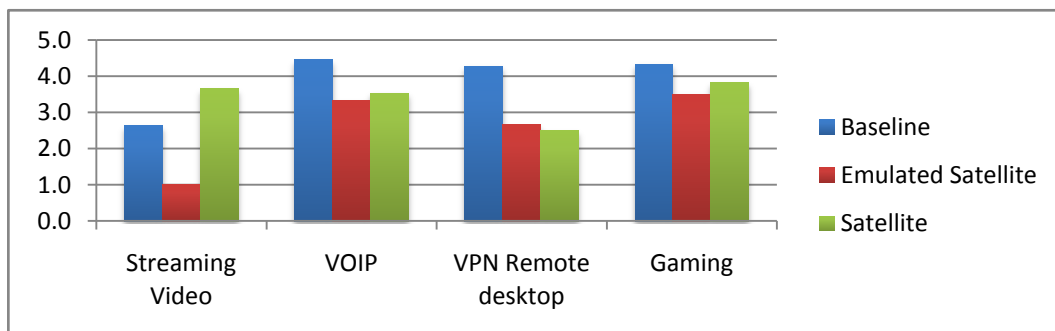


Figure 35 – Speed of Response Score for Each Application

Figure 36 below presents the assessment of delay for each application for each system. As with speed of response, the satellite connection was assessed as best for streaming video, whereas the baseline was assessed as best for the other three applications.

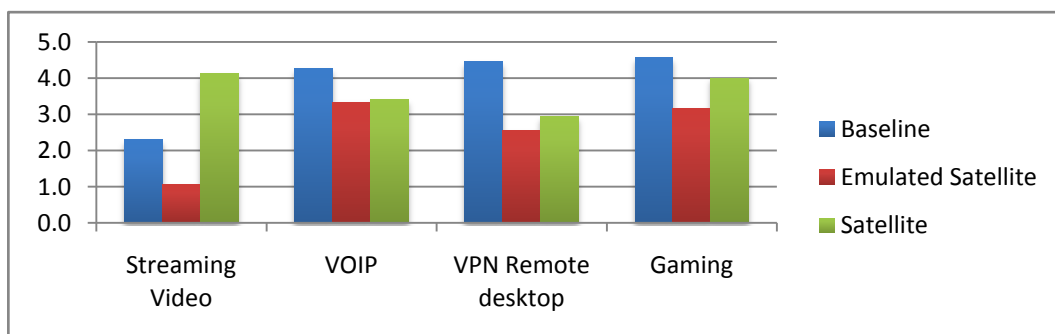


Figure 36 – Delay Score for Each Application

Figure 37 presents the assessment of overall service for each application for each system. This is consistent with the speed and delay assessments, with the satellite connection assessed as best for streaming video, and the baseline assessed as best for the other three applications.

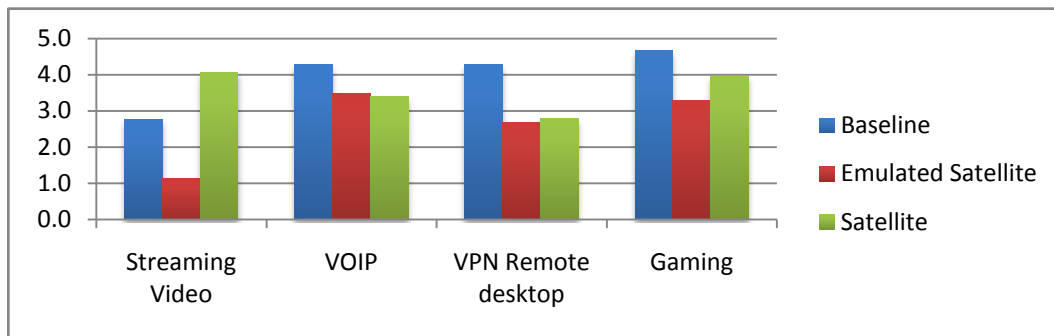


Figure 37 – Overall Service Score for Each Application

Figure 38 below presents the overall performance score (average of speed, delay and service) by age group. As can be seen, the scores are comparable across the different age groups, although the oldest participants had a tendency to score higher and the youngest to score lower.

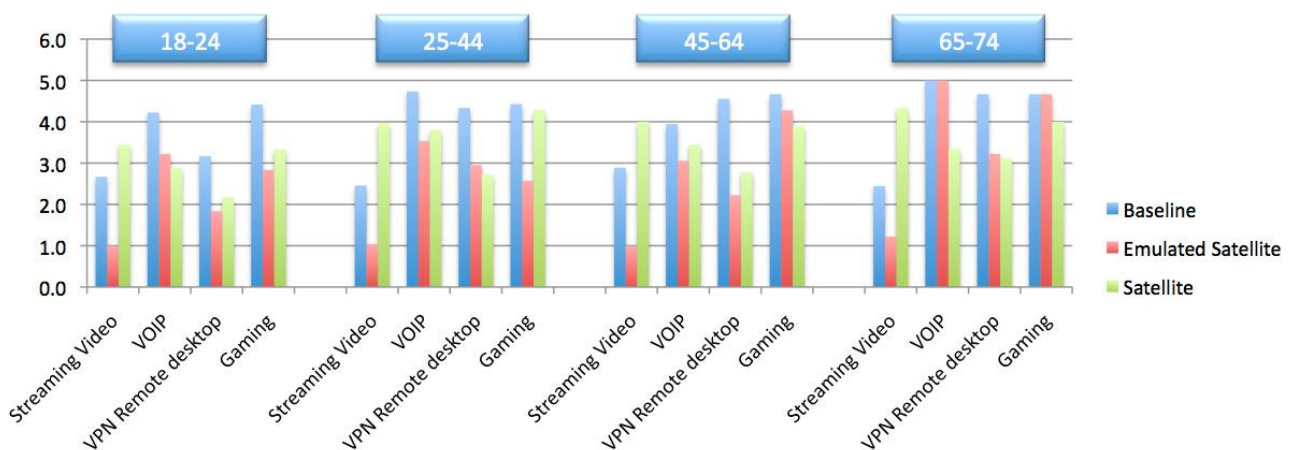


Figure 38 – Overall Performance Score by Age Group

4.2.3.2 Streaming Video

Participants were asked whether they would consider adopting the system for watching streamed videos, based on their experience during that run of the experiment. Figure 39 presents the participants' assessment of their likelihood of adopting the different systems for viewing video streams¹³. As can be seen, of those who would adopt, the vast majority would adopt the satellite connection.

¹³ The y-axis of the histogram is a count of the number of participants choosing each category for the different systems.

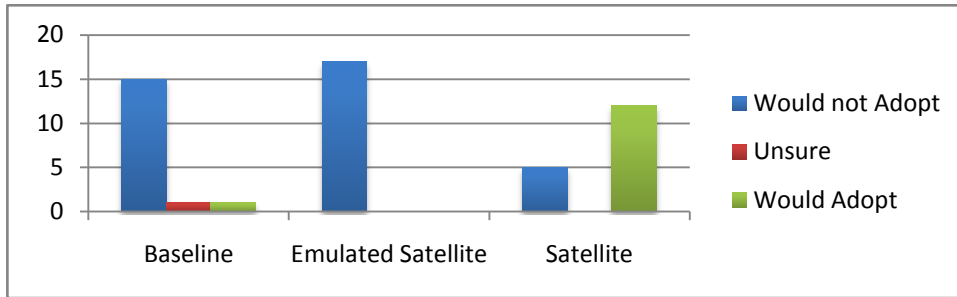


Figure 39 – Adoption Histogram for Video Streaming

Figure 40 below presents the average scores given by the participants for video streaming by adoption level. It can be seen that of those who would adopt, significantly higher scores were given to the satellite connection.

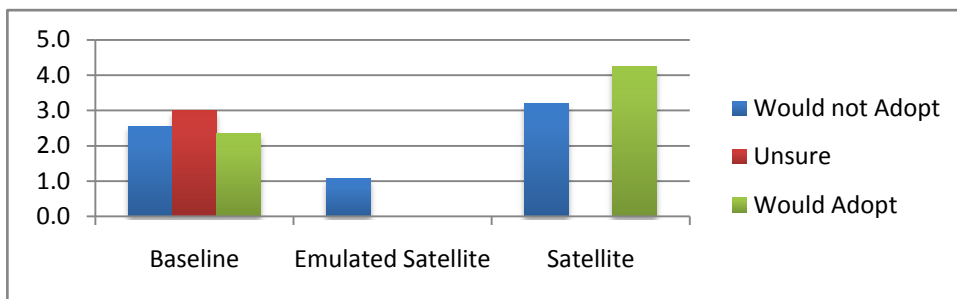


Figure 40 – Average Score by Adoption Level for Video Streaming

Figure 41 below presents the count of comparison with participants' current internet service: it can be seen that none of the participants rated the systems under test as being better than their current internet connection for video streaming.

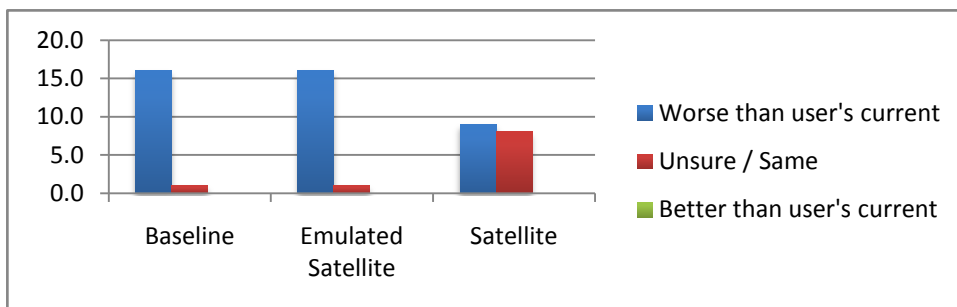


Figure 41 – Comparison Histogram for Video Streaming

Figure 42 below presents the participants' average score by comparison level. It can be seen that even when rated as worse than the participants' current internet connection, the satellite connection scored highest for video streaming.

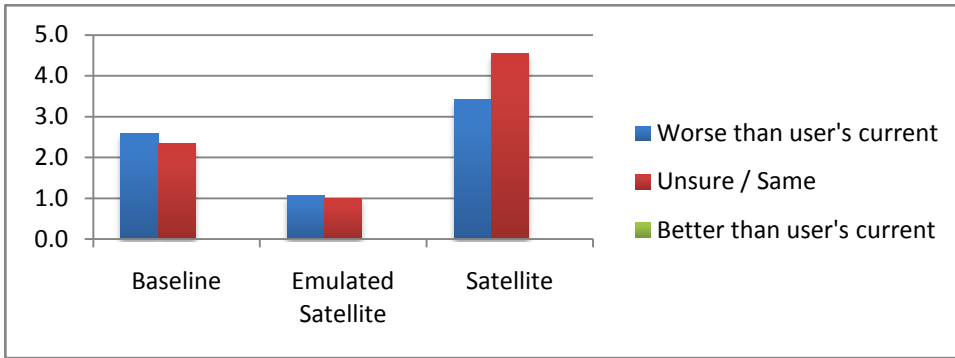


Figure 42 – Average Score by Comparison Level for Video Streaming

Figure 43 below presents the analysis of descriptive words for video streaming. The words have been separated into positive (at the bottom), neutral (in the middle) and negative (at the top). As can be seen, the satellite connection was scored as most positive, and the emulated satellite as most negative.

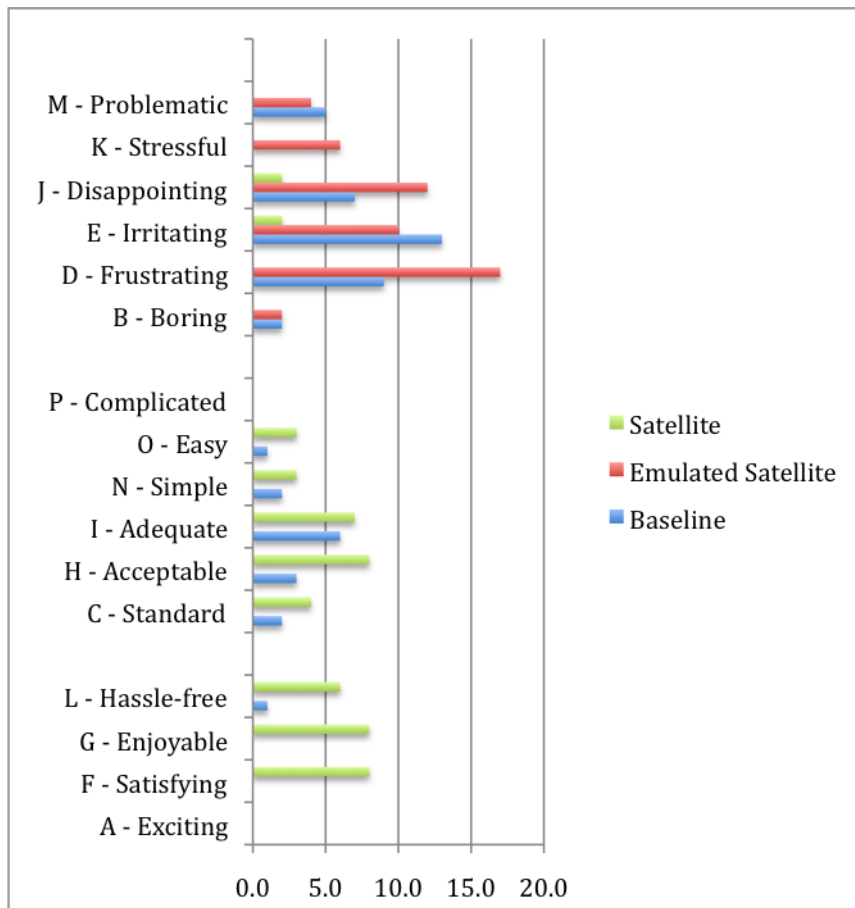


Figure 43 – Descriptive Words Histogram for Video Streaming

4.2.3.3 Voice over Network

Figure 44 below presents the participants' assessment of their likelihood of adopting the different systems for using VOIP¹⁴. As can be seen, of those who would adopt, the majority would adopt the baseline system, although a significant minority would adopt the satellite connection.

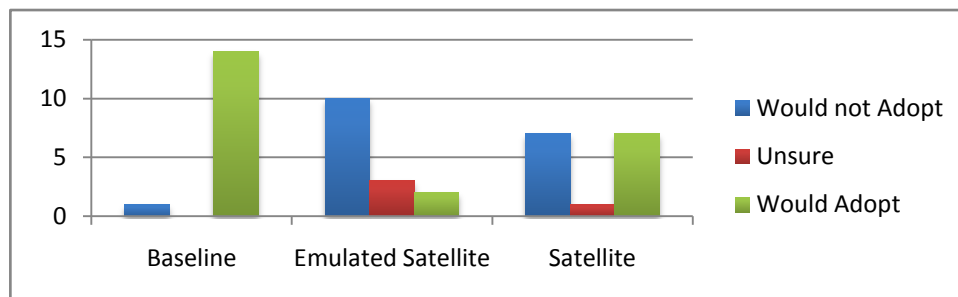


Figure 44 – Adoption Histogram for VOIP

Figure 45 below presents the average scores given by the participants for VOIP by adoption level. It can be seen that of those who would adopt, the scores are comparable across the three systems.

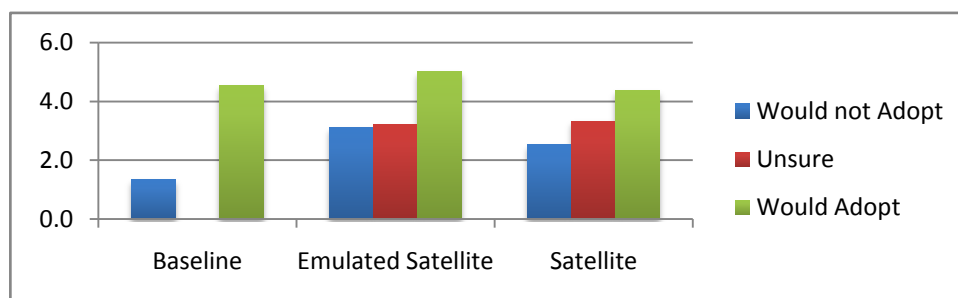


Figure 45 – Average Score by Adoption Level for VOIP

Figure 46 below presents the count of comparison with participants' current internet service: it can be seen that of those participants who rated the systems under test as being better than their current internet connection, most considered the baseline system to be better for VOIP.

¹⁴ The y-axis of the histogram is a count of the number of participants choosing each category for the different systems.

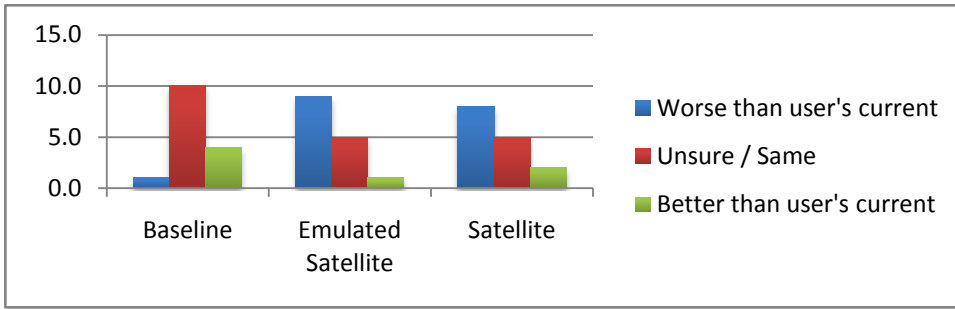


Figure 46 – Comparison Histogram for VOIP

Figure 47 below presents the participants' average score by comparison level. It can be seen that when rated as better than the participants' current internet connection, all three systems had comparable scores.

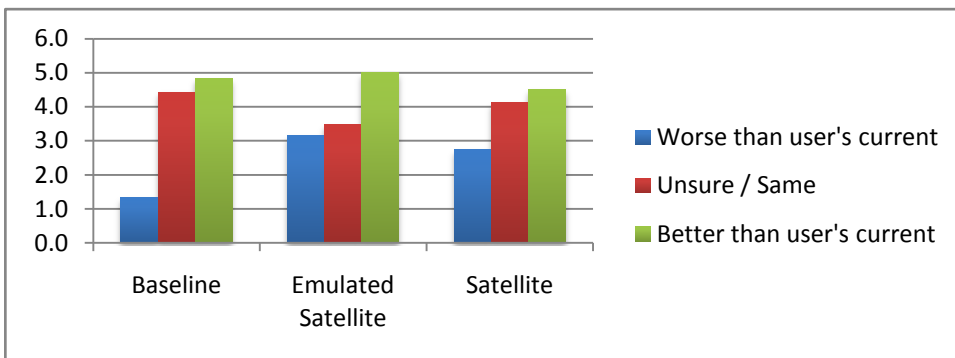


Figure 47 – Average Score by Comparison Level for VOIP

Figure 48 below presents the analysis of descriptive words for VOIP. As can be seen, the baseline connection was scored as most positive, and the satellite as most negative.

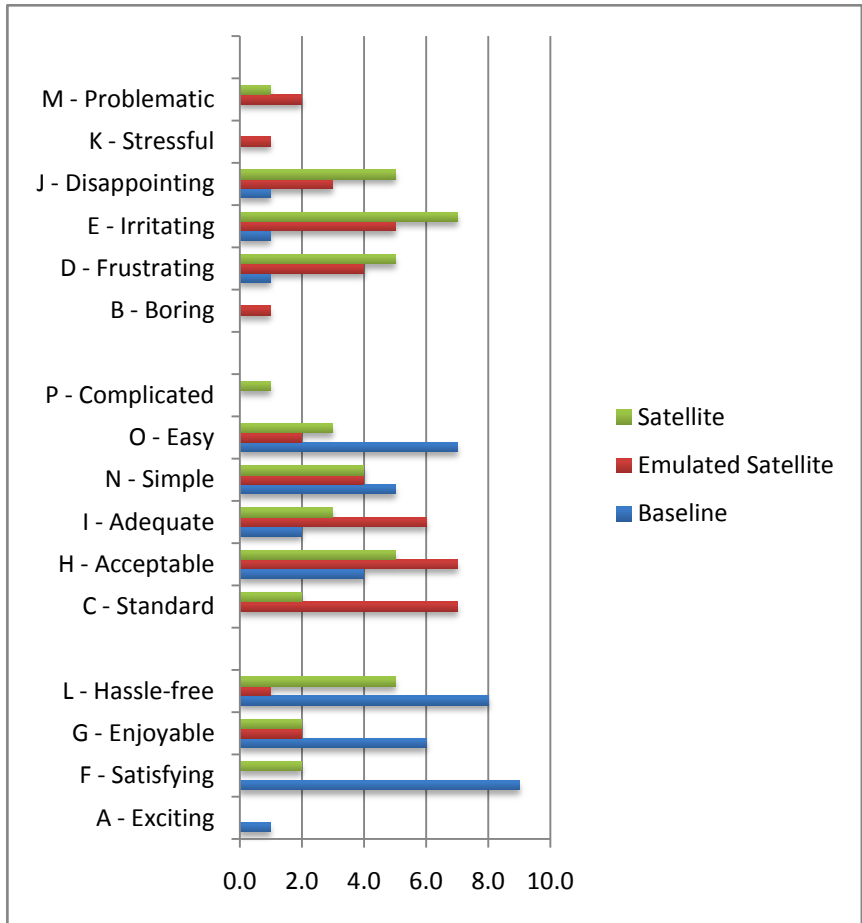


Figure 48 – Descriptive Words Histogram for VOIP

4.2.3.4 Remote desktop/VPN

Figure 49 below presents the participants’ assessment of their likelihood of adopting the different systems for using remote desktop/VPN¹⁵. As can be seen, of those who would adopt, the majority would adopt the baseline system.

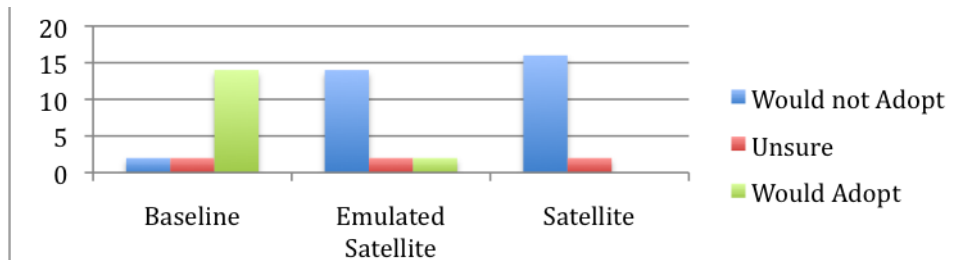


Figure 49 – Adoption Histogram for Remote desktop/VPN

¹⁵ The y-axis of the histogram is a count of the number of participants choosing each category for the different systems.

Figure 50 below presents the average scores given by the participants for remote desktop/VPN by adoption level. It can be seen that of those who would adopt, the scores are comparable for the baseline and the emulated satellite.

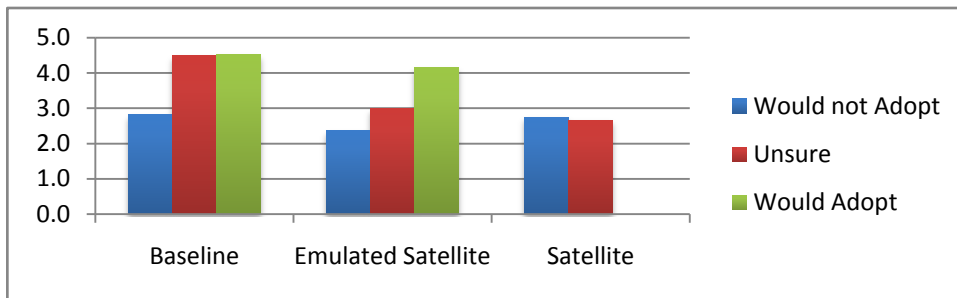


Figure 50 – Average Score by Adoption Level for Remote desktop/VPN

Figure 51 below presents the count of comparison with participants’ current internet service: it can be seen participants only rated the baseline as being better than their current internet connection for remote desktop/VPN.

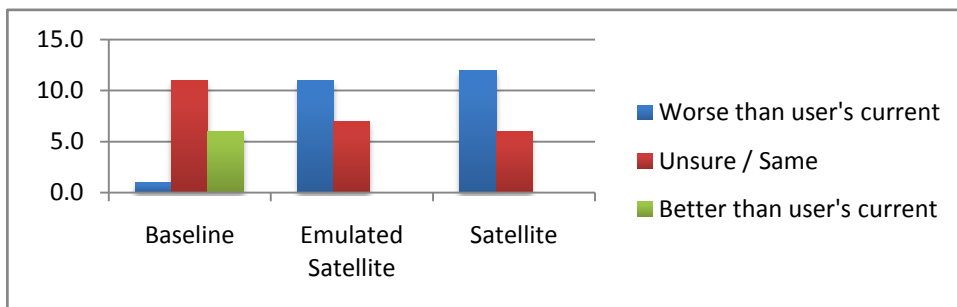


Figure 51 – Comparison Histogram for Remote desktop/VPN

Figure 52 below presents the participants’ average score by comparison level. It can be seen that when rated as worse than the participants’ current internet connection, the satellite received higher scores for remote desktop/VPN, even though no participants rated it as better than their current system.

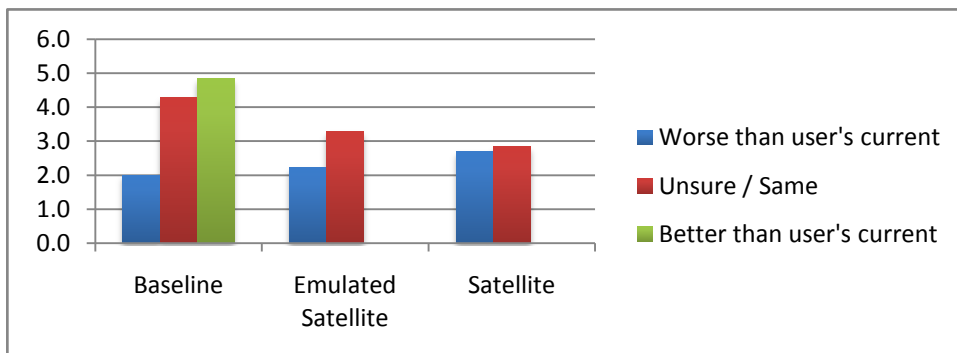


Figure 52 – Average Score by Comparison Level for Remote desktop/VPN

Figure 53 below presents the analysis of descriptive words for remote desktop/VPN. As can be seen, the baseline connection was scored as most positive.

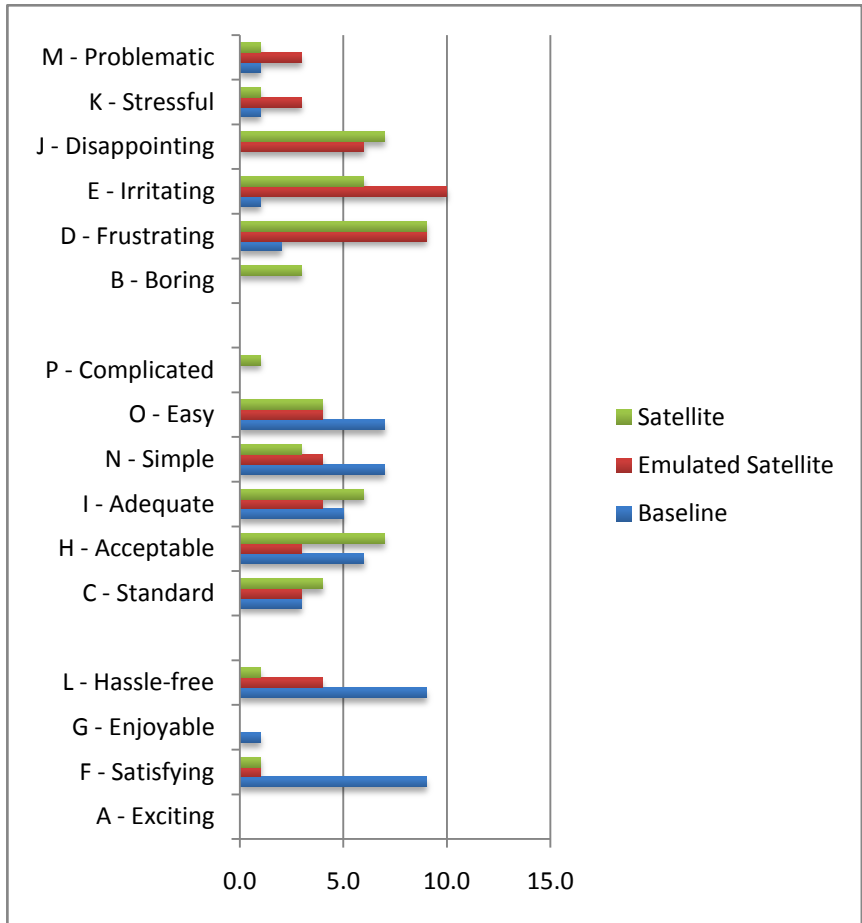


Figure 53 – Descriptive Words Histogram for Remote desktop/VPN

4.2.3.5 Gaming

Figure 54 below presents the participants’ assessment of their likelihood of adopting the different systems for gaming¹⁶. As can be seen, of those who would adopt, the majority would adopt the baseline system

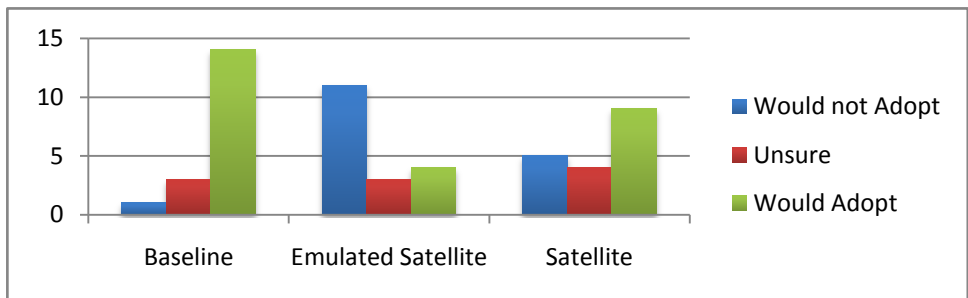


Figure 54 – Adoption Histogram for Gaming

¹⁶ The y-axis of the histogram is a count of the number of participants choosing each category for the different systems.

Figure 55 below presents the average scores given by the participants for gaming by adoption level. It can be seen that of those who would adopt, the scores are comparable across all three systems.

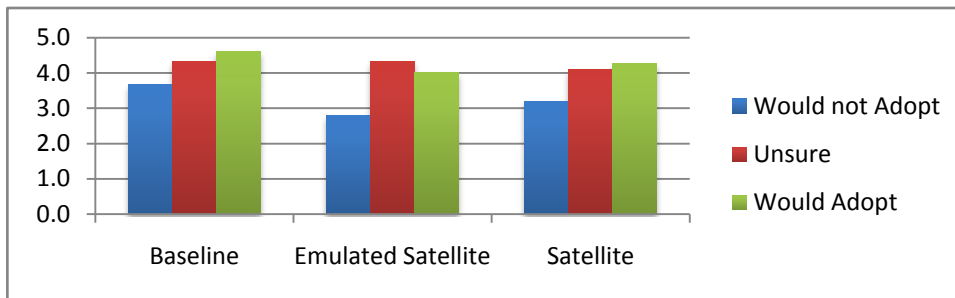


Figure 55 – Average Score by Adoption Level for Gaming

Figure 56 below presents the count of comparison with participants' current internet service: it can be seen that of those participants who rated systems as being better than their current internet connection for gaming, the majority thought that the baseline was better, though there were some who thought that the satellite was better.

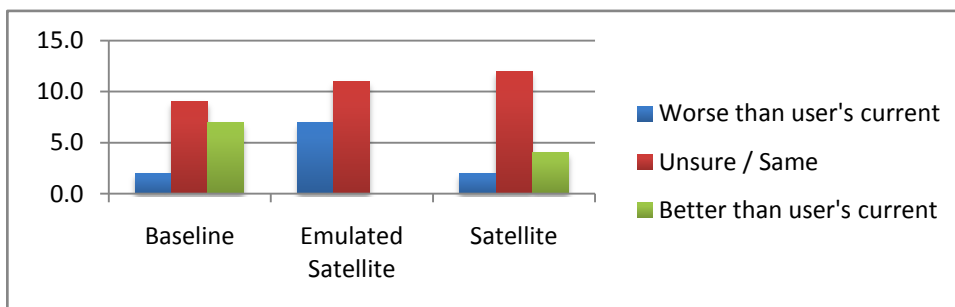


Figure 56 – Comparison Histogram for Gaming

Figure 57 below presents the participants' average score by comparison level. It can be seen that when rated as better than the participants' current internet connection for gaming, the baseline received higher scores than the satellite connection.

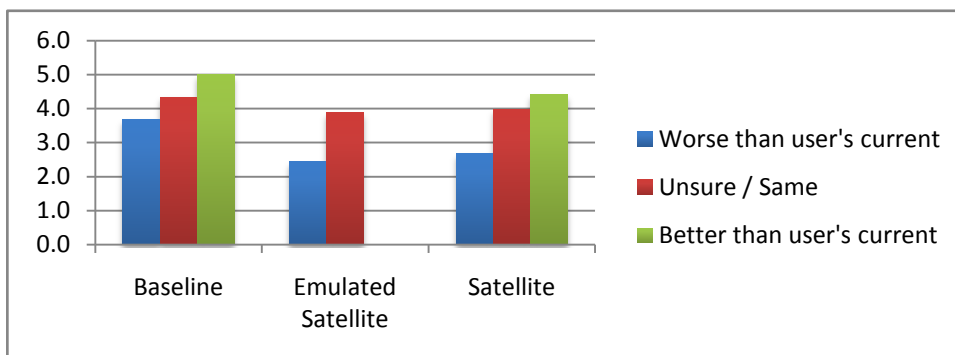


Figure 57 – Average Score by Comparison Level for Gaming

Figure 58 below presents the analysis of descriptive words for gaming. As can be seen, the baseline connection was scored as most positive and the emulated satellite as most negative.

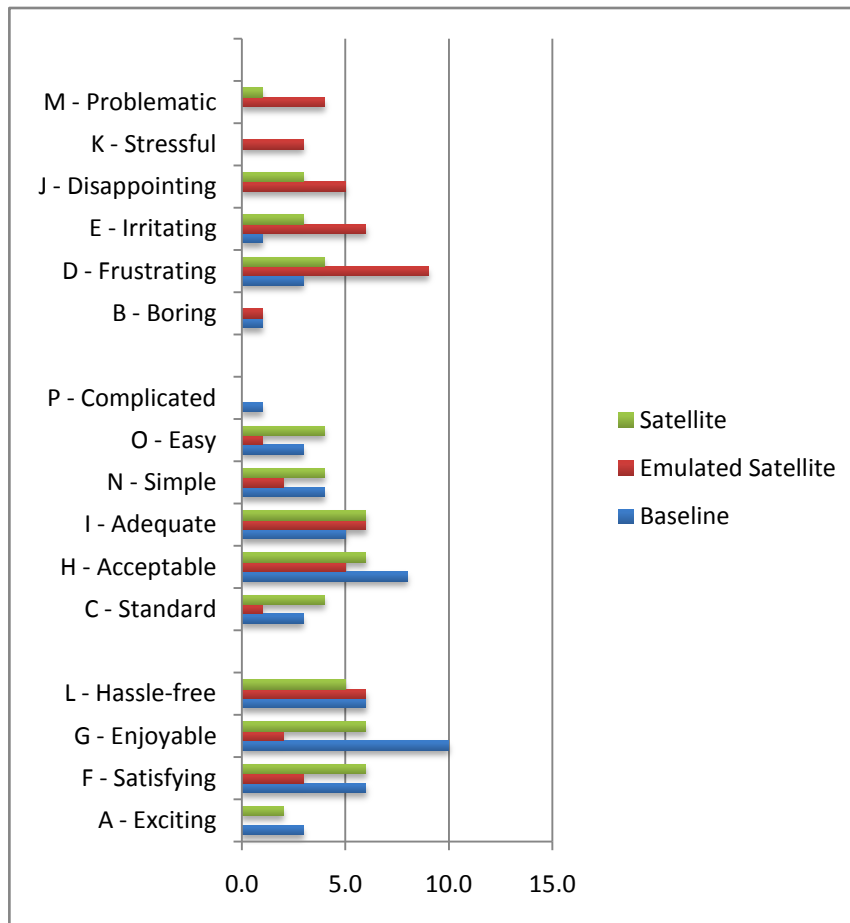


Figure 58 – Descriptive Words Histogram for Gaming

4.2.4 SUMMARY

Figure 59 below presents the overall score (made of up speed, delay and overall service) for all applications for all systems. It can be seen that overall the emulated satellite connection scored worst.

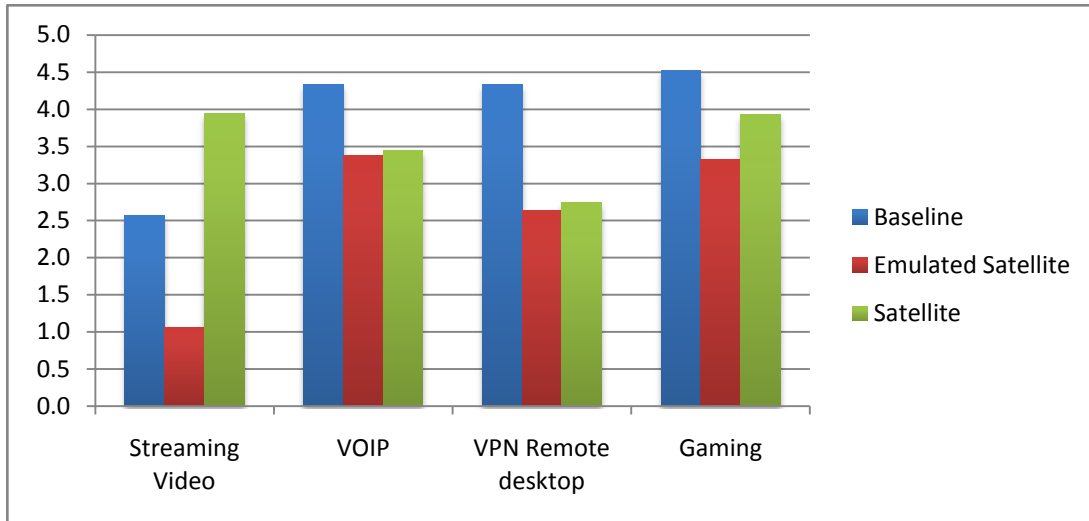


Figure 59 – Overall Score for All Applications

Figure 60 below presents the average of the adoption scores for all applications for all systems. In order to average these scores, individual responses were assigned numerical values using the convention that negative figures represent "would not adopt" (-1), positive ones "would adopt" (+1), and neutral for "unsure/undecided" (0). Again the emulated system scored worst.

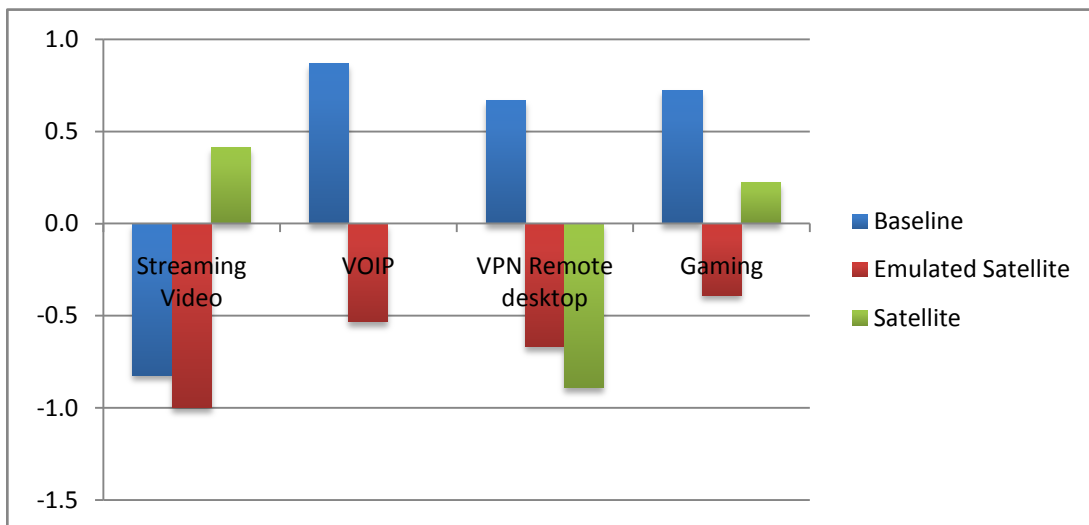


Figure 60 – Overall Adoption Levels for All Applications

Figure 61 below presents the average of the comparison scores for all applications for all systems. Similarly for this figure the individual scores were assigned numerical values: "worse than current system" (-1), "better than current system" (+1), and "same as current system" (0). It shows that even though the satellite connection for streaming video scored highest of the three it was still not rated as better than the participants' current systems.

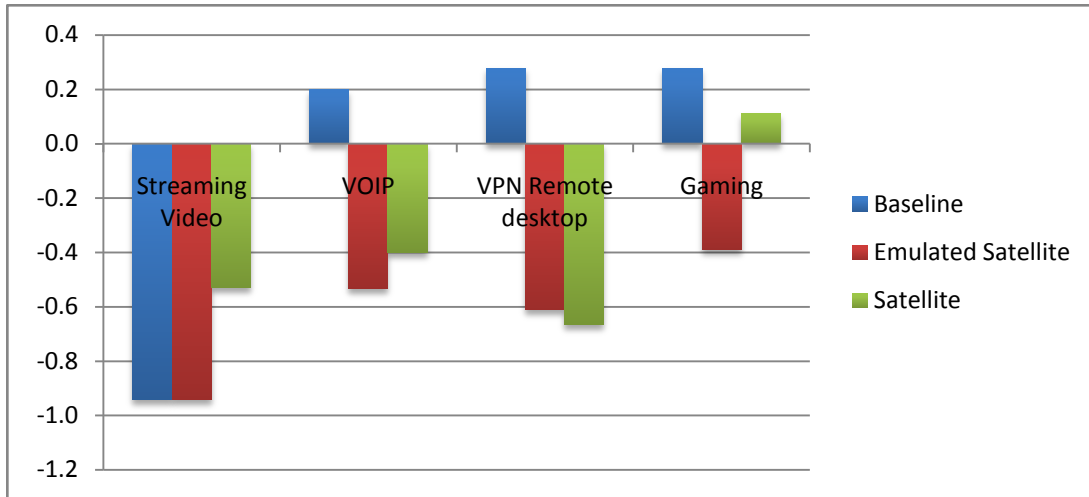


Figure 61 – Overall Comparison Levels for All Applications

In general, the emulated satellite scored the worst across all measures, the baseline scored high for everything except streaming video and the satellite connection scored high for streaming video and gaming.

4.3 DISCUSSION

From the results above it seems that the adoption rating is more sensitive than the more objective ratings of speed, delay and general service: i.e. participants generally only indicated positively for adoption when the objective ratings had a score of 4.4 or above. However on further examination of the data it can be seen that those who scored high but indicated that they would not adopt that system for that application were generally the less experienced older participants. This may indicate that they would not adopt the system because they did not think that they would use that application rather than because they did not think the system good enough to adopt. Alternatively it may show that because these users were not au fait with that type of application they could not reliably discern whether or not that system was good enough to adopt.

4.3.1 OBSERVATIONS

When scoring the baseline and satellite connections for speed of video streaming there was agreement across several participants that for the satellite the video streaming was better than the web browsing and for the baseline the web browsing was better than the video streaming.

Speed and reliability were generally considered to be the critical aspects of an internet supply.

It should also be noted that the advanced features (the TurboPage “accelerator”) of the satellite link used caused it, in general, to provide a significantly better internet supply than the emulated satellite. This was particularly evident in the streaming video application.

4.3.2 EXPERIMENTAL METHOD

The results show that the participants were consistent in their marking across the different collection measures: i.e. if they rated the speed, delay and overall service as good, they

were more likely to indicate that they would adopt that system for that application and to use more positive terms to describe it. This indicates that they were making an informed decision and thus that the results are valid for this demographic of participant. The participants were generally experienced internet users and the data also indicates that the more experienced the user, the more discriminating they are in their ratings of the systems, which is also a positive indication for the validity of the results.

5 CONCLUSIONS

5.1 RESULTS SUMMARY

The results of the quality of experience user trials show that the subjective impressions of performance are significantly dependent upon application. With the most basic¹⁷ of the four application tests (web browsing/streaming video), the real satellite link subjectively provided the best service and was assessed as the most likely to be adopted. Subjectively, it appeared to perform better than a terrestrial broadband system. Irrespective of the network service used for this application test, users clearly had high expectations for web browsing and video streaming, most likely due to familiarity with high-speed broadband at home and office, and also from the media. Therefore, even though the relative performance showed that the satellite was better than a standard ADSL link, a significant number of participants would not have adopted it for use with this application and none of them rated it as better than their current terrestrial Internet Service Provider (ISP).

In the remaining three applications (remote desktop/VPN, VoIP and online gaming), the overall assessment of the speed and quality of service clearly showed that the emulated satellite and the actual satellite link were considered significantly worse than a terrestrial broadband system. In the majority of these cases, the emulated satellite and the actual satellite link were not considered of an acceptable standard to be adopted for use and were generally considered to provide a worse service than the participants' current ISP. By contrast, the standard ADSL link was mainly rated as similar or slightly better compared to their current ISP.

Although three out of four applications indicated that terrestrial broadband was superior to satellite broadband, it is important to bear in mind that the one application (web browsing), where the satellite service outperformed the terrestrial service, is likely to be the most fundamental online activity. It is beyond the scope of this study to indicate what services rural users are most interested in; however, such an analysis would allow the results of the four applications to be combined together into a weighted sum. The important thing to stress, however, is that QoE is application dependent, and so tightly defining the importance of the various applications to rural community users will in large part dictate the attractiveness of satellite broadband.

It is likely that the explanation for the perceived QoE difference between the various applications relates to whether the content was able to be cached – i.e., whether it was static or dynamic. The real satellite link incorporated a pre-caching proxy service for HTTP traffic called "TurboPage". Internet surfers are already familiar with variable webpage latency, and how it takes different parts of websites different amounts of time to download. When the user is carrying out web browsing activities across predominantly static websites, the TurboPage pre-caching can successfully remove a large part of the "Internet latency" (and multiple TCP connection inefficiencies) and in principle allow a web page to download "all at once". The only remaining delay for the webpage to download is due in large part to the satellite link latency, which in many cases is better, and certainly less variable, than standard HTTP/TCP latency, thus resulting in an improved perceived performance. For static content, pre-caching proxy solutions would appear to be an effective mitigation technique to overcome the inherent satellite link latency. It is so good in fact that the QoE of the satellite link was rated above the terrestrial broadband for static content.

¹⁷ Basic in terms of interactivity e.g. simple searches and clicking links in a familiar web browser environment

In contrast, when the user is interested in dynamic applications (online gaming), applications that are real time (VoIP), or network traffic that is encrypted (VPN), pre-caching is not possible, and the satellite link latency adds to the inherent Internet latency resulting in worse perceived performance compared to terrestrial broadband. Furthermore, note that a pre-caching service has limited use with dynamic web pages that are customised per-user and require user-to-server communications per session. Pre-caching also cannot be used with encrypted (HTTPS) web pages.

What this indicates is that there is a trade-off between "richness versus speed". The more dynamic, interactive and user tailored an Internet application is, the "richer" it will appear to a user. However as an application grows richer, its performance begins to degrade over a satellite link, and most content becomes "on-demand" and highly tailored to the users, reducing the effectiveness of pre-caching. Furthermore, as there is a trend towards richer, more interactive and user specific dynamic websites (e.g. social networking) that use techniques such as AJAX, there is likewise a decrease in the scope of the content for which pre-caching can be an effective mitigation technique. Accessing the internet via a higher latency satellite link may therefore expose end-users to recognising whether services are static (e.g. BBC News) or dynamic (e.g. Facebook), something of which they would otherwise be unaware.

This exposure to the "richness" of an application/website means users may more consciously make the trade-off between content, utility and speed. One route for the users to consciously make this choice is by selecting the "lo-fi" or "mobile" versions of websites where that choice is available. Historically, many websites offered these versions for dial-up customers, and the modern trend is to push for mobile versions optimised for smart phones. These days many sites do have mobile versions (eBay, Amazon, BBC, Facebook, Wikipedia, etc) which mitigate the effect of the constrained bandwidth and speed of mobile connections. Ofcom should encourage these "alternative" sites to be openly available to people connecting from any low bandwidth or high latency link, mobile or not.

5.2 OBSERVATIONS

- Some participants indicated that they would adopt the actual satellite link for gaming. This may in part be due to online game developers having a long history of working with variable Qualities of Service (QoS) on players' Internet connections, and thus developing protocols optimised for constrained bandwidth and variable delay. However, on closer examination of the data, these individuals seem to be the more experienced gamers. It is likely therefore that their experience has given them skills to compensate for deficiencies in the Internet supply, while still achieving their goals within the game. This is likely to be a subconscious learnt skill. It could be argued that similar subconscious learning may well take place with users of satellite broadband to allow them to cope with the latency subconsciously to some degree.
- The user trials took place over five consecutive days during normal business office hours, with sunny or fine weather, without any incidents of rain. No statistical significance was observed due to time of day effects, however clearly there are system issues to do with contention ratios and high levels of demand. This short duration trial should therefore be considered as a snapshot in time for a real satellite link, which could have corresponded to either a good or bad loading on the satellite. There would be merit in running longer term trials, to determine what effect time of day/week, weather conditions or seasonal variation have on the QoE assessment.

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- The results for the comparison between the real satellite link and the emulated link seem to indicate that emulator was a reasonable first order approximation to a real link. The slight discrepancies between their results can be accounted for by the fact that the real link had an additional pre-caching feature which the emulator did not have.

5.3 LESSONS LEARNT

- Due to the gaming effect identified above, in any future experiments it is important to involve experienced gamers as subjects to assess gaming performance.
- The question it was difficult to ask (although of most interest) was, "*would it be adopted by people who can't get Internet access any other way?*". The results of this trial indicate that the answer is most probably yes, but with some caveats. Being able to answer this question really depends on finding a suitable demographic to ask, which is a nontrivial exercise. The primary reason is that such people are by their very nature, geographically remote and dispersed, which means that identifying and involving them in a trial would require a significant increase in resources.
- When assessing QoE it is important to understand that people have complex expectations and perceptions. It is not sufficient to assume that people who would adopt satellite broadband have dial-up as their only experience. People are mobile, and experience high-speed broadband in other locations such as places of work or visiting friends and relatives around the country. Moreover, even if they were static, people have expectations via TV advertising and general interactions with UK-wide media and communities that impact how people assess performance and value for money.

5.4 CONSEQUENCES FOR OFCOM

One immediate thing that Ofcom could do to improve the user experience would be to provide some recommendations/guidelines for people using satellite broadband. Such a guide could highlight the difference between static and dynamic content and advise people how to mitigate the effects. For example, the effect of a satellite link would be almost unnoticeable to people sending and receiving e-mail via IMAP and SMTP access with an offline desktop email client (e.g. Microsoft Outlook), but could potentially be frustrating for those using webmail services.

The results of this trial showed that use of satellite broadband should certainly not be discounted, as for basic Internet surfing (e.g. searching for information) it is entirely usable. However, for interactive services the results conform to stereotype. What is needed therefore it is a more fine-grained investigation to determine: at what point it switches from acceptable to unacceptable; how that point can be moved by incorporating new technology; and where that point crosses the threshold for adoption in rural areas? Specifically:

- Research should be conducted into dynamism/interactivity of the online experience and how this is likely to change in the future. What resources and technologies are content providers putting in place to support those on low bandwidth/high latency links? How can content providers be encouraged to increase their support?
- The pre-caching system for the real satellite link was exceptionally effective for static content. This demonstrates that it is possible to incorporate technology to overcome and mitigate the inherent latency. What is needed therefore is to extend the

technology beyond basic HTTP/TCP caching so as to improve the performance of other protocols and services. For example, encouraging more technical research on topics such as: satellite protocol enhancement (e.g. for encrypted traffic); protocol optimisation and compression; ways to identify the type of higher layer applications from traffic to feed into QoS mechanisms; and ways to enhance pre-caching for dynamic content.

- This trial carried out research on a standard commercially available satellite Ku-band service. Ka-band services are beginning to become available and will start to take over from Ku-band. Ka-band is likely to provide a performance and capacity improvement, but potentially with higher variability due to weather conditions. It would be interesting to extend these trials to investigate Ka-band QoE performance (ideally over a longer duration), and what the implications are for future rural broadband.
- Understanding the trend in Internet usage patterns for those in rural communities appears to be essential. The results of this trial indicated that QoE is highly dependent on application and so must be thought about in that context. A better definition of what are “basic” Internet services and what are “luxury” services would help guide future studies and understanding of what is “good enough”.

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A.3 ABBREVIATIONS

ACM	Adaptive Coding and Modulation
B3G	Beyond 3rd Generation
BB	BroadBand
BER	Bit Error Ratio
BoD	Bandwidth on Demand
BPSK	Binary Phase Shift Keying
CBR	Constant Bit Rate
CPE	Customer Premises Equipment
CRSC	Circular Recursive Systematic Convolutional
DAB	Digital Audio Broadcast
DAMA	Demand Assignment Multiple Access
DSL	Digital Subscriber Line
DSNG	Digital Satellite News Gathering
DTT	Digital Terrestrial Television
DVB	Digital Video Broadcast
DVB-H	Digital Video Broadcast - Handheld
DVB-S	Digital Video Broadcast -Satellite
DVD	Digital Video Disc
EC	European Commission
ECC	Electronic Communications Committee (of CEPT)

EDTV	Enhanced Definition TeleVision
eirp	Equivalent isotropically radiated power
ESA	European Space Agency
ETSI	European Telecommunications Institute
FAP	Fair Access Policy
FDM	Frequency Division Multiplex
FEC	Forward Error Correction
FIP	Fair Information Policy
FSS	Fixed Satellite Service
FTTH	Fibre To The Home
GATpS	Global Average Throughput per Subscriber
GDP	Gross Domestic Product
GEO	Geostationary Earth Orbit
GES	Gateway Earth Stations
GW	Gateway
HDTV	High Definition TeleVision
HNS	Additive White Gaussian Noise
HSPA	High Speed Packet Access
HSSI	High Speed Serial Interface
IETF	Internet Engineering Task Force
IMAP	Internet Message Access Protocol
IP	Internet Protocol
IPDV	IP packet Delay Variation
IPER	IP packet Error Ratio
IPLR	IP packet Loss Ratio
IpoS	IP over Satellite
IPTD	IP packet Transfer Delay

ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
ITQ	Invitation to Quote
ITU	International Telecommunications Union
ITU	International Telecommunications Union
LDPC	Low Density Parity Check (code)
MAC	Medium Access Control
Mbps	Megabits per second
MEO	Medium Earth Orbit
MF-TDMA	MultiFrequency –Time Division multiple Access
MMO	Massively Multiplayer Online
MPLS	Multi Protocol Label Switching
MSB	Most Significant Bit
NCC	Network Control Centre
NG	Next Generation
NOC	Network Operations Centre
OECD	Organisation of Economic Cooperation and Development
PEP	Performance Enhancing Protocols/ Proxy
PSTN	Public Switched Telephone Network
QEF	Quasi Error Free
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RCS	Return Channel by Satellite
RCS	Return Channel via Satellite
RCST	Return Channel Satellite Terminals
RF	Radio Frequency

RoHC	Robust Header Compression
RTT	Round Trip Time
SCPS	Space Communications Protocol Specifications
SDTV	Standard TeleVision
SLA	Service Level Agreement
SME	Small Medium Enterprise
SMTP	Simple Mail Transfer Protocol
SOHO	Small Office /Home Office
SSL	Secure Sockets Layer
STB	Set Top Box
STW	Sliding Time Window
TCP	Transmission Control Protocol
TD-CDMA	Time Division- Code Division Multiple Access
TDD	Time Division Duplex
TDM	Time Division Multiplex
TDMA	Time Division multiple Access
TLS	Transport Layer Security
TRL	Technology Readiness Level
UDP	User Datagram Protocol
USD	US Dollars
VCM	Variable Coding and Modulation
VNO	Virtual Network Operator
VoD	Video on Demand
VoIP	Voice over IP
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network

WAP	Wireless Application Protocol
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WP	Work Package
xDSL	Digital Subscriber Line (type unspecified)

Appendix B COMPARISON OF CURRENT GENERATION SATELLITE, AND NEXT GENERATION SATELLITE NETWORK SYSTEMS

B.1 SYSTEM TECHNICAL PARAMETERS

Characteristic	Current Generation Satellite Network System (Ku-band Satellite w/ 2nd Generation Terminal Technology) Feature / Functionality	Next Generation (2.5G) Satellite Network System (Ka-band Satellite w/ 3rd Generation Terminal Technology) Feature / Functionality	Third Generation (3G) Satellite Network System Feature / Functionality	Third Generation Benefits Relative to Current Generation Satellite Network Systems
<input type="checkbox"/> Satellite User Downlink Beam	Full geographic coverage via multiple large satellite beams.	Partial to Full geographic coverage via multiple small satellite beams	Full geographic coverage via multiple small and large satellite beams shaped, located and containing a variable number of carriers with variable bandwidth based on population distribution	-Beams more specifically shaped and focussed to meet customer demand and performance while utilizing satellite resources efficiently. -Provides higher bandwidth to users and user capacity where needed geographically
<input type="checkbox"/> Frequency Reuse	Low frequency reuse, typically 2 times	Medium frequency reuse, typically 20 times in ~50 MHz spot beams	High frequency reuse, typically 20 times in ~500 MHz spot beams	-High frequency reuse results in higher capacity and bandwidth per beam- better user performance.
<input type="checkbox"/> Estimated Subscriber Capacity	Maximum of 100,000 to-300,000 subscribers per satellite with few to none having high downlink rates. Very slow speeds during peak hours.	Maximum of 300,000 to 1 million subscribers per satellite with a moderate percentage having high downlink rates. Slow speeds during peak hours.	Maximum of 300,000 – 400,000 subscribers per satellite (600,000-800,000 total system) with all users having higher downlink rates with guaranteed QoS.	-All Australians living in rural (unwired) areas and 2% - 4% of Australians living in metro/regional (wired) areas will have the option of accessing cost-efficient ADSL2+ equivalent broadband via satellite
<input type="checkbox"/> Total Downlink Satellite Throughput Capacity	1-10 Gbps per satellite (~10-25kbps per user daily average)	Up to 40 Gbps per satellite (~30-40kbps per user daily average)	40+ Gbps per satellite (80+ Gbps total system) (~50-100kbps per user daily average)	-Satellite capacity matched to best meet subscriber distribution and throughput requirements -High satellite capacity allows true broadband for more subscribers by making sufficient uplink and downlink data throughput available for each user with ubiquitous coverage.

Characteristic	Current Generation Satellite Network System (Ku-band Satellite w/ 2nd Generation Terminal Technology) Feature / Functionality	Next Generation (2.5G) Satellite Network System (Ka-band Satellite w/ 3rd Generation Terminal Technology) Feature / Functionality	Third Generation (3G) Satellite Network System Feature / Functionality	Third Generation Benefits Relative to Current Generation Satellite Network Systems
<input type="checkbox"/> User Data Rate	Maximum beam capability per user given no contention: 5 Mbps down / 256 Kbps up	Maximum beam capability per user given no contention: Up to 30 Mbps down / 1.6 Mbps up	Maximum beam capability per user given no contention: Up to 100 Mbps down / 12 Mbps up	-System can provide required 12Mbps minimum downlink to all customers which is over double the speed of current satellite platforms. - Enterprise or special application satellite customers can have much higher throughput capabilities for large throughput applications. - Much higher uplink capability allows remote sites to be server locations, content providers, multimedia sources, video teleconferencing participants and corporate headquarters.
<input type="checkbox"/> Bit Error Performance	10-8 downlink; 10-6 uplink	10-10 downlink; 10-7 uplink; Adaptive Coding and Modulation (ACM) only on the downlink	10-10 downlink; 10-10 uplink; Adaptive Coding and Modulation (ACM) on the downlink and uplink.	-Customer experiences higher throughput and less delay due to fewer retransmissions. - ACM on uplink and downlink maintains performance during rain conditions
<input type="checkbox"/> Latency	Little latency-management techniques; no data compression, little web page caching and pre-fetching, 1st generation web acceleration, no SIP acceleration, little to no QoS or application enhancements.	Some latency-management techniques; 2.5 generation data compression, 2.5 generation web acceleration, SIP acceleration, application aware enhancements	Advanced latency-management techniques with more applications optimized for delay with application aware QoS: - Protocol Enhancing Proxy (PEP) for TCP/IP transmissions at higher arbitrary data rates - Pre-fetching to reduce response times - Prioritized traffic to meet timing and jitter requirements - IP header and data compression to reduce transmission time	-Third generation acceleration techniques minimize the inherent satellite link transmission delay and thus provide optimized end-to-end services for better user experience.

Characteristic	Current Generation Satellite Network System (Ku-band Satellite w/ 2nd Generation Terminal Technology) Feature / Functionality	Next Generation (2.5G) Satellite Network System (Ka-band Satellite w/ 3rd Generation Terminal Technology) Feature / Functionality	Third Generation (3G) Satellite Network System Feature / Functionality	Third Generation Benefits Relative to Current Generation Satellite Network Systems
<input type="checkbox"/> Availability (annual average which includes environmental conditions, planned outages and maintenance activities)	90.0% -No adaptations for rain conditions to ensure connectivity (i.e. coding and modulation)	>99.6% (for critical applications such as VoIP, http, email) - Adaptive coding and modulation for rain conditions on downlink only. -Adaptive power transmission. - High availability provided only to those areas within the narrow spot beams. Limited geographic coverage.	99.7% (for critical applications such as VoIP, http, email) - Adaptive coding and modulation for rain conditions on downlink and uplink. -Adaptive power transmission.	-Customers experience similar availability as 2.5 generation systems while using a mix of wide and narrow beams. This mix of beams provides ubiquitous coverage with a more efficient satellite. -Much higher tolerance to rain than current systems allowing more connection time to the user and better experience. -Next generation systems prioritize applications to maintain minimum resources during periods of congestion to provide customers with best performance
<input type="checkbox"/> Customer Premises Equipment (CPE) Cost	\$500-\$1000 USD	\$500-\$1500 USD	\$300-\$500 USD	-Customers pay lower CPE costs and gain access to a better performing satellite platform.
<input type="checkbox"/> CPE Dish Size and Equipment	Low link margins requiring CPE dish ~1 meter in diameter	High link margins requiring CPE dish ~0.65 meter in diameter	High link margins requiring CPE dish ~0.65 meter in diameter	-Smaller and less obtrusive dish on customer premises or line of site location, simplifying installation. - 2-3 times more bandwidth per dish size using better equipment and advanced transmission techniques.
<input type="checkbox"/> CPE Deployment	Fulfilment of subscriber by fast installation of satellite dish at premises. Instant availability of satellite service to the user.	Fulfilment of subscriber by fast installation of satellite dish at premises. Instant availability of satellite service to the user.	Fulfilment of subscriber by fast installation of satellite dish at premises. Instant availability of satellite service to the user.	-Customers located anywhere in Australia gain access to ADSL2+ equivalent broadband

B.2 SUBSCRIBER EXPERIENCE PARAMETERS

Characteristic	Current Generation Satellite Network System (Ku-band Satellite w/ 2nd Generation Terminal Technology) Feature / Functionality	Next Generation (2.5G) Satellite Network System (Ka-band Satellite w/ 3rd Generation Terminal Technology) Feature / Functionality	Third Generation (3G) Satellite Network System Feature / Functionality	Third Generation Benefits Relative to Current Generation Satellite Network Systems
<input type="checkbox"/> Overall Subscriber Experience	Comparable to dial-up Internet access.	Comparable to DSL Internet access	Comparable to ADSL2+ Internet access	-Customers are offered increasingly better service experience involving audio, video and file transfer. The service experience matches that of terrestrial service experience. -Most applications, outside real-time highly interactive gaming, perform comparably to terrestrial networks based on user perception. -Guarantee the retailer's SLA and thereby promote the options and experience of a user.
<input type="checkbox"/> Data Compression	None	Yes – 2.5 generation data compression	Yes – 3.0 generation data compression	-Compressing message headers, and in some cases the body of the message, before transmission over the satellite conserves the bandwidth usage and delay, thereby increasing effective data throughput and improving customer experience. - Third generation systems significantly reduce the bandwidth required for VoIP traffic by eliminating extraneous and redundant protocol information; improving delays over satellite and improving the customer experience.
<input type="checkbox"/> Data Compression Benchmarks	1Mb inbound file transfer – approx. 180 seconds (No Protocol Enhancing Proxy (PEP))	1Mb inbound file transfer – approx. 135 seconds (PEPv3)	1Mb inbound file transfer – approx. 9 seconds (PEPv3.5 with V.44 packet payload compression)	- Advanced PEP and compression techniques provide improved performance and better user experience with higher satellite efficiency.
<input type="checkbox"/> VoIP Codec	First Generation Codec (MOS <3.2)	Second Generation Codec (MOS 3.2)	-Third Generation Codec (MOS 3.4)	-Delivers voice quality comparable to cellular resulting in better user experience

Characteristic	Current Generation Satellite Network System (Ku-band Satellite w/ 2nd Generation Terminal Technology) Feature / Functionality	Next Generation (2.5G) Satellite Network System (Ka-band Satellite w/ 3rd Generation Terminal Technology) Feature / Functionality	Third Generation (3G) Satellite Network System Feature / Functionality	Third Generation Benefits Relative to Current Generation Satellite Network Systems
<input type="checkbox"/> Video Resolution	Standard Definition	Standard Definition	High Definition enabled through increased data throughput for both uplink and downlink to the users	- Increased data throughput, especially on the uplink, and advanced compression and error correction techniques will allow symmetric high definition video services. - Capability to support new applications, over ALL-IP network, with guaranteed user experience.
<input type="checkbox"/> Web Browsing	Web Acceleration generation 1.0	Web Acceleration generation 2.5	Web Acceleration generation 3.0	-Substitutes multiple sequential „get“ operations of non-cached web objects over the satellite link with pre-fetching of web objects at the satellite gateway utilizing proxy and then delivering to the satellite user using push techniques. -Results in faster web page loading over the satellite link.
<input type="checkbox"/> Web Browsing Benchmarks	Average time to fully open a set selection of web pages = >50 seconds (No PEP, no compression, no web acceleration)	Average time to fully open a set selection of web pages = 17.03 seconds (PEPv3, compression on, no web acceleration)	Average time to fully open a set selection of web pages = 11.89 seconds (PEPv3, compression on, advanced web acceleration- pre-fetch, caching)	- Advanced web acceleration techniques provide improved performance and better user experience- fast browsing, high efficiency, high throughput.
<input type="checkbox"/> TCP/SIP	TCP Acceleration No SIP Acceleration	TCP Acceleration SIP Acceleration	TCP acceleration SIP Acceleration	- SIP (Session Initiated Protocol) Acceleration is used for voice/video/other signalling over the ALL-IP network. Utilizing a SIP proxy server, the satellite gateway replaces multiple sequential SIP client operations over the satellite link to a single or lesser number of operations over the link and thereby increases the speed of SIP operation, resulting in faster response times and improved user experience.

Characteristic	Current Generation Satellite Network System (Ku-band Satellite w/ 2nd Generation Terminal Technology) Feature / Functionality	Next Generation (2.5G) Satellite Network System (Ka-band Satellite w/ 3rd Generation Terminal Technology) Feature / Functionality	Third Generation (3G) Satellite Network System Feature / Functionality	Third Generation Benefits Relative to Current Generation Satellite Network Systems
□ QoS Management	Not Applicable	Application aware enhancement	Application aware enhancement Application Aware QoS - Generic End-to-End QoS (MPLS) User QoS to Retailer QoS Mapping	<p>-Application Aware QoS recognizes the application by inspecting the IP packets and applies the QoS relevant to that application. The QoS guarantee is then applicable within the Satellite Access Network, and thus last mile rather than just at the gateway nodes, thereby extending the performance benefits of QoS management directly to the user. This is most beneficial to interactive services providing improved user experience. - Through End-to-End QoS management, the end user's experience is guaranteed to be acceptable for present and future applications. - Generic End-to-End QoS (MPLS) has the additional advantage over „Application Aware QoS“ by minimizing the delay introduced due to packet inspection and therefore minimizing response time. - User QoS to Retailer QoS Mapping results in better subscriber experience by way of retailer's SLA guarantee and promoting the increase of retailer and application service providers - Examples of various QoS and access scheme capabilities the system can support include but are not limited to: multilevel IP QoS with VoIP prioritization, Bandwidth on Demand (BoD) as needed, Constant Bit Rate (CBR) for guaranteed QoS applications, application-triggered BoD/CBR and CBR reallocation.</p>

Appendix C TOOWAY FAIR ACCESS POLICY (FAP)

The following is taken from the Tooway Statement on Fair Access Policy [Ref 40].

C.1 PURPOSE

The objective of the FAP is to assure a fair distribution of the available resource of the broadband network to all users, with the focus to provide the best experience of broadband to regular users and to control the resource sharing among the members of a heterogeneous and variable population of users.

Please note that all the following values may change following traffic evaluation without further notice.

C.2 INTENDED NOMINAL SERVICE

When not under FAP conditions (limitations) the user could expect:

1. A minimum of 50% of the peak speed 90% of the time.
2. A Minimum of 20% of peak speed 95% of the time.
3. Applications Web Browsing and mail services.
4. Very low speed and priority on all "peer to peer" applications.

C.3 DEFINITION OF FAP RELATED EXPRESSIONS

- Connected Terminal: A terminal that is connected to the network but not always producing traffic.
- Active Terminal: A terminal that is connected to the network and currently producing traffic.
- Activity Factor: The ratio between the number of active terminals and connected terminals.
- User – Subscriber – Terminal: For the FAP one VSAT is considered to be connected to one PC for one subscriber or user. The FAP does not consider if there is more than one PC or other device behind the VSAT.
- GATpS: Global Average Throughput per Subscriber calculated over the whole population of subscribers.

C.4 REGULAR USER

The subscriber uses the resources in accordance with the standard traffic models and complies with the two following conditions;

1. The short-term traffic volume of a single active user is exponentially distributed with consistent average with the service definition;
2. The temporal distribution of accesses from active users follows Poisson distribution with rate in accordance with hypothesised activity factors.

Over the group of all regular users, the GATpS is specified to 14 kbps with an Activity factor.

C.5 AB USER

These subscribers generate traffic, temporarily or permanent that exceeds the standard models. The FAP is designed to limit three different types of Ab Users.

1. Occasional Ab User: generates a very high traffic volume sporadically. GATpS > 30 kbps and exceed condition 1) mentioned above.
2. Frequent Ab Users generate traffic exceeding the standard models regularly in specific hours of the day or certain days of the week. Their Activity Factor is > 1/25 and they exceed condition 2) mentioned above.
3. Permanent Ab Users generate a continuous high level of traffic and exceed condition 1) as well as condition 2) mentioned above. Their GATpS is > 50 kbps and their activity factor is > 1/25.

C.6 FAP THE PRINCIPLE

Depending on the volume of traffic, that each individual user generates, the FAP reduces the available bandwidth of this specific user. The NOC measures the traffic volume in intervals of 5 minutes and makes the integral of the total volume over a certain period. The current FAP foresees periods in the following called Sliding Time Window (STW) of one hour, 4 hours, one day, one week and four weeks. Should the traffic inside a Sliding Time Window (STW) exceed the volume limit the FAP reduces the bandwidth to the specific user. As soon as the traffic volume of the STW reached the volume below the limit, the FAP releases the bandwidth limitation.

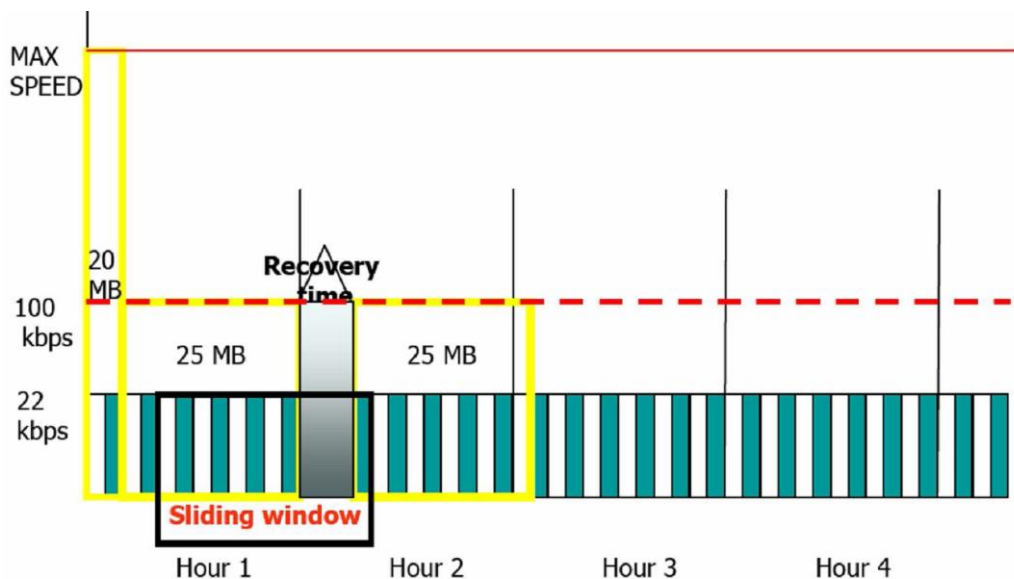


Figure 62 - FAP Sliding Time Window (STW) Mechanism

C.7 FAP RULES

1. Limits the use of resource done by Ab Users by limiting the traffic volume.
2. For each and every user the produced traffic is observed over multiple Sliding Time Windows (STW).
3. Volume Thresholds (VT) are pre-set for each STW.
4. If the traffic generated by a specific user exceeds any of the defined thresholds, the relevant STW is declared FAPped and the maximum throughput is considerably reduced for that user until the STW is no longer FAPped.

Fair Information Policy (FIP)

Instantaneous real time information can be given to each subscriber for:

1. Network congestion (FAP active or not);
2. Being FAPed or not.

TooWay Throttle Limits

Basic	Bronze	Silver	Gold
Traffic Volume Usage Last 1 Hour ----- Threshold: 60 MB Used:	Traffic Volume Usage Last 1 Hour ----- Threshold: 106 MB Used:	Traffic Volume Usage Last 1 Hour ----- Threshold: 160 MB Used:	Traffic Volume Usage Last 1 Hour ----- Threshold: 318 MB Used:
Last 4 Hour ----- Threshold: 120 MB Used:	Last 4 Hour ----- Threshold: 200 MB Used:	Last 4 Hour ----- Threshold: 300 MB Used:	Last 4 Hour ----- Threshold: 600 MB Used:
Last 1 Day ----- Threshold: 360 MB Used:	Last 1 Day ----- Threshold: 600 MB Used:	Last 1 Day ----- Threshold: 900 MB Used:	Last 1 Day ----- Threshold: 1800 MB Used:
Last 1 Week ----- Threshold: 960 MB Used:	Last 1 Week ----- Threshold: 1600 MB Used:	Last 1 Week ----- Threshold: 2400 MB Used:	Last 1 Week ----- Threshold: 4800 MB Used:
Last 4 Week ----- Threshold: 2400 MB Used:	Last 4 Week ----- Threshold: 4000 MB Used:	Last 4 Week ----- Threshold: 6000 MB Used:	Last 4 Week ----- Threshold: 12000 MB Used:

Figure 63 - TooWay Throttle Limits

Appendix D OVERVIEW OF APPROPRIATE DVB SATELLITE STANDARDS

D.1 OVERVIEW OF DVB-S

The DVB-S Satellite System is the oldest and most established of the DVB standards family, and arguably forms the core of DVB's success.

The DVB-S system is designed to cope with the full range of satellite transponder bandwidths and services using DVB-S are on-air across six continents. The video, audio and other data are inserted into fixed-length MPEG Transport Stream packets. The packetised data constitutes the payload, which can carry any combination of MPEG-2 video and audio. Thus service providers are free to deliver anything from multiple-channel Standard Definition Television (SDTV), 16:9 Widescreen Enhanced Definition Television (EDTV) or single-channel HDTV, to multimedia Data Broadcast Network services and Internet on the air.

D.1.1 SYSTEM DEFINITION

The System is defined as the functional block of equipment performing the adaptation of the baseband TV signals, from the output of the MPEG-2 transport multiplexer (see ISO/IEC DIS 13818-1), to the satellite channel characteristics.

The following processes are applied to the data stream (see Figure 64):

- Transport multiplex adaptation and randomization for energy dispersal;
- Outer coding (i.e. Reed-Solomon);
- Convolutional interleaving;
- Inner coding (i.e. punctured convolutional FEC code);
- Baseband shaping for modulation;
- Modulation.

DVB services via satellite are particularly affected by power limitations, therefore ruggedness against noise and interference is the main design objective, rather than spectrum efficiency.

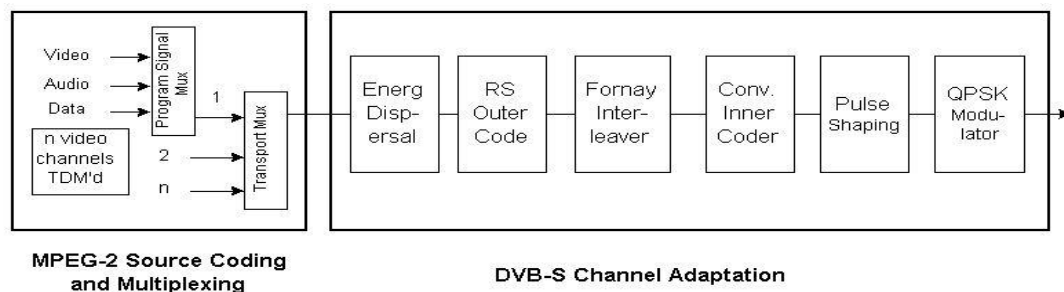


Figure 64 - Functional block diagram of the System

To achieve a very high power efficiency, without excessively penalizing the spectrum efficiency, the System uses QPSK modulation and the concatenation of convolutional and RS FEC codes. The convolutional FEC code can be configured flexibly, allowing the optimization of the system performance for a given satellite transponder bandwidth.

Although the System is optimized for single carrier per transponder Time Division Multiplex (TDM), it can be used for multi-carrier Frequency Division Multiplex (FDM) type applications.

The System is directly compatible with MPEG-2 coded TV signals (see ISO/IEC DIS 13818-1). The modem transmission frame is synchronous with the MPEG-2 multiplex transport packets.

If the received signal is above C/N and C/I thresholds, the Forward Error Correction (FEC) technique adopted in the System is designed to provide a "Quasi Error Free" (QEF) quality target. The QEF means less than one uncorrected error-event per transmission hour, corresponding to Bit Error Ratio (BER) = 10^{-10} to 10^{-11} at the input of the MPEG-2 demultiplexer.

D.1.2 ERROR PERFORMANCE REQUIREMENTS

The modem, connected in the IF loop, meets the BER versus E_b/N_o performance requirements given in Figure 65.

FEC (inner code)	E_b/N_o required for BER = 2×10^{-4} after Viterbi QEF after Reed Solomon
1/2	4.5 dB
2/3	5.0 dB
3/4	5.5 dB
5/6	6.0 dB
7/7	6.4 dB

Figure 65 - IF-Loop performance of the System

NOTE 1: The figures of E_b/N_o refer to the useful bit-rate before RS coding and include a modem implementation margin of 0.8 dB and the noise bandwidth increase due to the outer code ($10 \log 188/204 = 0.36$ dB).

NOTE 2: Quasi-Error-Free (QEF) means less than one uncorrected error event per hour, corresponding to BER = 10^{-10} to 10^{-11} at the input to the MPEG-2 demultiplexer.

D.2 OVERVIEW OF DVB-S2

DVB-S2 is the second-generation DVB specification for broadband satellite applications, developed on the success of the first generation specifications, DVB-S for broadcasting and DVB-DSNG for satellite news gathering and contribution services. DVB-S2 benefits from the technological achievements of the last decade. It has been designed for:

- Broadcast Services for standard definition TV and HDTV,
- Interactive Services including Internet Access for consumer applications,
- Professional Applications, such as Digital TV contribution and News Gathering, TV distribution to terrestrial VHF/UHF transmitters, Data Content distribution and Internet Trunking.

The DVB-S2 standard has been specified around three key concepts: best transmission performance, total flexibility and reasonable receiver complexity. A functional block diagram of the system is shown in Figure 66.

To achieve the best performance-complexity trade-off, DVB-S2 benefits from more recent developments in channel coding (adoption of LDPC codes) and modulation (use of QPSK, 8PSK, 16APSK and 32APSK). The result is typically a 30 percent capacity increase over DVB-S under the same transmission conditions. In addition, for broadcast applications, DVB-S2 is not constrained to the use of QPSK and can therefore deliver significantly higher bit rates over high power satellites, thus still increasing capacity gain with respect to DVB-S. Furthermore, when used for interactive point-to-point applications like IP unicasting, the gain of DVB-S2 over DVB-S is even greater: Variable Coding & Modulation (VCM) functionality allows different modulations and error protection levels to be used and changed on a frame-by-frame basis. This may be combined with the use of a return channel to achieve closed-loop Adaptive Coding & Modulation (ACM), thus allowing the transmission parameters to be optimised for each individual user, dependant on path conditions. A comparison of DVB-S and DVB-S2 for TV Broadcasting is shown in Table 24.

DVB-S2 is so flexible that it can cope with any existing satellite transponder characteristics, with a large variety of spectrum efficiencies and associated C/N requirements. Furthermore it is not limited to MPEG-2 video and audio coding, but it is designed to handle a variety of audio-video and data formats including formats which the DVB Project is currently defining for future applications. DVB-S2 accommodates any input stream format, including continuous bit-streams, single or multiple MPEG Transport Streams, IP as well as ATM packets. This future proofing will allow other current and future data schemes to be used without the need for a new specification.

It is based on the "tool-kit" approach, which covers all the application areas while still keeping the single-chip decoder at reasonable complexity levels, thus enabling the use of mass market products also for professional applications. Backwards compatible modes are available, allowing existing DVB-S services and STBs to continue working during any transitional period. When there is no problem of legacy receivers, NBC modes offer the full benefits of DVB-S2. Examples of DVB-S2 ACM link operation and transport of IP services are shown in Figure 67 and Figure 68 respectively.

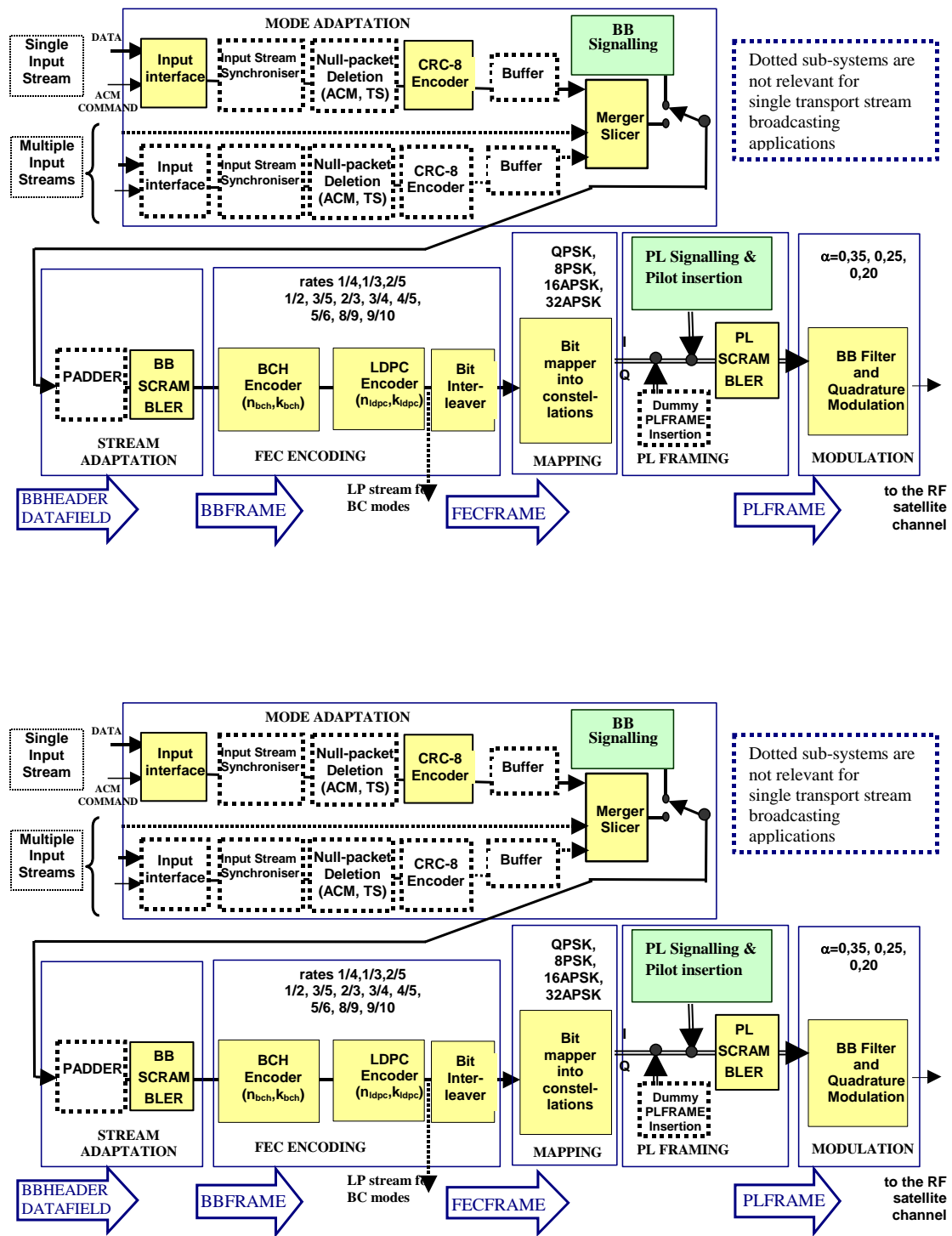
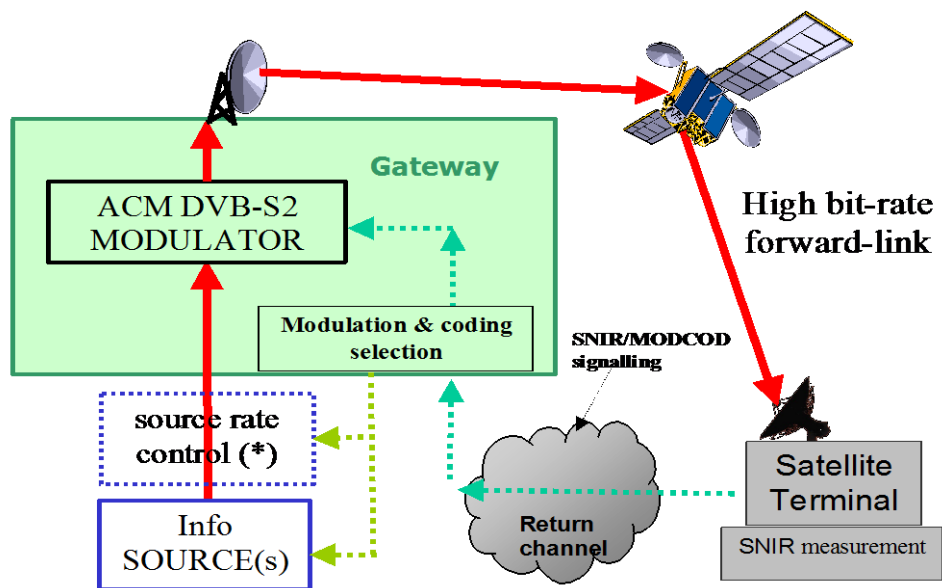


Figure 66 - Functional block diagram of the DVB-S2 system

Satellite EIRP (dBW)	51		53,7	
System	DVB-S	DVB-S2	DVB-S	DVB-S2
Modulation & coding	QPSK 2/3	QPSK 3/4	QPSK 7/8	8PSK 2/3
Symbol-rate (Mbaud)	27.5 ($\alpha=0,5$)	30.9 ($\alpha=0,20$)	27.5 ($\alpha=0,35$)	29.7 ($\alpha=0,25$)
C/N (in 27.5 MHz) (dB)	5.1	5.1	7.8	7.8
Useful bit-rate (Mbit/s)	33.8	46 (gain=36%)	44.4	58.8 (gain=32%)
Number of SDTV programmes	7 MPEG-2 15 AVC	10 MPEG-2 21 AVC	10 MPEG-2 20 AVC	13 MPEG-2 26 AVC

Table 24 - Example Comparison between DVB-S and DVB-S2 for TV Broadcasting



(*) Source rate control may be directly applied to source(s) or locally at the GTW input or via network traffic control

Figure 67 - Block diagram of a DVB-S2 ACM link

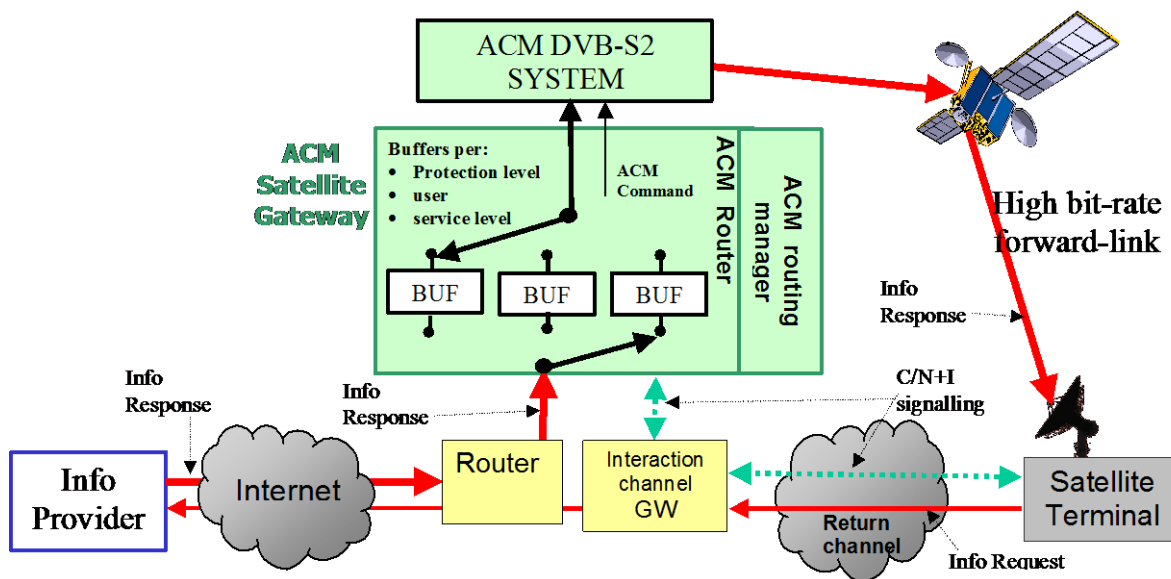


Figure 68 - Example of IP services using a DVB-S2 ACM link

To achieve the best performance, DVB-S2 benefits from more recent developments in channel coding and modulation. It is based on LDPC (Low Density Parity Check) codes, simple block codes with very limited algebraic structure, invented by Gallager in 1962. LDPC codes have decoding algorithms which consists of simple operations such as addition, comparison and table look-up; moreover the degree of parallelism is "adjustable" which makes it easy to trade-off throughput against complexity. Their key characteristics, allowing quasi-error free operation at only 0.6 to 1.2 dB from the Shannon limit, are:

- the very large LDPC code block length (64,800 bits for the normal frame, and 16,200 bits for the short frame);
- the large number of decoding iterations (around 50 SISO iterations);
- the presence of a concatenated BCH outer code (without any interleaver), defined by the designers as "cheap insurance against unwanted error floors at high C/N ratios."

In comparison, the DVB-S and DVB-DSNG soft-decision Viterbi decoder takes decisions on blocks of only 100 symbols, without iterations, and the RS code over blocks of about 1,600 bits (interleaving factor 12), offering already quite good performance, around 3 dB from the Shannon limit.

Digital transmissions via satellite are affected by satellite power and bandwidth limitations. Therefore DVB-S2 provides for many transmission modes (FEC coding and modulations), giving different trade-offs between power and spectrum efficiency. Code rates of 1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9 and 9/10 are available depending on the selected modulation and the system requirements. Coding rates 1/4, 1/3 and 2/5 have been introduced to operate, in combination with QPSK, under exceptionally poor link conditions, where the signal level is below the noise level. Computer simulations demonstrated the superiority of such modes over BPSK modulation combined with code rates 1/2, 2/3 and 4/5. The introduction of two FEC code block length (64,800 and 16,200) was dictated by two opposing needs: the C/N performance improves for long block lengths, but the end-to-end modem latency increases as well. Therefore for applications not critical for delays (such as for example broadcasting) the long frames are the best solution, while for interactive applications a shorter frame may be more efficient when a short information packet has to

be forwarded immediately by the transmitting station. Four modulation modes can be selected for the transmitted payload.

QPSK and 8PSK are typically proposed for broadcast applications, since they are virtually constant envelope modulations and can be used in non-linear satellite transponders driven near saturation. For some specific broadcasting applications (i.e. regional spot beams) and interactive application operating with multi-beam satellites, 16APSK provides extra spectral efficiency with very limited linearity requirements if proper pre-distortion schemes are employed. 32APSK modes, mainly targeted to professional applications, can also be used for broadcasting, but these require a higher level of available C/N and the adoption of advanced pre-distortion methods in the up-link station to minimise the effect of transponder non-linearity. Whilst these modes are not as power efficient as the other modes, the data throughput is much greater. 16APSK and 32APSK constellations (Figure 69) have been optimised to operate over a non-linear transponder by placing the points on circles. Nevertheless their performance over a linear channel is comparable with those of 16QAM and 32QAM respectively. All the modes are also appropriate for operation in quasi-linear satellite channels, in multi-carrier Frequency Division Multiplex (FDM) type applications.

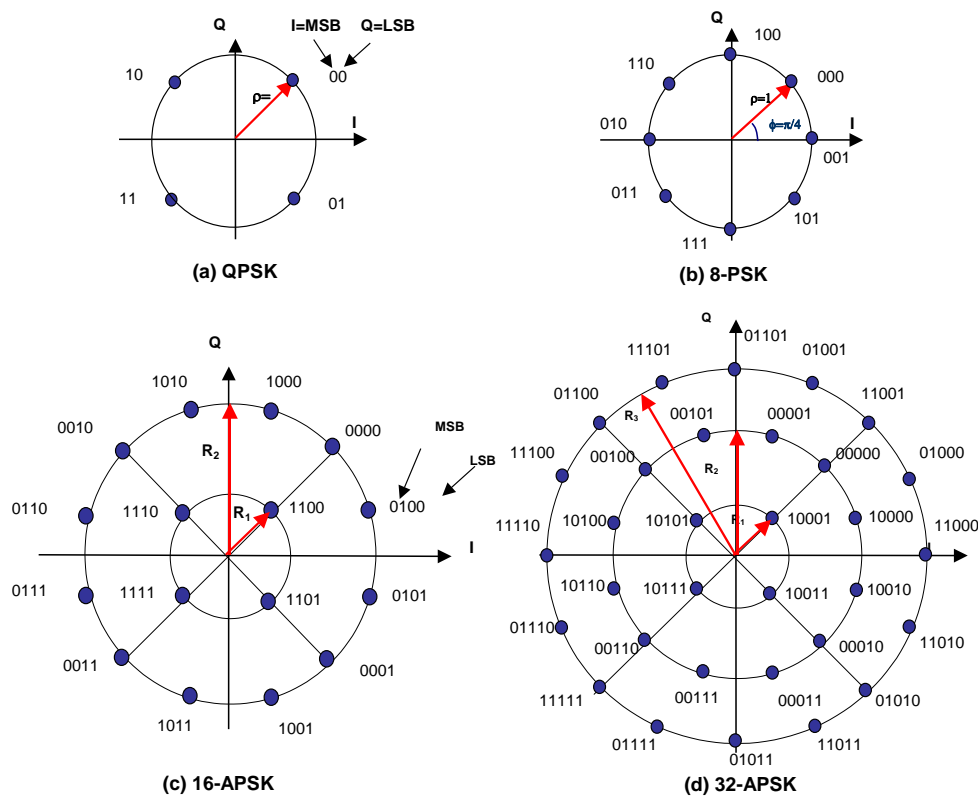


Figure 69 - The four possible DVB-S2 constellations before physical layer scrambling

By selecting the modulation constellation and code rates, spectrum efficiencies from 0.5 to 4.5 bit/second/Hz are available and can be chosen dependent on the capabilities and restrictions of the satellite transponder used (Figure 70).

DVB-S2 has three roll-off factor choices to determine spectrum shape. These are 0.35 as in DVB-S and two others, namely 0.25, 0.20 for tighter bandwidth shape restriction.

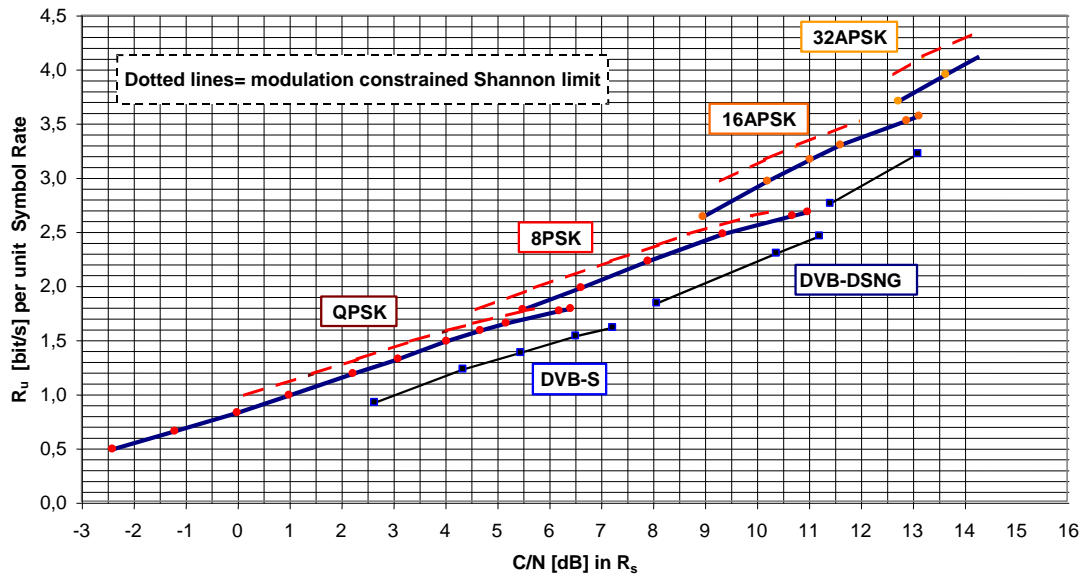


Figure 70 - Required C/N versus spectrum efficiency, obtained by computer simulations on the AWGN channel (ideal demodulation) (C/N refers to average power)

D.3 OVERVIEW OF DVB-RCS

Due to the recognised need for a specification in the digital interactive services supporting broadcast to the end user with return channel, the DVB Technical Module (DVB-TM) created an ad-hoc group in early 1999, called DVB-RCS (DVB – Return Channel via Satellite).

D.3.1 SYSTEM MODEL

Figure 71 shows the system model, which is to be used within DVB for interactive services.

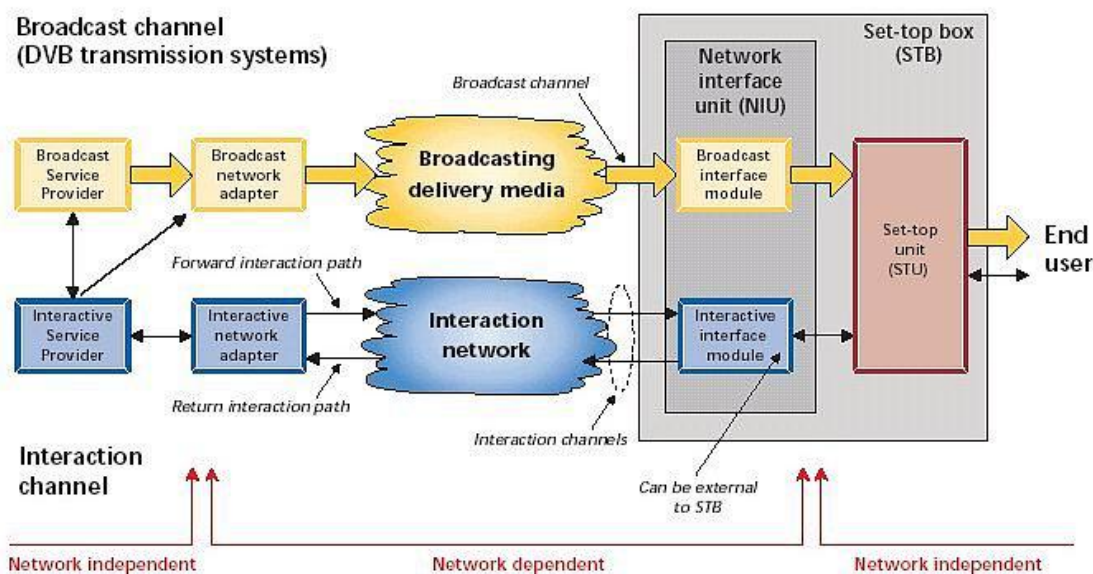


Figure 71 - DVB's General Reference Model for Interactive Networks

In the system model, two channels are established between the service provider and the user:

Broadcast Channel: a unidirectional broadband Broadcast Channel including video, audio and data is established from the service provider to the users. It may include the Forward Interaction Path.

Interaction Channel: a bi-directional Interaction Channel is established between the service provider and the user for interaction purposes. It is formed by:

- Return Interaction Path (Return Channel): from the user to the service provider. It is used to make requests to the service provider, to answer questions or to transfer data.
- Forward Interaction Path: from the service provider to the user. It is used to provide information from the service provider to the user and any other required communication for the interactive service provision. It may be embedded into the Broadcast Channel. It is possible that this channel is not required in some simple implementations, which make use of the Broadcast Channel for the carriage of data to the user.

The RCST is formed by the Network Interface Unit (consisting of the Broadcast Interface Module and the Interactive Interface Module) and the Set Top Unit. The RCST provides interface for both Broadcast and Interaction Channels. The interface between the RCST and the interaction network is via the Interactive Interface Module.

D.3.2 RETURN LINK BASE-BAND PHYSICAL LAYER SPECIFICATION AND MULTIPLE ACCESS DEFINITION

Specifications for the base-band physical layer are given in this chapter. Figure 72 represents the generic digital signal processing to be performed at the RCST transmitter side, from the burst formatting of the serial information bit-stream, to the modulation representing the digital to analogue conversion. The signal processing to be performed by each subset is described in the following sections.

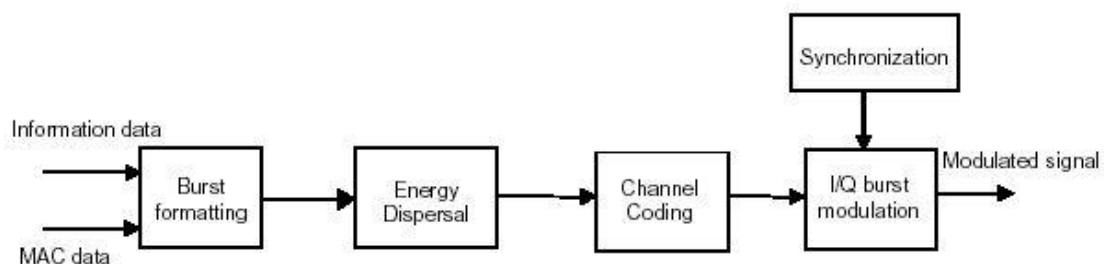


Figure 72 - Block diagram of the RCST return link baseband signal processing

Because the basic physical layer components of DVB-RCS are the same with DVB-S, we will just indicate some important or different parts in DVB-RCS.

D.3.2.1 Burst format

There are four types of bursts: traffic (TRF), acquisition (ACQ), synchronisation (SYNC) and the common signalling channel (CSC). The important MPEG2-TS TRF burst format is described in Figure 73.

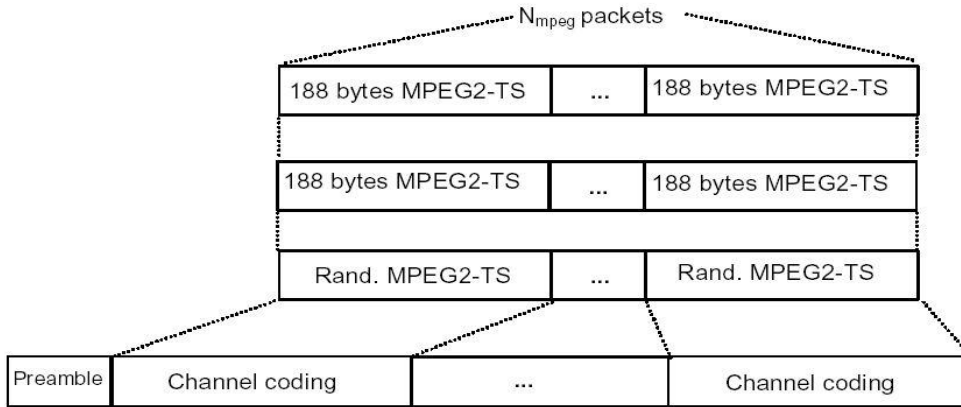


Figure 73 - Composition of the optional TRF burst carrying MPEG2-TS packets

D.3.2.2 MPEG2-TS TRF burst

In the case that MPEG2-TS Packets are the basic containers, a burst contains N_{mpeg} concatenated MPEG2-TS packets, each of length 188 bytes. The burst is composed of several channel coding blocks, the same description of DVB-S. See Figure 73 for a description of the MPEG2-TS TRF burst.

RCSTs can deduce the number of MPEG2 packets in a TRF time slot from the `time_slot_duration` field of the TCT, after subtracting the time duration of other fields. Transmission of MPEG2-TS TRF bursts is optional. The RCST will inform the NCC that it supports this mechanism in the CSC burst.

D.3.2.3 Coding

Channel error protection is provided to the data transmitted in bursts by means of coding. There are two possible methods in which data can be encoded, both of which are utilised in the case of RCSTs. These are Turbo Coding and Concatenated Coding.

It should, however, be noted that, during initial synchronisation, only one of the two codes is used and the RCST is not requested to change between coding schemes. Concatenated coding is performed by means of an outer by-passable Reed-Solomon code followed by an outer by-passable non-systematic convolutional code. Along with both coding schemes, a by-passable CRC can be applied to Common Signalling Channel (CSC) bursts and synchronisation (SYNC) bursts to allow error detection. All these techniques are described in more detail below.

D.3.2.4 Cyclic Redundancy Check

As mentioned above, CRC is used as a means of error detection for CSC and SYNC bursts. The use of CRC coding is optional in the case of convolutionally coded bursts but mandatory in the case of turbo coded CSC bursts.

In any case, the Network Control Centre (NCC) indicates to the RCST via the Time-Slot Composition Table (TCT) if the CRC is to be used. If used a CRC-16, whose polynomial is $(x^{16} + x^{15} + x^2 + 1)$, is applied and appended at the end of the burst before any other coding. This CRC is the remainder of the division of the burst payload by the polynomial.

D.3.2.5 Reed Solomon

As mentioned earlier, in the case that concatenated coding is used, the outer code is an RS code. In particular, a shortened version of the original RS(255,239,8) code is used.

At this point it should be mentioned that this outer coding is always bypassed if Turbo Coding is used. Also, in the case that both RS and CRC coding are used, the RS parity bytes are added only after the burst payload CRC has been calculated.

D.3.2.6 Inner Coding

The outer RS code described above is followed by an inner non-systematic convolutional code when concatenated coding is used. In more detail, the return channel will allow the use of a range of punctured convolutional codes all of which will be based on a mother convolutional code with the following parameters:

Constraint Length: $K = 7$ (implying 64 possible trellis states)

Generator Polynomials: $G_0 = 171, G_1 = 133$ (both in octal representation)

One very important feature of the provision of a choice between concatenated codes will be the possibility of selection of the most appropriate level of error correction depending on the type of service or the data rate. Supported coding rates will be: $1/2, 2/3, 3/4, 5/6$ and $7/8$.

As in the case of RS coding, the inner convolutional coding is bypassed if Turbo Coding is used. If concatenated coding is used, the inner convolutional coding can again be bypassed but in that case, the MSB is affected to the I-channel, the next bit to the Q-channel and so on.

D.3.2.7 Turbo Coding

This is the alternative to using concatenated coding. This alternative comes in the form of a double binary Circular Recursive Systematic Convolutional (CRSC) code.

D.3.2.8 Modulation

As indicated earlier, the modulation used is QPSK. In more detail, conventional Gray-Code QPSK modulation is used with absolute (no differential coding). The modulation process is summarised in Figure 74. As can be deduced from above, the first step is the insertion of the preamble.

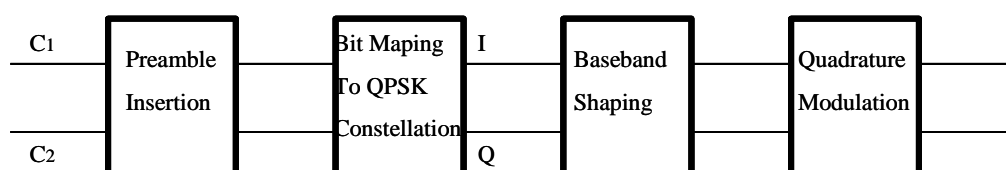


Figure 74 - Processing after the encoder

After the preamble insertion, the C1 and C2 outputs of the encoder are sent to the QPSK bit mapper without notification. After this the last remaining step is that of QPSK modulating the information. The processes of bit mapping and baseband processing of the streams of information are described below.

D.3.2.9 Bit Mapping to QPSK constellation

As mentioned above, after the preamble has been inserted the C1 and C2 outputs of the encoder are sent to the bit mapper. Bit mapping is performed as shown in Figure 75. If the Normalization Factor applied to the I and Q components is $\frac{1}{\sqrt{2}}$ then the resulting average energy per symbol will be 1. It should be noted that the C1 and C2 outputs of the encoder are mapped onto the I and Q channels respectively.

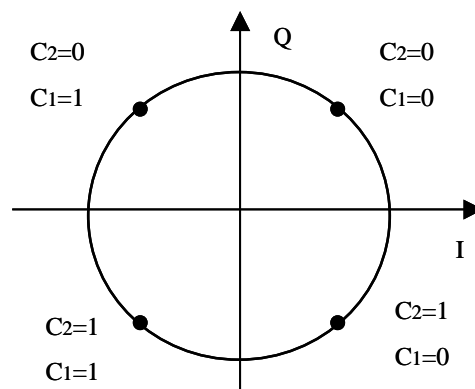


Figure 75 - Processing after the encoder

D.3.2.10 Baseband Shaping and Quadrature Modulation

Baseband shaping is performed before the modulation process by means of square root raised cosine filtering the I and Q signals. This is done by a square root raised cosine filter with a roll-off factor of 35% and whose theoretical function shall be defined as:

$$H(f) = \begin{cases} 1 & \text{if } |f| < f_N(1+\alpha) \\ \sqrt{\frac{1}{2} + \frac{1}{2} \sin\left[\frac{\pi(f_N - |f|)}{2\alpha f_N}\right]} & \text{if } f_N(1-\alpha) \leq |f| \leq f_N(1+\alpha) \\ 0 & \text{if } |f| > f_N(1+\alpha) \end{cases}$$

Where α in the above formula is the filter's roll-off factor and

$$f_N = \frac{1}{2T_s} = \frac{R_s}{2}$$

is the Nyquist frequency.

After this, the signal is QPSK modulated and at the RCST antenna output the allowed spectrum and group delay variation are determined according to the mask given in EN 300 421 for every return symbol rate supported by the terminal.

D.3.3 MULTIPLE ACCESS

The multiple-access capability is either fixed or dynamic slot MF-TDMA.

D.3.3.1 MF-TDMA

The satellite access scheme is Multi-Frequency Time Division Multiple Access (MF-TDMA). MF-TDMA allows a group of RCSTs to communicate with a gateway using a set of carrier frequencies, each of which is divided into timeslots. The NCC will allocate to each active RCST a series of bursts, each defined by a frequency, a bandwidth, a start time and duration.

D.3.3.1.1 Fixed MF-TDMA

In Fixed-Slot MF-TDMA, the bandwidth and duration of successive traffic slots used by an RCST is fixed, as illustrated in Figure 76 where the arrow indicates a typical sequence of slots assigned by the NCC to one RCST.

In this case, TCT parameters defining the burst parameters (symbol_rate, inner_code_type, inner_code_ordering, outer_coding, inner_code_puncturing, modulation and baseband shaping) of a Superframe are fixed.

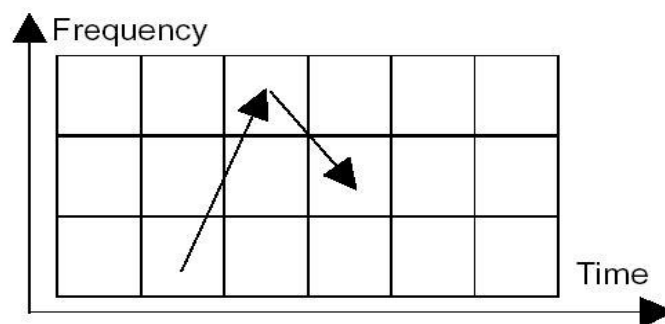


Figure 76 - Fixed-slot MF-TDMA

A fixed MF-TDMA RCST can send a mix of SYNC and single size TRF bursts provided that the burst parameters fulfil the previous requirement. If the NCC requests a change in these parameters, then they will apply to a new Superframe with a delay.

D.3.3.1.2 Dynamic MF-TDMA (Optional)

Dynamic-Slot MF-TDMA uses additional RCST flexibility to vary the bandwidth and duration of successive slots allocated to an RCST. In addition to changing carrier frequency and burst duration, the RCST may also change transmission rate and coding rate between successive bursts. The advantage of the more flexible RCST is more efficient adaptation to the widely varying transmission requirements typical of multimedia. The basic principle of the flexible RCST is illustrated in Figure 77, where the arrows show an RCST using successive slots with different bandwidths and durations.

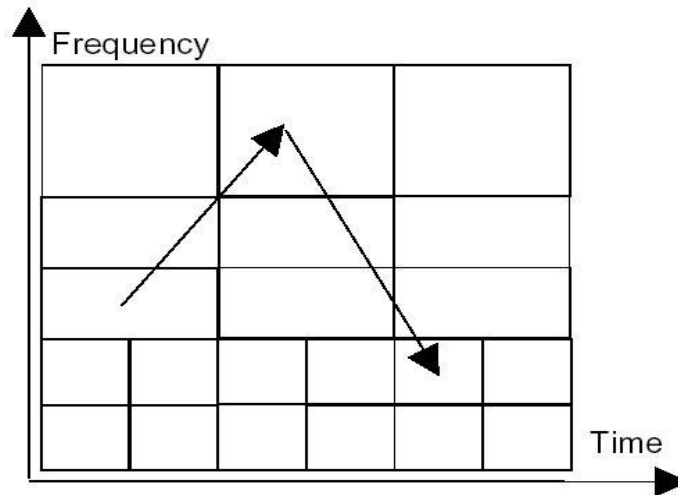


Figure 77 - Optional Dynamic-slot MF-TDMA, using a flexible RCST

D.3.3.1.3 DVB-RCS Bandwidth Assignment

In the DVB-RCS system, the forward link is shared among all the user RCS terminals. Packets are routed based on their destination spot-beam. This is done at the GW. Each spot beam can be viewed as a TDM (Time-Division Multiplexing) stream.

On return link, the spectrum is organised into MF-TDMA frames that are repeated periodically. Allocation of the bandwidth is based on traffic based on Demand Assigned Multiple Access (DAMA) algorithms to support the following services:

- Supports Constant Rate Assignment (CRA),
- Volume-based Dynamic Capacity (VBDC) Assignment,
- Absolute Volume-based Dynamic Capacity Requests (A-VBDC), and
- Rate-based Dynamic Capacity (RBDC) Assignment.

Although users may be offered 2.048 Mbit/s service, the actual throughput is far below the offered rate due to the Internet protocols, and the bandwidth received by the users also changes due to the DAMA and service types.

Please also notice that satellite propagation delay depend on the orbital location of the satellite and also on the user terminal location. The distance between earth station and GEO satellite can be calculated as:

$$D = \sqrt{R_0^2 + 2R_E(R_0 + R_E)(1 - \cos l \cos L)}$$

where R_E is earth radius, R_0 satellite altitude, l latitude and L longitude.

D.3.3.2 Frequency range

RCSTs have a specific frequency range for the frequency hopping from time-slot to time-slot. This frequency hopping range is communicated from an RCST to the NCC in a CSC burst during logon procedure. The frequency hopping capability of individual RCSTs are at the manufacturer's discretion and are at least 20 MHz (i.e. ± 10 MHz around centre frequency).

The frequency agility is specified in terms of short term frequency hopping and long term frequency tuning.

Frequency hopping covers changes of frequency between adjacent slots in time. The settling time between bursts does not exceed the guard interval. The settling time is the period required to achieve the necessary frequency tolerance.

Frequency tuning covers the change in centre frequency of hop ranges. The settling time does not exceed 1 second.

For further details see: -

D.3.3.2.1 DVB-S

Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services, ETSI EN 300 421 V1.1.2

Digital Video Broadcasting (DVB); Implementation of Binary Phase Shift Keying (BPSK) modulation in DVB satellite transmission systems, ETSI TR 101 198 V1.1.1

D.3.3.2.2 DVB-S2

Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications, ETSI EN 302 307 V1.2.1

Digital Video Broadcasting (DVB); User guidelines for the second generation system for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications, ETSI TR 102 376 V1.1.1

Digital Video Broadcasting (DVB); Adaptive Coding and Modulation for Broadband Hybrid Satellite Dialup Applications, ETSI TS 102 441 V1.1.1 DVB-S2

D.3.3.2.3 DVB-RCS

Digital Video Broadcasting (DVB); Interaction channel for satellite distribution systems, ETSI EN 301 790 V1.5.1.

Digital Video Broadcasting (DVB); Interaction channel for Satellite Distribution Systems; Guidelines for the use of EN 301 790, ETSI TR 101 790 V1.4.1.

Digital Video Broadcasting (DVB); Interaction channel for Satellite Distribution Systems; Guidelines for the use of EN 301 790 in mobile scenarios, ETSI TR 102 768 V1.1.1.

Appendix E BROADBAND SERVICE ON AVANTI HYLAS 1

Rural Broadband Service Offering, <http://www.ruralbroadband.co.uk/avanti.html>

Avanti Launch

Your broadband experience could be about to rocket, Avanti now have the Hylas 1 Ka-Sat satellite ready for service.

The Avanti services launch on the 20th April 2011 and we are now ready to take bookings for fixed install dates.

Due to the expected high demand we need a deposit of £299 (incl VAT) to book a fixed installation date. The remainder of the activation fee and first quarterly subscription will need to be paid in full before commencing installation.

As an introductory promotion to the new service, if you pay the full £599.99 installation fee plus the activation and first quarterly subscription on ordering, we will discount this bill by 5%. This could save you up to £67 (based on the Pro 8000 package).

Notes on the service:

- a) We can set your system to throttle down to a low speed when you hit your data limit or you can choose to go into excess usage charged at £6 per GB.
- b) If you require fixed IP addresses or routing for CCTV or office based mail or small business server then you will require a Pro service, the Consumer service has a non-routable IP address.
- c) Price for standard installation, includes up to 30m of cable.
- d) Contract is for a minimum of 12 months from activation. Pay for a year up front and only pay for 11 months, saving £238.80 (based on the Pro 8000 package).
- f) To create a wireless network, add a Wireless 'N' router to your order for £48 incl VAT.

Avanti Service Pricing April 2011 onwards

Package Name	Headline Speed	Inclusive GB	Activation Charge	Monthly Ex VAT	Monthly Inc VAT	Charge Per GB Excess Inc VAT
Consumer 500	0.5/0.12	3	£0.00	£12.00	£14.40	£6.00
Consumer 1000	1/0.25	5	£0.00	£20.00	£24.00	£6.00
Consumer 2000	2/0.5	6	£0.00	£28.00	£33.60	£6.00
Consumer 4000	4/1	8	£25.00	£39.50	£47.40	£6.00
Consumer 8000	8/2	10	£25.00	£49.50	£59.40	£6.00
Pro 2000	2/0.5	10	£25.00	£75.00	£90.00	£6.00
Pro 4000	4/1	15	£25.00	£118.00	£141.60	£6.00
Pro 6000	6/1.5	20	£25.00	£165.00	£198.00	£6.00
Pro 8000	8/2.5	25	£25.00	£199.00	£238.80	£6.00

Installation Price	£499.99 plus VAT	£599.99 inc VAT
Booking Deposit	£250 plus VAT	£299.00 inc VAT
Subscriptions	Quarterly in Advance	by card or direct debit
Other networking	By arrangement	
Phone Sevices	Coming Soon	

Table 25 - Avanti Service Charges

Appendix F PRIMER ON IP OVER SATELLITE

F.1 A SHORT REVIEW OF TCP/IP REFERENCE MODEL

We start with a short description of the Internet protocol (IP) reference model as shown in Figure 78. The main part of Internet protocol reference model is the suite of Transmission control protocol (TCP) and Internet Protocol (IP) known as the TCP/IP protocols.

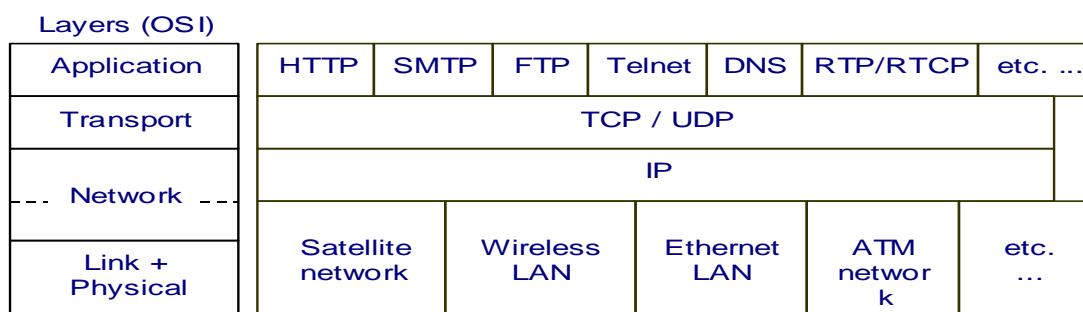


Figure 78 - The Internet reference model [Ref 10]

The application layer protocols are designed as functions of user terminals or server. The classical Internet application layer protocols include HTTP for WWW, FTP for file transfer, SMTP for Email, Telnet for remote login, DNS for domain name service and more are added including real time protocol (RTP) and real time control protocol (RTCP) for real time services and others for dynamic and active web services. All these should be independent from the networks.

The link and physical layer are related to network technologies. They are not part of the TCP/IP suite, including satellite networks, LANs, ATM, etc. They transport IP packets physically from one edge of the network to the other edge by encapsulating the IP packet in the network frame. The source host sends IP packets and destination host receives the packets. The network nodes route the IP packets to the next routers or gateways until they can route the packets directly to the destination hosts.

In the following, the TCP/IP protocol is explained briefly.

F.2 NETWORK LAYER: IP PROTOCOL

In the reference model, the network layer is the Internet protocol (IP) is based on datagram approach. IP provides only best effort service without any guarantee of quality of service (QoS). It is responsible for moving packets of data from node to node. Each node forwards the packets based on a four-byte destination address (the IP address).

Figure 79 shows the format of the IP packet [9]. Each field of the IP packet header is described in the following.

1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8				
Version				IHL				Type of service				Total length															
Identification								-	D F	M F	Fragment offset																
Time to live				Protocol																							
Source Destination address																											
Destination address																											
Options (0 or more words)																											

Figure 79 - The Internet Protocol (IP) packet header format.

- The **version** field keeps track of which version of the protocol the datagram belongs to. The current version is 4, also called IPv4. IPv5 is an experimental version. The next version to be introduced into the Internet is IPv6, but the header has been changed dramatically. We discuss this later.
- The **IHL** field is the length of the header in 32-bit words. The minimum value is 5 and maximum 15, which limits the header to 60 bytes.
- The **type of service** field allows the host to tell the network what kind of service it wants. Various combinations of Delay, Throughput and reliability are possible.
- The **total length** includes both header and data. The maximum value is 65535.
- The **identification** field is needed to allow destination host to determine which datagram a newly arrived fragment belong to. Every IP packet in the network is identified uniquely.
- **DF**: Don't Fragment. This is to tell the network not to fragment the packet, as a receiving party may not be able to reassemble the packet.
- **MF**: More Fragment. This is to indicate that more fragment to come as a part of the IP packet.
- The **fragment offset** tells where in the current datagram this fragment belongs.
- The **time to live** is a counter used to limit packet lifetime to prevent the packet staying in the network forever.
- The **protocol** field tells it which transport process to give it to. It can be TCP or UDP. It can also be possible to carry data of other transport layer protocols.
- The **checksum** field verifies the IP header only.
- The **source** and **destination addresses** indicate the network number and host number.
- **Options** are variable length as shown in Table 26. Five functions are defined: security, strict routing, loose source routing, record route and timestamp.

Options	Descriptions
Security	Specifies how secret the datagram is.
Strict source routing	Gives complete path to follow.
Loose source routing	Gives a list of routers not be missed.
Record route	Makes each router append its IP address.
Timestamp	Makes each router append its address and timestamp.

Table 26 - Option fields of the IPv4 packet header

F.2.1 IP LAYER SERVICES AND ROUTING MECHANISMS

The IP adopts a completely different approach from traditional communication networks to provide and to end packet delivery services. It is connectionless, providing best effort services. Connectionless means that packets are delivered without setting any end-to-end connection. Best effort means that it does not try to recover from any problem due to packet loss, transmission error and network congestion which is left to the upper layer protocol, such as TCP to deal with.

The whole network consists of many sub-networks each of which can be of any type of network technology including LAN, MAN and WAN. User terminals can communicate directly with each other in the same sub-network using broadcast frames in shared media such as LANs, point-to-point link frame such as dialup link and multi-service frame such as WANs.

Routers are at the edge of the sub-networks and connect the sub-networks together, and can communicate with each other directly and also with user terminals in the same sub-networks. In other words, the Internet routers are interconnected together by many different network technologies. Each packet generated by source terminals carries destination addresses and source addresses of the terminals, and can be delivered to the destination terminal on the same sub-network or to a router on the same sub-network. The router will be able to receive the packet and forward it to the next router making use of the routing protocols until the packet reaches its destination.

In the Internet reference model, there is only one network layer protocol which is the Internet Protocol (IP). It is a unique protocol making use of the transmission services provided by the different types of networks below, and providing end-to-end network layer service to the transport layer protocols above.

The IP packets may be carried across different type of networks, but their IP format remains the same. Therefore, any protocol above IP layer can only access the functions provided by the IP packet and the differences of the networks are screened out by the IP layer as shown in Figure 80.

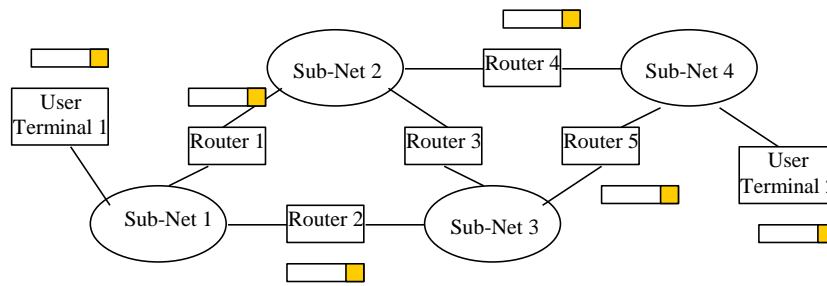


Figure 80 - Internet packets over routers and sub-networks.

F.2.2 MAPPING BETWEEN INTERNET AND PHYSICAL NETWORK ADDRESSES

The Internet address is to identify sub-network in the context of Internet. Each address consists of two parts, one of which identifies uniquely a sub-network and the other a host computer. The physical address is used to identify the network terminal related to the transmission technologies. For example, we use a telephone number to identify individual telephones in the telephony networks, and Ethernet address to identify each network interface card (NIC) uniquely for Ethernet networks.

Each host (computer, PC, or workstation) by installing an Ethernet network interface card (NIC) will have the unique Ethernet address worldwide. A host can send data to another host or to all hosts in the Ethernet by broadcasting using the other hosts' addresses or Ethernet broadcasting address.

Each host also has a unique IP address in the Internet. All the hosts in the Ethernet have the same network identifier (Net-id) forming a sub-network. The sub-networks can be connected into the Internet by using routers. All the routers exchange information using routing protocols to determine the topology of the Internet and calculate the best router to be used for forwarding packets to their destinations.

Clearly, the host can send a packet to the other host within the same sub-network. If the other host is outside of the sub-network, the host can send the packet to another router. The router can forward the packet to the next one until the packets reach their destinations or send to the host if the router is on the destination network. Therefore, the Internet can be seen as a network of interconnected routers by using many different network transmission technologies. But the transmissions of the Internet packets between the routers need to use the native addresses and data frame of the network technologies. As the native address identifies an access point to the network technology and the Internet address identifies the host, a mapping is required to specify the identified host attached to the network access point together forming a part of the subnet.

The network manager can set up such a mapping manually for small networks, but we prefer to have network protocols to mapping them automatically in a global scale.

F.2.3 ADDRESS RESOLUTION PROTOCOLS (ARP, RARP AND DHCP)

ARP is a protocol used to find the mapping between the IP address and network address such as Ethernet address. Within the network, a host can ask for the network address giving an IP address to get the mapping. If the IP address is outside the network, the host will forward the IP address to a router (it can be a default or proxy) [Ref 12].

RARP is the protocol to solve the reverse problem, i.e., to find the IP address giving a network address such as Ethernet. This is normally resolved by introducing a RARP server. The server keeps a table of the address mapping. An example of using RARP is when a booting machine has not got an IP address and should contact a server to get an IP address to be attached to the Internet [Ref 13].

The Dynamic Host Configuration Protocol (DHCP) automates network-parameter assignment to network devices from one or more DHCP servers. Even in small networks such as wireless LAN at home, DHCP is useful because it makes it easy to add new machines to the network [Ref 14].

F.2.4 INTERNET ROUTING PROTOCOLS

Each router in the Internet has a routing table showing the next router or default router to forward packets for all destinations. The Internet becomes larger and larger it is impractical or impossible to configure the routing table manually though in the early days and small network manual configuration of networks was carried out for convenience but error prone. Protocols have to be developed to configure the Internet automatically and dynamically.

A part of the Internet owned and managed by a single organisation or by a common policy can form a domain or autonomous system (AS). The interior gateway routing protocol is used for IP routing within the domain. Between domains, the exterior gateway routing protocol has to be used as political, economical or security issues often need to be taken into account.

F.2.5 THE INTERIOR GATEWAY ROUTING PROTOCOL (IGRP)

The original routing protocol was the routing information protocol (RIP) using a distance vector algorithm [Ref 15]. Within this domain, each router has a routing table of the next router leading to the destination network. The router periodically exchanges its routing table information with its neighbour routers, and updates its routing table based on the new information received.

Due to its slow convergence problem, a new routing protocol was introduced in 1979, using a link state algorithm. The protocol was also called 'link state routing protocol'. Instead of getting routing information from its neighbour, each router using the link state protocol and collects information on their links and sends link state information of its own and received link state information of the routers together to the other neighbours by flooding the network with the link state information. Every router in the network will have the same set of link state information and can calculate independently the routing table. This solved the problems of the RIP for large-scale networks.

In 1988, the IETF began work on a new interior gateway routing protocol, called Open Shortest Path First (OSPF) based on the link state protocol, which became a standard in 1990 [Ref 16]. It is also based on the published open literature (this is the reason the work "open" appears in the name of the protocol), and designed to supports a variety of distance metrics, adaptive to changes in topology automatically and quickly, support routeing based on type of services, and real time traffic, support load balancing, support for hierarchical systems and some levels of security, and also deals with routes connected to the Internet via a tunnel.

The OSPF supports three kinds of connection and networks including point-to-point lines between exactly two routers, multicast networks (such as LANs), and multi-access networks without broadcasting (such as WANs).

When the booting, router sends a "HELLO" message, adjacent routers (designated routers in the each LANs) exchange information. Each router periodically floods link state information to each of its adjacent routers. Database description messages include the sequence numbers of all the link state entries, sent in the Internet packets. Using flooding, each router informs all the other neighbour routers. This allows each router to construct the graph for its domain and compute the shortest path to form a routing table.

F.2.6 THE EXTERIOR GATEWAY ROUTING PROTOCOL (EGRP)

All an interior gateway protocol has to do is move packets as efficiently as possible. Exterior gateway routers have to worry about politics a great deal. EGRP is fundamentally a distance vector protocol, but with additional mechanisms to avoid the problems with the distance vector algorithm [Ref 17][Ref 18]. Each EGRP router keeps track of the exact path used to solve the problems of distance vector.

F.3 TRANSMISSION CONTROL PROTOCOL (TCP)

The Transmission Control Protocol (TCP) is a connection-oriented, end-to-end reliable protocol [Ref 19]. It provides reliable inter-process communication between pairs of processes in host computers. Very few assumptions are made as to the reliability of the network technologies carrying the Internet packets. The TCP assumes that it should work, with potentially unreliable datagram service from the lower level protocols (such as IP). In principle, the TCP should be able to operate above a wide spectrum of communication systems ranging from hard-wired LANs and packet-switched networks and circuit-switched networks to wireless LAN, wireless mobile networks and satellite networks.

Figure 81 illustrates the TCP segment header. The functions of the fields are as the following:

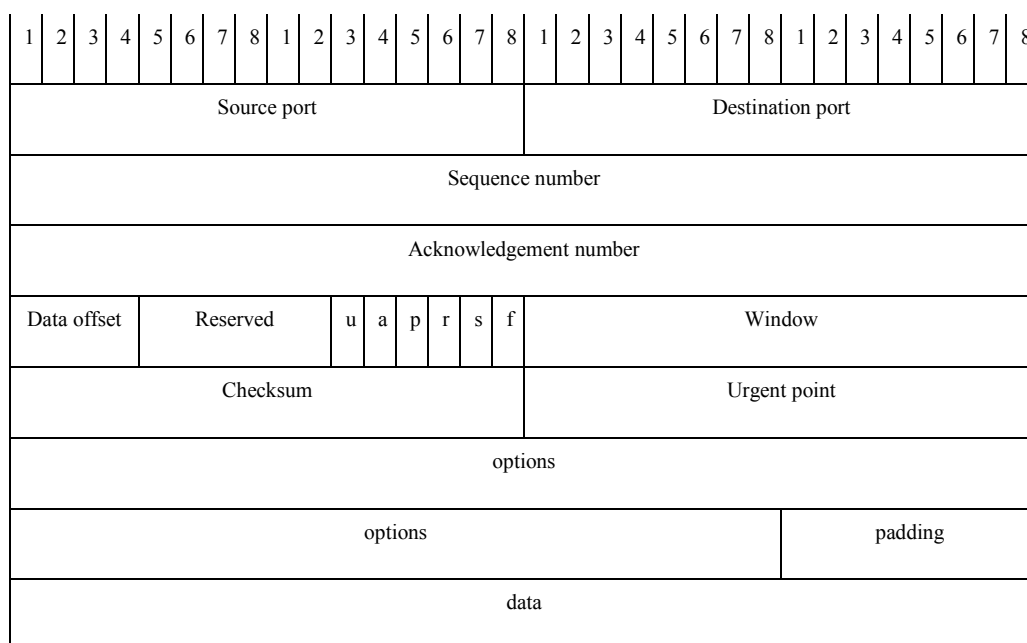


Figure 81 - The TCP segment header

- **Source Port** and **Destination Port** fields, each of which has 16 bits, specify source and destination port numbers to be used by the process as addresses so that the

processes in the source and destination computers can communicate with each other by sending and receiving data from the addresses.

- **Sequence Number** field consists of 32 bits. It identifies the first data octet in this segment (except when SYN control bit is present). If SYN is present the sequence number is the initial sequence number (ISN) and the first data octet is ISN+1.
- **Acknowledgment Number** field consists of 32 bits. If the ACK control bit is set this field contains the value of the next sequence number the sender of the segment is expecting to receive. Once a connection is established this is always sent.
- **Data Offset** field consists of 4 bits. The number of 32 bit words in the TCP Header. This indicates where the data begins. The TCP header (even one including options) is an integral number of 32 bits long.
- **Reserved** field of 6 bits for future use (Must be zero by default).
- **Control Bits** consists of 6 bits (from left to right) for the following functions:
 - URG: Urgent Pointer field significant,
 - ACK: Acknowledgment field significant,
 - PSH: Push Function,
 - RST: Reset the connection;
 - SYN: Synchronize sequence numbers, and
 - FIN: No more data from sender.
- **Window** field consists of 16 bits. The number of data octets beginning with the one indicated in the acknowledgment field, which the sender of this segment is willing to accept.
- **Checksum** field consists of 16 bits. It is the 16 bit one's complement of the one's complement sum of all 16 bit words in the header and text. If a segment contains an odd number of header and text octets to be checksum, the last octet is padded on the right with zeros to form a 16 bit word for checksum purposes. The pad is not transmitted as part of the segment. While computing the checksum, the checksum field itself is replaced with zeros.
- **Urgent Pointer** field consists of 16 bits. This field communicates the current value of the urgent pointer as a positive offset from the sequence number in this segment.
- Options and Padding fields have variable length. The option allows introducing additional functions to the protocol.

The TCP are free to associate ports with processes however they choose. However, several basic concepts are necessary in any implementation. Well-known sockets are a convenient mechanism for a priori associating a socket address with standard services. For instance, the "Telnet-Server" process is permanently assigned to a socket number of 23, FTP-data 20 and FTP-control 21, TFTP 69, SMTP 25, POP3 110, and WWW HTTP 80.

F.3.1 USER DATAGRAM PROTOCOL (UDP)

This User Datagram Protocol (UDP) is defined to make available a datagram mode of transport layer protocol [Ref 20]. This protocol assumes that the Internet Protocol (IP) is used as the underlying protocol.

This protocol provides a procedure for application programs to send messages to other programs with a minimum of protocol mechanism. The protocol provides connectionless

service and does not provide any guarantee on delivery, duplicate protection and order of delivery, or even make any effort to recover any lost data. Therefore, it makes the protocol very simple and particularly useful for real time data transportation.

1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Source port								Destination port																							
length								checksum																							
Data																															

Figure 82 - The UDP datagram header

Figure 82 illustrates the UDP datagram header format. The functions of the fields of the UDP datagram header are discussed here.

- Source Port field is an optional field, when meaningful, it indicates the port of the sending process, and may be assumed to be the port to which a reply should be addressed in the absence of any other information. If not used, a value of zero is inserted.
- Destination Port field has a meaning within the context of a particular Internet destination address.
- Length field indicates the length in octets of this user datagram including this header and the data. (This means the minimum value of the length is eight.)
- Checksum is the 16-bit one's complement of the one's complement sum of a pseudo header of information from the IP header, the UDP header, and
- The data, padded with zero octets at the end (if necessary) to make a multiple of two octets.

The major uses of this protocol are the Internet Name Server, and the Trivial File Transfer, and recently for real time applications such as VoIP, video streaming and multicast where retransmission of lost data is undesirable. The well-know ports are defined in the same way as the TCP.

Appendix G QUALITY OF SERVICE (QoS) PARAMETERS AND PERFORMANCE OBJECTIVES

G.1 BACKGROUND

The term Quality of Service (QoS) is extensively used today. It is not only used in analogue and digital transmission in telephony networks and communication but also in broadband networks, wireless networks, multimedia services and even Internet. Networks and systems are gradually being designed in consideration of end-to-end performance required by user applications. Most traditional Internet applications such as e-mail and ftp are sensitive to packet loss but can tolerate delays. For multimedia applications (voice over IP and video conference) this is general the opposite. They can tolerate some packet loss but are sensible to delay and variation of the delay.

Therefore, networks should have mechanisms for allocating bandwidth resources to guarantee a specific of QoS for real-time applications. QoS can be described as a set of parameters that describes the quality of a specific stream of data.

G.2 END USER QoS CLASS AND REQUIREMENTS

Based on the end-user application requirements, ITU-T recommendation G.1010 defined classification of performance requirements into end-user QoS Categories [Ref 31].

Based on the target performance requirements, the various applications can be mapped onto axes of packet loss and one-way delay as shown in Figure 83. The size and shape of the boxes provide a general indication of the limit of delay and information loss tolerable for each application class.

It can be seen that there are eight distinct groups which encompass the range of applications identified. Within these eight groupings there is a primary segregation between applications that can tolerate some information loss and those that cannot tolerate any information loss at all, and four general areas of delay tolerance.

This mapping can be summarised in Figure 84, to provide a recommended model for end-user QoS categories, where the four areas of delay are given names chosen to illustrate the type of user interaction involved.

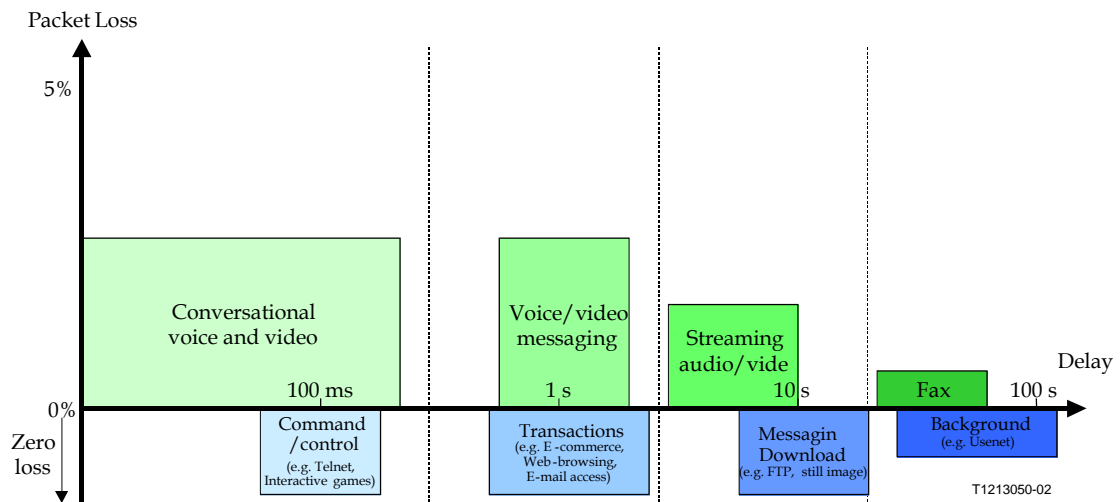


Figure 83 - Mapping of user-centric QoS requirements into network performance [Ref 31]

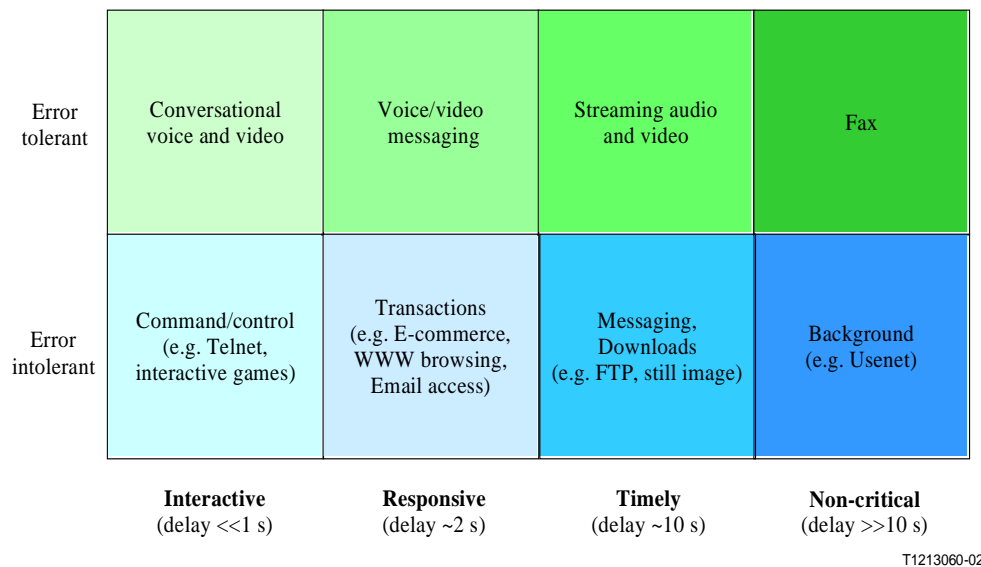


Figure 84 - Model for user-centric QoS categories [Ref 31]

G.3 NETWORK PERFORMANCE (NP)

Network performance (NP) contributes towards QoS as experienced by the user/customer. Network performance may or may not be on an end-to-end basis. For example, access performance is usually separated from the core network performance in the operations of single IP network, while Internet performance often reflects the combined NP of several autonomous networks.

There are four viewpoints of QoS defined by ITU-T G.1000 recommendation, corresponding different perspectives:

- Customer's QoS requirements;

-
- Service provider's offerings of QoS (or planned/targeted QoS);
 - QoS achieved or delivered;
 - Customer survey ratings of QoS.

Among these four viewpoints, the customer's QoS requirements may be considered as the logical starting point. A set of customer's QoS requirements may be treated in isolation as far as its capture is concerned. This requirement is an input to the service provider for the determination of the QoS to be offered or planned.

G.4 INTERNET QUALITY OF SERVICE (IP QoS)

The original Internet Protocol (IP) was design for connectionless network with best effort to deliver IP packet across the Internet. Best effort means no QoS requirement. It needs to provide new services and applications different classes of QoS including guaranteed QoS, controlled load QoS, in addition to the best effort services. These presented great challenge to the new generation network to provide IP-related QoS. Important network QoS parameters include end-to-end delay, delay variation and packet loss. These have to be measured in an end-to-end reference path, where the propagation delay of satellite links should be taken into account properly.

There are many issues on IP-based networks and services defined by the ITU-T [Ref 30], which taking into account:

- Dynamic allocations of resources (like packet loss and delay) among network segments;
- Assuring that required end-to-end network performance objectives are in fact achieved;
- Seamless signalling of desired end-to-end QoS across both network and end-user interfaces;
- Performance monitoring of IP-based networks and services;
- Rapid and complete restoration of IP layer connectivity following severe outages (or attacks) of heavily loaded networks.

ITU-T, Y1540 defines parameters that may be used in specifying and assessing the performance of speed, accuracy, dependability, and availability of IP packet transfer of international Internet Protocol (IP) data communication service [Ref 32]. The defined parameters apply to end-to-end, point-to-point IP service and to the network portions that provide such service. Connectionless transport is a distinguishing aspect of the IP service that is considered in this Recommendation.

The end-to-end IP service refers to the transfer of user-generated IP datagram (i.e. IP packet) between two end hosts as specified by their complete IP addresses.

G.5 LAYERED MODEL OF PERFORMANCE FOR IP SERVICE

Figure 85 shows the layered model of performance for IP service. It illustrates the layered nature of the performance of IP service. The performance provided to IP service users depends on the performance of other layers:

- Lower layers that provide (via "links") connection-oriented or connectionless transport supporting the IP layer. Links are terminated at points where IP packets are forwarded

(i.e., "routers", "SRC", and "DST") and thus have no end-to-end significance. Links may involve different types of technologies, for example, ATM, SDH, PDH, ISDN etc.

- The IP layer that provides connectionless transport of IP datagrams (i.e., IP packets). The IP layer has end-to-end significance for a given pair of source and destination IP addresses. Certain elements in the IP packet headers may be modified by networks, but the IP user data may not be modified at or below the IP layer.
- Higher layers, supported by IP, that further enable end-to-end communications. Upper layers may include, for example, TCP, UDP, FTP, RTP, and HTTP. The higher layers will modify and may enhance the end-to-end performance provided at the IP layer.

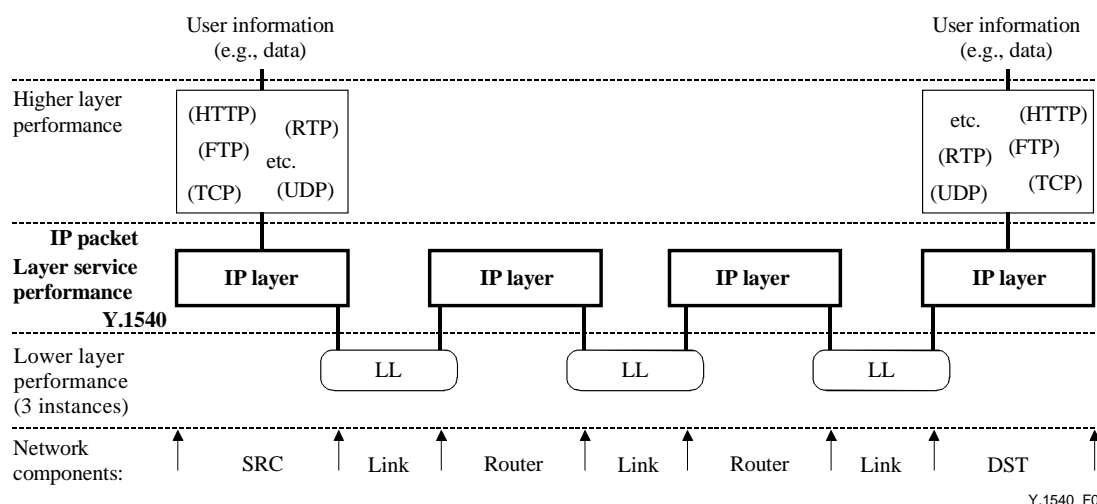


Figure 85 - Layered model of performance for IP service [Ref 32]

G.6 IP PACKET TRANSFER PERFORMANCE PARAMETERS

IP packet transfer delay (IPTD) – It is for all successful and error packet outcomes across a basic section or a network section ensemble (NSE). Mean IP packet transfer delay is the arithmetic average of IP packet transfer delays for common used in overall performance.

End-to-end 2-point IP packet delay variation (IPDV) – it is defined as the variation in IP packet transfer delay. Variations in IP delay will cause TCP retransmission timer thresholds to grow and may also cause packet retransmissions to be delayed or cause packets to be retransmitted unnecessarily.

IP packet error ratio (IPER) - IP packet error ratio is the ratio of total error IP packet outcomes to the total of successful IP packet transfer outcomes plus error IP packet outcomes in a population of interest.

IP packet loss ratio (IPLR) - IP packet loss ratio is the ratio of total lost IP packet outcomes to total transmitted IP packets in a population of interest.

IP packet severe loss block ratio (IPSLBR) - An IP packet severe loss block ratio is the ratio of the IP packet severe loss block outcomes to total blocks in a population of interest. This parameter can identify multiple IP path changes due to routing updates, also known as route flapping, which causes significant degradation to most user applications.

G.7 IP NETWORK PERFORMANCE OBJECTIVES FOR QoS CLASSES

ITU-T Recommendation Y.1540 addresses the topic of network transfer capacity (the effective bit rate delivered to a flow over a time interval), its relationship to the packet transfer QoS parameters, and objectives specified for each QoS class. The IP Network Performance Objectives are shown in Table 27.

Transfer Capacity is a fundamental QoS parameter having primary influence on the performance perceived by end-users. Many user applications have minimum capacity requirements; these requirements should be considered when entering into service agreements. [Ref 32] does not define a parameter for capacity; however, it does define the Packet Loss parameter. Lost bits or octets can be subtracted from the total sent in order to provisionally determine network capacity.

Network performance parameter	Nature of network performance objective	QoS Classes					
		Class 0	Class 1	Class 2	Class 3	Class 4	Class 5 Unspecified
IPTD	Upper bound on the mean IPTD	100 ms	400 ms	100 ms	400 ms	1 s	U
IPDV	Upper bound on the $1 - 10^{-3}$ quantile of IPTD minus the minimum IPTD	50 ms	50 ms	U	U	U	U
IPLR	Upper bound on the packet loss probability	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	U
IPER	Upper bound	1×10^{-4}					U

Table 27 - Provisional IP network QoS class definitions and network performance objectives [Ref 32]

G.8 GUIDANCE ON IP QoS CLASS USAGE

Table 28 gives some guidance for the applicability and engineering of the network QoS Classes [Ref 33].

QoS class	Applications (examples)	Node mechanisms	Network techniques
0	Real-time, jitter sensitive, high interaction (VoIP, VTC)	Separate queue with preferential servicing, traffic grooming	Constrained routing and distance
1	Real-time, jitter sensitive, interactive (VoIP, VTC).		Less constrained routing and distances
2	Transaction data, highly interactive (Signalling)	Separate queue, drop priority	Constrained routing and distance
3	Transaction data, interactive		Less constrained routing and distances
4	Low loss only (short transactions, bulk data, video streaming)	Long queue, drop priority	Any route/path
5	Traditional applications of default IP networks	Separate queue (lowest priority)	Any route/path

Table 28 - Guidance for IP QoS classes [Ref 33]

Appendix H SAMKNOWS NETWORK STATISTICS FOR THE REAL SATELLITE LINK

During the trials, a "Samknows" test unit was plugged into the satellite link to transparently run quality of service tests in the background. The results of the tests are shown in the following graphs.

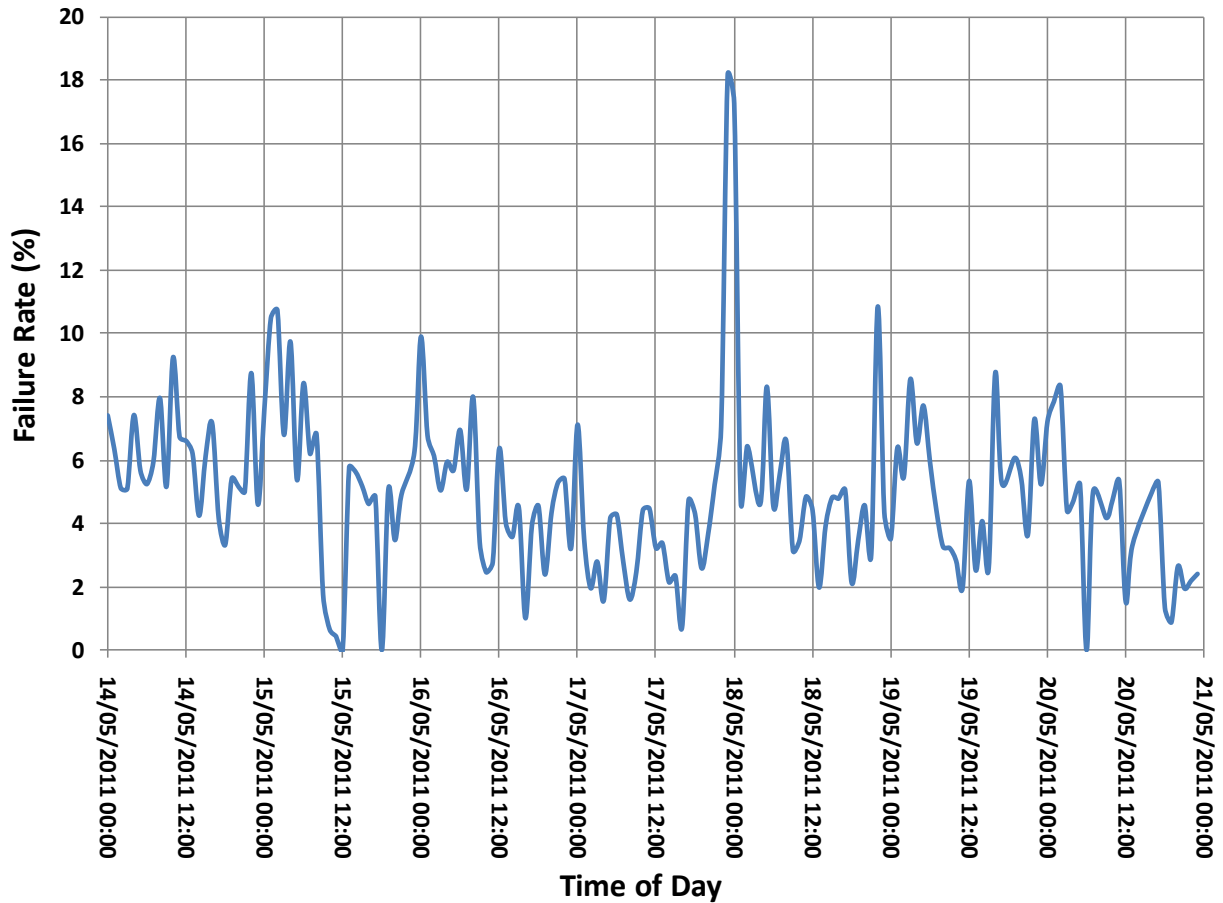


Figure 86 - Average packet loss rate

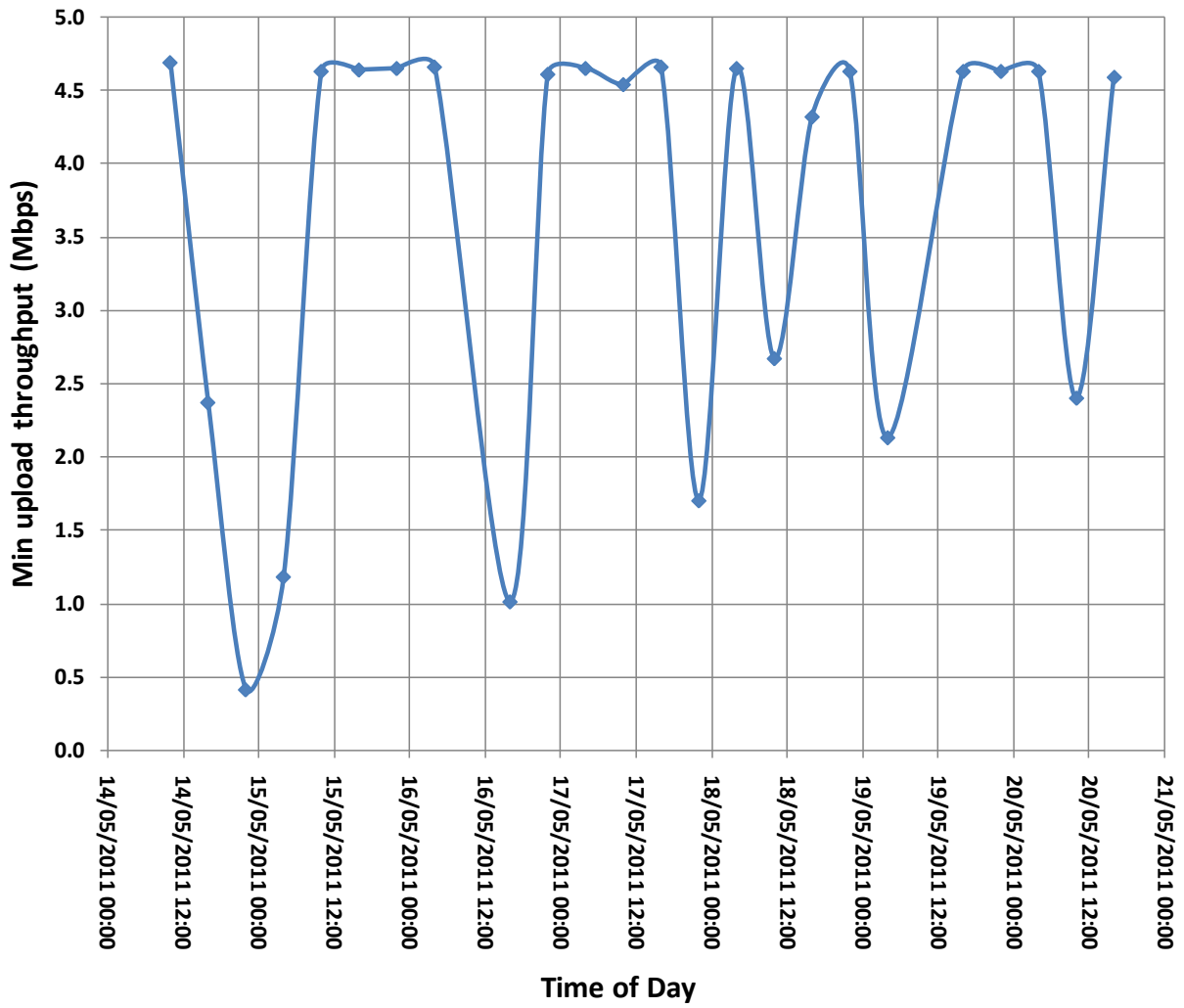


Figure 87 - Minimum upload throughput

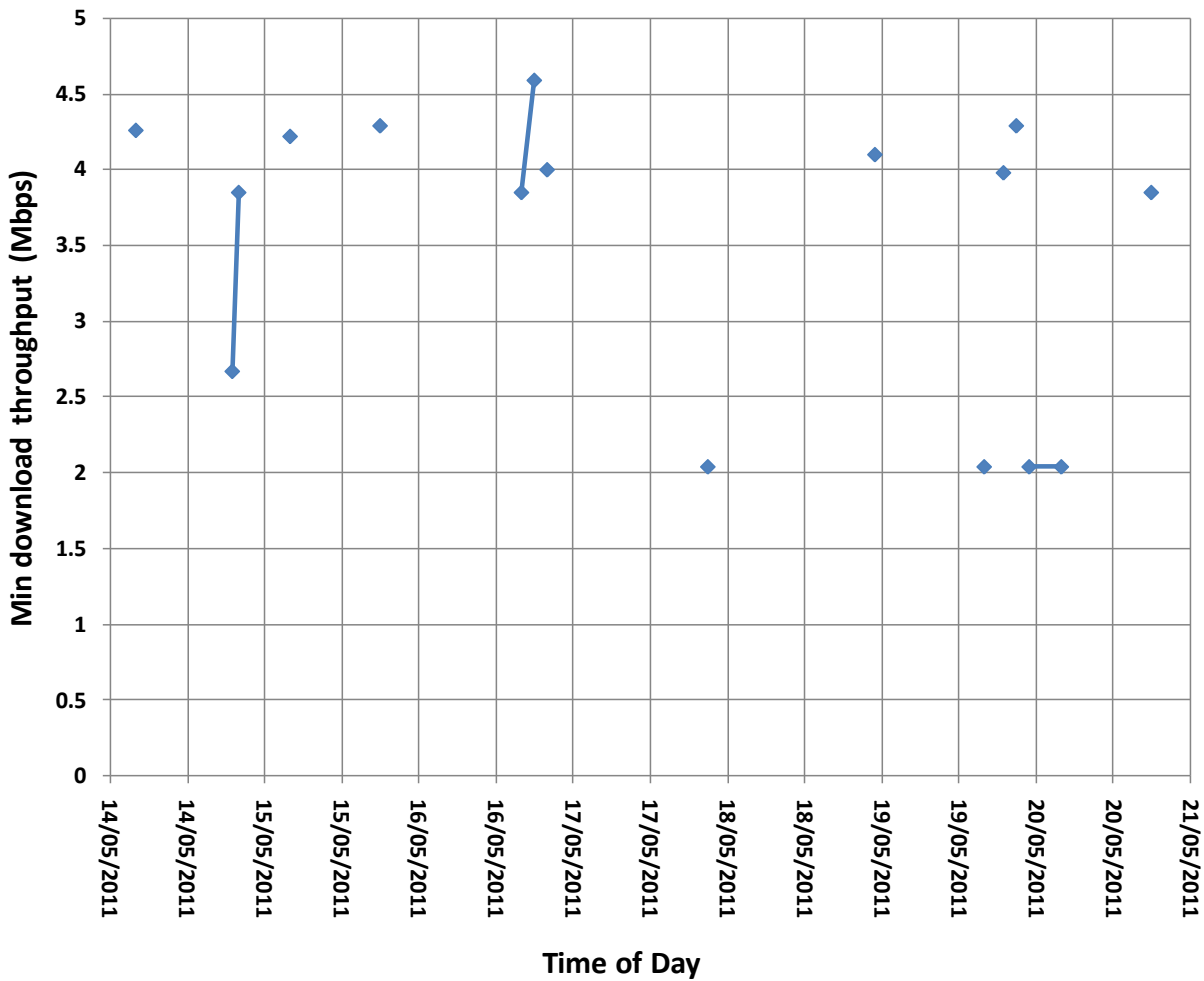


Figure 88 - Minimum download throughput

Note that many of the download tests failed - this is likely because the test aborts if the connection has not ramped up to a stable speed quite quickly enough. The unit was configured using terrestrial data gathering parameters, and hence may have affected the results of this test.

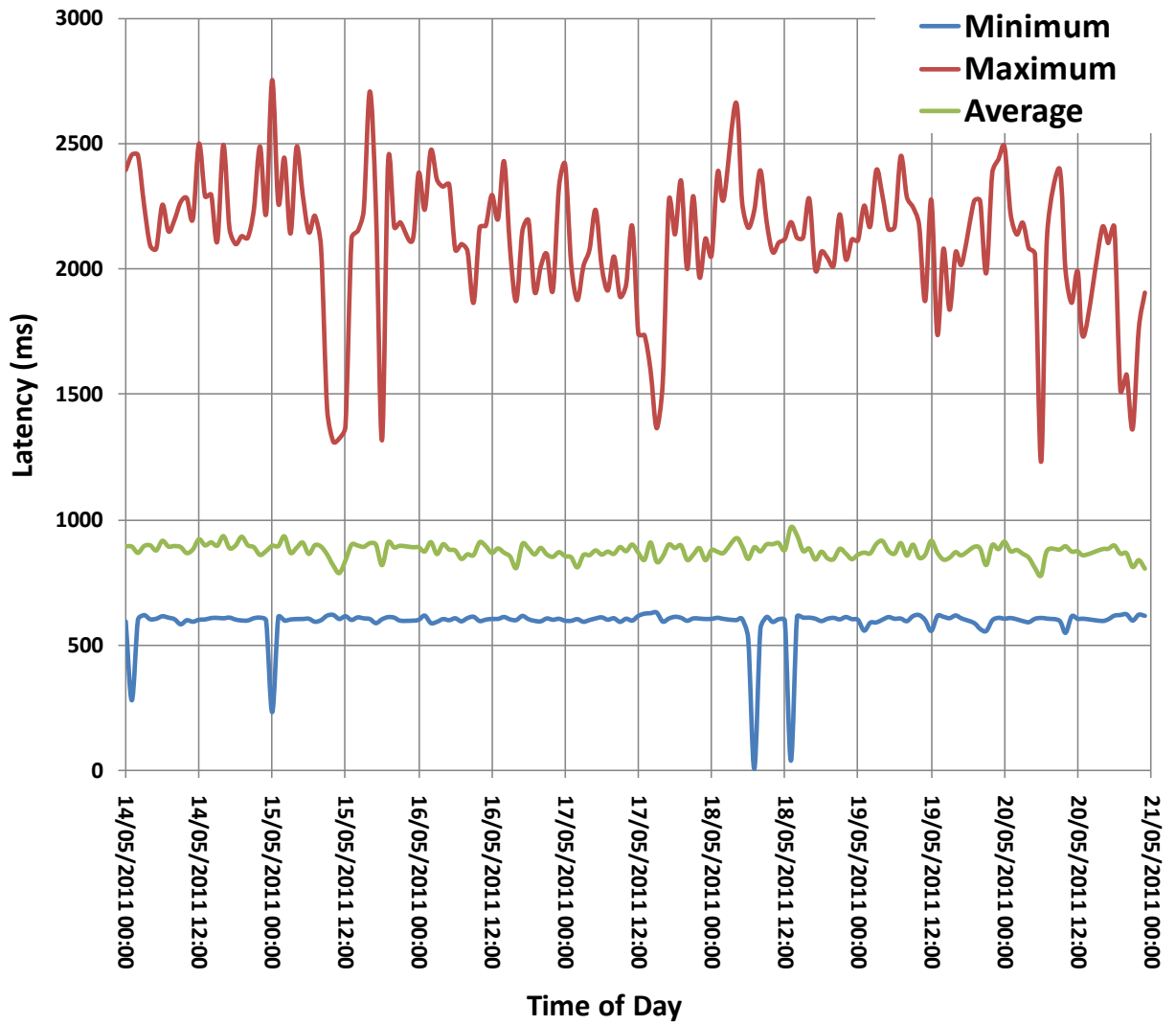


Figure 89 - Satellite link latency

Appendix I EXAMPLE SCRIPTS

I.1 INTRODUCTION

Hello

Thank you for agreeing to take part in this experiment.

We are carrying out some research for Ofcom looking at whether a satellite broadband connection gives a good enough quality of user experience.

The point of this experiment is to look at how the different Internet connections impact on your ability to use the Internet. Within this experiment we are not looking at the technical differences, but how the different connections affect your enjoyment and satisfaction with the experience, whether there are things about the connection that irritate you, etc.

You are going to be asked to complete some simple tasks using three different Internet connections. You will not know which connection you are using. After completing each of the tasks we will ask you some questions about your experience and there will be a few more questions right at the end.

We will remove any information that might identify you from the data we collect before publishing it in any form.

Do you have any questions at this point?

I.2 REMOTE DESKTOP/VPN

We are going to ask you to use the Windows remote desktop application to perform a series of simple tasks, representing the sort of thing that you might do over a remote link.

1. On the desktop you will find a link to a remote desktop application
2. Click the OpenVPN button, then click the RDP button.
3. Once the connection is established:
 - Please find the file called "address list" and open it
 - Please find Mark Ward/Nik Whitehead/Janice Wordsworth address in the file
 - Make a note of Mark Ward/Nik Whitehead/Janice Wordsworth's email address and save it in a text file.
4. Now disconnect the OpenVPN

Now that you have done this, please can you answer the following questions?

Thinking about the application that you have just been using and using a scale of 1 to 5 where 1 is the worst and 5 is the best:

7. How would you rate the speed of response? (1 – 5)
8. How would you rate the amount/number of delays? (1 – 5)

-
9. Thinking about the internet service (rather than the application) how would you rate the general experience? (1 - 5)

Can you select three of the following terms that best represent your experience? (Show sheet of descriptive words)

A - Exciting

B - Boring

C - Standard

D - Frustrating

E - Irritating

F - Satisfying

G - Enjoyable

H - Acceptable

I - Adequate

J - Disappointing

K - Stressful

L - Hassle-free

M - Problematic

N - Simple

O - Easy

P - Complicated

10. For each of these terms, would this make you more or less likely to adopt this internet connection?

a. Word 1

b. Word 2

c. Word 3

11. How does it compare with your normal use of the internet for this application?
Better/same/worse/don't normally use?

12. Any other comments?

I.3 GAMING

We would like you to play an on-line game for a few minutes. The game is Unreal Tournament and is basically a "first person shooter" game. Your task is to play the game for 5 minutes without getting killed yourself and to kill as many opponents as possible.

1. On your desktop there is a games application called Unreal Tournament

2. Start Unreal Tournament

- a. Select Join Game
- b. Select Favourites Tab
- c. Select Join Game
- d. Enter Game Password ("test" without quotes)

3. Play. Game will end after 5 mins.

Now that you have done this, please can you answer the following questions?

Thinking about the application that you have just been using and using a scale of 1 to 5 where 1 is the worst and 5 is the best:

4. How would you rate the speed of response? (1 – 5)
5. How would you rate the amount/number of delays? (1 – 5)
6. Thinking about the internet service (rather than the application) how would you rate the general experience? (1 – 5)

Can you select three of the following terms that best represent your experience? (Show sheet of descriptive words)

- A - Exciting
- B - Boring
- C - Standard
- D - Frustrating
- E - Irritating
- F - Satisfying
- G - Enjoyable
- H - Acceptable
- I - Adequate
- J - Disappointing
- K - Stressful
- L - Hassle-free
- M - Problematic
- N - Simple
- O - Easy

P - Complicated

7. For each of these terms, would this make you more or less likely to adopt this internet connection?
 - a. Word 1
 - b. Word 2
 - c. Word 3
8. How does it compare with your normal use of the internet for this application?
Better/same/worse/don't normally use?
9. Any other comments?

I.4 VoIP

We would like you to use the internet to have a telephone conversation for a few minutes.

Please go into the Skype application and find Howard Tripp – he is in the favourites list.

Once you are connected, Howard will chat to you about your last holiday/your next holiday/last time you went out. You do not have to talk about your real experiences if you do not want to, please feel free to use your imagination if you wish.

The content of this conversation will not be reported or used in any way, we are just interested in your experience of chatting over the internet.

I.4.1 VARIANT 1

1. When did you last go on holiday?
2. Where did you go?
3. Who went with you?
4. What did you enjoy most about it?
5. Was there anything you didn't enjoy?
6. Would you go there again?

I.4.2 VARIANT 2

1. Are you planning to go on holiday this year?
2. If so:
 - a. Where are you planning to go?
 - b. Have you been there before?
 - c. Who is going to go with you?
 - d. What are you most looking forward to?
3. If not:
 - a. If you were, where would you like to go?
 - b. Have you been there before?
 - c. Why would you like to go there?
 - d. Who would you like to take with you?

I.4.3 VARIANT 3

1. When did you last go out for the evening?

-
2. Where did you go/what did you do?
 3. Who went with you?
 4. What did you enjoy most about it?
 5. Was there anything you didn't enjoy?
 6. Would you go there again?

Now that you have done this, please can you answer the following questions?

Thinking about the application that you have just been using and using a scale of 1 to 5 where 1 is the worst and 5 is the best:

7. How would you rate the speed of response? (1 – 5)
8. How would you rate the amount/number of delays? (1 – 5)
9. Thinking about the internet service (rather than the application) how would you rate the general experience? (1 – 5)

Can you select three of the following terms that best represent your experience? (Show sheet of descriptive words)

- A - Exciting
- B - Boring
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- D - Frustrating
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- I - Adequate
- J - Disappointing
- K - Stressful
- L - Hassle-free
- M - Problematic
- N - Simple
- O - Easy
- P - Complicated

10. For each of these terms, would this make you more or less likely to adopt this internet connection?

-
- d. Word 1
 - e. Word 2
 - f. Word 3

- 11. How does it compare with your normal use of the internet for this application?
Better/same/worse/don't normally use?
- 12. Any other comments?

I.5 VIDEO-AUDIO STREAMING

Now we would like you to watch a video clip.

- 1. Please go into Firefox
- 2. Find the BBC News website
- 3. Find the video clip and watch it – we hope you enjoy it/find it interesting.
 - a.
 - b.
 - c.

Now that you have done this, please can you answer the following questions?

Thinking about the application that you have just been using and using a scale of 1 to 5 where 1 is the worst and 5 is the best:

- 4. How would you rate the speed of response? (1 – 5)
- 5. How would you rate the amount/number of delays? (1 – 5)
- 6. Thinking about the internet service (rather than the application) how would you rate the general experience? (1 – 5)

Can you select three of the following terms that best represent your experience? (Show sheet of descriptive words)

- A - Exciting
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7. For each of these terms, would this make you more or less likely to adopt this internet connection?
 - g. Word 1
 - h. Word 2
 - i. Word 3
8. How does it compare with your normal use of the internet for this application?
Better/same/worse/don't normally use?
9. Any other comments?

Appendix J QUESTIONNAIRES

During the experiment, these questions will be used as a prompt and the responses will be recorded on a mark-up sheet.

J.1 ETHICS

Before we start, please can you confirm the following statements?

1. I confirm that I understand the purpose of the experiment and what I will be asked to do and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason. If I do so I understand that any information that I have provided as part of the study will be destroyed and my identity removed unless I agree otherwise.
3. I agree to the experiment being recorded: this may include audio, video, photography and/or computer data logging.
4. I agree to the use of anonymised quotes in publications
5. I understand that any information which might potentially identify me will not be used in published material
6. I agree to take part in this experiment.

J.2 DEMOGRAPHIC QUESTIONS

Now we would like to ask some questions about you....

What is your age?

15 - 24

24 - 44

45 - 64

65 - 74

75+

What is your gender?

Male

Female

J.3 EXPERIENCE

In regard to the following uses of the Internet, how would you assess your use in terms of your experience with this type of application?

J.3.1 VOIP

- High - very experienced confident user
- Medium – use it

-
- Low – have tried it occasionally, not confident with using it
 - Never used

J.3.2 STREAMING VIDEO/AUDIO

- High - very experienced confident user
- Medium – use it
- Low – have tried it occasionally, not confident with using it
- Never used

J.3.3 ONLINE GAMING

- High - very experienced confident user
- Medium – use it
- Low – have tried it occasionally, not confident with using it
- Never used

J.3.4 GENERAL INTERNET USE

- High - very experienced confident user
- Medium – use it
- Low – have tried it occasionally, not confident with using it
- Never used

J.4 TIME

In regard to the following uses of the Internet, how would you assess your usage in terms of time spent using the application?

J.4.1 VOIP

- High - more than 2 hours/day
- Medium - between 1 and 2 hours/day
- Low - less than 7 hours/week
- Never

J.4.2 STREAMING VIDEO/AUDIO

- High - more than 2 hours/day
- Medium - between 1 and 2 hours/day
- Low - less than 7 hours/week
- Never

J.4.3 ONLINE GAMING

- High - more than 2 hours/day
- Medium - between 1 and 2 hours/day

-
- Low - less than 7 hours/week
 - Never

J.4.4 GENERAL INTERNET USE

- High - more than 2 hours/day
- Medium - between 1 and 2 hours/day
- Low - less than 7 hours/week
- Never

When considering an Internet supplier and not considering monetary cost, what do you consider the most important features? Choose up to 3.

- Speed
- Bandwidth (number of different users/uses at the same time)
- Response time (delays, latency)
- Reliability (interruptions to service)
- Download limit
- Other – please specify

When considering an Internet supply, what would cause you most problems/cause you to complain? Choose up to 3

- Slow speed
- Inconsistent speed
- Limited bandwidth
- Delays in response times
- Unreliable service – interruptions to supply
- Inconsistent or unpredictable service – sometimes good, sometimes bad
- Small download limit
- Other – please specify

J.5 POST EXPERIMENT ASSESSMENT QUESTIONS

Thinking about the application that you have just been using and using a scale of 1 to 5 where 1 is the worst and 5 is the best:

10. How would you rate the speed of response? (1 – 5)
11. How would you rate the amount/number of delays? (1 – 5)
12. Thinking about the Internet service (rather than the application) how would you rate the general experience? (1 – 5)

Can you select three of the following terms that best represent your experience? (Show sheet of descriptive words)

A - Exciting

B - Boring

C - Standard

D - Frustrating

E - Irritating

F - Satisfying

G - Enjoyable

H - Acceptable

I - Adequate

J - Disappointing

K - Stressful

L - Hassle-free

M - Problematic

N - Simple

O - Easy

P - Complicated

13. For each of these terms, would this make you more or less likely to adopt this Internet connection?

j. Word 1

k. Word 2

l. Word 3

14. How does it compare with your normal use of the Internet for this application?
Better/same/worse/don't normally use?

15. Any other comments?

J.6 WASH-UP QUESTIONS

1. Did you notice a difference between the three different connection types?
2. If so, which application(s) do you think it was most noticeable in?
3. Would you like to add any other comments about your experience during the experiment?

Appendix K RUNNING ORDER

Participant	System	Gaming	Remote Desktop/VPN	VoIP	Video/audio streaming
User 1	Baseline	~	7	4	6
	Emulator	~	5	8	1
	Satellite	~	9	2	3
User 2	Baseline	4	~	2	5
	Emulator	6	~	7	8
	Satellite	3	~	9	1
User 3	Baseline	7	3	9	~
	Emulator	4	6	2	~
	Satellite	5	8	1	~
User 4	Baseline	5	~	2	4
	Emulator	1	~	3	6
	Satellite	7	~	9	8
User 5	Baseline	8	9	5	~
	Emulator	1	3	6	~
	Satellite	7	4	2	~
User 6	Baseline	~	4	5	1
	Emulator	~	8	7	6
	Satellite	~	2	3	9
User 7	Baseline	5	8	9	~
	Emulator	4	3	6	~
	Satellite	7	2	1	~
User 8	Baseline	~	7	9	6
	Emulator	~	4	2	1
	Satellite	~	3	8	5
User 9	Baseline	7	~	4	2
	Emulator	6	~	1	3
	Satellite	5	~	8	9

Participant	System	Gaming	Remote Desktop/VPN	VoIP	Video/audio streaming
User 10	Baseline	~	3	9	6
	Emulator	~	8	4	7
	Satellite	~	5	1	2
User 11	Baseline	1	2	6	~
	Emulator	3	4	7	~
	Satellite	5	9	8	~
User 12	Baseline	4	~	6	3
	Emulator	9	~	1	8
	Satellite	5	~	7	2
User 13	Baseline	2	1	5	~
	Emulator	6	8	4	~
	Satellite	3	7	9	~
User 14	Baseline	~	6	7	3
	Emulator	~	5	1	2
	Satellite	~	8	9	4
User 15	Baseline	3	~	4	7
	Emulator	1	~	5	6
	Satellite	9	~	2	8
User 16	Baseline	2	4	~	9
	Emulator	5	8	~	3
	Satellite	7	6	~	1
User 17	Baseline	8	5	~	4
	Emulator	6	1	~	7
	Satellite	2	3	~	9
User 18	Baseline	2	5	~	8
	Emulator	7	9	~	1
	Satellite	6	3	~	4
User 19	Baseline	6	5	~	7

Participant	System	Gaming	Remote Desktop/VPN	VoIP	Video/audio streaming
	Emulator	1	3	~	4
	Satellite	8	9	~	2
User 20	Baseline	1	7	~	8
	Emulator	9	5	~	3
	Satellite	6	2	~	4
User 21	Baseline	3	2	~	8
	Emulator	4	9	~	7
	Satellite	6	5	~	1
User 22	Baseline	3	4	~	9
	Emulator	8	6	~	1
	Satellite	7	2	~	5

Table 29 – Full Running Order



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