BROADBAND MOBILE SATELLITE SERVICES:

THE KU-BAND REVOLUTION

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ABSTRACT

In this paper we analyze the emergence of new system architectures and products that are able to deliver broadband services into mobile environments using Ku-band. In particular, we analyze the latest technological solutions that have been developed to cope with the stringent requirements of a mobile environment. Such solutions have brought broadband to environments such as business jets, commercial aircrafts, trains, and cars, which are today the new frontiers where broadband MSS can be offered.

1. INTRODUCTION

After 25 years where mobile satellite services (MSS) have been delivered using L-band infrastructures, with the arrival of broadband services it is evident than the scarce frequency resource in L-band is a structural limit to the scalability of such services. At the same time, Ku-band satellites have been until recently positioned to cover land masses only, and therefore they did not seem well suited to offer MSS that, by nature, require coverage over land and sea masses. But recent evolution in the market demand for ubiquitous broadband services, with service quality comparable to those today available via ADSL or fibre networks, has generated a new business opportunity for satellite operators and satellite service providers. Consequently, market offers have appeared, starting from regional maritime services in Ku-band, evolving to global broadband services for aeronautical, and more recently maritime, scenarios, from the launch of the “Connexion by Boeing” offer [6] to the provision of GSM services onboard cruise ships [7].

These offers have initially suffered of the typical problems of new technologies, with relatively bulky and expensive equipment, but have opened a new opportunity for developing and deploying advanced system architectures and new products tailored to the different market opportunities.

In this paper we analyze the emergence of new system architectures and products that are able to deliver broadband services into mobile environments using Ku-band. In particular, we analyze the latest technological solutions that have been developed to cope with the stringent requirements of a mobile environment. Such solutions have brought broadband to environments such as business jets, commercial aircrafts, trains, and cars, which are today the new frontiers where broadband MSS can be offered.

Two main topics are analyzed: antenna systems and modulation and coding techniques. Each mobile environment requires particular solutions for these topics, tailored to the specific physical conditions, and compatible with a sound business model. Moreover, a global network architecture can optimize costs by sharing the same infrastructure among different commercial offers.

We show different antenna solutions, demonstrating that this is the key element that impacts on the service efficiency, and as such it needs to be tailored specifically for each mobile environment. We present solutions, commercially deployed or still under study, and ranging from phased-array flat antennas, to reflector(s)-based antennas, to other innovative concepts.

Concerning modulation and coding, the latest spread spectrum technologies are presented, where state-of-the-art CDMA-based systems are coupled with ACM (Adaptive Coding and Modulation) techniques to achieve maximum efficiency.

We discuss the application of “multipath routing” technology, where the satellite link is coupled in a synergic way with other wireless links, so as to augment the availability of the service in situations where satellite alone could not be sufficient.

The global network architecture must in these cases take into account other networks, other than the satellite one. It is important to offer a seamless continuous service to the end users, even in the presence of shadowing or link switching. Thus, new problems have been studied and solved to guarantee the interaction of satellite networks with terrestrial wireless networks.

This paper is organized as follows. In Section 2 the main advantages of Ku-band, when compared to L-band, are presented. In Section 3 the main issues to be solved are presented in a general fashion. In Section 4 a brief presentation of advanced technologies, applicable in different scenarios, is done. Sections 5 to 7 present the different mobile environment and their specificities. Finally, some conclusions are drawn.

2. FROM L-BAND TO KU-BAND

Historically, connectivity services for mobile vehicles have been delivered through the use of satellites transmitting in L-band (out of which only a few tens of MHz are assigned to satellite use from regulatory authorities), beginning with Marisat in 1976. Targeted to telephone communication at first, these services have evolved towards IP connectivity and, more recently, the delivery of IP broadband. The use of L-band gives important benefits, such as small onboard antenna size and little or no attenuation due to rain.

However, the amount of L-band available, and more specifically the portion allocated to MSS, is limited. Moreover, frequency reuse due to different orbital slots is extremely limited.

Broadband applications require a much greater amount of bitrate for the final user than normally available. One technical solution has been to create small spots of coverage, so that the same frequency can be re-used in different spots, thus increasing the total amount of available bandwidth for ‘unicast’ communication (while ‘broadcast’ type of communication is penalized by the multi-spot approach).

In the past, some operators failed to run a successful business out of their L-band technology (Globalstar, Iridium). Other operators succeeded in creating a large base of users (Inmarsat, Thuraya). The advantages for L-band operators are:

- small terminals (even handheld) as the antenna size is small and just coarse pointing is required;
- the coverage is wide, over seas and lands;
- the signal is not attenuated by rain, and less prone to shadowing due to trees than Ku-band;
- there is a large installed base (vessels, aircrafts).

On the other hand, L-band suffers from the lack of bandwidth, and this has consequences on the costs to the users. For example, the cost of a minute of Inmarsat communication can range from several Euros to tens of Euros. These costs are hardly compatible with a ‘broadband’ user experience at reasonable prices.

To definitely overcome the problems due to the scarcity of L-band, the only choice is to move to a higher frequency band. Ku-band (frequencies between 11 and 14 GHz, out of which 2+2 GHz assigned to satellite use) is an ideal candidate to offer broadband services. Although only a part of the overall Ku spectrum is usable in a mobile environment (in particular, only 500 MHz – from 14 to 14.5 GHz – can be used in the uplink direction from a mobile vehicle), bandwidth can be augmented by frequency reuse at different orbital positions.

In the recent years, on the top of TV distribution which is its principal application today, Ku-band has succeeded to provide broadband services to fixed users, either with one-way (asymmetric) or two-way (symmetric) data flow. The cost of the user terminals has become affordable, and spectrum utilization is efficient enough, so as to allow good prices to be proposed to final customers.

EUTELSAT has been the first operator to deploy the use of Ku-band for mobile communication in Europe with the Euteltracs product. Euteltracs is targeted to localization and messaging for terminals installed on trucks. After 15 years of operation, Euteltracs counts today more than 30000 active terminals over all Europe.

The natural evolution is today the commercial deployment of broadband services in Ku-band towards all mobile environments: boats, trains, aircrafts, cars… Building upon the past experience, and thanks to recent developments in antenna and modem design, the costs of a service in Ku-band are now only a fraction of those in L-band. Thus, new markets are reachable (see Figure 1 for a graphical summary).

Ku-band still has some limitations when compared to L-band, and in particular:

- bigger antennas, that require precise pointing and tracking while in motion;
- need to extend coverage over oceans for the aeronautical and maritime case;

We will see in the rest of this paper how these problems have been solved.

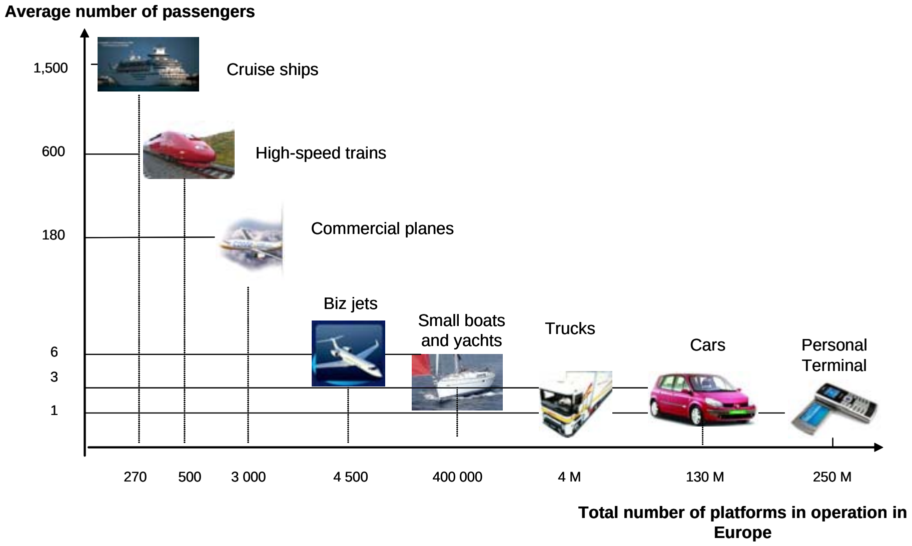

Figure 1 – Addressable market for different mobile environments

3. ISSUES IN MOBILE BROADBAND

Current applications and services require data rate in the range of up to 2 Mbit/s for the return link and several Mbit/s for the forward link, taking into consideration the average number of potential user's in an aircraft, a train or a vessel. These figures are certainly going to increase, as the number of IP-based applications is ever increasing, and reaches a wider audience each day. Thanks to the explosion of DSL-like connection systems, users at home have become familiar with bandwidth-demanding applications. In order to be attractive from a commercial point of view, the service offered in the mobile environment should at least allow for the same type of applications that the user already has at his home or office, at not exceedingly high costs.

The main issue to be solved in a mobile broadband scenario is the one of cost. In fact, while classical telephony needs could be satisfied with a few allocated kbits, newer broadband applications are much hungrier in bandwidth. Even simple web browsing requires peaks of (at least) hundreds of kbits in order to allow the download of a web page in a reasonable time. Moreover, users are becoming acquainted with broadband at low price at home (DSL offers with Mbits connectivity are usually in the range of tens of € per month), and expect a comparable experience in a situation of mobility. Users feel connectivity as something that should be reasonably ‘cheap’, while they are ready to pay more for premium content (e.g., top movies in a Video-on-Demand offer) or advanced services.

It is thus fundamental to optimize the cost of the system at the maximum possible extent. Restricting the discussion to the connectivity domain, the main cost drivers are:

- the total cost of the installation of the equipment on the mobile vehicle. This is usually dominated by the cost of the antenna system; however, the cost of the other parts, and of the installation work itself can be significant too;
- the cost of the satellite segment. This is related to how performing is the modem in total bits/sec/Hz (i.e. with respect to bandwidth utilization) and how the same bandwidth is shared between multiple users or mobiles;
- the cost of the ground segment. This is due to cost of material and installation, and operating costs due to maintenance and operations of the ground equipment.

While a more detailed discussion will be done for each particular type of mobile, some general considerations on the optimization of costs are given here below.

Optimization of the installation costs.

- the installation must be simple and must take little time (in particular, some type of mobiles, e.g. trains, simply cannot be immobilized for long periods);
- there must be a fairly limited number of equipments to be installed – putting more software packages on the same hardware simplifies both installation and future maintenance;
- as far as possible, the antenna must be efficient, simple, reliable and reasonably cheap.

Optimization of satellite segment costs.

- the antenna and modem must have good performance on the satellite link;

- in particular, a good protocol must be used in the two directions (for example DVB-S2 for the forward link);
- most importantly, the antenna must be as efficient as possible (gain, sensitivity, interference profile) within the limitations of the specific mobile environment;
- new techniques of ‘VCM’ (Variable Coding and Modulation) or ‘ACM’ (Adaptive Coding and Modulation) must be used, where suitable, to optimize satellite segment performance with respect to a single mobile at any specific moment;
- the same satellite segment should be shared by a large amount of users/vehicles, of course with a reasonable QoS strategy, to share the costs.

Optimization of ground segment costs.

- a centralized hub/NOC allows to share operational costs among several services;
- the hub/NOC should be highly automated and not rely too much on human intervention.

From a more technical point of view, the main issue to be solved is that of satellite interference. In fact, mobile vehicles usually require small or low-profile antennas. This type of antenna has a large beamwidth, thus has the double problem:

- in reception, it grabs noise coming from satellites adjacent to the one used;
- in emission, it interferes with adjacent satellites. The amount of allowable interference is limited by ETSI regulation.

While an accurate choice of the satellite segment to be used can help in smoothing these problems, the antenna design plays a major role. It is thus important that, within the size constraints coming from the vehicle, the antenna has a good gain and a good interference profile (if the antenna interferes too much, it will be forced by regulation to transmit at lower EIRP, thus at lower bitrate). Also the tracking algorithm and mechanics are important not to loose some dB due to poor tracking accuracy.

The modem also plays an important role in bounding adjacent satellite interference in the return link, in that some coding techniques (in particular spread spectrum) allow using a higher bitrate while remaining within the ETSI regulation mask.

Another problem related to low-profile antennas is the equivalent surface at low elevation angles. Even a fairly large low-profile antenna offers a limited surface to a satellite at low elevation. Thus, the performance of the antenna will be limited and the satellite link cannot be used at its optimum. Thus, low-profile antennas should be used only when necessary, and their profile be accurately designed for the specific vehicle.

4. TECHNOLOGICAL SOLUTIONS

4.1 Satellite Link Optimization for Mobile Use

Satellite communications have been used for some years now, introducing communication standards such as DVB-S and modulation and coding techniques such as TDMA. Today, one of the major issues in Broadband Mobile Satellite Services is to adapt these modulation and coding techniques to a mobile environment.

In satellite communications, the physical layer spectral efficiency depends mainly on satellite coverage and antennas performances. In our case, we can assume an EIRP in the range 44-54 dBW, and a G/T in the range 0-10 dB/K.

In the railway scenario, trains are generally operating on land masses well covered by Ku-band satellites, which implies that we have good performances. However the antenna must often be small and/or low-profile, interference with adjacent satellites should therefore be constrained within the limits imposed by radio regulations.

In the maritime and aeronautical scenario, we must take into account that boats and aircrafts can be either at the centre or at the edge of a beam. Thus, the satellite link has varying characteristics, and should be optimized for each situation.

For big boats, it is often possible to install big antennas that improve the overall performance and limit interference with adjacent satellites. However, this is not possible for smaller boats and aircrafts.

There are two major issues to solve in terms of the satellite link:

- interference generated to, and received from, adjacent satellites;
- optimisation of the link for different coverage scenarios (centre or edge of the beam).

We will see in next sections that the first issue can be solved using spread spectrum for the return link, and the second one using ACM (adaptive coding and modulation) or VCM (variable coding and modulation) for the forward link.

4.2 Spread spectrum and CDMA

Spread spectrum technology uses wide band, noise-like signals. Spread spectrum transmitters use similar transmits power levels to narrow band transmitters. Because spread spectrum signals are so wide, they transmit at a much lower spectral power density, measured in Watts per Hertz, than narrowband transmitters. As a consequence, the interference generated on adjacent satellites operating at the same frequencies, due to the use of small antennas with a large beamwidth, is greatly reduced.

For this reason, spread spectrum is the technology of choice when working with small or low-profile antennas, as is the case in almost all mobile environments.

One of the foreseen spreading techniques is Code Division Multiple Access (CDMA). In these systems all users transmit in the same bandwidth simultaneously. The frequency spectrum of a data-signal is spread using a code uncorrelated with that signal. As a result the bandwidth occupancy is much higher then required.

4.3 Adaptive Coding and Modulation

Most existing satellite systems use QPSK modulation with concatenated Convolutional and Reed-Solomon error correction codes, as per the DVB standard. In addition, the RF links are run using fixed margins, with the size of the margin dependent upon the maximum attenuation predicted for the service area. One way to increase the system data throughput is to manage each terminal separately and have each one use the highest possible level of modulation in combination with the highest possible code rate as the instantaneous link conditions allow. As link conditions fade for each individual terminal, the modulation level and code rate is changed to maintain BER requirements. This technique, called Dynamic Link Assignment (DLA), significantly increases average information throughput per unit bandwidth. In addition to these increases in capacity, the technique may lower satellite and terminal EIRP requirements. These gains allow the service cost to be reduced.

Additionally, DLA provides a significant advantage for spot beam systems. In the typical spot-beam system, the satellite antenna gain from edge of coverage to beam centre varies by about 13 dB. As a result, the satellite EIRP varies by the same amount over the beam coverage. Dynamic links as opposed to fixed links allows each terminal to automatically sense where it is in the spot beam and to operate at as high a modulation level and code rate as possible. This also significantly increases the transponder data throughput.

In scenarios such as aeronautical and maritime one, taking the “worst case” modulation greatly reduces the overall performance. On the other hand, optimizing the modulation parameters for each aircraft according to its current position allows extending the area of service towards the edges of the spot, while at the same time fully exploiting the good link parameters at the centre of the spot.

In other scenarios, such as the railway one, the VCM solution can be sufficient. According to the fact that trains do not travel through the whole coverage map, it is acceptable to fix once and for all a modulation for each vehicle. However, VCM allows to multiplex on the same transponder data intended for different mobiles with different parameters.

Figure 2, taken from [1], shows the advantages of using VCM/ACM techniques in the case of the DVB-S2 protocol. If the coding and modulation parameters are fixed (such as in DVB-S), then there is a global C/N and bitrate so that all mobiles with the required C/N (or better) will receive the specified bitrate. By using VCM, different mobiles can be preconfigured so as to optimize the link for their own C/N: for example mobiles at the centre of the spot may receive a higher bitrate, or consume less bandwidth. By using ACM, this adaptation is dynamic, thus taking into account the movement of the mobile or changes in the weather conditions.

By simply working with QPSK and 8PSK modulation, DVB-S2 allow a variation of 13 dB for the C/N of terminals sharing the same multiplex.

Figure 3 illustrates the possible performance gain due to ACM, by showing what represent a 13 dB variation of EIRP on the EUTELSAT Atlantic Bird 2 coverage. The smaller area corresponds to 54 dBW of EIRP, i.e. the best possible coverage. The wider area corresponds to 41 dBW (cut at an elevation of 10 degrees, the minimum at which a mobile antenna can operate). Aircrafts in the centre of the smaller area and aircrafts within the wider marked area can share the same DVB-S2 multiplex, each one optimizing the satellite resource.

By using ACM/VCM techniques, it is possible to extend the service to areas with worse coverage, while at the same time maintaining good performances at the centre of the spot. In this way, the problem of coverage over seas, typical of Ku-band spots, is vastly reduced.

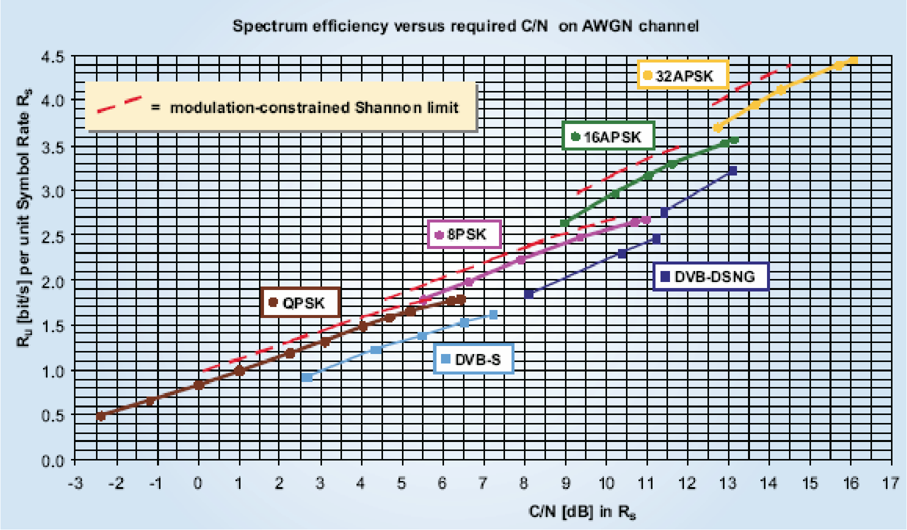

Figure 2 – Required C/N versus spectrum efficiency in different modes of DVB-S2 (Source: [1])

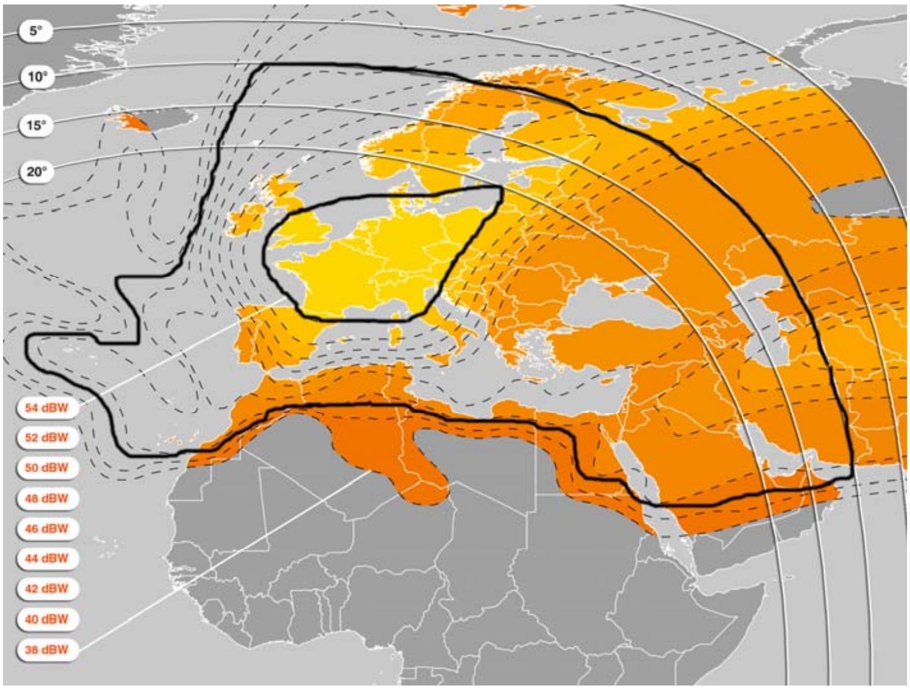

Figure 3 – Downlink European coverage of EUTELSAT Atlantic Bird 2, with the 54 dBW and the 41 dBW contours

4.4 **TCP** Acceleration and Quality of Service

In order to offer connectivity to mobiles, the most reasonable choice is to offer an “IP pipe” capable of transporting any type of IP traffic. Today the TCP/IP protocol suite is capable of handling a large range of application and services, in a flexible and powerful way. However, some care must be taken in the case of mobile broadband services.

First of all, the performance of the TCP protocol over the satellite link is limited by the delay of the link and the different nature of errors. Even if the bandwidth is available, TCP is not able to use it fully.

TCP acceleration is a well known technique to augment the performance of the TCP/IP protocol stack over links with peculiar characteristics, such as the satellite. A number of protocols that implement this technique have been proposed, see [3] for a survey.

Another issue is the management of the available bandwidth, in particular in the case of congestion, in order to guarantee a fair quality of service to each user in the system. The amount of bandwidth to be allocated for a particular user is in part determined by the commercial offer: premium users may receive a *guaranteed* bandwidth, or simply a higher priority, or access to particular services such as Voice-over-IP (VoIP). Then the technical constraints apply: amount of bandwidth available at the terminal level, according to the implemented VCM/ACM scheme, and so on.

Given the nature of current satellite networks, the main problems to be addressed to guarantee a fair quality of service are:

- the ‘forward’ and ‘return’ link are often implemented in rather different way. So the bandwidth management must be applied in a co-ordinated manner to both directions;
- modems and hubs often implement some kind of bandwidth management at the *terminal* level. The system must be able to treat appropriately the quality of service offered to *single users,* that may share or not a terminal.

In order to optimize bandwidth costs, it is very likely that the satellite link is almost always full. So it is very important to accurately manage congestion as a ‘normal’ situation, and be able to offer a good service under this condition.

4.5 The Network Architecture

An architecture for the Mobile Broadband Satellite Services does not reduce to a hub and a number of modems. Other elements, integrated into a coherent network architecture, are needed to provide the service while matching the business constraints.

The NOC, in collaboration with onboard servers, must be able in particular to:

- share the same system among the maximum possible number of terminals/users (even on different type o mobiles);
- apply suitable bandwidth management at user level;
- manage different type of links and the transparent handovers;
- when applicable, manage different satellite spots, in principle served by hub located in different places.

5. THE MARITIME CASE

Compared to trains and aircraft, the maritime environment is the one with least constraints. For example, the vessel is more stable than trains (roll rates are slower, vibration is less), however the antenna steering range may exceed the range of trains, which is typically unproblematic since space, size and weight are not critical issues. This has allowed the deployment of some broadband commercial services in Ku-band:

- DSAT MARITIME services offer a cost-effective solution available from medium bit-rate communications (64 kbit/s) to broadband applications (up to 2Mbit/s). It provides a hub-less, fully meshed multi-services network. A central Network Control Centre is operated by EUTELSAT. Service is in full operation in Ku-band on EUTELSAT W1, W2 and W3 satellites. Data transmission includes:

point to point, point to multipoint; broadcast, streaming media; interconnection of LANs, Internet Access; interconnection of PBX, Public phone with pre-paid card.

- DSTAR MARITIME service delivers cost-effective real broadband IP services (up to 2 Mbit/s) for “always-on” connectivity. Data transmission allows for a full range of applications, including broadband Internet access, e-mail and fax, video-on-demand, voice over IP and videoconferencing.

As a recent application on Ku-band broadband services, WINS (a joint venture between Maltasat International and Skylogic, EUTELSAT’s broadband affiliate) offers GSM telephony and broadband services on luxury cruise ships. See [7] for more information.

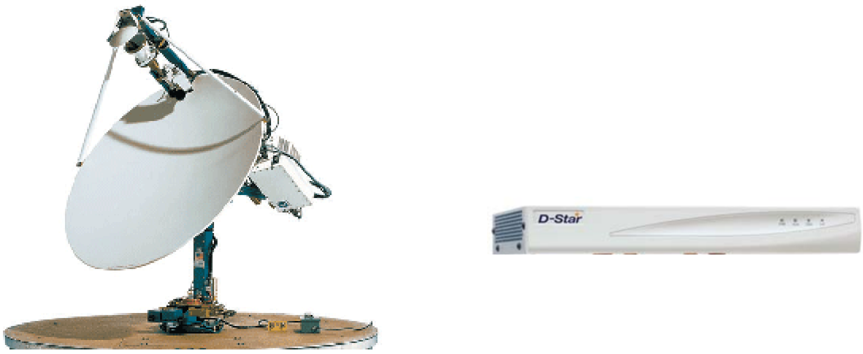

Figure 4 – The antenna used for DSAT, and the modem used for D-STAR Maritime services

The evolution in the maritime scenario is to provide service to smaller boats, such as yachts. The cost of the service (both equipment and bandwidth) is once again the key point to be tackled. We expect that in the near future new 2-way system will be developed at lower price and size, so that installation is possible on smaller boats.

Today a typical solution for small boats is to use an asymmetric link, where the Ku-band is used only in the ‘forward’ link (hub to mobile). For the return link, the choice can be made among terrestrial (e.g. GPRS) or other satellite (e.g. L-band) solutions. The advantage is that a receive-only antenna system in Ku-band in much cheaper that an equivalent 2-way antenna system. Moreover, many boats already have a TVRO antenna installed, that could be used also for broadband reception. On the other hand, the return channel is usually less demanding in bandwidth (as it is mostly used for TCP acknowledgment), so the higher cost of the GPRS or L-band link has a limited impact. Of course the trade-off depends also on the expected use of the system.

If the boat moves over long routes, the use of ACM is recommended, in order to optimize satellite segment utilization according to the exact location of the boat.

6. THE RAILWAY CASE

In this setting, the availability of a terrestrial infrastructure allows for the use of terrestrial (even if wireless) links, such as GPRS or Wi-Fi. Even if some of these links are narrowband, they can be used as return channel in an asymmetric traffic flow, where broadband is received by satellite.

However, the train presents different problems (such as temporary link loss due to tunnels, or obstacles in the satellite line-of-sight; interference from the power lines; vibrations) that must be overcome. Different EU-funded projects have tackled this problem (for example FIFTH, and, more recently, MOWGLY [5]).

The provision of Internet and multimedia services on-board trains is nowadays one of the crucial challenges which characterise the competition among railway operators. These operators are planning to include in their offerings to passengers an effective solution for accessing Internet – both for business and entertainment purposes – to enjoy digital TV, to distribute “railway operator” specific contents and so on. Satellite-based systems seem to be particularly suited to providing broadband connectivity to trains’ passengers. Following (or, somehow, generating) this new trend, several projects proposing technical, satellite-based solutions for multimedia services provision in the railway environment have been recently undertaken around the world.

The railway environment has a lot of challenges that must be tackled to provide a good service. In principle, trains can be served using terrestrial wireless technology. For example, existing GPRS or UMTS networks can be used, but the connection speed can hardly be considered broadband when shared among a large number of users. Or, technologies such as Wi-Fi and, more recently, Wi-Max have been proposed; in this case, the costs of deployment of an ad-hoc network are very high, except for short lines (e.g. commuter trains near a big city)..

A better solution is to integrate satellite and terrestrial wireless in a hybrid system that can take the advantage of both technologies. Ku-band satellite can offer broadband almost everywhere in the countryside, and terrestrial wireless networks can complement satellite coverage in shadowed zones (tunnels, stations, urban zones, or areas shadowed by trees or hills). The on-board equipment shall implement a ‘multipath-routing’ technology capable of:

- selecting, with the appropriate advance, the most appropriate communication link. This selection can be done based on a-priori knowledge of the availability of the links, on real-time monitoring of link quality, on economic considerations (required bandwidth and associated cost).

- switching the data flow from a link to another. The switch should, as far as possible, be transparent to the end user, so at least preserve the active TCP sessions. This switching can be between two different type of link (vertical handover) or between two cells of a cellular network (horizontal handover).

The routing technology above is a key point for the final quality of service as perceived by the end user. A number of companies have proposed solutions to this problem, that are currently under trial or operation. Some solutions are based on the use of GPS localization of the train, coupled with a geographical database constantly updated, which allows the router, for example, to take appropriate measures way before the train enters into a tunnel.

An implementation of this switching functionality is the “Smart Router”, whose logical decomposition is shown in Figure 5, developed by Rockwell Collins France and MBI within the MOWGLY European project.

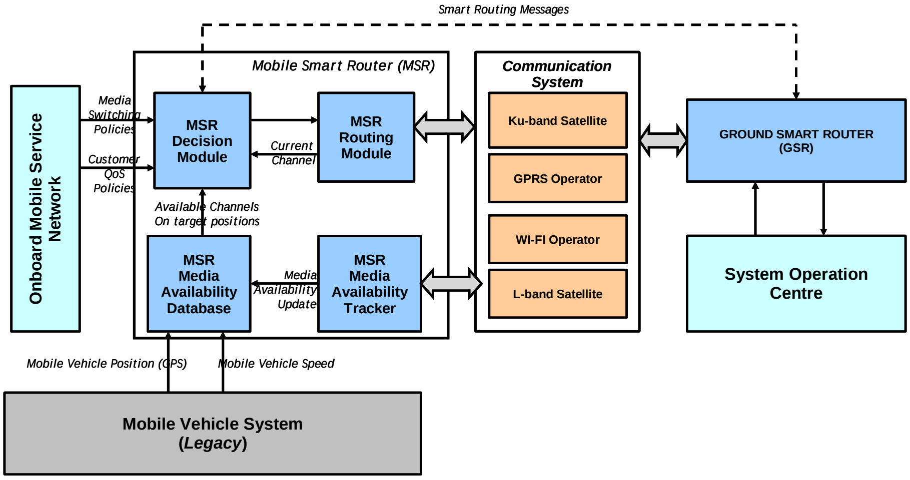

Figure 5 – Logical decomposition of the “Smart Router” (courtesy of Rockwell Collins Francs / MBI)

The antenna choice, as always, is of great importance. One must consider that each type of train can accommodate a different size of antenna, also according to the tracks that the train will follow. Some double-deck trains only allow 8 cm or so for the height of the antenna. Single-deck trains in UK have quite stringent requirements too (up to 25 cm). Other trains can allow heights of 45 cm or even more.

These requirements have driven the industry to the development of specialized low-profile antennas. These antennas can be either ‘classical’ single or dual reflector antennas, or ‘flat’ antennas based on phased arrays technology.

In any case the problem to solve is to have a high equivalent surface in the direction of the satellite, while maintaining a reduced height.

Two antennas dedicated for train applications are being developed within the MOWGLY European project [5], of which EUTELSAT is a partner. The first antenna, shown in Figure 6, is an offset dual-reflector Gregorian antenna developed by Teleinformatica&Sistemi and installed on a tracking platform by ORBIT. The antenna has a 80x20 cm main reflector and achieves a G/T of 9 dB/K and an EIRP of 43 dBW. ORBIT also provides a refined pointing system based on the use of a narrowband receiver, able to discriminate the target satellite from adjacent ones. This antenna is already in use in a few pre-commercial trials in Europe.

The second antenna is a flat antenna with a 80x15 cm phased array, mechanical steering in azimuth, and electronic steering in elevation. Both antennas are expected to be used in on-field trials before the end of 2006 coupled with DVB-S2.

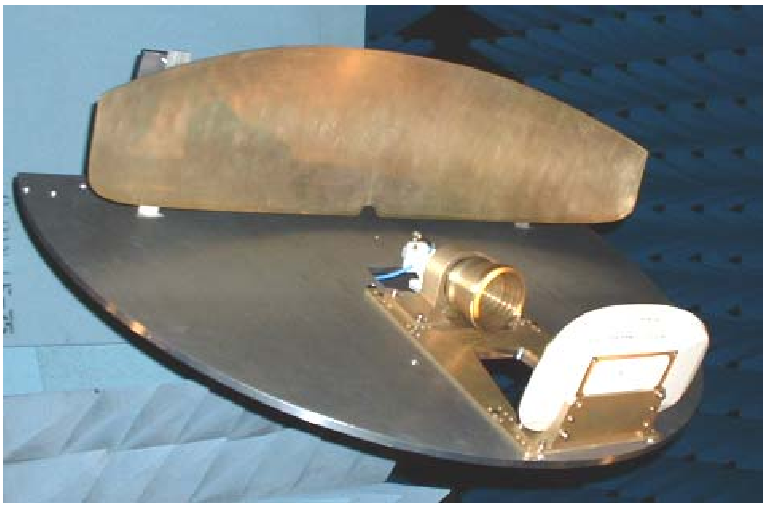

Figure 6 – A prototype antenna suitable for the Pendolino trains (courtesy of Teleinformatica&Sistemi – Patent pending)

In real commercial cases, the ideal solution is to have the highest possible antenna for the particular train. In fact, a low-profile antenna has intrinsically poorer performances (in gain and sensitivity), and a poorer interference pattern; as a consequence, a lower bitrate can be achieved and at a higher cost.

The antenna size also impacts on the modem. In fact, a small antenna with a poor interference pattern requires a spread spectrum technology to minimize interference while maintaining good performance.

The modem must also be able to cope with the frequent fast fading typical of trains, for example shadowing due to electric poles. On TGV lines, for example, these poles create about 20 dB attenuation during 6 ms, periodically every 600 ms. Appropriate strategies have been implemented both on the forward and the return link, in order not to loose the signal lock, and to limit the number of lost packets (using e.g. FEC, buffering).

7. THE AERONAUTICAL CASE

In the case of aircrafts, satellite communications have no concurrence in practice (terrestrial solutions have been studied and tried in the past, but without success). Today, all aircrafts have L-band based communication equipment, used at least for emergency and administrative matters. However, the use of L-band for services to customers (e.g. telephony) has proved to be too costly to have a commercial success. Although the L-band offer has evolved towards more performing systems (e.g. B-GAN), broadband offers will likely remain more costly than Ku-band offers.

A commercial service in Ku-band has been started in recent years by Connexion By Boeing (CBB). This service, started for commercial aircrafts, is now in operation on a few commercial airlines. The end user price is about $30 for Internet connection on a long-haul flight. However, initial investments have been so high that it is now difficult to recover from them.

This is a list of the main existing aeronautical solutions:

- Inmarsat Swift 64 provides passengers in the corporate jet market access to the Internet with speeds of 64 kbps. The service is distributed to seats with conventional IP cabling/routing systems.
- Connexion™ by Boeing (CBB) is available to the private business jet market and was launched on commercial aircrafts by Lufthansa in May 2004 . It is based on the use of Ku-band. CBB provides real-time, high-speed Internet access to air travellers in flight. The business model for this service is far from being proven. It has been announced that Boeing might shut down Connexion after U.S. airlines have failed to show an interest, and turn a profit in 6 years.
- I-4/B-GAN™**:** with its fourth generation of satellites, the Inmarsat I-4, Inmarsat built a “Broadband Global Area Network” that is operational since 2005 with bit rates up to 432kbit/s.
- TV reception: reception of live television via Ku-band satellites is offered to airlines. Solutions for analogue DirectTV or digital DVB-S based systems are available by using the same satellite beam as the one used for home satellite television. Such systems are therefore only available above continent.

A broadband service targeted to business jets is offered by ARINC. Skylogic, an EUTELSAT affiliate, operates the broadband access service for this system through its European hub, so that US customers can seamlessly roam in the European coverage area. This system uses spread spectrum technology developed by Viasat in its Arclight product. Some important features of this system are the following:

- spreading occurs over the full transponder bandwidth. Consequently, the interference on adjacent satellites is greatly reduced with respect to narrow-band systems, thus allowing mobile terminals to transmit at higher speed (currently up to 512 kbps);
- the forward and return channel are superimposed in the same transponder, using PCMA (Paired Carrier Multiple Access). This allows to open the service on a new area by allocating just one transponder for the service (while other system, such as the one by CBB, require at least two separate transponders for the two directions);

The antenna size for the ARINC service is as small as 30 cm, and it is usually accommodated in the tail of the aircraft. The complete onboard system is shown in Figure 7 below.

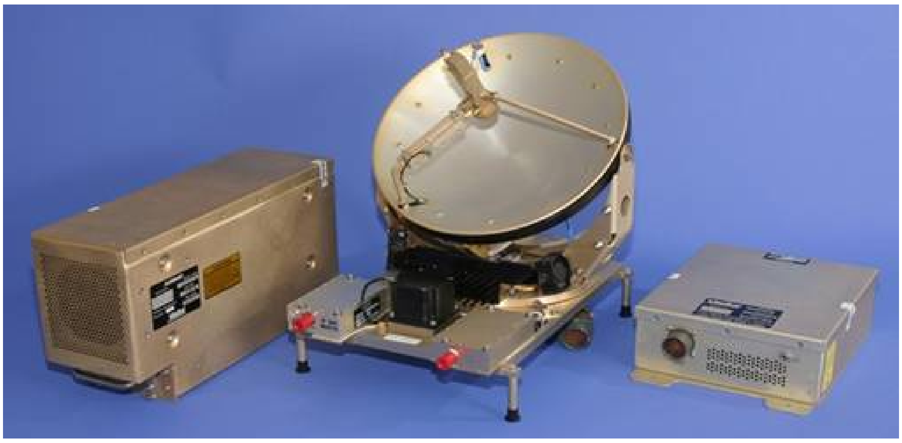

Figure 7 – The complete onboard system for the ARINC service on business jets: the Viasat modem, the RANTEC tail-mount antenna, and the antenna control unit (courtesy of Viasat).

The system also allows dynamic bandwidth allocation, so that satellite resource is assigned only when a terminal is using it. Consequently, the satellite segment can be dimensioned with respect to the maximum number of terminals simultaneously active, which, in the case of business jets, is much smaller than the total number of terminals.

In aeronautical applications, there are strong requirements on the onboard equipment, related either to the security of the aircraft (fire, vibration, shocks, …) and to the extreme environmental conditions (temperature, attitude changes, …). Equipment to be placed on aircraft is thus more costly than in other environments, and the installation itself can be quite complicated.

The size and weight of the system are important. In particular, the size of the antenna, and of its radome, directly impact on the drag of the aircraft. Added to the total weight of the equipment, this translates into more fuel consumption (or less accommodated voyagers), thus into higher operating costs.

In order to optimize bandwidth usage, it is important to use ACM technologies. In fact, during a long flight, the satellite link characteristics can vary considerably (in power and sensitivity of the transponder).

Handover between different coverage areas can also occur. In this case, the continuity of the connections has to be guaranteed by the NOC, in collaboration with some onboard equipment.

8. CONCLUSIONS

The use of Ku-band is bringing a revolution in the field of MSS services, as it allows real broadband to be provided on mobiles at reasonable prices. This is the result of intrinsic properties of Ku-band, and of recent developments in technology and its economic factors. Today a Ku-based solution can be deployed on almost any mobile, and further evolutions are to be expected to fill the remaining gaps.

In this paper we have discussed the different issues related to a broadband offer in Ku-band. One of the key elements is the antenna, which must be tailored to the specific environmental conditions. However, we have shown other elements that significantly contribute to the overall performance and economics of the system.

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