Eutelsat Experiences on Remote Terminals for High Speed Mobility in Ku and Ka Band

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Abstract. Eutelsat plays key role in the provision of mobile services over geosynchronous satellites. Starting with narrowband services for land transports, through broadband maritime service until the most recent IP and multimedia services on board high speed means of transport (trains and airplanes), Eutelsat is present in this market for several years, as services provider or just supplying capacity. This paper gives a technical overview, from the Eutelsat's point of view, of the evolution the mobility via satellite is having. The references are to the existing services in Ku and those planned to be deployed in Ka band.

Keywords: earth stations, antenna pattern, waveform, VSAT, handover.

1 Introduction

For several years the Eutelsat's services portfolio includes mobility, which is today improving from narrow-band towards broadband IP based applications. Furthermore, the new commercial satellites working in Ka band, as the Eutelsat's Ka-Sat, and the introduction of more efficient waveforms leaves hope for a further development of the mobility-via-satellite business.

Nevertheless, the high level of innovation introduced by these new generation satellites makes the exploitation of the Ka band a real technological challenge. In fact, if on the one hand the multi-spot coverage (see Fig.1) permits to dramatically increase the global available capacity and reduce the customer economical charges, on the other hand the ground segment attains a level of complexity never reached before in others satellites services.

Such a complexity concerns the fact that the entire satellite service is provided from a ground infrastructure extended to the Mediterranean Basin comprising eight gateways linked to an optical fibre ring and managing the entire IP services. In the case of mobile services these gateways must be able to manage the spot-beam handover (HO). Additionally, a high level of complexity concerns also the end user mobile terminals that must be able to execute automatically the different steps of the HO process, similarly to mobile terrestrial networks based on standards as the WiMAX [1]. The effect of the HO process on the perceived quality of the service must be negligible.

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Furthermore, at the end user side, one of the most crucial points remains the implementation of reliable antennas capable to apply the polarization or frequency switching required by the HO and matching the constraints coming from the different mobile environments. If in Ku band, the target reliability and performances have been achieved for maritime applications and high speed mobile applications – mainly avionic and railway applications [1 - 3] – it is not yet the case for Ka band which still requires investment for development.

This paper introduces a brief historic of the experiences done by Eutelsat with the Ku band mobile broadband services, hinting at some of the major problems faced in the development phase. Then, the evolutions attended with the capacity coming with Ka-Sat (launched on 26th December 2010 and scheduled to be operational on Q2 2011) are described: the new technologies available for the production of very low profile antennas, the integration of the mobile antennas as elements of a global ground infrastructure, the complexity introduced by the multi-spot coverage in all the layers of a satellite communication system, including of course the radiofrequency devices.

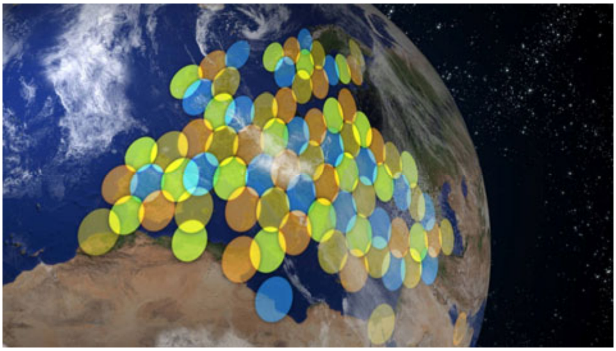

Fig. 1. Example of multi spot coverage in Ka band

2 VSAT Services in Ku Band

2.1 An Overview

Even if the terms very small aperture terminals (VSAT) has been introduced in order to indicate relatively little transmitting and receiving earth stations, today “VSAT” is frequently associated to IP services which end user ground segment is small and cheap. The increased power of the most recent satellite and the more efficient modulation and channel access techniques contributed in about one decade to reduce the cost and size of the terminals, at the point that also the meaning of the term “small” has been reviewed: if on 2009 a Ku band VSAT was generally a 1.8m antenna, today the most deployed dishes are around 90 cm, which is by now considered too big and anti-aesthetic. Additionally, the spreading of VSATs into much extended networks targeting at markets differentiated from the mere rural segment, led to even more dramatic reduction in the price.

Soon, the 21st Century saw the deployment of mobile broadband service in addition to the fix ones. If the narrow-band mobility was already a reality in Ku band, the Euteltracs service being one of the most popular services (with its 36000 remotes deployed throughout Europe), the need for broadband and voice services on-board vessels soon became evident. Even if the Ku band did not propose a world-wide coverage (which on the contrary is proposed by Inmarsat), such a limitation did not impacted the deployment of services in maritime fleets with vessels placed into restricted areas, as the Mediterranean basin, very well covered by geosynchronous satellites.

The civil maritime antennas inherited the technology, as usual, from the military world. Therefore, several manufacturers invested in the development of theirs own maritime stabilized steering antennas. The size of the dishes evolved in the same way as for the fix VSAT: today the catalogs for maritime antennas include also 60cm dishes.

Further progresses, in both the antenna and modems design, have been done in order to extend the satellite broadband services on board trains, airplanes and land transport.

Fig. 2. The low profile satellite antenna on board the French high speed train

Eutelsat participated to the initial projects for the provision of satellite connectivity on board aircrafts (the *Connection by Boeing* service run in Europe on Eutelsat capacity). But the most recent conquest is the deployment of a network providing multimedia services and Internet access on board the high speed trains of the French East line for the railway operator SNCF: the project was initially known as *Connexion TGV* and today has been renamed as *Box TGV*. This kind of applications introduces heavy constraints in terms of robustness under mechanical solicitations (mainly shocks and vibrations), occupied volume and aerodynamic impact. The equipment design must keep into account the applicable standards and the used materials must respect the safety normative.

For *Connexion TGV,* spread spectrum channel access techniques are used in oder to reduce the off-axis interferences generally associated to small antennas. The low profile steering antennas adopted have been designed and manufactured by *OrTeS*, a joint venture between *Teleinformatica e Sistemi* and, *Orbit* who cooperated with Eutelsat through all the phases of the project: from the approval-of-concept to the deployment [1-3]. Fig. 2 shows an high speed train equipped with a OrTeS antenna. Both modems and antennas have been approved for the railway usage, being compliant with the applicable railway standards.

A similar system has been adopted on board business jets for the provision of IP connectivity. In this case the antennas adopted have further reduced size: the application of spreading techniques is then mandatory.

2.2 Return on Experiences

Connexion TGV permitted to all partners involved in the project to mature an important technical background. First of all, from the point of view of the equipment: a fundamental rule is that even if a device complies with the railway standard ,this does not mean that it will work well on board the train because the countless unknown variables. The big headache came from the electrical power supply: electrical buffers and stabilizers are mandatory, but not sufficient, for the mitigation of the voltage interruptions. Particular care must be dedicated to the electrical grounding and, more in general, to the connectivity, which impacts directly the reliability of the installation.

After almost two years from the first two installations, we have the first feedbacks concerning the reliability of the solution. If on one hand the *mean time between failures* (MTBF) required by the customer is respected, unfortunately the technology is suffering a little-bit its youngness, even if on the over 50 terminals installed only a couple of them have been replaced in short time due to manufacturing defects. In some cases, malfunctioning appears and disappears without apparent reasons and corrective actions are difficult to be undertaken without an efficient logs reporting. This is becoming today a big deal: the devices adopted on board the means of transport are so complex that a detailed monitoring and alarms reporting is fundamental. An efficient reporting would help in debugging the failures but also in preventing major problems. On the other hand, there is a risk that such a detailed errors reporting became so articulated that it would be exploitable only by adepts.

Another important point concerns the radome. No environment can prove better then the railway one how important is the mechanical robustness of the radome. This element takes the important role of protecting from impacts the underneath elements but, in case of very hard shocks causing the detachment of some elements of the antenna, the radome prevent the ejection of broken pieces that could be transformed into real projectiles.

Fig. 3 and Fig. 4 clarify this concept: the first shows the deformation of the radome after a very violent impact. Fortunately the fragments of damaged reflector have not been ejected because the radome was not pierced assuring the safety for the antenna surroundings. Fig. 4 shows the spectacular effect of a rail ballast stone that hammered into a radome: the antenna was working perfectly but for safety reasons the radome has been replaced.

Fig. 3. A radome issued from a very violent impact

Fig. 4. A stone of the rail ballast hammered into a radome

These examples prove the importance of having a robust radome, which anyway must be transparent for the electromagnetic waves: R&D activities on this domain are solicited. Additionally, since the radome is the part of the antenna the most exposed to the impacts end than most subjected to replacement, a design permitting to reduce its cost is the welcome. It must be also considered that reducing the height of the antenna would permit to reduce the probability of impact with external corps: in that sense the flat antennas based on phased array techniques have an unmistakable advantage (unfortunately it is not yet proven if they are the best trade-off between performances and size).

3 Ka Band

The usage of small mobile satellite antennas has a direct consequence on the signal spectral efficiency. In fact, reduced gains impose to opt for more powerful (but less efficient) coding schemes, whereas the relatively large beam lobes increases the interferences which can be limited only inserting some kind of spectrum spreading (or modulations with lower cardinality). Then, the cost per transmitted information unit is higher.

The usage of the Ka band represents a milestone in that sense. This sentence is justified mainly by the fact that the cost of the capacity is dramatically reduced. A rough comparison can be done considering the *capacity serving a certain geographical area.* The capacity offered in one Ka-Sat spot beam with 250 km diameter is 237 MHz in both directions. The satellite covers the entire Europe with 82 spots, which corresponds to about 20 GHz per direction. A standard bent pipe Ku band satellite provides few tens 36 MHz transponders over an European coverage. Therefore, the ratio between the amount of Ka and Ku band capacities explains why the Ka band is cheaper.

Ka-Sat major drawback is in the complexity of the ground segment: in the case of mobile services the cellular coverage offered by the multi spot configuration imposes the usage of HO enabled systems, similarly to the most common terrestrial wireless communication devices: for details we refer to [3]. For the scope of this paper is enough remembering that the mobile antennas must be able to swap polarization and/or central frequency on the base of a HO command sent by the base band system, i.e. the modem. On the contrary, such a behavior is not required in terrestrial wireless where the HO does not involve physical reconfigurations in the antenna: these changes on a satellite earth station dramatically increase the hardware complexity.

3.1 Ka Band Antennas Specifications

In most part of the cases, we have already mentioned, mobile satellite transmissions require small antennas. Anyway, the adjective “small” takes several meaning and, commonly, a good trade-off among volume occupation, weight and performances is required. Anyway there are cases where the room available for the antennas is extremely reduced: it is the case of the double deckers high speed trains – where the train gauge profile admit a few centimeters margin for the installation of objects on the roof – and of the airplanes – due to evident aerodynamic reasons.

Furthermore, we cannot neglect that for several customers “small” means “good-looking”: it is not unusual to find customers deciding for a small satellite dish, independently on the performances it can achieve, just because it is fine.

All these reasons led Eutelsat to issue an RFI addressed to the antenna manufacturers and asking for the feasibility of very low profile antennas in Ka band. This RFI has been based on a link budget computed for a Digital Video Broadcasting via satellite (DVB-S2) [6] forward link (FW) at a symbol rate of 30 Msym/s, LDPC code rate 2/5.

For the return channel (RC) different configurations based on the DVB with interactive channel (DVB-RCS) standard [7] have been considered, with a single reference code rate, i.e. turbo 1/3. This estimation has been done by Eutelsat with the only aim of having a reference for the identification of the performances required to the ground segment, and does not take into account the possibility of applying adaptive codes and modulations techniques in both FW and RC.

Tables 1 and 2 report the link budget results for the FW and the RC. Even if the computation has been done considering the worst case in terms of both gateway and remote terminals coverage, it proves that the main limitation comes from the *quality factor* of the antenna, i.e. the G/T ratio. Ideally this parameter should be of the order of 14 dB/K, but analysis has been done on the extremes of a physically reasonable interval of values, i.e. 11 – 14 dB/K. In fact, we are aware that the upper value of G/T can be reached with reflector antennas similar to that already used by Eutelsat on board high speed trains [2][3], but the drawback is the size (0.48×1 m) and weight that limit the usage only on board few types of trains.

Table 1. FW link budget results

	Mobile antenna (G/T= 11dB/K)	**Mobile antenna (G/T= 14dB/K)**
Clear sky margin	3.7 dB	5.6 dB
Yearly availbility	99.7 %	99.83 %

Table 2. RC link budget results

	256 kbit/s	**512 kbit/s**	**1024 kbit/s**
Clear sky margin	7.5 dB		
Yearly availbility	99.9%		
BW occupation	500 kHz	1 MHz	2 MHz
Eirp	~35.5dBW	~38.5dBW	~41.5dBW

The singular result of this RFI has been that into a limited cylindrical volume comprised between 800×800×250 mm and 1200×1200×80 mm, the only technology permitting to reach a G/T maximum of 13 dB/K (variable with the elevation position), is based on a phased array with hybrid positioning system (electronic steering in elevation and mechanical azimuth rotation). Obviously, the G/T would further reduce if the volume constraint was more stringent: in order to close the link, less efficient encoding schemes, even down to 1/3 or 1/4 must be envisaged.

Phased array with hybrid positioning is a well known technology already commercialized in Ku band (Cohbam and Starling give two examples). Its implementation in Ka band would only be a geometrical scaling issue. Conversely, the implementation of the circular polarization switch subsystem required for the spot-beam handover, requires a dedicated design that has not been foreseen for the Ku band antennas (where the polarization is mainly linear). Today, the solutions envisaged to enable the polarization switch feature are based on a dielectric polarizer mechanically rotated.

The link budget for the transmission from the remotes shows that the required mobile antenna *equivalent isotropic radiated power* (e.i.r.p.), given by the product $G_T \times P_T$ between the antenna gain and the transmitted power, can reach 41 dBW. Generally speaking, the e.i.r.p. is not a real issue, because it depends on the power P_T available on the radio amplifier. The real problem comes from the fact that small antennas have a small G_T and high side-lobes generating *adjacent satellite interferences* (ASI) which is stronger as more as more as P_T is high. The ASI effect is regulated by standards as better discussed in the following.

Several techniques are used to mitigate the ASI: on one side lower rate coding schemes permits to reduce the e.i.r.p. thanks to a higher protection. on the other side spreading techniques, even if it does not have a direct impact on the link budget, permit to reduce the power density of the transmitted signal. These techniques are well known: for example Eutelsat has adopted a system using a direct sequence spreading scheme with very high *spreading factors* [2] whereas DVB-RCS+M standard [7] foresees spreading based on bursts repetition. Further proprietary techniques (derived from *code division multiple access* - CDMA) have been adopted by others satellite systems on which a direct sequence spreading is combined with the *time division multiple access* (TDMA).

3.2 Interference Limitations

One of the most important points arisen during recent experiences is the compatibility of the antennas with the European ETSI [5] or the American FCC [6] and the Eutelsat standards [4] (as well the equivalent standards issued by other satellite operators) for the earth stations. The compatibility with these standards permits on the one hand to reduce the interferences generated by the emitting antennas on the adjacent satellites (through the control of the off-axis e.i.r.p. density) and on the cross polarized transponders, and on the other hand to reduce the interfering signal density received by the ground stations.

Unfortunately, there is a widespread propensity at neglecting the importance of these standards on the base of several justifications (usually not technical) and always overlooking the effects of these assumptions, in particular when these effects do not appear immediately. In fact, it is very common that a service is not apparently impacted by the choice of one or a set of dishes rather than another (frequently the choice is done only on the base of cost assumptions); but the same service are degraded when the number of remote terminals grows up, the cross transponder changes its load configuration or, more generally, when the loading of the transponders reach the full load conditions.

For the mobile antennas, such a problem is even more accentuated, because the operating conditions of the remote earth stations change with their geographical position or with the used satellite (when satellite roaming is foreseen). As example, we mention the case of a maritime system who worked (apparently) regularly in a well defined geographical area but once moved into another zone under the same satellite coverage the interferences received by the antenna (due to a unconventionally large receiving pattern) from another satellite were so high that the modem was not any more able to lock the signal.

The Eutelsat standard, formally known as EESS 502 or standard M [4], is periodically revised because, differently from the ETSI or the FCC one, it accounts also the standard operational conditions of each Eutelsat satellite. In some cases the standard accounts also the frequency coordination agreements among the different satellite operators.

Even if the standard M seems too stringent to some antenna manufacturers, it does not aim at obstructing the deployment of antennas. Frequently, Eutelsat comes to arrangements leading to relaxing the theoretical constraints in order to match the manufacturing physical limitations with an acceptable impact on the interference effects. As an example, Eutelsat assumptions for the HotBird™ 6 Ka band edge coverage (i.e. G/T=10dB/K) the same e.i.r.p. off-axis density per 40 kHz proposed by the ETSI standard[1], i.e.

$$\begin{cases} 19-25\log\phi-10\log N \ \text{dBW} & \text{for} \ 1.8^\circ<\phi\le 7.0^\circ \\ -2-\log N \ \text{dBW} & \text{for} \ 7.0^\circ<\phi\le 9.2^\circ \\ 22-25\log\phi-10\log N \ \text{dBW} & \text{for} \ 9.2^\circ<\phi\le 48^\circ \\ -10-10\log N \ \text{dBW} & \text{for} \ \phi>48^\circ \end{cases} \tag{1}$$

This mask takes into account the possibility of having an adjacent satellite with characteristics similar to HotBird™ 6.

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[1] Without going into further details, there is a difference between the masks defined in the standard M and the EN 301 459 standard. In particular the standard M replaces the 1.8° angle with $1\le\alpha<2$. For the sake of simplicity we maintain here the same notation as ETSI.

Anyway, for the Ka-Sat, which edge coverage G/T=18 dB/K, assuming the hypothesis of having a similar adjacent satellite the mask should be dropped down of 8 dB (because the higher sensibility of the satellite). Since the constraints imposed by a so defined off-axis mask are physically too stringent for most part of the Ka antennas, the standard has been relaxed of 4 dB and the new mask is given by

$$\begin{cases} 15-25\log\phi-10\log N \ \text{dBW} & \text{for } 1.8^\circ<\phi\le 7.0^\circ \\ -6-\log N \ \text{dBW} & \text{for } 7.0^\circ<\phi\le 9.2^\circ \\ 18-25\log\phi-10\log N \ \text{dBW} & \text{for } 9.2^\circ<\phi\le 48^\circ \\ -14-10\log N \,\text{dBW} & \text{for } \phi>48^\circ \end{cases}. \tag{2}$$

Similarly, passing from HotBird™ 6 to Ka-Sat, the cross polar discrimination limitations have been relaxed, in order to keep into account the effects of using the circular polarization, instead of linear, in Ka-Sat.

For the mobile systems, the standard M will be reviewed in the next future in order to take into account further parameters and dynamic behaviors as for example the tracking algorithm performances and the corresponding pointing accuracy or the up-link power control techniques adopted.

Particular care will be taken in considering the applicable operational conditions that could permit to approve systems otherwise unacceptable. This is the case of mobile antennas having an excellent behavior on the azimuth cut (but a bad elevation pattern, which is common in low profiles antennas) that are deployed into restricted geographical area on transports assuring small variations of the installation plane. In this case the antenna skew sweeps a very narrow range and the azimuth pattern – or patterns measured on few degrees inclination angles – can be taken into account.

Even if today these parameters have not been yet included in the standard, Eutelsat will proceed in deep analysis of the antenna characteristics, before approval: for this reason the manufacturer shall be invited to details several key parameters of the antenna (e.g. patterns measured on particular cuts, details of the tracking algorithm, etc).

4 Conclusions and Further Activities

The request for IP connectivity and multimedia services on board transports is today growing up. Several examples of commercial applications can be mentioned: this paper refers to the services deployed in Ku band by Eutelsat and highlights the technical problems Eutelsat faced in the design and implementation of a railway satellite service for which a return on experience is reported.

The launch of Ka-Sat opens further perspectives for the development of new services that take advantage from the dramatically lower cost of the capacity. In the framework of the mobility, some drawbacks come from the higher complexity required to the remote mobile terminals. This subject has been already extensively analyzed in the past [1]: together with a description of the technologies available for the implementation of a Ka band antennas, this paper adds some details concerning the standards to be applied to the earth stations in order to reduce the interferences on the satellite.

Today Eutelsat co-operates with an antenna manufacturer for the implementation of a prototype antenna in Ka band to be used as approval-of-concept for the mobile services on Ka-Sat. In parallel, even if Ka band offers very good opportunities for the technical and commercial development of the mobile services, Eutelsat keep always in its portfolio solutions in Ku band that offer the incontestable advantage of a long experience and of a technology that is ready to use. Thus, others Eutelsat activities in this domain concern the extension of the existing Ku band mobile services to other trains, aircraft and vessels fleets.

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