

‘Mobile Wideband Global Link sYstem’ (MOWGLY) – Aeronautical, Train and Maritime Global High-Speed Satellite Services

P. Vincent - Alcatel Alenia Space, A. Arcidiacono - Eutelsat, N. Chevet - Airbus, L. Audounet - Rockwell Collins France, G. Naym - Orbit, J. Alvarez - Alstom, L. Babarit - Alcatel CIT, A. Vaccaro - MBI, M. Le Saux - Pointshot Wireless, M. Holzbock - Triagnosys, R. Lo Forti - TeS, C. Charatsaris - Video&Suono, R. Alvarez - Ineco, P. Bates - Broadreach Network, M. Smith - Advantech, B.G. Evans - University of Surrey

MOWGLY is introduced as a new research and development initiative, within the 6th EU Framework Programme, towards the commercial deployment of a global satellite system that provides high-speed data services to airplanes, trains and vessels. The intended multiple-access technique and air-interface technology are specified and the basic system architecture is overviewed. Critical parameters for the system definition and design, including market analysis, traffic modeling, telecom regulations and mobility effects, are analyzed and discussed. Possible modifications to the DVB-S2/DVB-RCS standards in order to cope with the limitations of the mobile environments are also discussed.

I. Introduction

The undergoing rapid wide-spreading of broadband internet for personal as well as professional use, shows a clear trend towards increasingly band-width demanding, high speed services and applications. The demand for broadband services within mobile environments follows naturally, especially from professional user groups. While terrestrial UMTS and future 4G technology will provide mobile broadband access within urban and sub-urban environments, provision of cost-effective broadband services to airborne, maritime and high-speed train passengers only seems feasible via a satellite system.

This paper presents a review of the main issues involved in the design of a particular broadband satellite system, within the recently embarked EU-FP6 project: ‘Mobile Wideband Global Link sYstem’ (MOWGLY). MOWGLY* follows in a series of EU research projects such as NATACHA, Wireless Cabin¹, FIFTH, which to a large extent have prepared the ground for an initial system development up to an experimentation level. Following the market analysis, the survey of telecom regulations and the definition of provided services, the main objectives of the project are the system design, development, field trial experimentation and verification of services. MOWGLY will bring the long undergoing European initiative for broadband aeronautical, train and maritime services, one step before commercial deployment.

In order to achieve the challenging objective of providing services, that are affordable by the wider public and also to minimize the big technical risks associated to satellite communications networks, network coverage will be provided by the existing Eutelsat GEO constellation operating at the Ku band. The network design will however allow easy adaptability with an evolved network, serviced by multiple spot-beam satellites operating at the Ka band.

Another key element in MOWGLY is the selection of DVB-S2² and DVB-RCS³ standards as the basis for the design of the physical layers in the forward and the return link, respectively. DVB-S2 is the evolution of the widely adopted satellite digital tv broadcasting standard DVB-S and supports a multiplicity of data services (point-to-point, point-to-multipoint, internet access and broadcasting). It also features variable/adaptive coding and modulation, use of state-of-the-art coding (LDPC) and supports continuous bit streams, single/multiple MPEG streams, IP and ATM

* The MOWGLY consortium consists of: ALCATEL ALENIA SPACE FRANCE, AIRBUS, ROCKWELL COLLINS FRANCE, ORBIT, EUTELSAT, ALSTOM Transport, ADVANTECH, ALCATEL CIT, MBI, POINT SHOT., TRIAGNOSYS, Teleinformatica e Sistemi s.r.l., VIDEO&SUONO, University of Surrey, INECO, Broadreach_Network Limited.

packets. DVB-RCS specifies a Multi-Frequency (MF) TDMA system for the return link, which also supports multiple types of data streams and features QPSK modulation and Turbo-Coding.

Relying on well understood, standardized technology contributes towards the low-cost service and the low-risk objectives. However antenna size constraints (especially on airplanes and trains), complicate the requirement for compliance with existing telecom regulations and inter-satellite interference limitations, as far as emitted Power Spectral Density (PSD) is concerned. Moreover high velocity propagation effects and handovers between coverage regions, introduce additional system design complications^{4,5,6}. A key objective in MOWGLY is to evaluate, compare and propose solutions to these limiting factors. For example spectrum spreading of the signal in the return link is a possible answer to the regulatory constraints, while signal processing techniques (e.g. channel interleaving) can make the link robust against fading effects. The intended outcome of this investigation will be the definition of a set of specifications, which will be used by standardization authorities as a baseline for the standardization of DVB-S2/RCS for mobile environments.

II. System Architecture

The aim of MOWGLY is to provide broadband connectivity to a range of mobile terminals, consisting of aircrafts, high speed trains and maritime vessels such as cargo ships, cruise ships and passenger ferries, with global coverage being an obvious requirement. It is planned that available services will be initially targeted to the passengers of the aforementioned vehicles, with possible future extension to services provided specifically for use by the crew or for maintenance, management and security purposes.

Passengers will be allowed to connect to terrestrial IP networks and gain access to a range of services that can be divided at a first level to three main categories: *access*, *interconnection*, and *entertainment* services. Examples include web-browsing, email access, transparent VPN/Intranet connectivity, as well as streaming (audio/video/data) live TV and live radio. For each of the vehicle types different services/applications will be emphasized depending on the existing availability of infrastructure and connectivity. Passengers will be able to access these services through their own mobile/portable terminals such as laptop computers, PDA's or other compatible devices, by connecting to wireless networks onboard the vehicle. This access scheme not only migrates the need for costly installations of fixed access points and/or onboard devices but also makes the service seem more familiar to the passengers as they use devices to which they are accustomed. In the long term, the passenger services are planned to be complemented by crew, maintenance and management services. Examples of such services would be telemedicine, vehicle maintenance data monitoring and forwarding to a maintenance centre as well as security applications such as video surveillance feeds to a security centre. Combined, the passenger and crew/maintenance services will provide passengers with an entirely new travelling experience. Travel time will be made more pleasant for leisure travellers and significantly more productive for business travellers, while the operation and maintenance of such vehicles will be performed in a more efficient manner.

The key drivers that have influenced the design of the MOWGLY system architecture are:

- Efficient Use of Satellite Bandwidth.
 - Reuse of existing/planned fixed access satellite service coverage.
 - Use of an efficient waveform on forward and return links.
 - Use of a powerful DAMA scheme on the return link.
 - Efficient always-on services without wasting satellite resources.
- Use of an open and flexible networking architecture
- Introduction of QoS features.
- Minimization of operation costs.
- Provision of mobility support.

Stemming from the above drivers, the foreseen system architecture is illustrated at top level in Figure 1. DVB-S2 and DVB-RCS are the air interface standards chosen by MOWGLY as the broadband access standards to use, due to their compatibility with the envisaged services as well as the fact that they are tried and tested solutions. In terms of the infrastructure, existing fixed broadband satellite infrastructure will be reused to the maximum possible extent so as to ensure the competitiveness and early market penetration of MOWGLY. This will also mitigate the risks and costs associated with the need for deployment of an entirely new network from scratch.

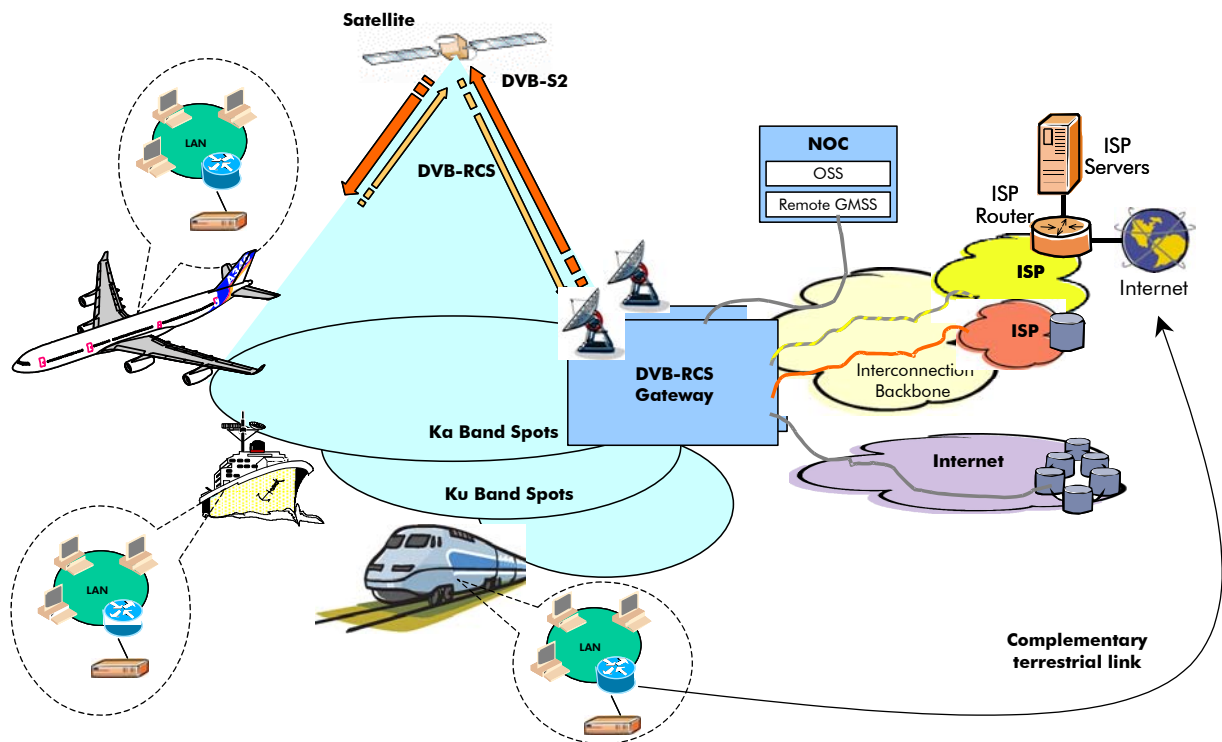


Figure 1-MOWGLY Architecture

At a first stage, the system can be divided into three major segments; the ground infrastructure segment, the space segment and the terminal segment that consists of the aircraft, trains and maritime vessels. The ground segment is comprised by a number of **HUBS** whose role is to provide the basic ground infrastructure required to handle broadband access services, as well as the **Network Operation Centre** and the **Service Centre**. The latter two will be integrated in a single site that will be the core of the entire network.

The Network Operation Centre: The authentication/accounting system will be hosted in the platform's centralized Network Operating Centre (NOC), which will also provide monitoring and management services for all remote equipment.

It will be possible to have the status of any device on the network in real time, correlating the critical events in order to activate escalation procedures. The monitoring tools of the NOC will be also able to notify in real time any system failure and keep track of the performance of each system at any time.

The Service Centre: All services defined by **MOWGLY** will be available for users travelling on aircraft, trains and ships using a single common framework. Any technical solution used for the lower level implementation of the network will be transparent for the final users that will access these services using a dedicated application.

The Hub: Manages a sub-network in a star configuration that provides mainly satellite resource management, equipment management, interface with the collective mobile terminals and interface with the WAN functions.

The space segment enables communication of each of the hubs with a large number of vehicles. It is comprised of a **geostationary constellation** made up from transparent, **bent-pipe satellites** that act as reflectors of information from the ground segment to the mobile terminals. The forward link, which is based on the world-wide DVB-S2 standard, provides connectivity from the Hubs to the Satellite Terminals. DVB related standards also specify how a DVB broadcast carrier combines data from multiple sources into one high-speed transmission stream. The return

link, based on DVB-RCS, with its MF-TDMA access scheme provides a cost-effective solution for sharing the return bandwidth between the Satellite Terminals.

The mobile terminal segment is comprised of the serviced vehicles, namely aircrafts, high speed trains and maritime vessels. Each of these vehicles is fitted with a **Satellite Terminal**. This is the onboard collective mobile terminal that provides subscriber access to the network. As an example, Figure 2 illustrates the architecture of an aircraft satellite terminal.

- **Antenna and Antenna control unit:** In the case of aircraft and trains the antenna will be integrated into the vehicle surface. This sub-system is responsible for tracking the appropriate satellite depending on the terminal position, converting the received signal (Ku/Ka) into intermediate L band (LNB) compatible with the modem (demodulator) and converting and amplifying the L band signal (BUC) received from the modem (modulator) into a Ku/Ka band signal.
- **Modem:** Responsible for converting the RF signal received from the antenna into a digital signal, and for converting the digital signal into the RF signal provided to the antenna. The modem will support mobility-related constraints (Doppler effect, etc.) as well as being able to deal with the different vehicle-specific environment constraints in terms of hardware/software.
- **Onboard gateway:** Manages communication with the ground segment and provides network acceleration service (caching ...). It also manages access priority and QoS. The goal for the gateway not to require modifications of the user's laptop settings in order to access the onboard services.
- **On-Board Network:** In the case of aircraft, this feature is provided through the airline in-flight information system available onboard. This is a certified system that encompasses a wireless network (WiFi) covering the whole cabin that will be used to provide passenger access to MOWGLY services.

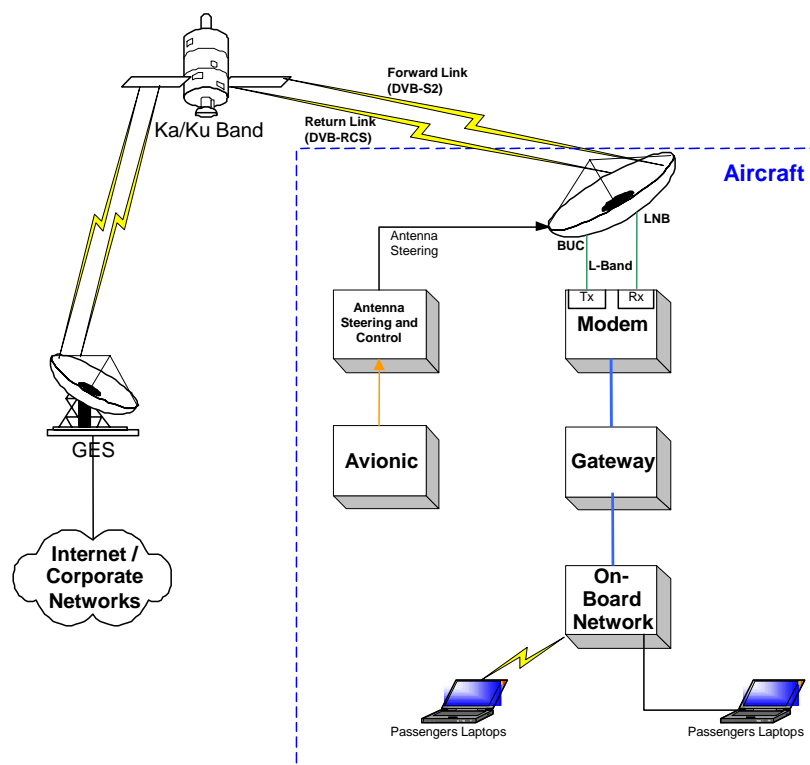


Figure 2. The onboard terminal

III. Market and Traffic Analysis

Market and traffic analysis are addressed early on in MOWGLY as critical parameters for creating a business model and assessing the business case for the commercial system. It turns out (through confidential business analysis) that the business model (and hence the commercial success of the project) is strongly dependent on variables, some of which are determined through traffic analysis. Obviously getting an accurate estimate of the number of potential customers is one of them. On the other hand market analysis complements traffic analysis in this respect by quantifying the effect of competition and analyzing service demand and usage profiles. Traffic analysis is also basic for determining the system dimensioning and coverage requirements. Complemented again by market analysis, more crucial questions can be answered such as the capacity requirements per region, service definition and as far as the project itself is concerned, the mission requirements.

IV. Project schedule

The overall work logic and schedule of the MOWGLY project is shown in the figure below.

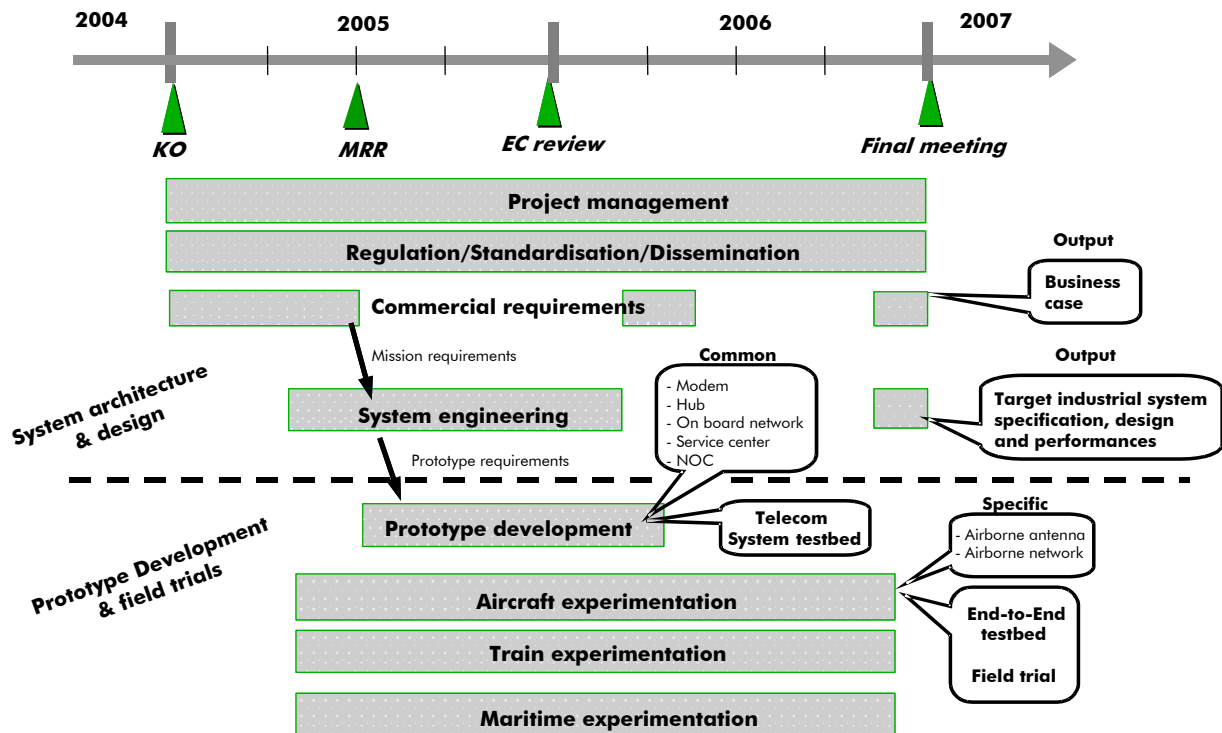


Figure 3. The project schedule

V. Mobility Effects and Adaptation of DVB standards

As it is described in section I, the DVB-S2 and DVB-RCS standards will be used as the basis for the design of the forward and return link air interfaces, respectively, in the MOWGLY system. Obviously, these standards refer to a non-mobile system and therefore the complications due to system mobility need to be identified and addressed. It is recognized that the three different types of vehicles (aircraft, vessels, trains) operate in different environments and therefore the mobility effects that the communications system needs to address in each of these cases are distinct.

A. Propagation Channel Characterization

The aeronautical propagation environment at the K band (18.685 GHz) has been characterized through a measurement campaign, whose results are presented in reference 10. The results show that in Line-of-Sight (LOS) conditions, the contribution of multipaths from the aircraft's structure is insignificant and the received power level is virtually constant over time. The channel in this case can be accurately modeled as Rician with a factor of $c=34$ dB. During maneuvering, the LOS can be shadowed by the aircraft's tail or wings. In these cases the received power level undergoes significant attenuations: a maximum of 3dB by the tail and a maximum of 12.5dB by the wings. These levels of attenuation are enough to lose link synchronization and connection. However the system is intended to be used under steady state flight conditions (cruising altitude) and thus the percentage of time which corresponds to maneuvering can be assumed to be insignificant. Therefore in the system design, it is assumed that (in terms of short-term power fluctuation) the aeronautical channel behaves like an AWGN channel.

For the rail environment a stochastic channel model has been proposed in reference 6, which is consistent with channel measurements performed at the Ku band. In this model three channel states are possible: LOS, shadowing (e.g. due to trees) and blockage (e.g. due to tunnels), where state transitions are modeled by a Markov-chain process. In LOS the received signal undergoes Rician fading with a factor of about $c=17$ dB. In shadowing two fading processes take place; fast fading, which is again Rician and slow fading which is modeled by a log-normal distribution. In blockage the received signal strength was too small to be measured and no model is available. On top of these random fading effects there is also a deterministic fading mechanism which is due to the electric trellis bridges along the rail-track. These create a nearly periodic fading effect (in which signal attenuation can reach 8dB), which in the model is superimposed to the statistical fading component.

All these effects create unfavorable conditions for maintaining the communication link. Even in LOS the link performance degradation can be 2-3 dB (depending on the train speed), compared to ideal (AWGN channel) performance. In non-LOS conditions the link BER is irreducible due phase tracking slips¹¹. Some possible fading counter measures have been proposed in reference 5, which are evaluated within MOWGLY.

The maritime environment is much more straight-forward; most of the time LOS conditions can be assumed, in which case the channel is Rician but the Rice factor depends strongly on the roughness of the sea and the antenna elevation angle.

B. Doppler Frequency Offsets

One concern in the aeronautical and rail environments is the Doppler shift due to the high speed of the vehicles. As it is pointed out in reference 11, the requirement for compensation depends on the data rate, as the frequency offset tolerance of the demodulator is given as a percentage of the symbol rate. This limits the minimum symbol rate, especially in the aeronautical scenario where the offsets are big. The off-set can be calculated using available positioning and velocity information. In the return link frequency off-set estimation and correction needs to be performed.

C. Initial Synchronization

Another issue (also discussed in reference 11), which is common for all three platforms, is the difference in the link delay for each mobile user. Depending on the size of the coverage region the difference in delay can reach a few (3-5) ms. Due to the random log-on position of each terminal this introduces a timing synchronization problem during log-on, unless sufficiently long guard time intervals on the Common Signaling Channel (CSC) bursts are allowed. However this is not a desirable solution as a significant proportion of the bandwidth resources will be sacrificed. Hence there is a requirement for a more efficient solution such as link delay calculation and forward transmission, using knowledge of position and velocity.

D. Hand-Overs

Hand-over procedures need to be defined in the network. In the short-medium term, where single-beam satellites will be used, only inter-satellite hand-overs will need to be supported by the network but in the longer term inter spot beam hand-overs will need to be supported too. The hand-over mechanisms, for both cases, will be defined and evaluated through simulation within the project. Again, modifications will need to be made on the DVB standards in order to specify the necessary signaling commands.

E. Power Control

In the DVB-RCS standard there is a provision for closed loop power control, although the mobile terminal can also take the initiative to adapt the transmit power. So generically both open loop and closed loop options are available. Since the multiple access technique in the system is not CDMA, the role of the power control is not

critical for the system's performance. However, it is important for minimizing intra- and inter-system interference in the return link and inter-modulation products caused by the satellite transponder non-linearity. In addition it useful for limiting power consumption at the satellite.

Due to the long round trip delay, closed loop power control is not suitable for correcting fast changing variations to the signal's power. Due to this limitation closed loop power control is only suitable for correcting long-term average power fluctuations, mainly due to weather conditions. On the other hand, open loop power control is not limited by the round trip delay, however multipath fading (even at low vehicle speeds) cannot be compensated due to the channel asymmetry in the forward and return links. Open loop power control could be useful for correcting short-term shadowing effects (e.g. tree shadowing in the rail environment or tail shadowing in the aeronautical environment).

F. Adaptive Coding and Modulation

Very flexible (per frame adaptation) Adaptive Coding&Modulation (ACM), is a key feature of DVB-S2 that can improve dramatically bandwidth efficiency in the system. In order to exploit the full potential of ACM in the mobile environment, ideally mode adaptations should follow not only the long term – slow fluctuations in the signal power but also the short duration fading events. However, likewise with power control, adaptation to short term variations is limited by the long round-trip delay in the link. In a similar manner to power control, closed loop ACM cannot follow the speed of fast multi-path fading. ACM and power control will most probably have a co-operative role in the forward link. Power control will be responsible for keeping the operating SNR point constant within the given mode. However if the actual transmit power crosses the mode's power level boundaries, the mode will be adapted. This type of adaptation schemes will be evaluated through system level simulations within MOWGLY.

VI. Status of Telecom Regulations

Deregulation and privatization of telecom operators in the past years made that securing appropriate spectrum resources and safe regulatory environments has become a long-haul and critical issue in the development of new satellite services.

In that respect, MOWGLY faces a particularly sharp problematic, due to its requirements for mobility and wide service area. On the other hand, MOWGLY benefits from the recent improvements of the international, regional and national regulations, as brought to allow emerging Ku-band mobile satellite services on a safe and stable basis without undue interference to existing applications.

More precisely, one remembers that in June 2003 the International Telecommunications Union granted status to these applications, including designation a portion of Ku-band for ships and aircrafts transmissions to satellites, definition of the associated technical limitations to bound interference in international airspace and waters and recommendations to administrations for regulating and licensing these applications in and near their national territories.

Since then, European and US regulators in particular have been transposing, harmonizing and complementing this international frame for application in their national airspace and waters. This is under completion, with surprisingly some major differences between both sides of the Atlantic, and it offers MOWGLY the rare opportunity to have almost stabilized regulations in these two important regions at an early stage of the project.

From an industrial viewpoint, the MOWGLY consortium has dedicated an important workforce to analyzing these existing international, European and US regulations so as to ensure full compliance of the system design and operations, and enable safe and stable services and revenues, starting with next year maritime, rail and aircraft experimentations.

For the next stage, the consortium will pursue its efforts and refine its understanding of local situations, in particular beyond Europe and USA. In this activity, MOWGLY strength relies on the implantation of its members in various countries and to their world-wide recognized expertise in that field.

VII. Conclusion

An introduction has been given to the MOWGLY project and system concept. The project is currently over its first 6-month stage. So far, the traffic and market analyses have led to a positive business assessment and the project has now entered its second phase, in which mission requirements are translated into system design specifications. A critical process during this phase of the project will be the correct assessment of the mobility issues and their impact on the DVB-S2/RCS standards. Efficient and cost-effective solutions will need to be proposed in order to ensure correct system operation and minimum impact on the terminal's cost. The effectiveness of the proposed solutions will first be evaluated through simulations and eventually assessed during the experimentation phase of the project.

Regulatory constraints applicable to the MOWGLY system are complex and multi-dimensional. This is mainly due to the very recent introduction of similar systems in the market and the fundamental requirement to operate globally. An encouraging progress has been taking place recently towards harmonization across Europe and between Europe and USA, although in other regions regulatory constraints need to be addressed on a national level.

References

- ¹M. Holzbock, Y-F. Hu, A. Jahn and M. Werner, "Advances of aeronautical communications in the EU framework", *Int. J. Satell. Comm. Network*. Vol. 22, pp.113-137, 2004.
- ²ETSI EN 302 307 V1.1.1 (2005-03): "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications".
- ³ETSI EN 301 790 (V1.4.1): "Digital Video Broadcasting (DVB): Interaction channel for Satellite Distribution Systems". M. Holzbock, C. Senninger, "An aeronautical Multimedia Service Demonstrations at High Frequencies", *IEEE Multimedia Magazine*, Vol. 6, Issue 4, pp.20-29, Oct.-Dec. 1999.
- ⁴M. Holzbock, C. Senninger, "An aeronautical Multimedia Service Demonstrations at High Frequencies", *IEEE Multimedia Magazine*, Vol. 6, Issue 4, pp.20-29, Oct.-Dec. 1999.
- ⁵M. Alvarez Diaz, S. Scalise, G. Sciascia, R. Mura, P. Conforto, H. Ernst, "DVB-S Air Interface over Railroad Satellite Channel: Performance and Extentions", 6th Baiona Workshop on Signal Processing in Communications, Baiona, September 8-10, 2003, Universidad de Vigo Spain / IEEE, Proceedings Sixth Baiona Workshop, (2003).
- ⁶G. Sciascia, S. Scalise, H. Ernst, R. Mura, "Statistical characterization of the railroad satellite channel at Ku-band", International Workshop of COST Actions 272 and 280, ESTEC, Noordwijk, The Netherlands, 26-28 May 2003, ESA/ESTEC, Proceedings COST 272/280, (2003).
- ⁷M. Holzbock, O. Lucke and M. Werner, "Advances of Improved Multi Service Traffic Modelling and Satellite System Dimensioning for Collectively Mobile User Groups," to be presented in 23rd AIAA ICSSC conference, Rome, Italy, September 2003.
- ⁸L. Battaglia, M. Werner and M. Holzbock, "Revenues and Performance of Global Satellite Aeronautical Communications", Proceedings of 21st AIAA ICSSC, Yokohama, Japan, April 2003.
- ⁹J. Reuter – Airbus, S. Poulain, B. Chene, M-P. Saint-Genes, M. Cougoule, H. Seidel, "Services and System Requirements for Aeronautical Mobile Broadband Communication", Proceedings of 21st AIAA ICSSC, Yokohama, Japan, April 2003.
- ¹⁰M. Holzbock, A. Jahn, E. Lutz, "Aeronautical Channel Measurement Trials at K band", 4th Ka Utilization Conference, Venice, Italy, Nov. 1998.
- ¹¹Electronics and Telecommunications Research Institute (ETRI), "Analysis of the DVB-RCS standard applicability to Broadband mobile services", presented in the Advanced Satellite Mobile Systems – Task Force (ASMS-TF) meeting, Dresden, Germany, June 2005.