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# Design and Simulation of a DVB-S2-like Adaptive Air interface Designed for Low Bit Rate Emergency Communications Satellite Link in Ku/Ka/Q/V Bands

Ponia Pech<sup>1</sup>, Marie Robert<sup>2</sup>, Alban Duverdier<sup>2</sup> and Michel Bousquet<sup>3</sup>

<sup>1</sup>TeSA, <sup>2</sup>CNES, <sup>3</sup>ISAE/SUPAERO

France

## 1. Introduction

Access to information is of paramount importance in emergency situations when a disaster or a natural catastrophe (earthquakes, landslides, tsunamis, tidal wave, volcanic eruptions, floods, cyclones, other tornados or forest fires) occurs in a given place. The rescuers must have access to telecommunications means in order to be able to transmit critical information (such as the number of victims, of persons needing medical assistance or to be transported towards care centers, hospital locations, the nature of injuries, etc.) to the center that is in charge of coordinating the heavy logistical rescue operations. However, when an extensive area is affected (in developing countries in particular, but this holds true in first world countries also), it is most often impossible to use some telecommunications equipments, because of a destruction of the base stations or an unavailability of electric power. Thus, it is an absolute priority, in order to manage a situation of post-disaster, to restore the communications infrastructure. Three distinct and consecutive phases can be distinguished (Pech et al., 2008):

- **Phase 1:** This is the phase that immediately follows the disaster, where no means of communications is available, and where minimal emergency communications must be established as quickly as possible. This is in this phase that the very rapid deployment (less than some hours) of a satellite system seems most suited. The ground equipments that can be envisaged in this type of system are transportable or portable terminals, not necessarily mobile, that can be operational everywhere between 5 and 30 minutes without the assistance of a technical expert staff. Transmissions must be secured and have a strong availability.
- **Phase 2:** In a second stage, the restoration of a more elaborated communications network involving a transportable user terminal with a higher capacity also ensuring wireless connectivity (GSM, Wi-Fi, WiMax, etc.) is necessary to exchange more complex information. This local infrastructure can be linked to the national telecommunications

- public network through a DVB-RCS-like professional satellite terminal, or an Inmarsat’s BGAN (Global Broadband Area Network) device (Inmarsat).
- **Phase 3:** After several weeks, even several months, once the first necessities are met and the situation is being reestablished little by little, a restoration of the nominal communication infrastructure can be envisaged.

Emergency satellite systems intended to address the needs of the rescue teams both in phase 1 and phase 2 have been the subject of numerous recent studies and developments, such as for instance the FP6 WISECOM project (cf. Fig. 1) (WISECOM, 2007), diverse standardization works TISPAN (ETSI. EG 202 339, 2004), EMTTEL (ETSI. TS 102 181, TS 102 182 and TR 102 410), and ITU-R WP-4B work on wideband spreading signals (IUT-R. IUT-R WP 4B, 2006), and research studies on UWB (*Ultra Wide Band*) satellite transmission carried out with the French Space Agency (CNES - *Centre Nationale d’Etudes Spatiales*) and Thales Alenia Space France (Leconte et al., 2006; Dervin, 2007). Another related research field which has drawn much attention these last years from academia and industries alike is telemedicine, for instance with the OURSES (French acronym meaning *Offer of Services Rural Use using Satellite*) project (Girault et al., 2008; Mailhes et al., 2008).

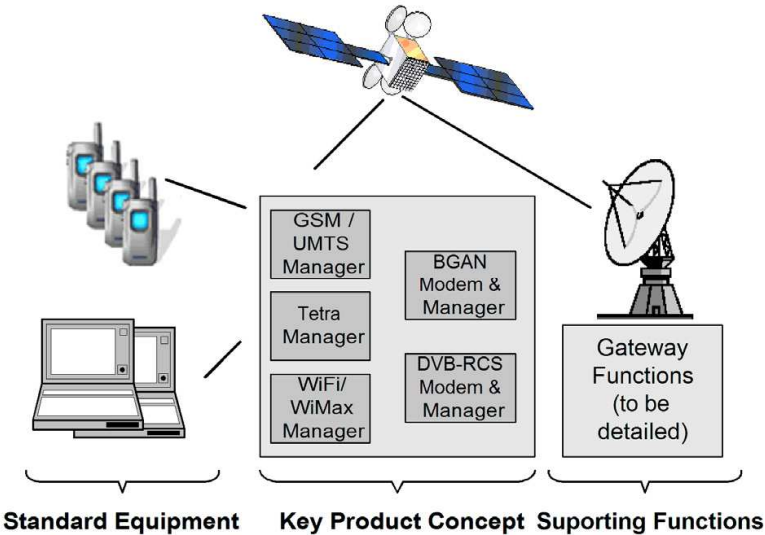


Fig. 1. The WISECOM architecture

The present study inserts itself only within the framework of the aforementioned phase 1. The purpose here is to propose and study a solution allowing to establish very quickly a minimal low bit rate satellite link (in the order of several tens of kbps) in an emergency situation, while using the available resources of the satellite, and a single-user ground terminal with a low transmission power, a small diameter antenna, and a dedicated Tx/Rx system, characterized by an electric consumption which shall be as low as possible (battery or solar panels). The bi-directional transmission link is modeled within the Juzzle [4] open source environment software with an emphasis on the return channel, deploying an adaptive strategy based on the DVB-S2 adaptive modulation and coding (ACM) scheme. This paper expounds the link budget dimensioning and a customized, enhanced DVB-S2 air interface proposed to support minimal emergency communications in a severely impaired channel environment in high frequencies; it also outlines the combined Excel/Matlab/Juzzle high-level transmission link software simulation platform that is being developed in order

to assess the performance of the proposed transmission scheme. Focus is placed on the underlying theoretical models involved in the simulator which follows a cross-layer approach, integrating propagation, DVB-S2-based physical layer, and traffic components.

2. System architecture, scenario, and traffic characterization

2.1 System architecture and scenario

The proposed system architecture and scenario are as follows (Pech et al., 2008): the emergency mission signals are superimposed with those of the primary system characterized by a star topology, a classic multibeam, multicarrier, broadband bent-pipe satellite operating either in Ku/Ka or Q/V-bands, and with a 120-MHz transponder (cf. Fig. 2). Thus a dedicated channel for the emergency mission is not required. The gateway has at its disposal a bandwidth of 480 MHz, while the user links share a total bandwidth of 240 MHz, in four 120-MHz sub-bands and two polarizations, with a reuse frequency factor of 1 over 4. The frequencies used for the return link are enlisted in Table 1. Furthermore, all-IP (Internet Protocol) architecture is assumed.

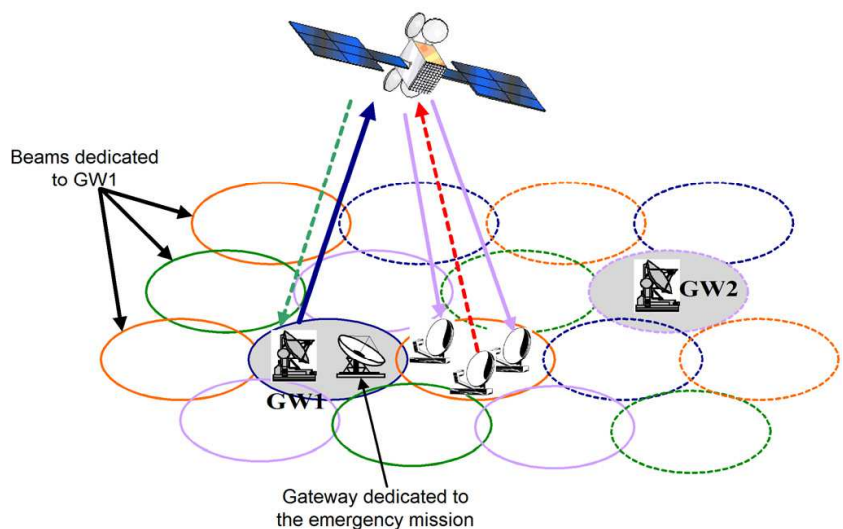


Fig. 2. System architecture

The main characteristics of the satellite are summarized in Table 2. For the emergency mission, a set of 4 different types of user terminals is considered: two mobile user terminals of very low transmission power (between 0.5 and 2 W), the first one (UTA) having a patch antenna, and the second one (UTB) an omnidirectional antenna; and two deployable or transportable user terminals: UTC is a rapidly deployable “mini-gateway” mounted on a van, transmitting at up to 50 W, while UTD can be transported by a human user and has a transmission power of up to 5 W.

2.2 Traffic characterization

In phase 1 of a post-disaster emergency situation, the services which are most required to be provided as a minimum requirement are voice services, and transfer of small text or video files (SMS - Short Message Service / MMS - Multimedia Messaging System). Special emphasis will be laid upon Voice Over IP (VoIP), and more generally IP applications, as the

ever increasing widespread use of IP technologies will greatly contribute to enhancing mobility and nomadicity between private and corporate access. The data to be transmitted are characterized mainly in terms of bit rate, error rates (Bit Error Rate – BER, or Packet Error Rate – PER), delay, jitter, average and maximum packet sizes. The salient Quality of Service (QoS) features of the two types of applications which are envisaged are presented hereafter:

- Real-time, delay-sensitive but not or very little loss-sensitive applications: especially VoIP. A strictly minimum bit rate of 5.3 kbps (assuming ITU H.323 G.723.1 ACELP codec) is required (Nguyen et al., 2001). It has been shown however that optimal bandwidth occupation for VoIP over satellite is around 12 kbps. VoIP bit rate also varies depending on the codec, on whether RTP (Real-Time Protocol) is compressed, and on the overhead introduced by the header of the protocol suite (Ethernet, IP, UDP, RTP). For instance, with RTP, a total of 54 bytes are transmitted, out of which only 20 belong to the payload. The bit rate can thus be considered to range between 5.3 and 13 kbps. A minimum MOS (Mean Opinion Score) requirement of 3.5 as suggested in WISECOM (WISECOM, 2007) ensures a good voice quality. In this respect, ITU-T G.114 Recommendation (IUT-T, 2000) specifies a maximum latency value of 150 ms for one-way VoIP communications. As for the jitter, the mean packet inter-arrival time at the receive side must be roughly close to that at the transmit side, with a small standard deviation. Lastly, in terms of packet corruption and loss, some experiments have shown that the satellite link is quite robust to packet corruption in clear sky or moderately degraded channel environment with a BER of up to a  $10^{-5}$  (that is, Frame Erasure Rate or FER of 2%) (Nguyen et al., 2001). The performance of VoIP over satellite as obtained by Nguyen et al. (Nguyen et al., 2001) from the COMSAT laboratories will be used as a reference test bench.

- Data-like loss-sensitive, but not or very little delay-sensitive applications, for instance SMS/MMS, email applications, file exchange and Internet browsing: the transmitted mean bit rate shall be at least 32 kbps for Web browsing and file exchange, and 200 kbps for email applications (Inmarsat). BER values of up to  $10^{-6}$  can be supported (WISECOM, 2007). Moreover, the time interval between the sending of an SMS and its reception by the receiver must be between 6 and 8 s in average, given that actually 98% of sent SMSs are successfully delivered by a mobile user to a fixed network within a 5-s time period, according to some telecom operators [ETSI, February 2006; ETSI, October 2004]. Since the integrity of SMS messages is 100%, it is obvious that SMSs are well fitted to emergency communications.

### **3. Air interface, channel modelling and link budget**

#### **3.1 Enhanced DVB-S2 air interface**

It is proposed to adopt the ETSI DVB-S2 ACM MODCODs (ETSI, EN 302 307, January 2004) for the return channel as it provides excellent performance close to Shannon's theoretical limit due to an advanced Forward Error Correction (FEC) scheme (concatenated BCH and LDPC codes), and allows an attractive waveform flexibility in presence of channel fading, with its inherent ACM capability. Incidentally, this adoption of DVB-S2 ACM schemes for the return channel was recently standardized within the DVB-RCS+M working group (ETSI, EN 301 790 V1.5.1, May 2009), but in the latter standard, very short (4 kbps) DVB-S2



PLFRAMEs were envisaged instead of normal and short lengths (64,800 bits for the normal frame, and 16,200 bits for the short frame). By contrast, here, standard-length DVB-S2 PLFRAMEs are assumed. In quasi-error free (QEF) environment (PER of  $10^{-7}$ ), in an Additive White Gaussian Noise (AWGN) channel, DVB-S2 operates at ideal  $E_s/N_0$  ranging from 16 dB down to -2.35 dB. The performance of the receiver in terms of signal acquisition/reacquisition time, decoding thresholds, etc., all are well known (ETSI, TR 102 376, February 2002). The present novelty is the use of DVB-S2 along with spread spectrum and other adaptive mechanisms for return channel interactive services while DVB-S2 was specifically designed for the forward link and broadcasting services. This thus raises some performance challenges to be coped with.

Since the considered applications are all assumed here to be IP-based ones, the DVB-S2 waveform is coupled with an efficient encapsulation mechanism, namely the GSE (*Generic Stream Encapsulation*) protocol at the Segmentation and Reassembly (SAR) layer, aimed at segmenting network layer IP datagrams (PDUs or *Payload Data Units*) into link layer DVB-S2 basic data units called BBFRAMEs (*base band frames*). The GSE mechanism was designed with the purpose of fully taking advantage of the innovative features of the DVB-S2, primarily in terms of reliability, flexibility, and enhanced capacity. MPE (*Multi-Protocol Encapsulation*) and ULE (*Unidirectional Lightweight Encapsulation*) have been the standard encapsulation techniques that were classically used in DVB-typed satellite systems, and as such they received abundant attention in the literature. Nonetheless, GSE constitutes a much more efficient encapsulation scheme fitted to the DVB-S2 standard in that it allows to fully exploit the adaptive ACM capability, implementing QoS scheduling decisions and flexible placement and enhanced fragmentation of PDUs in the flow (Cantillo, 2008).

In particular, DVB-S2 GS (*Generic Stream*) data flows may be packetized or continuous streams. The first ones are suited to carrying PDUs of constant size, whereas the latter category was designed to seamlessly adapt to input stream of any format, including continuous bit streams and variable-sized PDUs such as IP datagrams. GSE can avoid using MPEG2 packets as with MPE and ULE, which would be sub-optimal in the framework of DVB-S2. In effect, the GS flow is more suited to interactive services as it overcomes the inadequate MPEG2-TS constraints of constant bit rate and end-to-end delay. In addition, due to the large sizes of a BBFRAME payload (up to 40 times as long as an MPEG2 packet), datagram fragmentation occurs less often. Measures in the Internet network backbone show that the mean size of an IP datagram is about 500 bytes, which roughly amounts to  $7000 \setminus 500 \approx 14$  IP datagrams carried in the longest available BBFRAME, against 2 or 3 fragmentations on the MPEG2-TS layer, and up to 10 in the case of ATM (Cantillo, 2008). GS streams are tailored into 21 possible BBFRAME frames, thus offering a variety of efficiency versus error protection compromises, and predefined sizes ranging from 384 to 1,779 bytes (short BBFRAMEs), or 2,001 to 7,274 bytes (for long BBFRAMEs). Consequently, all these characteristics of GSE result in IP datagrams being delivered more rapidly, efficiently and optimally in a cross-layer perspective, with reduced overhead and complexity (Cantillo, 2008).

A last technique deployed for the purpose of enhancing the DVB-S2 transmission performance is Spread Spectrum (SS) in its Direct Sequence (DS) variant. Besides its resistance to interference, jamming and multipath impairments, a quite powerful property of SS exploited in the framework of this study is its processing gain  $G_p$ , defined as the ratio of the spread bandwidth over the original bandwidth in dB. This processing gain can thus

be added to the signal side of the SNR calculation (Ayala et al., 2004). This fruitful property is due to the power-bandwidth trade-off that exists in any radio communication system: using a spread spectrum signal enables the system to operate at negative signal to noise ratios, thus allowing to deploy smaller terminals with reduced transmission power with respect to the non-spread case. This consequently means improved battery lifetime in the case of portable terminals, as well as an easier and quicker deployment of the terminals. Therefore the adequacy of SS is straightforward for emergency communications, in heavy rain environment (Yoon et al., 2008).

It must be pointed out that spread spectrum should not be confused with the standard DVB-S2 scrambling process. Spreading must be applied to each symbol of the PLFRAME including the PLHEADER and the pilot symbols, and is followed by scrambling, which applies a scrambling code to the spread signal (ETSI, EN 302 307, April 2009). Although there is some similarity between the two processes since both multiply an original signal with a pseudo-random noise (PRN), SS enlarges the bandwidth of the signal whereas scrambling does not since it only randomizes the  $(I+jQ)$  samples of the PLFRAME for energy dispersal (ETSI, EN 301 790 V1.5.1, May 2009). The Direct Sequence Spread Spectrum (DS-SS) block can only be inserted before the base-band filter and the modulator. In this technique, the PRN is directly applied to the data entering the carrier modulator. The modulator therefore sees a much higher bit rate, which corresponds to the chip rate of the PRN sequence. The purpose of modulating an RF carrier with such a code sequence is to produce a direct-sequence-modulated spread spectrum with  $((\sin x)/x)^2$  frequency spectrum, centered at the carrier frequency. There is no changing the point in the system where the DS-SS must be placed otherwise it would be a quite different SS technique. As a result, that means that a standard DVB-S2 transmitter cannot be used as a black box, but that the transmission chain must undergo some design adaptations, so as to conform to the provision envisaged in clause 5.1 of the mobile version of the DVB-RCS standard (ETSI, EN 301 790 V1.5.1, May 2009).

### 3.2 Channel modelling and link budgets

On the basis of such an air interface, a thorough point-to-point link budget analysis has been carried out for the four selected frequency bands Ku, Ka, Q and V in order to determine, first how much admissible capacity on the return link is provided for each MODCOD for the different user terminals, UTA, UTB, UTC and UTD as referred to in section §2.1; and second, which DVB-S2 MODCOD is required when a specific attenuation threshold is crossed (or equivalently to meet a given system availability). Link budget calculations and analyses have been performed both with and without SS, and have carefully focused on interference calculations, since the ratio  $C/I$  is of paramount importance in the link budget. However, link budget computation over the whole coverage is not needed, since it is assumed that the geographical area affected by the disaster is quite limited in extent (less than 100 km<sup>2</sup> which is the size of a large city such as Paris in France) which allows to consider that the link budget parameters are roughly constant over the area.

For this purpose, static (that is to say, temporal and spatial variability is not taken into account) statistical ITU-R channel models are needed to calculate the total atmospheric attenuation to be introduced into the link budgets.

Actually, the effect of each attenuation component may strongly depend on the link frequency. From Ku band to higher frequency bands, propagation through the satellite

channel is mostly impaired by rain, gas (oxygen), clouds, water vapor, amplitude scintillation, depolarization, and a degradation of the receive terminal figure of merit ( $G/T$ ) due to an increase of its noise temperature (Castanet et al., 2003). For example, oxygen attenuation is neglectable at Ku/Ka bands, but is permanently present in the atmosphere at higher frequencies, and exhibits close lines of strong absorption between 50 and 70 GHz, making satellite communications impossible at 60 GHz. Rain attenuation impairs the propagation channel most, with fade depth of up to 20 dB already at Ka band, for 0.01 % of the time (cf. Fig. 3).

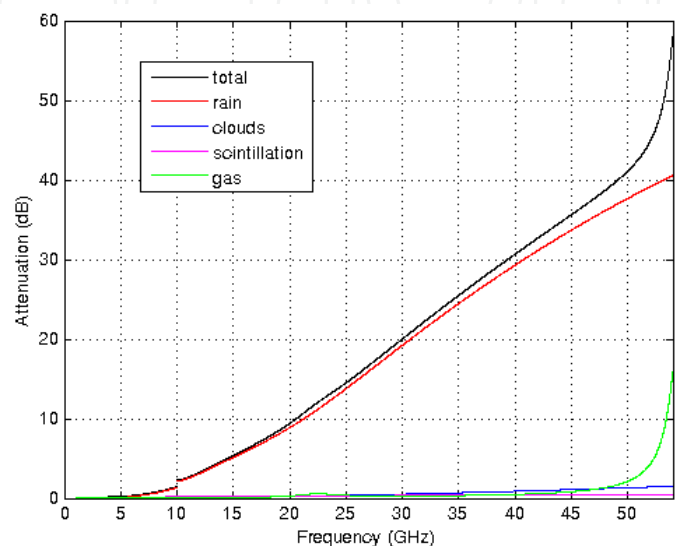


Fig. 3. Total attenuation vs the frequency at Louvain la Neuve, Belgium (Pech, 2003)

The acceptable maximum bit rates for each user terminal were determined according to the channel propagation state in Ku, Ka, Q and V bands, and the calculations also took into account the SS spreading factor  $L$  ( $L=1$  corresponds to the case where SS is unused), as well as the size of the DVB-S2 PLFRAME (64,800 bits for normal frame, or 16,200 bits for short frame). A sample of obtained results is given in Table 1 for an uplink attenuation corresponding to 0.01 % of the time in the case of normal PLFRAME, and assuming that all  $M = 200$  user terminals are of the same type. When there is only one user terminal transmitting, no spread spectrum interference is present. As a matter of fact, the link budget computations have to be refined by taking into account the effect of the mutual interferences due to spread spectrum. Such analysis was presented for instance by Viterbi in (Viterbi, 1985). It leads to considering the following signal energy per chip (of duration  $T_s$  and bandwidth  $W_s = 1/T_s$ ) over noise ratio as the actual operating point of the system:

$$\frac{E_s}{N_0'} = \frac{E_b/N_0}{1 + (M - 1)(R_b/W_s)(E_b/N_0)} \tag{1}$$

where there are  $M$  identical user terminals transmitting to a same gateway at the same power and with spread spectrum;  $N_0$  is the background noise spectral density received by each user;  $E_b$  is the received energy per information bit of duration  $T_b$  and rate  $R_b = 1/T_b$  bps.  $N_0'$  is the sum of thermal noise  $N_0W_s$  and of the interference contribution of the other  $M-1$  users. In other words, the total noise spectral density is related to  $N_0$  through the equation:



$$N_0' = N_0 + (M - 1)E_s$$

(2)

Frequency band	Uplink atten. (dB)	Maximum bit rate (kbps) (L, MODCOD)			
		User terminal			
		UTA	UTB	UTC	UTD
Ku (14 GHz)	6.5	889.7 (1,9)	889.7 (1,9)	889.7 (1,9)	889.7 (1,9)
Ka (30 GHz)	24.7	236 (32,5)	102 (32,6)	3977 (8,28)	3977 (8,28)
Q (45 GHz)	43.5	0	0	3977 (16,28)	591 (8,5)
V (54 GHz)	71.5	0	0	1770 (8,13)	29 (32,1)

Table 1. Maximum allowed bit rates for an uplink attenuation corresponding to 0.01 % of the time, with their required spread factors *L* and MODCODs. The 28 MODCODs of the DVB-S2 standard are involved, and referred to by their indices from 1 (QPSK 1/4) to 28 (32 APSK 9/10). By required MOCODs, it is meant the least robust, but robust enough MODCODs required by the terminals to establish a communication link.

From the results presented in Table 1, the following conclusions can be drawn:

- In Ku band, the portable/mobile terminals UTA and UTB yield quite sufficient bit rate performance, for a moderate channel attenuation level of 6.5 dB.
- In Ka band, these terminals can still transmit very reasonably: maximum bit rates of 236 kbps and more than 100 kbps are yielded by UTA and UTB terminals respectively.
- In Q band, the portable user terminals UTA and UTB can still transmit at low bit rates for an uplink attenuation of up to 30 dB, but require the activation of DS-SS. For *A<sub>UL</sub>* greater than 32 dB, increasing *L* is not sufficient enough to establish the communications link.
- In Q and V bands, the link cannot be established for these low transmit power terminals even though SS is used when the uplink attenuation exceeds 32 dB. Therefore the use of a more powerful terminal, at least UTD (man-transportable terminal, with a transmit power of 5W) is necessary. For the latter, a maximum bit rate of almost 600 kbps is attainable for an uplink attenuation of 43.5 dB (Q band).
- In V band, the link cannot be established anymore for the low to moderate transmit power terminals UTA, UTB and UTD even though SS is used. Nonetheless, minimum communications with VoIP could be established with an uplink attenuation of up to 60 dB, but at the cost of having a very high spread factor *L*, in the order of 5,000, which is not permitted by the bandwidth constraint. UTD is still usable with a maximum bit rate yielding 29 kbps. As the transmit power must be kept as low as possible, it is straightforward that the mini-gateway UTC does not need to be deployed to reach the goal of establishing a minimum emergency link.

## 4. Integrated simulation platform

### 4.1 General description

A software model of the enhanced DVB-S2 transmission link was developed in mixed standard C and Java languages within an open source software environment called Juzzle (SILICOM). The whole simulation platform is an integrated Excel/Matlab/Juzzle software package which also implements the C DISLIN (Michels, 2008) data plotting library. GSL GNU scientific library (Galassi, 2008) could also be incorporated in a future revision of the simulator. The former library is a set of C subroutines and functions that are used to display data graphically as post-processing functions within Juzzle, whereas the latter is a collection of routines written from scratch in C for numerical computing. These routines present a modern Applications Programming Interface (API) for C programmers, allowing wrappers to be written for very high level languages.

The philosophy of the integrated simulation platform tool is as follows:

*Step 1:* The user has the possibility of tuning the values of all the parameters of the point-to-point link budget in the Excel sheet, including the detailed characteristics of the terminals (location, EIRP, transmit power, etc.), the operating frequency band, and the DVB-S2 physical layer parameters (modem roll-off, type of PLFRAME, etc.). Once the system parameters have been validated, an Excel macro enables to create all the system and transmission parameters input files that feed both an off-line propagation pre-processing Matlab routine and the Juzzle core component.

*Step 2:* The offline pre-processing propagation module written in C must be run in order to generate the needed attenuation time series for the return link in Ka and EHF bands using the enhanced stochastic Maseng-Bakken model developed by Lacoste and Carrié (Lacoste, 2005; Lacoste et al., 2005; Castanet et al., 2008; Carrié et al.; Lemorton et al., 2007). The module uses the Juzzle C data-driven engine. An example of such an attenuation time-series is shown in Fig. 4 (taken from Pech et al., 2009). The synthesizer relies on the theoretical principles of the enhanced Maseng-Bakken model which was used by Lacoste (Lacoste et al., 2005; Castanet et al., 2008), and recently improved by Carrié (Carrié et al.). Actually, this new stochastic model enables to either stochastically interpolate initial samples to synthesize fast fluctuations of rain attenuation or generate “on-demand” rain attenuation events starting from the three parameters: duration of the event, maximum attenuation and position of the peak attenuation.

The model improvement lies in the characterization of the conditional probability  $p(A(t) | A(t-Dt_1), A(t+Dt_2))$  which enables very fast interpolation or stochastic generation of rain events “on-demand”. Three of the input parameters ( $m$ ,  $s$ ,  $A_{\text{offset}}$ ) can be assessed for all link configurations using ITU-R recommended models. For the last parameter,  $b$ , a rough estimate equal to  $10^{-4} \text{ s}^{-1}$  can be used independently of the sampling rate and whatever the link considered in North-western Europe for elevation angles between  $25^\circ$  and  $38^\circ$  and frequencies between 12 GHz and 50 GHz (Carrié et al.).

The “event-on-demand” time series synthesizer derived from this first model offers the possibility to configure the maximum level and the duration of the rain attenuation events to be generated. This model exhibits the physical soundness of the real rain impairments

phenomenon and enables generation of rain attenuation events databases representative of experimental databases (Carrié et al.).

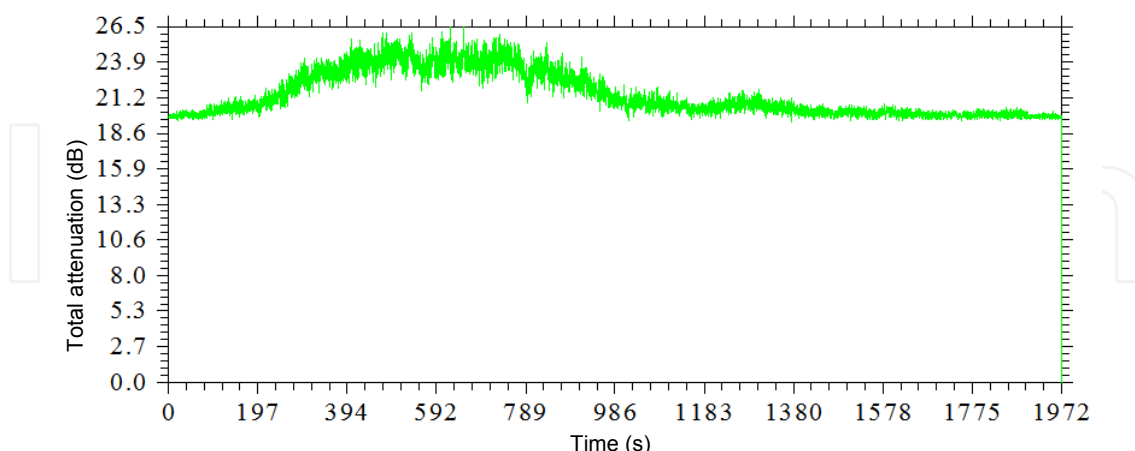


Fig. 4. Total attenuation time-series (in dB) generated by the offline module within the Juzzle simulator at 54 GHz

*Step 3:* The Juzzle on-line core component contains the complete high level system link model and enables to post-process and display a number of performance results.

*Step 4:* Last but not least, a Matlab routine is provided with the aforementioned simulator components, allowing to post-process the results file containing the collected performance parameters. It could be envisaged to replace this Matlab component in the future with a GSL-based module embedded in the Juzzle environment, as mentioned previously.

#### 4.2 The Excel sheet link budget calculator

The Excel sheet link budget calculator was developed in order to help dimension the satellite emergency system to be simulated. It is a powerful tool allowing to:

- configure the whole system (satellite, air interface, characteristics of Earth terminals both from the emergency system and the primary system, etc.);
- compute the return link budgets both for the emergency system and the primary system.

The Excel sheet is composed of 12 window tabs. The tool was developed with a library of Visual Basic functions grouped into 10 distinct categories. It also calls an extern dynamic link library (DLL) named "propa.dll" (Lacoste, 2006; Lacoste, February 2006), which was developed by the CNES and comprises routines that enable to calculate the various propagation attenuation and scintillation components on an Earth-space link according to standardized ITU statistical prediction methods:

- Rec. ITU-R P.676 (ITU-R, 2005) due to dry air and water vapour;
- Rec. ITU-R P.840 (ITU-R, 1999): attenuation due to clouds;
- Rec. ITU-R P.618 (ITU-R, 2007): attenuation due to rain and melting layer, scintillation fade, total impairment.

4.3 The Juzzle simulation platform

The Juzzle simulation platform is composed of two separate and standalone Juzzle components (a propagation generator component and a processing core component), and an extern post-processing Matlab routine.

The architecture of the Juzzle link model is shown in Fig. 5 hereafter with all its components:

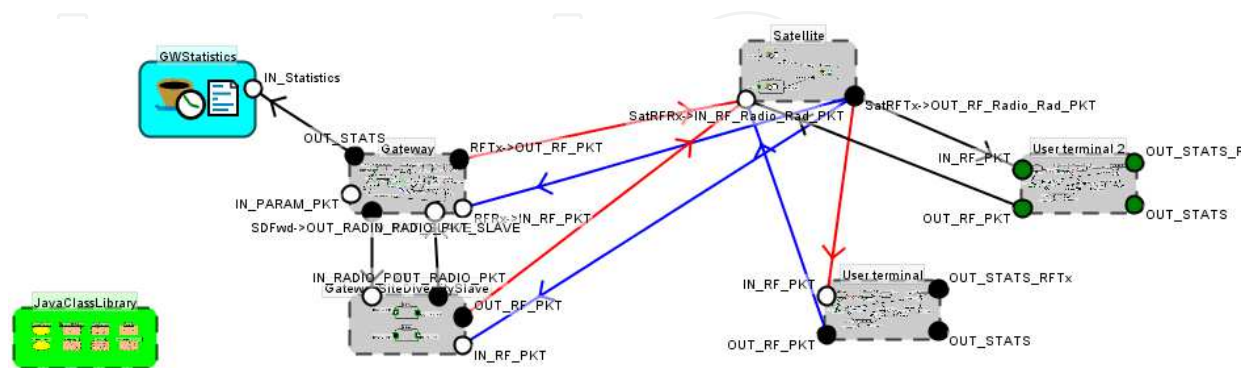


Fig. 5. Juzzle link model

The core processing module was developed in Java due to the portability, reusability, and object-oriented feature of the programming language. This module uses the Java event engine allowing to model the various delays within the system more easily.

The module models the emergency satellite system at high level as shown in Fig. 5, with the following nodes: two user terminals (“User terminal 1” and “User terminal 2”), the gateway, and the satellite, especially in terms of radio packet transmission, and its related link budget computation functions. As a result, the simulator is a powerful and complex integrated simulation platform handling more than 700 parameters, and being composed of 44 Java classes.

The component also possesses a statistics node whose tasks is to write down in an output ASCII text file a number of probe parameters allowing to compute performance statistics related to the link quality (BER, system margin,  $C/(N_0+I_0)$ , MODCOD, DS-SS spread factor, bit rate, etc.). As of today, exactly 30 parameters are monitored, but their number can be increased at will, with the restriction that the larger the number of parameters, the larger the results file. For instance, a simulation over a simulated time of 59,900 seconds produces a 1.428-GB output file.

The software simulation platform is described in more details in the next sections.

4.3.1 Traffic modules

Four types of traffic are modelled: VoIP, Web browsing, and SMS for the return link, and Internet aggregate traffic as an example of continuous forward link traffic. The corresponding underlying theoretical models employed are given in the following:

a) VoIP traffic

This source is modelled by a classic ON/ OFF state machine (Pech, 2003). The model is represented by an ON/OFF source which operates as an alternating process of talk and

silence periods which are distributed according to negative exponential laws with means  $a^{-1}$  and  $b^{-1}$  respectively.

### **b) Web browsing traffic model**

Basically, the Web traffic model relies on an ON/OFF two-state model. The specificity of the model lies in its representing the traffic from a user behavioural point of view, by modeling a user's session, that is, a user Web request instead of focusing on the notion of a Web page. The overall traffic stream of a user is composed of a superimposition of the packet arrival processes of all TCP connections within a user's session. Moreover, it is a hierarchical model in which session, connection and IP levels are included (Choi & Limb, 1999).

### **c) SMS traffic**

SMS traffic is simply modeled by a generator of SMS messages whose mode of operation is as follows (ETSI, 3GPP TS 23.040, October 2004; ETSI, 3GPP TS 23.038, September 2004): a random number  $N$  ranging from 1 to 10 (produced by a uniform random number generator) of concatenated 140-byte (amounting to 160 alphanumeric characters) SMS messages is generated every period  $T_{SMS}$  where  $T_{SMS}$  is distributed according to a negative exponential distribution. The number  $N$  is generated each time the SMS traffic source is invoked, that is, when the basic service is switched into. The scheme is repeated (ARQ: Automatic Repeat reQuest) every two minutes provided the basic service (i.e. a bit rate of less than 4 kbps) is still selected.

### **d) IP aggregate traffic source**

The traffic source is modeled by a Fractional Gaussian Noise (FGN) using the Fast Fourier Transform (FFT). Paxson's FFT method (Paxson, 1997) consists in synthesizing a sample path having a same power spectral density (PSD) as a Fractional Gaussian Noise (FGN) process. This sample path can then be used in simulations as traces of real self-similar traffic. The algorithm is basically based on a fast approximation of the PSD of an FGN process using the FFT. The algorithm relies on an implementation of Paxson's self-similar generator written in ANSI C, and provided with in the form of a routine `fft_fgn.c` developed by Christian Schuler.

## **4.3.2 Adaptive strategy module**

The adaptive strategy mechanism is at the heart of the simulator, and relies on a combination of several techniques aimed at ensuring high availability of the transmission links in spite of severe channel impairments in the selected frequency bands (*e.g.* about 20 dB in Ka band and more than 80 dB in Q band 0.01 % of the time). The techniques employed are: ACM, spread spectrum with varying DS-SS spread factor ( $L$ ), gateway site diversity (SD) (to improve the downlink budget for the return channel when it is impaired by rain), and ARQ-like time diversity (TD). ARQ is only applied to SMSs, the user terminal automatically attempting at retransmitting the same SMS message at different times, when the channel conditions improve. Currently, retransmission is done on a pure deterministic basis, that is, periodically after a fixed time interval. Nevertheless, in the future, more



elaborate strategies could be devised exploiting fade duration, fade slope, and inter-fade statistics so as to implement an efficient method able to predict the channel attenuation in the medium term (several minutes).

It is moreover assumed that all of the user terminals of the emergency mission which are deployed over the geographical area affected by the disaster are of the same type and undergo the same ACM mode. This makes sense since the area is assumed to be quite limited in extent, more precisely smaller than 100 km<sup>2</sup>, which allows to consider that the link budget and transmission parameters are roughly constant over the whole area. Nevertheless, it must be kept in mind that this uniform ACM scheme over the whole area is also a consequence of a simplistic assumption concerning the channel propagation modelling, in which no spatial variability is taken into account. Only a temporal variability is modeled using Carrié's enhancement of Lacoste's CNES/ONERA rain fading time series stochastic generator based on Maseng-Bakken model (Lacoste, 2005; Lacoste et al., 2005; Castanet et al., 2008; Carrié et al.; Lemorton et al., 2007).

The tabulated results of the link budget analysis previously mentioned enabled to carefully construct appropriate and efficient channel-aware link adaptive strategies, specific to each frequency band, the purpose of which is to ensure very high availability of the link, and enough capacity to authorize at least SMS communications even during a severe rain event (extremely strong storms), and VoIP as a minimum guaranteed service the rest of the time.

The adaptive strategy combines ACM with spread-factor-varying SS, the spread factor  $L$  being adapted (increased) before ACM activation depending on the attenuation level with respect to predefined thresholds, and with three different service classes being defined:

1. *Premium service*: VoIP, and Web browsing/SMS with a bit rate of about 180 kbps;
2. *Gold service*: VoIP/SMS with a bit rate of 4 to 16 kbps;
3. *Basic service*: SMS only with a bit rate of less than 4 kbps.

For each frequency band, these services are switched from each other through the DS-SS spread factor  $L$  (from 1 to up to several thousands). Within each service (or primary bit rate mode), the channel fluctuations are dynamically compensated for by full DVB-S2 ACM MODCOD switching.

Whenever the return link downlink channel is impaired by rain above a pre-determined attenuation threshold, and when the above compensation techniques still do not allow to close the link budget, SD is deployed on the feeder link. In other words, the downlink signal from the satellite is rerouted towards a slave gateway station which is located in a place not affected by rain. This brings an additional site diversity gain  $G_{SD,DL}$  into the link budget, that can be calculated with the ITU-R P.618-9 Recommendation (ITU-R, P.618-9, January 2007).

It should now be noted that an optimal adaptive mechanism would obviously need to exploit, not only the static statistical characteristics of the channel fade components, but also their dynamic properties – in other words, an informed knowledge of fade / inter-fade duration, and fade slope ITU-R statistics and models (cf. Fig. 6). Furthermore, two additional considerations must be pondered when devising a relevant adaptive strategy to meet the system requirements for the targeted emergency mission: (a) the system total delay requires some short-term fade prediction to be made within a time horizon of several

seconds; (b) and a higher layer MODCOD switching criterion other than merely the  $E_s/N_0$  or the BER, such as the PER could be used so as to yield better performance at the application level. The former consideration is due to a necessity of correctly estimating at time  $t$  the channel attenuation  $A(t+\Delta t)$  at time  $t+\Delta t$ , knowing that otherwise using  $A(t)$  to decide at time  $t$  which MODCOD is to be used would be mostly inadequate since quite rapid variations may occur in the channel attenuation time evolution. To properly model a rain attenuation predictor, an accurate link delay budget must be established, including in particular the 500-ms satellite Round-Trip Delay (RTD), and the channel estimator calculation time (Aroumont et al., 2006) (using the DVB-S2 pilot symbols which are spread over different frames). The second consideration relies on some error modelling that enables to derive the PER from a physical layer-oriented QoS parameter like the BER (Pech et al., 2002).

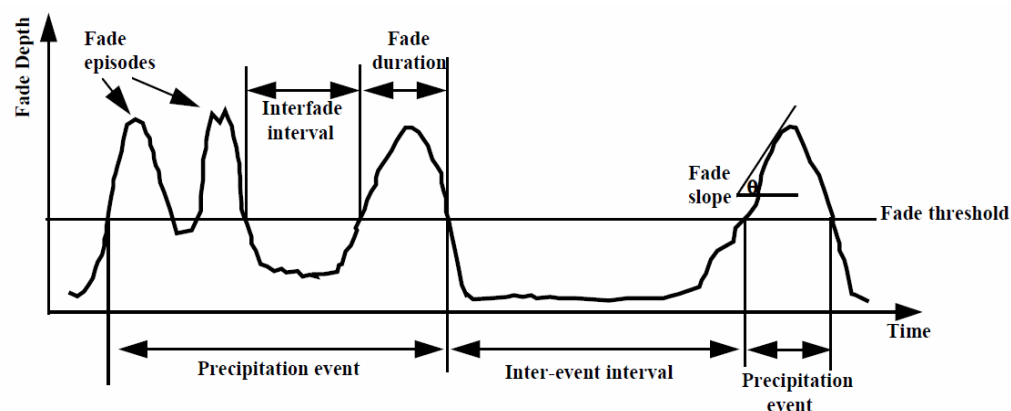


Fig. 6. Secondary statistics of fade

Currently, to obtain the attenuation to be applied to the channel, the simulator performs an attenuation prediction by linear interpolation or extrapolation, and takes into account the satellite geostationary Round Trip Propagation Delay (RTPD).

#### 4.4 Extern Matlab post-processing module

This module is a post-processing module in charge of computing the transmission link performance mainly in terms of link availability, bit rate, error rates (BER or PER), delay, jitter, average and maximum packet sizes in order to characterize the application-level QoS, but also in terms of IP throughput, IP traffic characteristics (Tou et al., 2008) (inter-packet delay, IP delay variation, one way delay with maximum and minimum values, packet losses), and IP over frame efficiency over the DVB-S2 (Girault et al., 2008) (in connection with the encapsulation overhead and the MODCODs selected, and more generally the implemented adaptive strategy), as well as in terms of attenuation prediction errors. Some performance figures related to VoIP over DVB-S2 links have been made available in recent studies (Jegham et al., 2008), and could serve as a reference basis for the present project, in particular regarding a comparison between GSE and MPE/ULE encapsulation schemes. The module also allows to investigate the impacts of rain fading on the service performance. It provides a set of post-processing graphical plotting functions that will enable to optimize the performance of the adaptive strategy, tune its parameters (*e.g.* hysteresis and detection margins), and assess the ability of the proposed air interface to ensure a robust low bit rate satellite communication link for emergency mission.

5. Some results

The acceptable maximum bit rates for each user terminal were determined according to the channel propagation state in Ku, Ka, Q and V bands, and the calculations also took into account the SS spreading factor  $L$  ( $L=1$  corresponds to the case where SS is unused), as well as the size of the DVB-S2 coded frame FECFRAME (64,800 bits for normal frame, or 16,200 bits for short frame). A sample of obtained results regarding to the admissible maximum bit rates and their associated MODCODs and spread factors was given in Table 1 which is copied into Table 2 hereafter for the sake of commodity:

Frequency band	Uplink atten. (dB)	Maximum bit rate (kbps) (L, MODCOD)			
		User terminal			
		UTA	UTB	UTC	UTD
Ku (14 GHz)	6.5	889.7 (1,9)	889.7 (1,9)	889.7 (1,9)	889.7 (1,9)
Ka (30 GHz)	24.7	236 (32,5)	102 (32,6)	3977 (8,28)	3977 (8,28)
Q (45 GHz)	43.5	0	0	3977 (16,28)	591 (8,5)
V (54 GHz)	71.5	0	0	1770 (8,13)	29 (32,1)

Table 2. Maximum bit rates allowable for an uplink attenuation corresponding to 0.01% of the time, with their required spread factors  $L$  and MODCODs

The results obtained without SS show in particular that the portable/mobile terminals UTA and UTB yield quite sufficient bit rate performance in Ku band, and for a moderate channel attenuation level of 6.5 dB. These terminals can still transmit very reasonably in Ka band. But in Q and V bands, the link cannot be established for these low transmit power terminals even though SS is used. Therefore, the use of at least UTD is necessary. For the latter, a maximum bit rate of almost 600 kbps is attainable for an uplink attenuation of 43.5 dB (Q band). In V band, UTD still is usable with a maximum bit rate yielding 29 kbps. The behaviour of the adaptive strategy for UTD in function of the total uplink attenuation is shown in Fig. 7. As the transmit power must be kept as low as possible, it is straightforward that the mini-gateway UTC does not need to be deployed in order to establish a minimal emergency link.

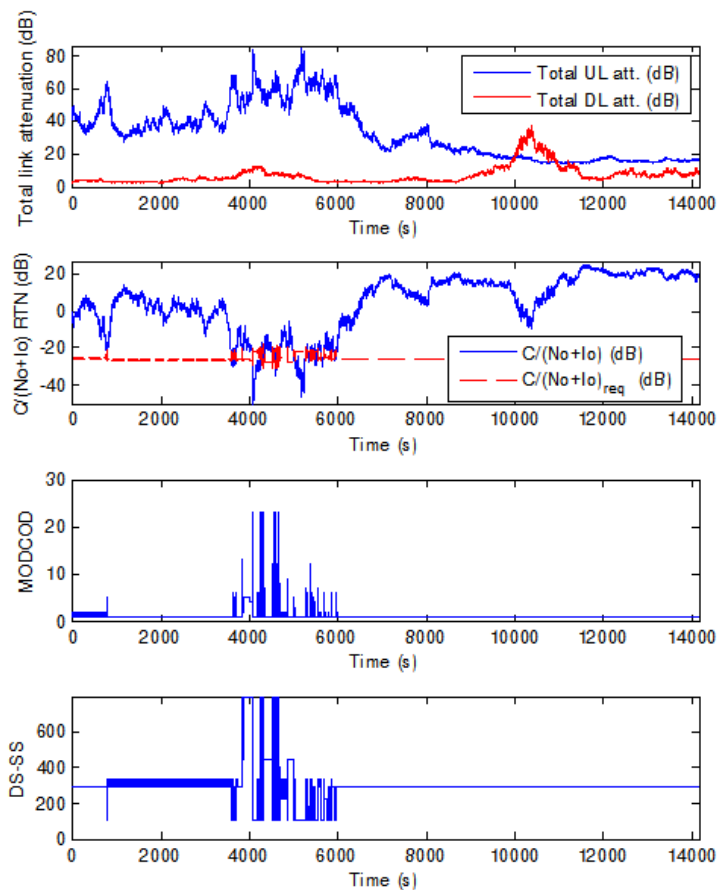


Fig. 7. Adaptive strategy behaviour for UTD in V band vs the total uplink attenuation

6. Conclusion

This chapter has presented the architecture of a multibeam, bent-pipe satellite system, used to rapidly establish a low bit rate link for emergency communications in Ku/Ka and Q/V bands. The characteristics of the proposed system have been described. An enhanced DVB-S2-like air interface has been proposed, involving DS-SS technique and other adaptive mechanisms such power control, and site diversity. Link budget analyses have shown that even though SS may be deactivated, very low transmit power user terminals UTA and UTB yield reasonable performance for the envisaged purpose up to the Q band, but for rather moderate channel attenuation values. This highlights the relevance and efficiency of a solution combining ACM, SS, bit reduction, and SD techniques in a new adaptive strategy in order to improve transmission performance. Such an adaptive strategy has been successfully implemented within the more general framework of an integrated Excel/Juzzle/Matlab software simulation platform designed to model the system in a high level cross-layer approach mixing propagation, physical layer, and higher layers components. Some selective results of the simulations carried out using this DVB-S2-like satellite link software simulator have been partially presented highlighting its ability to perform relevant analyses of the performance of the system both at the physical layer and the network level.

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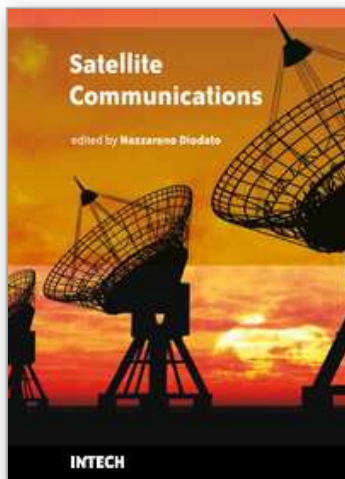


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