Satellite Communications: Research Trends and Open Issues

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***Abstract*—A panoramic view on the study and design of digital satellite communication links is the focus of this paper. Starting from the characterization of satellite propagation channel in different application environments (from broadcast to fixed terminals, to broadband mobile satellite access), we address physical layer aspects related to satellite communications in the attempt of providing the Reader with an overview of the new trends and open issues in this field.**

I. INTRODUCTION

In recent years, the wireless communication world witnessed a dramatic reduction of the time lag between scientific research discoveries and their implementation in commercial systems. The hectic activity of technical and commercial fora, e.g., the 3rd Generation Partnership Project (3GPP) and the Digital Video Broadcasting (DVB) project, has indeed brought the scientific research right into the standardization rooms. If, on the one hand, this is a striking positive event for the scientific researchers, on the other hand, it also makes more critical to keep an updated understanding of the research trends and open issues to be investigated. The following are only a few examples of this hype.

In the mobile arena, the 3GPP group is working around the clock on the development of the Long Term Evolution (LTE) of the UMTS radio access, exploiting OFDM-based technologies, state-of-the art coding schemes, and Multiple Input Multiple Output (MIMO) techniques in search of higher and higher system efficiency. Broadcasting systems are also following this trend. According to the decision of the DVB project, the DVB-T system, developed in 1997, is being redesigned by the DVB-T2 group. Again, the DVB-T2 specifications will be OFDM-based and will include state-of-the-art solutions such as MIMO, low density parity check (LDPC) coding schemes, upper layer forward error correction (FEC), smart and fast synchronization techniques.

Satellite communications are not immune from this wave of innovation. In the DVB forum, after the publication of the DVB-S2 standard and the approval of the DVB-SH specifications, in March 2006 the Commercial Module approved the mission of extending DVB-RCS to mobile scenarios yielding the DVB-RCS+M mode. The objective is to provide broadband interactive services to mobile users located on aircrafts, boats, and vehicles such as high speed trains, busses, and cars [1]. Some of the countermeasures proposed for these challenging fading environments make use of [1], [2]: (i) spatial or (ii) time diversity (e.g. two receive antennas configuration or channel interleaver/spreading techniques, respectively), and (iii) upper layer FEC. On the ETSI side, the ETSI S-UMTS group initiated several new activities related to the study of OFDM-based air interfaces for 4G mobile satellite systems [3] confirming the clear trend towards the adoption of multicarrier modulation techniques in satellite air interfaces, in particular in the lower frequency bands (e.g., below 3GHz). Cooperative communication techniques are being also considered for hybrid satellite/terrestrial networks with the aim of extending the satellite coverage (e.g., with ancillary terrestrial components, ATC) and of supporting terrestrial networks unable to provide their services (e.g., because of lack of coverage, emergency situations, network overloads, *etc.*).

1-4244-0939-X/07/$25.00 © 2007 IEEE

In the framework of the most recent developments in the satellite communications, starting from the characterization of satellite propagation channel in different application environments (from broadcast to fixed terminals, to broadband mobile satellite access), we address physical layer aspects related to satellite communications in the attempt of providing the Reader with an overview of new trends and open issues.

II. MOBILE BROADBAND CHANNEL MODELS

Models for broadband satellite channels are typically referred to Ku (10-12 GHz) and higher frequency bands. They combine together those effects also found in fixed broadband channel models such as atmospheric attenuation as detailed in [4] and references herein with those deriving by mobility conditions, such as large and small scale fades respectively caused by obstacles much larger than the signal wavelength (e.g. buildings or trees) and by the irregularities of such obstacles (e.g. foliage shadowing), typically resulting in the well known multipath propagation phenomena.

As far as the effects of mobility are concerned, typical values of the coherence bandwidth for outdoor environments are in the range between 7 and 11 MHz at L-band (1-2 GHz) and around 30 MHz at EHF band (40 GHz), as reported in [5] after direct measurements with omnidirectional antennas. In the latter case, only few echoes with strong attenuation (-22 to -27 dB) were observed. If directive antennas are used, echoes with significant delays are in most of the practical cases filtered out by the antenna radiation pattern. Therefore, frequency non selective models have been so far normally employed for Ku-band and Ka-band signals carrying data rates of practical interest, i.e. up to several tens of Mbps. This topic is however subject of more detailed investigations by the European Space Agency (ESA) through dedicated measurements. Under the assumption of no frequency selectivity, the large scale fades are normally modeled by means of a Markov chain which determines the transitions among channel states, whereas the small scale fades within each state are modeled by means of suitable statistical distributions, such as Rice, Rayleigh, *etc.* [4]. Four mobile environments can be identified, namely aeronautical, maritime, railway and land-vehicular. For the first two, during normal conditions, the mobile channel can be modeled as a single-state Ricean channel, with very high Rice factor, in practice very close to an AWGN channel. Potential fades due to e.g. the aircraft wings depend only on the geometry of the aircraft and on the antenna radiation pattern, hence they are deterministic effects not suitable for a statistical characterization. For the land-vehicular case, narrowband Markov models for Ku and Ka bands can be found respectively in [6] and [7]. For the specific subcase of the railway environment, in absence of direct measurements (another potential topic for further investigation), the common practice is to model the channel as a single-state Ricean channel with a relatively high Rice factor in the order of 17 dB with space-periodical superimposed erasures due to the metallic posts feeding the train pantograph [8].

For those cases where atmospheric attenuation shall be combined with statistical impairments due to the presence of obstacles along the line-of-sight, an analytical approach for a combined modeling technique is proposed in [9]. However, it should be also taken into account that, as shown by some preliminary studies, the fade slope of rain attenuation may significantly change in mobility condition. As a matter of fact, the combination of atmospheric effects with statistical fades due to mobility is one of the most interesting issues for future researches is this field.

III. CODING AND MODULATION

Deep space missions traditionally provide the state-of-the art technology in channel coding techniques as the received signal power in such applications is very low and thus powerful error correcting codes are needed to provide with large coding gains. For such communication links the additive white Gaussian noise (AWGN) channel is usually assumed. Since the late 1960s, there has been a shift from the use of convolutional codes (CC) with low complexity decoding (e.g. sequential decoding) to the use of concatenated codes consisting of CC and Reed Solomon (RS) codes. The appearance of turbo codes (TC) in 1993 and later the rediscovery of low-density parity-check (LDPC) codes in 1996 currently provide the state-of-the-art technology in deep space communications (e.g. data telemetry links [10]) as well as in new demanding applications (e.g. near-earth observation missions requiring high data rates [11]), respectively [1] as their performances can be within a fraction of one decibel from the Shannon channel capacity limit. Both TC and LDPC codes are based on two fundamental ideas: (i) a simple encoder with a predefined structure that is able to produce long codewords with good distance properties (using an interleaver of large size and a parity-check matrix with low density of ones compared to the block size, respectively), and (ii) the use of low complexity techniques to decode such codewords based on iterative (i.e. feedback) decoding, which can provide near optimum maximum likelihood (ML) performance (e.g. maximum a posteriori probability (MAP) algorithm and sum-product algorithm (SPA), respectively).

The use of advanced channel coding techniques (e.g. TC and LDPC codes) is the state-of-the-art technology used in current satellite systems to provide broadcasting services to fixed terminals in the Ku/Ka frequency bands into two-ways (i.e. DVB-S2 [12] in the forward link and DVB-RCS [13] in the return link, respectively), in which the AWGN channel is usually assumed. In particular, DVB-S2 considers irregular LDPC codes of either 16200 or 64800 bit codewords and 11 coding rates (i.e. ranging from 1/4 to 9/10). With respect to DVB-RCS, double-binary turbo codes are assumed with 12 frame sizes (i.e. ranging from 48 to 752 bit couples) and 7 coding rates (i.e. ranging from 1/3 to 6/7).

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[1] Note that [11] provides additionally optimized LPDC codes for deep space applications, but these are intended to complement the current TC used in [10], which have coding rates less than or equal to 1/2. The LDPC codes selected in [11] have coding rates equal to 1/2, 2/3, and 4/5, respectively.

To deal with challenges posed by mobile scenarios, FEC at upper layers (i.e. recovering erroneous packets by the use of erasure RS or LDPC codes, which add redundant packets at the transmitter) is under study in the DVB-RCS+M framework. This technique is used in order to protect transmitted packets as much as possible (e.g. target packet error rate of 10^{-7}) and avoid retransmissions, due to the limited access or even absence of a return (i.e. feedback) channel for potentially high number of users. In high-speed train applications (e.g. in the presence of blockage areas or tunnels), another solution is the interworking between different access schemes, i.e. combining the direct signal coming from the satellite and that coming from terrestrial components (usually referred to as gap fillers).

The advanced channel codes mentioned above are under consideration in future satellite broadcasting systems to mobile terminals (handhelds, PDAs, *etc.*) with applications such as digital satellite radio and multimedia (e.g. video) services in the lower L/S frequency bands (e.g. SES SDR [14], and DVB-SH [15] [2], respectively). With respect to the channel code selection, both SES SDR and DVB-SH assume the TC used in 3GPP2 standard, due to its lower complexity at the very low coding rates. In particular, the TC in SES SDR assumes two frame sizes of either 762 or 12282 bits and 14 coding rates (i.e. ranging from 1/5 to 6/7), whereas the TC in DVB-SH assumes two frame sizes of either 1146 or 12282 bits and 8 coding rates (i.e. ranging from 1/5 to 2/3). Upper layer FEC is optional in SES SDR and mandatory in DVB-SH (referred to as extended multi-protocol encapsulation (MPE) FEC).

Apart from the traditional modulation formats, such as the phase shift keying (PSK), e.g. quadrature PSK (QPSK) is used in DVB-RCS standard, or to a lesser extend the quadrature amplitude modulation (QAM), the amplitude phase shift keying (APSK) has been the state-of-the art technology for satellite transmission signals. This modulation format has been recently adopted by DVB-S2 standard, in order to provide with high spectral efficiencies (e.g. 16-APSK [3], 32 APSK). Its hybrid constellation can be viewed as a double, triple, *etc.*, ring of a PSK constellation by defining two parameters: (i) the relative radius of the outer PSK ring against the inner PSK ring, and (ii) the relative angle between them. The most important advantage of APSK as compared to QAM has been the greater tolerance against the non-linear distortion caused by satellite transponders in combination with appropriate predistortion techniques at the transmitter.

Ideally, any code should perform close to the channel capacity with moderate decoding complexity and for arbitrary value of block size and coding rate. To this date, this can be achieved by both TC and LDPC codes, provided that the block size is rather large, e.g. thousands of bits. Some open questions to be answered are [11]: (i) *Code performance at a required BER value and the absence of error floor, if possible* (LPDC codes perform better and lower the error floor as compared to TC for large block sizes); (ii) *Coding rate selection* (LDPC codes outperform punctured TC for higher coding rates); (iii) *Encoding complexity* (TC can be encoded faster than LDPC codes, unless a simplified version of LDPC codes is used, that it repeat-accumulate (RA) codes); (iv) *Decoding complexity* (LPDC codes can achieve higher throughputs than TC allowing with parallel decoding architectures); and (v) *Any intellectual property rights* (TC have been patented, in contrast to LDPC codes).

IV. SYNCHRONIZATION & ESTIMATION

If on the one side enhancements in terms of coding and modulation techniques allow satellite systems to reduce the required signal to noise ratio, on the other hand the very low signal to noise ratio challenges the synchronization and channel estimation algorithms, posing a host of issues that needs to be addressed in the design of satellite communication systems. To this end, iterative code-aided synchronization is an active area of research. Iterative schemes based on turbo decoding ideas can in fact improve the performance of stand-alone estimation techniques at low signal to noise ratios. The iterative processing at receive decoding and the associated high sensitivity against synchronization errors make it natural the turbo synchronization concept. The mathematical framework, based on the Expectation-Maximization (EM) algorithm, was presented in [20]; thus, parameter estimation can be embedded in the recursive decoding process. Instead of a more classical task segregation approach, marginal posterior probabilities (soft information) coming out of the MAP decoder are used to assist the ML estimation. An affordable complexity requires a suboptimal implementation, with one turbo iteration at each EM iteration. The performance becomes very sensitive to initial estimates, and although turbo synchronization can potentially achieve data-aided performance without pilots, it is recommended the insertion of symbol pilots so as to assist the initialization. In addition, they can be easily embedded in the estimation process: their positioning and amount are interesting matters of study. In any case, it may be difficult to get good starting estimates with short bursts in very low signal to noise ratios: pilots become essential, and the decision as to whether turbo synchronization is an option must be studied in a case based approach [22]. Not only synchronization, that is, phase, frequency and timing estimation can benefit from this approach; see [21] for an EM approach to SNR estimation.

Code acquisition and frame synchronization are also classical problems in need of novel robust solutions able to work in low signal to noise ratio scenarios and frequency uncertainty, not only for communications but also for navigation applications [23]. Code synchronization is achieved through acquisition and tracking; the acquisition is typically the most critical part due to the large uncertainty region and low signal to noise ratio. Thus the mean acquisition time and the overall complexity are of paramount importance. Even further, the low signal to noise ratio makes frequency estimation unfeasible in a blind way. As a result, a correct frame acquisition is key to

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[2] DVB-SH is an extension of the corresponding terrestrial DVB-H system, whereas there are many commonalities with SES SDR standard.

[3] 16-APSK is also one of the solutions adopted for single transmission signals (using TDM) in both SES SDR and DVB-SH.

locate the pilots inserted in the corresponding frame and start estimating the remaining parameters, e.g., frequency offsets.

New issues need also to be solved in multiuser scenarios making use of centralized interference mitigation schemes. The potential gains achievable in both uplink (multiuser detection) [19] and downlink (precoding) [18] require the use of advanced signal processing schemes. Multibeam satellites can increase their capacity by convenient frequency reuse, making it necessary to cancel the co-channel interference somehow. Proper interference mitigation calls for the resolution of a number of issues. In the forward link, joint encoding must be performed at the gateway handling the corresponding co-channel beams[4]. In the reverse link, multiuser detection can be performed at the gateway receiving the signals from all the involved beams. The precise knowledge of the channels coefficients is necessary for a proper performance in both cases. Robust timing recovery and frame synchronization are required: initial synchronization must be operated amidst strong co-channel interference before cancellation comes into play, since channel identification is necessarily based on a common time basis. Precoding in the forward link (either linear or non-linear) gives rise to complex constellations, posing additional hurdles to the estimation of synchronization parameters.

When it comes to mobile environments, new important challenges are posed as well. In particular, signal blockages and terminal movement introduce substantial difficulties to the physical layer synchronization stage. Synchronization time becomes an issue under mobility circumstances: fast re-acquisition is a need to recover from signal blockage and for a seamless handover when moving along different beams. Carrier recovery in fast varying Ricean multipath fading channels need more pilots or sophisticated estimation schemes. Carrier frequency error is critical due to the low signal to noise ratio and large expected errors from Dopplers shifts.

The application of multicarrier modulation to satellite communications is not void of interesting topics for further research. In particular, channel estimation is a key issue for an acceptable performance of OFDM reception. In this regard, the study of good pilot symbols distribution for improved channel estimation is an important line to pursue, also for MIMO scenarios. Gap-fillers are mandatory to provide a good service to mobile receivers. In single frequency networks, with the same frequency assignation to the satellite-earth and terrestrial links, gap-fillers operation require a careful design to fight unavoidable coupling from transmit to receive antennas. Synchronization at different levels must be addressed for a successful OFDM-based satellite setting: synchronization in a multiple-access receiver (OFDMA), network synchronization issues, single-frequency networks in the mobile scenario and fast re-synchronization are all aspects to be carefully designed.

V. COOPERATIVE SATELLITE COMMUNICATIONS

The techniques described above support the design of more and more efficient physical layer solutions that are, however, still unable to bring satellite coverage indoor or in tunnels, where signal relay is essential. Towards this end, cooperative communications offer more than just simple signal amplification and are getting the attention of satellite communication system designers in order, not only to extend satellite coverage in uncovered areas, but also to serve low cost user terminals with no satellite reception/transmission capabilities.

The concept of cooperative communications is a recent trend in terrestrial networks that enables users to cooperate with one another in order to provide higher quality of service and data rate. In general, cooperative systems have a source node multicasting a message to a number of cooperative relays, which in turn resend a processed version to the intended destination node. Therefore, diversity is achieved by actually exploiting two fundamental features of the wireless medium: its broadcast nature and its ability to achieve diversity through independent channels. In a word, cooperative communications can be seen as a means of achieving spatial diversity without the need of using multiple antennas at either the transmitter or the receiver [16].

Considering the above, the issue that raises to the surface is how existing work on terrestrial cooperative communication networks can be utilized towards the solution of the aforementioned problems, taking into account the satellite networks' special features. In terrestrial networks, for instance, two are the most common relaying techniques, namely decode-and-forward (DF) and amplify-and-forward (AF); they correspond to employing full decoding at the relaying terminals and forward the re-encoded message to the destination, and employing a simple analog amplification without any sort of decoding, respectively. Transferring this concept to satellite networks, however, requires that the appropriateness of these techniques need to be re-examined, taking into account possible synchronization and bandwidth allocation issues that may entail. Additionally, the issue of optimally selecting the participating relaying terminals (that still remains an open one in terrestrial networks) is of high importance in satellite networks as well, and generally involves relaying algorithms that need to attain a well-balanced tradeoff between implementation complexity and performance. Regarding the physical layer, relay selections must take into account both the performance enhancement that follows the selection of the relay with the strongest end-to-end link (i.e., from the satellite to the destination terminal), and fairness issues that are endowed with the concept of requesting from the available relaying terminals equal amount of energy to consume in the long-run.

These trends also involve the question of whether it is more appropriate to employ fixed relays (i.e., fixed infrastructure-based repeaters that are placed in properly chosen spots, e.g., at tunnel entrances) or mobile, such as portable devices carried by other users/subscribers. The advantages and drawbacks of

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[4] For non-regenerative bent-pipes, the gateway can only mitigate the interference of the beams that it manages

the relaying characteristics of the above techniques are to be assessed, and yet represent another important topic. For example, although using existing subscriber devices as relays may not entail any extra infrastructure cost, it raises concerns on whether these users are willing to assist other users' communication, since such an aid towards other subscribers is naturally followed by an individual power and bandwidth cost. To this end, the collaboration motives that have already proposed for terrestrial cooperative networks [16] need to be re-examined within a satellite point of view.

Along with the classical implementation of the cooperative concept, i.e., repetition-based forwarding of the received message by the relays, special techniques that have already developed in MIMO systems are readily to be applied in a distributed fashion, forming thus virtual MIMO systems. In particular, distributed space time coding (DSTC) techniques offer the advantage of high diversity gains followed by less spectral efficiency cost compared to repetition-based protocols; their operation is based upon the concept of having the multiple relays forwarding the received signals according to a space-time rule, operating similarly as the multiple transmitting antennas of a space-time coded MIMO system [17]. For our case of interest, both the fixed and the mobile relaying terminals can play the role of virtual multiple antennas. However, certain implementation issues must be taken into account in each case, related again to the special channel characteristics of the satellite links. Particularly for mobile relaying terminals, the main concern of applying DSTC is that the presence of sufficiently enough available relays is not always assured, especially when referring to highway or railway coverage. In such case, the employed techniques need to be carefully chosen, depending on the each time networks capabilities and complexity tolerance.

VI. CONCLUSIONS

Future satellite communications cannot prescind from the evolution of terrestrial broadcast and broadband communication systems. In this perspective, development of new satellite systems tends to align with that of terrestrial communications, leading to a full integration between the two networks which allows to offer high data rates and high quality of service anytime, anywhere. In this framework, we highlighted some of the fundamental trends that, in the Authors opinion, will drive future research activities in the satellite communication areas. In particular, the diffusion of OFDM-based air interfaces along with the introduction of cooperative communications and MIMO techniques to overcome some of the typical satellite impairments call for wideband and MIMO channel modeling, new coding and synchronization schemes which include also new paradigms like distributed coding, virtual MIMO, and interference cancelation techniques.

ACKNOWLEDGMENT

This work has been supported by the IST FP6 Project SatNEx-II.

REFERENCES

[1] S. Scalise, G. E. Corazza, C. Párraga Niebla, P. Chan, G. Giambene, F. Hu, A. Vanelli-Coralli, M. A. Vázquez-Castro, *Towards the revision of DVB-S2/RCS standard for the full support of mobility*, IEEE COMSOC, SSC Newsletter, Vol. 16, No. 2, Nov. 2006, pp.6-8.

[2] S. Cioni, C. Prraga Niebla, S. Scalise, G. Seco Granados, A. Vanelli-Coralli, M. A. Vzquez Castro, *Advanced fade countermeasures for DVB-S2 systems in railway scenarios*, to appear, EURASIP Journal Wireless Comm. and Net., 2007.

[3] N. Chuberre, A. Bolea-Alamanac, L. Combelles, G. Corazza, B. Evans, P. Glennon, R. Goodings, H.J. Lee, B. Martin, A. Vanelli-Coralli, *A vision on standardisation role in future Mobile Satellite Systems* IEEE COMSOC, SSC Newsletter, Vol. 17, No. 1, June 2007, pp.8-10.

[4] S. Scalise, L. Castanet, M. Luglio, M. Neri, et al., "Satellite Channel Impairments", in *Digital Satellite Communications* edited by G.E. Corazza, Springer, 2007.

[5] E. Lutz, M. Werner, and A. Jahn, *Satellite Systems for Personal and Broadband Communications*, Springer, 2000.

[6] S. Scalise, H. Ernst, and G. Harles, "Measurement and Modelling of the Land Mobile Satellite Channel at Ku-Band", *IEEE Transactions on Vehicular Technologies*, to appear in Januray 2008.

[7] F. Perez Fontan, M.A. Vazquez Castro, C. Enjamio Cabado, J. Pita Garcia, E. Kubista, "Statistical modelling of the LMS channel", *IEEE Transactions on Vehicular Technology*, vol. 50, pp. 1549–1567, Nov. 2001.

[8] S. Scalise, R. Mura, and V. Mignone, "Air Interfaces for Satellite Based Digital TV Broadcasting in the Railway Environment", *IEEE Transactions on Broadcasting*, vol. 52, no. 2, pp. 158–166, 2006.

[9] W. Li, C. Look Law, V.K. Dubey, and J.T. Ong, "Ka-Band Land Mobile Satellite Channel Model Incorporating Weather Effects", *IEEE Communications Letters*, vol. 5, no. 5, May 2001.

[10] *TM Synchronization and Channel Coding*, CCSDS recommendation, 101.0-B.1, Blue Book, Issue 1, Sep. 2003.

[11] *Low density parity check codes for use in near-earth and deep space applications*, CCSDS experimental specification, 131.1-O.1, Orange Book, Issue 1, Aug. 2006.

[12] ETSI EN 302 307, v. 1.1.2 *Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for broadcasting, interactive services, news gathering and other broadband satellite applications*, June 2006.

[13] ETSI EN 301 790, v. 1.4.1 *Digital Video Broadcasting (DVB): Interaction channel for satellite distribution systems*, Sep. 2005.

[14] ETSI TR 102 525, v. 1.1.1 *Satellite Earth Stations and Systems (SES); Satellite digital radio (SDR) service; Functionalities, architecture and technologies, Technologies for the radio interface*, Sep. 2006.

[15] *System specifications for satellite services to handheld devices (SH) below 3 GHz*, DVB document A110, Bluebook, Mar. 2007.

[16] F. H. P. Fitzek and M. D. Katz (edited), *Cooperation in Wireless Networks: Principles and Applications*, Springer, 2006.

[17] J. N. Laneman and G. W. Wornell, *Distributed space–time coded protocol for exploiting cooperative diversity in wireless networks*, IEEE Trans. Inf. Theory, vol. 49, no. 10, pp. 2415–2525, Oct. 2003.

[18] Caire G, Debbah M, Cottatellucci L, De Gaudenzi R, Rinaldo R, Mueller R, Gallinaro G. *Perspective of adopting interference mitigation techniques in the context of broadband multimedia satellite systems*, Proceedings of AIAA Conference, Rome, Italy, September 2005.

[19] J.P. Millerioux, M.L. Boucheret, C. Bazile and A. Ducasse. *Iterative interference cancellation and channel estimation in multibeam satellite systems*, Wiley IJSCN, vol. 25, p. 263-283, 2007.

[20] N. Noels, V. Lottici, A. Dejonghe, H. Steendam, M. Moeneclaey, M. Luise, and L. Vandendorpe. *Theoretical framework for soft information based synchronization in iterative (turbo) receivers*, EURASIP J. Wireless Commun. Netw. (JWCN), vol. 2005, no. 2, pp. 117-129, Apr. 2005.

[21] Roberto Lopez-Valcarce, Carlos Mosquera and Wilfried Gappmair. *Iterative envelope-based SNR estimation for nonconstant modulus constellations*, in VIII IEEE Workshop in Signal Processing Advances for Wireless Communications, 2007.

[22] Godtmann, S., Hadaschik, N., Steinert, W., Pollok, A., Ascheid, G. and H. Meyr. *Coarse and Turbo Synchronization: A Case-Study for DVB-RCS*, in NEWCOM-ACoRN Workshop, Vienna, Austria, Sept. 2006.

[23] Marco Villanti, Claudio Palestini, Raffaella Pedone and Giovanni E. Corazza. *Robust Code Acquisition in the Presence of BOC Modulation for Future Galileo Receivers*, IEEE ICC 2007, Glasgow, UK.