Uplink Reference Signal Design for LTE Compatible GEO Multiple-beam Mobile Satellite Communication System

Ying Si*, Ming Ma*, Yadan Zheng*, Shubo Ren*, Jianjun Wu*

*Satellite and Wireless Communication Lab, School of Electronics Engineering and Computer Science, Peking University, Beijing 100871, China

siying@pku.edu.cn, just@pku.edu.cn

***Abstract*—For 3GPP long term evolution (LTE) uplink, reference signal (RS) is an important kind of physical signal which is primarily used for demodulation and channel sounding. However, in the multiple-beam satellite environments, the inter-beam and intra-beam interference will break the orthogonality of uplink RS (UL-RS) from different user equipments (UEs), resulting in system performance degradation. In this paper, according to the characteristics of the satellite channels and inter/intra-beam interference, we analyze the compatibility problem, calculate the available capacity for the existing UL-RS in multiple-beam satellite environment, and propose a novel uplink RS scheme which includes UL-RS sparsing, OCC scrambling and resource configuration for LTE compatible GEO multiple-beam mobile satellite communication system. Simulation results prove the effectiveness of the proposed UL-RS scheme.**

***Keywords*—Design, Multi-beam, Satellite, UL-RS**

I. INTRODUCTION

The modern satellite communications trends to install the high-speed communications system, as well as has the features of broadband, mobile, broadcast[1]. However, the mobile satellite system (MSS) has been treating more and more by the industry recently as an extension of the terrestrial cellular mobile networks, instead of being a powerful rival. This trigs the convergence of satellite and terrestrial communications systems. The higher level integration of satellite component with the terrestrial networks, such as system level or network level, usually requires similar or compatible air interfaces, especially the physical layers. Anyway, the commercial satellite industry usually adopted those technologies of its terrestrial counterpart, mainly due to the rapid and successful development of the later.

The trajectory of wireless transmission technology development in MSS is same to the terrestrial system: from the 2G system based on TDMA to the 3G system based on CDMA [4]. The compatibility of the satellite system with existing terrestrial 3G system and some possible improved schemes are discussed in [5][6][7]. Along with the development of the terrestrial mobile communication system, the research of the 4G technology in MSS has begun [8]. The important role of satellite communications in 4G networks has been analyzed [15][16], and the availability of the 3GPP LTE/WiMAX adaptation for mobile broadband satellite communications has also been thoroughly evaluated [17][18][19]. Although several LTE physical layer adaptation problems were discussed in previous works, including uplink synchronization, random access, interleaving, adaptive modulation and coding, etc., there still remain some issues undiscussed. One among them is the uplink reference signal adaptation to the MSS environment, which is responsible to the coherent demodulation, channel quality detection of MSS uplinks. Research about UL-RS compatibility and performance in the satellite environment is not found till now.

In a typical GEO mobile satellite system, a multi-beam antenna will be employed to increase the total system capacity [2]. The beams of the MSS system serve as the cells of the terrestrial cellular system. But unlike the terrestrial cells, the signals from different beams in satellite system will meet together at the satellite transponder, and then be transmitted to the same gateway. This configuration results in more large inter-beam interference [3]. Consequently, the direct adaptation of LTE UL-RS into MSS system will possibly become inefficient or even deteriorated.

In this paper, we set out from UL-RS configuration in terrestrial LTE specification, and consider the special interference environment and resource constraints in satellite system. The compatibility of terrestrial LTE UL-RS in satellite environment is studied, and the available capacity under existing configuration is discussed. On this basis, an improved MSS UL-RS scheme is proposed, which is somehow compatible to its terrestrial counterpart. Simulation results show that the proposed scheme can improve the UL-RS performance in satellite environment, which verifies the effectiveness and the usability of the design.

Section 2 describes the system consideration in this paper, including current LTE UL-RS configuration, system model and UL-RS adaptability analysis. Section 3 proposes a novel design of UL-RS, which can apply to multiple-beam satellite system. In section 4, the simulation system is designed and the simulation results are analyzed. Finally section 5 presents a summary of the whole paper.

II. System Consideration

In current LTE R8 specifications, two kinds of UL-RS: DeModulation RS (DMRS) and Sounding RS (SRS) are defined. Considering the changes in the channel environment in Mobile Satellite System (MSS), especially the increasing of interference level, the system UL-RS performance is decreased, which cannot meet the MMSCS requirements.

A. LTE UL-RS configuration

Existing UL-RS in LTE R8 can be divided into DMRS and SRS according to its functions. There are several differences between the two types. Firstly, DMRS is mainly used for channel estimation in coherent demodulation, while SRS is adopted for channel quality detection in uplink frequency selective scheduling. Secondly, the ZC sequence with cyclic shift (CS) is used for both SRS and DMRS. CS is used to guarantee orthogonality in code domain and comb for frequency domain. The available CS number is 12 for DMRS and 8 for SRS. Users, who occupy different combs, are using different frequency domain resources that are ideally orthogonal. Finally, in time domain, DMRS occupy the middle SC-FDMA symbol in a regular slot, while the available SC-FDMA symbol for SRS are last one in regular slot or two symbols in special slot. More details can be found in [9]. Physical resource allocation of UL-RS is listed in Figure. 1.

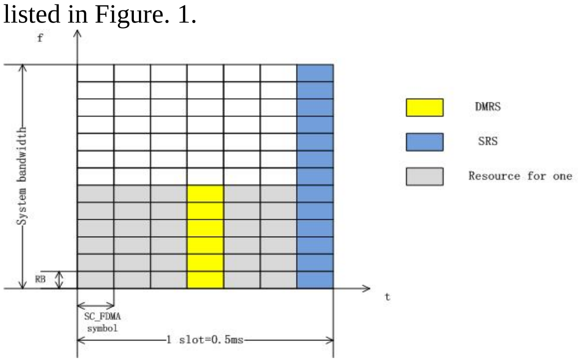

Figure. 1 LTE R8 UL-RS physical resource allocation

B. MSS system description

GEO satellite communication system consists of UEs, GEO satellites, and gateway stations. For simple exchange mode, the satellite only play as a transponder and will not deal with data. Air interfaces consist of connections from UEs to satellites and from satellites to gateway stations. Both of the two kinds of interfaces can use the same specifications, which will not be distinguished here.

For MMSCS, interference, which needs to be overcome and eliminated, is an important factor which leads to system performance degradation. Interference can be divided into intra-beam and inter-beam by different interference source. The inter-beam and intra-beam interference model are introduced here, the uplink interference model is shown in Fig.2.

For uplink intra-beam interference, the interference source is users which are allocated in same time and frequency resource in same beam. Furthermore, in satellite system, channel model can be regarded as LOS condition, distances between satellite and users in same beam are more or less the same. In sum, we consider the ideal situation that all users within the same beam suffer a same large scale fading value which is calculated in [10].

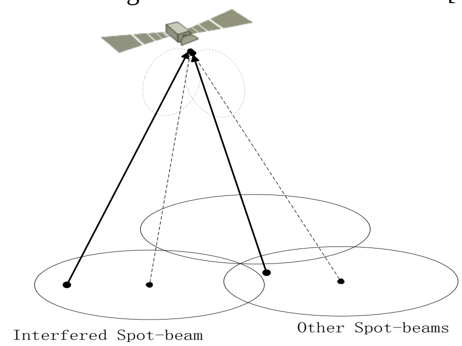

Figure. 2 Uplink interference model in MMSCS

For uplink inter-beam interference, we use the model which is introduced by [3][11][12][13]. In details, this model determines the inter-beam interference value by calculating an inter-beam interference factor k. According to the above model, we approximately consider the inter-beam interference for UL-RS as local noise power multiplying by k value. The specific calculation processing of k value can be found in [13]. In case of frequency reuse factor is 1, the k value is 1.366.

C. UL-RS adaptability

In line with the interference model, the UL-RS in MMSCS suffers inter-beam and intra-beam interference, which break the orthogonality among different UEs. The broken orthogonality leads to bad effect on system performance, along with capacity and coverage issues. For LTE R8 specifications, considering frequency and code domain, the available UL-RS capacity is CS number multiplying comb number in an ideal situation, which is 12 for DMRS and 16 for SRS. However, due to inter-beam and intra-beam interference in the multiple-beam satellite environment, the actually available number of users is less than the theoretical calculations. The simulation results in chapter 4 also prove this adaptability analysis, which means the current LTE R8 UL-RS design cannot meet the MMSCS demands, improvement and redesign is required.

III. Proposed MSS UL-RS Scheme

For UL-RS in MMSCS, interference is the main factor which is responsible for performance degradation. Therefore, we can improve system performance by redesign UL-RS, eliminate interference and enhance the ability to resist interference. The following part focuses on novel design of UL-RS to reduce the impact of inter-beam and intra-beam interference. In LTE system, the available physical resource includes time, code and frequency three domains. The issues which are considered are how to design UL-RS on these three dimensions to improve system performance.

A. UL-RS sparsing

In MMSCS, comparing to terrestrial channel, satellite channel has the characteristics that includes stronger LOS path and longer coherence time [14]. It means that the satellite channel environment changes more slowly than terrestrial system. In terrestrial system, channel estimation should be done in each slot due to the rapid changes in channel parameters. UL-RS resource in different slots cannot be integrated. However, as mentioned earlier, the low frequency of satellite channel variation ensure the channel estimation result can be maintained over an extended period with little difference between the actual channel, which provides possibility of using UL-RS resource in several slots to overcome inter-beam interference.

The UL-RS sparsing scheme is shown as Figure. 3. After using this scheme, we can obviously increase the resource utilization, resulting to an improvement of system performance.

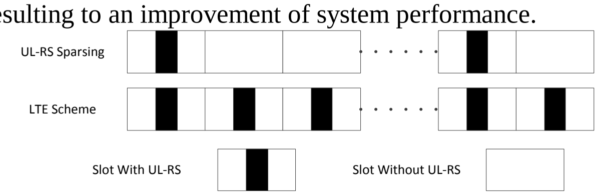

Figure. 3 New UL-RS sparsing scheme

B. OCC Scrambling

Inter-beam interference is an important factor which leads to UL-RS performance degradation. According to the inter-beam interference model which is described in chapter 2, the effects from other beams can be seen as background noise, which makes the main purpose of interference cancellation mechanisms is to raise the receiver SNR. On the condition that the signal transmission power is limited, the above issue is equivalent to how to reduce uplink receiver background noise.

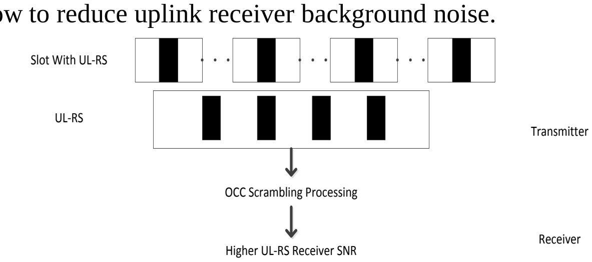

Figure.4 OCC scrambling processing

Based on the above discussion, this paper presents an OCC scrambling scheme to improve UL-RS performance. We add OCC to the original UL-RS sequence as scrambling code, reduce the equivalent receiver noise and improve system performance. Detailed derivation and parameter selection are listed below. The scrambling processing is listed in Fig. 4.

We select OCC of length 2 as C = [1,-1] and UL-RS sequence as S. On condition without OCC, the noise is n, receiver signal is R_o and receiver SNR is SNR_o. For condition with OCC, noise in different slot is n_1 and n_2, receiver signal is R_n and receiver SNR is SNR_n.

$$R_o = S + n; \tag{1}$$

$$SNR_0 = P_s / P_n; \tag{2}$$

$$R_n = \{\{[S \times C(0)] + n_1\} \times C(0) + \{[S \times C(1)] + n_2\} \times C(1)\} / 2 \\ = S + (n_1 - n_2)/2; \tag{3}$$

$$SNR_n = P_s / P_n = SNR_0 \times 1/2; \tag{4}$$

Through the above derivation, we can get the result that after using OCC code of length 2, the equivalent noise at the receiver has a 3dB reduction, which is equal to a 3dB improvement of system SNR. Similarly, the receiver SNR raises 6dB when we deploy an OCC of length 4. The longer OCC code we use the better SNR and system performance we achieve. However, taking into account the channel variation situation, channel estimation accuracy, processing complexity and delays issues, trade-off with the system improvement results, we choose the OCC code as [1,-1,1,-1], which is used for 4 consecutive slots. It is clear that the advantage of OCC scrambling is the improvement of receiver SNR and channel estimation performance.

TABLE I New Design of UL-RS Configuration

Parameters	SRS	DMRS
CS(Old)	8	12
CS(New)	4	6
comb(Old)	2	1
comb(New)	4	2
Available Resource(Old)	8 × 2 = 16	12 × 1 = 12
Available Resource(Old)	4 × 4 = 16	6 × 2 = 12

C. Resource configuration

In addition to inter-beam interference, the presence of intra-beam interference also greatly affects the performance of UL-RS. Unlike inter-beam interference, intra-beam one is mainly owing to the non-orthogonality among different users. Therefore, in this case we should design an interference cancellation mechanism which can maximize the orthogonality among different user signals without the influence on system capacity and coverage issues.

Compared with the terrestrial environment, the satellite receiver SNR is lower, which means that on the condition that the UL-RS sequence from different users are not orthogonal, the intra-beam interference will lead to larger performance degradation. In current UL-RS configuration, frequency domain orthogonal is better than code domain. Therefore, we design a frequency and code domain combined parameters design scheme to eliminate the intra-beam interference. In details, on one hand, we reduce the existing CS number for UL-RS to increase the code domain interval and orthogonality. On the other hand, adjust the comb number in frequency domain to ensure the available resource is fixed. However, large comb number has bad effect on frequency domain channel estimation accuracy, available UL-RS length and base sequence number, leading to a limitation of comb increasing. In conclusion, we change half the CS and twice the comb comparing to the original configuration for both DMRS and SRS. The specific configuration changes and available resources number are shown in Table. 1.

In case of ideal orthogonal circumstances and one SC-FDMA symbol, available physical resources for DMRS and SRS are 12 and 16. The calculation results are unchanged after modifications in this paper. It is to say that the available system capacity will not decrease for the worst case. However, the orthogonal between different resources in the original configuration is poor; resulting in not all capacity can be used. The new design can greatly improve the actual available resources. For coverage issue, the performance is related to receiver SNR, which has been improved by the inter-cell interference cancellation method. Therefore, the novel design has good effect on both capacity and coverage problem, which is satisfactory and usable.

IV. Simulation and Results

For UL-RS performance analysis in MMSCS and verification of above design and discussion, we set up a simulation system as the following Fig.5. The system include modules such as initialization, multi-beam scenario generation, UL-RS resource allocation and sequence generation, add channel, channel estimation and statistical results. The simulator is based on the new design of UL-RS, using wideband satellite channel model in ITU R.M. 1225 and DFT algorithm for channel estimation. DMRS and SRS are both contained in this system. The channel estimation results for different situation using the above simulator are listed below.

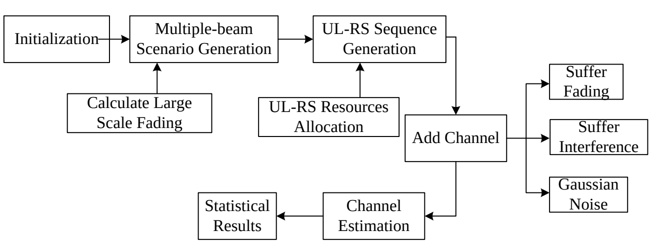

Figure. 5 System simulation model

For the existing LTE R8 DMRS and SRS configuration, Fig.6 and Fig.7 show the channel estimation results under three different situations: without interference, with intra-beam interference and with inter-beam interference. The results show that the channel estimation results cannot fit the system demands in the case of no interference is added. Furthmore, after considering the inter-beam and intra-beam interference, the system performance has dropped significantly, which means that some new design and improvement are needed for multi-beam satellite system. The new scheme should be able to reduce the current interference level or the impact of interference on system performance.

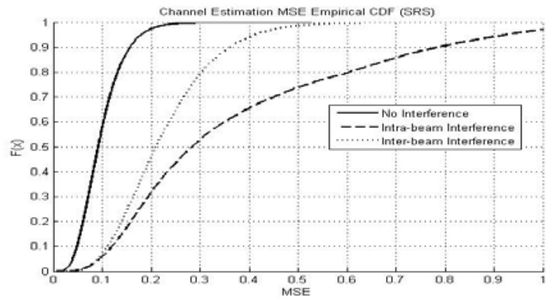

Figure.6 SRS channel estimation results under different interference type

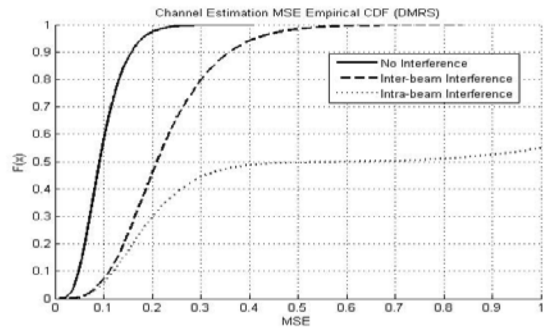

Figure. 7 DMRS channel estimation results under different interference type

Fig.8 and Fig.9 present the inter-beam interference cancellation performance for DMRS and SRS. The inter-beam interference cancellation method brings a large performance improvement. The longer OCC is added, the better channel estimation performance we get. The system performance has been ideal to verify the discussion in chapter 3 when the length of OCC is 4. Therefore, we choose the OCC length as 4, which can eliminate the uplink inter-beam interference, guarantee the system performance.

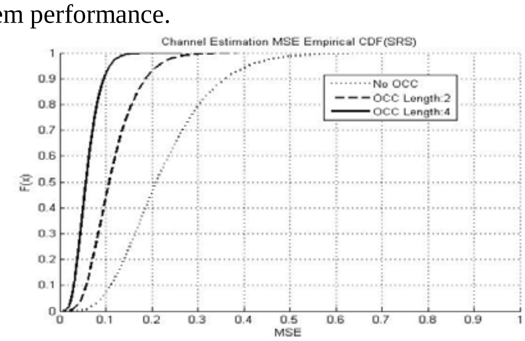

Figure. 8 SRS channel estimation results for inter-beam interference cancellation

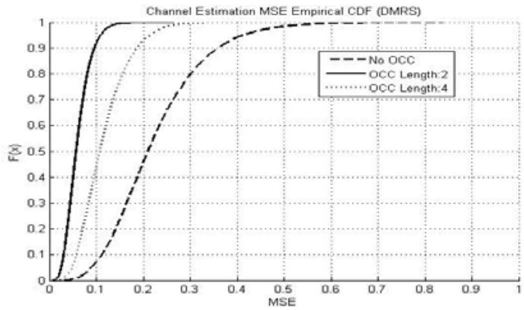

Figure. 9 DMRS channel estimation results for inter-beam interference cancellation

From Fig.10, we can obtain the intra-beam interference cancellation performance for both SRS and DMRS. After using the new design, we get a significant system performance gain without affecting the theoretical available resources capacity, which prove the feasibility and effectiveness of the intra-beam cancellation design.

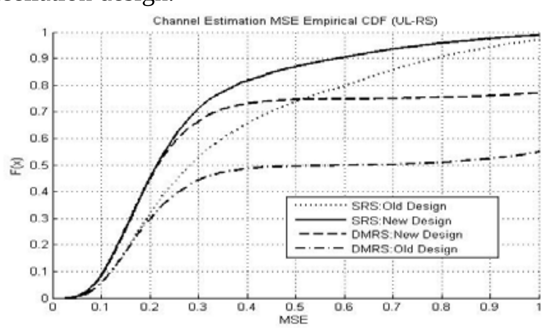

Figure 10 UL-RS channel estimation results for intra-beam interference cancellation

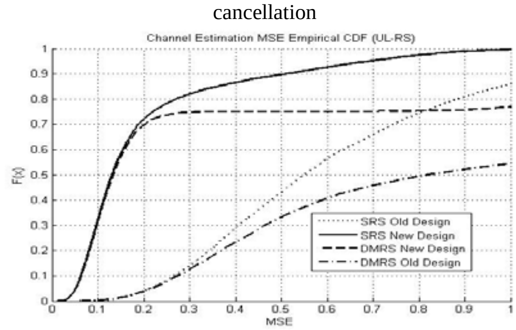

Figure. 11 UL-RS channel estimation results for new design

Combining the inter-beam and intra-beam interference, the system channel estimation performance for LTE R8 configuration and the novel design in this paper are listed in Fig.11, both SRS and DMRS are included. The simulation and analysis results show that after deploying the new design, an obvious improvement is achieved for channel estimation performance, capacity and coverage aspects and basically no complexity and processing difficulty is added. Therefore, according to the above simulation and discussion, we conclude the conclusion that the new viable and valid design in this paper can greatly improve the UL-RS performance in GEO multiple-beam mobile satellite communication system.

V. Conclusion

For MMSCS, UL-RS is used to estimate and detect uplink channel, uplink data demodulation and uplink frequency domain scheduling. However, channel environment in MMSC is different from terrestrial system. The large intra-beam and inter-beam interferences make the orthogonality of different users' UL-RS worse, which will affect channel estimation and channel detection and decrease the system performance. In this paper, the compatibility of the LTE R8 UL-RS configuration with satellite environment and its theory capacity are calculated and analyzed. The capacity and cover problems are put forward when UL-RS are used in satellite system. Then we propose a novel UL-RS scheme to eliminate intra-beam and inter-beam interference, and improve the capacity and coverage. Finally simulation results are presented, which prove that UL-RS configuration in LTE R8 cannot be used in multiple-beam satellite system directly. Simulation results also show that the proposed design can improve the performance and meet the requirement. These results are not only significant reference for multiple-beam mobile satellite communication system design compatible with LTE specification, but also lay a foundation for further top layers study.

Acknowledgment

This work is supported by the National Science Foundation of China (Grant No. NFSC #61071083) and the National High-Tech Research and Development Program of China (863 Program), No. 2012AA01A506. Corresponding author: Jianjun Wu; Phone: +86-10-62752848; E-mail: just@pku.edu.cn.

References

[1] Mohamed Ibankahla, Quazi Mehbubar Rahman, Ahmed Iyanda Sulyman, Hisham Abdulhussein Al-asady, Jun Yuan, Ahmed Safwat, "High-Speed Satellite Mobile Communications: Technologies and Challenges." , Proceeding of the IEEE, Vol.92, No.2, Feb, 2004.

[2] P.D. Patel, C.Eng., K.K.Chan, "Optimisation of controured beams for satellite antennas", IEE Proceedings, Vol.132, Pt. H, No.6, Oct, 1985.

[3] A.J. Viterbi, A.M. Viterbi and E. Zehavi, "Other-cell interference in cellular power-controlled CDMA", IEEE Trans. on Common., vol. 42, pp. 1501-1504, Feb. /March/April 1994.

[4] ETSI. "Satellite Earth Stations and Systems (SES); Satellite component of UMTS/IMT-2000; General aspects and principles [S].", ETSI TR 101 805v1.21, 2002

[5] Jianjun Wu, Shubo Ren, Xi Luan, Xiaoyan Xu, and Yuxin Cheng, "Scheme of Uplink Synchronization for Mobile Satellite system compatible with TD-SCDMA frame", The 7th Forum of New Technology and Service in Satellite Communication, Beijing, 2011.3, pp. 185-194

[6] Jian Guo, Shubo Ren, Xiaoyan Xu, and Jianjun Wu, "Uplink Capacity Analysis of GEO Satellite Mobile Communication System Compatible with TD-SCDMA", ICCNT 2011, pp.247-251.

[7] Ying Si, Xi Luan, Shubo Ren and Jianjun Wu. "An Interleaver Scheme for TD-SCDMA Compatible GEO Satellite Communication System", ICIST 2011, pp. 627-630.

[8] Arif A, Dutta S, Tseytlin M. “S-Wimax: Adaption of IEEE 802.16e for Mobile Satellite Services [J].”, IEEE Communications Magazine, 2009, 47(6)，pp:150-155.

[9] 3GPP Technical Specification 36.211, “Evolved Universal Terrestrial Radio Access(E-UTRA); Physical Channels and Modulation (Release 8)”, www.3gpp.org

[10] Wu Shiqi, Feng Kai, “Link Budget Margin of Mobile Satellite Communication System”， Telecommunication bulletin, 1995.12.

[11] “Satellite antenna patterns in the fixed-satellite service”. CCIR report 558-3 (MOF F), Nov. 1989.

[12] Kilic, O., “Interference Analysis for Spot Beam Partitioning in Cellular Satellite Communication System”, Antennas and Propagation Society International Symposium, 2008. AP-S 2008. IEEE, pp. 1-4.

[13] Jian Guo, Shubo Ren, Ying Si, Jianjun Wu. “Analysis of Other Spot-beam Interference in TD-SCDMA Compatible Satellite System”. International Conference on Wireless Communications and Signal Processing, WCSP2011.

[14] Sadowsky, John S. Lee, David K. “The MUOS-WCDMA air interface”, Military Communications Conference, 2007. MILCOM 2007, IEEE, pp: 1-6.

[15] E. Corbel, I. Buret, J.-D. Gayrard, G.E. Corazza, A. Bolea-Alamanac, “Hybrid Satellite & Terrestrial Mobile Network for 4G : Candidate Architecture and Space Segment Dimensioning,” Advanced Satellite Mobile Systems, 2008. ASMS 2008. 4th, pp.162-166, Aug. 2008.

[16] ESA technical report, “Final Report: Study of Satellite Role in 4G Mobile Networks,” May 2009.

[17] Francesco Bastia, et al., “LTE Adaptation for Mobile Broadband Satellite Networks,” EURASIP Journal onWireless Communications and Networking, Volume 2009, pp.1-13, Mar. 2009.

[18] Arif Ansari, et al., “S-WiMAX: Adaptation of IEEE 802.16e for Mobile Satellite Services,” IEEE Communications Magazine, pp.150-155, Jun. 2009.

[19] Hee Wook Kim, Tae Chul Hong, Kunseok Kang, Bon Jun Ku, Sooyoung Kim and Sungmoon Yaeo, “A Satellite Radio Interface for IMT-Advaced System Using OFDM”, ICTC 2010, pp.303-308.