A Satellite Radio Interface Compatible with Terrestrial 3GPP LTE System

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Abstract. In this paper, a candidate satellite radio interface, satellite orthogonal frequency division multiplexing (SAT-OFDM), for the satellite component of IMT-Advanced is presented. The SAT-OFDM is based on long term evolution (LTE) terrestrial radio interface for maximum commonality with IMT-Advanced terrestrial radio interface. This paper deals with the configuration and performance of the 3GPP LTE based satellite radio interface. And then, as an enhancement of the satellite-specific radio interface, it addresses the possible adaptation of 3GPP LTE to the satellite in order to maximize the performance over satellite link.

Keywords: mobile satellite system, OFDM, LTE, radio interface.

1 Introduction

Considering cost-effective, in a future IMT-Advanced satellite system, a satellite radio interface needs to be compatible with a maximum degree of commonality with emerging terrestrial standards. Therefore, the techniques adopted for the satellite system have to be similar to or even the same as those of the terrestrial system. The adaptation of a compatible radio interface with maximum commonality will result in possibility to reuse terrestrial component technology to minimize the change of user equipment (UE) chipset and network equipment for low cost and fast implementation.

As emerging terrestrial radio interfaces, the third generation partnership project (3GPP) long term evolution (LTE) and the institute of electrical and electronics engineers (IEEE) mobile worldwide interoperability for microwave access (WiMAX) radio interfaces are being considered [1]. Both two radio interfaces adopted orthogonal frequency division multiplexing (OFDM) scheme, which is intrinsically able to manage the most typical radio frequency distortion without the help of complex equalization techniques and has scalability easily to fit different bandwidth [2]. There had not been much attention to the study on OFDM based satellite radio interfaces because of severe peak to average power ratio (PAPR) problems, considering a high cost power amplifier in satellite systems. Nevertheless, recent study results reported the

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adaption of OFDM technique in the satellite systems to give benefits such as capability of high data rate transmission and commonalities with the terrestrial systems.

In this regards, the satellite orthogonal frequency division multiplexing (SAT-OFDM) is being developed as a candidate satellite radio interface to provide various IMT services over satellite environments. The radio interface can be applied for Geo-stationary earth orbit (GEO) satellite for the provision of global IMT service. It adopts orthogonal frequency division multiple access (OFDMA) for downlink and single carrier frequency division multiple access (SC-FDMA) for uplink. The radio interface has a high degree of commonality with the terrestrial radio specifications, 3GPP long term evolution (LTE) technology for IMT-Advanced services, but it also has many different features. Those features are inevitable to consider the satellite-specific characteristics such as long round trip delay and slow fading satellite channel, and are implemented in the form of random access, interleaving, power control and so on. Furthermore, the radio interface has two operational modes which are expressed as normal and enhancing modes. The normal mode is fully compatible with 3GPP LTE Release 8, while the enhancing mode provides performance enhancement by incorporating new satellite-specific features. The satellite radio access network (RAN) should support both modes while the UE can support either the normal mode only or both modes.

This paper first address brief IMT-Advanced system description using the SAT-OFDM radio interface in Section 2. A detail introduction of the SAT-OFDM is presented in Section 3. Then some satellite-specific features defined in the enhancing mode of SAT-OFDM are introduced as the possible further enhancements to its normal mode. In Section 4, we demonstrate performance of the SAT-OFDM in normal mode in order to validate the feasibility of 3GPP LTE as a satellite radio interface. Finally, we will draw conclusions in Section 5.

2 Satellite IMT-Advanced System Using the SAT-OFDM

2.1 Architectural Description

Figure 1 describes an overall system architecture using the SAT-OFDM. The satellite will provide various mobile services similar to those of terrestrial IMT systems outside terrestrial and complementary ground component (CGC) coverage under the intrinsic limitations induced by transmit power and long round trip delay constraints. On the other hands, the CGC can be deployed in regions where satellite signal is hard to be received, particularly in urban areas in order to provide mobile satellite broadcasting/multicasting services. It can be collocated with terrestrial base station sites for the cost-effective deployment. The satellite component can provide voice and data communication service in regions outside terrestrial coverage. The areas not adequately covered by terrestrial component include physically isolated regions, gap of terrestrial component and areas where terrestrial component permanently, or temporarily, collapses due to disaster.

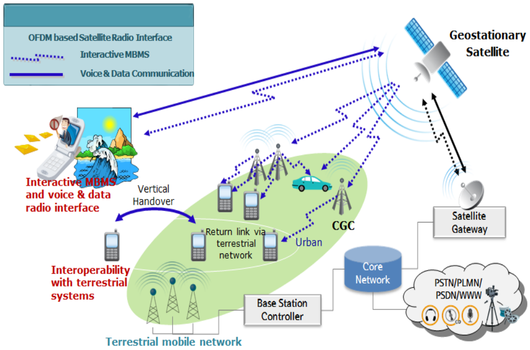

Fig. 1. IMT-Advanced system concept using SAT-OFDM

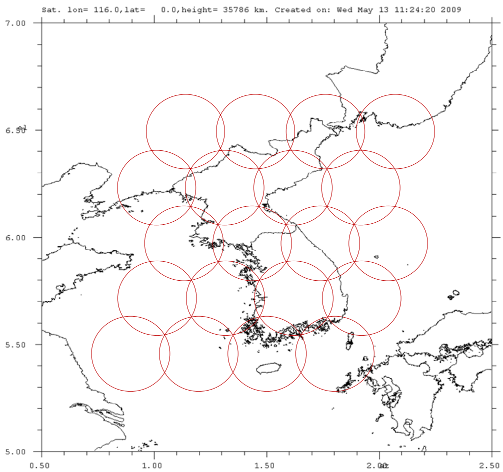

Fig. 2. Multi-beam configuration example with a 24m satellite antenna

The two way communication scenario is regarded as coverage extension and service continuity of the terrestrial part. In the scenario, handover technique with terrestrial part would be most importantly considered. For the cost-effective interworking, future satellite radio interfaces should be compatible as well as have maximum common functionality with an envisaged LTE based terrestrial radio system. Also, terrestrial part technology can be reused to decrease user equipment (UE) chipset and network device for fast and low-cost development. In addition, the SAT-OFDM can be used to provide efficient interactive multimedia broadcasting services since the envisaged terrestrial mobile radio interfaces can handle services for broadcast as well as a bi-directional communications in a cellular system. Indeed, the satellite component has an advantage of efficiently delivering the same content over worldwide geographical area.

This interface is able to deal with several satellite constellation types, i.e. low earth orbit (LEO), medium earth orbit (MEO), GEO or highly elliptical orbit (HEO). It is noted, however, descriptions in the following sections are mostly based on the GEO constellation type. Several architectures are envisaged depending on throughput requirements e.g. global beam, multi-beam, and multi-satellite configurations. The example in Fig. 2 assume multi-beam configuration over Korean coverage.

2.2 System Description

The SAT-OFDM based on the key technical characteristics listed in Table 1 could provide a wide range of telecommunication services in ITU-R Recommendation M.1822 to mobile users [3]. Quality of service (QoS) for various telecommunication services supported by the radio interface would be different from that in the terrestrial component of IMT-Advanced due to inherent satellite features such as long round trip delay. In this interface, maximum transfer delay of one way of the real time services at the bearer transport level could be less than 400 ms in the range of values $1x10^{-2}$ to $1x10^{-7}$ of bit error rate (BER).

The user equipment may be of various types: handheld, portable, vehicular, transportable or aeronautical. The data rate and mobility restriction for each type of terminal are described in Table 3. For the maximum capacity assessment it is necessary to distinguish data rates for the downlink from those of the uplink.

The SAT-OFDM will support handover of communications from one satellite radio channel to another. The handover strategy is mobile-assisted network-decided handover and only hard handover is supported. The SAT-OFDM system can support beam handover, inter-satellite handover, inter-frequency handover.

Table 1. Key characteristics of SAT-OFDM

Multiple access method	OFDMA (downlink) SC-FDMA (uplink)
Duplex	Frequency division duplexing (FDD)
Chip rate	A multiple or submultiple of 3.84 Mcps
subcarrier spacing	15 kHz
Carrier spacing	1.3, 3, 5, 10 15, 20 MHz
Frame length	10 ms
Inter-spot synchronization	No accurate synchronization needed (Accurate synchronization needed for inter-beam coordination)
Multi-rate/Variable-rate scheme	Variable modulations and coding rates + multi-layer
Channel coding scheme	Convolutional coding 1/3 Turbo coding 1/3
Multiple-access scheme	OFDMA (downlink), SC-FDMA (uplink)

3 SAT-OFDM Radio Interface

3.1 Multiple Access

Overall uplink transmission of the SAT-OFDM is described in Figure 3. The SAT-OFDM has basically the same transmission blocks with 3GPP LTE Release 8 radio interface for commonality but can also modify some blocks or add new blocks in order to adopt satellite-specific features. Its downlink transmission is same as uplink transmission except DFT and IDFT blocks.

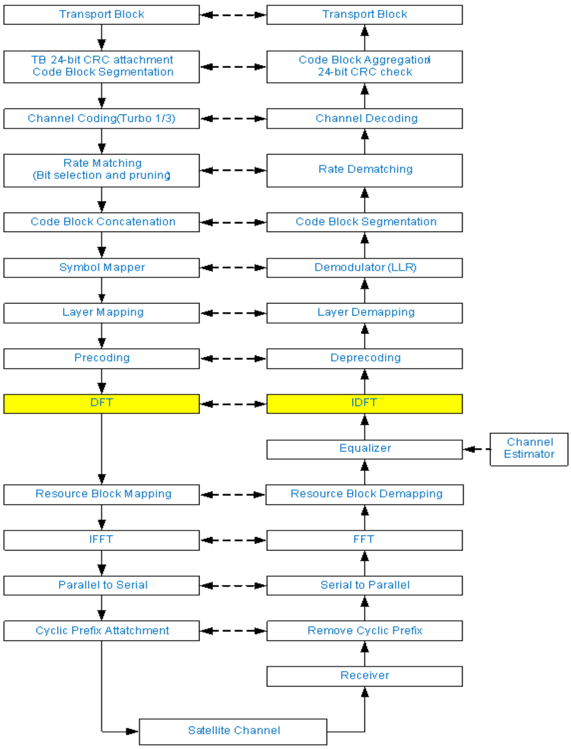

Fig. 3. Uplink transmission in the SAT-OFDM

Multiple input and multiple output antennas (MIMO) transmissions is supported with two or four satellites or two polarizations and two or four received antennas in the downlink. The MIMO transmission supports multi-layer with up to four data streams. Multi-user MIMO, in which different streams are allocated to different users, is also supported in uplink as well as downlink.

For the SAT-OFDM physical layer, the multiple access method in downlink is based on OFDM with a cyclic prefix (CP) while that in uplink is based on SC-FDMA with a CP. In addition, frequency division duplex is supported in order to support transmission in paired S-band spectrum. The bandwidth agnostic physical layer is defined based on resource block concept which allows the SAT-OFDM physical layer to adjust to various bandwidth allocations. One resource block consists of either twelve subcarriers with a subcarrier bandwidth of 15 kHz or twenty four subcarriers with a subcarrier bandwidth of 7.5kHz each during a slot interval of 0.5ms. The FDD radio frame structure consists of twenty slots with a slot interval of 0.5ms and has a frame duration of 10ms. A subframe of 1ms length is formed by two adjacent slots.

The physical channels are defined in the SAT-OFDM as followings.

- Downlink physical channels for transmission of user data and control, information
  - PDSCH (Physical Downlink Shared Channel)
  - PMCH (Physical Multicast Channel)
  - PDCCH (Physical Downlink Control Channel)
  - PBCH (Physical Broadcast Channel)
  - PCFICH (Physical Control Format Indicator Channel)
  - PHICH (Physical Hybrid ARQ Indicator Channel)
- Downlink physical signals for cell search and channel estimation
  - RS (Reference Signal)
  - SCH (Synchronization signal)

Uplink

- Uplink physical channels for transmission of user data and control information
  - PUSCH (Physical Uplink Shared Channel)
  - PUCCH (Physical Uplink Control Channel)
  - PSRACH (Physical Satellite Random Access Channel)
- Physical signals for channel estimation
  - RS (Reference Signal)

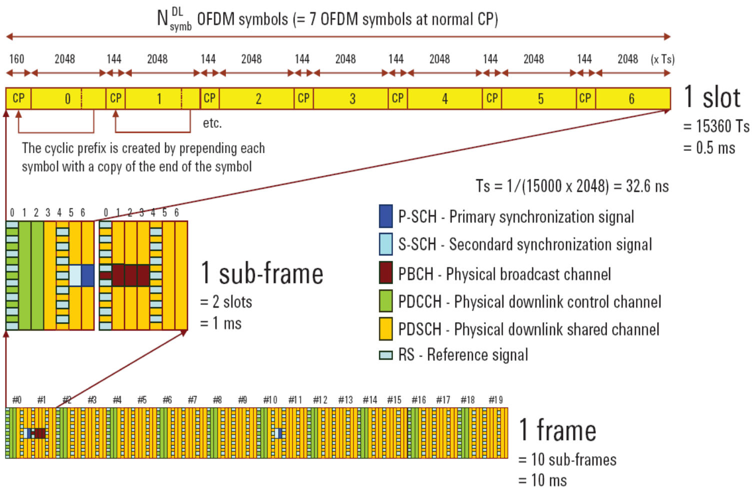

Fig. 4. Downlink frame structure of the SAT-OFDM

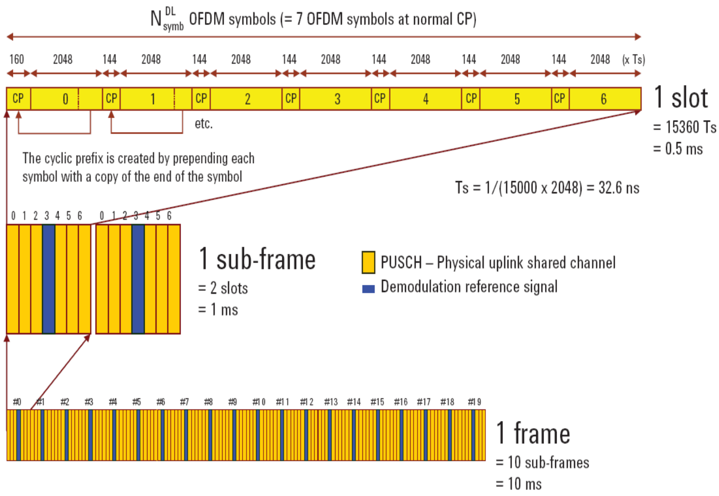

Fig. 5. Uplink frame structure of the SAT-OFDM

Figure 4 and 5 show downlink and uplink frame structure of the SAT-OFDM including whole physical channels. The smallest resource unit in both uplink and downlink transmissions is denoted as a resource element (RE). A physical channel is relevant to a set of the REs carrying information generating from higher layers. On the other hands, a physical signal is used only for the physical layer but does not accomplish information generating from higher layers.

4 Some Candidate Satellite-Specific Features for Performance Enhancement

The SAT-OFDM has a high degree of commonality with the terrestrial radio specifications based on 3GPP long term evolution (LTE) technology for IMT-Advanced services but it also has many different features. Those features are required in order to consider the satellite-specific characteristics such as long round trip delay and slow fading satellite channel. For this purpose, the following techniques can be included for enhancing mode operation.

4.1 AMC Scheme Combined with Long-Term Interleaving

This scheme can be used for an efficient adaptive modulation and coding (AMC) operation in satellite environment [4]. Adaptive transmission techniques such as AMC are applied in order to satisfy the required transmission speed and QoS. Because of a long RTD in the GEO satellite systems, the adaptive transmission technique for the satellite systems should be different from that for the terrestrial radio interface. Considering the RTD of a GEO system, the updating interval of the AMC scheme should be an order of a second, and thus the AMC of the satellite systems cannot effectively counteract to short term fading. A long time interleaving technique is used in conjunction with AMC, and it is also used to compensate the short term fading.

4.2 Cooperative Transmission between a Satellite and CGCs

This scheme is used for performance enhancement in an integrated satellite/CGC configuration [5]. The concept of system model where a cooperative diversity technique is employed is as following. The satellite transmits data to the user terminals and all ground components. In order to achieve diversity gains via utilization of space-time coding (STC) schemes, each of the ground components must convert the received signals into a pre-defined encoded signal format, and then retransmit them to the UE. The CGCs and satellite can be cooperated in order to transmit space-time coded signals. For this, the CGCs can encode the transmitted satellite signal rather than serving as simple repeaters. A UE can receive the STC-encoded signals. If the UE receives the multiple signals from CGCs as well as the satellite, then it can get STC diversity gains by using these signals. In addition, a delay compensation algorithm is needed in the cooperative scheme. Since we can estimate processing delay to convert to a pre-defined STC encoded format at the CGCs as well as propagation delay difference between the links from the satellite and CGCs, the delay compensation for the signal transmitted from the CGCs can carry out successful synchronization at the UE. A coarse and fine compensation can be made at the satellite gateway and each ground component, respectively.

4.3 Narrowband PUSCH Transmission

In satellite systems the available bandwidth is constrained due to power limited environments, particularly in uplink. This means that the bandwidth that can be dedicated to one transport block also should be constrained. The constraint can be in the constitution of fewer subcarriers. Because the transport block size for narrowband transmission should be maintained for no modification on terrestrial LTE MAC layer, the data in the transport block is better inserted in such a way that it occupies a larger number of symbols compared to the terrestrial LTE system. For this, LTE physical layer should be modified in order to reduce the size of resource block (RB) and increase of the length of transmission time interval (TTI) of terrestrial LTE. In terrestrial LTE, 1 ms of TTI is considered in order to reduce latency of service delivery and make fast resource adaptations. However, considering a satellite system has already a few hundred miliseconds of very long round trip delay and mainly suffers from slow channel fading effects, the 1ms of short TTI doesn't give any advantages in the mobile satellite systems and prevents to get a time diversity gain to compensate slow channel fading effects. Therefore, the increase of the length of TTI in the satellite system will be under a reasonable adaptation of terrestrial LTE to satellite environment [7].

5 Performance Evaluations

Satellite and UE characteristics considered in performance evaluation are summarized in Table 2 and 3, respectively. Furthermore, the Fontan's static model for the land mobile satellite (LMS) channel is considered for the link and system level simulation. This model is competent to describe both narrow- and wideband conditions. Model parameters obtained from a complete experimental data base are also given for many elevation angles and environments at around 1.5GHz and 2GHz [8]. For evaluation, the LMS 3-state Markov chain model based on the measurements parameters for open environment at 40^{o} elevation in S-band is adopted.

Table 2. Satellite multi-beam with 24m satellite antenna

Number of spot beams	20
Downlink (satellite to UE) Frequency (satellite to UE) (MHz) Polarisation On board e.i.r.p. per carrier (dBW)	2170~2200 LHCP or RHCP 73
Uplink Frequency (UE to satellite) (MHz) Polarisation Rx Antenna gain (dB)	1980~2010 LHCP or RHCP ~ 30

Table 3. UE maximum transmit power, antenna gain and eirp

UE type	**Max. transmit power**	**Ref. antenna gain**	**Max. EIRP**	**Antenna temp.**	**G/T (dB/K)**
Handset Class 1 Class 2 Class 3	 2W 500mW 250mW	 0dBi	 3dBW -3dBW -6dBW	 290K	 -33.6
Portable	2W	3dBi	5dBW	200K	-26
Vehicular	8W	4dBi	13dBW	250K	-25
Transport.	2W	14dBi	17dBW	200K	-14

Baseline configuration parameters are listed in Table 4 for simulation assessment of the SAT-OFDM. Evaluation is performed in open environment defined in ITU-R Report M.2176, which identifies visions and requirements for the satellite component of IMT-Advanced [8]. We assumed that UEs are randomly distributed over whole coverage and are located outdoor with the mobility of 3km/h. For assessment of beam spectral efficiency, beam spectral efficiency is defined in ITU-R Report M.2176 as the aggregate throughput of all users divided by the channel bandwidth as well as the number of satellite beams. Aggregate throughput means the number of correctly received bits, i.e. the number of bits contained in the service data units (SDUs) delivered to Layer 3. Also, full buffer best effort service profile is considered. VoIP capacity is drawn assuming a 12.2 kbps codec with a 50% activity factor such that outage percentage of users is less than 2%, where it is assumed that a user experience a voice outage if less than 98% of the VoIP packets is delivered successfully to the user within a one-way propagations delay about of 400 ms, considering maximum transfer delay of one way for the real-time services in the satellite component.

Table 4. Baseline evaluation configuration parameters

Parameters	Values used for evaluation
Deployment scenario	Open environment, GEO satellite
Duplex method and bandwidths	FDD: 5(Up) + 5(Down) MHz, 2.1 GHz carrier frequency
Frequency reuse plan	Reuse factor 6
Number of beams	20 (3dB of beam edge loss)
Transmission scheme	SISO
Scheduler	Channel dependent
Power control	None (allocate full power)
Link adaptation	Non-ideal based on delayed SRS-based measurements: MCS based on LTE transport formats and SRS period and bandwidths according to LTE Rel-8
HARQ scheme	Incremental redundancy or Chase combining None for VoIP traffic
Receiver type	MMSE
Satellite antenna	ITU-R Recommendation S.672, 50dBi gain
UE antenna	Omnidirectional, 0dBi gain
UE transmit power	250 mW
Channel estimation	Non-ideal
Feedback and control channel errors	None
HARQ/ARQ interaction	HARQ/ARQ interaction scheme for full buffer traffic.
MAC/RLC header overhead	Assume minimum size of specification
Layout	Hexagonal grid
Inter-site distance	180 km
Satellite system noise temperature	450 K
G/T	23.47 dB/K
Target packet error rate	1 %
Path loss	189.5 (LoS) + 2.5 (fading margin) dB

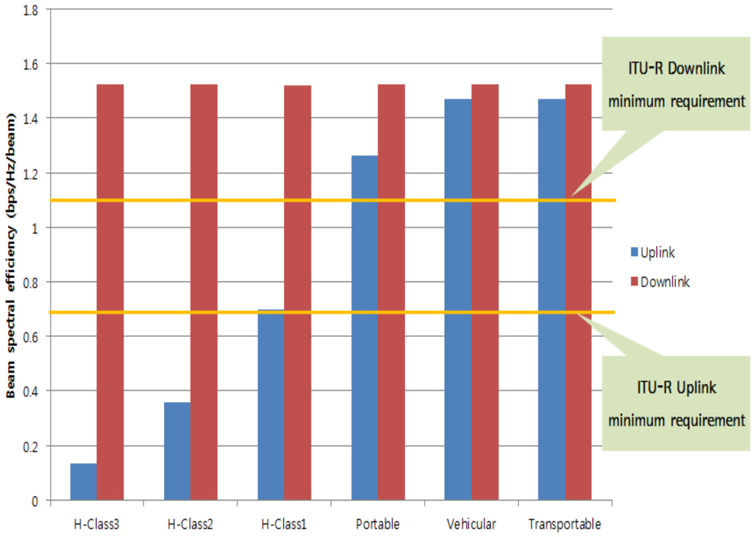

Fig. 6. Beam spectral efficiency (bps/Hz/beam)

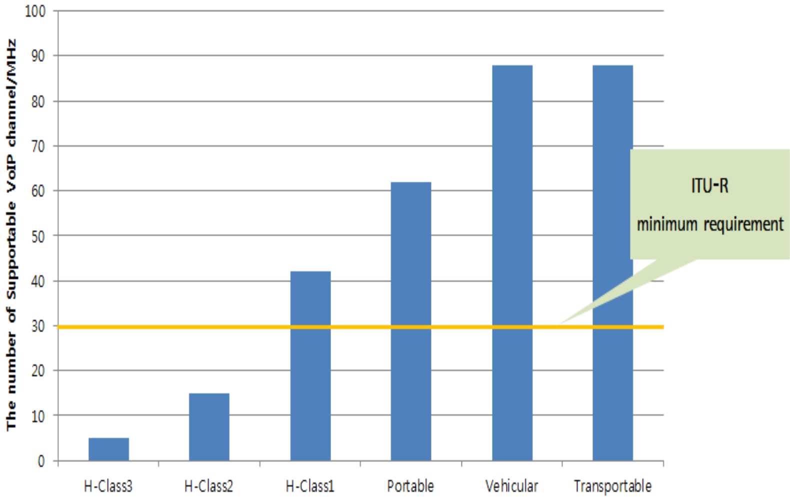

Fig. 7. Beam spectral efficiency (bps/Hz/beam)

Figure 6 and 7 show system level simulation results with respect to average beam spectral efficiency and VoIP capacity, respectively. As seen in the figures, the normal mode of the SAT-OFDM satisfies ITU-R minimum requirement for the satellite component of IMT-Advanced from the handheld class 3 UE to the transportable UE. Here, ITU-R minimum requirements are beam spectral efficiency of 1.1 in downlink and 0.7 bps/Hz/beam in uplink and the number of supported VoIP users of 30 active users/beam/MHz. On the other hands, the handheld classes 1 and 2 UEs don't provide EIRP enough to satisfy ITU-R minimum requirement. However, those UEs with low transmit power also can make performance increased in the enhancing mode of the SAT-OFDM such as narrowband PUSCH transmission [7].

6 Conclusions

In this paper, we presented the SAT-OFDM as a satellite radio interface for IMT-Advanced. It has a great degree of commonality with the 3GPP LTE based terrestrial radio interface for IMT-Advanced. With the SAT-OFDM satellite radio interface, IMT equipments realizing 3GPP LTE radio interface with widen agility in the satellite IMT frequencies can operate over satellite environments with reasonable performance. This paper also highlighted candidate enhancing features of the radio interface to improve the satellite link performance at the expenditure of a restricted change to the UE chipset. Therefore, the SAT-OFDM satellite radio interface can decrease the cost impact on satellite-enabled terrestrial UEs as well as still make sure interoperability with 3GPP cellular networks. It is expected to accelerate the smoother convergence between mobile satellite systems and terrestrial mobile systems.

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