Narrowband Uplink Transmission in LTE-based Satellite Radio Interface

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***Abstract*— In this paper, we introduce narrowband uplink transmission scheme to adapt orthogonal frequency division multiple access scheme to satellite environments. Maximizing the commonalities with the terrestrial system is one the most important factors for cost-effective service delivery, which will finally bring successful deployment of the system. For this purpose, we adopt an orthogonal frequency division multiplexing based radio interface. At the same time, the interface should be tailored in order to be operable in a power limited uplink scenario of satellite systems. In this paper, we present a narrowband uplink transmission, which was developed for this purpose, in long term evolution based satellite radio interface. Simulation results show that the proposed scheme can increase an uplink spectral efficiency at power-limited handheld terminal.**

Keywords-narrowband transmission; handheld terminal; mobile satellite communications.

I. INTRODUCTION

Considering cost-effective, in a future Mobile Satellite Service (MSS) 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 bring possibility to reuse terrestrial part technology to minimize the modification of User Equipment (UE) chipset and network equipment for low cost and fast development.

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 handle the most common radio frequency distortion without the need for complex equalization techniques and scales easily to fit different bandwidth [2].

Not much attention has been paid to the study on OFDM based satellite radio interfaces due to serious Peak to Average Power Ratio (PAPR) problems, especially for a high cost power amplifier in satellite systems. Nevertheless, recent study results reported the adaption of OFDM technique in the satellite systems to give benefits such as capability of high speed transmission and commonalities with the terrestrial systems [3]-[5]. For example, DVB-SH adopted OFDM technique [3], which is the same signal format defined in DVB-H for terrestrial systems. The main reason for adopting OFDM stems from the fact the satellite terrestrial transmitters form a Signal Frequency Network (SFN). Furthermore, European Telecommunications Standardization Institute (ETSI) has started feasibility study on OFDM based satellite radio interface, and reported that OFDM based scheme might provide better performance that the conventional Wideband Code Division Multiple Access (WCDMA) based scheme [4]. Recently, a new satellite radio interface is being developing based on the 3GPP LTE standard to maximize the commonalities with the terrestrial system using OFDM [6]. Some satellite specific technologies were proposed including frequency reuse techniques, uplink synchronization techniques, random access techniques, and interleaving technique combined with adaptive modulation and coding.

In this paper, we consider physical layer modifications to terrestrial LTE to make it operable over a satellite channel, which characteristically is power constrained. Following introduction, in Section II, we propose a narrowband uplink transmission in LTE based satellite radio interface. In Section III, we show a few simulation results and then, draw conclusion in Section IV.

II. NARROWBAND UPLINK TRANSMISSION IN LTE BASED SATELLITE RADIO INTERFACE

Mobile satellite system would be power-limited system as well as hand-held terminal has a limited maximum transmitted power. Considering that total transmitted power would be distributed over whole subcarriers in one Resource Block (RB), the large RB size of 180 kHz in terrestrial LTE makes sufficient power not be allocated on one subcarrier at handheld terminals. In this case, high modulation and coding rate scheme may not be supported. Therefore, in this paper, a narrowband RB transmission is defined in order to solve this problem. For high layer commonality, the size of transport block in the RB is same as in terrestrial LTE.

Figure 1 shows Uplink Physical Uplink Shared Channel (PUSCH) structure in order to support narrowband transmission. The PUSCH carries data from the uplink shared channel transport channel [7]. 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 form of fewer subcarriers. Because the size of the transport block for narrowband transmission should be maintained for no

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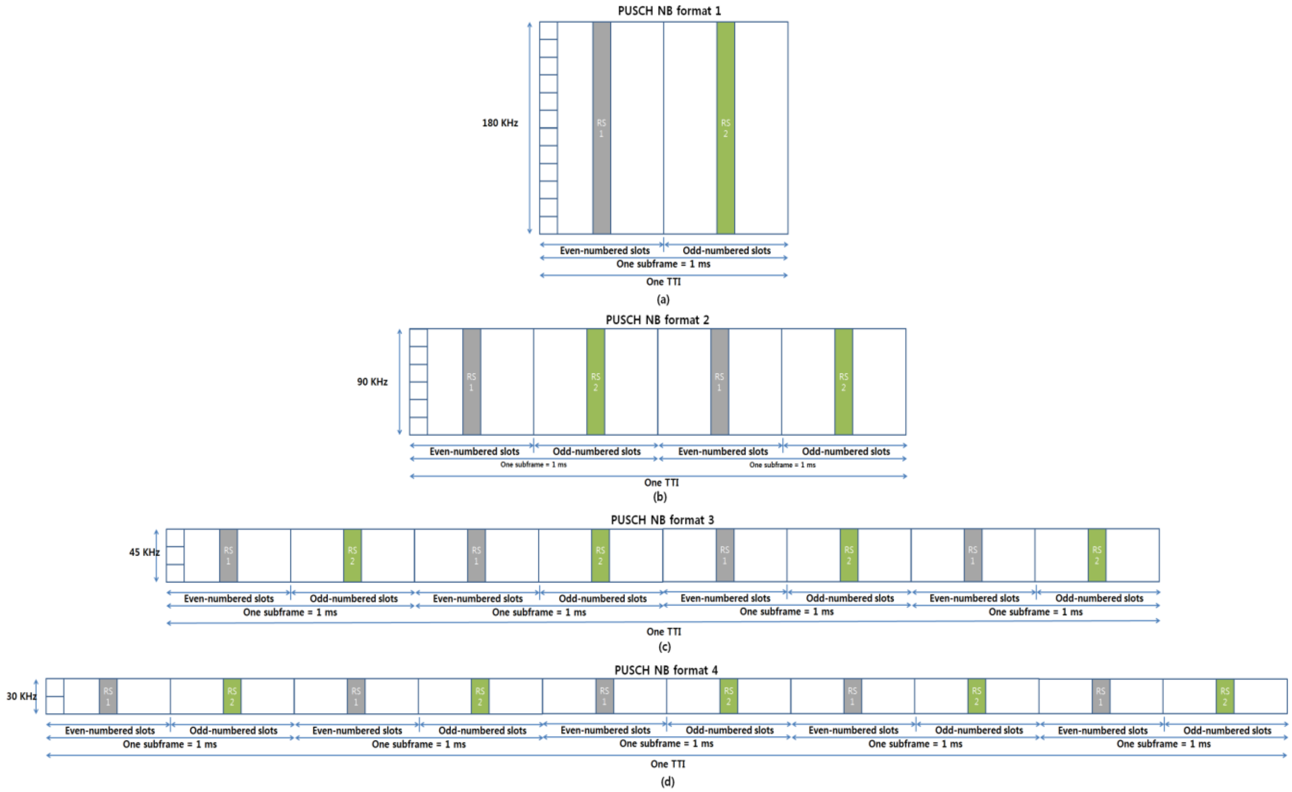

Figure 1. Uplink PUSCH channel structure for narrowband transmission.

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 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 that 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 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.

Figure 1(a) shows the conventional PUSCH structure with the large RB size of 180 kHz, which has 12 subcarriers and 2 slots. The information bits are first channel-coded with a turbo code of mother code rate with 1/3, which is adapted to a suitable final code rate by a rate-matching process. This is followed by symbol-level channel interleaving, which follows a simple 'time-first' mapping – in order words, adjacent data symbols end up being mapped first to adjacent Single Carrier-Frequency Division Multiple Access (SC-FDMA) symbols in the time domain, and then across the subcarriers. The coded and interleaved bits are then scrambled by a length-31 Gold code prior to modulation mapping, DFT-spreading, subcarrier mapping and OFDM modulation. For channel estimation and data demodulation, a Reference Signals (RSs) 1 and 2 are transmitted in each even-numbered and odd-numbered slots of a TTI, respectively.

Figure 1(b) shows the proposed narrowband PUSCH structure with the RB size of 90 kHz, which has 6 subcarriers and 4 slots. Its channel bandwidth is decreased to the half and TTI is increased to twice, compared to those of the conventional PUSCH. A simple 'time-first' mapping is also made for efficient transmission in power-limited satellite uplink. Within one TTI, adjacent data symbols end up being mapped first to adjacent SC-FDMA symbols in the time domain, and then across the subcarriers. On the other hand, in order to reuse the conventional RSs 1 and 2 in narrowband PUSCH as well as get a time diversity gain, the first half of RSs 1 and 2 are transmitted in the first and second slots, respectively, and then the rest half of RSs 1 and 2 are mapping in the third and fourth slots, respectively.

In a same way to Fig. 1(b), Fig. 1(c) and 1(d) also show the proposed narrowband PUSCH structure with the RB sizes of 45 and 30 kHz, respectively. As we can see, the number of subcarriers in the narrowband PUSCHs is limited to products of 2, 3 and 5 for commonality with terrestrial LTE because DFT size in terrestrial LTE is limited to those for low complexity of DFT implementation.

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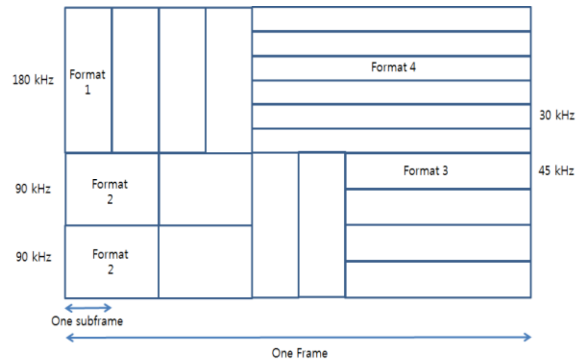

Figure 2. Uplink PUSCH channel structure for narrowband transmission.

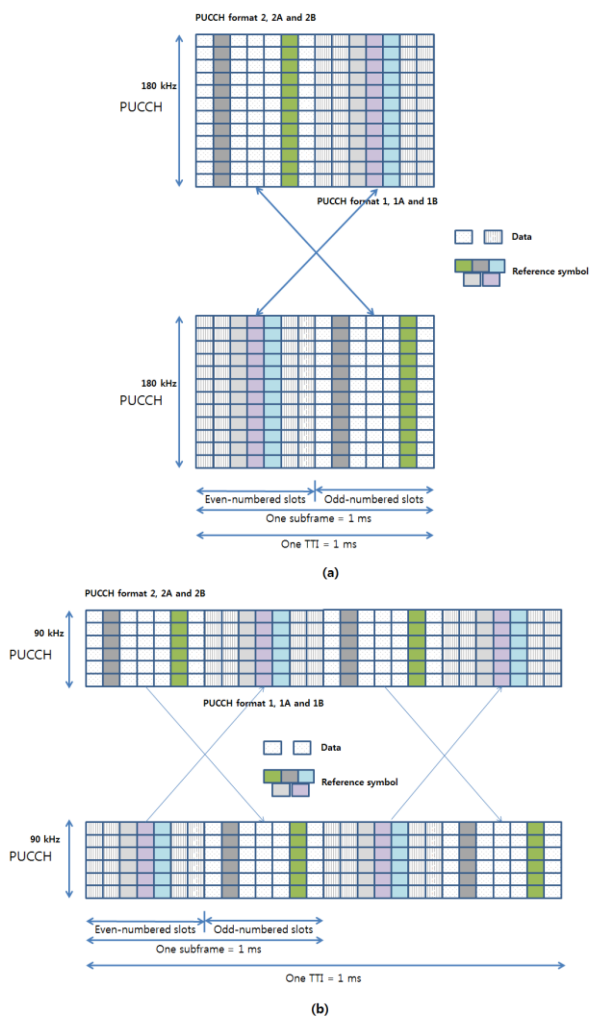

Figure 3. Uplink PUSCH channel structure for narrowband transmission.

Figure 2 illustrates a method to support the narrowband PUSCH transmission in conventional terrestrial LTE frame structure. We assume that one TTI corresponds to one frame duration in a satellite radio interface. Because the terrestrial LTE is operated with 180 kHz size of RB, narrowband PUSCHs should be grouped with 180 kHz bandwidth size within one TTI in order to be compatible with terrestrial LTE. For example, Formats 1 and 4 are transmitted in the above 180 kHz bandwidth and formats 1, 2 and 3 are mapped in the below 180 kHz in Fig. 2.

In the same principle, Physical Uplink Control Channel (PUCCH) structure will be shown in Fig. 3. PUCCH is used by a UE to transmit any necessary control signaling only in subframes, in which the UE has not been allocated any RBs for PUSCH transmission. The control signaling on the PUCCH is transmitted in a frequency region on the edges of the system bandwidth. In order to minimize the resource needed for transmission of control signaling in one subframe is a single slot at or near one edge of the system bandwidth, followed by a second RB at or near the opposite edge of the system bandwidth, as shown in Fig. 3. Similarly to PUCCH structure, Figures 3(a) and 3(b) represent the conventional PUCCH formats 1 and 2 and their narrowband transmissions version for adaptation to satellite uplink. Fig. 3(b) shows the narrowband PUCCH structure with the RB size of 90 kHz, which has 6 subcarriers and 4 slots. Other narrowband PUCCH structures can be applied in a same way to Fig. 2(c) and 2(d) for narrowband PUSCH structures.

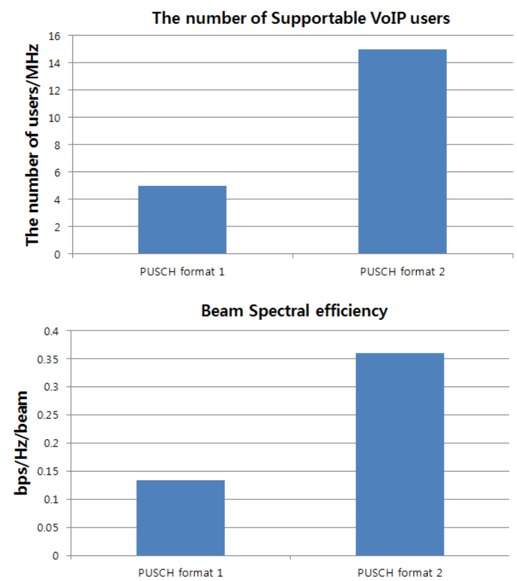

Figure 4. System level simulation results

III. SIMULATION RESULTS

For system-level simulation, we exploit the evaluation configuration parameters in the Table 1. 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 as the aggregate throughput of all users (the number of correctly received bits, i.e. the number of bits contained in the Service Data Units (SDUs) delivered to Layer 3) divided by the channel bandwidth by the number of beams. Also, full buffer best effort service profile is considered. VoIP capacity is derived assuming a 12.2 kbps codec with a 50% activity factor such that percentage of users in outage is less than 2%, where a user is defined to have experienced a voice outage if less than 98% of the VoIP packets have been delivered successfully to the user within a one-way radio access delay bout of 400 ms, considering maximum transfer delay of one way for the real-time services in the satellite component.

TABLE I. EVALUATION CONFIGURAITON 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

Based on these assumptions, we compare performance of a narrowband PUSCH (format 2 in Fig. 1) with the conventional PUSCH (format 1 in Fig. 1). Figure 4 shows system level simulation results with respect to average beam spectral efficiency and VoIP capacity. As seen in the figure, the use of narrowband PUSCH format 2 can get the increase of total system throughput more than three times of that in the use of the conventional PUSCH channel. Furthermore, an UE using the narrowband PUSCH format 2 can support slightly higher data rate than an UE using the conventional PUSCH even if the narrowband PUSCH format 2 has the half of the conventional PUSCH bandwidth.

From the performance analysis of a narrowband PUSCH format 2, we expect that the use of narrowband PUSCH format 3 and 4 could make total throughput increase more than that of the narrowband PUSCH format 2 as well as conventional PUSCH format.

IV. CONCLUSIONS

The proposed narrowband transmission scheme is more granular than in terrestrial LTE and allows allocation of reduced bandwidth resources to an UE, consistent with the power constrained nature of the satellite channel. In the proposed scheme, higher power allocation on each subcarrier in RB can make higher modulation and channel coding rate be used, thus we can achieve the increase of total system throughput. On the other hand, modification of physical layer and no change of the transport block size from terrestrial LTE in the proposed scheme can make us design fully compatible satellite LTE radio interface over MAC layer.

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