Filter Analysis for Filtered OFDM

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***Abstract*—A fifth generation (5G) network system will face various application requirements, not only higher data rate, but also low latency, high reliability, flexibility and so on. To meet the diversified demands for 5G, in this paper, one of the most promising air interfaces for 5G, named as filtered-OFDM (f-OFDM) is investigated. With subband-based filtering, an f-OFDM system is able to serve different types of services with most appropriate numerologies, leading to an improved overall performance. In the process of adapting f-OFDM, realistic and proper cell environments for 5G are analyzed and simulated by 3-dimensional (3D) ray-tracing. To modify the f-OFDM system, we analyze a relationship between a subband filter and a cyclic prefix by comparing channel characteristics of long term evolution (LTE) and 5G system. The performance of the modified scheme is evaluated and compared with that of the LTE by both link-level and system-level simulations. Our simulation results show that, in a specific scenario, f-OFDM obtains throughput gains over the conventional system.**

***Keywords*—5G air interface, filtered-OFDM, subband filtering, 3D ray tracing.**

I. Introduction

The upcoming fifth generation (5G) networks has been expected to evolve in a different way than previous one. While there are various techniques for 5G to support higher data rate and spectral efficiency up to Gbps, such as mmWave [1], massive multiple-input and multiple-output [2], [3], and in-band full duplex [4]–[6], there are other scenarios aiming at different performance requirements. For instance, Tactile Internet or vehicle-to-vehicle communication should be designed with ultra low-latency and ultra high reliability [7]. The machine type communication requires especially low power consumption [8]. Additionally, the out-of-band emission (OOBE) suppression should be considered for opportunistic and dynamic spectrum access [9]. To meet all these diverse performance requirements for 5G applications, the air interface should be revisited.

In forth generation (4G) networks, orthogonal frequency division multiplexing (OFDM) is a good solution not only to improve spectral efficiency but also to mitigate inter-symbol interference (ISI) from the frequency selectivity due to the multipath channel. Moreover, a relatively simple implementation by fast Fourier transform (FFT) algorithm makes OFDM have held a dominant position at present air interface. However, it has become a debate that OFDM might be insufficient to meet the various performance requirements for 5G applications [10]. The strict synchronization to keep the orthogonality between subcarriers causes heavy overheads, especially for uplink transmission. Another limitation of OFDM is high OOBE [11] which can be alleviated by a guard band, introducing the decrease of bandwidth efficiency instead. In addition, OFDM requires unified numerology for wide bandwidth, which is not suitable for supporting different types of services.

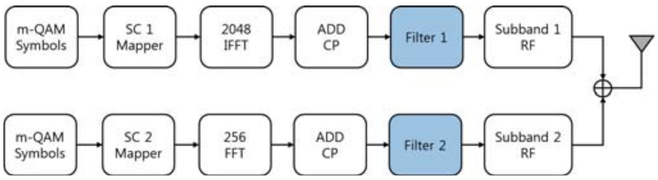

Figure 1: A block diagram of an f-OFDM transmitter.

To avoid above-mentioned limitations of OFDM, filtered OFDM (f-OFDM) was presented in [12]. This is based on subband splitting and filtering, which can integrate several OFDM systems with different numerologies. Using the f-OFDM system, it is possible to overcome the shortcomings of the conventional OFDM system. First of all, the strict synchronization can be relaxed by subband filtering. Secondly, OOBE can be suppressed by a properly designed filter and guard band usages can be reduced. Lastly, different types of services can be jointly provided in the same band. In general, it could be said f-OFDM is the most promising 5G waveform among the all 5G waveforms with both forward and backward compatibilities [12].

In terms of subband filtering, decision for the filter length is an important role to the performance of the f-OFDM system. The filter length leads to long tails in the time domain, both forward and backward and even causing ISI when it comes to be comparable to channel delay spreads. In this paper, the 5G urban micro cell deployment is assumed for the representative case of the above issue, which is plausible scenarios for 5G networks. With proper adjust to the subband filter, the performance of the f-OFDM system will be analyzed.

The remaining sections are orgaized as follows: Section II presents the system model of this paper. In Section III, an long term evolution (LTE) cell and 5G urban micro cell are compared. Section IV analyzes a bit error rate (BER) and system level performances of OFDM and f-OFDM. Finally, Section V concludes the paper and mentions future work.

II. System Model

A system model of f-OFDM is depicted in Fig. 1. In general, f-OFDM has multiple subbands of which subcarrier spacing and transmission time interval are different. For

Figure 2: A 3D digital map of GangNam Station, Seoul, South Korea

simplicity, in this paper, we assume a f-OFDM system with two subbands. For 20 MHz bandwidth for each subband, the baseband sampling frequency is assumed as 30.72 MHz, which is exactly eight times of UMTS chip rate supporting backward compatibility. The coexistence of conventional and low latency scenario numerologies are incoporated by setting the proper time-frequency arrangement for each subband. The symbol duration and subcarrier spacing of subband 1 are 66.67 μs and 15 KHz, while those of subband 2 are 8.33 μs and 120 KHz, respectively. Similar to 4G LTE system, the 10 % of channel bandwidth of each subband is used for guard carriers to simulate negligible OOBE condition. cyclic prefix (CP) length is calculated by root mean square (RMS) delay spread obtained by the realistic outdoor environments of GangNam Station as shown in Fig. 2. The digital map is used for three dimensional (3D) ray-tracing tool, Wireless System Engineering (WiSE) developed by Bell Laboratory [13]. As previously mentioned, about 2 μs CP is used at both subbands to adapt to urban micro cell for 5G, which requires the shorter length of the CP than that of 4G LTE, 4.47 μs.

The soft truncated sinc filter is applied to both subbands to provide appropriate time- and frequency- localization, limiting the ISI and OOBE simultaneously. The filter order is one forth of the FFT size or a modified length, which will be discussed later, for improving overall performance.

III. Comparison between LTE cell and 5G urban micro cell

In an LTE system, a CP length is calculated considering the maximum delay spread, which depends on the radius of rural macro cell. After adding a CP to mitigate ISI, an f-OFDM symbol passes through finite impulse response (FIR) bandpass filter to suppress OOBE, of which filter order is one forth of the FFT size in general. In the case that the filter length is so long which exceeds the CP length, ISI rises up. The FIR filter length, however, is not limited to the CP length since most of energy of the filter is contained within its main lobe in time domain, [14]. Especially, when the ratio of the CP length to the symbol length is relatively high such as the LTE CP, 6.7 % overhead, the ISI caused by the long filter length can be alleviated, although the number of taps of the effective

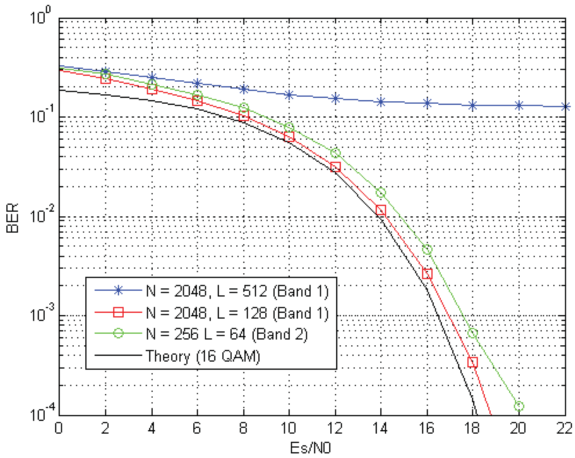

Figure 3: Theoreical and numerical results of BER over an AWGN channel for the f-OFDM system.

channel ($n_{\mathrm{ch,eff}} = n_{\mathrm{ch}} + L_{\mathrm{tx}} + L_{\mathrm{rx}}$) is larger than the length of CP where L_{tx} and L_{rx} are the order of the transmit FIR filter and receive FIR filter, respectively.

In case of 5G networks, it is promising that a large number of small cells are deployed for dense network, making maximum delay spreads shorter than 4G networks [15]. In other words, the CP overhead is low enough to cause a severe ISI problem. Thus, to adapt f-OFDM system to 5G environment, it is necessary to optimize the order of FIR filter considering both the maximum delay spread and the FFT size.

IV. Simulation Results

Figure 3 shows the BER performance of f-OFDM systems over an additive white Gaussian channel. It can be shown on the result of subband 1 that the BER becomes significantly worse when the CP length is relatively shorter than the symbol length, whereas the subband 2 is robust to ISI with same filter length $N/4$. As mentioned above, the better BER performance can be obtained by manipulating the filter order (in this case $N/16$), even the lower filter length leading to less suppression of OOBE. This tradeoff can be analyzed in system level simulations.

Figure 4 shows the cumulative density function (CDF) of the spectral efficiency of LTE based multi-band OFDM and f-OFDM systems. The overall tendency of low spectral efficiency ($0.5 \sim 2.5$ bps/Hz/cell) comes from high CP overhead by the short symbol duration, which is not significant in this analysis. The conventional f-OFDM system was expected to perform better than OFDM system due to its low OOBE of each subbands, but it is shown severe degradation of the spectral efficiency, about 56.6 % at the median CDF. This can be interpreted that the poor BER by the excessive filter length contributes to this effect. In contrast, the proposed f-OFDM system with the proper filter length enhances the performance dramatically, about 28.4 % at the median CDF. The throughput gain comes from not only improvement of the

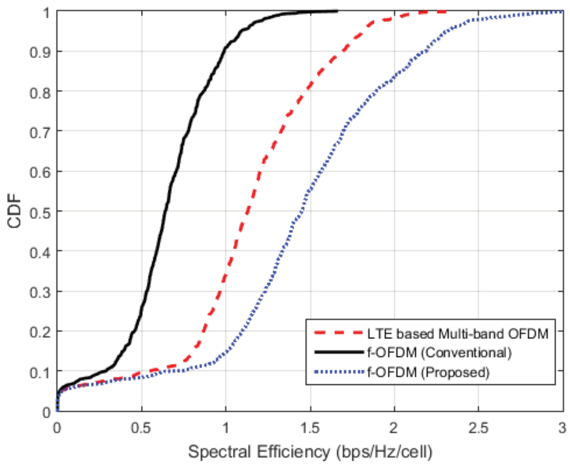

Figure 4: The CDF of spectral efficiency of LTE and f-OFDM systems in 5G urban micro cell.

BER performance, but also the well-optimized filter length with affordable OOBE.

V. Conclusions and Future Work

In this paper, we have presented a filtered-OFDM with modifed filter length to adapt to realistic 5G networks environment. After introducing the necessity of the f-OFDM system for 5G, the system model and the methodology of the f-OFDM has been provided. The detailed comparison between LTE and 5G system characteristics has been highlighted, addressing significant conditions for the f-OFDM system. The results has been observed in both the link-level and the system-level simulation, and has represented the encouraging effects of the proposed system. To support various applications for 5G such as Tactile Internet and Internet of things, discussed optimization issues should be studied more for the prompt realization of 5G networks.

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