

Inconsistent Guard Time Span With on Mobile 4G System

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Abstract: Guard time span (GT) is implemented as Cyclic Prefix (CP) to completely alleviate Inter-symbol Interference (ISI) and to preserve orthogonality among OFDMA subcarriers as long as the guard time span is sufficiently greater than channel delay spread. In conventional OFDMA systems GT span is fixed and chosen to be much longer to tolerate worst case condition irrespective of current propagation channel state. This technique, however, degrades the overall spectral efficiency as well as consumes transmitter energy proportional to the span of the guard time. This fact motivates the need to vary the guard time span based channel parameters especially for mobile applications. The primary goal of this paper is to vary the GT span based channel delay spread for mobile 4G technology.

Keywords : Guard Time; Mobile 4G; OFDMA; Delay Spread.

I. Introduction

Mobile 4G is very new technology on horizon being developed under IEEE802.16e-2005 standard [1] to revolutionize broadband wireless access systems. This technology designed to provides interoperable broadband wireless connectivity to fixed, nomadic, portable and mobile users. Ultimately, it can provides low-cost, high speed data rates up to 75 Mbps at vehicular speeds greater than 120 Km/h covering an area over a radius potentially of up to 30 miles without the need of direct line-of-sight (LOS). To accomplish these goals and to overcome the problems associated with multipath channel, mobile WiMAX uses essential features like OFDMA as the radio interface, adaptive modulation and Multi Input Multi Output (MIMO) technology [2].

Orthogonal Frequency Division Multiple Access (OFDMA) is a multicarrier transmission technique that extends OFDM for use as a multiple access technology, in which the available bandwidth is split into equidistant narrow band subchannels, each consisting of a set of subcarriers. For each subcarrier, the modulation and coding can be adapted separately. By virtue of its long symbol time and use of Guard time span OFDMA can effectively cope with the larger delay spread, thereby increasing the data throughput and minimizing the equalization process. Moreover, OFDMA presents a number of advantages such as high spectral efficiency, resilience to Radio Frequency (RF) interference and lower multipath distortion, which make it an attractive choice for next generation wireless communication systems, commonly referred to beyond 3G (B3G) [3].

Guard time span is one of the key OFDMA parameters. This span is a copy of the last portion of the useful symbol time appended to the beginning of each transmitted symbol to completely alleviate Intersymbol Interference (ISI) as long as the GT is greater than delay spread of the channel. By implementing the GT as cyclic prefix (CP) the system being immune to Intercarrier Interference (ICI) that causes a severe degradation of Quality of Service (QoS) in OFDMA systems. In addition, the CP span has advantage of allowing perfect channel estimation as well as timing and frequency synchronization [4]. Conventional OFDMA system uses large-static guard time span to tolerate worst case channel condition irrespective of current channel state. This technique, however, causes a loss in bandwidth efficiency as well as waste transmitter energy. The amount of power wasted depends on how large a fraction of the OFDMA symbol duration the guard time is. By using Inconsistent GT span, significant improvement in data throughput can be obtained specifically under ideal or moderate channel conditions whereas mobile user nearby base station or passing indoor environments. Since phones need to run on battery, optimization provides the ability to reliably send information at the lowest possible power level, which has advantage of extending the battery life of mobile devices.

In this paper we address the influence of varying guard time span on mobile 4G system performance operating on multipath fading channel. We use disparate spans to investigate the resultant packet error rate (PER) used to describe the transmission channel quality. In the simulation, we use the standard mobile 4G parameters specified in [5]. The rest of this paper is organized as follows. In section 2, we describe briefly the general concept of OFDMA systems. In particular, section 2.1 and 2.2 gives general overview about guard time optimization and delay spread measurements, respectively. Section 3 shows how to calculate data rates and loss in SNR due to guard time insertion. In Section 4, simulation results are presented, while section 5, discuss the conclusion.

II. System Description

The block diagram of OFDM transceiver based mobile 4G system is shown in Figure 1. The serial k input binary bits are first forward error encoded (FEC), punctured and interleaved to allow detection and correction of errors that may occur during signal transmission. After encoding, the n coded bits are mapped to a sequence of complex data symbols. Symbols are further grouped to form transmitted frames, each with N symbols. For OFDMA, the mapping process depends on different parameters such as data transmit, zone type, segment and subchannel group [1]. The modulated data are serial to parallel converted (S/P) and then fed to the Inverse Fast Fourier Transform (IFFT) part, where each symbol is modulated by the corresponding subcarrier. Following the transformation process, the timed signal is serialized by using P/S converter. To make the system more immune to the time selectivity of the channel, a guard time samples v is added as a cyclic prefix at the beginning of each transmitted OFDMA symbol. The signal samples are then passed through Digital to Analogue (DAC) converter then transmitted in a frame along with preamble, which used for channel estimation and synchronization. In the receiver side the, the received signal is first filtered, sampled and then serial to parallel converted. The guard time v samples are discarded and the remaining samples of each frame are demodulated by means of a FFT.

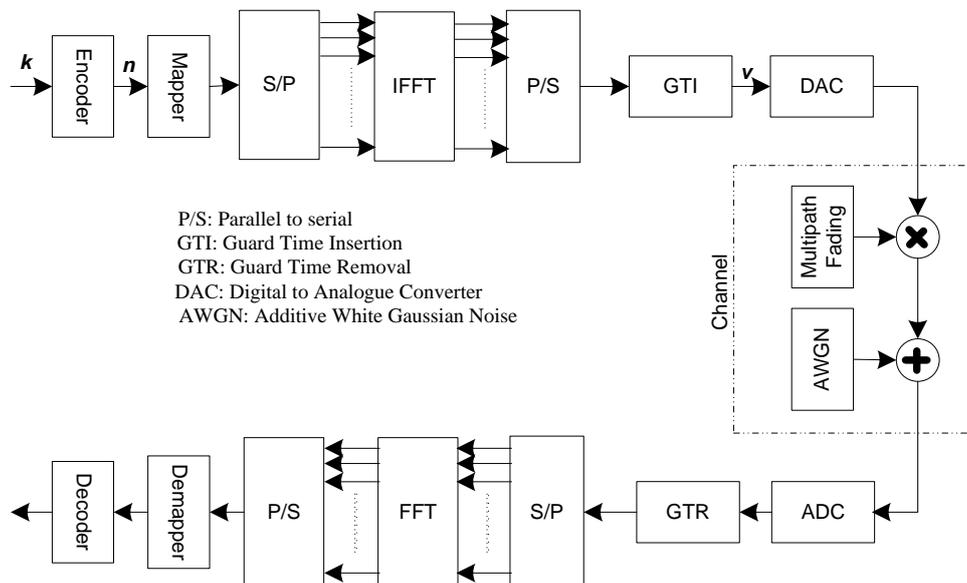


Figure 1: OFDMA Transceiver Block Diagram

2.1 Guard Time Optimization

A common rule of thumb used to select guard time span is to characterize the propagation channel delay spread. Practically GT span is either chosen two to four times of the maximum anticipated delay spread or kept 25% of the useful symbol time, which implies a 1 dB reduction in Signal to Noise Ratio (SNR). But it is still desirable to minimize the SNR degradation due to GT span [6]. However, in typical wireless mobile communication channel, mobile user expected to undergoes a wide range of operating conditions within short period of time or propagation distance. In such cases, the channel impulse response might be vary rapidly in some locations whereas in other vary slowly, with minimal delay spread. Based on that, fixing the GT span is impractical especially for mobile applications. This fact motivated the use of span guard time span [7]. On contrary adaptation requires a form of accurate either estimation or actual field measurements of channel delay spread. The later method are expensive, time consuming and unreliable. Thus it is crucial to find out an estimation technique that can quantify and update delay spread values wherever the mobile user is [8]. Some other related works have been reported as in [9] – [11].

2.2 Delay Spread Estimation

Time dispersion or delay spread introduces severe ISI at the receiver, which degrade the data transmission. Practically, its value found to be directly related to the propagation environment not on the system operating frequency [6]. Obviously, delay spread is not constant in wireless mobile communication channel. Measurements campaign [12] made in the U.S. covering wide range of geographies and topographical areas revealed that delay spreads are usually not exceeding 12 microseconds over measured locations. It was found that urban areas have RMS delay spreads on the order of 2-3 microseconds, about 5-7 microseconds in open and hilly residential areas, and high rise urban areas exhibit larger delay spreads in excess of 20 microseconds especially when the mobile traverses bridges. Measurements done by Seidel and Rappaport [13] in four

European cities showed that delay spreads are less than 8 microseconds in macro-cellular channels, less than 2 microseconds in micro-cellular channels, and between 50 and 300 nanoseconds in pico-cellular channels. For indoor office building, the RMS delay spread is 35 nanoseconds, while at factory buildings, the delay spread goes up to 300nanoseconds [14].

In summary, depending on the terrain, distances, antenna directivity and other factors, the channel delay spread values can span from very small values (tens of nanoseconds) to large values (microseconds). On the other hand, channel models defined by standard organization are heavily dependant especially when it is difficult to have an accurate description of the wireless channel. For example, ITU-R M.1225 [15] outdoor to indoor, pedestrian and vehicular channel models are baseline for design, development and testing of mobile 4G device.

III. Calculation Example

The following example shows how to calculate the GT, data rate and loss in SNR due to guard time insertion for mobile 4G system. Table 1 summarizes the primitive parameters that used for calculation and simulation works.

Table 1: Mobile 4G primitive parameters

Parameters	Value
Carrier frequency	2300 MHz
System channel bandwidth (BW)	10 MHz
Sampling frequency ($F_s = \text{floor}(n \times BW / 8000) \times 8000$)	11.2 MHz
FFTsize (N_{FFT})	1024
Subcarrier frequency spacing ($\Delta f = F_s / N_{FFT}$)	10.9375 KHz
Useful symbol time ($T_b = 1 / \Delta f$)	91.43 μs
Guard time span ($G = T_g / T_b$)	span
Frame duration	2ms
Modulation and coding	16 QAM 1/2
Data subcarriers (N_{data})	560
Pilot subcarriers	280
Guard subcarriers	184
$BW_{efficiency} = \frac{\Delta f \times N_{used}}{BW}$	91.1%

3.1 Guard Time

The OFDMA symbol consists of subchannels that carry data subcarriers carrying information, pilot subcarriers that are dedicated for synchronization and channel estimation purposes, DC subcarrier and guard subcarriers to provide high inter-channel interference margin. To determine subcarrier spacing and useful symbol time, sampling factor n is commonly set to be 8/7 for OFDMA PHY, yield sampling frequency $F_s = 11.2MHz$. In order to keep the subcarrier spacing fixed at 10.9375 KHz across different channel bandwidth, scalability feature of OFDMA chooses 1024 FFT span with 10 MHz occupied bandwidth. This implies 91.1% bandwidth efficiency, but this percentage varies for other sampling factors and channel bandwidths. Thus, T_b is the inverse of the subcarrier spacing Δf . Then GT is $T_g = G \times T_b$, where G is $\frac{T_g}{T_b}$ ratio.

The choice of G made according to the radio channel condition. Thus, OFDMA symbol time (T_s) comprising guard time span (T_g) and useful symbol span (T_b), where $T_s = T_b + T_g$.

3.2 Data Rate

The goal of a communications system is to provide higher data rates to the end users while minimizing the probability of errors. As per IEEE 802.16e-2005 standard, the maximum transmission raw data rate can be obtained using:

$$R = \frac{N_{data} \times b \times \frac{k}{n}}{T_g + T_b} \quad (1)$$

Where b is the number of bits per symbol for the modulation being used, N_{data} is number of used subcarriers for data transmission and $\frac{k}{n}$ is the overall coding rate given in Table1. Further, it is also useful to describe channel capacity in terms of spectral efficiency using

$$\eta = \frac{C}{BW} \text{ (bits/s/Hz)} \quad (2)$$

It is clear that, by changing the guard time span from 3% of the symbol span to 25% decreases the amount of data transmitted significantly which make OFDMA guard time is basic parameters for data rate computations. Table 2 provides an optimistic data rates achieved as function of modulation, coding and guard time span taking into account that these values do not consider some overheads such as preambles and signaling messages present in every frame.

3.3 SNR Loss

While increasing GT span to resist ISI and ICI, the overall power efficiency degrades proportionally. In particular, the loss in E_b/N_o at the transmitter side becomes:

$$SNR_{loss} = -10\log_{10}\left(1 - \frac{T_g}{T_g + T_b}\right) \quad (3)$$

At the receiver, GT is removed before further processing, thus receiver energy remains unchanged. Table 2 shows the expected energy loss as function of GT. It can be noted that, however, minimizing power loss is needed because mobile terminals need to run on battery.

Table 2: OFDMA data rate and SNR loss.

$\frac{T_g}{T_b}$	Data rate (Mbps)			Loss (dB)
	QPSK 1/2	16 QAM 1/2	64 QAM 3/4	
1/4	4.90	9.80	22.00	0.97
1/8	5.40	10.80	24.50	0.51
1/16	5.80	11.50	26.00	0.26
1/32	6.00	11.80	26.80	0.14
0	6.20	12.30	27.60	0

1. Computer Simulation

The performance of mobile 4G with span GT under multipath fading channel is evaluated using computer simulation.

4.1 System Parameters

The simulation parameters selected according to the IEEE 802.16e standard. As well, we chose the most relevant parameters that suit our local spectrum regularity. The parameters are; 10 MHz nominal bandwidth, 1024 FFT size and 2.3 GHz operating frequency. This spectrum is the most likely licensed band to roll out IEEE 802.16e services in Malaysia [MCMC]. To reduce the simulation time we use 2 ms frame duration instead of required 5 ms. For efficient downlink (DL)/uplink (UL) asymmetric traffic support, the TDD duplexing mode is used with more than 60% of the frame time occupied by the DL subframe. The DL subframe uses Partially Used Subchannels (PUSC) zone type with maximum two number of symbols per slot. After preamble insertion, the FCH and DL_MAP are allocated. The former describes the subchannel used and transmission parameters. The later provides specific information about the DL bursts and their offsets.

For system performance evaluation, we chose 16 QAM modulation scheme and convolutional turbo coding (CTC) with overall coding rate $\frac{1}{2}$. In particular, the ITU-R M.1225 channel model type A has been adopted to simulate mobile 4G for vehicular environment. The channel modeled multipath fading with six power decaying taps characterized by Ralyleigh distribution. The associated channel parameters are; 595 us RMS delay spread, 2510 ns maximum delay and 60 Km/h maximum speeds. The required bit energy per noise density 10 dB has been considered averaging over 1000 frames for probability of errors computation. In addition, the transmitted signal is corrupted by Additive White Gaussian Noise (AWGN) with noise density calculated as function of GT span using:

$$NDensity = P_s - 10\log(1 + G) - \frac{E_b}{N_o} - 10\log(R) \quad (4)$$

Where P_s , signal power. The simulation assumptions for the evaluation are shown in Table1.

4.2 Performance Evaluation

When forward error correction techniques are used in wireless systems for packet data transmission on multipath fading channel, Packet Error Rate (PER) is a useful criterion for channel quality evaluation rather than Bit Error Rate (BER).

To show the influence of varying the guard time span to the link quality for mobile 4G system, some simulation were made and the results are shown in Figure1: Simulation results for span guard time span. The GT implemented as Cyclic Prefix (CP) with various spans comprising; CP=0, 0.0274, 0.1625 and 0.25. Without CP systems are more susceptible to ISI, which is lower the data transmission rate. While with 25% of the symbol time spent on the CP, receivers are capable to collect longer multipath fading, but at the cost paid to SNR.

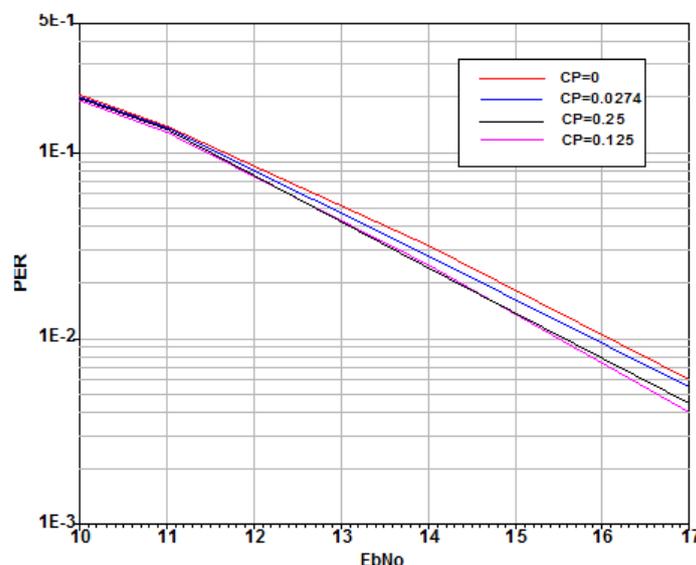


Figure 1: Simulation results for span guard time span.

From Figure1 it can be seen that PER does decrease as CP increase. The PER is plotted versus $\frac{E_b}{N_o}$ (the ratio of bit energy to noise power spectral density). It also shows that CP curves are almost identical below 11 dB and perform comparably beyond 15 dB. It reveals that guard ratio of 0.125 slightly outperforms the other spans in PER reduction. In theory, the PER with CP=1, over sufficient and impractical value, should be the same as that with 0.25 but the results are slightly different because they pass through diverse fading channels and the receiver is not ideal for them.

In fact, this behavior of the mobile receiver is expected when dealing with relatively small (RMS) delay spread comparing with one OFDMA symbol (2.746 %). Accordingly the effect of CP on system performance is also small. Consequently, it is mandatory to examine such a system under various channel models that have larger delay spread as in (channel model) for comparison and getting high system performance. Obviously, the optimal CP span is approximately 0.125, a value that presently defined in mobile 4G profile.

IV. Conclusion

Mobile 4G system performance as function of guard time span has been simulated under ITU-R vehicular channel model A. the results proves that guard time span is useful for OFDMA system operating on a frequency selective channel. Also it can be concluded, CP is strongly depends on maximum delay spread, not on RMS delay, and the optimal span found to be 1/8 of the OFDMA symbol time that minimize the degradation of SNR, caused by ISI. Lastly, varying guard time span is mandatory for mobile 4G to enhance overall system performance as well as to provide higher data rates.

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