Effect of Variable Guard Time Length on Mobile WiMAX System Performance

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***Abstract* -** Guard time length (GT) is one of the key OFDMA parameters. It is implemented as Cyclic Prefix (CP) to completely alleviate Intersymbol Interference (ISI) and to preserve orthogonality among OFDMA subcarriers as long as the guard time length is sufficiently greater than channel delay spread. In conventional OFDMA systems a fixed GT length is 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 length of the guard time. This fact motivates the need to vary the guard time length for mobile applications based on channel parameters. The primary goal of this paper is to investigate the effect of varying the GT length based on channel delay spread for mobile WiMAX technology. The overall system performance and resultant packet error rate (PER) are slightly improved as function of the guard time length.

Keywords: Guard Time; Mobile WiMAX; OFDMA; Delay Spread.

1. Introduction

Mobile WiMAX is an emerging technology developed under IEEE802.16e-2005 standard [1] to revolutionize broadband wireless access systems and to complement existing mobile communication 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 WiAMX uses essential features like OFDMA as a 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 length (GT) OFDMA can effectively cope with larger delay spreads, thereby increasing 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 length is one of the key OFDMA parameters. This length 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 length has advantage of allowing perfect channel estimation as well as timing and frequency synchronization [4].

Conventional OFDMA system uses static and longer guard time length 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 variable GT length, 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, variable GT 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 length on mobile WiMAX system performance operating on mutipath fading channel. We use disparate lengths to investigate the resultant

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packet error rate (PER) used to describe the transmission channel quality. In the simulation, we use the standard mobile WiMAX 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 the need for variable guard time length and measured delay spread values, 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.

2. System Description

The block diagram of OFDM transceiver based mobile WiMAX 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 inserted 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 (guard time removal, GTR) and the remaining samples of each frame are demodulated by means of a FFT.

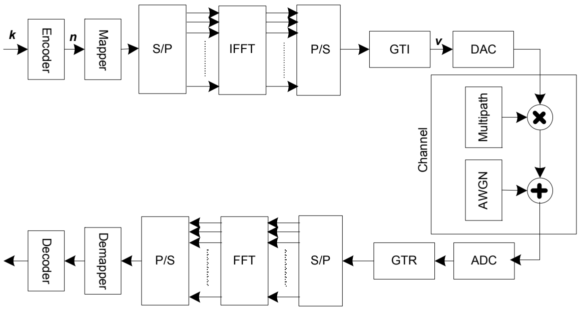

Figure 1: OFDMA Transceiver Block Diagram

2.1 Variable Guard Time Length

A common rule of thumb used to select guard time length is to characterize the propagation channel delay spread. Practically GT length 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 length. 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 length is impractical especially for mobile applications. This fact motivated the use of variable guard time length [7]. On the other hand, variation 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 regarding the variation of GT have been reported [7], [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 *et al.* [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 300 nanoseconds [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 WiMAX device.

3. Calculation Example

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

Table 1: Mobile WiMAX primitive parameters

Parameters	*Value*
Carrier frequency	2300 MHz
System channel bandwidth (BW)	10 MHz
Sampling frequency ($F_S = floor(n \times BW/8000) \times 8000$)	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 length ($G = T_g / T_b$)	variable
Frame duration	2ms
Modulation scheme	16 QAM
Overall coding rate	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 Length

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 length 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. The OFDMA symbol time (T_s) comprising the guard time length (T_g) and useful symbol length (T_b), thus $T_s = T_b + T_g$.

3.2 Data Rate

The goal of a communication 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:

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

Where b is the number of bits per symbol for the modulation being used, N_{data} is number of used subcarriers for data transmission. The useful channel capacity is:

$$C = R \times \frac{k}{n} \qquad (2)$$

Where $\frac{k}{n}$ is the overall coding rate given in Table 1. Further, it is also useful to describe channel capacity in terms of spectral efficiency using:

$$\eta = \frac{C}{BW} \text{ (Bits/s/Hz)} \qquad (3)$$

It is clear that, by changing the guard time length from 3% of the symbol length 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 length 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 length 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:

$$SNR_{loss} = -10\log_{10}(1 - \frac{T_g}{T_g + T_b}) \qquad (4)$$

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. Since OFDMA useful symbol length is fixed, minimization can be done only by varying GT length.

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

4. Computer Simulation

The performance of mobile WiMAX with variable 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. 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 Subcahnnels (PUSC) zone type with maximum two symbols per slot. After preamble insertion, the FCH and DL_MAP are allocated. The Frame Control Header describes the subchannel used and transmission parameters, while DL_MAP 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 ½. In particular, the ITU-R M.1225 channel model type A has been adopted to simulate mobile WiMAX for vehicular environment. The channel modeled multipath fading with six power decaying taps characterized by Ralyeigh distribution. The associated channel parameters are; 595 microsecond RMS delay spread, 2510 nanosecond 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 length using:

$$NDensity = P_S - 10\log(1+G) - \frac{E_b}{N_o} - 10\log(R) \qquad (5)$$

Where P_S is the signal power. The simulation assumptions for the evaluation are shown in Table 1.

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 length to the link quality for mobile WiMAX system, some simulation were made and the results are shown in Figure 2: Simulation results for variable guard time length. The GT implemented as Cyclic Prefix (CP) with various lengths comprising; CP=0, 0.02746, 0.125 and 0.25. Without CP systems can theoretically transmit up to 30 Mbps using 64 QAM but are more susceptible to ISI. 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.

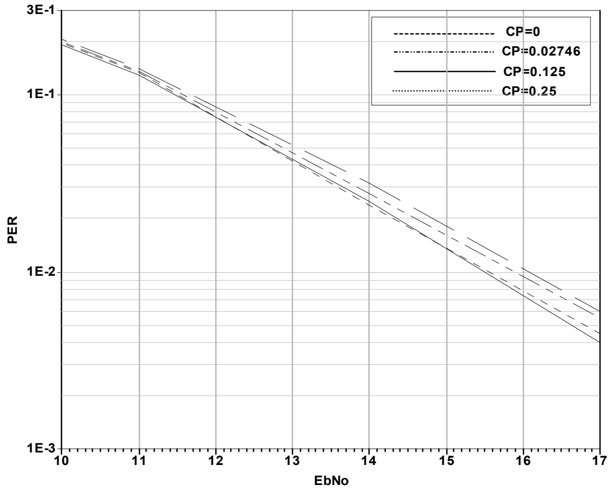

Figure 2: Simulation results for variable guard time length.

From Figure 2, 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 at higher values (beyond 15 dB). Also, it reveals that CP ratio of 0.125 slightly outperforms the other lengths in PER reduction. Accordingly, using this value the data transmission rate is slightly increased (25 Mbps) with minimal energy consumption. Further, theoretically PER with CP=1, over sufficient and impractical value, should be the same as that with 0.25 but the results are different because they pass through diverse fading channel and the receiver is not ideal for them. This value is not shown in Figure 2 above.

In fact, this behavior of the mobile receiver is expected when dealing with relatively small delay spread comparing with one OFDMA symbol. Accordingly, the CP overhead is also small (<0.3 dB). Consequently, it is mandatory to examine such system under various channel models that have larger delay spread as in [15] for comparison and getting high system performance. It can also be proved that the optimal CP length is approximately 0.125 which coincide with the value that defined in mobile WiMAX profile.

5. Conclusion

Mobile WiMAX system performance as a function of guard time length has been simulated for ITU-R vehicular channel A model. The results prove that variable guard time length is useful for OFDMA system operating on time dispersive channel. Furthermore, CP is strongly dependant on maximum delay spread, not on RMS delay. In this paper, it is found that the optimal guard time length that minimizes the SNR degradation caused by ISI is 12.5 % of the OFDMA symbol time. Lastly, varying guard time length based on channel parameters is recommended for mobile WiMAX system to enhance the overall system performance.

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