FRAME LENGTH DESIGN FOR MULTIBAND-OFDM ULTRA WIDEBAND NETWORKS

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Abstract: A new design of the optimal MAC frame payload length for maximizing the saturation throughput of the Prioritized Contention Access (PCA) of the WiMedia Ultra Wideband (UWB) standard in Rayleigh fading channel is presented in this paper. In the WiMedia standard, the Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) is used as the basic physical scheme. The proposed design is based on the throughput analysis carried out by extending an original Enhanced Distributed Contention Access (EDCA) model for 802.11e into the MB-OFDM UWB protocol. The extended model considers the effects of the bit error rate, the transmission opportunity limits, and the uniqueness of WiMedia MAC timing structure. The station throughput is sensitive to the frame payload length, and the optimal frame payload length increases exponentially when the value of the signal-to-noise ratio is higher. The optimal payload length is independent of the number of the active stations, data rate, and the priority of the Access Categories (ACs). Therefore, a station can dynamically adapt the length of the transmitted frame in the MAC layer according to the current SNR level so as to maximize its saturation throughput in the MB-OFDM UWB network.

1 INTRODUCTION

Ultra wideband (UWB) technology is an emerging candidate for short-range wireless communications and precise location systems (Win and Scholtz, 1988). The Federal Communication Commission (FCC) defines UWB signal as a wireless transmission in the unlicensed 3.1-10.6 GHz band that possesses a -10 dB bandwidth greater than 20% of its centre frequency or one exceeding 500 MHz (Federal Communications Commission, 2002). In recent years, extensive research work in both academia and industry has been focused on the design and implementation of UWB systems due to its ability to provide very high data rate with low power and low cost for Personal Computing (PC), Consumer Electronics (CE), and mobile applications in a short-range. In 2002, the IEEE 802.15.3a Task Group was initially formed planning to standardize the specifications of an UWB Physical layer (PHY) for the high-speed Wireless Personal Area Networks (WPAN). One of the two leading PHY specifications is Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) UWB, supported by WiMedia Alliance (WiMedia Alliance, 2008) who later standardized its own Medium Access Control (MAC) specification based on MB-OFDM UWB (Batra et al., 2003).

The WiMedia MAC protocol (ECMA International, 2005) is implemented in a distributed manner, implying that no central coordinator is used for network management. The beacon frame is transmitted by every station for synchronization, network topology control, and channel access coordination. This distributed architecture brings high reliability and better mobility than the centralized networks. Other advantages include the ease of system design, performance evaluation, and simulation (Vishnevsky et al., 2008). This MAC-PHY specification was then adopted by ECMA (ECMA International, 2005) as a standard for short-range wireless communications, and has already received intensive support from the global industry.

In the WiMedia MAC protocol, two fundamental medium access mechanisms are defined, one is the contention based Prioritized Channel Access (PCA), and the other one is the reservation based Distributed Reservation Protocol (DRP). PCA is designed for network scalability and is very similar to the En-

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hanced Distributed Channel Access (EDCA) mechanism used in the IEEE 802.11e systems (IEEE Std. 802.11e, 2003). In PCA, four priorities are assigned to four types of applications called Access Categories (ACs, i.e. backgroud, best effort, video, and voice). Higher prioritized AC has higher probability to access the channel due to shorter backoff period. Every AC has a pre-defined transmission period, known as Transmission Opportunity (TXOP). DRP is used mainly for isochronous traffic, by which network stations are allowed to arbitrarily reserve a period of time for exclusive data transmission.

In comparison with other MACs, the WiMedia MAC has not received a lot of attention in the literature. In (Zang et al., 2005), the theoretical maximum throughput of the WiMedia MAC is evaluated for a error-free wireless channel. In (Wong et al., 2007), a three dimensional discrete-time Markov chain was used to analyze the saturation throughput of the PCA schemes by employing simplified DRP rules and fixed Bit Error Rate (BER). The effects of the TXOP limitation and the backoff counter freezing were not considered in the paper. A packet aggregation and retransmission MAC scheme for the error-prone high-data-rate UWB Ad Hoc networks was proposed in (Lu et al., 2007). The control procedure of the proposed MAC scheme is based on the IEEE 802.11 (IEEE Std. 802.11, 1999) model.

This paper focuses on the design of the optimal MAC frame payload length (frame length) for maximizing the saturation throughput of the WiMedia PCA scheme over the Rayleigh fading channel. A large frame length tends to result in high Packet Error Rate (PER), and a small one usually leads to high transmission overhead for the system. Both of these situations will decrease the saturation throughput. Therefore, there is an optimal frame length value for the system to achieve the maximum throughput. The frame length adaptive function can be implemented in the MAC layer.

The proposed design is based on the saturation throughput analysis. Since the PCA is very similar to the extensively studied EDCA mechanism (Xiao, 2005)(Deng and Chang, 1999)(Mangold et al., 2002), the throughput analysis is carried out by extending the EDCA model proposed in (Kong et al., 2004) for IEEE 802.11e into the UWB region. In (Kong et al., 2004), an analytical model of the EDCA scheme using a three-dimensional discrete time Markov chain was developed. This model accurately reflects the prioritized backoff procedures by considering the backoff deferring due to other station's transmission, and different length of the backoff procedure, as well as the contention between different ACs within a station.

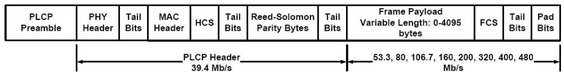

Figure 1: The format of PCLP.

This original model is extended by taking into account a BER model based on the Rayleigh fading channel, TXOP limitations, and the uniqueness of WiMedia MAC timing structure. The new model is more accurate for accomplishing the WiMedia MAC protocol specifications.

The paper is organized as follows. In section 2 WiMedia PHY and MAC protocol is reviewed. In section 3 the PCA's saturation throughput performance is analyzed following the introduction to the extended analytical model, and the optimal frame length design is provided . The numerical results analysis is carried out in section 4. Concluding remarks are given in Section 5.

2 WIMEDIA MAC AND PHY PROTOCOL OVERVIEW

This section provides a review of the WiMedia PHY and MAC specifications, and specifically focuses on the introduction of the WiMedia PCA schemes.

2.1 WiMedia MB-OFDM PHY

In the WiMedia PHY protocol, the UWB bandwidth is divided into fourteen sub-bands, each with 528 MHz. The OFDM symbols are allocated to each sub-bands for transmission. In each of the sub-band, a total number of 122 sub-carriers are used for data transmission.

Data packets coming from the MAC layer to the PHY are converged into Physical Layer Convergence Protocol (PLCP) frame. The frame consists of a PLCP preamble, a PLCP header and a frame payload, as depicted in Figure 1. The preamble and header serve as aids in the demodulation, decoding, and delivery of the frame payload at the receiver. It is assumed in this manuscript that no bit error will occur within the PLCP preamble and header since they are transmitted at the lowest data rate (39.4 Mbps) in small sizes. MAC frame payload is formatted into PLCP frame payload which can be transmitted at the data rate from 53.3 to 480 Mbps.

Before a transmission, the PLCP header and payload are first coded using punctured convolutional code. Next, the data stream is interleaved and then mapped using either Quadrature Phase Shift Keying

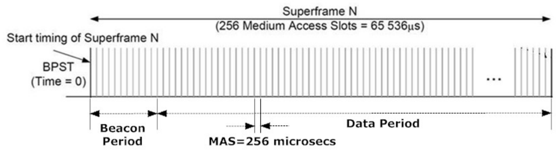

Figure 2: WiMedia MAC superframe structure.

(QPSK) (data rate$\leq$200 Mbps) or Dual-Carrier Modulation (DCM) (data rate>200 Mbps). Subsequently, each mapped symbol is modulated into a OFDM symbol by the OFDM modulator using Inverse Fast Fourier Transform (IFFT). Finally, the OFDM symbols are mapped onto the corresponding sub-carriers according to the time-frequency code and transmitted into the UWB wireless channel.

Rayleigh fading is used in the analysis to model the UWB channel fading (Lai et al., 2007). Thus, the average BER of the transmitted data can be expressed as

$$P_{BER} = 1/2[1-\sqrt{\gamma/(1+\gamma)}], \tag{1}$$

where γ is the average SNR per bit.

Since the convolutional coding process enables the receiver to correct several bit errors of the data stream transmitted over the fading channel, the value of the PER can be calculated as (Taub and Schilling, 1986)

$$p'_e = \sum_{i=n+1}^{L_c} \binom{L_c}{n+1} P_{BER}^{(n+1)} (1-P_{BER})^{(L_c-n-1)}, \tag{2}$$

where L_c is the length of the convolutional coded payload, and n is the maximum number of bit that can be corrected by the convolutional coding.

For simplicity, the value of the PER is approximated as

$$p_e = 1-(1-P_{BER})^{8L}, \tag{3}$$

where L is the length of the payload in bytes. It can be observed that $p_e \geq p'_e$ when the payload size is large. So, p_e represents an upper bound expression for the PER.

2.2 WiMedia MAC

The basic time division of the WiMedia MAC is superframe. It contains a variable length beacon period and a data transmission period. A superframe comprises 256 Medium Access Slots (MASs) of 256 μs each. The structure of a superframe is shown in Figure 2.

Every superframe starts with a beacon period (BP) during which the beacon frames are mandatorily transmitted by each station to provide timing reference, carry control information, and broadcast channel reservation information for the entire superframe.

A BP consists of up to 96 beacon slots (BSs), each lasts 85 μs and could only be exclusively occupied by one station during a superframe. The first two BSs at the start of a BP are called signaling BS, while the following slots including 8 extension BSs are used for stations to join the existing communication group. It is assumed in this paper that each BP is always compact, which means there is no empty BSs existing except for the fixed-length signaling and the extension BSs. Thus, the length of a BP only depends on the number of the active stations within a communication group.

The PCA schemes provide prioritized backoff procedure to different ACs. Basically, before starting a data transmission, a station must sense the channel as idle for a period called Arbitrary Inter-frame Space (AIFS), plus an additional backoff period. The length of the AIFS is smaller in higher prioritized ACs.

After sensing the channel as idle for the duration of AIFS, the station starts the backoff period. The duration of a backoff period is specified by a backoff counter which will decrease by one when the channel is still sensed as idle during that backoff slot. Only when the backoff counter reaches zero, can the station initiate the transmission. The value of the backoff counter is uniformly sampled from the interval [0, CW[AC]], where CW[AC] is the Contention Window (CW) size of the AC and is randomly selected from [CWmin, CWmax]. Its initial value is set to CWmin. Generally, the value of CWmin, CWmax, and the difference between them are lower in higher prioritized ACs. The value of CW[AC] will be set to min(CWmax[AC], 2CW[AC]+1) in order to reduce the frame collision probability if the pervious transaction for the this AC was not finished or failed.

If the channel is sensed as busy during either the AIFS or backoff period, the station will defer from sensing the channel for a period of time called Network Allocation Vector (NAV). This parameter indicates the duration of the ongoing transmission. When the deferring ends, the paused backoff procedure will be resumed after the channel being sensed as idle for another AIFS.

Each station has the data packets of each AC buffered in its own queue, as shown in Figure 3. Each AC is recognized as a virtual station and contends for medium access by applying the PCA rules. If a collision occurs among different ACs within a station, known as virtual collision, the higher priority AC will be granted medium access by a virtual collision handler.

Once a station accesses the channel, it has a duration of TXOP for one or more frame transmissions or retransmissions without backoff. The maximum

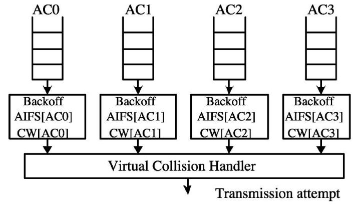

Figure 3: ACs queues and virtual collision.

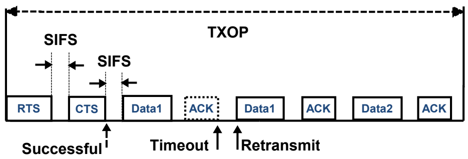

Figure 4: RTS/CTS exchange, successful transmission, retransmission and collision time.

number of frames that can be successfully transmitted during a TXOP is denoted by N_{TXOP}. It is assumed in this paper that Request-to-Send/Clear-to-Send (RTS/CTS) scheme is used. Thus, before a frame transmission, an RTS frame and a CTS frame are exchanged between the communication pairs. When the RTS/CTS frame processing is successfully completed, the frame transmission will start. A successful frame transmission is confirmed when the sender successfully receives an immediate acknowledgement (Imm-ACK) from the target receiver within an expected period. Otherwise, the sender must retransmit the previous frame as long as the remaining time in the TXOP is adequate for the new transmission. Figure 4 shows the transmission mechanisms.

The length of a TXOP is further restricted by the start of the next BP (also the end of a superframe) or the next DRP reservation. No PCA transmission may delay or foreshorten BP or DRP reservation.

The DRP scheme provides a collision-free channel access. The scheme allows the stations to arbitrarily reserve a number of MASs within the data transmission period for exclusive communication. For simplicity, it is assumed that only PCA scheme is implemented, and the DRP scheme is not implemented.

3 THROUGHPUT ANALYSIS AND FRAME LENGTH OPTIMIZATION

The saturation throughput is a fundamental performance indicator defined as the stable throughput limit reached by the system as the offered load increases (Bianchi, 2000). The analysis considers a fixed number of stations, denoted by M. Each of the station has multiple ACs and every AC is assumed to always have packets for transmission. A station will transmit as many packets as it can including retransmissions during its TXOP. The analysis ignores the signal propagation delay because propagation delays are small (in nano-second) in a short-range UWB network.

3.1 Analytical Model

To extend the model presented in (Kong et al., 2004) for the WiMedia PCA scheme, new assumptions and new transition probabilities will be introduced to the three-dimensional Markov chain. Initially, as stated in section 2, the limitation of a TXOP is further restricted by the next BP. For simplicity, it is assumed that any ongoing TXOP will be finished before the end of a superframe, and that collision information will be inferred to the transmitter before the end of the current superframe. A collision is confirmed by the transmitter if the expected ACK from the target receiver is not received within the expected period. The duration of inferring this collision equals to that of a successful transmission, as shown in Figure 4. The probability that a station is activated within the PCA period is calculated to statistically ensure that every TXOP starts and ends within the PCA period. This probability is denoted as P_{PCA}, and given in (Wong et al., 2007) as

$$P_{PCA} = N_{PCA}/N_{SF} \tag{4}$$

$$N_{PCA} = N_{SF} - N_{BP} \tag{5}$$

$$N_{BP} = \lceil (M + N_{BSig+BExt})T_{BS}/T_{MAS} \rceil,\ M \leq M_{MAX}, \tag{6}$$

where N_{PCA}, N_{SF}, and N_{BP} are the number of MASs occupied by a PCA period, a superframe, and a BP, respectively. The parameters T_{BS} and T_{MAS} are the duration of a beacon slot and MAS duration in μs, respectively. The parameter $N_{BSig+BExt}$ is the length of the signaling and extension BS in total, and M_{MAX} is the maximum number of stations allowed in a BP. There is still probability that the next BP will arrive between two adjacent TXOPs, or during the backoff period.

The channel busy probability p_b in the Markov chain of (Kong et al., 2004) caused by the transmission of any station in a considered slot time is extended to $p_b + P_{BP}$, since the WiMedia MAC also defines the channel as busy during the BP. The previous backoff process will resume subsequently.

The new stationary probability for an AC$_i$ to attempt to access the channel within the PCA period in a randomly chosen time slot is expressed as

$$\tau_i = [(1 - {p_i}^{m+1})/(1 - p_i)]b_{0,0,0}, \tag{7}$$

where m is the maximum number of the backoff stage, and $b_{0,0,0}$ is the probability for a station to be in the original state. The expression of $b_{0,0,0}$ given in (Kong et al., 2004) is extended as

$$b_{0,0,0} = [\frac{1+N(p_b+P_{BP})}{(p_b+P_{BP})}\frac{1-(1-(p_b+P_{BP}))^{A_i+1}}{(1-(p_b+P_{BP}))^{A_i+1}} + \lceil T_{si}\rceil(1-{p_i}^{m+1}) + (1+\lceil T_c\rceil p_i)\frac{1-{p_i}^{m+1}}{1-p_i} + \frac{1+N(p_b+P_{BP})}{2(1-(p_b+P_{BP}))^{A_i}}\sum_{j=0}^{m} W_j {p_i}^j]^{-1} . \tag{8}$$

In (8), p_i is the collision probabilities of the AC$_i$, and p_b is the channel busy probability. The value of W_j is CW size depends on the backoff stage j and satisfies $W_{j+1} = 2W_j + 1$. In addition, the parameters T_{si} and T_c are the length of AC$_i$'s TXOP and the collision time which is the period elapsed before a station confirms a collision, respectively. A_i is the duration of each AC$_i$'s AIFS.

Furthermore, the value of N in (8) is the expected frozen time calculated using the value of the NAV and the length of the BP. Since the value of the NAV equals to the corresponding TXOP the expression of N can be expressed as

$$N = \sum_{i=0}^{3} p_{si} TXOP_i + P_{BP}N_{BP}, \tag{9}$$

where p_{si} (16) is the probability that an AC$_i$'s frame can be transmitted successfully. Note that all the time-related values are expressed with the same unit: backoff slot σ.

The probability that a station attempts to access the channel in any given time slot can be found using equation (7). It is equal to the probability that the station has any type of AC's data buffered for transmission and is expressed as

$$\tau = 1 - \prod_{i=0}^{3}(1-\tau_i) . \tag{10}$$

Then, the collision probability of the AC$_i$ can be written as

$$p_i = 1-(1-\tau)^{M-1}\prod_{i'>i}(1-\tau_{i'}), \tag{11}$$

where $i' > i$ means that AC$_i'$ has higher priority than AC$_i$. Equation (11) considers that a collision will occur if at least one of the other stations transmits or the higher prioritized AC$_i$ in the station is transmitted at the same time.

The probability that the channel is occupied by a given AC$_i$ is the probability that the data is transmitted or collide, and is given by

$$\upsilon_i = [\lceil T_{si}\rceil(1-{p_i}^{m+1}) + \lceil T_c\rceil\frac{1-{p_i}^{m+1}}{1-p_i}]b_{0,0,0} . \tag{12}$$

Thus, the probability that the channel is occupied by a given station is

$$\upsilon = 1-\prod_{i=0}^{3}(1-\upsilon_i) . \tag{13}$$

Furthermore, the probability that a channel is busy, p_b, which is also the probability that there is at least one station transmitted or collide on the channel can be expressed as

$$p_b = 1-(1-\upsilon)^M . \tag{14}$$

The successful access probability of the AC$_i$ within a time slot is the probability that the backoff counter for this AC reaches zero at any backoff stage. This probability is illustrated as

$$p_{ti} = [\lceil T_{si}\rceil(1-{p_i}^{m+1})]b_{0,0,0} . \tag{15}$$

Finally, the probability that the AC$_i$'s frame can be transmitted successfully is the probability that there is no other higher priority ACs in the same station and only one station is transmitting. This probability is given as

$$p_{si} = \frac{M p_{ti}(1-\upsilon)^{M-1}\prod_{i'>i}(1-\upsilon_{i'})}{1-(1-\upsilon)^M} . \tag{16}$$

Equations (7)–(16) form a set of nonlinear equations, which means that it can be solved by means of numerical methods.

3.2 Throughput

The normalized system throughput, S_i, is defined as the fraction of time in which the channel is used to successfully transmit the payload bits, and is expressed as

$$\begin{aligned} S_i = {} & [p_{si}p_bP_{PCA}N_{TXOP}(1-p_e)L/R]\cdot \\ & \{[(1-p_b)+P_{BP}]\sigma + p_{si}p_bP_{PCA}T_{si} \\ & + p_bP_{PCA}(1-\sum_{j=0}^{3}p_{sj})T_c\}^{-1} . \end{aligned} \tag{17}$$

In (17), the factor $p_{si}p_bP_{PCA}N_{TXOP}(1-p_e)L/R$ is the mean amount of time needed for the payload information to be successfully transmitted in the PCA period, and R is the fixed data rate.

Furthermore, the term $[(1-p_b)+P_{BP}]\sigma$ is the expected number of the idle time slots due to either non-transmission or BP's occupation. The term

$(1-\sum_{j=0}^{3} p_{sj})T_c$ denotes the mean collision time for the AC, and the value of the T_c can be calculated using

$$T_c = T_{RTS} + 2T_{SIFS} + T_{CTS_{Timeout}}, \quad (18)$$

where T_{SIFS} is the duration of the Small Inter-frame Space (SIFS), and T_{RTS} is the time for the transmission of an RTS frame. T_{RTS} is denoted as

$$T_{RTS} = T_{Preamble} + T_{Header}, \quad (19)$$

where the value of $T_{Preamble}$ and T_{Header} are the duration of the PLCP preamble and header, respectively.

In (18), the value of $T_{CTS_{Timeout}}$ equals to the successful transmission time of a CTS which further equals to the value of T_{RTS}. The reason is that the size of the RTS and the CTS frames are the same. Thus, the value of T_c equals to the duration for a successful RTS/CTS frame exchange, denoted as T_s.

The value of the N_{TXOP} is calculated by

$$N_{TXOP_i} = \lfloor \frac{T_{TXOP_i} - T_G - T_s}{T_{PPDU} + 2T_{SIFS} + T_{ACK}} \rfloor, \quad (20)$$

where T_G is the guard time, and T_{PPDU} is the transmission time for the PLCP Protocol Data Unit (PPDU), expressed as

$$T_{PPDU} = T_{Preamble} + T_{Header} + T_{SYM} N_{Frame} \ . \quad (21)$$

In (21), the value of T_{SYM} is the OFDM symbol interval, and N_{Frame} is the number of OFDM symbols of the PLCP payload. The calculation of these parameters is specified in the WiMedia standard.

Finally, by substituting (18)–(21) into (17), the normalized throughput for an AC can be obtained.

3.3 Frame Length Optimization Design

The optimal frame length L in bits can be obtained by solving the equation $dS_i/dL = 0$ which can be expressed as

$$\frac{dS_i}{dL} = \frac{(1-P_{BER})^L + L(1-P_{BER})^L log(1-P_{BER})}{G+HL} - \frac{LH(1-P_{BER})^L}{(G+HL)^2} = 0 \ . \quad (22)$$

In (22), the parameter G is denoted as

$$G = A \times D, \quad (23)$$

where the factor A and D are expressed respectively as

$$A = [(1-p_b) + P_{BP}]\sigma + p_{si} p_b P_{PCA} T_{si} + p_b P_{PCA}(1 - \sum_{j=0}^{3} p_{sj}) T_c, \quad (24)$$

$$D = T_{Preamble} + T_{Header} + 2T_{SIFS} + T_{ACK} + 6\lceil (L_{FCS} + L_{Tail}) T_{SYM} / N_{IBP6S} \rceil \ . \quad (25)$$

Furthermore, the factor H in (22) is denoted as

$$H = A \times E, \quad (26)$$

where the term E is expressed as

$$E = 6\lceil T_{SYM}/N_{IBP6S} \rceil \ . \quad (27)$$

Finally, the optimal length, L_{opt}, can be calculated from (22) as

$$L_{opt} = \{Glog(1-P_{BER}) + [G^2 log^2(1-P_{BER})^2 - 4HGlog(1-P_{BER})]^{1/2}\} \cdot [-2log(1-P_{BER})H]^{-1} \ . \quad (28)$$

It can be observed that the value of the optimal frame length strongly depends on the value of the BER which is decided by the value of the SNR. Equation (28) also shows that the value of the optimal frame length is independent of the transmit data rate.

4 NUMERICAL RESULTS

The saturation throughput performance of the ACs is initially investigated as a function of the frame length. Subsequently, the variation of the optimal frame length value against the value of the SNR is analyzed. The used data rate is set to 200 Mbps, and the number of the active stations is set to 10. It is assumed that each station has all types of the ACs activated (AC_0 to AC_3). AC_3 has the highest priority. The parameters used to obtain numerical results are summarized in Table 1.

Both Figure 5 and Figure 6 illustrate that the saturation throughput is sensitive to the frame length and reaches the maximum at certain frame length value. For example, when the SNR value is set to 24.0 dB which corresponds to the BER value of 1.0e-3, the saturation throughput of all the ACs reaches their corresponding maximum value when the frame length increases to a value slightly more than 110 bytes. It can be seen that the AC_2 has the highest maximum saturation throughput value instead of the AC_3. The reason is that the AC_2 presents the longest TXOP duration (1024 μs) which is much longer than that of the AC_3 (256 μs). The throughput value gradually decreases to nearly zero when the frame length increases to more than 500 bytes due to the large value of the PER.

It is also noticeable that the value of the optimal frame length corresponding to the maximum saturation throughput becomes larger when the SNR is higher. For example, when the SNR is set to 14.0

Table 1: Calculation and Simulation Parameters.

Parameter	Value	Parameter	Value
M	10	N_{IBP6S}	375
T_{Header}	5.08μs	$T_{Preamble}$	9.375μs
T_{SYM}	312.5ns	T_G	12μs
T_{SIFS}	10μs	σ	9μs
T_{MAS}	256μs	T_{BS}	85μs
$N_{BSig+BExt}$	10	N_{SF}	256
AIFSN$_{AC_0}$	7	AIFSN$_{AC_1}$	4
AIFSN$_{AC_2}$	2	AIFSN$_{AC_3}$	1
TXOP$_{AC_0}$	512μs	TXOP$_{AC_1}$	512μs
TXOP$_{AC_2}$	1024μs	TXOP$_{AC_3}$	256μs
CW$_{AC_0}$	[15,1023]	CW$_{AC_1}$	[15,1023]
CW$_{AC_2}$	[7,511]	CW$_{AC_3}$	[3,255]

dB, the optimal frame length value of AC$_2$ is approximately 12 bytes which is smaller than 110 bytes obtained when the SNR is 24.0 dB. The reason is that higher SNR values lead to lower BER values, and this results in a lower PER value according to equations (1) and (3).

Furthermore, the results show that the optimal frame length value is not affected by the change of the priority of the AC. For instance, when the SNR value is set to 14.0 dB, all of the ACs have almost the same optimal frame length value of approximately 12 bytes. This observation is clearly illustrated in Figure 7. It can be seen that the values of the optimal frame length of all the ACs increase exponentially as the SNR value is higher. The variation profiles are almost the same for all of the ACs under different SNR conditions.

Finally, Figure 8 illustrates the effect of the number of the active stations on the size of the optimal frame length. It can be seen that the value of the optimal frame length of AC$_2$ is always stable for any number of the active stations from two to thirty. Thus, it means that the optimal value of the frame length can be treated as independent of the number of the active stations, the data rate, and the priority of the AC in the WiMedia standard. Therefore, a station can dynamically adapt the size of the transmitted frame length in the MAC layer according to the current SNR level so as to maximize its saturation throughput in the MB-OFDM UWB network.

5 CONCLUSIONS

A new design of the optimal frame length for maximizing the saturation throughput of the WiMedia PCA scheme over Rayleigh fading channel is proposed. Initially, the analytical model of (Kong et al., 2004) originally for EDCF scheme is extended into the MB-OFDM UWB region for the throughput analysis. Subsequently, the proposed optimal frame length design is carried out based on the extended model. The new model inherits the advantages of the original model and more importantly, the new model takes into account the effect of TXOP limits and the

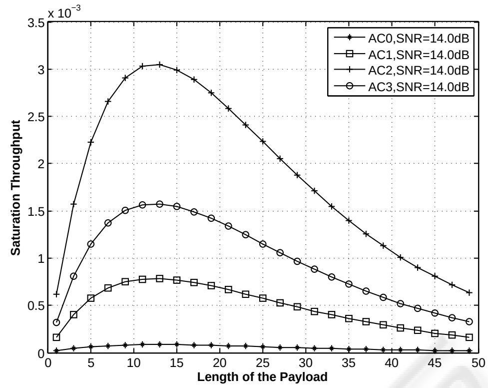

Figure 5: Saturation throughput of the ACs against the frame length (SNR=14.0dB).

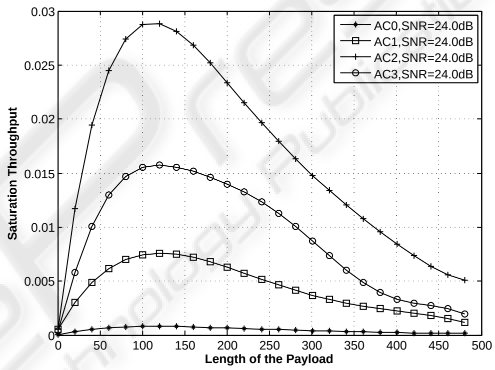

Figure 6: Saturation throughput of the ACs against the frame length (SNR=24.0dB).

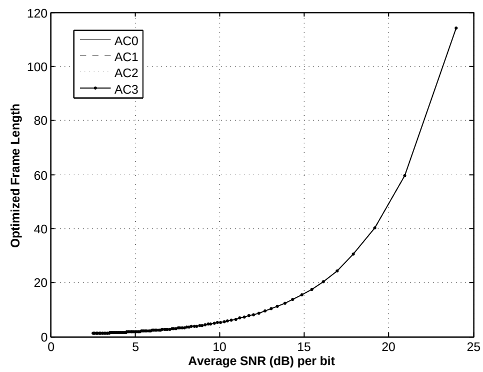

Figure 7: The optimal frame length varies with respect to the SNR.

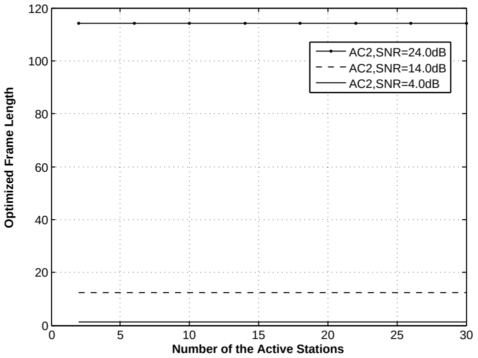

Figure 8: The optimal frame length varies with respect to the number of active stations.

effect of the Rayleigh fading channel on the BER value.

The results obtained in the simulation show that the value of the throughput is sensitive to the frame length and reaches the maximum at certain frame length value. The optimal frame length increases exponentially when the value of SNR is higher and can be treated as independent of the number of the active stations, the data rate, and the priority of the AC in the WiMedia standard. A station can then dynamically adapt the transmitted frame length value in the MAC layer according to the current value of the used SNR so as to maximize its saturation throughput in the MB-OFDM UWB network.

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