Packet Error Rate Analysis of IEEE 802.11b under IEEE 802.15.4 Interference

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***Abstract*— This paper presents an interference model of IEEE 802.11b wireless local area network (WLAN) affected by IEEE 802.15.4 wireless personal area network (WPAN). The packet error rate (PER) of the IEEE 802.11b under the interference of the IEEE 802.15.4 is analyzed, and is obtained by the bit error rate (BER) and the collision time. The safe distance ratio can be obtained from the PER. Further, this paper suggests a packet length to reduce the effect of the IEEE 802.15.4 interference and obtain a maximum throughput of the IEEE 802.11b. The analytic results are validated using the simulation.**

I. INTRODUCTION

As the 2.4 GHz Industrial, Scientific, and Medical (ISM) band utilization increases, it becomes important to understand how different wireless devices may affect each other. Because IEEE 802.11b (WLAN) [1], IEEE 802.15.1 (Bluetooth) [2], and IEEE 802.15.4 [3] are commonly used in this ISM band, a device adopting one standard exposes to a high level interference of other devices adopting other standards.

Every wireless standard has been designed for different purposes and desired performances. For example, the IEEE 802.11b is used to establish the wireless link that covers offices or buildings. The objective of the IEEE 802.15.4 is to provide the low complexity, low-cost and extremely low-power for wireless connectivity among inexpensive, fixed, portable and moving devices. Because of different purposes, they can be collocated within the interfering range of each other as illustrated in Fig. 1. Also, IEEE 802.11b and IEEE 802.15.4 devices can collocated within a notebook or a PDA. Therefore, the coexistence performance of the IEEE 802.11b and the IEEE 802.15.4 needs to be evaluated.

There are some previous studies about coexistence between the IEEE 802.11b and the IEEE 802.15.4 [4] [5] [6] [7]. In [4], the packet error rate (PER) of the IEEE 802.11b under the IEEE 802.15.4 interference is obtained from an experiment without analysis. In [5], the impact of an IEEE 802.15.4 network on the IEEE 802.11b devices is analyzed by the PER. However, the PER in [5] is analyzed without considering the collision time that IEEE 802.11b packets is overlapped by IEEE 802.15.4 packets. In [6], the PER of the IEEE 802.15.4 under the interference of the IEEE 802.11b is evaluated using a simulation. In [7], the PER of the IEEE 802.15.4 under the interference of the IEEE 802.11b is evaluated using the analysis and the simulation. The PER is obtained from the BER and the collision time in [7].

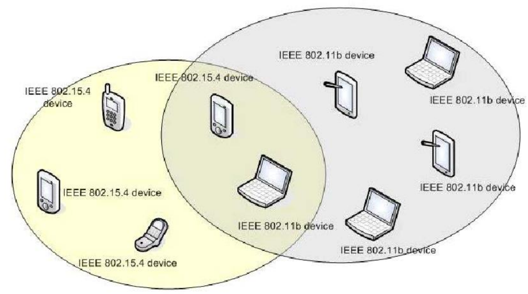

Fig. 1. IEEE 802.11b and IEEE 802.15.4 collocated within the interfering range

In this paper, the PER of the IEEE 802.11b under the interference of the IEEE 802.15.4 is analyzed. The PER can be obtained by the BER and the collision time. The BER is obtained from the signal to noise and interference ratio (SNIR). The collision time is defined as the time that IEEE 802.11b packets is overlapped by IEEE 802.15.4 packets. The safe distance ratio between the two systems can be obtained by the PER. This paper suggests an appropriate packet length to reduce the effect of the IEEE 802.15.4 interference and obtain a maximum throughput of the IEEE 802.11b. The analytic results are verified in the simulation.

This paper is organized as follows. Section 2 briefly overviews the IEEE 802.11b and the IEEE 802.15.4. In Section 3, the BER of the IEEE 802.11b under the IEEE 802.15.4 is evaluated. Section 4 describes the interference model of the IEEE 802.11b and the IEEE 802.15.4. The PER and throughput are obtained in Section 4. Analytic and simulation results are shown in Section 5. Finally, conclusions are presented in Section 6.

II. IEEE 802.11B AND IEEE 802.15.4 OVERVIEW

A. *IEEE 802.11b*

The IEEE 802.11b is a standard for Medium Access Control (MAC) and Physical Layer (PHY) specifications for wireless LANs. Four data rates have been specified for the IEEE

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802.11b. The basic data rate is 1 Mbps encoded with differential binary phase shift keying (DBPSK). The data rate of 2 Mbps is available using differential quadrature phase shift keying (DQPSK). Higher rates, 5.5 and 11 Mbps, are also provided using complementary code keying (CCK).

The IEEE 802.11b MAC uses a Distributed Coordination Function (DCF) for media access. The DCF is an implementation of carrier-sense multiple access collision avoidance (CSMA/CA) which follows the 4-way handshaking protocol.

The backoff window is based on a random value uniformly distributed in the interval $[\mathrm{CW}_{\min}, \mathrm{CW}_{\max}]$, where $\mathrm{CW}_{\min}$ and $\mathrm{CW}_{\max}$ represent the Contention Window parameters. If the medium is determined busy at any time during the backoff slot, the backoff procedure is suspended. The Fig. 2 shows the basic access mechanism for data transmission.

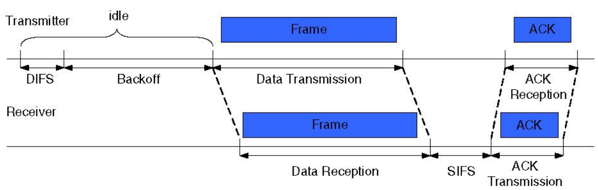

Fig. 2. IEEE 802.11b data transmission scheme

The Error detection is performed by checking the Frame Check Sequence (FCS) that is attached to the packet payload. If an error is found, the packet is dropped and is then later retransmitted.

B. IEEE 802.15.4

The IEEE 802.15.4 defines the PHY and MAC sublayer specifications for low-rate wireless personal area networks (LR-WPANs). The IEEE 802.15.4 can be implemented for simple devices that consume minimal power and typically operate in the personal operating space (POS) of 10m.

The IEEE 802.15.4 supports two types of topologies, the star or the peer-to-peer topology. In the star topology, the communication is conducted between devices and a PAN coordinator. The PAN coordinator performs its function as the primary controller of the PAN. In the peer-to-peer topology, any device can communicate with any other device as long as both devices are in mutual communication range.

A summary of the features of the IEEE 802.15.4 is shown in Table I.

TABLE I
IEEE 802.15.4 HIGH LEVEL CHARACTERISTICS

PHY (MHz)	Channel	Spreading parameters		Data parameters	
		Chip rate (kchip/s)	Modulation	Bit rate (kb/s)	Symbols
868	1	300	BPSK	20	Binary
915	10	600	BPSK	40	Binary
2450	16	2000	O-QPSK	250	16-ary Orthogonal

The 868 and 915 MHz PHY are available in Europe offering one channel and North America offering 10 channels, respectively. While 2.4 GHz PHY is available worldwide offering 16 channels. The transmit power capability of 1 mW is typically specified in the standard. The IEEE 802.11b and the IEEE 802.15.4 channel at the 2.4GHz is illustrated in Fig. 3.

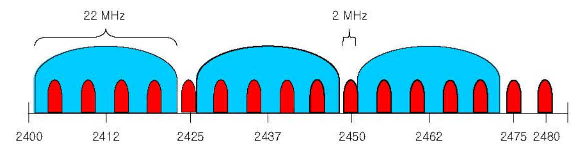

Fig. 3. IEEE 802.11b and IEEE 802.15.4 channel

The IEEE 802.15.4 MAC sublayer supports two types of channel access mechanisms, unslotted CSMA/CA mechanism in nonbeacon-enable network and slotted CSMA/CA mechanism in beacon-enable network. In nonbeacon-enabled mode, when a node wishes to send data to the coordinator, it simply transmits its data frame, using unslotted CSMA/CA. However, the node must poll the coordinator to receive data from the coordinator. In beacon-enabled mode, use of a superframe structure is supported. The superframe structure is shown in Fig. 4. The superframe is composed of an active portion and an inactive portion. An active portion is divided into two sections, the contention access period (CAP) and the contention free period (CFP). The guaranteed time slots (GTS) are located within CFP.

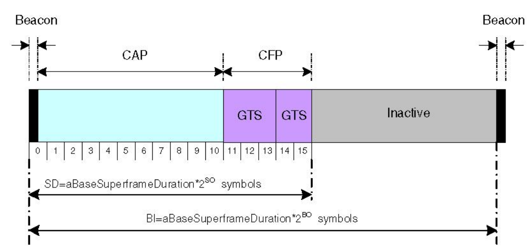

Fig. 4. Superframe Structure

III. BIT ERROR RATE EVALUATION OF THE IEEE 802.11B UNDER THE IEEE 802.15.4

The IEEE 802.11b PHY provides dynamic data rate, which is obtained as the combination of different modulations and codes. It is possible for the data rate to shift up to 11Mbps using CCK. E_b/N_o is used to denote the ratio of the average energy per information bit to the noise power spectral density at the receiver input in the case of an additive white Gaussian noise (AWGN) channel. The BER for 11Mbps data rate, P_B, can be expressed as

$$P_B = 1 - \frac{1}{\sqrt{2\pi}} \int_{-X}^{\infty} \left(\frac{1}{\sqrt{2\pi}} \int_{-(v+X)}^{v+X} \exp\left(-\frac{y^2}{2}\right) dy \right)^{\frac{N}{2}-1} \cdot \exp\left(-\frac{v^2}{2}\right) dv \tag{1}$$

, where $X = \sqrt{2 \cdot E_b/N_o}$, and N equal to 8 [8].

Fig. 5 shows the relationship between the bit error probability and the E_b/N_o.

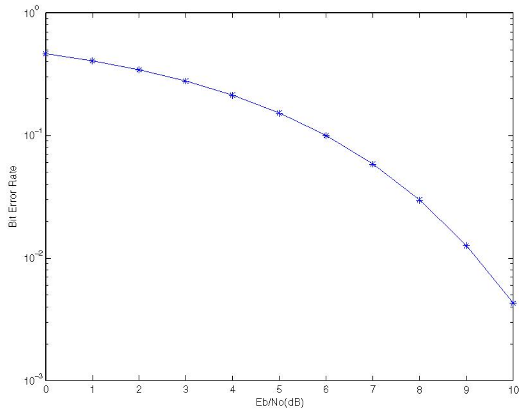

Fig. 5. Bit Error Probability for IEEE 802.11b

When the bandwidth of the IEEE 802.11b is overlapped with that of the IEEE 802.15.4, the interfering IEEE 802.15.4 signal can be considered as the partial band jammer noise for the IEEE 802.11b [9]. For the partial band jammer noise, the SNIR can be defined as

$$SNIR = 10\log\left(\frac{P_c}{P_{N_o} + P_i}\right) + ProcGain \qquad (2)$$

where P_c is the power of the desired signal, P_{N_o} is the noise power and P_i is the power of the interferer. The $ProcGain$ is the spreading gain of the IEEE 802.11b. By replacing E_b/N_o in (1) with SNIR in (2), the BER of the IEEE 802.11b under the IEEE 802.15.4 can be obtained.

Path loss models represent the difference (in dB) of the signal strength between the transmitter and the receiver. In order to facilitate the analysis, a simplified indoor propagation model is used in this paper [10].

$$L_p(d) = \begin{cases} 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) & , d \le d_o \\ 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) + 10n\log_{10}\frac{d}{d_o} & , d > d_o \end{cases} \qquad (3)$$

where d is the distance between the transmitter and the receiver. d_0 is the length of the line of sight (LOS). λ is the wavelength of the propagating wave; c/f_c where c is the light velocity and f_c is the carrier frequency. n is the path loss exponent that indicates the rate at which the path loss increases with distance between the transmitter and the receiver. For the indoor propagation model, the path loss exponent, n, is 3.3.

Assumed that the transmitter power is fixed as $P_{T,x}$, the receiver power can be expressed as follows,

$$P_{R,x} = P_{T,x} \cdot 10^{-\frac{L_p(d)}{10}} \qquad (4)$$

where the subscript x is either W for the IEEE 802.11b or Z for the IEEE 802.15.4.

IV. Interference Model of the IEEE 802.11b and the IEEE 802.15.4

This paper assumed that both IEEE 802.11b and IEEE 802.15.4 transmit the packets without consideration of whether the channel state is busy or not for the worst interference environments and the interfering signal is occurred from proximally located the IEEE 802.15.4. If the carrier detection method is used to determine the channel state, this assumption can be tenable without loss of generality.

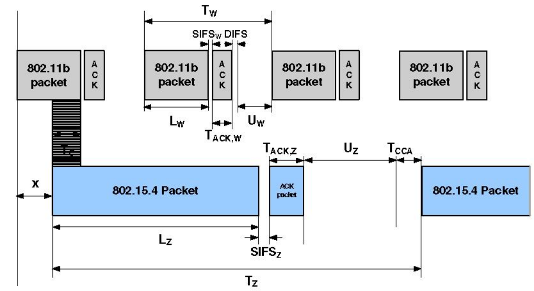

Fig. 6. Interference Model between IEEE 802.11b and IEEE 802.15.4

The interference model can be illustrated like Fig. 6. Let T_X, L_X, and U_X be the inter-arrival time, the packet duration, and the average random backoff time, respectively, where the subscript X is either W for the IEEE 802.11b or Z for the IEEE 802.15.4. The T_C is the collision time that overlap IEEE 802.11b packets and IEEE 802.15.4 packets in time. Besides, other parameters are listed in Table II.

TABLE II
PARAMETERS OF THE INTERFERENCE MODEL

T_W	inter-arrival time between two IEEE 802.11b packets
L_W	duration of IEEE 802.11b packet
$SIFS_W$	short IFS of IEEE 802.11b
$DIFS$	DCF IFS of IEEE 802.11b
$T_{ACK,W}$	duration of IEEE 802.11b ACK packet
U_W	average backoff time of IEEE 802.11b
σ_W	slot time of IEEE 802.11b
T_Z	inter-arrival time between two IEEE 802.15.4 packets
L_Z	duration of IEEE 802.15.4 packet
$SIFS_Z$	short IFS of IEEE 802.15.4
$LIFS$	long IFS of IEEE 802.15.4
$T_{ACK,Z}$	duration of IEEE 802.15.4 ACK packet
U_Z	average backoff time of IEEE 802.15.4
σ_Z	slot time of IEEE 802.15.4

Both standards use carrier sense multiple access with collision avoidance (CSMA/CA) and perform a backoff process before transmitting packets. Because both standards transmit the packets without consideration of the channel state in assumption, the transmissions of both standards are independent. Therefore, the backoff time is randomly chosen within the minimum contention, CW_{min}.

The inter-arrival times, T_W and T_Z, can be expressed as:

$$T_W = L_W + SIFS_W + T_{ACK,W} + DIFS + U_W \qquad (5)$$

and

$$T_Z = L_Z + T_{CCA} + SIFS_Z + T_{ACK,Z} + U_Z \qquad (6)$$

where T_{CCA} denotes the two clear channel assessment (CCA) slot time of the IEEE 802.15.4 and $U_X = \sigma_X \cdot CW_{min,X}/2$.

Assume that the time offset x is uniformly distributed in $[0, T_Z)$, then, the collision time, T_C can be obtained as :

$$T_C = \begin{cases} L_W - x & x < L_W \\ 0 & L_W \le x < U_Z \\ x - U_Z & U_Z \le x < U_Z + L_W \\ L_W & U_Z + L_W \le x < T_Z \end{cases} \quad (7)$$

The packet error rate (PER) can be derived from the BER and the $T_C^{(b)}$; T_C/T_b, where T_b is the bit duration of the IEEE 802.11b. The PER, P_P is expressed as

$$P_P = 1 - (1 - P_B)^{T_C^{(b)}} \quad (8)$$

In this paper, if no retransmission limit is assumed for each received frame in error and U_W is fixed as $\sigma_W \cdot CW_{min,W}/2$, the average transmission time for a packet can be given as follows [11].

$$T_{av} = T_W + (1 - P_P) \cdot \sum_{i=0}^{\infty} i \cdot {P_P}^i \cdot T_W = \frac{T_W}{1 - P_P} \quad (9)$$

Hence, the throughput of the IEEE 802.11b under the IEEE 802.15.4 interference, R_W, is given by

$$R_W = \frac{Data}{T_{av}} = \frac{D_W \cdot L_W \cdot (1 - P_P)}{T_W} \quad (10)$$

where $Data$ is the payload size of the packet in bits, and D_W is data rate.

V. Analysis and Simulation Result

For analysis and simulation, the IEEE 802.11b has the data rate of 11 Mbps. The IEEE 802.15.4 adopts the slotted version. Fig. 7 shows the analysis and simulation scenario.

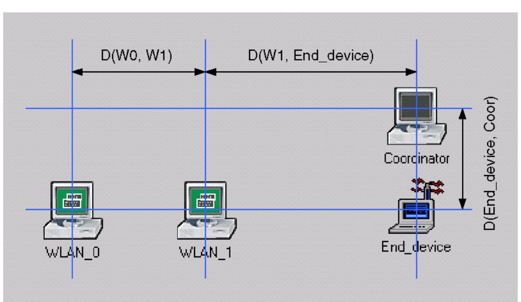

Fig. 7. Simulation Model between IEEE 802.11b and IEEE 802.15.4

As illustrated in Fig. 7, D(W0, W1), D(End_device, Coor), and D(W1, End_device) expressed the distance between two IEEE 802.11b devices, the distance of two IEEE 802.15.4 devices, and the distance between the IEEE 802.11b WLAN_1 and the IEEE 802.15.4 End_device, respectively. In this paper, it is assumed that the IEEE 802.11b WLAN_0 and the IEEE 802.15.4 End_device transmit data packets and the other devices only send ACK packets for the received packets. For simplicity, acknowledgement (ACK) packets of both the IEEE 802.11b and the IEEE 802.15.4 are not considered. The configuration and simulation parameters used in this paper are shown in Table III.

TABLE III

Configuration and Simulation Parameters

Parameters \ Devices	IEEE 802.11b device	IEEE 802.15.4 device
Transmitted Power	30mW	1mw
Inter-arrival time	0.001s	0.001s
Payload size	1500 bytes	105 bytes
Slot time	20 μs	320 μs
CW_{min}	31	7
Center frequency	2.418 GHz	2.416 GHz

Fig. 8 shows the PER of the IEEE 802.11b under the interference of the IEEE 802.15.4. In the Fig. 8, The D(W0, W1) and D(End_device, Coor) is fixed to 5m and 1 m, respectively. The D(W1, End_device) is varied from 0m to 5m.

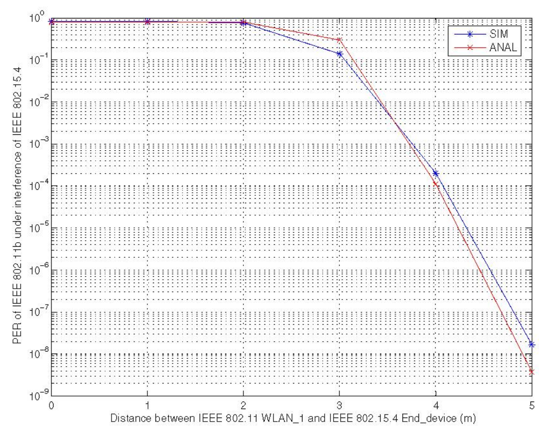

Fig. 8. PER of IEEE 802.11b under interference of IEEE 802.15.4

In Fig. 8, the in-band interference power is assumed as $P_{R,Z}$, the received signal power of the IEEE 802.15.4. When the D(W1, End_device) is longer than 4m, the PER of the IEEE 802.11b is about 10^{-4} in simulation.

Fig. 9 shows the safe distance ratio for the IEEE 802.11b under the interference of the IEEE 802.15.4 in terms of the PER. The safe distance ratio is defined as $D(End\_device, Coor)/D(W0, W1)$. The D(W0, W1) is varied from 1m to 5m. The D(End_device, Coor) is fixed to 1 m. The D(W1, End_device) is varied with respect to the D(W0, W1).

In Fig. 9, when D(W0, W1) is equal to 5m, The PER is the highest, and then followed by 4m, 3m, 2m and 1m. This is due to the WLAN_0's signal power received by the WLAN_1. As the D(W0, W1) is increased, WLAN_0's signal power received by the WLAN_1 is decreased. Note that though D(W0, W1) is any distance from 1m to 5m, the safe distance ratio is 0.8 and the PER of each distance is averagely 3.5×10^{-4}.

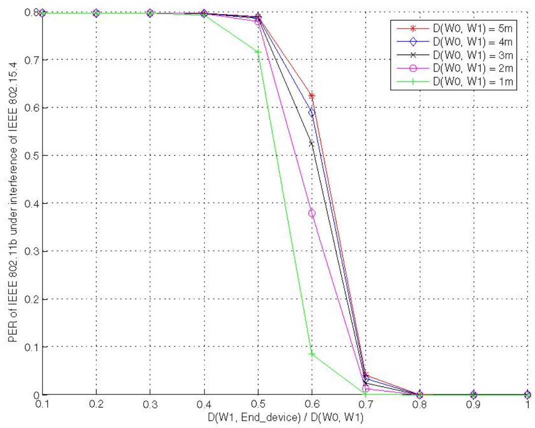

Fig. 9. Safe distance for IEEE 802.11b under interference of IEEE 802.15.4

The high packet error rate is shown within 3m as Fig. 8 and Fig. 9. To reduce the effect of the IEEE 802.15.4 interference within 3m, the packet length of the IEEE 802.11b must be decreased. If the packet length is decreased, the PER of the IEEE 802.11b is low. However, the throughput of the IEEE 802.11b is also decreased. Therefore, this paper suggests proper packet length to reduce the effect of the IEEE 802.15.4 interference and to obtain a maximum throughput of the IEEE 802.11b.

Fig. 10 shows the throughput at an IEEE 802.11b receiver, WLAN_1, as a function of packet duration under the IEEE 802.15.4 interference.

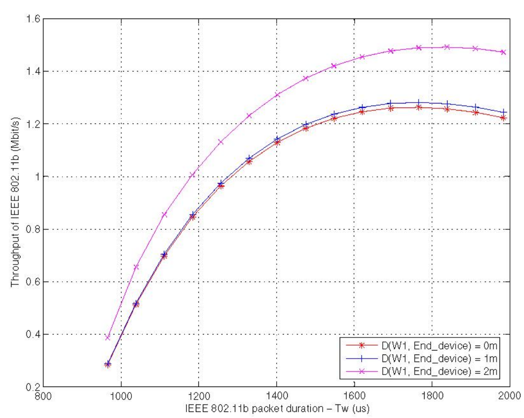

Fig. 10. Throughput of IEEE 802.11b under interference of IEEE 802.15.4

The suggested packet length is obtained from the function of packet duration, T_W.

As using the suggested packet length at each D(W1, End_device), the WLAN_1 can reach the maximum throughput at each distance. Table IV summarizes the suggested packet length of the IEEE 802.11b with respect to distances.

VI. Conclusion

In this paper, the packet error rate (PER) of the IEEE 802.11b under the IEEE 802.15.4 interference is analyzed. The PER of the IEEE 802.11b is obtained from the bit error rate (BER) and the collision time. The BER of the IEEE 802.11b is given by closed equation from the complementary code keying (CCK) modulation scheme. The collision time is calculated under assumption that the packet transmission of the IEEE 802.11b and the IEEE 802.15.4 are independent. Since the bandwidth of the IEEE 802.11b, 22MHz, is larger than that of the IEEE 802.15.4, 2MHz, the IEEE 802.15.4 signal is considered as the partial band jammer noise for the IEEE 802.11b.

If the distance between the IEEE 802.11b and the IEEE 802.15.4 is longer than 4m, the interference of the IEEE 802.15.4 can be negligible to the performance of the IEEE 802.11b, i.e., the PER is about 10^{-4}. Regardless of any distance between two IEEE 802.11b,if the safe distance ratio is 0.8, the interference effect of the IEEE 802.15.4 can also be negligible, i.e., the PER is about 3.5×10^{-4}.

Further, if there are the IEEE 802.11b and the IEEE 802.15.4 within distance less than 3m, this paper propose that the IEEE 802.11b should transmit the suggested payload size to minimize the effect of the IEEE 802.15.4 interference and obtain a maximum throughput.

This result can suggest coexistence criteria for the IEEE 802.11b and the IEEE 802.15.4.

TABLE IV
Suggested packet length for IEEE 802.11b under interference of IEEE 802.15.4

Distance / Length	0m	1m	2m
Packet length of IEEE 802.11b (bytes)	1203	1203	1303

References

[1] *IEEE Standard for Wireless LAN Medium Access Control(MAC) and Physical Layer(PHY) Specification*, 1997.

[2] *IEEE Standard for Wireless Medium Access Control(MAC) and Physical Layer(PHY) Specifications for Wireless Personal Area Networks (WPANs)*, 2002.

[3] *IEEE Standard for Wireless Medium Access Control (MAC) and Physical Layer(PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)*, 2003.

[4] A. Sikora, "Coexistence of IEEE 802.15.4 (ZigBee) with IEEE 802.11 (WLAN), Bluetooth, and Microwave Ovens in 2.4 GHz ISM-Band," *http://www.ba-loerrach.de/stzedn/*, 2004.

[5] I. Howitt and J. Gutierrez, "IEEE 802.15.4 low rate wireless personal area network coexistence issues," *Wireless Communications and Networking, 2003*, 2003.

[6] N. Golmie and D. Cypher, "Performance analysis of low rate wireless technologies for medical applications," *Computer Communications*, vol. 28, pp. 1266–1275, 2005.

[7] S. Y. Shin and W. H. Kwon, "Packet Error Rate Analysis of IEEE 802.15.4 under IEEE 802.11b Interference," *Wired/Wireless Internet Communications, 2005*, pp. 279–288, 2005.

[8] M.Borgo and A.Zanella, "Analysis of the hidden terminal effect in multi-rate IEEE 802.11b networks," *Proc. Wireless Personal Multimedia Communications, 2004*, 2004.

[9] R. Z. R. Peterson and D. Borth, Eds., *Introduction to Spread Spectrum Communications*. Prentice Hall Publications, 1995.

[10] T. S. Rappaport, Ed., *Wireless Communications: Principles and Practice*. Prentice Hall Publications, 1996.

[11] T. Walke, Ed., *Mobile Radio Networks: Networking, Protocols and Traffic Performance*. Wiley, 2001.