IEEE 802.15.4 환경 하에서의 IEEE 802.11b의 성능 해석

Performance Analysis of IEEE 802.11b under IEEE 802.15.4 Environment

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Abstract

Coexistence of different wireless systems that share the 2.4 GHz ISM frequency band is becoming one of the most important issue. This paper presents a model of the interference that IEEE 802.11b affected by IEEE 802.15.4. The packet error rate (PER) of IEEE 802.11b under the interference of IEEE 802.15.4 is analyzed. The PER is obtained by using the bit error rate (BER) and the collision time. 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 analytical results are validated using simulation.

Keywords

WLAN, WPAN, interference, bit error rate(BER), packet error rate(PER), partial band jamming

I. INTRODUCTION

Due to the increase of 2.4 GHz Industrial, Scientific, and Medical (ISM) band (i.e., 2.400-2.4835GHz) utilization, 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] devices are commonly used in this ISM band, a device adopting one standard exposes to a high level of interference of the other device adopting the other standard.

Every wireless standard has been designed for different purposes and desired performance. For example, IEEE 802.11b is used to establish wireless link that covers a fairly limited area as well as large area(i.e.,offices or buildings). The objective of IEEE 802.15.4 is to provide the characteristics of low complexity, low-cost and extremely low-power for wireless connectivity among inexpensive, fixed, portable and moving devices. Because of different purposes between IEEE 802.11b and IEEE 802.15.4, they can be collocated within the interfering range of each other. Figure 1 depicts that the IEEE 802.11b and IEEE 802.15.4 are collocated within the interfering range respectively. Also, it cannot be denied the possibility of the collocation between IEEE 802.11b and IEEE 802.15.4 like a case of existing IEEE 802.11b and IEEE 802.15.1 device in a notebook or a PDA. Therefore, the coexistence performance of IEEE 802.11b and IEEE 802.15.4 needs to be evaluated.

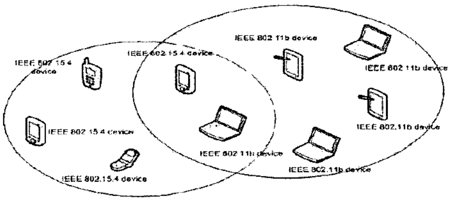

Fig. 1. IEEE 802.11b and IEEE 802.15.4 collocated within the interfering range

Though there are a lot of previous studies about coexistence between IEEE 802.11b and IEEE 802.15.1, those about coexistence IEEE 802.11b and IEEE 802.15.4 are not quite satisfactory. In [4], test report, the packet error rate (PER) of IEEE 802.11b with IEEE 802.15.4 interference is only obtained from experiment without the 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 this paper, the PER of the IEEE 802.11b under the interference of the IEEE 802.15 4 is analyzed. The BER is obtained from signal to noise and interference ratio of the partial band jamming. The collision time is defined as the time that overlaps IEEE 802.11b and the IEEE 802.15.4 packets. 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 verified in the simulation results.

This paper is organized as follows. Section 2 briefly overview IEEE 802.15.4. In Section 3, the bit error rate (BER) of IEEE 802.11b under IEEE 802.15.4 is evaluated. Section 4 describes the interference model of IEEE 802.11b and IEEE 802.15.4. In Section 5, analytic and simulation results are shown. Finally, conclusions are presented in section 6.

II. IEEE 802.15.4 OVERVIEW

IEEE 802.15.4 defines the physical layer (PHY) and medium access control (MAC) sublayer specifications for low-rate wireless personal area networks (LR-WPANs). 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 provides Two different device types, a full-function device(FFD) and a reduced-function device(RFD). The FFD can be operated in three modes such as a personal area network(PAN) coordinator, a coordinator, or a device. FFD can communicate with other FFDs or RFDs. While an RFD is intended for simple applications and can only communicate with an FFD.

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 single central controller (i.e., PAN coordinator). A device is typically either the initiation point or the termination point for network communications. 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. In addition, a PAN coordinator is contained in topology.

A summary of the features of the IEEE 802.15.4 is shown in Table 1.

Table 1. 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

1. Physical Layer

The feature of the IEEE 802.15.4 PHY are activation and deactivation of the radio transceiver, energy detection(ED), link quality indication (LQI), channel selection clear assessment (CCA), and transmitting as well as receiving packets[3]. IEEE 802.15.4 PHY was designed to be operated in three license-free bands, the 868 MHz, 915 MHz and 2.4 GHz band PHYs.

The 868 MHz and 915 MHz PHY are available in Europe offering one channel with a data rate of 20 kb/s and North America offering 10 channels with a data rate of 40 kb/s respectively. The 868 and 915 MHz PHY uses binary phase shift key (BPSK) as a modulation. While 2.4 GHz PHY is available worldwide offering 16 channels with a data rate of 250kb/s. The offset quadrature phase shift key (OQPSK) is used as a modulation in this band. The transmit power capability of 1 mW is typically specified in the standard. Also the maximum transmit power shall be conformed with local regulation.

These three PHY use a common frame structure. A preamble, a start of packet delimiter, a packet length, and PHY payload, (i.e., PSDU) together form PHY protocol data unit (PPDU). Figure 2 shows the a common frame structure.

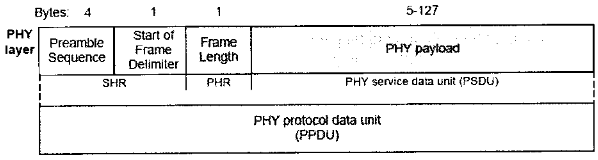

Fig. 2. IEEE 802.15.4 Frame Structure

2. Medium Access Control Sublayer

The IEEE 802.15.4 medium access control (MAC) sublayer supports two types of channel access mechanism, unslotted CSMA-CA mechanism in nonbeacon-enable network and slotted CSMA-CA mechanism in beacon-enable network.

In non-beacon mode, when a node wishes to send data to the coordinator, it simply transmits its data frame, using unslotted CSMA-CA. There are an advantage that the node does not have to regularly turn on the receiver to receive the beacon. However, to receive data from the coordinator the node must turn on the receiver and poll the coordinator. Moreover the coordinator cannot send data to the node without node's MAC command requesting the data.

In beacon mode, use of a superframe structure is supported. The superframe structure is shown in Figure 3. The superframe is composed of an active portion and inactive portion. An active portion is 16 equally sized time slots grouped in two sections, the contention access period (CAP) and the contention free period (CFP). The time slots allocated for the CFP, guaranteed time slots (GTS), are located within CFP.

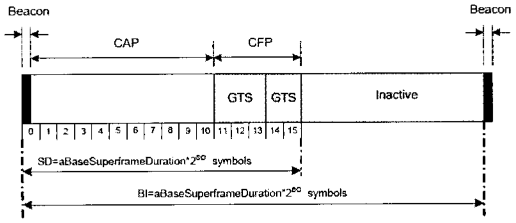

Fig. 3. Superframe Structure

III. Bit Error Rate Evaluation of the IEEE 802.11b under the IEEE 802.15.4

The physical layer of IEEE 802.11b provides dynamic data rate, which is obtained as the combination of different modulations and codes. The data rate is possible to shift up to 11Mbps using DSSS and Complimentary Code Keying (CCK). Denoting by E_b/N_o, 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 bit error rate (BER) for 11Mbps data rate, P_B, can be expressed as

$$CDOT\exp\left(-\frac{y^2}{2}\right)dy\Big)^{\frac{N}{2}-1} \cdot \exp\left(\frac{-v^2}{2}\right)dv \tag{1}$$

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

Figure 4 shows the relationship between the bit error probability and the E_b/N_o.

When the bandwidth of IEEE 802.11b is overlapped with the one of IEEE 802.15.4, the interfering IEEE 802.15.4 signal can be considered as the partial band jammer noise for IEEE 802.11b.

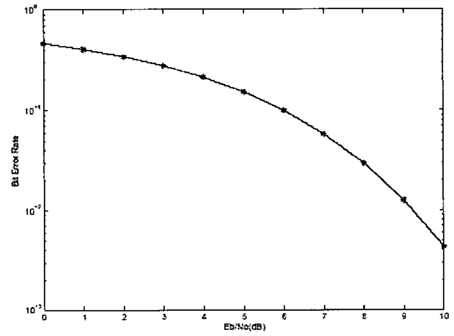

Fig. 4. Bit Error Probability for IEEE 802.11b under IEEE 802.15.4

For the partial band jammer in this paper, the signal-to- interference plus noise ratio can be defined as

$$SNIR = 10\log\left(\frac{P_C}{P_{N_0}+P_i}\right) + procGain \quad (2)$$

where P_c is the power of the desired signal, P_{N_0} 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_0 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 this paper, a indoor propagation model is used as path loss model [7].

$$L_p(d) = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right),\ d \le d_o \quad (3)$$

where d is the distance between the transmitter and the receiver. d_0 is 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.

$$L_p(d) = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) + 10n\log_{10}\frac{d}{d_o},\ d > d_o \quad (4)$$

where n is the path loss exponent which characterizes the relationship between the increases in path loss values with increase in distance between the transmitter and the receiver. For the indoor propagation model, this value, n, is 3.3.

Assumed that the transmitter power is fixed P_{Tx}, and then the receiver power is as follows,

$$P_{R_x} = P_{T_x} \cdot 10^{-\frac{L_p(d)}{10}} \quad (5)$$

IV. INTERFERENCE MODEL OF THE IEEE 802.11B AND THE IEEE 802.15.4

This paper is mainly concerned with evaluating the IEEE 802.11b system performance in an interference environment. Therefore, this paper considers a IEEE 802.11b receiver as reference and derive the packet error probability at this device.

This paper assumed that the interfering signal is occurred from proximally located IEEE 802.15.4 and 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.

Collision occurs when both the IEEE 802.11b packets and the IEEE 802.15.4 packets, interfering packets, overlap in time and frequency.

The interference model can be illustrated like Figure 5.

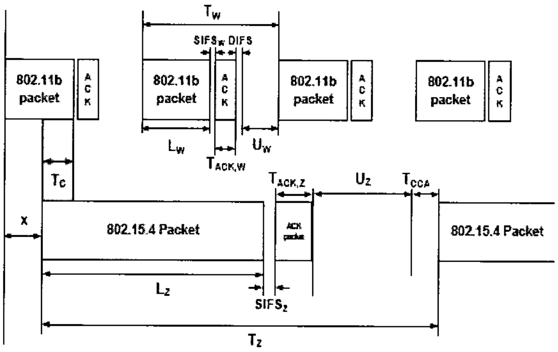

Fig. 5. Interference Model between IEEE 802.11b and IEEE 802.15.4

Let T_W and T_Z be the inter-arrival time of the IEEE 802.11b and the IEEE 802.15.4 respectively. L_W and L_Z are the packet duration of the IEEE 802.11b and the IEEE 802.15.4, respectively. U_W and U_Z are the average random backoff time of the IEEE 802.11b and the IEEE 802.15.4 respectively. The T_C is the collision time that overlap IEEE 802.11b packets and the IEEE 802.15.4 packets in time.

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 easily expressed as:

$$T_W = L_W + SIFS_W + T_{ACK,W} + DIFS + U_W \tag{6}$$

and

$$T_Z = L_Z + T_{CCA} + SIFS_Z + T_{ACK,Z} + U_Z \tag{7}$$

where T_{CCA} denotes the two clear channel assessment (CCA) slot time and $U_X = \sigma_X \cdot CW_{\min,X}/2$, the subscript X is either W for the IEEE 802.11b of Z for IEEE 802.15.4. Besides, other parameters are listed in Table 2.

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

$$T_C = \begin{cases} L_W - x & x < L_W \\ 0 & L_W \le x < U_Z \\ x - U_Z & U_Z \le x < U_Z + L_W \\ L_W & U_Z + L_W \le x < T_Z \end{cases} \tag{8}$$

Table 2: 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
$CW_{min;W}$	minimum CW size of IEEE 802.11b
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
$CW_{min;Z}$	minimum CW size of IEEE 802.15.4
U_Z	average backoff time of IEEE 802.15.4
σ_Z	slot time of IEEE 802.15.4

Figure 6 shows the collision time with varying time offset x. The packet error rate (PER) can be derived from the BER and the $T_C^{(b)}$; T_C/T_b. The PER is expressed as

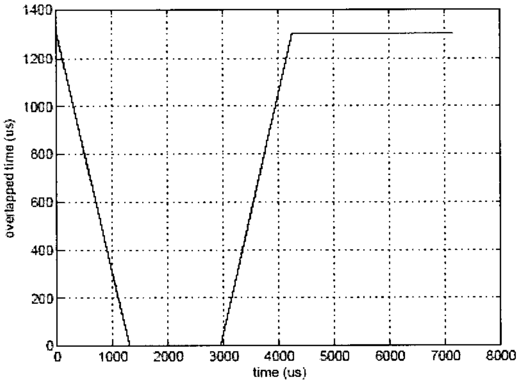

Figure 6: Collision Time

$$P_P = 1 - P\{correct\ IEEE\,802.11b\ packet\} = 1 - (1 - P_B)^{T_C^{(b)}} \tag{9}$$

where T_b is the bit duration of IEEE 802.11b.

In this paper, if no re-transmission 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.

$$T_{av} = T_W + (1 - P_P) \cdot \sum_{i=0}^{\infty} i \cdot P_P^i \cdot T_W = \frac{T_W}{1 - P_P} \tag{10}$$

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

$$R_W = \frac{Data}{T_{av}} = \frac{D_W \cdot L_W \cdot (1 - P_P)}{T_W} \tag{11}$$

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, IEEE 802.11b used complementary code keying (CCK) modulation with 11 Mbps. IEEE 802.15.4 adopted the slotted version. Figure 7 shows the analysis and simulation scenario.

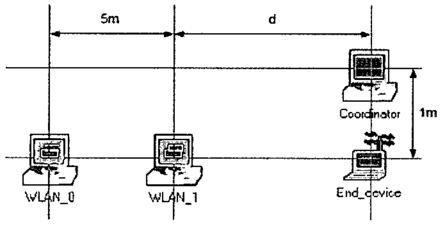

Fig. 7. Simulation Model between IEEE 802.11b and IEEE 802.15.4

As illustrated in Figure 7, the distance between two IEEE 802.11b devices is fixed to 5m and that of two IEEE 802.15.4 devices is fixed to 1m. The variable, *d* expressed the distance between the IEEE 802.11b WLAN_1 and IEEE 802.15.4 End_device. In this paper, assumed that the IEEE 802.11b WLAN_0 and IEEE 802.15.4 End device transmit data packets and the other devices only send ACK packets for the received packets. For simplicity, ACK packets of both the IEEE 802.11b and the IEEE 802.15.4 are not considered. The distance, d between the WLAN_1 of IEEE 802.11b WLAN devices and IEEE 802.15.4 End_device is varied from 0m to 5m.

The simulation parameters used in this paper are shown in Table III.

Table 4: Simulation Parameters

Standard / Parameters	IEEE 802.11b	IEEE 802.15.4
Transmitted power	30mW	1mW
Payload size	1500Bytes	105Bytes
CW_{min}	31	7
Center frequency	2.418GHz	2.416GHz

Figure 8 shows the PER of the IEEE 802.11b under the interference of the IEEE 802.15.4.

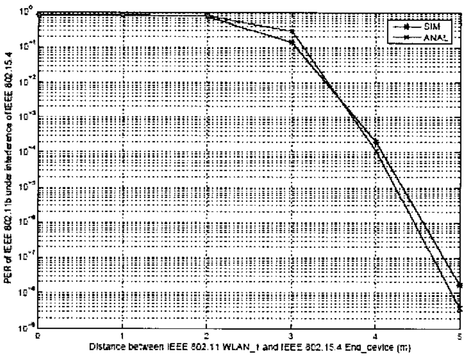

Fig. 8. PER of the IEEE 802.11b under interference of the IEEE 802.15.4

In Figure 8, the in-band interference power is assumed as $P_{Rx\_IEEE\,802.15.4}$, the received signal power of the IEEE 802.15.4. When the distance, d, is longer than 4m, the PER of the IEEE 802.11b is about 10^{-4} in simulation.

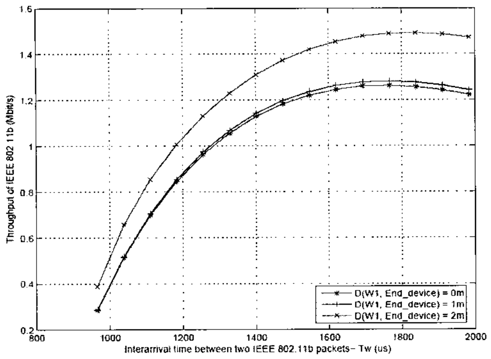

Fig. 9. Throughput of IEEE 802.11b under interference of IEEE 802.15.4

The high packet error rate is shown within 3m as Figure. 8. 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. Figure. 9 shows the throughput at an IEEE 802.11b receiver, WLAN_1, as a function of packet duration under the IEEE 802.15.4 interference.

The suggested packet length os obtained from the function of packet duration, T_W. As using the suggested packet length at each distance between the WLAN_1 of IEEE 802.11b WLAN devices and IEEE 802.15.4 End_device, the WLAN_1 can reach the maximum throughput at each distance. Table 4 summarizes the suggested packet length of the IEEE 802.11b with respect to distance.

VI. CONCLUSION

In this paper, the packet error rate(PER) of the IEEE 802.11b under IEEE 802.15.4 is analyzed. The PER is obtained from the bit error rate (BER) and the collision time. Since the IEEE 802.11b adopts the complementary code keying (CCK) modulation, the BER is given by approximate equation. The collision time is calculated under assumption that the packet transmission of the IEEE 802.11b and IEEE 802.15.4 are independent.

As a main result, if the distance between two devices of IEEE 802.11b and 802.15.4 is longer than 4m, the performance of the IEEE 802.11b doesn't decrease in the interference of the IEEE 802.15.4. i.e., the PER is about 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 reduce the effect of the IEEE 802.15.4 interference and obtain a maximum throughput of the IEEE 802.11b.

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

Table 4: Suggested packet length for IEEE 802.11b

Distance Length	1m	2m	3m
payload of IEEE 802.11b(bytes)	1203	1203	1303

[Reference]

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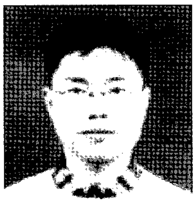

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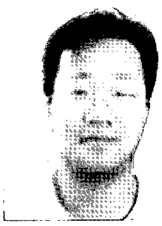

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