IEEE 802.15.4 환경 하에서의 IEEE 802.11b의 성능 해석

Performance Analysis of IEEE 802.11b under IEEE 802.15.4 Environment

윤대길[1] 신수용[1] 권욱현[1] 김정준[2] 김용호[2], 신영희[2], [1]서울대학교 전기컴퓨터공학부 [2]KT 컨버전스 연구소
Dae-Kil Yoon[1] Soo-Young Shin[1] Wook hyun Kwon[1] Jung-Jun Kim[2] Young-Ho Kim[2] Young-Hee Shin[2]
[1]School of Electrical Engr. and Computer Science, Seoul National University [2]KT convergence Laboratory

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 may experience because of 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. The analytical results are validated using simulation.

Keywords

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

I. INTRODUCTION

As the 2.4 GHz Industrial, Scientific, and Medical (ISM) band (i.e., 2.400-2.4835GHz) utilization increases, it becomes important to understand how different wireless devices, operating in this band, may affect each other. Because IEEE 802.11b (WLAN)[1], IEEE 802.15.1 (Bluetooth)[2], and IEEE 802.15.4[3] devices and so on 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 and device 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.

As above-mentioned, 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. Even though conditions given above occur, designed performance must be maintained respectively. Therefore, the coexistence performance of IEEE 802.11b and IEEE 802.15.4 needs to be evaluated.

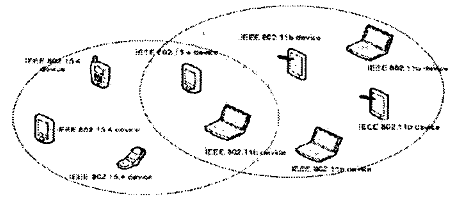

Fig. 1. IEEE 802.11b and IEEE 802.15.4 collocated within the interfering range

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 and not considered the analysis. In [5], the impact of an IEEE 802.15.4 network on the IEEE 802.11b devices is analyzed. The PER of IEEE 802.11b under IEEE 802.15.4 is derived as the probability of activity at given clusters and number of interferers. However the bit error rate (BER) as a function of ratio of bit energy to noise power spectral density for the IEEE 802.11b packets is not considered. Also, a transmitted packet length is not considered in [5].

In this paper, the PER of the IEEE 802.11b under the interference of the IEEE 802.15 4 is analyzed by using the BER and the collision time. 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. The analytic results are verified in the simulation results using OPNET.

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.

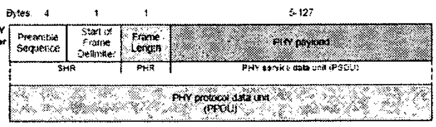

Fig. 2. IEEE 802.15.4 Frame Structure

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.

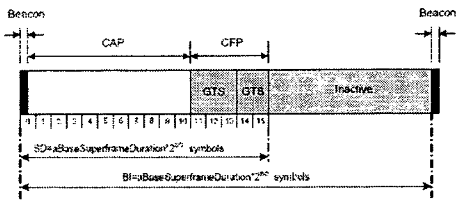

Fig. 3. Superframe Structure

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

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

, 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.

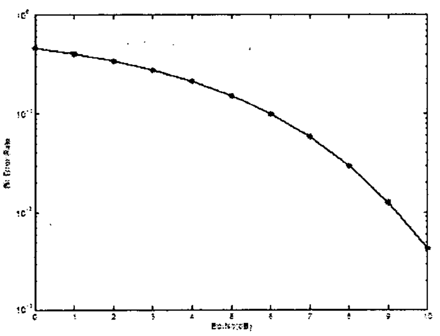

Fig. 4. Bit Error Probability for IEEE 802.11b under IEEE 802.15.4

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

$$SNIR = \frac{P_C}{P_{N_0} + \sum_{k=1}^{N_I} P_i(k)} \quad (2)$$

where P_C is the power of the desired signal, P_{N_0} is the noise power and $P_i(k)$ is the power of the k-th interferer for K = 1, ... , N_I, with N_I denoting the number of active interferers[6]. By replacing E_b/N_o with SNIR, the BER of the IEEE 802.11b under 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, Free Space Path Loss model is used as path loss model[7].

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

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.

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

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 free space, this value, n, is 2.

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 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.

A collision occurs when both the IEEE 802.11b packets and the IEEE 802.15.4 packets, interfering packets, overlap in time and frequency. The collision is detected at the IEEE 802.11b receiver in the form of Signal to Interference Ratio(SIR) that depends on the power transmitted, the distance traveled, and the path loss model used.

The interference model can be illustrated like Figure 5.

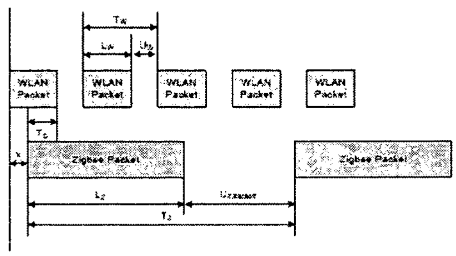

Fig. 5. Interference Model between IEEE 802.11b and IEEE 802.15.4

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.

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

$$T_W = L_W + SIFS_W + T_{ACK,W} + DIFS + \frac{CW_{\min,W} - 1}{2} \quad (6)$$

and

$$T_Z = L_Z + T_{CCA} + SIFS_Z + T_{ACK,Z} + \frac{CW_{\min,Z} - 1}{2} \quad (7)$$

where T_{CCA} denotes the two clear channel assessment slot time of the IEEE 802.15.4. Besides, other parameters are listed in Table 2.

Then, the collision time, T_C can be obtained as :

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

Table 2: Parameters of the Interference Model

T_W	inter-arrival time between two IEEE 802.11b packets
L_W	length of IEEE 802.11b packet
$SIFS_W$	short IFS of IEEE 802.11b
$LIFS$	long 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
T_Z	inter-arrival time between two IEEE 802.15.4 packets
L_Z	length 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

,where $L_W \le T_Z - L_Z$, and x is assumed to a random variable that is uniformly distributed between zero and T_Z.

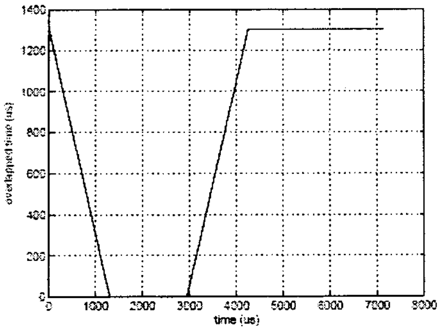

Figure 6: Collision Time

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

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

,where T_b is the bit duration of IEEE 802.11b.

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.

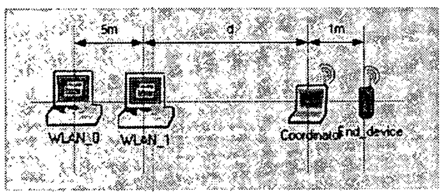

Fig. 7. Simulation Model between IEEE 802.11b and IEEE 802.15.4

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 1 m. The variable, d expressed the distance between the IEEE 802.11b WLAN_1 and IEEE 802.15.4 Coordinator. In paper, assumed that the IEEE 802.11b WLAN_1 and IEEE 802.15.4 End device transmit data packets and the other devices only send ACK packets for the received packets. The distance, d between the WLAN_1 of IEEE 802.11b WLAN devices and IEEE 802.15.4 Coordinator is varied form 0m to 5m. Figure 8 shows the PER of the IEEE 802.11b under the interference of the IEEE 802.15.4 with the same center frequencies.

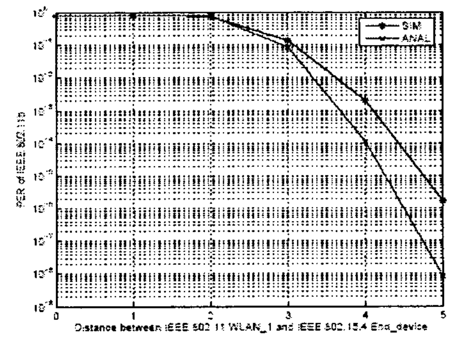

Fig. 8. PER of the IEEE 802.11b under interference of the IEEE 802.15.4

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.

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 5m, the performance of the IEEE 802.11b doesn't decrease in the interference of the IEEE 802.15.4. The simulation results are shown to prove the analysis.

This result can suggest coexistence standard for the IEEE 802.11b and IEEE 802.15.4. Also, this result can be available for designing a network collocating both IEEE 802.11b and IEEE 802.15.4.

[Reference]

[1] IEEE Std.802-11, "IEEE Standard for Wireless LAN Medium Access Control(MAC) and Physical Layer(PHY) Specification," 1997.

[2] IEEE Std.802-15.1, "IEEE Standard for Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specification for Wireless Personal Area Networks (WPANs)," 2002.

[3] IEEE Std.802-15.4, "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 IEEE802.15.4 (ZigBee) with IEEE802.11 (WLAN), Bluetooth, and Microwave Ovens in 2.4 GHz ISM-Band," *http://www.ba-loerrach.de/stzedn/, 2004.*

[5] I. Howitt and J.A. Gutierrez, "IEEE 802.15.4 low rate - wireless personal area network coexistence issues," *IEEE Wireless Communications and Networking, vol. 3, pp. 1481-1486, 2003.*

[6] R.E Ziemer R.L. Peterson and D.E. Borth, "Introduction to Spread Spectrum Communications," *Prentice Hall Publications, 1995.*

[7] Theodore S. Rappaport, "Wireless Communications: Principles and Practice," *Prentice Hall Publications, 1996.*