Probability Analysis of channel collision between IEEE 802.15.4 and IEEE 802.11b using Qualnet Simulation for various Topologies

G.M.Tamilselvan and Dr.A.Shanmugam

***Abstract*—Coexistent heterogeneous wireless networks may interfere with each other and result in significant performance degradation when devices are collocated in the same environment. With the increasingly deployed Wireless Personal Area Network (WPAN) and Wireless Local Area Network (WLAN) devices, channel conflict has become very frequent and severe when one WPAN technology coexists with other WLAN technologies in the same interfering range. In this paper, we study the coexistence issue between IEEE 802.15.4 and IEEE 802.11b. We present analytical models on the non-conflicting channel allocation probabilities, focusing on the coexistence scenarios of IEEE 802.15.4 coexisting with IEEE 802.11b. The interference model of IEEE 802.15.4 wireless Personal area network (WPAN) affected by IEEE 802.11b wireless Local area network (WPAN) also presented. The packet error rate (PER) of the IEEE 802.15.4 under the interference of the IEEE 802.11b is analyzed, and is obtained by the bit error rate (BER) and the collision time. The BER is obtained from signal to noise and interference ratio. The safe distance ratio can be obtained from the PER. The analytic results are validated for various topologies using Qualnet 4.5 simulation. Further this paper investigates the PER of IEEE 802.15.4, with the consideration of the mobility models of the WLAN nodes.**

***Keywords*—Bit Error Rate, Coexistence, Collision time, IEEE 802.11b, IEEE 802.15.4 .**

I. Introduction

Various wireless technologies have been developed for WPAN purposes. For instance, Bluetooth [1] (as described by the IEEE 802.15.1 standard [2]) has been proposed as a cable replacement technology for wireless personal devices. IEEE 802.15.3 standard [3] has been proposed for High Rate WPAN (HR-WPAN) applications, and IEEE 802.15.4 standard [4] has been drafted for Low Rate WPAN (LR-WPAN) uses. Since IEEE 802.15.1, IEEE 802.15.3, and IEEE 802.15.4 all operate in the same 2.4GHz ISM (Industrial-Scientific-Medical) frequency band, channel allocation conflicts are inevitable between these WPAN technologies. The coexistence issues will become even severe while these WPAN technologies also coexist with other 2.4GHz based wireless/radio technologies (e.g. IEEE 802.11b/g [5], cordless phone, and microwave oven). It soon becomes important to understand the characteristics of each channel allocation scheme and how each channel allocation scheme interacts with the others. Table I summarizes some of the relevant properties of the wireless standards mentioned above.

TABLE I: WIRELESS TECHNOLOGIES IN 2.4GHZ ISM FREQUENCY BAND

IEEE Standard	**802.11b/g**	**802.15.1**	**802.15.3**	**802.15.4**
Frequency Band	2.4GHz	2.4GHz	2.4GHz	2.4GHz
rev Bandwidth	22MHz	1MHz	15MHz	2MHz
Number of Channels	11	79	5	16
Max Rate (Mbps)	11/ 54	0.72	55	0.25
Transmission Range	100m	10m	10m	20m
Applications	WLAN	WPAN	HR-WPAN	LR-WPAN

Some related researches study the coexistence problem between the IEEE 802.15.4 and the 802.11b [5], [6].In [5], the packet error rate (PER) of the IEEE 802.15.4 under the IEEE 802.11b and IEEE 802.15.1 is obtained by experiments only. In [6], the impact of an IEEE 802.15.4 network on the IEEE 802.11b devices is analyzed. Channel Conflict Probabilities between IEEE 802.15 based Wireless Personal Area Networks is modeled in [7]. Packet Error Rate of IEEE 802.15.4 under IEEE 802.11b interference is analyzed in [8].In [9] Packet Error Rate of IEEE 802.11b under IEEE 802.15.4 interference is analyzed. To the best knowledge of the authors channel conflict probabilities between IEEE 802.11b and IEEE 802.15.4 has not been modeled in the literature.

In this paper, we present analytical model to calculate the channel collision probability between IEEE 802.11b and IEEE 802.15.4 networks. The coexistence issue between IEEE 802.15.4 and IEEE 802.11b using PER analysis for various parameters is studied with help of Qualnet 4.5 simulation.

The rest of the paper is organized as follows. In section II, we present analysis on the probability of channel collision between IEEE 802.11b and IEEE 802.15.4 networks. In section III, PER of the IEEE 802.15 4 under the interference of IEEE 802.11b is analyzed with the help of Qualnet 4.5 simulation. Section finally, conclusions are presented in Section IV.

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II. PROBABILITY OF CHANNEL COLLISION BETWEEN IEEE 802.11B AND IEEE 802.15.4

To proceed to the analysis of our study, we briefly recap the channel allocation mechanism of the IEEE 802.11b and IEEE 802.15.4 standards. Basically, IEEE 802.11b employs Direct Sequence Spread Spectrum (DSSS) technique, and it defines 14 channels with 22 MHz bandwidth for each one. In U.S. and most of the countries in the world, the first 11 channels are used; whereas, the first 13 channels are used in Europe and Singapore, and all of the 14 channels are used in Japan. The central frequencies of IEEE 802.11b channels are separated by 5 MHz as shown in Eq. 1.

$$f_{IEEE802.11b} = 2412 + 5k;\ k = 0 : : : 13 \quad (1)$$

However, since adjacent IEEE 802.11b channels are partially overlapped, the so-called adjacent channel interference will happen if two IEEE 802.11b nodes in close operate using adjacent channels. In this case, the overall network performance will become degraded. Therefore, in practice, only the maximum non-overlapping channels (i.e., channel 1, 6, and 11) are employed in most of nowadays IEEE 802.11b networks. Therefore, the analysis presented in this paper would be based on the assumption that only the maximum non overlapping channels are used in IEEE 802.11b networks (as shown in Fig. 1).

On the other hand IEEE 802.15.4 also employs DSSS on PHY layer, and it is operated in three frequency bands. Among a total of 27 channels (with 2MHz width for each channel) across these three bands, sixteen channels are available in the 2.4GHz band with 250 kbps maximum data throughput, 10 in the 915MHz band with 40 kbps maximum data throughput, and 1 in the 868 MHZ band with 20 kbps maximum data throughput. The center frequency of these channels is defined as follows:

$$f = \begin{cases} 868.3;\ k = 0 \\ 906 + 2(k-1);\ k = 1 \dots 10 \\ 2405 + 5(k-11);\ k = 11 \dots 26 \end{cases} \quad (2)$$

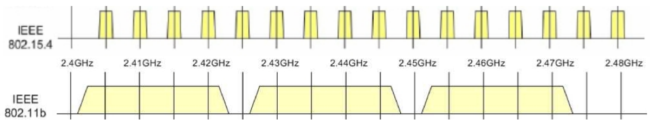

Fig. 1 Channel allocations of IEEE 802.11b and IEEE 802.15.4 technologies.

In this section, we present analysis on the non-conflicting channel allocation probability, i.e., P_{good}, when an IEEE 802.15.4 network coexists with n IEEE 802.11b networks. For simplicity, we assume the employed channels of the n IEEE 802.11b networks are not conflicted (i.e., non-overlapping channels and $n \leq 3$). Note that we do not consider scenarios consisting of multiple IEEE 802.15.4 networks. When one IEEE 802.15.4 network coexists with n IEEE 801b networks, there are two possible cases: a) the IEEE 802.15.4 network operates on one of the four non-overlapped channels (i.e. the IEEE 802.15.4 channels are not overlapped with IEEE 802.11b channels, as shown in Figure 1); b) the IEEE 802.15.4 network operates on one of the overlapped channels.

In the first case, the probability of non-conflicting channel allocation is always 1 regardless of the number of coexisting IEEE 802.11b networks. Whereas in the second case, the probability of non-conflicting channel allocation is $\frac{3-n}{3}$. By un-conditioning the two cases, the P_{good} for a single IEEE 802.15.4 network coexisting with n IEEE 802.11b networks can be calculated by:

$$Pgood = \begin{cases} \frac{4}{16} + \frac{12}{16} \times \frac{3-n}{3};\ 0 \leq n \leq 3, \\ 0;\ otherwise \end{cases} \quad (3)$$

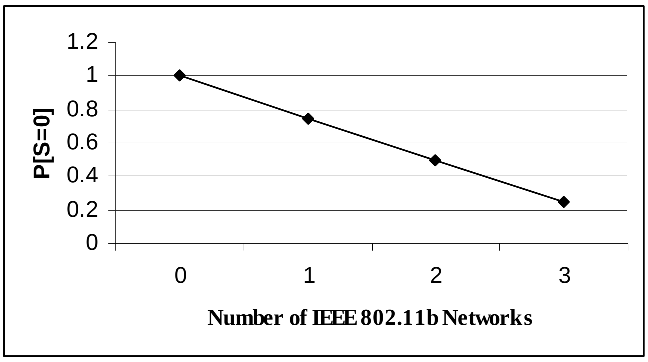

Fig. 2 Analytical results of P[S=0] while one IEEE 802.15.4 network coexist with multiple IEEE 802.11b networks

Figure 2 illustrates the relationship of P_{good}, i.e. P[S=0] and the number of coexisting IEEE 802.11b network for a single IEEE 802.15.4, which shows P_{good} decreases linearly as n increases. These analytical results will be validated in the subsequent sections with Qualnet 4.5 simulation.

III. PER ANALYSIS OF IEEE 802.15 4 NETWORK UNDER THE INTERFERENCE OF IEEE 802.11B NETWORKS

A. *Bit Error Rate Evaluation of IEEE 802.15.4 under IEEE 802.11b*

The PHY of the IEEE 802.15.4 at 2.4 GHz uses offset quadrature phase shift keying (OQPSK) modulation. Denote that the $E_b=N_0$ is 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. Then the bit error rate (BER), P_B, can be expressed as

$$P_B = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \quad (4)$$

Where Q(x) is

$$Q(x) = \frac{1}{\sqrt{x}} \int_x^\infty \exp\left(\frac{-u^2}{2}\right) du \quad (5)$$

Figure 3 shows the relationship between the bit error rate and the E_b/N_0 simulated in Matlab.

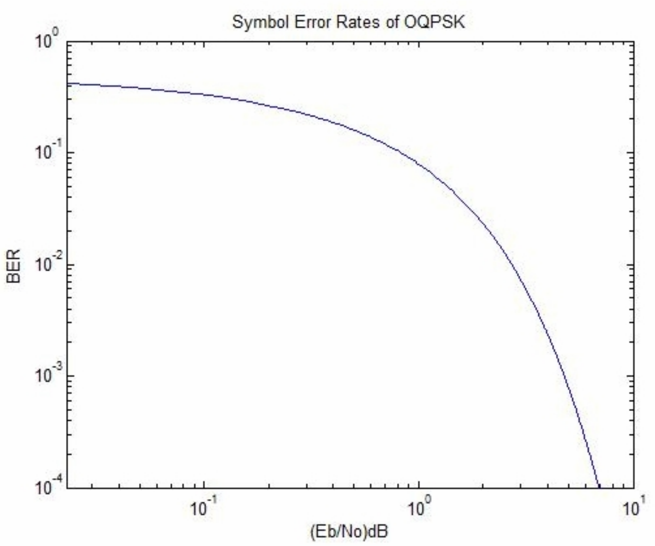

Fig. 3 Theoretic Bit Error Rate of OQPSK

B. Collision Time Evaluation of IEEE 802.15.4 under IEEE 802.11b

In this paper, blind transmissions are assumed for both IEEE 802.15.4 and IEEE 802.11b. In other words, they transmit the packets without consideration of the channel state whether busy or not to make the worst case interference environments. If both standards use the carrier detection method to determine the channel state, the blind transmission will occur. Then, the interference model can be illustrated as shown in Figure 4. In Figure 4, T_X, L_X, and U_X denote the inter-arrival time, packet duration, and average random backoff time, respectively, where the subscript X is either Z for the IEEE 802.15.4 and W for the IEEE 802.11b. The other parameters are listed in Table 2. The T_C is the collision time.

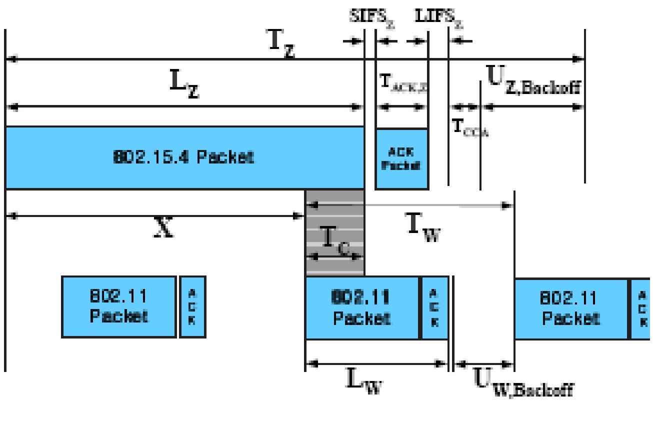

Fig. 4 .Interference model between IEEE 802.15.4 and IEEE 802.11b

If the blind transmissions are assumed, the transmissions of the IEEE 802.15.4 and IEEE 802.11b are independent. Since the both protocols transmit packets without consideration of the channel state, the contention window not changed by the busy channel. The transmission of the IEEE 802.11b packet is assumed to be error-free, so there is no increase of the contention window of the IEEE 802.11b. Therefore, in both protocols, the backoff time is randomly chosen within the minimum contention window, i.e., CW_{min}.

Then, the inter-arrival times, T_W, T_Z can be easily obtained as:

$$T_Z = L_Z + T_{CCA} + SIFS_Z + T_{ACK,Z} + \frac{CW_{\min,Z} - 1}{2} U_Z \quad (6)$$

and

$$T_W = L_W + SIFS_W + T_{ACK,W} + DIFS + \frac{CW_{\min,W} - 1}{2} U_W \quad (7)$$

where T_{CCA} denote the CCA time of the IEEE 802.15.4. The tale 2 shows the parameters of the interference model.

TABLE II: PARAMETERS OF THE INTERFERENCE MODEL

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
$T_{ACK,Z}$	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
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
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

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

$$T_C(x) = \begin{cases} L_Z - 2(T_W - L_W), 0 \le x \le L_Z - 2T_W \\ 2L_W, L_Z - 2T_W < x \le T_W - L_W \\ 3L_W + x - T_W, T_W - L_W < x \le L_Z - (T_W + L_W) \\ L_Z - 2(T_W - L_W), L_Z - (T_W + L_W) < x \le L_Z - T_W \\ 2L_W, L_Z - T_W < x \le 2T_W - L_W \\ 3L_W + x - 2T_W, 2T_W - L_W < x \le L_Z - L_W \\ L_Z - 2(T_W - L_W), L_Z - L_W < x \le 2T_W \\ 2L_W, 2T_W < x \le T_Z \end{cases} \quad (8)$$

Fig. 5 shows the collision time with varying time offset x.

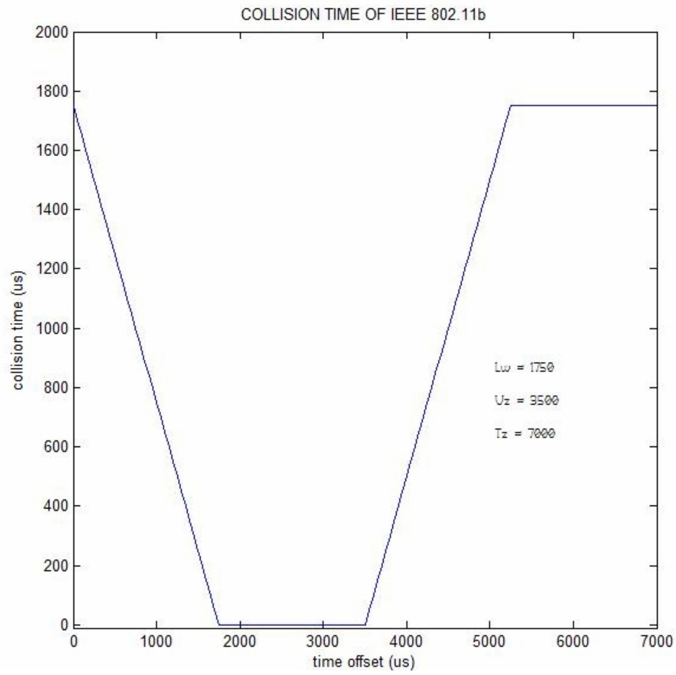

Fig. 6 Collision Time

Now, the packet error rate (PER) is easily obtained from the BER and the collision time, T_C. For simplicity, acknowledgement (ACK) packets of both IEEE 802.11 and IEEE 802.15.4 are not considered. Let's denote the P_B and P_B^I that the BER without and with interference, respectively. If the bit duration of the IEEE 802.15.4 is b, then the PER, P_P, is expressed as

$$P_P = 1-\left(1-(1-P_B)^{L_Z-\left[T_C/b\right]}\right)\left(1-(1-P_B{}^I)^{\left[T_C/b\right]}\right) \quad (9)$$

In this section the PER of IEEE 802.15.4 under the interference of IEEE 802.11b is analyzed using Qualnet 4.5 simulation. For simulation, the slotted CSMA/CA of the IEEE 802.15.4 model is developed using Qualnet 4.5. The complementary code keying (CCK) modulation with 11 Mbps is used for the IEEE 802.11b. The payload size of the IEEE 802.15.4 is 105 bytes, and that of the IEEE 802.11b is 1500 bytes. The simulation scenario is shown in Figure 6.

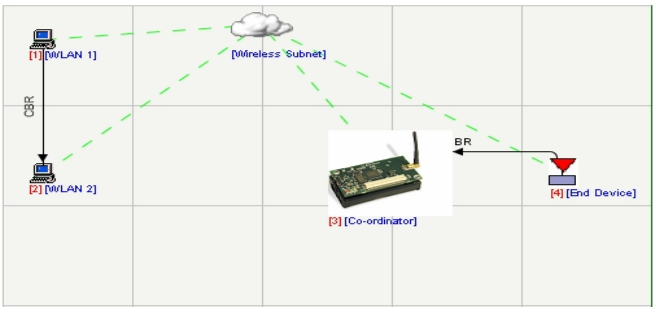

Fig. 7 Simulation Model between IEEE 802.15.4 and IEEE 802.11b

For simplicity, only the IEEE 802.15.4 End device and IEEE 802.11b WLAN 1 transmit data packets. The other nodes send only the ACK packets for the corresponding data packets. The distance between two IEEE 802.15.4 devices and that of the two IEEE 802.11b devices are fixed to 1 m. The distance between IEEE 802.15.4 Coordinator and the IEEE 802.11b WLAN 1 is d, which is variable. Figure 7 shows the PER of the IEEE 802.15.4 under the interference of the IEEE 802.11b with the same center frequencies. The distance between Coordinator and WLAN 1, d, varies from 1m to 10m.

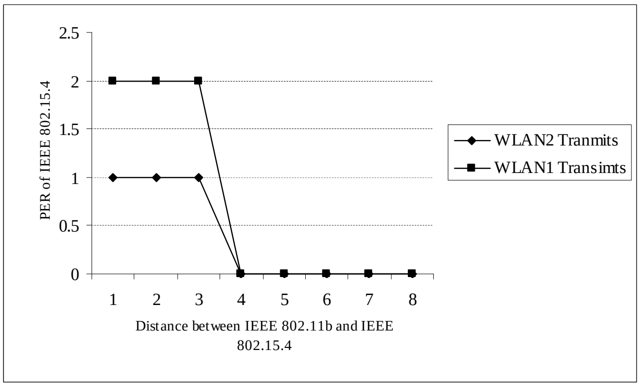

Fig. 8 PER of the IEEE 802.15.4 without considering the power spectral density of the IEEE 802.11b

From this simulation it is observed that when WLAN1 transmit data packets result in more PER than WLAN2 transmit data packets. When the transmission direction of IEEE 802.11b and IEEE 802.15.4 is opposite to each other then negligible packet error rates is obtained. When the number of IEEE 802, 11b nodes are increased the packet error rate of IEEE 802.15.4 node is increased accordingly.

Fig. 8 shows the PER of IEEE 802.15.4 with 105 bytes of IEEE 802.15.4 payload when the number of WLAN transmission varies from 1 to 5. The distance between WLAN and IEEE 802.15.4, ranges from 1 to 8 m Since the PERs of IEEE 802.15.4 are near 1 with distance < *4 m*. As the number of WLAN sources increases, the PER of IEEE 802.15.4 increases because contentions among multiple WLANs increase the channel usage and cause collisions, which is more powerful interference source to. Also distance decreases, the PER of IEEE 802.15.4 increases because of increased interference by WLAN packet transmissions.

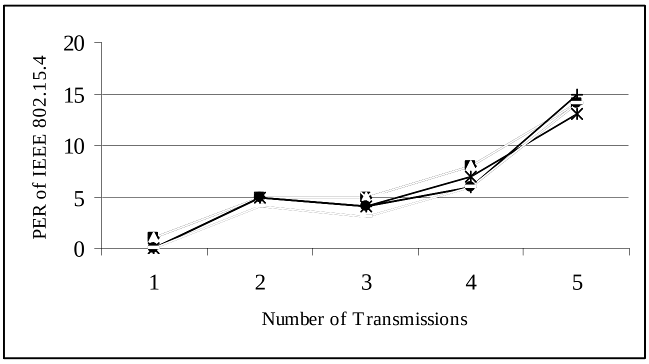

Fig. 9 PER of IEEE 802.15.4 for multiple IEEE 802.11b transmissions

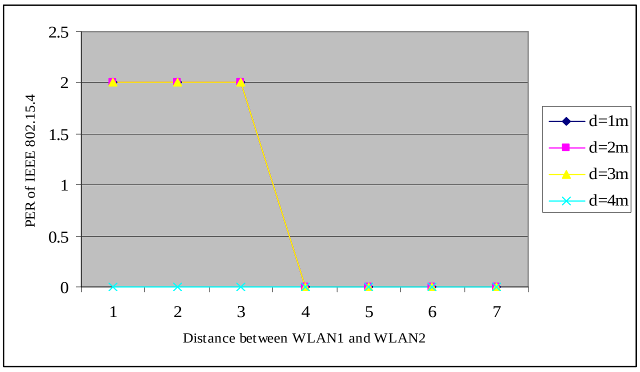

Fig. 10 .PER of the IEEE 802.15.4 for various Distances d between WLAN1 and WLAN2

The PER of IEEE 802.15.4 is calculated by varying the distance between WLAN1 and WLAN2. Figure 9 shows that the PER is negligible for the distances, d >3m.The same PER analysis can be extended for grid topology and circular topology with 20 nodes

Figure 10 shows the simulation of grid topology. PER of IEEE 802.15.4 is calculated for every increase of 5 nodes.

In this simulation 50% of the nodes are assumed for transmission. The Fig 11 Shows the PER of IEEE 802.15.4 for every increment of 5 nodes. It is found that PER increases when the number of nodes increases. The PER is calculated with the assumption that 50% of the WLAN nodes are transmission nodes.

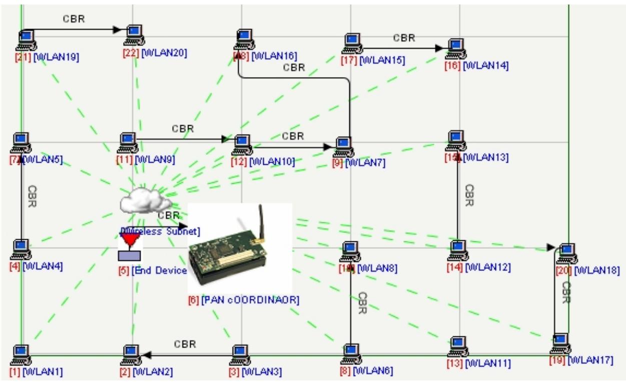

Fig.11 Grid topology Simulation Model between IEEE 802.15.4 and IEEE 802.11b

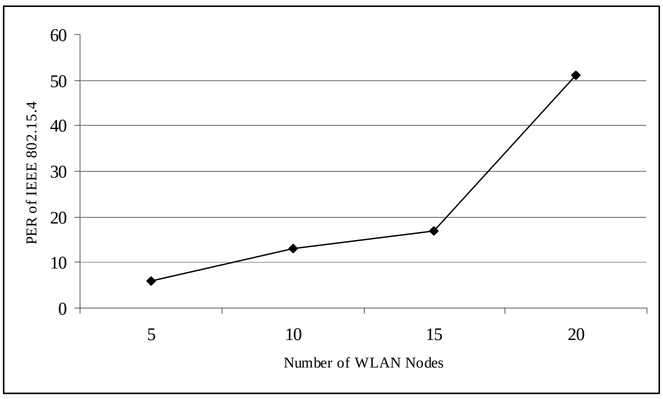

Fig. 12 PER of IEEE 802.15.4 for Grid Topology with 20 nodes

Circular topology Simulation Model between IEEE 802.15.4 and IEEE 802.11b is shown in Figure 12.The distance between WLAN nodes and the distance between WPAN devices is 1m.The distance between PAN coordinator and WLAN nodes are configured as 5m.Total number of WLAN nodes are 20 and all the nodes are placed at equal distance from the PAN coordinator. End device transmits data packets to Coordinator, and Coordinator may respond with ACK packets. For circular topology, the distance between ZigBee Coordinator to each WLAN source is identical. When more than two WLAN sources tries to transmit packets, contentions will occur which result in collisions. The simulation is carried out with the assumption of transmission strategy. When multiple nodes transmit simultaneously the contention occurs. The analysis is completed for each 10% of increased node transmission. The analysis results are plotted in Figure.13

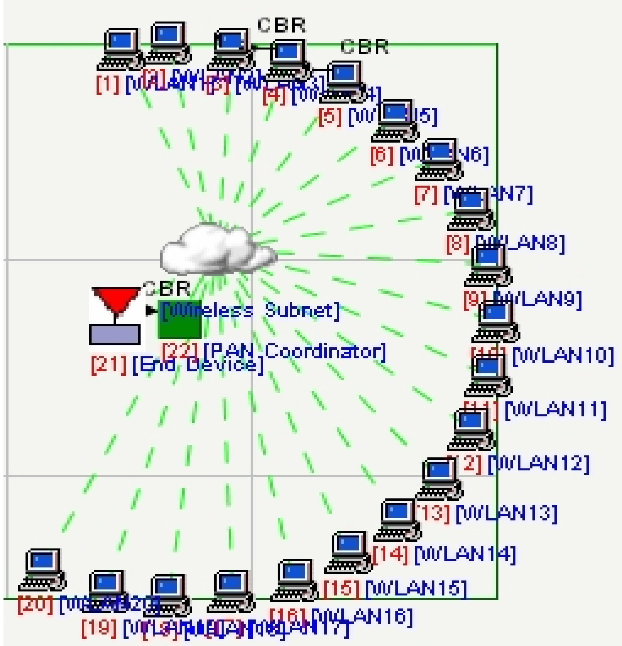

Fig. 13 Circular topology Simulation Model between IEEE 802.15.4 and IEEE 802.11b

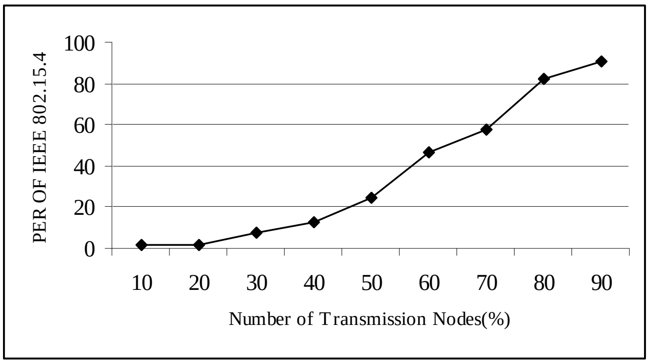

Fig. 14 PER of IEEE 802.15.4 for circular Topology with 20 nodes

The Fig 13 shows the PER of IEEE 802.15.4 for circular topology. PER increases with the increase of number of transmission nodes. Because of collision the number of packets received with error is increased.

The PER of IEEE 802.15.4 for circular topology, when the nodes are moving randomly is calculated and shown in Figure, 14.PER is calculated when the transmitting nodes are moving randomly with the maximum speed of 10 metre/sec.From the figure it is clear that PER is not increasing merely when the number of simultaneous transmission increases. When the WLAN nodes are moving randomly the proximity between the nodes decide the packet error rate. Less proximity results in least error even though the transmitting nodes are moving randomly.

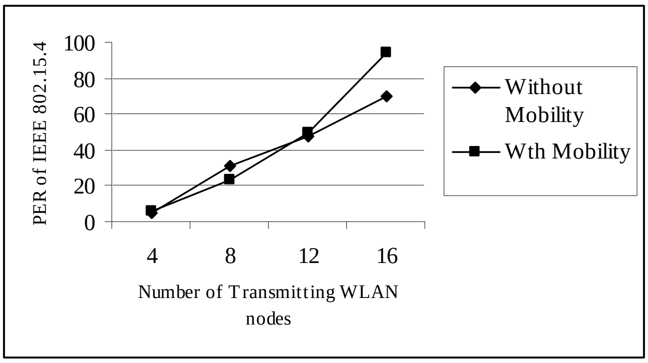

Fig. 15 PER of IEEE 802.15.4 with the Mobility model for Circular topology

The Figure 15 shows the PER of IEEE 802.15.4 for grid topology with mobility model. The error depends on the proximity of transmitting WLAN nodes. Irrespective of the increment of transmitting nodes when the node move away from the PAN Coordinator the PER is less. The mobility model assumed for this grid topology is random way point .The transmitting nodes are moving with the speed of 3 meter/sec.

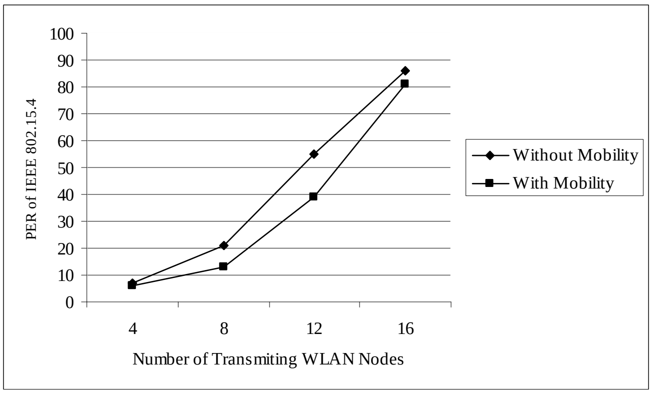

Fig. 16 PER of IEEE 802.15.4 with the Mobility model for Grid topology

IV.CONCLUSION

We in this paper present analysis on probabilities of channel conflicts between IEEE 802.15.4 and IEEE 802.11b networks. The analytical results show that the channel conflict probability does increase (almost linearly) as the number of IEEE 802.11b networks increases. The packet error rate (PER) of the IEEE 802.15.4 under the IEEE 802.11b interference is analyzed. If the distance between the IEEE 802.15.4 and the IEEE 802.11b is longer than 4m, the interference of the IEEE 802.11b can be negligible to the performance of the IEEE 802.15.4, i.e., the PER is about zero. For the exact analysis of PER, the Grid and circular topology is examined. The simulation is completed with the assumption of mobility model. In future the analysis can be extended for grid, circular and random topology with the consideration of power spectral density of IEEE 802.11b and IEEE 802.15.4 networks.Interfernce mitigation techniques can be incorporated with this scenario for error free transmission.

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