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COEXISTENCE OF IEEE 802.15.4 WITH IEEE 802.11b

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Abstract

The recurrent collocation of IEEE 802.15.4 Wireless Sensor Networks (WSNs) and IEEE 802.11b Wireless Local Area Networks (WLANs) consequence in coexistence issues, as these networks share the same 2.4GHz Industrial, Scientific, and Medical (ISM) band. As a result, their performance may degrade. We have proposed a coexistence model of IEEE 802.15.4 and IEEE 802.11b networks, which attend to their coexistence behavior and explain their coexistence performance. The packet error rate (PER) of the IEEE 802.15.4 under the interference of the IEEE 802.11b is taken as a foremost performance measure , and is obtained from the bit error rate (BER). The signal to noise and interference ratio is used to calculate the BER. The minimum distance between IEEE 802.15.4 and IEEE 802.11b is observed from the PER. Throughput, average end-end delay and average jitter is used as performance measures to analyze the performance of IEEE802.15.The methodical results are validated for various topologies with and without mobility model using Qualnet 4.5 simulation.

Keywords:

Bit Error Rate, Coexistence, IEEE 802.11b, IEEE 802.15.4, Throughput, End-End Delay and Jitter

1. INTRODUCTION

The IEEE 802.15.4 Wireless Sensor Networks (WSNs) are deployed universally for various applications. Because of their applications, for example, in hospitals and home the IEEE 802.15.4 Wireless Sensor Networks (WSNs) are becoming increasingly popular. WSNs are often collocated with IEEE 802.11b Wireless Local Area Networks (WLANs), which gives rise to coexistence issues as they both operate in the license-free 2.4GHz Industrial, Scientific, and Medical (ISM) band.

For WPAN purpose various wireless standards like IEEE 802.15.1 (Bluetooth)[1][2], IEEE 802.15.3 (High Rate WPAN - UWB)[3] and IEEE 802.15.4 (Low Rate WPAN-Zigbee)[4] have been developed. Channel allocation conflicts are unavoidable between these WPAN technologies as all these standards operate in the same 2.4GHz ISM (Industrial-Scientific-Medical) frequency band. The coexistence issue is found to be severe while these WPAN technologies coexist with other 2.4GHz based wireless/radio technologies (e.g. IEEE 802.11b/g [5], cordless phone, and microwave oven). So, the analysis of coexistence issue between these technologies turns out to be significant in wireless world.

There have been some studies about the coexistence issues between the IEEE 802.11b WLANs and IEEE 802.15.4 WSNs[5][6] .In [5], the experiment is brought about to calculate the packet error rate (PER) of the IEEE 802.15.4 under the interference of WLAN and Bluetooth. The performance analysis of IEEE 802.11b under the interference of IEEE 802.15.4 is investigated in [6]. The divergence in Channel utilization between IEEE 802.15 based Wireless Personal Area Networks is modeled in [7]. The Packet Error Rate analysis for peer-peer topology of IEEE 802.15.4 under the WLAN interference is evaluated in [8].In [9] Packet Error Rate of IEEE 802.11b under IEEE 802.15.4 interference is analyzed for various values of payload. The Coexistence of IEEE802.15.4 with IEEE802.11, Bluetooth, and Microwave Ovens in 2.4 GHz ISM-Band is explored in [10].In [11], PER analysis of IEEE 802.15.4 for circular and grid topology is given. In this paper, the performance metrics such as throughput, end-end delay and jitter are analyzed for various topologies with interference size varied from 10%-90%.

Further, the paper is organized as follows. In section II, channel collision probability between IEEE 802.11b and IEEE 802.15.4 networks is presented. In section III, the performance analysis of the IEEE 802.15 4 under the interference of IEEE 802.11b is analyzed. Finally, conclusions are presented in Section IV.

2. CHANNEL COLLISION PROBABILITY BETWEEN IEEE 802.11b and IEEE 802.15.4

The channel allocation mechanism of the IEEE 802.11b and IEEE 802.15.4 standards are concised in this section before discussing the analysis. The IEEE 802.11b takes up 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 in Japan all of the 14 channels are used. The central frequencies of IEEE 802.11b channels are separated by 5 MHz as shown in equation 1.

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

If two IEEE 802.11b nodes in close operate using adjacent channels, adjacent channel interference will happen because adjacent IEEE 802.11b channels are partially overlapped. 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 because the overall network performance will become degraded due to overlapping. So, 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).

As like IEEE 802.11b, IEEE 802.15.4 also take up 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:

$$f=\begin{cases}868.3; k=0\\ 906+2(k-1); k=1\ldots10\\ 2405+5(k-11); k=11\ldots26\end{cases} \quad (2)$$

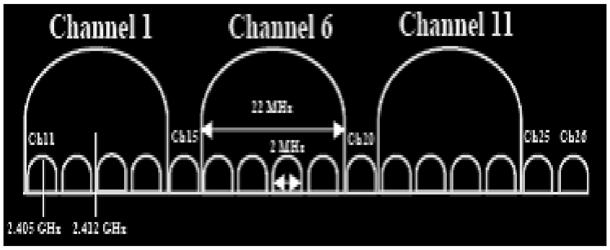

Fig.1. 802.11b and 802.15.4 channels in the 2.4GHz ISM band

The 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 is presented in this section. The non conflicting channels for the n IEEE 802.11b networks are assumed (i.e., non-overlapping channels and $n \leq 3$). Heterogeneous network with multiple IEEE 802.15.4 networks are not considered for analysis. 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 Fig.1.; b) the IEEE 802.15.4 network operates on one of the overlapped channels.

From the above discussed cases, the probability of non-conflicting channel allocation is always 1 regardless of the number of coexisting IEEE 802.11b networks in the first case. Whereas, the probability of non-conflicting channel allocation is $\frac{3-n}{3}$ in the second case. By un-stipulating 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 the following equation 3.

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

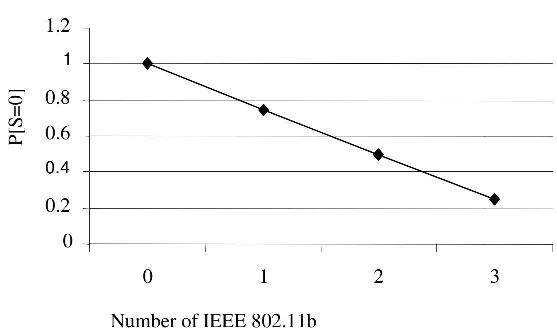

Fig.2. Analytical results of P[S=0] while one IEEE 802.15.4 network coexist with multiple IEEE 802.11b networks

Fig.2 shows the non-conflicting channel allocation probability, for increasing number of IEEE 802.11b Networks. The non-conflicting channel allocation probability decreases linearly when the number of IEEE 802.11b Networks increases. These analytical results will be validated in the subsequent sections with Qualnet 4.5 simulation.

3. PERFORMANCE ANALYSIS OF IEEE 802.15.4 NETWORK UNDER THE INTERFERENCE OF IEEE 802.11b NETWORKS

In communication systems, BER is simply defined as the ratio of the number of erroneous bits received divided by the total number of bits transmitted. It is used as a performance metric for the evaluation of the digital modulation techniques. Error probability is parameterized by the energy metric called energy per bit, E_b. The SNR or SINR values are often expressed in terms of the signal energy per bit as follows:

$$SINR=\frac{P_R}{N_oB+P_I}=\frac{E_b}{N_oBT_b} \quad (4)$$

where P_R is the received signal strength, P_I is the power of the interference, N_o represents the spectral noise density, B is the bandwidth of the transmitted signal and T_b is the time to transmit a bit. The quantity E_b/N_o is often called the SINR per bit, and SINR = E_b/N_o for binary signaling. For performance specification, we are interested in the bit error probability P_b as a function of E_b/N_o.

The modulation scheme used in physical layer of the IEEE 802.15.4 at 2.4 GHz is offset Quadrature phase shift keying (OQPSK). In the case of an additive white Gaussian noise (AWGN) channel, 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, . Then the bit error rate (BER), P_b, can be expressed as in equation.5.

$$P_b=Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \quad (5)$$

where Q(x) is

$$Q(x)=\frac{1}{\sqrt{x}}\int_x^{\infty}\exp\left(\frac{-u^2}{2}\right)du \quad (6)$$

Fig. 3 shows the relationship between the bit error rate and the E_b/N_0 simulated in MATLAB.

The packet error rate (PER) is calculated from bit error rate $\left(\overline{P_b}\right)$. The probability of not having a bit error is the probability that all the bits are received correctly. Therefore the conditional probability of PER is one minus the probability of no bit errors and is computed as in Eq.7.

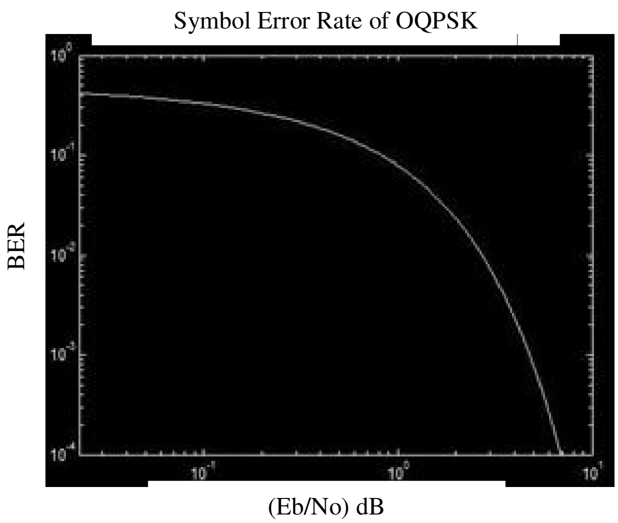

Fig.3. Theoretic Bit Error Rate of OQPSK

$$PER = 1 - \left(1 - \overline{P_b}\right)^N \qquad (7)$$

where N represents the number of bits in a packet. The experimental platform does not provide an error correction mechanism and Eq.7 is the final form of the PER.

Table.1.Simulation configuration and parameters

Parameter	IEEE 802.11b	IEEE 802.15.4
Number of Nodes	2 for peer-peer 20 for others	2
Transmission Power	15dbm	3dbm
Modulation	CCK	OQPSK
MAC Protocol	802.11	802.15.4
Routing Protocol	Bellman ford	AODV
No of Packets	100	100
Payload Size	1500bytes	105bytes
Simulation Time	30s	
Packet Interval	1s	
Packet Transmission Time	25s	
Test bed size	10m × 3m for peer-peer 10m×10m for others	
Topology	Peer-Peer,Circular.Grid and Random	

The PER of IEEE 802.15.4 under the IEEE 802.11b interference is analyzed in this section. For simulation, the slotted CSMA/CA of the IEEE 802.15.4 model is developed using Qualnet 4.5.The simulation configuration and parameters used in this paper is shown in Table.1.

The peer-peer topology simulation scenario for simple coexistence heterogeneous network with 2 WLAN and 2WPAN nodes is shown in Fig. 4.

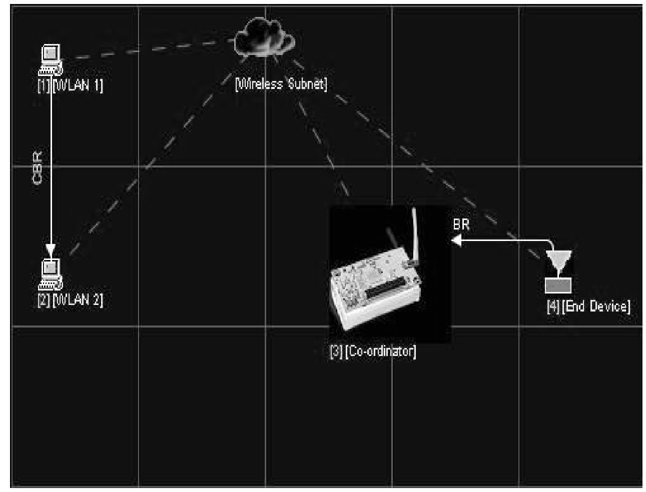

Fig.4. Simulation Model between IEEE 802.15.4 and IEEE 802.11b

The transmission of data packets is assumed for only IEEE 802.15.4 End device and IEEE 802.11b WLAN 1 for the purpose of analysis .The other nodes send only the ACK packets for the corresponding data packets. In the above shown scenario, 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. The simulation result for the peer-peer topology is shown in Fig.5 (a-e). The performance of IEEE 802.15.4 is measured under the interference of IEEE 802.11b with the same center frequencies. The distance between Coordinator and WLAN 1, d, varies from 1m to 8m.

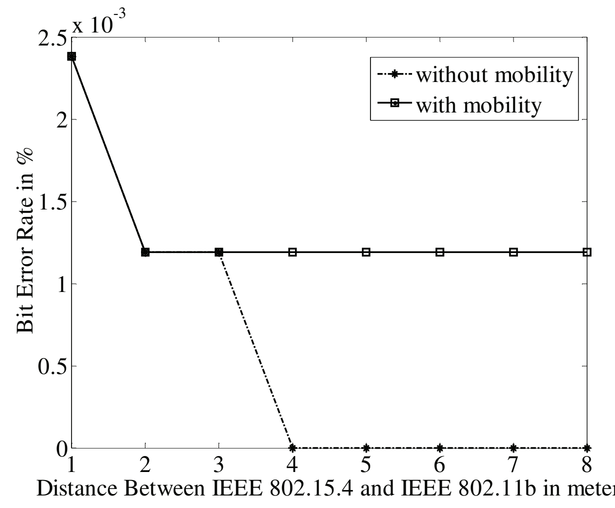

Fig.5a. Bit Error Rate (BER) analysis of IEEE 802.15.4 for Peer-Peer Topology

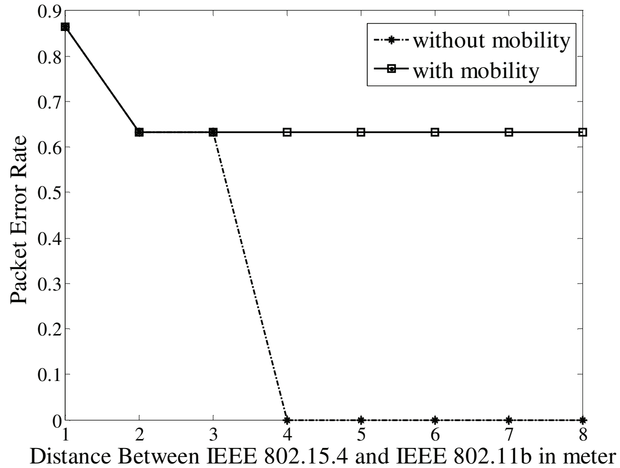

Fig.5b. Packet Error Rate (PER) analysis of IEEE 802.15.4 for Peer-Peer Topology

The Fig.5 (a & b) shows the analysis of bit error rate (BER) and packet error rate (PER. In case of static situation the BER and PER becomes zero when the distance between WLAN and the PAN coordinator is more than 3m.If the mobility model is adopted the above said performance metrics never becomes zero because the terrain size is fixed as 10m×3m.

The Fig.5c shows the throughput analysis of IEEE 802.15.4 .Throughput is increased when the distance between IEEE 802.15.4 and IEEE 802.11b is more than 2m.It is observed from the result that when two different devices are placed in close proximity results in performance degradation.

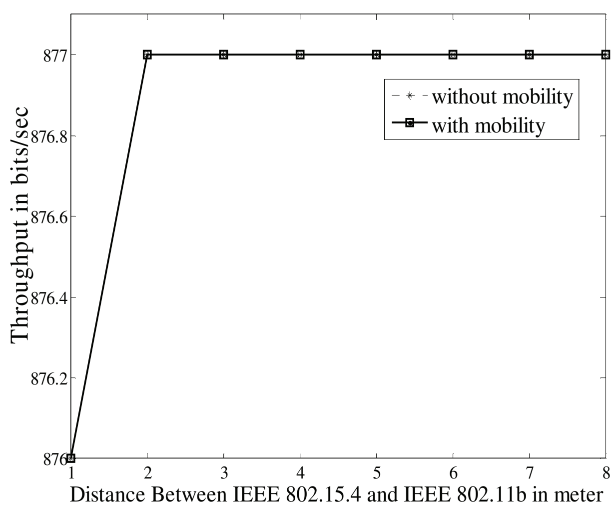

Fig.5c. Throughput analysis of IEEE 802.15.4 for Peer-Peer Topology

Like throughput the average end-end delay also decreased when the distance between IEEE 802.15.4 and IEEE 802.11b is more than 2m. The corresponding analysis is shown in Fig.5d.

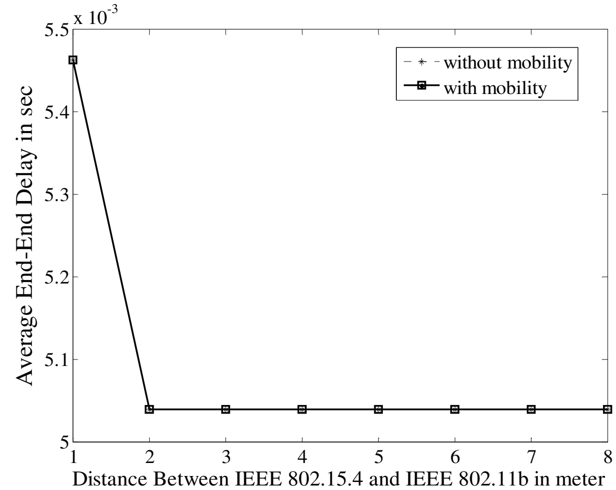

Fig.5d. Average End-End delay analysis of IEEE 802.15.4 for Peer-Peer Topology

The Fig.5e shows the average jitter analysis of IEEE 802.15.4 .It is increased from 0.0013 to 0.0017.For this simple scenario shown in Fig.4 the throughput, average end-end delay and average jitter of IEEE 802.15.4 are same when the nodes are in both static and movable situation.

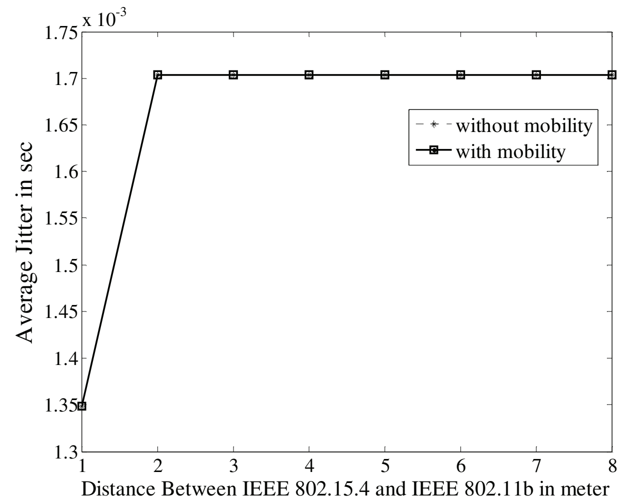

Fig.5e. Average Jitter analysis of IEEE 802.15.4 for Peer-Peer Topology

The Fig.6 shows the circular topology scenario for coexistence of heterogeneous networks with 2 WPAN nodes and 20 WLAN nodes. The simulation results are observed for each 10% of WLAN interference. The performance metrics are analyzed for every 10% of WLAN interference in circular topology.

In circular topology the WPAN nodes are placed at the centre and WLAN nodes placed at equal distance form PAN coordinator. The distance between the End device and PAN coordinator is fixed as 1m.The WLAN nodes are separated by 1m from one another. The distance between Pan Coordinator and WLAN node is fixed as 5m.

In WPAN nodes end devices are reduced functional device (RFD) and PAN coordinator is fully functional device (FFD).The RFD can only transmit the information but the FFD can act as a router coordinator and end device.

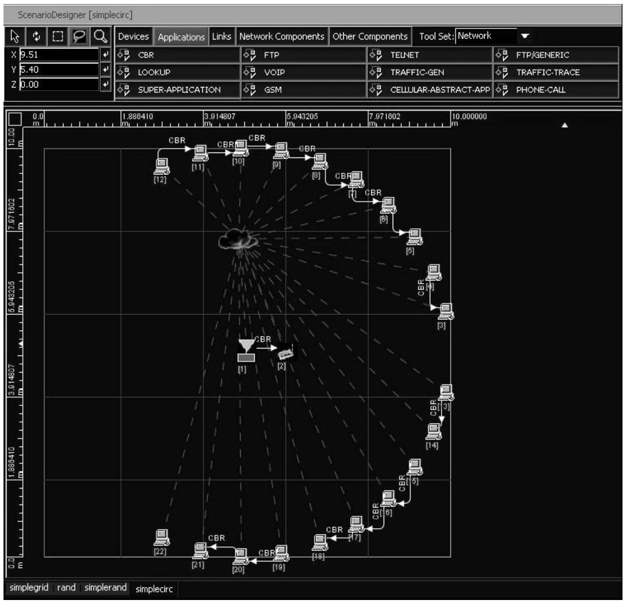

Fig.6. Simulation Model between IEEE 802.15.4 and IEEE 802.11b for Circular Topology

The simulation results for circular topology for various performance metrics are shown in Fig.7 (a-e). The Fig.7 (a & b) shows the analysis of bit error rate (BER) and packet error rate (PER).

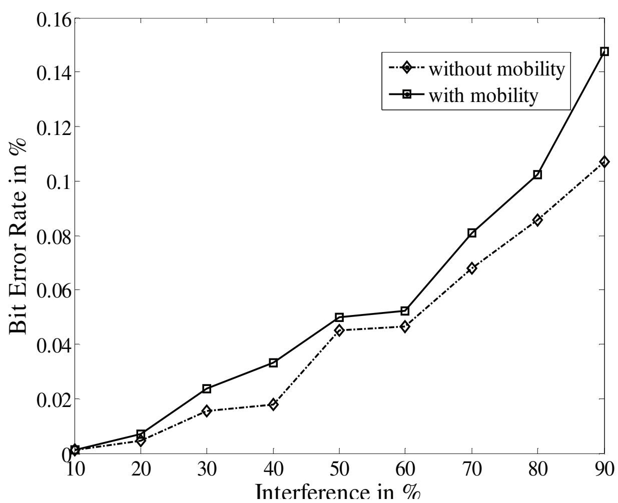

Fig.7a. Bit Error Rate (BER) analysis of IEEE 802.15.4 for Circular Topology

In case of static situation the bit error and BER are increasing linearly when the interference increases. With the random way point mobility model the bit error and BER is increased linearly as like in the static situation and the bit error and BER are considerably more. The packet error rate (PER) increases linearly in both the cases when interference increases and the results coincide.

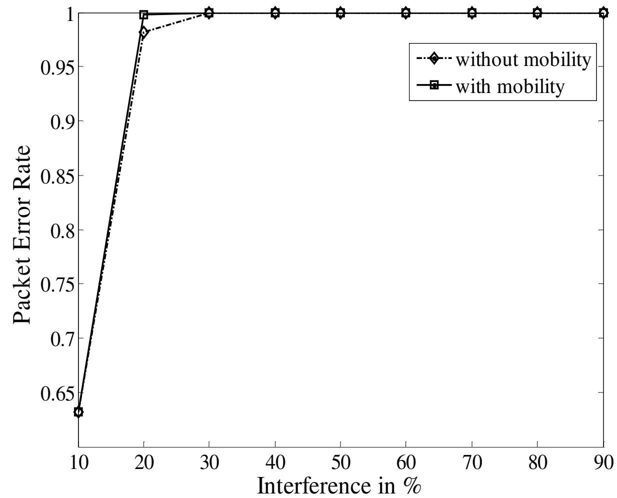

Fig.7b. Packet Error Rate (PER) analysis of IEEE 802.15.4 for Circular Topology

The Fig.7c shows throughput analysis for circular topology with and without mobility. The throughput decreases when the interference size increases.

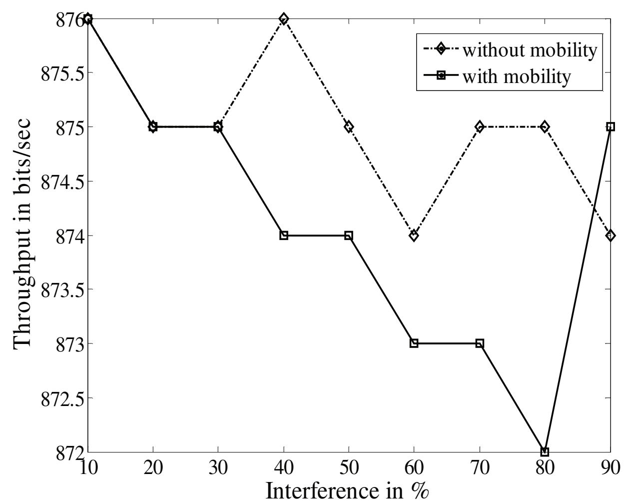

Fig.7c. Throughput analysis of IEEE 802.15.4 for Circular Topology

The average end-end delay and average jitter analysis is shown in Fig.7d and Fig.7e respectively. The average end-end delay and average jitter increases linearly when interference increases for both the cases.

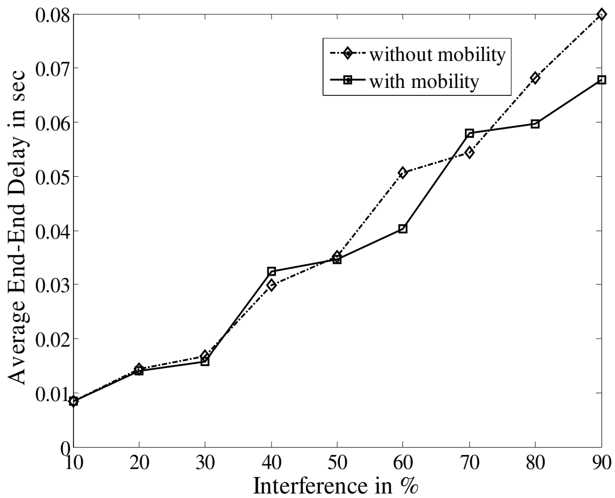

Fig.7d. Average End-End delay analysis of IEEE 802.15.4 for Circular Topology

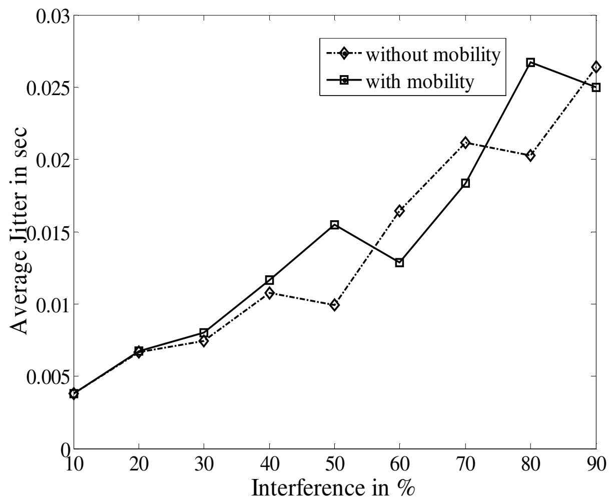

Fig.7f. Average Jitter analysis of IEEE 802.15.4 for Circular Topology

The Fig.8 shows the grid topology scenario for coexistence of heterogeneous networks with 2 WPAN nodes and 20 WLAN nodes. The simulation results are observed for each 10% of WLAN interference. The performance metrics are analyzed for every 10% of WLAN interference in circular topology.

The simulation results for grid topology for various performance metrics are shown in Fig.9 (a-e).

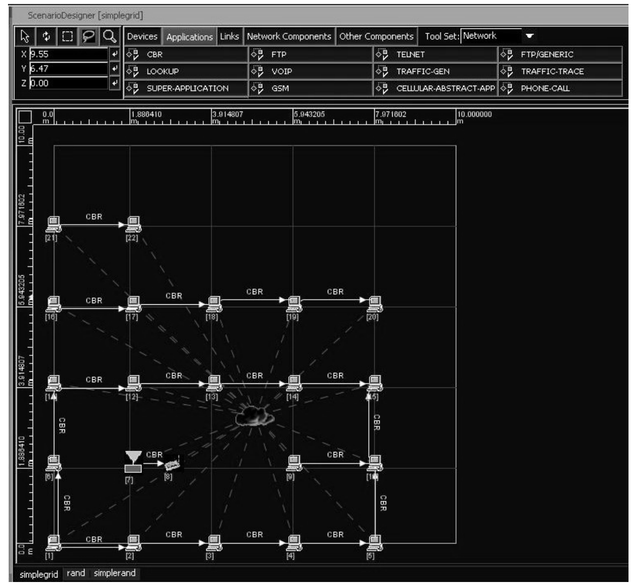

Fig.8. Simulation Model between IEEE 802.15.4 and IEEE 802.11b for Grid Topology

The Fig.9 (a & b) shows the analysis of bit error rate (BER) and packet error rate (PER) respectively. In case of static situation the bit error and BER are increasing linearly when the interference increases. With the random way point mobility model the bit error and BER is increased linearly as like in the static situation and the bit error and BER are considerably more. The packet error rate (PER) increases linearly in both the cases when interference increases and the results coincide when the interference increased more than 20%.

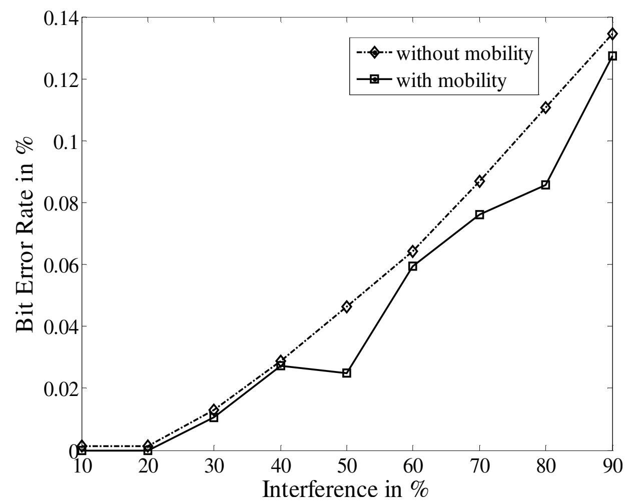

Fig.9a. Bit Error Rate (BER) analysis of IEEE 802.15.4 for Grid Topology

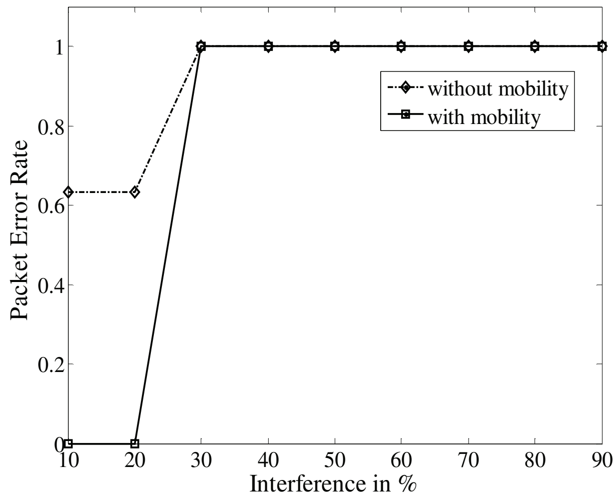

Fig.9b. Packet Error Rate (PER) analysis of IEEE 802.15.4 for Grid Topology

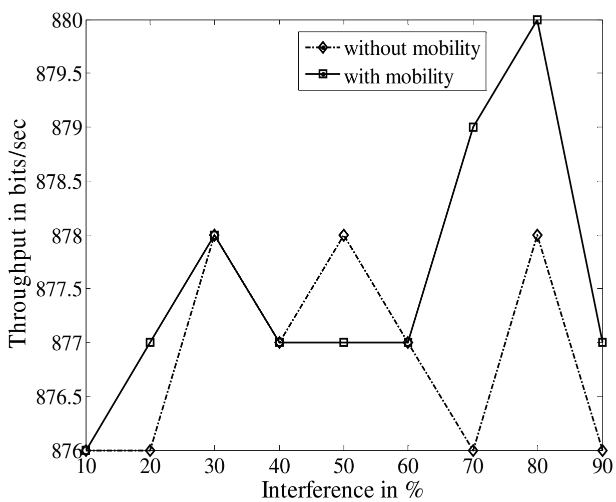

Fig.9c. Throughput analysis of IEEE 802.15.4 for Grid Topology

The Fig.9c shows throughput analysis for grid topology with and without mobility. The throughput decreases when the interference size increases.

The average end-end delay and average jitter analysis is shown in Fig.9d and 9e respectively. The average end-end delay and average jitter increases linearly when interference increases for both the cases.

The Fig.10 shows the Random topology scenario for coexistence of heterogeneous networks with 2 WPAN nodes and 20 WLAN nodes. The simulation results are observed for each 10% of WLAN interference. The performance metrics are analyzed for every 10% of WLAN interference as in circular and grid topology.

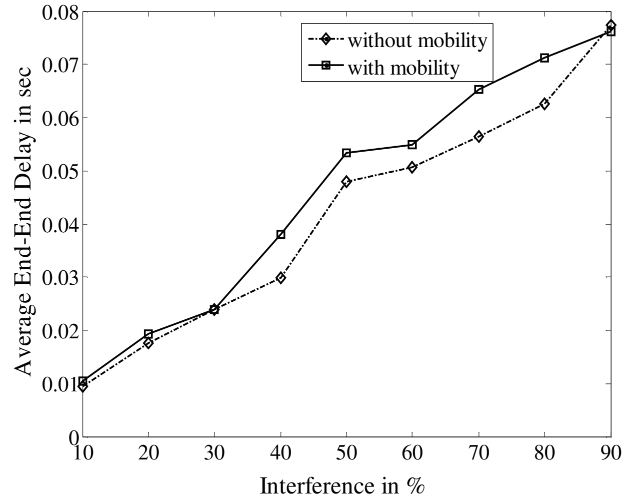

Fig.9d. Average End-End delay analysis of IEEE 802.15.4 for Grid Topology

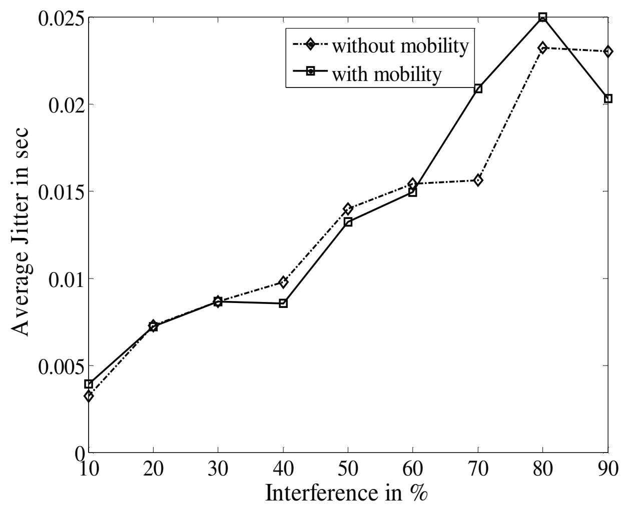

Fig.9e. Average Jitter analysis of IEEE 802.15.4 for Grid Topology

The simulation results for random topology for various performance metrics are shown in Fig.11 (a-e).

The Fig.11 (a & b) shows the analysis of bit error rate (BER) and packet error rate (PER) respectively. In case of static situation the bit error and BER are increasing linearly when the interference increases. With the random way point mobility model the bit error and BER is increased linearly as like in the static situation and the bit error and BER are considerably more. The packet error rate (PER) increases linearly in both the cases when interference increases and the results coincide when the interference increased more than 10%.

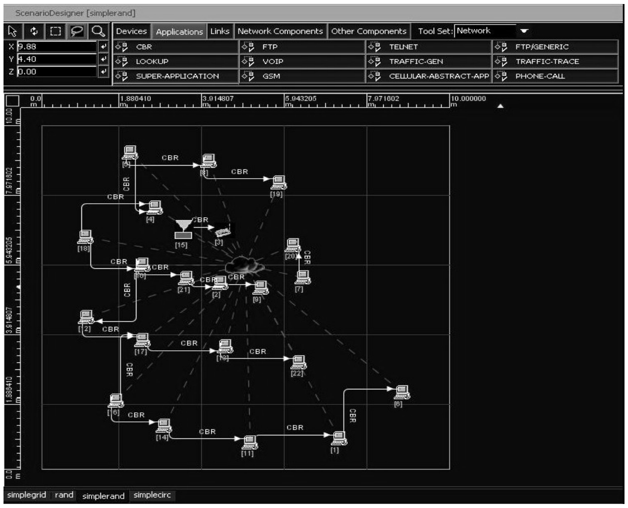

Fig.10. Simulation Model between IEEE 802.15.4 and IEEE 802.11b for Random Topology

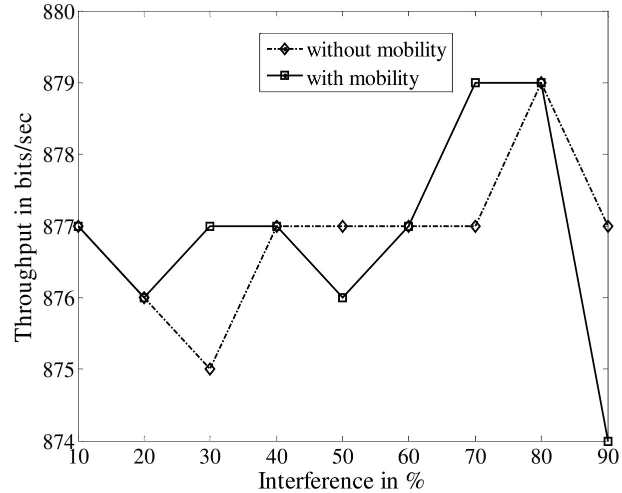

Fig.11c. Throughput analysis of IEEE 802.15.4 for Random Topology

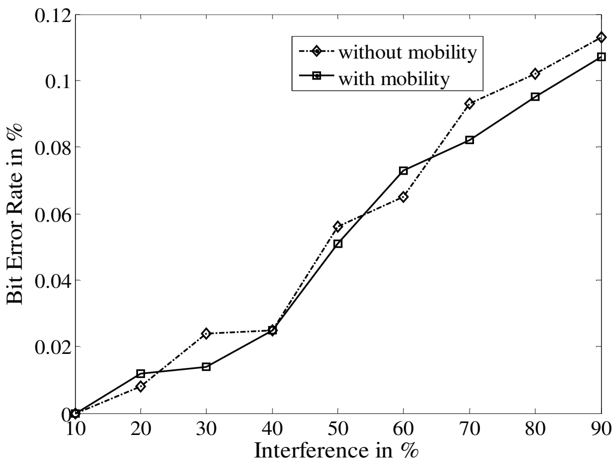

Fig.11a. Bit Error Rate (BER) analysis of IEEE 802.15.4 for Random Topology

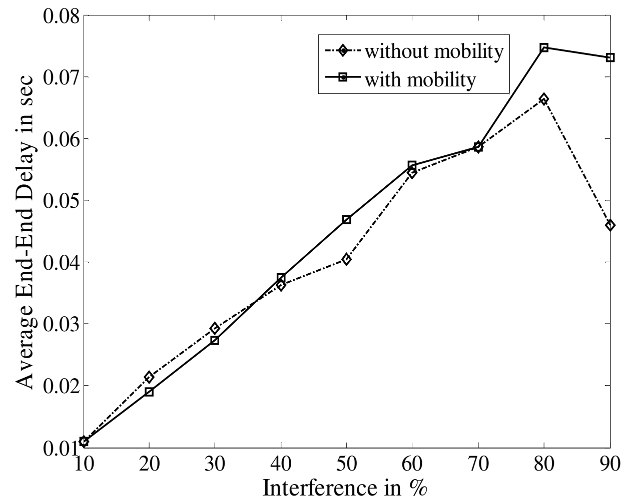

Fig.11d. Average End-End delay analysis of IEEE 802.15.4 for Random Topology

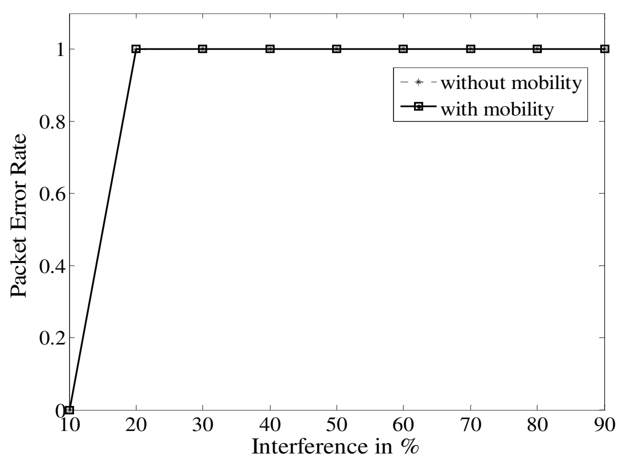

Fig.11b. Packet Error Rate (PER) analysis of IEEE 802.15.4 for Random Topology

The Fig. 11c shows throughput analysis for grid topology with and without mobility. The throughput decreases when the interference size increases.

The average end-end delay and average jitter analysis is shown in Fig.11d and Fig.11e respectively. The average end-end delay and average jitter increases linearly when interference increases for both the cases.

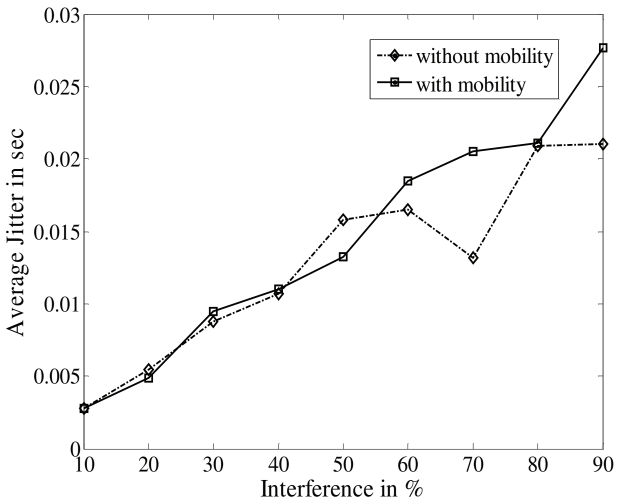

Fig.11e. Average Jitter analysis of IEEE 802.15.4 for Random Topology

4. CONCLUSION

In this paper the analysis on probabilities of channel conflicts between IEEE 802.15.4 and IEEE 802.11b networks is presented. The performance of IEEE 802.15.4 is measured under the interference of IEEE 802.11b by using various performance metrics such as bit error, BER, packet error rate (PER), throughput, average end-end delay and average jitter. The safe distance between the IEEE 802.15.4 and the IEEE 802.11b is calculated for not degrading the performance of IEEE 802.15.4. For the exact analysis of the performance metrics the peer-peer, Circular, Grid and Random topology is examined. In this paper the random way point mobility model also used to extend the analysis. In future the various topologies can be implemented in real time using Exata emulator. We can also use Free scale processor based zigbee modules to analyze the performance.

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