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Analyzing the Coexistence of IEEE802.11g Systems with IEEE802.15.4 WPAN Systems

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ABSTRACT--- With the increasing demand of smart wireless devices, which operate in the 2.4GHz ISM band using different technologies such as IEEE 802.11g (Wi-Fi) and IEEE 802.15.4 (ZigBee), it becomes necessary to understand the impact of their coexistence on the performance of the involved heterogeneous networks. The coexistence performance of these technologies basically depends on factors like the spread spectrum employed, transmission powers, data rates, payload, message length, type of modulation etc. In this work, coexistence is analyzed based on transmission power and traffic scheduling techniques that reduce interference between wireless devices (WLAN and WPAN) operating in the 2.4GHz ISM band. Simulation studies are carried out using OMNET++ with varying values of channel power, traffic scheduling, Bandwidth, Message length and data rate. From the simulations it is observed that the device powers beyond a limit cause packet failures of other devices to increase exponentially, which in turn indicates the allowed power levels suitable to the environment.

Keywords-- Coexistence, Channel Access, Traffic scheduling, Bandwidth Utilization, Opportunistic Access, Spectrum Allocation

I. INTRODUCTION

With the advancements happened in wireless communications, many applications and services are introduced for different wireless devices. Communication Technologies that are based on both licensed and unlicensed frequencies are used for these purposes. Of them, cellular communication based technologies use licensed frequencies, while many others like Wi-Fi, Bluetooth, Zigbee etc., operate in unlicensed spectrum bands. This leads to spectrum overcrowding in these bands. Because of this spectrum overcrowding in these bands, interference levels are increased when traffic increases. This leads to higher values of bit error rates and packet error rates. Appropriate mechanisms of coexistence for spectrum sharing are needed to overcome this problem. However, it poses a great challenge for coexistence, especially when different MAC/PHY protocols are used by the devices that operate in those bands, at the given location. Coexistence analysis of WLAN systems of IEEE 802.11g (known as Wi-Fi, in general terminology) with WPAN systems of 802.15.4 is carried out in this work. Both of these two networks operate in the unlicensed frequencies of 2.4GHz ISM band. While Wi-Fi is mostly used for Internet access, video streaming and similar other services, WPAN is generally used for the low duty cycle monitoring and control applications such as healthcare and home/industrial automation. When the above mentioned two networks utilize the same shared medium and work in close proximity with each other, in office or hospital building or residential environments, they cause interference to each other. But the impact is expected to be more on the data receptions of WPAN systems, because of their lower power levels when compared with WLAN systems [1]. The WPAN systems considered here are referred to as Zigbee systems also because Zigbee uses 802.15.4 technology at the bottom two layers. Section-II of the paper deals with the details of Wi-Fi and Zigbee, in terms of their power levels, channel widths etc. Section-III deals with the details of coexistence issues in 2.4 GHZ ISM band in which these two technologies operate. Section-IV contains the details of network models of these two systems and the environment considered for analyzing the interference. Section-V presents the simulation results of the interference phenomenon that takes place. Section-VI concludes the paper.

II. WI-FI VS ZIGBEE

All the 802.11 standards belong to a family of specifications developed by the IEEE for wireless LAN (WLAN) technology. WLAN is designed for short-range wireless connectivity among various wireless devices. There are several specifications in 802.11 family, though this paper discusses about 802.11g which operates in the 2.4GHz ISM band. It provides a maximum raw bit rate 54 Mbps through complementary code keying (CCK) using direct sequence spread spectrum (DSSS). Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is used for channel access purpose. 2.4 GHz ISM band is considered as several channels (11 in the context of USA and 1in Europe) of 5 MHz each. Each Wi-Fi network requires 20 MHz bandwidth. This bandwidth can be selected by choosing any one of the 11 (or 13) channels as the center frequency. Three non- overlapping selections can be made in the band, as shown below Fig-1.

IEEE 802.15.4 was designed for low power, low data rate networks with a low cost objective. These are generally referred to as Wireless Personal Area Networks. The idea here is that, these would be used for low to moderate radio range applications but for some cases, amplification is also possible, if needed. The raw bit rate of these devices is 250kbps, by using 2.4GHz through DSSS. Channel access is done by Carrier Sense Multiple Access (CSMA) by random backoffs. It uses 2.4GHz and 915MHz ISM bands.

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Coexistence: The ability of two or more spectrum dependent devices or networks to operate without harmful interference is known as coexistence. Coexistence mechanisms are broadly classified into Centralized, Distributed and Decentralized mechanism.

Centralized mechanism: It is also called cooperative technique for spectrum usage in a fair manner. Here, RF selection of all the networks is based on the Database. By using this mechanism coexistence can be minimized. Drawback of this mechanism is that it is costly and yet ineffective and scalability problems will also arise.

Distributed mechanism: In this technique, spectrum usage decisions are made independently by each device or network and then this usage information is passed to other devices or networks through control channels. Drawback of this mechanism is that willingness is needed from all the devices to share their information. When all networks use common control channel it leads to decode each other's messages that can cause insecurity. Scalability problem will also arise if the devices are more in number.

Decentralized mechanism: In this technique, spectrum sensing is done only by individual observation. Channel selection and interference mitigation are done individually. Advantage of this technique is scalability. Drawback here is the limitation in sensing by individual device.

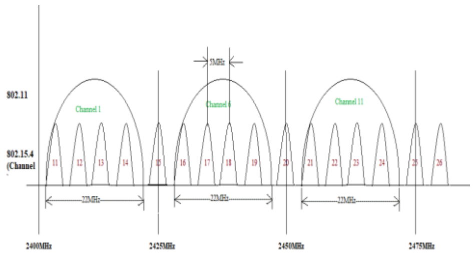

Fig.1: Channel Allotment for Wi-Fi and ZigBee

III. THE COEXISTENCE PROBLEM IN ISM BAND

Radhakrishnan Natarajan et al. [2] researched the effect of IEEE 802.11 on IEEE802.15.4 and IEEE802.15.1 BLE (Bluetooth Low Energy) in the 2.4GHz ISM band. They experimented on four network configurations to find out packet error rates by considering 3 parameters i.e., interferer packet interval, channel separation and distance. For network reliability they quantified on the effect of spatial, temporal and frequency parameters of the interference. It was found that IEEE802.15.4 was affected by WLAN of short interference packet interval for example 10ms. It was also found that the reliability of BLE can be improved by considering appropriate MAC layer mechanisms for packet retransmission.

Mohamed Rihan et al. [3] studied the effect of IEEE 802.15.4 coexistence in the ISM Band, through experimentation done by using OPNET V.16 for ZigBee coexisting with WLAN. They considered different performance metrics such as packet loss ratio, received signal strength, end to end delay, link quality indicator and media access delay. Their simulation results show that negative effect was there on the performance of ZigBee networks by increasing the packet sizes of WLAN. They also concluded that intra technology interference has less Packet Error Rate than the inter technology interference.

Jakub Neburka et al. [4] studied the impact of ZigBee on IEEE 802.11b/g networks and vice versa. Dependence of error vector magnitude and bit error rate on power imbalance, i.e., the difference between power levels of ZigBee and Wi-Fi signal in the 2.4GHz ISM Band, was investigated. Their simulation model focussed on the intra channel coexistence, when IEEE 802.11b/g operated at 2.412GHz (channel 1) and zigbee operated at 2.405GHz (channel 11). Their simulation results showed that imbalance power between RF signals will reduce the BER rates of ZigBee communication.

El-keyi et al. [5] proposed a novel probabilistic path loss model for indoor application. Simulation was done by using ns-3 simulator. They studied the coexistence between IEEE802.11 and IEEE802.15.4 by log-distance path loss model which is severely affected by signal degradation by Reflection, wall penetration, scattering and diffraction. They introduced path loss model which reflects the throughput degradation of both WLAN and WPAN networks as the increased number of nodes leading to interference. The impact depends on the node density and the traffic data rate.

IV. NETWORK MODEL

We have analyzed the Wi-Fi 802.11g protocol and ZigBee 802.15.4 protocol in OMNeT++ which is an open source communication network simulator. The model is developed in the INET frame-work. Fig.2 shows the heterogeneous coexisting network scenario. Initially the simplest configuration was designed which consists of two Hosts of each Wi-Fi and WPAN network namely one Host is transmitter and another Host is receiver respectively. Heterogeneous coexisting network is designed in such a way that one Host (WPAN receiver) from each network is very nearby to a Host (Wi-Fi receiver) from the other network and the other Host (WPAN and Wi-Fitransmitters) in each network is far away.

Assuming that the distance between Wi-FiHost1 transmitter to Wi-FiHost2 receiver is "W" and the receivers of Wi-FiHost2 to WPANHost2 is "d" , it is considered that $d \ll W$ .The relevant parameters are summarized in Table.1

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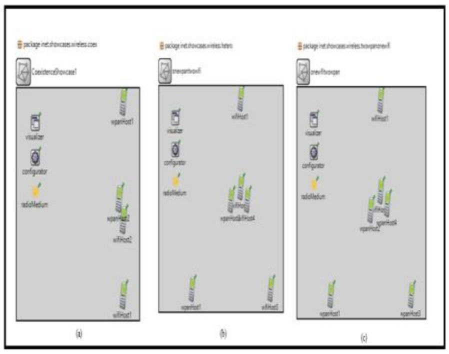

Fig.2: Heterogeneous coexisting network scenario.

Table.1 List of parameters

Parameter	Wi-Fi 802.11g	WPAN 802.15.4
Carrier frequency	2.412GHz	2.412GHz
Bandwidth	20MHz	2.8MHz
Bit rate	11Mbps	250kbps
Send Interval	0.8ms	15.8ms
Message Length	1000Byte	90Byte
Maximum Transmission Unit	2304Byte	118Byte
Start time	0s	0s

Radio medium Model: The radio medium model describes the shared physical medium where communication takes place. It keeps track of radios, noise sources, ongoing transmissions, background noise, and other ongoing noises. The radio medium computes when, where and how transmissions and noises arrive at receivers. It also efficiently provides the set of interfering transmissions and noises for the receivers.

Free Space Path Loss Model: The distance in any designed network can be converted into signal attenuation using a Free Space Path Loss Model. Several path loss models are there, but in this model we considered

Free Space Path Loss = $(\text{wavelength})^2/16*\pi*\text{system loss}*\text{distance}^{\text{alpha}}$

Where alpha=2 and system loss=1.

Send interval and Start time: When the transmission of one device is going on in a wireless network, the packets may or may not be affected in time, while the data transmission started by another wireless network may cause interference to the present ongoing data transmission in the network. So it creates interference to the ongoing data transmission which may affect fully or partially [6].

Fig.3 shows that packet transmission of Wi-Fi and WPAN. The transmission of Wi-Fi data packets are done periodically that causes interference to WPAN in 3 cases.

Case 1: In case1 WPAN packets collide completely with the Wi-Fi transmission because both the Wi-Fi and WPAN transmissions start at the same time. So Wi-Fi's high power severely affects the packets of low power WPANs.

Case 2: In case2, WPAN packet loss is zero i.e., no collision condition, when Wi-Fi transmission is not done ie., off condition at the time of WPAN packets transmission is done successfully without any errors.

Case 3: Intra collision may happen due to the send interval of WPAN devices, ie., packet loss of WPAN will exists by WPAN send interval only. In this case packet loss is affected by WPAN devices only and not by the Wi-Fi transmission.

In case1, the number of interfered packets is N, In case2 the number of interfered packets is 0 and In case3 the number of interfered packets is less than N.

Fig.4 shows that packet transmission of Wi-Fi and WPAN. The transmission of WPAN data packets done periodically causes interference to Wi-Fi in 3 cases.

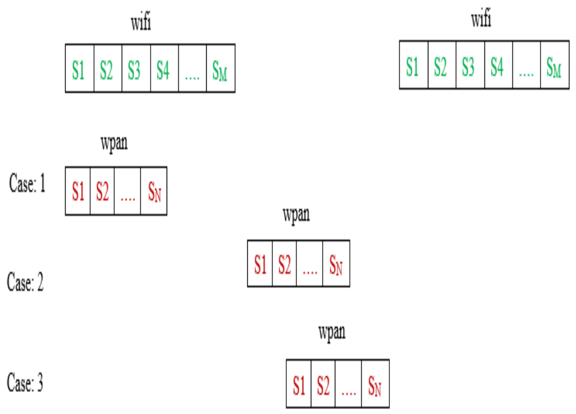

Fig.3: Packet error rate of WPAN which effects interference by Wi-Fi

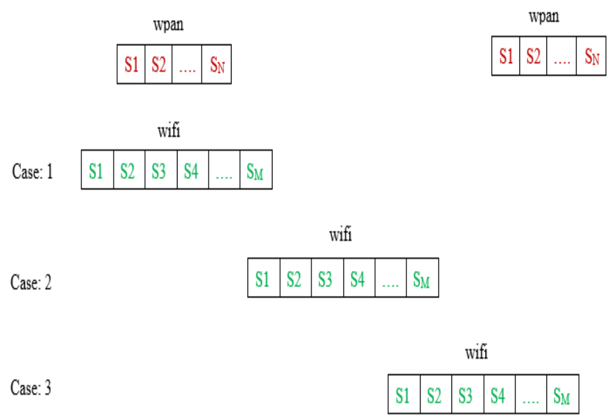

Fig.4: Packet error rate of Wi-Fi which effects interference by WPAN

V. SIMULATION RESULTS

We analysed IEEE 802.11g (Wi-Fi) and 802.15.4 (ZigBee) protocols in OMNeT++ network simulator, which is an open software. These two protocols are analyzed in the INET framework and this frame work is developed by OMNeT++ developers by using OMNeT++ API. All simulations were run for considerable amount of time, and calculated the packet loss for both ZigBee and Wi-Fi by varying transmission power levels.

One Wi-Fi one ZigBee combination network

Fig.5 illustrates one Wi-Fi and one ZigBee combination, by taking different power levels of Wi-Fi on x-axis and %failure of ZigBee with different constant powers on y-axis. If we increase the power level of Wi-Fi device this affects the packet loss for ZigBee device. Initially ZigBee power was kept constant at 1.4mw and Wi-Fi power was gradually increased from 1.4mw to 100mw and the % failure of ZigBee was slowly increased to 100% at high power levels of Wi-Fi. In this simulation we gave send interval values for Wi-Fi as 0.8ms and 1.6ms, and for ZigBee it is 15.8ms, and the start time for both the devices is same i.e., 0s and the message length values for Wi-Fi is 1000 bytes and for ZigBee it is 90 bytes. At 0.8ms send interval, Wi-Fi is fully

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occupied by its own transmission. If we double (increase) the send interval time to 1.6ms, Wi-Fi transmits its data up to 0.8ms interval and remaining time will be idle. This idle time will be opportunistically used by ZigBee device. Here we analyzed that the Wi-Fi at 0.8ms send interval % failure of ZigBee is more when compared to Wi-Fi 1.6ms send interval.

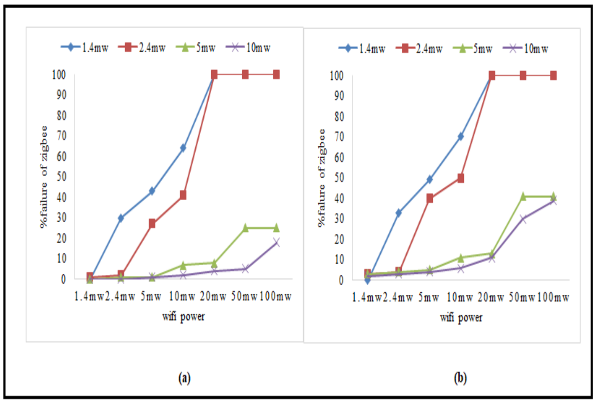

Fig.5: One Wi-Fi One ZigBee combination network with same start time

Fig.6 illustrates the 2 Wi-Fi's and one ZigBee combination, by taking different power levels of Wi-Fi on x-axis and %failure of ZigBee with different constant powers on y-axis. In this simulation we gave send interval values for Wi-Fi as 0.8ms and 1.6ms, and for ZigBee it is 15.8ms. The start time for both the devices is same i.e., 0s and the message length values for Wi-Fi is 1000 bytes and for ZigBee it is 90 bytes. If we increase the power levels of both the Wi-Fi devices this will affect the packet loss for ZigBee and Wi-Fi (self-coexistence) devices. Initially ZigBee power was kept constant at 1.4mw and Wi-Fi power was gradually increased from 1.4mw to 100mw and the percentage packet loss is slowly increased to 100% at high power levels of both the Wi-Fi's.

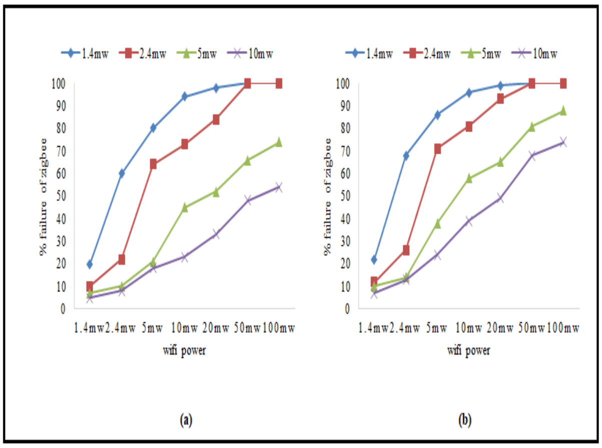

Fig.6: Two Wi-Fi one ZigBee combination with same start time

Fig.7 shows the two Wi-Fi's and one ZigBee combination with different start times, by taking different power levels of Wi-Fi on x-axis and %failure of ZigBee with different constant powers on y-axis. In this simulation we gave send interval values for Wi-Fi as 0.8ms and 1.6ms, and for ZigBee it is 15.8ms. The start time for Wi-Fi 1 is 0ms and for Wi-Fi 2 it is 0.8ms and the message length values for Wi-Fi is 1000 bytes and for ZigBee it is 90 bytes. For given send interval two Wi-Fi devices access the channel continuously, so the ZigBee device gets very less chance to access the channel, so that failure rate of ZigBee is more in this combination.

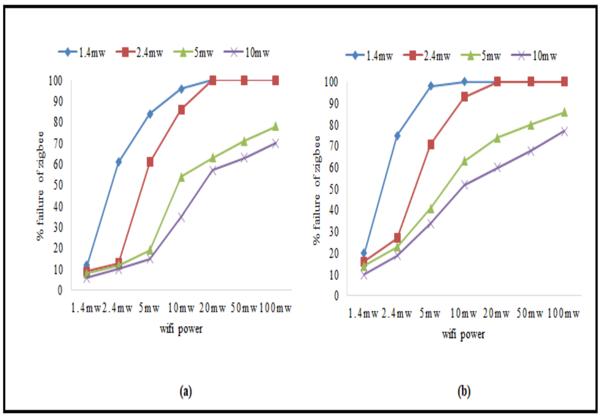

Fig 7: Two Wi-Fi one ZigBee combination with different start time

VI. CONCLUSION

In this paper, we analyzed the coexistence scenario between 802.11g and 802.15.4 networks. Impact of factors such as transmission power and traffic scheduling between WLAN and WPAN devices operating in the 2.4GHz ISM band, are investigated. Simulation analysis shows that when only one Wi-Fi and one ZigBee Combination was there, % failure of ZigBee is less, even if Wi-Fi power increases. When multiple Wi-Fi networks are there, impact on Zibee was considerable. Packet start times of Wi-Fi and ZigBee also have shown their impact. Staggered starting times resulted in lesser % failure to Zigbee device transmissions.

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