Review Article

A Survey on Interference Avoiding Methods for Wireless Sensor Networks Working in the 2.4 GHz Frequency Band

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Abstract

Wireless sensor networks (WSN) are a very important and relevant field of research for modern control and monitoring applications in today's communications and information networks. The increased use of wireless devices across a variety of settings, from smart buildings to smart homes, energy consumption monitoring, healthcare applications, plus a myriad of mobile devices' applications worldwide have multiplied the already crowded radio spectrum anywhere causing problems. Hence, interference among concurrent transmissions causes severe performance degradation due to the coexistence of different wireless networks working on the very same frequency band, something which has an impact on the different applications' performance. The WSN working on the 2.4GHz frequency band experience interference from competing networks like Bluetooth, Wi-Fi (IEEE 802.11b/g) and also gets negatively influenced by applications like microwave oven and cordless phone. Because of said interference, the performance of the WSN is getting degraded. Furthermore, the operation of low power WSN is extremely vulnerable and unpredictable under interference conditions. Hence there is an increasing need for research on interference avoiding methods and on improving the coexistence mechanisms among different wireless devices operating on the same frequency band. This paper presents a comprehensive review on the important aspects of experimental analysis, estimation, modeling, and avoiding of interference for WSN and offers some insight in dealing with aforementioned problem.

Keywords: Wireless sensor networks, Bluetooth, Data Communication, Interference, 2.4 GHz Frequency and, Wi-Fi, ZigBee.

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1. Introduction

Progress on advanced research in wireless data communications and embedded micro-sensing applications like MEMS (Micro-Electro-Mechanical Systems), IoT (Internet of Things) technologies has made WSNs prominent [1]. Wireless sensor networks (WSNs) are widely used in industry today since they are able to efficiently sense various parameters in a myriad of industrial and service processes with high accuracy and low power consumption. The development of a multiplicity of sensors and networks everywhere based on sensor nodes have impacted our work environments and our everyday life. A WSN normally comprises of many low-cost wireless nodes, each proficient for collecting various types of information, processing, and communicating data with adjacent nodes in the network [2]. Numerous WSN applications found appropriate for applications such as surveillance, smart homes, automation, precision agriculture, vehicular traffic supervision, environment monitoring, and disaster recognition [3]. Modern industrial, scientific, and medical (ISM) applications based wireless devices operate in 2.4 GHz unlicensed frequency band. The WSN has become ubiquitous particularly in office, campus and residential buildings [4]. Likewise, the 2.4GHz frequency-based technologies like ZigBee, Wi-Fi or WLAN, and Bluetooth are working in the common frequency band

often causing some degree of interference. The domestic applications like micro-wave oven and cordless phone are also radiating in 2.4GHz band. Thus applications working on 2.4GHz frequency band are influencing one another's performance. Particularly, the performance of ZigBee based WSN is highly influential because of other technologies and therefore is getting degraded in terms of high packet drop, and increased frame error rate (FER) because of data collisions and increased energy consumption. The coexistence of various wireless technologies operating in 2.4GHz is shown in Fig.1 pictorially. The efficient packet delivery makes WSN reliable. The data generated at source must be propagated to the destination in a proficient way without any influence of other variables causing the distortion of the data [5]. On the other hand, the variables affecting the interference in the 2.4GHz frequency band include the distance between source and destination, inefficient routing, obstacle causing the fading and shadowing. To this we must add the environmental conditions (temperature), and node behavior [6]. The important factor to be considered in coexistence environments is interference. The interference is considered as a serious issue particularly for the low power wireless networks like WSN. The interference shows impact on the link quality. The devices operating in the same frequency band, same location and transmitting signals or data with high energy (Wi-Fi) will cause substantial degradation in low-power network (WSN) performance [7-8].
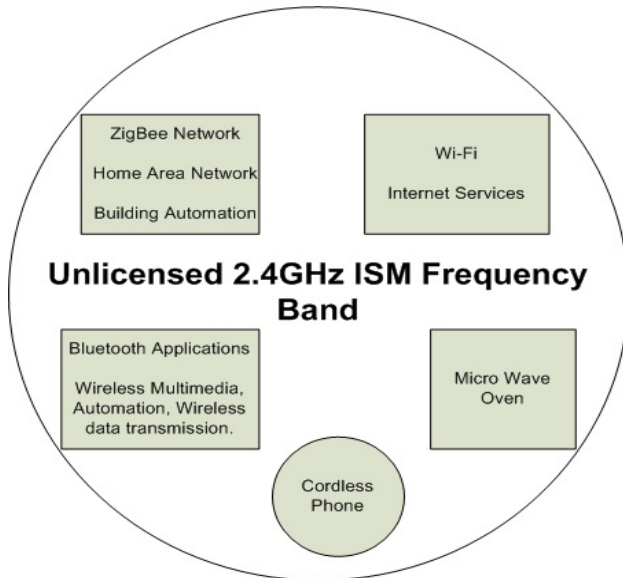
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Fig. 1. The modern wireless technology based applications operating in 2.4GHz frequency band.

The main consequence of the interference is increased packet error rate (PER), packet loss ratio (PLR), and increased data congestion. The network traffic is increased significantly due to the packet retransmissions that increase the overhead and in turn increase the network load. Interference results in the inaccessibility to the channels, increased delay and depletion of battery levels of the node [9]. The interference leads to the contention delay and increased latencies. The interference can be classified in to two types, internal interference and external interference. The internal interference occurs because of the disturbances experienced from the nodes of the same network. It can be minimized by selecting an organized network configuration, node placement, network topology, routing and systematic channel access algorithms design etc. Also in today's world of wireless communications, the presence of different wireless systems is a potential for interference. Wireless systems can interfere with each other at distances of 2000 feet (600 meters) or more. The external interference is occurring because of different technologies or applications (Microwave-oven) operating in the common frequency band [10]. The external interference avoidance is a very complex and very few works have been reported on this area. Hence there is a requirement of high research on this area.

A systematic research on the various techniques for avoiding interference may lead to the deployment of a safer, more efficient operating WSN, which is not simple task [11]. Interference is complex because, firstly, the interference is

intermittent and dynamic, hence designing solutions for avoiding interference is very complex. Secondly, it is extremely difficult to predict the sources of external interference and their behavior at a given location and time [12]. There are 3 major pointers for assessing network performance (i.e., latency, throughput and packet loss). The time taken to transmit a packet across a network is generally defined as Latency. Throughput is expressed as the amount of data being transmitted/received by unit of time. Packet loss is assessed based on the number of packets lost per 100 packets of data transmitted by a host [13]. Figure 1 shows different technologies like ZigBee, Bluetooth, Wi-Fi, and Cordless phone all of which share unlicensed 2.4GHz frequency band. The microwave oven also radiates in the same frequency band, hence the distortion caused by this appliance has to be also considered and dealt with accordingly.

ZigBee has secured the prominent place and is considered for technologies, like IoT (Internet of Things) communication. The ZigBee Alliance has improved a two-way wireless communication standard allowing products with little price, and low power consumption. The ZigBee device can be easily embedded into consumer electronics aimed with sensor and actuator based controlling applications and building automation [14]. ZigBee is built on the top of IEEE 802.15.4 standard and strengthens the interoperability among different technologies in terms of automation and control. The performance of ZigBee can be optimized by adjusting the parameters relative to physical (PHY) layer, medium access control (MAC) layer, and network (NWK) layers [15]. The adjustment of network layer parameters also improves the network life time. The initial two layers, PHY layer and MAC sub-layer specifications were defined by IEEE 802.15.4. The ZigBee alliance defined the operation and working specifications in both NWK layer and application sub-layer (APS) [16].

Wireless LAN (WLAN) is designed for fast and reliable information transmission system to provide local self-regulating network communication between computing systems by means of wireless instead of a cable structure [17]. WLANs specification is based on IEEE 802.11 standard. WLANs use high-frequency electromagnetic transmission, either by employing radio frequency (RF) or infrared (IR), to communicate information from one point to another with low mobility range [18]. Bluetooth on the other hand is based on IEEE 802.15.1standard, and it is intended for very small-range, low-budget wireless communications suitable to replace the cables. The devices linked using Bluetooth can function either as a master node or a slave node [19]. An overview of different parameters and technical specifications of wireless technologies like Zigbee, Bluetooth and WLAN or Wi-Fi and technologies are discussed in Tab. 1 as following.

Table 1. Comparison of ZigBee, WiFi and Bluetooth parameters working in the 2.4 GHz frequency Band. [21-25]

Parameters	Zigbee	Wi-Fi	Bluetooth
Physical Layer Standard	IEEE 802.15.4	IEEE 802.11	IEEE 802.15.1
Maximum Data Rate	20, 40 & 250 Kbps	11 Mbps	1Mbps
Power Consumption	Years	Hours	Days
Modulation	DSSS/QPSK	OFDM	FHSS/BPSK
MAC	CSMA/CA	TDMA/TDD CSMA/CA	TDMA/TDD
Number of channels	26	11-14	79
Networking topology	Star, Mesh and Cluster-tree	Star	Star
Frequency operating band	868 MHz, 900-928 MHz and 2.4GHz	2.4 GHz and 5 GHz	2.4 GHz
Coverage	10-300 M	76 M (for low speed)	10M

		33 M (for high speed)	
Nodes per network	232 nodes in 8bit addressing, 65,536nodes in 16bit addressing	20-32 nodes	7 nodes
Complexity and cost	Low	Very High	Medium
Security features	128-bit Advanced Encryption Standard	Authentication Service Set Id(SSID), WEP	64 & 128 bit encryption
Key attributes	Reliable, Low power, Cost effective	Speed Flexibility	Cost convenience
Initial access	The device connects with the existing network under the 30m radius.	Connection of a device requires 3-5 seconds	Connection of a node needs some 10 seconds
Typical Applications	Monitoring and Control	Web, Email, Video	Cable replacement

There is a need for improved solutions for effective interference management. Something which requires continuous monitoring, identification of the sources causing interference, and consequently initiating the steps to avoid the identified interference [20-22]. Figure 2 shows a modern smart home considering ZigBee for automation, Wi-Fi for accessing internet and Smart meter (Home Gate Way) for Smart grid based energy management. Figure 2 consists of 4 ZigBee coordinators, connected through wireless connection to about

17 ZigBee nodes. Where, each ZigBee coordinator is connected to about 4 to 5 ZigBee nodes. There are 4 WiFi access points (AP) and about 5 WiFi clients, each AP is connected to 1 to 2 WiFi clients. The position of all the nodes is assumed and placed such that they fall under each other's influence. The ZigBee coordinator and WiFi access points are connected to Home Gate-Way (HGW) through wired network as shown in the figure. The HGW can be considered as Smart Meter that is very important for Smart grid applications.
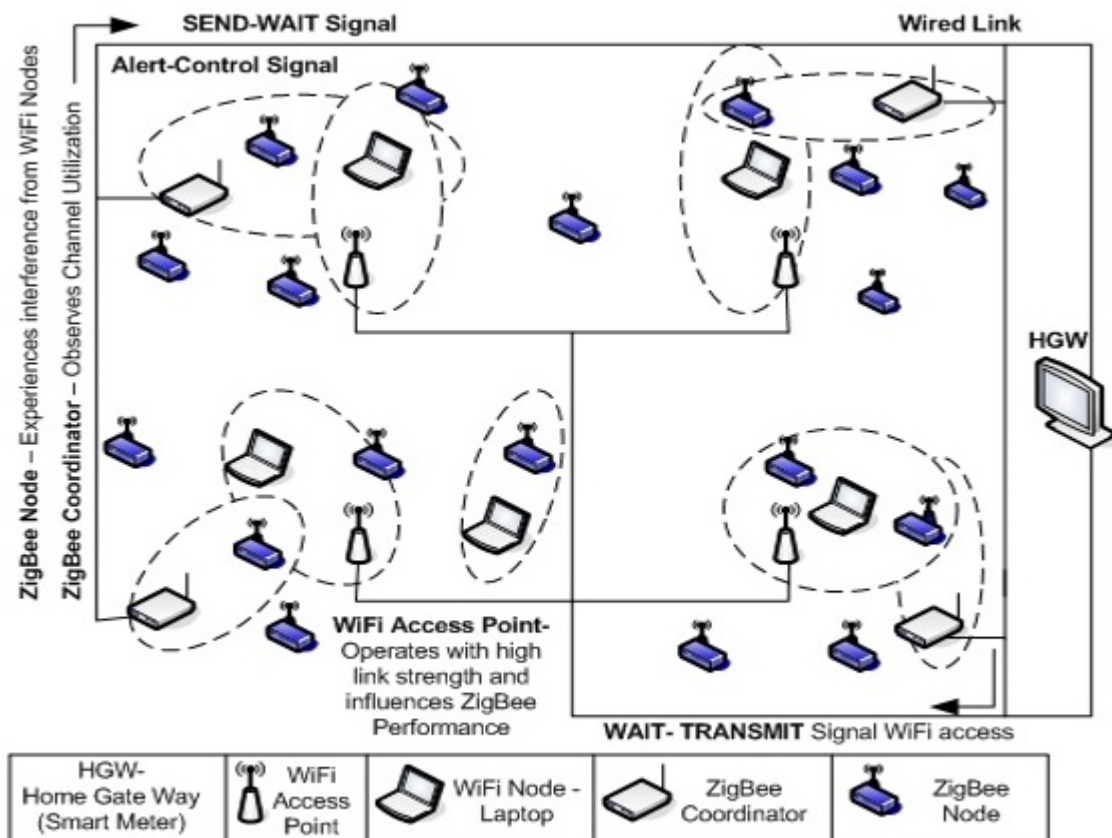

Fig. 2. The architecture of the smart home environment with ZigBee and Wi-Fi nodes coexisting to each other.

In this paper we present a detailed survey on existing interference avoiding techniques for ZigBee based WSN. We have studied the sources of the interference and classified them in detail. Firstly, we have presented the methodologies for analyzing, estimating and avoiding the interference for the effective operation of WSN coexisting with other technologies like Wi-Fi and Bluetooth technologies working in same 2.4GHz frequency band. Secondly, we have presented

methodologies for avoiding interference from the nodes of same ZigBee network (internal interference). Thirdly we have presented the survey of various works on measurement and modelling of the interference in 2.4 ISM band. Fourthly various ways of experimenting, analyzing interference using hardware and software solutions were studied. In the fifth section, various modern applications of coexisting systems were presented and

finally a discussion based on the study performed were presented.

This paper is organized as follows. Section 2 presents the classification of interference for WSN. The interference measurement and modeling are described in section 3. The details of experimenting with interference using simulators, emulators and testbeds are discussed in section 4. In the Section 5 presents the application for WSN that works under the influence of WiFi. The discussion and insights are presented in section 6. Section 7 discusses the open research issues and finally, section 8 concludes the paper.

2. Interference

The 2.4GHz ISM band is jointly shared by multiple technologies for data communication aimed at different applications. In general ZigBee nodes have 27 channels, of them only channel '0' works in 868 MHz band, in 915MHz band consists of channels '1-10', and the channels '11-26' will operate in 2.4GHz frequency band. WLAN (Wi-Fi) technology has '11-14' channels varying geographically (11 channels are available in the USA, 13 channels in Europe, 14 channels are available only in Japan) operating in 2.4GHz ISM band [23]. In case of WLANs among the available 11-14 channels operating in 2.4GHz band only 3 channels i.e.,1, 6 and 11 are available for data communication [24]. Bluetooth has '80' channels working in 2.4GHz ISM band. The channel distribution and overlapping of the wireless technologies working in the 2.4GHz frequency band is as shown in the following Figure 3. From Figure 3 the following points can be observed: channel '1' of Wi-Fi is influencing channels 11th to 14th of ZigBee. Channel 6 of Wi-Fi is influencing 16th channel to 20th channel of ZigBee and channel 11 of Wi-Fi is overlapping with 20th channel to 24th channel of ZigBee. Though the Bluetooth channels are distributed across 2.4GHz band, based on the literature, it can be inferred that the effects of interference from other technologies on Bluetooth are very less influential. Tab. 2 below shows the technical specifications comparison for Wi-Fi, Bluetooth and ZigBee technologies [12] [13] [25]. In this section, two types of interferences, external interference and internal interference are discussed in detail.
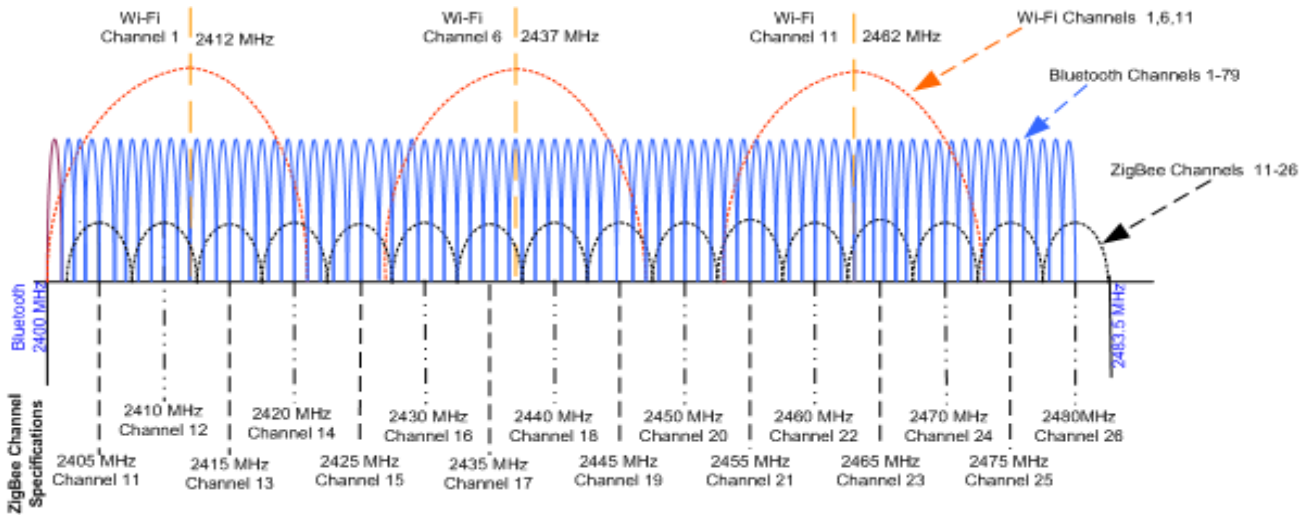

Fig. 3. Channel specifications of the wireless technologies operating in 2.4GHz Frequency Band.

Table 2. The Comparison of 2.4GHz frequency band technologies

2.4GHz Technology Comparison				
	Data Rate	**Number of Channels**	**Minimum Quit Bandwidth Required**	**Interference Avoidance Method**
Wi-Fi	11Mbps	13	22 MHz (Static)	Fixed Channel Collision Avoidance
Bluetooth	723Kbps	79	15 MHz (Dynamic)	Adaptive Frequency Hoping
ZigBee	128Kbps	16	1 MHz (Dynamic)	Fixed Channel Collision Avoidance

A. Interference from other coexisting technologies working on same frequency band

WSN (ZigBee network based on IEEE 802.15.4 standard) operating in the 2.4GHz frequency band is coexisting with other technologies like Wi-Fi (IEEE 802.11) and Bluetooth. Microwave oven used domestically and cordless phone for wired communication both also emanate electromagnetic noise in the 2.4GHz ISM band. All of the above serve as examples for external interference (WSN experiencing interference from other coexisting technologies) and has a strong impact on the performance of WSN. The effects of the interference on WSN is a reduction of the packet delivery ratio and decreases the network lifetime because of increased listening and reduced node sleeping schedules. Because of the external interference, the latency and packet retransmissions of the network are also increased [26] [27]. The effects of external interference on WSN from the other technologies like Wi-Fi, Bluetooth, and micro wave oven are discussed in detail in the following sections.

a. The coexistence of WSN and Wi-Fi based networks in the common area.

N. CihanTa *et al.* [28] have presented the analytical frame work on the issues of the coexistence between WSN and Wi-Fi networks. Based on the experimentation it was inferred that the network parameters in a Wi-Fi network can be dynamically adjusted to optimize channel/bandwidth utilization of the WSN while minimizing the effects of interference. They have also

presented the MATLAB simulation results of their theoretical framework proposed. Beata. K *et al*. [29] have described the effects of Wi-Fi standard on the transmission of WSN. A measurement-based verification is presented to evaluate the influence of Wi-Fi on WSN. This type of measurement can be useful for designing WSN, because they are often located near to the wireless networks which may cause disturbances or loss of data transmission. Yanchao Mao *et al* [30] have investigated the interference between 802.11b/g and 802.15.4 networks. They have carried out different experiments for analyzing the influence of interference in terms of link quality and measured performance of WSN under the influence of 802.11b/g, and vice-versa. The following points were observed: (1) The 802.11b interferes with WSN in a higher frequency range but with less interference strength, compared to 802.11g. (2) WSN also has a considerable impact on the working of 802.11b/g. (3) finally it was understood that different modulation methods of 802.11b/g show different impact on the link quality of WSN.

Ioannis Glaropoulos *et al.* [31] have used an analytical model and a hardware set up for analyzing the coexistence of ZigBee, and WLAN. The proposed system concentrates on two features, namely energy& timing. The results obtained show that the power levels and timing parameters jointly have an influence on the functioning of WSN. James Hou *et al.* [32] have proposed the methodology to prove that ZigBee is vulnerable to interference and have proposed potential solutions analytically, to resolve interference problem for improving the ZigBee performance. M. Danilo Abrignani *et al.* [33] have investigated the interference created by IEEE 802.11 upon ZigBee network. The investigations were made on different parameters and understood that effect of interference from Wi-Fi is severely affecting the performance of ZigBee based point-to-point network. Performance is evaluated in terms of PLR, average round trip time and overhead. Tests were conducted on the European Laboratory of Wireless Communications for the Future Internet (EuWin) testbed at the University of Bologna. Furthermore, environmental conditions were taken into consideration during experiments so as to account for this factor as well. Srinivasan *et al.* [34] have done extensive practical experiments on the coexistence of 802.11b and WSN and have observed the following: (i) 802.11b is avoiding clear channel assessment (CCA) of WSN, which has an effect on increased delays. (ii) 802.11b has very high power and acts as the high source of noise for WSN nodes, which leads to high packet losses. (iii) It is also observed that the presence of WSN nodes does not have any effect on the 802.11b nodes.

Authors in [35] have proposed an approach for analyzing the performance of ZigBee technology under the influence of Wi-Fi. It is inferred that the influence of Wi-Fi on the ZigBee performance increases as it moves nearer and, on the contrary, the effect decreases as the distance is increased. The authors have analyzed the advantages of adjusting the offset values for improving the performance of both ZigBee and Wi-Fi. Daniele Croce *et al.* [36] have proposed a mathematical model for characterizing the Wi-Fi receivers in presence of controlled interference sources (training phase) using hidden Markov chains. The above process identifies the sources for the cause of error patterns. Based on the experimental results obtained the effect of ZigBee interference was clearly understood. Kunho Hong *et al.* [37] have presented a framework to regulate the WLAN data traffic when there exist ongoing ZigBee data transmissions. Because of WLAN interference, the MAC delay exceeded the maximum tolerable delay (threshold) of ZigBee. They aimed to ensure that the delay experienced by ZigBee sensors (especially for alarm signals) did not exceed the

threshold delay, while upholding the throughput of WLAN's as high as possible.

An adaptive interference avoidance algorithm was proposed in [38], to improve the functioning of ZigBee network under WLAN interference. It uses a WLAN queuing model derived based on Markov chains. The work in [39] have proposed the CACCA algorithm for improving the performance of WSN in the coexisting mediums. The coexisting wireless technologies working in same frequency band are supporting each other. They have analyzed PER incurred by ZigBee network under the influence of Wi-Fi and achieved better ZigBee performance in terms of PER. Chieh-Jan Mike Liang *et al.* [40] have put forward the BuzzBuzz algorithm. The algorithm is based on the quantified interference patterns between Wi-Fi and ZigBee networks at a bit-level. The algorithm also considered the effects of ZigBee node on the behavior of nearby Wi-Fi transmitters, producing symmetric interference among the both. Based on these observations, they introduced targeted redundancy mechanisms, namely multi-headers and error correction to improve 802.15.4 reception rates. The BuzzBuzz performance was also evaluated on TinyOS based implementation through stress tests on a testbed. TinyOS is an open source, BSD-licensed operating system designed for low-power wireless devices, such as those used in sensor networks. Peizhong Yi *et al.* [41] have introduced an interference avoidance algorithm based on frequency agility. This algorithm detects interference with WLAN using the energy detection scanning for ZigBee nodes. It avoids the interference by dynamically moving the node experiencing an interference to a safe channel.

Panlong Yang *et al.* [42] have proposed a sink based MIMO design (ZIMO) for avoiding the interference between ZigBee and h igh-powered Wi-Fi signals. ZIMO handles the interference from Wi-Fi access points by defending the ZigBee signals. The Wi-Fi signals interfered by ZigBee node can be recovered by the ZIMO sink. ZIMO consists of frame detection & identification, spectrum slicing, interference cancellation and interference nullification, and ZigBee decoder. Ruitao Xu *et al.* [43] have proposed an interference avoidance technique for Multi-channel ZigBee networks (MuZi). It has three main functionalities: interference estimation, channel exchanging and connectivity maintenance. While estimating the Wi-Fi interference, the intensity and density of interference are also considered. In channel exchanging, the optimum channel is selected based on these above parameters. Yubo Yan *et al.* [44] have presented a Wise ZigBee coexistence system (WizBee) having single antenna sink. It applies interference cancellation technique to avoid Wi-Fi interference and obtain ZigBee signals. For Wi-Fi data decoding, it uses Soft-Viterbi decoding algorithm on each sub carriers. The decoded data is used for channel coefficient estimation. WizBee does not require any modification to the existing ZigBee protocols and ZigBee devices.

The following tables summarize the characteristics of the protocols and works considered above. Tab. 3 summarize all the works considered in this section in terms of mathematical parameters, simulation or experimental parameters considered for evaluation. The notations in terms of alphabets can be considered as follows, (A). Channel Utilization, (B). Signal-to-Interference-Plus-Noise Ratio (SINR) or Received Signal Strength Indicator (RSSI), (C). Bit Error Rate (BER) or PER or PLR, (D). Delay, (E). Node mobility, (F). Throughput, (G). Energy Consumption, (H). Path Loss, (I). Distance. Tab. 4 signifies the parameters considered for evaluation of the work in terms of MAC approach. The Tab. 5 represents the detailed description of all the protocols considered in this section.

Table 3. Parameters considered for evaluation

Reference Number	Mathematical									Simulation									Experimental								
	A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I
28	✓		✓	✓		✓				✓	✓	✓															
29	✓	✓	✓	✓	✓					✓			✓		✓												
30	✓			✓	✓		✓						✓		✓	✓											
31		✓	✓			✓														✓				✓		✓	
32	✓		✓			✓															✓			✓			
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34	✓			✓	✓														✓			✓	✓			✓	
35	✓		✓	✓	✓	✓	✓												✓				✓				
36	✓	✓	✓		✓															✓	✓			✓			
37		✓	✓	✓									✓	✓						✓	✓						
38	✓		✓			✓														✓	✓	✓					
39	✓		✓	✓																✓	✓			✓			
40		✓	✓						✓											✓	✓			✓			✓
41	✓	✓	✓																	✓	✓						✓
42		✓	✓				✓				✓	✓															
43		✓	✓																	✓	✓			✓			
44		✓	✓																	✓	✓						✓

Table 4. Parameters Considered in terms of MAC approach for understanding Interference

Reference Number	Collision rate	Power consumed	Latency	Throughput	Reliability	Channel access		Spatial reuse	QOS support	Mobility
28	Low	Low	High	Medium	High	CSMA_CA		Yes	No	No
29	Low	Low	Medium	High	High	CSMA_CA		No	Yes	Yes
30	Low	Low	Medium	Medium	Medium	TDMA		No	Yes	Yes
31	High	Medium	Low	Low	Medium	CSMA-CA		No	No	Yes
32	Medium	Medium	Low	Low	Medium	CSMA-CA		No	No	No
33	High	Low	Medium	Medium	Medium	CSMA-CA		No	Yes	No
34	Low	High	Low	High	High	CSMA-CA		No	Yes	Yes
35	Low	Low	Low	High	High	CSMA-CA		Yes	Yes	Yes
36	Low	Low	Medium	High	Medium	CSMA-CA		No	No	No
37	Low	Low	Small	High	High	CSMA-CA		No	Yes	No
38	Low	Medium	Small	High	High	CSMA-CA		Yes	Yes	No
39	Low	Low	Small	High	High	CSMA-CA		No	Yes	No
40	High	Medium	Medium	Medium	Low	CSMA-CA		Yes	No	Yes
41	Medium	Low	Low	Medium	Low	CSMA-CA		Yes	Yes	Yes
42	Low	Medium	Low	High	Medium	CSMA-CA		No	Yes	No
43	Low	Low	Low	Medium	Medium	CSMA-CA		No	Yes	No
44	Low	Medium	Small	Medium	Medium	CSMA-CA		No	Yes	No

Table 5. Detailed description of the Considered Protocols

Reference Number	Algorithm	Technologies Considered	Important parameter	Inference	Simulation/ Experimentation
28	Throughput Analysis	ZigBee-WiFi (IEEE 802.11	Channel Utilization Capacity	Channel parameters of Wi-Fi need to be adjusted for efficient ZigBee network operation.	MATLAB
29	Algorithm 1-Home Gateway Operation. Algorithm 2- Zigbee coordinator Operation	Zigbee-WLAN (IEEE 802.11g)	Time Delay	WLAN traffic was controlled, when ZigBee transmissions are going on.	ns-2
30	Adaptive interference avoidance algorithm	Zigbee-WLAN (IEEE 802.11b/g)	Clear Channel Assessment and collision probability	Algorithm controls ZigBee frame length and improves the ZigBee performance both under saturated and non-saturated WLAN.	OPNET and MATLAB
31	Measurements methodology	Zigbee-WLAN (IEEE 802.11b/g)	SINR, Path Loss	Interference has a huge impact on the transmission delay and throughput. Above parameters increases if distance between ZigBee and Wi-Fi node increases.	Experimentation using testbed.
32	Measurements methodology	IEEE 802.15.4-IEEE 802.11b/g	Throughput, Packets Received Ratio.	802.11b has high impact on 802.15.4 compared to 802.11g. Different modulation techniques has different impact on link quality indices of 802.15.4.	Experimentation

33	Measurements methodology	ZigBee and Wi-Fi (802.11b)	RSSI, Packet loss ratio	Power and timing have effects on the performance of Zigbee.	Experimentation based Analytical model.
34	Measurements and Analysis Methodology	ZigBee and Wi-Fi (802.11b)	Clear to Send(CTS) and Request to Send (RTS)	A Hybrid Mediator is initiated for RTS-CTS based requests and makes Wi-Fi nodes to sleep and allows ZigBee transmission.	Experimentation
35	Coexistence aware-Clear Channel Assessment	ZigBee and Wi-Fi	PER, CCA, Packet success ratio	The algorithm implemented shall make one technology to back-off other technology.	Experimentations using testbed
36	BuzzBuzz Algorithm	ZigBee and Wi-Fi	RSSI, Packet delivery ratio	Wi-Fi interference is avoided through header and payload of ZigBee.	Experimentation - outdoor
37	Frequency agility-based interference avoidance algorithm	ZigBee and WLAN	PER	Algorithm identifies the safe distance and safe offset frequency, to avoid interference with small latency.	MATLAB Simulation and Implementation using testbed.
38	ZIMO Algorithm	ZigBee and Wi-Fi	RSSI, SINR, Throughput	ZIMO addresses the issues of interference from the WiFi and protects the ZigBee signal	Experimentation
39	WIZBEE Design	ZigBee and Wi-Fi	Channel estimation	WizBee is a single antenna sink supports coexistence.	Experimentation using testbed.
40	Experimental setup	ZigBee and Wi-Fi	Packet loss rate, Overhead,	Performance of the protocol is studied is effects of routing protocol are also evaluated.	EuWin Testbed
41	Empirical measurements	ZigBee and Wi-Fi	Packet delivery ratio	Ideologically explained the assumptions to be made during the protocol design.	Experimental setup
42	Analysis of interference using the Simulation.	ZigBee and Wi-Fi	BER, SINR, Pathloss	Considering a small-offset can reduce SINR by 10 times.	MATLAB Simulation
43	Experimental model	Zigbee and Wi-Fi	Error analysis	Effects of ZigBee on the Wi-Fi receiver is analyzed.	Experimental setup
44	MuZi Algorithm	Zigbee and Wi-Fi	BER, SINR, PLR	Avoids Interference using 3 steps, Assessment of interference, switching channel and connectivity maintenance.	Experimentation using testbed

a. The coexistence of WSN, Wi-Fi, and Bluetooth networks in the common area.

Bluetooth works based on frequency hopping spread spectrum (FHSS). When using FHSS, each available frequency band is divided into sub-frequencies, and signals rapidly change ("hop") among these in a predetermined order. Hence, interference at a specific frequency will only affect the signal during that short interval. FHSS can, however, cause interference with adjacent direct-sequence spread spectrum (DSSS) systems. This makes Bluetooth robust to interference in the unlicensed 2.4GHz frequency band [25]. In the coexistence environment, the packet losses of Bluetooth are negligible when compared to that of ZigBee [21]. Boano *et al.* [45] have analyzed the effects of Bluetooth on WSN (ZigBee). It is inferred that the effects of Bluetooth have a very low impact on ZigBee when compared to that of Wi-Fi devices or microwave ovens. Soo Young Shin *et al.* [46] have developed an analytical model to evaluate the performance of ZigBee under WLAN and Bluetooth interference. It was observed as the performance of ZigBee is more effected because of Bluetooth than Wi-Fi in the coexisting mediums. Rosario G. Garroppo *et al.* [47] have conducted an experimental study for analyzing the mutual interference among ZigBee, Wi-Fi and Bluetooth devices. Apart from mutual interference among each pair of devices, simultaneous interference among all the three devices is also analyzed. In all the experiment scenarios, the Frame Error Rate (FER) and goodput parameters of ZigBee are being affected in the presence of WLAN and Bluetooth.

Kuruvilla Mathew *et al.* [48] have investigated the effects of signal penetration of Bluetooth and ZigBee in regions having thick shrubs. They have also investigated the effects of environmental conditions considering both technological and environmental interferences. From the experimental results, they have shown that ZigBee signal penetration is degraded when there is interference from other signals. Jaana Suhonen *et al.* [49] have analyzed the performance of ZigBee and Bluetooth robot cars. Both the cars are operated under the interference caused by sources like Bluetooth and WLAN. For each interference source, the utilized bandwidth is independently measured. The properties of the power spectrum and noise resistance of both the cars are analyzed and observed as ZigBee performance is getting affected in the presence of Bluetooth.

b. The Coexistence of WSN network with domestic appliances

The electromagnetic interference has a great influence on wireless propagation and severely effects the data communication in the 2.4GHz frequency band [51]. The Microwave oven used for the domestic kitchen purposes radiate electromagnetic interference. Zhou *et al.* [50] have evaluated the effects of electromagnetic interference from microwave oven on wireless networks. It is inferred that it is affecting almost half of the spectrum available in 2.4GHz band using spectrum analyzer. Boano *et al.* [45] have analyzed the influence of Microwave ovens using the RSSI sampling by employing the off-the-shelf motes. They have modeled the interference generated based on the periodicity of generated pattern. Then they have also proposed solution for quantifying the impact of interference on the packet reception ratio (PRR) of WSN. Wenqi Guo *et al.* [52] have investigated the problems disturbing coexistence of ZigBee systems with other technologies. A systematic experimental study was conducted on the ZigBee performance under the influence of microwave ovens for several different link configurations. The experimentation arranged has tested the wireless propagation

of ZigBee between source and receiver for a particular time period with respect to distance between nodes and channel variations. The above experimentation was mainly conducted to understand the consistency of ZigBee under the influence of electromagnetic interference from microwave oven. The ZigBee consistency was understood based on the PER, RSSI and Link quality indicator (LQI). It was very clear from the results obtained that the performance of ZigBee was severely getting affected when Microwave oven is switched ON.

The following tables summarize the characteristics of the protocols and works considered above. The Tab. 6 summarize all the works considered in this section in terms of mathematical parameters, Simulation or experimental parameters considered for evaluation. The notations in terms of alphabets can be considered as follows, (A). Channel Utilization, (B). RSSI or SINR, (C). BER or PER or Packet Loss Ratio (PLR), (D). Delay, (E). Node mobility, (F). Throughput, (G). Energy Consumption, (H). Path Loss, (I). Distance. Tab. 7 signifies the parameters considered for evaluation of the work in terms of MAC approach. The Tab. 8 represents the detailed description of all the protocols considered in this section.

Table 6. Parameters considered for evaluation

Reference Number	Mathematical									Simulation									Experimental								
	A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I
45	✓	✓	✓			✓			✓											✓	✓	✓		✓	✓	✓	✓
46		✓	✓						✓			✓															
47		✓	✓		✓				✓												✓			✓			✓
48		✓							✓												✓						✓
49		✓			✓				✓											✓						✓	✓
50	✓	✓	✓		✓	✓			✓										✓	✓		✓		✓			
51			✓						✓											✓	✓				✓		✓

Table 7. Parameters Considered in terms of MAC approach for understanding interference

Reference Number	Collision rate	Power consumed	Latency	Throughput	Reliability	Channel access	Spatial reuse	QOS support	Mobility
45	Medium	Low	Medium	Good	High	CSMA_CA	Yes	Yes	No
46	Medium	Low	High	High	Medium	CSMA_CA	No	Yes	No
47	High	Low	High	Low	High	CSMA-CA	No	Yes	No
48	Low	High	Medium	High	High	CSMA-CA	No	No	No
49	Medium	Low	Low	High	Medium	TDMA	No	No	No
50	High	Low	Low	High	High	CSMA-CA	Yes	Yes	Yes
51	High	Medium	Low	Medium	Medium	CSMA-CA	No	Yes	No

Table 8. Detailed description of the Considered Protocols

Reference Number	Algorithm	Technologies Considered	Important parameter	Inference	Simulation/ Experimentation
45	JAM Lab Experimental test bed	ZigBee, Bluetooth, Wi-Fi, Microwave oven	RSSI, PRR	A JamLab is an interference testing platform to the best accuracy levels. It can test both spatial and temporal patterns.	Experimentation developed a test bed
46	Simulation	ZigBee-Bluetooth-Wi-Fi	PER-BER, SINR	The distance between the different types of technologies affects each other performance. The best suited distances is presented.	OPNET Simulator
47	Hardware based analysis	ZigBee-Bluetooth-Wi-Fi	Frame Error Rate, Goodput	WiFi has affected badly to a level of 41% drop for Zigbee and to a level of 68% drop for Bluetooth. WiFi performance was almost unaffected because of the other two.	Experimental Analysis using hardware.
48	Hardware based analysis	Bluetooth-Zigbee	Distance and environmental effects	The environmental effects on the Bluetooth and the Zigbee Propagation and their mutual effects on performance.	Experimental analysis
49	Hardware based analysis	Bluetooth-Zigbee-Microwave oven	RSSI, Frequency, distance	The mutual effects of different technologies upon each other performance is studied.	Experimental analysis
50	Self-Adaptive Spectrum(SAS) management	Crowded spectrum in 2.4GHz is considered	PRR, Throughput, time, Energy	SAS improves the performance of the Single frequency MAC protocol to coexist with multi-frequency capability.	Experimental analysis
51	Hardware analysis	Zigbee-Bluetooth-WiFi	PER-Packet Loss Ratio	Mutual effects of different 2.4GHz based technologies is studied.	Experimental Analysis

B. Interference from the nodes of same network

For the efficient performance of the WSN not only the external interference but also the internal interference has to be considered with equal importance. Internal interference is because of the disturbances experienced from the nodes of the same network. Most of the times internal interference is

because of the concurrent transmission of the data by multiple nodes in the same network at the same instance.

a. The performance of network when concurrent (parallel) transmission is scheduled

Most of the QoS based research performed on WSN is based on assumptions such as that the network is built collision free or has some form of Interference cancellation mechanism incorporated, works with low power and observes pure channel behavior. The research performed in [157] [170]is based on the WSN (ZigBee) built for indoor environments and have considered that there is no effect of other technologies in terms of interference. But the authors have stated the essence of the considering the disturbances, to increase the reliability of WSN. In [53] [54], the authors have performed research on the concurrent transmissions by the low power data communication. Authors have inferred that the concurrent transmission in WSN leads to the interference that shows the impact on the link quality. The experimentation was carried based on the measurements of SINR conducted by Mica motes based CC100 radios and observed following. Firstly, for efficient data communication between two nodes the SINR should exceed the threshold. Then it is assumed as link quality is high for the transmission of the data and the packet reception ratio (PRR) is above 90 percent in this case and this falls under connected region. If the SINR is below the threshold, then perhaps there are chances of transmission getting successful in spite of concurrent transmissions but the PRR will be less than 90 percent generally this type of connections are assumed as transitional or disconnected regions. Secondly, SINR threshold value is different based on the type of hardware and so the transmission power levels also vary accordingly so SINR does not depend on the location of the network.

b. Though nodes are invisible to each other even then concurrent transmissions have impact of the performance of WSN

The authors in [55], have performed research on real road tunnels, with precise concurrent transmissions. They have designed a network with three nodes in real time. Two nodes communicate with each other and the third node is distant and is not visible from the first two. The authors have noticed that the third node has created a significant noise for the first two nodes communication and observed that there is a substantial reduction in the packet delivery ratio than estimated.

c. Internal Interference from adjacent channels

It is very important to study the cross-channel interference on the performance of WSN. It results in the significant increase in the PLR. The research works proposed in [55] [58] have shown the effects of cross channel interference on WSN and have inferred that there is a significant increase in data collisions and hence measured in terms of increased PLR. Yafeng Wu et al. [59] [60] have implemented the WSN practically using MicaZ motes and introduced adjacent channel interference. It was inferred that the PRR decreased by 40%. The works in [61] & [62] have proposed the hardware solutions to reduce the load on multi-channel interference quantities by utilizing the spectral power density of the transmitter.

The following tables summarize the characteristics of the protocols and works considered above. The table 9 summarize all the works considered in this section in terms of mathematical parameters, Simulation or experimental parameters considered for evaluation. The notations in terms of alphabets can be considered as follows, (A). Duty cycle, (B). RSSI or SINR, (C). BER or PER or PLR, (D). Delay, (E). Node mobility, (F). Throughput, (G). Energy Consumption, (H). Path Loss, (I). Distance. Table 10 signifies the parameters considered for evaluation of the work in terms of MAC approach for assessing the internal interference. The table 11 represents the detailed description of all the protocols considered for evaluating the internal interference, in this section.

Table 9. Parameters considered for evaluation

Reference Number	Mathematical									Simulation									Experimental								
	A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I
53		✓	✓																	✓	✓						✓
54	✓		✓			✓			✓	✓	✓	✓					✓										
55	✓	✓				✓		✓	✓										✓	✓	✓	✓					✓
56		✓	✓																	✓							
57			✓	✓					✓												✓	✓					
58				✓		✓	✓															✓		✓	✓		
60		✓	✓	✓							✓	✓	✓							✓	✓	✓					
61		✓	✓			✓	✓													✓	✓			✓	✓		
62		✓	✓																	✓	✓						

Table 10. Parameters Considered in terms of MAC approach for assessing Internal Interference

Reference Number	Collision rate	Power consumed	Latency	Throughput	Reliability	Channel access	Spatial reuse	QOS support	Mobility
53	Medium	High	Medium	Medium	Low	CSMA-CA	No	Yes	No
54	Low	Very Low	Low	High	High	CSMA-CA	No	Yes	No
55	Low	Medium	Low	High	High	CSMA-CA	No	Yes	No
56	Low	Low	Low	High	High	CSMA_CA	No	Yes	No
57	Medium	Low	Medium	Medium	High	CSMA-CA	No	Yes	No
58	Low	Low	Low	High	High	CSMA-CA	No	Yes	Yes
60	Low	Medium	Medium	Medium	Medium	CSMA-CA	No	Yes	No
61	Low	Medium	Medium	Medium	Medium	CSMA-CA	No	Yes	No
62	High	Medium	Medium	Medium	Medium	CSMA-CA	No	Yes	No

Table 11. Detailed description of the Considered Protocols for evaluating the internal interference

Reference Number	Algorithm	Technologies Considered	Important parameter	Inference	Simulation/ Experimentation
53	Hardware based design	ZigBee, Surrounding Characteristics	PRR, SINR	When many interferers are present the interference cannot be estimated.	Experimentation based on the testbed
54	Hardware based design	ZigBee, Surrounding Characteristics	PRR, HOP counts, Duty cycle	The proposed RFT algorithm reduces the energy consumed by network 82.5% when compared to state of art systems.	Experimentation based on the testbed
55	Hardware based design	ZigBee, Surrounding Characteristics	PDR, Duty Cycle, RSSI	Effects of different spatial characteristics of the tunnels on MAC and routing based protocols is effectively studied.	Experimentation based on the testbed
56	Hardware and software based design	ZigBee, Surrounding Characteristics	SINR, BER	The concurrent transmissions in the wireless networks increases the reliability. The effects of concurrent transmissions on interference and capture effect is studied thoroughly.	Experimentation based on the testbed
57	Hardware and software based design	ZigBee, Surrounding Characteristics	PER, Transmission delays	Thoroughly investigated the effects of the concurrent transmission at the collocated networks.	Experimentation based on the testbed
58	IAMMAC- Simulation based implementation	ZigBee, Surrounding Characteristics	End-End Delay, PDR, Energy Dissipation, Goodput	IAMMAC is proposed for wireless sensor and actor networks. IAMMAC has improved the channel assignment.	Simulation using NS2
60	Simulation and Hardware experiment	ZigBee, Surrounding Characteristics	RSSI, Throughput and Packet losses	The algorithm and protocol implemented will facilitate the better channel assignment even in the very large networks.	GloMoSim simulation and Hardware implementation.
61	Hardware based design	ZigBee, Surrounding Characteristics	RSSI, SINR, PRR, Throughput, PDR	Multichannel overhead is reduced and Link quality is improved.	Real time implementation
62	Hardware based design	ZigBee, Surrounding Characteristics	PRR, RSSI	ZigBee communication is affected by the adjacent channel interference and WiFi. Can be altered by reducing RSSI levels.	Real time Experimental implementation

3. Measurement and Modeling Of Interference

The external interference shows a great impact on the characteristics of the wireless transmission. The assessment of the network parameters is unpredictable as it depends on the indoor and outdoor environments. The interference is intermittent in nature; the effect may be temporary making the unavailability of the channel considered. Hence it is very important to understand the effects of interference on data communications while designing WSN. The WSN can become robust by adapting the dynamically changing interference patterns [63]. The WSN can be adjusted to different interference patterns dynamically by accurate measurement of parameters associated to interference and can reduce the effects to a great extent. Firstly, there is a need for understanding the parameters in relative to surrounding interference (indoor or outdoor environment) and there is a need for accurate measurement of those parameters [64]. The measurement should be simple and energy effective in terms of node life.

Secondly, selection of essential metrics must be done for estimating the interference based on the obtained measurements. Based on the metrics selected, WSN can dynamically switch according to the changing interference patterns either by dynamic channel selection or by ranking based channel selection. Thirdly the effective lightweight algorithms must be designed to dynamically adjust the parameters as soon as the changes in the surrounding environment is observed [65].

A. Measurement of Interference Using Sensor Nodes
The WSN considers the RF Noise (floor) value for measuring the interference level, this value is estimated based on the signal power at receiver side [24]. In ZigBee radio the RF noise measurements are typically measured from energy detection method defined by IEEE 802.15.4 as a part of channel selection and is typically converted in RSSI value that is measured in dBm (decibels relative to one milliwatt) [66]. The RF noise value can be obtained at any instance at any point in between

the transmitter and receiver. There are also other parameters, considered for measuring the interference and those are Link Quality Indicator (LQI) and PRR, but these values can be obtained only when the packet is received at the receiver [67]. Using RF noise, one can estimate the presence of the interference at any point in the considered environment. Whereas using the RSSI, LQI and PRR, one can identify the interference only upon packet reception and can react accordingly (by switching channel) to reduce high packet loss [68]. The low LQI value is not only because of external interference but also may be because of the unreliable link quality. Similarly, PRR may be low because of some routing or software issues other than external interference [69].

The work proposed in [70] have measured the interference at each channel of ZigBee node using RF noise levels at a sampling rate of 20 samples per second under the presence of Wi-Fi. They have also proposed some important metrics used for better understanding of interference levels. Firstly, they have collected the cardinality of RSSI values at every channel. If the channel experiences the high cardinality, then it has high interference and the channels having low cardinality then channels experience low interference [71]. Based on the application requirement the authors [72] have considered RSSI values in between arrange 0 to-80dBm (this range is considered as optimal) as the number is increasing then the inference is going to be decreasing. If the number of RSSI values measured are above the threshold, then signal is said to highly interfered. The work in [73] considered -90dBm as threshold which may not be optimal because the off the shelf nodes are not typically calibrated. Most of the authors have also used RF noise measurement system by using the energy detection(ED) system. But as low power wireless node relies on battery, this type of measuring system was found as costlier in terms of high operating energy. As the sensor node should be active mode during the measurement process it leads to the depletion of battery levels. Based on this authors of [69] [74][75][76] have used PRR or clear channel assessment (CCA) based failure measurement for estimating the interference level. Main drawback of above papers is that they can be assessed only after the interference has affected and can only be learnt at receiver side.

B. Interferer Identification
The precise measurement of interference based on different methods as stated above can help in the identification of the source of the interference. Identification of the source of interference (interferer) can help in increasing the reliability and robustness of the WSN. Based on the RF noise measurements the type of interferers is identified. Also, there are some other hardware estimators for identifying interferers based on LQI, PRR, RSSI, and Signal to noise ratio (SNR). Kaushik R. C *et al.* [77] have presented an algorithm to identify the interferer based on the obtained channel power measurements. Based on this interferer´s characteristics a better channel is chosen for data transmission and packet scheduling. It is also observed that there is a considerable amount of energy saving, thereby increasing the life time of the nodes in the network. The authors in [78] have proposed a method to detect the interference based on classification mechanism. A ZigBee node scans the available channels to detect the interference that is generated by Wi-Fi devices or Microwave ovens. The mechanism proposed creates a signature for all the available of ZigBee channels. The signature is useful in determining the interference. Based on signature an adaptive channel selection scheme was proposed for proper channel scheduling and packet scheduling.

Zacharia *et al.* [79] have introduced an algorithm to identify the source of interference using the RSSI readings. The algorithm allows the channel to record the RSSI samples for one second. Based on the samples the algorithm determines interferer and the causes of interference and classifies the type of interferers also. Although this work has estimated many samples, still there is a drawback, like it is unclear with ongoing interference when multiple sources of interference occur at the same time. Frederik H *et al.* in [80] have proposed an interferer detection based on the LQI and RSSI combined properties. The algorithm proposed is based on the light weight detection. The type of interference classification is very simple and is based on WSN regular operation. The LQI is useful, when the packet is transmitted and is received with high link strength but fails the cyclic redundancy check (CRC). Then algorithm checks for RSSI values for each sample per payload byte. This information is useful in identifying the exact portion of the corrupted packet. Based on supervised training the classifier assigned to each corrupted packet will group them into a class based on the type of interferer. N. Boers *et al.* [81] [82] proposed a work based on the characteristics of the interference type. The authors define the interference based on the types of spikes (infrequent, periodic, periodic and frequent spikes) obtained based on the RF noise. The RSSI sample values are also recorded and taken in to consideration for estimating the type of the interference. If the channel is unclear with above types, then it is estimated based on dominant pattern. The decision trees are defined based on the above three patterns for a classifier to identify the type of interferer.

C. Modeling Interference
The hardware limitations like low energy usage-based network operations make it very difficult to build algorithms for modeling interference. The important problems of WSN are connectivity, coverage, routing, and end-to-end delay and in addition, complex computation increases the load on the nodes. Hence, a precise and simple methodology must be proposed to understand the complexity of WSN and interference-based problems [85]. A two state – Markov model [87] was proposed for modeling interference that was simple in design and has less computational overhead. The methodology proposed uses the RF noise measurements for assessing the interference. When the RSSI values inferred from the RF noise measurement are greater than the certain threshold then channel is treated as busy, otherwise, the channel is treated as idle. The protocol parameters are estimated using two-state Markov interference model in the coexistence environment, for understanding the interference effects on the performance of WSN. The authors in [86] have considered the channel quality parameter by measuring the accessibility of channel over the time. This system is systematically differentiating the channels based on the availability and ranking for efficient use. The categorization is based on firstly, the channels with sudden or small interval-based interference will have high inactive periods, and secondly channel with high-frequency periodic interference will also affects the performance of WSN. Among both, the first type channels are better compared to second type. It was inferred as the former channels are assuring high successful packet transmission compared to later group of channels.

The work in [26] have estimated the initial end to end delay, the RSSI value, and channel occupancy ratio. In the second stage using the hidden Markov model, the estimation of interference effects caused by dynamic sources is measured. Then for every transmission, the delay is compared with threshold delay and RSSI values are estimated. Then based upon obtained values the better channel is chosen. The authors

in [45] have modeled the external interference pattern for every device and based on the type of interfering source. The characteristics considered are like period of the signal, duty cycle, and output power. Particularly they have used this for understanding the microwave oven-based interference. The work in [87] has proposed bursty interferer model for estimating the interference caused by Wi-Fi and Bluetooth. Interference follows two states ON-OFF. This transition between two states is modeled by Bernoulli's random variable. The variable is further used to control the duration of interference and the bustiness. Based on this a second model was proposed, semi-periodic interferer model. This produces the continuous blocks of interference and is very useful in estimating the periodic data collection.

1. Experimenting with Interference

The interference is considered as an important concern by many researchers because it has a huge impact on the performance of the WSN [88]. For assuring stable and efficient performance of the WSN, the changing interference patterns from other technologies need to be understood. The simulation work carried must be taken to real-time implementation and the accurate performance of the WSN must be validated. Lack of tests may lead to limited or complete system failure [89]. An accurate performance needs to be tested and requires proper hardware infrastructure. Implementing through hardware also needs expertise and understanding of the co-design mechanisms to build accurate patterns. Particularly the design and implementation of interference patterns and validations under interference may consume lot of time and resources [90] [91]. There are a plethora of variables affecting the real-time implementation of WSN, that includes, antenna design, geometry (static or mobile), environmental conditions (temperature), the presence of obstacles [92]. The parameters like routing, multipath **fading**, and shadowing are also important for real-time implementation. The above may be considered in simulation-based implementation but while real-time implementation the properties of each device may be different and cannot be estimated easily [93]. The process of experimentation in terms of real-world applications with different types of radio interference can be the frustrating issue because several key aspects need to be addressed [94].

A. Requirements for Real-Time Implementation
The summary of the properties on the experiments of WSN carried through simulation and hardware implementation involving the interference characteristics are discussed below.

Realism and accuracy: In the real-time generally the interference patterns do not hold for longer periods of the time and they are bursty in nature. It is very important to generate bursty patterns from different kind of sources operating in the same environment [95]. Often to build expected type or planned type of scenario it is very complex either in simulation or real-time scenarios. For accuracy and robustness of WSN against interference, systematic and realistic arrangements must be installed for getting better validation of results [96].
Device Diversity: A WSN protocol designed considering the bursty nature of Wi-Fi may suffer randomness of Bluetooth or may be despairing to Microwave oven characteristics [97]. In the presence of multiple devices with the dissimilar operation, a multichannel protocol avoids the congested channels and may give good results under only single source of interference.

Operating concurrently with different types of devices, is often complex and protocol may perform poorly [98].
Spatial Diversity: The wireless propagation and antenna design characteristics play a most important role in the building suitable network. The placement of these nodes should be adjusted for creating appropriate cases for testing the performance of WSN. The worst scenario cannot be created in real-time scenario. It is because the nodes may not always operate whenever user wishes them to work. The placement of the node has an important role and significantly affects the performance of the WSN [99].
Temporal Diversity: The node mobility effects the wireless propagation. The characteristics of different wireless nodes changes based on the type of location and timing. Often the transport protocols, experience this kind of variations. In the implementation side for executing real-time it is very complex than spatial diversity problem [100]. Wi-Fi working gets effected because of following problems, the wireless propagations vary based on timing i.e., day and night, and on different traffic scenarios, so this characteristic is complex in simulation rather than real-time. Hence it is very confusing and difficult for generating the interference patterns for testing the temporal characteristics [101].
Scalability and Controllability: The WSN cases proposed and interference patterns should be working as per the proposed plan. The planning and execution are very intricate. For example, set up of several micro wave ovens for activation of external interference and may not be possible if the network devices are not programmed properly, may not certainly possible in simulation [102].
Repeatability: For an instance, the properties of a WSN were tested under some Wi-Fi nodes and noted the performance. If a user wants to repeat the test under the same conditions, then certainly the parameters may differ slightly or entirely under the same conditions. Often, it very difficult to predict the characteristics of wireless nodes at different times and different locations [103].

B. Experimenting with Simulators
The algorithms designed and implemented using simulations give much recommended results but still, they are lagging in terms of real-time implementations [104]. The most important advantage with simulators is that, they offer satisfactory scalability, repeatability, and controllability [105]. The issues in WSN implementation start with physical layer modeling like log-normal shadowing model (path loss, routing) and unit disk model (latency) [106] [107]. This problem can be rectified by relocating the nodes for better communication and also it is very important to locate the interferers in the network which severely affect the network performance [108].

The identification of the network parameters is very important for increasing the efficiency and making the results obtained more realistic [109]. For example, TOSSIM has limited capabilities in terms of trace-based models and cannot perform noise-based estimations effectively that allows the burstiness [110]. The work in [111] is based on TOSSIM and developed the mechanism for locating jamming nodes in the network. The simulators should allow the programmer in selecting the parameters and based on their requirement. Often the simulations are implemented with limited capabilities thereby user may not be encouraged further to extend than available. For example, if a user wants to study the effects of different types of interferers at the same time then this may not be allowed by software functionalities. In general designing, the software and coding in the software based on the current research requirement is very time taking process [112].

The software design should give the results accurately and should match with the results of real-time experiments. In some cases, there are some important patterns that should be generated to interpret the correct results. In real-time the results obtained using hardware experiments must be incorporated in the simulation so as to obtain the results in the most accurate and realistic levels [113]. The software COOJA will support with above capabilities [114]. The work in [115] is based on the multichannel protocol for avoiding the interference from disturbing nodes and avoids usage of selected channels, this work was implemented using COOJA. The results presented in [26] [58] are implemented using the ns-2.34 simulator, the authors of above papers have implemented algorithms for avoiding interference. The ns-2.34 is open source software and allows the user to develop their own libraries based on the requirements. The coding is generally done based on the TCL and C++. There is also another open source software ns-3 available for network researchers, but many libraries are still in the developing stage and the working language is based on C++ in combination with Python. Both ns-2 and ns-3 are popular for network designing and there is a need for effective programming for creating libraries for analyzing the interference patterns [116]. The essential characteristics of interference like (path loss exponent, the line of sight, payload size, receiver sensitivity, CCA threshold) are embedded in software OPNET. The proposed work in [117] [118] is based on OPNET.

Though the above simulators have implemented the interference patterns to a great extent, some works have extended the capabilities of existing simulators with the new type of interference cases or implemented with the new type of simulators. The proposed work in [120] has used OMNeT++ software for studying the coexistence parameters and their performance in coexistence environment of IEEE 802.15.4 and IEEE 802.11b based networks. The work in [121] [122] is based on the Wireless HART, have used this simulator thoroughly for examining the coexistence issues and nodes behavior in 2.4GHz ISM band. A new SIDE-based emulator is proposed for testing interference using scripted external impulsive patterns defined based on user-required configuration [123]. The work in [124] is based on the C++ based simulator, the work is aimed at testing the performance of IEEE 802.11b within WSN with the varied number of nodes and data rates respectively. The Tab. 12 below presents, the description of different software's and emulators used for developing and evaluating WSN in coexisting environments.

Table 12. The Simulation tools and EMULATORs used for the designing and Evaluating WSN.

S.No	Software	Description	Merits	Demerits
1.	ns-2 [26] [58] [149] [150]	The Simulator 'REAL' developed in 1988 by Cornell University. The ns-2 has emerged as a variant of the REAL in 1989. Later ns-2 was supported by DARPA (many other corporate research centers) in 1995. The ns2 is a open source free software. It is very useful for academia and networking research. It is basically a discrete event simulator based on C++ and OTCL (Object oriented Tool Command Language). The C++ is generally used for extending the existing libraries, according to the research requirements. The OTCL is used for the implementation and execution of the networks programs.	• ns-2 is available at free of cost. • Easy to add new protocol coding. • ns-2 is compatible for LINUX, Macintosh and Windows (using third party software using Cygwin). • Supports Standards like IEEE 802.11, 802.15, 802.16, IR, and UWB. • Widely used by networking-based community. • Frameworks like Mannasim, SensorSim, and NRL Sensorsim can enhance ns-2 performance.	• ns-2 cannot support real-time experiments. • Source code still had bugs and need to be fixed. • Need to learn programming.
2.	ns-3 [116] [151] [152]	ns-3 is an open source free software launched in 2008. It is a discrete event scheduler based on C++ with Python bindings.	• ns-3 is an open source and available at free of cost. • ns-3 is compatible for LINUX and Windows (using Cygwin). • Supports Standards like IEEE 802.11, 802.15, 802.16, IR, UWB, 6LoWPAN. • Supports routing protocol got low power and lossy networks (RPL). • ns-3 has overcome the difficulties of ns-2, importantly memory management and overhead.	• ns-3 in developing mode. • ns-3 has less number of written codes when compared to ns-2. • Works efficiently in Linux version. In case of Windows the Python binding does not work with Cygwin.
3.	MATLAB/Simulink [153] [154] [155]	MATLAB is most efficient and reliable software for researchers. It supports many mathematical functions and give solutions to numerous problems. It supports FORTRAN algorithms, C language and JAVA for programming.	• The detailed analysis on Physical layer is possible. • The software can effectively analyze the performance of protocol	• Commercial software but affordable to individual, requires license for running software.

		MATLAB is enriched with Simulink. The Simulink supports GUI (graphical User Interface) and supports all the linear and non-linear systems.	up to last node in the network. • Matlab/ Simulink supports Real-time implementation. • Communication tool box can be effectively used for building WSN. • PROWLER is an event driven WSN simulator also works under MATLAB. It has also an extension JProwler supports JAVA language for WSN.	• The implementation of WSN using MATLAB can be quite difficult depending on parameters to measure.
4.	OPNET [117] [118] [156]	OPNET is an efficient and powerful networking software. OPNET is based on the interactive GUI interface for designing the network interfaces. OPNET is initially designed for the Military applications. OPNET is very expensive for commercial usage. OPNET is a high-level event-based network simulation tool. It contains huge database of accurate network models which assure accurate results even at packet level.	• Good support (online). • Convenient models. Supports all wired, wireless and even covers the satellite models also. • Graphical and programmable interface. • Models can be utilized for association between different platforms. • Effectively powerful tool. • All the models can be controlled easily. • Every parameter can be modelled and any property can be measured.	• Expensive • Latest version (5.0) is compatible for Solaris platforms. • Demand modelling. • Models requires huge memory. • Less tutorial. • Buggy, deep-rooted and hard to modify ready-made models.
5..	QualNet [157] [158] [159]	QualNet software is an advanced networking based commercial software from Scalable Technologies. The Initial version was known as GloMoSim, served basically for educational purpose. QualNet is very useful for the design and analysis of the network aimed for various networks. The GUI based virtual models are available for all the wired and wireless models. There are many libraries available for providing all the advanced features. The designing of wired, wireless networks, GSM and satellite network systems are also possible with QualNet.	• Faster than real-time evaluation of networks and network centric system. • Provides real network fidelity and accuracy. • Convenient with Windows, Ubuntu, Centos. • Supports JAVA and C language for programing.	• Very expensive software. • The Java based user interface work slowly. • Installation on Linux systems is very difficult.
6.	OMNeT++, Mixim or Castlia [160] [161]	OMNeT++ is a discrete event simulator. Extensively used for modeling communication networks. OMNeT++ addresses the gap between open-source, research-oriented simulation software such as ns-2 and expensive commercial alternatives like OPNET. OMNet++ is based on C++ simulation library. Compatible with Windows, Linux versions and Macintosh. Commercial version is called as "OMNEST".	• OMNet++ is available free for education and research purpose. • Structured systematically. • Highly segmental. • Not limited to network simulation. • Source code is open source. • Simulation model for internet, IPV6, mobility is also available.	• The resources available in the library are limited. • The problems of compatibility also exist.
7.	NetSim [162] [163] [164]	NetSim supports hardware implementation and simulation of both CISCO products. It supports stochastic discrete network models. Supports various protocols for establishing networking requirements. The results obtained through simulation are almost identical to hardware implementation. This software works only with Windows. The programming is based on C and JAVA.	• The libraries of all the protocols are available in C- coding. Hence user has advantage of modifying based on the requirements. • GUI works efficiently. • This software has better visualization for data packet communication. • Easy to learn software.	• The software is proprietary. • It allows only single event discrete simulation.
8.	TOSSIM simulator [165] [166] [167]	TOSSIM is a discrete event-based network simulator for Tiny OS. It was built on Python and C++ coding and also supports Nes C. It works very efficiently and capture the results at bit level also. Supports many protocols effectively. It can work both on Linux and Windows (Cygwin). Supports numerous models	• TOSSIM is an open source software and available at free of cost. • It is considered as simple and powerful emulator for wireless sensor networks.	• TOSSIM is specifically designed for TinyOS. • It considers many assumptions on the network metrics. • Cannot consider or evaluate the problems

		in networking with capacity of thousands of nodes in the network. It can also handle Analog to Digital applications.	• It is very resourceful to capture any number of interactions from the developed protocol.	on signal strength of the radio.
9.	J-Sim [168] [169]	J-Sim is based on the object-oriented programming structure aimed for discrete time network simulations. J-Sim is completely developed using JAVA. J-Sim is very well compatible with Windows, Linux and Solaris. J-Sim can also interpret with ns-2 based TCL codes. J-Sim is providing very dynamic environment for programming. It allows multiple language programming. The network performance results obtained are mostly very accurate and suits real-time.	• The availability of J-Sim is open access. • The efficient programming structures. • It is compatible with real-time modelling and also suitable for discrete event simulation.	• The GUI model available has limited capabilities. Hence only programming must be done for the entire network development. • For operation with this software one should be familiar with queuing models.
10.	LabView [170] [171]	LabVIEW is a standard software for programming and evaluation of the WSN. It has many libraries and tool boxes for developing WSN. The LabVIEW can support and evaluate all the NI instruments. LabVIEW is very highly used by modern automation applications. It is compatible with Windows and Linux. The programs executed using the LabVIEW software are called as Virtual Instruments (VI). According to the requirements the C programs can be easily inserted using this software.	• The Development of the network can be carried out easily and effectively. • The response time is reduced for decision making applications.	• Expensive commercial software.
11.	COOJA [172] [173]	COOJA is an advanced and effective tool for WSN. It is compatible with the Linux and Contiki and can be used with virtualization tool VMWare. This software works based on the Java and user can extend libraries using C language. COOJA is considered as an ideal choice for RPL.	• COOJA is an open source software available for free. • Motes (TMote Sky and others) can also be emulated at a less detailed level.	• The available documentation to learn about software is very less. Only the website is resource and some forums.

C. Experimenting with the Hardware

The WSN implemented using real-time hardware will give more accurate results when compared to the simulation experiments [125]. Though the results obtained in this format are more reliable but real- time implementation is very costlier. The other way of testing is through the laboratory testbeds. The problems with the testbeds are that they are already available, for testing the performance of WSN in coexisting environment, they may not have the capabilities to generate the interference patterns. To introduce the interference pattern to the existing testbeds it is again costlier and time taking. Introduction of the Wi-Fi or Microwave modules cannot be placed easily on to the test bed [126]. The relocation of the testing items based on the requirement of the experiment is also a difficult task [127]. The Easitest [128] is a testbed implemented for understanding the coexistence issues between the Wi-Fi and ZigBee, but the resources involved are limited. In [129] authors have recommended the associations for the testbed federation based on the software defined radios (SDR) for testing performance of difference radio-based networks. Using SDR one can easily examine the performance of different nodes under different interference patterns. The availability of SDR hardware is costlier. The most important aspect in the research of WSN is misinterpretation of the data. While testing the WSN environment, many assumptions were taken in to consideration. For an example there is a myth like the effects of interference on WSN during the night times is almost negligible when compared to the day time. Consideration of the obstacles in the testing may or may not affect the wireless propagation of data [130]. The important consideration in the real-time hardware WSN experiments is that there is no instance in the system that can be once again repeated as wireless propagation is dependent on innumerable factors.

D. WSN based on noisy environments

Many authors have evaluated enormous amounts of information on the interference patterns under realistic conditions in relation with the WSN. The authors of the following papers have evaluated the performance of the WSNs under noisy environments. Near the test-case, the presence of cordless phone, microwave ovens, and people moving in the WSN surroundings were considerable effects on the performance of WSN in terms of shadowing and multi-path fading that makes the experimentation more realistic [131-134]. The authors in [135] and [136] have conducted the tests near university campuses and have evaluated the performance of WSN under the coexistence of Wi-Fi nodes. The work in [137] has conducted research on bursty interference surrounded by the university library and have reported heavy traffic from other networks.

The works in [138] [139] were based on the spectrum usage of the residential environment and have proposed a frequency adaptive control mechanism for coexistence area. The advantage of this type of noisy environment is that this environment is available naturally and doesn't require extra effort for generating the interference based test case. The disadvantage of this type of environment however is that interference exists by default in the location considered, but experiments were carried at the expense of non-repeatability of the interference patterns.

E. WSN under Specific Interference Patterns

Some research groups have studied the influence of interference on WSN by generating specific type of interference patterns. Thus, based on the necessity of testing, the required module is generated to test the performance of the WSN. The proposed work in [140] was tested based on the university testbed using 94 TelosB nodes. The performance of

the WSN was verified when transferring a file near Wi-Fi nodes. It was observed that no information was transferred to the destination. The work in the [141] is based on the indoor WSN using 40 motes testbed and two Wi-Fi nodes. Backpressure algorithm was implemented in real-time and it was observed that there was a significant improvement in the packet delivery even under the extreme interference conditions. The performance of Wi-Fi networks under the presence of 24WSN nodes were tested in indoor office environments. It was observed that the localization error increases to a 141% and affects the performance of Wi-Fi nodes [142]. The performance of a protocol for Wi-Fi network was tested in the presence of WPAN nodes testbed [143].

The authors in the [144] and [145] have evaluated their protocol in real-time for improving the performance of ZigBee under the presence of the WLAN nodes. The interference estimators were implemented using the off-the-shelf radio-based motes to detect the interference from the Wi-Fi nodes for improving ZigBee nodes performance. In this case it was observed as the packet loss rate had been reduced to a great extent because the estimators had switched the frequency of the node as soon as the interference was detected [146]. The impact of high interference level was measured and reduced in [147], the measurements and implementation were carried in a two-storied building and have tested the performance of WSN under the presence of WLAN. The testbed proposed in [148] EasiTest is supporting multiple technologies for understanding the effects of interference at the packet level.

Generating a certain interference pattern using the existing infrastructure is the most popular approach. The setup time for generating required interference time is very less. But only disadvantage of this type of approach is, it cannot avoid the sudden disturbances from other devices appearing instantly.

2. Applications of WSN under the Influence of Wi-Fi

The advances in technologies like automation, monitoring and controlling are trusting WSN particularly for remote and automatic operations. WSN is considered by many advanced applications like Smart Grid, Smart cities, IoT, Green Building Automation, Wireless Body Area Networks, and Industrial Automation. Figure 4 is a pictorial representation of WSN applications. The following applications employ WSN for some automation applications. All the nodes of WSN are under the vicinity of coexisting technologies. Hence interference avoidance is an important parameter to be considered for efficient operation of the WSN. Some of the important works proposed based on the type of application is presented below.
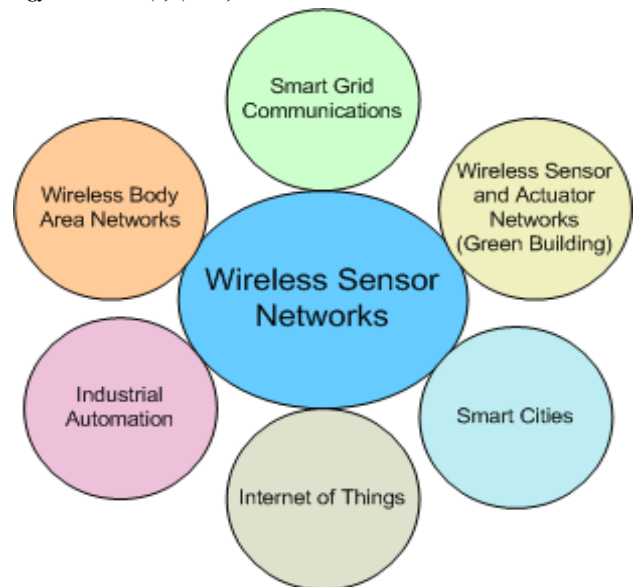
Fig. 4. Applications of Wireless Sensor Networks

A. Smart Grid Applications
Smart Grid has introduced modern information and communication technologies (ICT) for existing electrical power systems. The extension of ICT towards the consumer side (domestic applications) is generally done through WSN [174]. Etimad Fadel *et al.* [175] have presented a detailed survey on the role of WSN for various smart grid applications. Irfans Anbagi *et al.* [176] have proposed two WSN algorithms, DRX and FDRX algorithms for monitoring Smart Grid applications using WSAN. Primarily the research proposed is on improving the QoS parameters of ZigBee communication and have not considered the interference issues, but for future research scope, the authors have expressed concern of testing their proposed algorithm under the presence of Wi-Fi nodes. The algorithm PSOLACES was proposed in [150], the authors have analyzed the interference in indoor environment. A solution for avoiding interference using PSOLACES was proposed by improving ZigBee performance working under the influence of Wi-Fi and the work presented was specifically for consumer premises in smart grid applications. The CMCMAC [26] and FEC-CMCMAC [9] were proposed with an aim for improving the ZigBee network performance in terms of latency requirements even under the influence of the Wi-Fi aimed for smart grid applications. The proposed mechanism in [37] aimed at improving ZigBee performance by controlling WLAN transmission in the smart home was developed for smart metering applications.

B. Wireless Body Area Networks
Advanced health monitoring is increasing in the developing countries. The utilization of WBAN based information is becoming a medical need for understanding and estimating the patient health issues and is also very useful for providing promising solutions [177]. Mengjiao Tang *et al* [178] have proposed a system for WBAN based coexisting medium. The proposed model will utilize the Hidden Markov model for analyzing the ZigBee and Wi-Fi conflicts on channel issues. Based on the data obtained the system suppresses Wi-Fi propagation when ZigBee transmits the data. A. Meharouech *et al.* [179] have proposed SIM-BBN model for WBAN. The SIM-BBN proposes game theoretical approach for addressing the interference mitigation at two stages i.e., mutual interference (ZigBee-ZigBee) and cross interference (ZigBee –

Wi-Fi) based. Thus SIM-BBN addresses both the internal and external interferences. Y. Kim *et al.* [180] have proposed a detailed mathematical model for analyzing the interference in coexisting environment of ZigBee-WBAN and Wi-Fi. They proposed an adaptive control algorithm for enhancing the performance of the ZigBee-WBAN by guaranteeing the data transmission from source to destination within the maximum tolerable delay even under the influence of Wi-Fi.

C. Internet of Things

IoT uses different technologies like ZigBee, Wireless HART that work based on IEEE 802.15.4 standard. The work proposed in [193] employs WSN based IoT for industrial automation and recommends to reduce the interference issue for the efficient operation of WSN in the coexisting environment. The author has proposed the adaptive frequency hopping mechanism and proactive routing mechanism for avoiding the shadowing effects caused because of other coexisting wireless technologies. B. A. Nahas *et al.* [194] has proposed MiCMAC algorithm for 6LoWPAN based IoT network based on efficient channel hopping and reduces the effects of interference from the Wi-Fi. The authors in. [195] have proposed interference avoidance mechanism for the IoT based body to body area networks. The authors have analyzed cross technology interference and proposed an optimization model for mitigating the interference in the IoT network.

3. Discussion

With the increased use of monitoring and automation technologies, there is a need for improving the QoS parameters in terms of interoperability standards worldwide. Based on the above literature review, for almost a decade now there has been a significant experimentation and research carried out on interference issues. But still, the topic is unclear and unripe when finding reasons of interference and therefore it requires further research for making WSN applications robust. There are only a few studies performed to analyze the performance of a protocol under the interference conditions considering different patterns. The heavy traffic and propagation in 2.4GHz ISM band should be studied extensively; and the communication protocols and their behavior under different interoperable conditions must also be considered. There is some relevant research performed and presented on identifying interference conditions and avoiding it, but still, the comprehensive study on different interference patterns has not been presented yet. The following points are observed based on the literature above,

- The experimentation using the simulators is considered as complex by many researchers because still precise variables of different interference patterns are unavailable. Hence majority experiments are carried in real-time and are limited to prove the effects of interference. Very few works have been proposed to avoid interference.
- Most of the experiments in real-time are set up using a small number of nodes coexisting with one or two interfering nodes. The above set can only disturb some packets of data during wireless transmission. But the experimentation may not hold good enough, for cases like strong interference or noise, which may destroy the network communication within the small area or cluster.

- Most of the times WSN interference experimentation is carried under the consideration of Wi-Fi. Some works are considered under the interference of Bluetooth or Microwave oven. Specifically, interference study is considered between ZigBee and Wi-Fi often other technologies are neglected.
- It was observed from the above literature that most of the experiments either in simulation or in the real-time, data transfer is continuous which is not true in the real world. Multichannel WSN scenarios often show some congested channels and making them restricted, affecting the operation of WSN. There is a requirement to withstand the intermittent or bursty interference among various channels.

The proposed works in [38] and [39], have significantly improved the throughput of ZigBee nodes in spite of external interference issues between WSN and Wi-Fi networks. The authors in [41] have presented the effects of temporal variations occurring in WSN because of Wi-Fi. The authors of [42] have proposed a better optimization model addressing the cross-technology interference issue, which occur between the wireless technologies operating in the coexistence to each other working in the same frequency band. This methodology also has addressed internal and external interference efficiently. The authors in [150] have proposed a better channel selection methodology by considering external interference conditions and significantly reduced the frame error rate in WSN.

The following measurement methods for assessing the interference are highly recommended. The work proposed in [44] is based on assessment of degree of density and intensity. The effects of Wi-Fi on the WSN link quality can be understood based on the above assessment and this increased throughput for almost 3 times to the initial condition before assessment. The work proposed [67] has efficiently decreased errors in the LQI. The ELQET [68] has significantly improved the quality of WSN transmission and reduced the data loss to a great extent. The model proposed in [70] has reduced the end-to-end delay even under external interference conditions.

7. Open Research Issues

The efficient data communication in WSN is very important. Hence in this section some open research issues are discussed to strengthen the future research on WSN in relation to interference avoidance,

1. **Reliability of data communication**: For obtaining the high reliability in WSN it is very important to consider factors like interference, proper placement and distance between nodes, effects of mobile nodes, building material and weather conditions [183]. Reliability is a factor of the bandwidth and latency. The Reliability for WSN is obtained by calculating the packet error ratio. It is very difficult to assess the reliability parameter in WSN because the transmitter node and receiver node are unaware of each other in the network. Also nodes are not sure whether data is received successfully or not. Hence for determining reliability there are also other parameters like RSSI and LQI can be considered. Based on the value obtained one can determine the quality of the link. RSSI can be estimated on the receiver side with values 'mW or dB' this define the link quality. LQI is determined on the scale of '0 to 108' based on which one can estimate the effects caused because of the

interference and multipath errors [184]. Still identification of various disturbances causing the interference can be carried systematically in future.

2. **Cross-layer dynamics:** The WSN most often experience problems like multi-path fading, path loss and shadowing problems. To overcome problems above the cross-layer designing between PHY and MAC layers is recommended to obtain the better results [192] [124], [22]. The assessment of MAC performance analysis based on the interaction with the wireless channel will optimize the performance of the protocol and assure for the correctness of the design [185]. The effects of hidden terminals and multi-path fading (depends on network traffic and the distance between the nodes) decreases reliability of WSN and for optimizing this cases Cross-layer designing between PHY and MAC layer is highly recommended [186].

3. **MAC layer:** WSN is based on IEEE 802.15.4 that defines the PHY and MAC layer specifications. In spite of considerable research done, still IEEE 802.15.4 based MAC suffers several issues. In general, most of the IEEE 802.15.4 based technologies are operating under the influence of other technologies. Hence MAC parameters should be defined based on the interference conditions [187]. Another improvement in case of MAC can be achieved by adjusting the clear channel assessment (CCA) parameter. The increasing the CCA of a particular node will increase the priority of that particular node in the network and this is most important for WSN based actuator networks. The CCA is based on the network size and the traffic intensity, also improves the QoS parameters [188][189].

4. **Channel Selection:** After the establishment of the WSN, the ZigBee coordinator selects the best channel after energy detection-based scanning for network operation. For this, energy scanning is performed every time when a node is ready to transmit the data. The ZigBee node performs energy scanning for all the available 16 channels and finds the strongest channel for data transmission. There is also a need for performing additional research in this area for efficient channel selection among available [190] [191].

8 Conclusion

In the modern times the use of wireless devices is increasing every day and its market is expected to continue to grow as popular new wireless devices will only continue to increase and diversify, especially with the advent of IoT applications worldwide. As the numbers of wireless nodes deployed are increasing, particularly in the unlicensed band, there is a strong need for increasing the robustness of data-communications. Since the last decade there was a profound research going on for improving the QoS parameters of WSN but still, there is a lot to be done in terms of future work for making WSN reliable by considering the effects of interference. The research community has addressed only few works in relation to the interference avoidance. Most of the research communities have recommended the development of protocols based on following types of parameters like radio diversity, channel taxonomy, multichannel protocol, and data redundancy (Forward error correction and backward error correction). The improvements that were proposed is based on the above parameters, and to some extent improved the robustness of wireless protocols working in 2.4GHz ISM band.

In order to increase the reliability of WSN still further in the coexistence mediums, many new standards are emerging. Based on the recent research activities Ultra-wideband (UWB) based WSN were standardized. UWB devices are available at low cost, low complexities, and possess high immunity to interference. Based on the pace of increased use of WSN, new frequency bands should be allowed in order to avoid the interference problems currently appearing. For example, nodes working based on IEEE 802.11b/g in 2.4GHz are moving to IEEE 802.11ac going to work in 5GHz. However, increased dependence on WSN for monitoring and control will introduce many devices working in the same frequencies. Hence there is a need for research in increasing the reliability and robustness of such a system for harmonious coexistence. Based on the studies carried so far on the WSN research, there is a need for improving the self-learning capacity of wireless nodes. The wireless nodes must detect the channel conditions and should dynamically adjust by themselves for various channel parameters at runtime so as to increase the communication efficiency and increase the node lifetime. In the recent times, researchers have begun focusing on the prime objective of this paper, that is interference avoidance mechanisms and it is expected that WSN may also become self-learning in the near future.

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Abbreviations

AP: Access Point
APS: Application Sub-layer
BPSK: Binary Phase Shift Keying
BER: Bit Error Rate
CCA: Clear Channel Assessment
CA: collision avoidance
CSMA: Carrier-Sense Multiple Access
CTS: Clear to Send
CRC: Cyclic Redundancy Check
dBm: decibels relative to one milliwatt
DSSS: Direct-Sequence Spread Spectrum
ED: Energy Detection
FEC: Forward Error Correction
FER: Frame Error Rate
FHSS: Frequency-Hopping Spread Spectrum
HGW: Home Gate Way

ICT: Information and Communication Technologies
IEEE: Institute of Electrical and Electronics Engineers
ISM: Industrial, Scientific, Medical
IoT: Internet of Things
IR: Infrared
LQI: Link Quality Indicator
MEMS: Micro-Electro-Mechanical Systems
MAC: Medium Access Control
NWK: Network Layer
ns: Network Simulator
OFDM: Orthogonal Frequency Division Modulation
PER: Packet Error Rate
PHY: Physical Layer
PLR: Packet Loss Rate
QPSK: Quadrature Phase Shift Keying
QoS: Quality of Service

RF: Radio Frequency
RSSI: Received Signal Strength Indicator
RTS: Request to Send
SINR: Signal-to-Interference-Plus-Noise Ratio
TCL: Tool Command Language
TDD: Time Division Duplexing

TDMA: Time Division Multiple Access
WLAN: Wireless Local Area Network
Wi-Fi: Wireless Fidelity
WSN: Wireless Sensor Networks
WPAN: Wireless Personal Area Networks
WBAN: Wireless Body Area Networks