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Performance of Ad Hoc Wireless Networks under Coexistence Scenario: A Case Study

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Abstract: Owing to the possibility of interference, signal contention, and performance degradation, coexisting IEEE 802.11 (Wi-Fi) and IEEE 802.15.4 (Zigbee, 6LoWPAN) technologies in the 2.4 GHz ISM band presents considerable issues. More packet loss, delay, and decreased throughput for low-power networks can arise from IEEE 802.11's larger bandwidth, higher transmission power, and higher data rates overpowering IEEE 802.15.4's lower power and narrower bandwidth transmissions. This work explores the main facets of their coexistence, emphasising the effects of interference on performance measures including throughput, latency, and energy efficiency and frequency overlap. Dynamic frequency selection and channel allocation algorithms are only a few of the interference reduction techniques that are examined in the analysis. This research offers valuable insights into the more harmonious coexistence of these two wireless technologies in shared surroundings, enabling dependable operation for low-power IoT networks and high-speed Wi-Fi applications. These insights are gained through simulation and experimental validation.
Keywords: IEEE 802.11, IEEE 802.15.4, interference and throughput

I. INTRODUCTION

The 2.4 GHz ISM band is widely used by many standards, including IEEE 802.11 (Wi-Fi) and IEEE 802.15.4, which support low-power, low-data-rate protocols like 6LoWPAN and Zigbee, as a result of the rapid proliferation of wireless communication technologies [1]. Although these technologies have different uses (IEEE 802.15.4 for low-power, energy-efficient communications in IoT and sensor networks, and Wi-Fi for high-speed, high-bandwidth applications), coexisting in the same frequency range raises a number of difficulties [2].

The performance of IEEE 802.15.4 networks can be negatively impacted by interference from Wi-Fi due to its high transmission strength, wide bandwidth, and frequent transmissions, which can dominate the shared spectrum [3]. In low-power applications, on the other hand, packet collisions, increased delay, decreased throughput, and energy inefficiencies might result from Wi-Fi interference, even if IEEE 802.15.4 devices with lower power are less likely to cause it [4].

This coexistence problem is especially critical in settings like smart homes, industrial automation, and urban IoT networks where both technologies are implemented concurrently. Under such circumstances, it becomes essential to guarantee dependable and effective communication for both low-power and Wi-Fi networks [5]. The demand for effective spectrum sharing among various wireless technologies has increased in recent years due to the expansion of smart devices, Internet of Things (IoT) applications, and wireless sensor networks (WSNs) [6]. Many IoT protocols rely on IEEE 802.15.4, which was created for low-power, low-data-rate applications [7]. This standard allows devices to interact for longer periods of time while using less energy, including smart home sensors, industrial monitoring systems, and healthcare wearables [8]. But coexistence problems have gotten worse as these gadgets work more and closer to IEEE 802.11 Wi-Fi networks, which are common in homes, workplaces, and public areas [9].

The main issue comes from the fact that the 2.4 GHz frequency spectrum is shared by IEEE 802.11 and IEEE 802.15.4. Mutual interference results from these two standards operating simultaneously in this crowded spectrum, despite their different operational objectives and design features [10]. IEEE 802.15.4 packets, which are delivered at lower power and on narrower channels, are more likely to collide with Wi-Fi due to its much higher transmission power, larger channel width, and higher data speeds [11]. This problem is made more difficult by the frequency overlap, which is especially noticeable in cities with large populations of Wi-Fi access points and Internet of Things devices [12]. A better knowledge of how these two technologies might share the spectrum is therefore required.

There has been a lot of research on IEEE 802.11 and IEEE 802.15.4's individual performance characteristics, but less on how these technologies really coexist in mixed-use situations [13]. Further complicating cohabitation is the interaction between their respective Medium Access Control (MAC) protocols, which both use Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) [14].

This is because the two networks try to access the shared channel using different criteria and backoff algorithms. IEEE 802.15.4 networks may suffer significant performance loss in situations where Wi-Fi dominates the channel, especially with regard to packet delivery success, latency, and power efficiency—all of which are crucial for battery-operated devices [15].

This work attempts to investigate the coexistence dynamics of IEEE 802.15.4 and IEEE 802.11 technologies, emphasising the methods via which interference arises, the ensuing performance loss, and methods for reducing these impacts [16]. Through an examination of crucial elements like frequency overlap, transmission power differences, and medium access control (MAC) protocols, this research will offer an in-depth overview of the two technologies' interactions in the 2.4 GHz band for a variety of uses [17].

II. LITERATURE SURVEY

In 2023 Jianlin ***et al***,[1] presented the IEEE 802.19.3 standard, which is intended to offer better data rate capabilities than the IEEE 802 802.15.4g standard, was issued in April 2021 for the coexistence of heterogeneous Sub-1 GHz band wireless technologies. The authors discovered substantial interference across various Sub-1 GHz devices through models and experiments. Coexistence concerns need to be addressed immediately since interference like this can make applications that depend on these technologies operate poorly.

In 2021 Ali ***et al***,[2] to enhance coexistence with WLAN, the authors of this paper suggest backoff methods for IEEE 802.15.4 (WPAN) that consider data gathered at a multi-interface node. Simulated findings show that when WLAN traffic is kept below 40%, the proposed approaches can result in a significant boost in packet delivery rates—up to 26%. This shows how the suggested solutions work in actual situations and highlights how useful they could be in IoT setups.

In 2021 Kefa ***et al***,[3] in this paper, the authors suggested utilising the IEEE 802.15.4 wireless standard's carrier sense multiple access with collision avoidance (CSMA-CA) adaptive channel access technique for WBAN in stationary and mobile networks. The suggested technique performs noticeably better than TCP-MAC and the standard IEEE 802.15.4 protocol, according to the results. In particular, the average delay is lower than that of the standard protocol and TCP-MAC by 67% and 56.8% at a WBAN speed of 0.5 m/s and by 54.1% and 26.31% at a speed of 1 m/s, respectively.

In 2019 Ali ***et al***,[4] authors attempt to provide more accurate performance estimates for coexisting wireless networks by considering the interference between these two technologies. This is especially critical as the density and complexity of these networks are deployed for upcoming applications like 5G and the Internet of Things. The article describes the improvements made to the INET framework's interference module to take into consideration interferences that occur both within and between network types—that is, inter-technology and inter-channel. With this improvement, situations in which several wireless technologies are in use at the same time can be more accurately described.

In 2019 Resy Verma,[5] presented a helpful insight has been obtained from evaluating an IEEE 802.15.4 standard-based network's performance using the Packet Delivery Ratio (PDR) on a range of operating channels. This datapoint can be used to forecast and comprehend interference behaviour in practical applications. The goal of this work is to analyse the interference that the three non-overlapping IEEE 802.11b/g/n channels—1, 6, and 11—cause on the IEEE 802.15.4 standard's useable 2.4GHz spectrum.

In 2018 Mahmoud ***et al***,[6] presented a novel analytical framework to study the dynamic impact of Wi-Fi interference on ZigBee networks. It utilizes mean field approximation to simplify the analysis of complex Markov models, revealing that even light Wi-Fi traffic can significantly affect ZigBee performance. The study highlights the importance of considering dynamic interactions, such as traffic patterns, that influence network behaviour. A new method is introduced to model nonstationary transition probabilities under intermittent interference. While focused on ZigBee, the approach has broader applicability to other wireless protocols like Bluetooth. The authors in article [7], presented that the guide busy tone (GBT) effectively mitigates Wi-Fi interference in ZigBee networks, improving communication reliability. GBT uses a full-duplex technique, allowing ZigBee to reserve channels even under heavy Wi-Fi traffic. It increases packet delivery to nearly 100%, crucial for high-reliability applications. The authors in article [8], proposes learning based self-coexistence control techniques for 802.11ah devices to mitigate the interference impact of 802.15.4g network and presents a α-Fairness based energy detection clear channel assessment (ED-CCA) method, which can achieve fair spectrum sharing between 802.11ah. In paper [9], the authors proposed an approach to enable a cooperative control for sharing time and frequency for sharing the same space and spectrum band with the Time-Slotted Channel Hopping (TSCH) based sensor network. In paper [10], the authors described that when devices from several technologies use the same frequency bands without successfully negotiating for medium access, cross-technology interference happens. Their proposed approach, which uses a Time Division Multiple Access (TDMA) mechanism based on an energy pattern beacon, effectively reduces interference by allowing devices to synchronise their access to the media.

The authors in paper [11], analyses the coexistence of IEEE 802.15.4, BLE, and IEEE 802.11 in the 2.4 GHz ISM band using several key methods. A geometric model defines network interactions, and a path-loss model calculates the SIR. The PHY layer model computes the SER, while a temporal model evaluates time-varying interference and its impact on PER. Experimental validation ensures real-world accuracy, and MAC layer analysis suggests cooperative strategies for better coexistence.

In paper [12], authors develop a comprehensive mathematical model to evaluate the throughput performance of the carrier sense multiple access with collision avoidance (CSMA/CA) protocols of coexisting 802.15.4 WPAN and 802.11 WLAN and proposes to employ the developed models for channel allocation to achieve fair throughput sharing among WPAN nodes.

The authors in paper [13], observe the coexistence of 802.11 (Wi-Fi) and 802.15.4 networks, highlighting significant performance degradation due to Wi-Fi's aggressive nature. It identifies challenges in meeting delay guarantees for 802.15.4 in environments with bursty Wi-Fi traffic. Analytical models using queuing theory and Markov Chains are developed to address throughput and delay. A joint MAC protocol tuning method is proposed to optimize both networks. The models are validated through simulation, with future work suggested to enhance real-world coexistence.

In paper [14], authors developed a Markov chain-based analytical framework to model the coexistence of IEEE 802.15.4 and IEEE 802.11 networks. It derives key performance metrics such as transmission success rates and collision probabilities, validated through simulations. The study finds that 802.15.4 performance decreases with longer 802.11 packet lengths.

The authors in paper [15], addresses the coexistence challenges between 802.15.4 (ZigBee) and 802.11 (Wi-Fi) in the 2.4 GHz band, highlighting unfair asymmetric performance issues. It proposes an adaptive backoff mechanism for 802.15.4 that dynamically adjusts to Wi-Fi traffic, improving performance in mixed environments. Simulations show robust results, even with imperfect signal detection. The mechanism mitigates Wi-Fi interference and enhances network efficiency, particularly in high saturation conditions. Overall, the solution significantly improves low-power wireless network operation in shared frequencies.

The authors in paper [16], highlights that backwards compatibility in WLAN networks, while necessary, reduces overall performance due to the slower transmission rates of legacy IEEE 802.11b devices. It identifies a performance anomaly where newer devices are starved of bandwidth by older ones, lowering throughput. Overall, the paper provides insights into improving WLAN performance amidst legacy device constraints.

In paper [17], authors introduce a coexistence interface to manage multiple wireless radios (e.g., WLAN, Bluetooth, 802.15.4) within a device, reducing interference. It monitors radio activity through dual-input signals and uses arbitration logic to prioritize communication. This improves communication efficiency and reduces conflicts. The interface is particularly useful in devices using multiple wireless technologies, such as in IoT and smart homes. Overall, it enhances wireless communication and device performance.

The authors in paper [18], focuses on throughput performance, examining metrics like data transmission rates, delay, jitter, and packet loss. The analysis likely includes comparisons between standards such as 802.11a/b/g/n and newer versions like 802.11ac/ax. The findings provide insights into how 802.11e enhances Wi-Fi efficiency in QoS-demanding environments.

In paper [19], authors analysed how power, distance, and channel conditions affect the throughput of infrastructure and ad-hoc Wi-Fi networks. Higher transmission power increases range but may cause interference, while greater distance reduces throughput due to signal degradation. Poor channel conditions, such as interference and noise, lower throughput by causing packet loss and delays. Infrastructure networks benefit from access point management, while ad-hoc networks often face performance issues due to direct peer communication. This work highlights the need for optimizing these factors to improve Wi-Fi network performance.

The authors in paper [20], analyse the impact of interference on low-power, short-range communication systems like wireless sensor networks. It highlights how spectrum-sharing with other technologies, such as Wi-Fi and Bluetooth, degrades network performance. The work introduces techniques to classify different types of interference using methods like signal analysis or machine learning. This classification helps in identifying interference sources and proposing mitigation strategies, such as channel switching.

A. IEEE 802.11 Technology

IEEE 802.11 is a series of standards for wireless local area networks (WLANs), or Wi-Fi, that were created by the Institute of Electrical and Electronics Engineers (IEEE). These protocols specify how wireless devices interact with one another in a network, enabling data flow between routers, PCs, and cell phones without the need for physical connections. There are multiple variations of the 802.11 family, all of which are intended to increase range, security, performance, and speed. Among the most important versions are 802.11b, 802.11a, 802.11g, 802.11n, 802.11ac, and 802.11ax (sometimes called Wi-Fi 6), which have improved to offer faster speeds and more efficiency. More modern models, like 802.11ax, use both the 2.4 GHz and 5 GHz bands and can attain speeds of up to 9.6 Gbps, whereas earlier models, like 802.11b, operated in the 2.4 GHz frequency band with a maximum speed of 11 Mbps.

The newest developments include beamforming, which focusses the Wi-Fi signal on particular devices for a higher-quality connection, and MIMO (numerous Input, Multiple Output), which enables numerous antennas to enhance performance. The introduction of protocols like WPA (Wi-Fi Protected Access) and WPA2 has also improved Wi-Fi security by offering more robust encryption and defence against unwanted access. Security is further improved by the more modern WPA3 standard, which fixes flaws in earlier iterations. Furthermore, a wide range of applications are supported by 802.11 technology, including industrial Internet of things (IoT) devices, public Wi-Fi hotspots, and home and business networks. All things considered, IEEE 802.11 is still developing to satisfy the growing need for wireless communication that is quicker and more dependable.

B. IEEE 802.15.4 Technology

IEEE 802.15.4 is a wireless communication standard that was created especially for applications requiring low data rates and minimal power. IEEE 802.15.4 is designed for devices that must run with low energy consumption and usually transfer little amounts of data, in contrast to IEEE 802.11 (Wi-Fi), which concentrates on high-speed wireless networks. This makes it perfect for use in Internet of Things (IoT) applications, smart homes, wireless sensor networks, and industrial automation. With a frequency range of 2.4 GHz (and in some areas, sub-GHz bands like 868 MHz and 915 MHz), IEEE 802.15.4 can handle data rates of up to 250 kbps, which is adequate for the type of low-bandwidth connection required by the majority of sensor and control systems. Direct Sequence Spread Spectrum (DSSS) is one of the approaches used by the standard to reduce interference and improve reliability in shared radio frequency environments. Because of the low power needs, devices that use this standard typically have a tiny communication range, frequently measuring only tens of meters. In order to provide strong networking capabilities like mesh networking, which enables devices to connect over greater distances by passing data through intermediary nodes, higher-level protocols like Zigbee, 6LoWPAN, and Thread are built upon the foundation of the 802.15.4 standard. Energy efficiency, which is one of IEEE 802.15.4's main advantages, enables battery-powered devices to function for months or even years without requiring a recharge. This is crucial for applications like smart metering and remote sensing.

C. Coexistence of IEEE 802.11 and IEEE 802.15.4 networks

It is difficult for IEEE 802.11 and IEEE 802.15.4 to coexist since they frequently share the same unlicensed 2.4 GHz frequency spectrum. The low-power, low-data-rate communication of IEEE 802.15.4 networks can be readily overtaken by Wi-Fi, which is intended for high-speed data transfer and usually needs more power. Due to this interference, 802.15.4 devices which are frequently utilised in sensor networks, smart homes, and industrial Internet of things applications may experience data loss, increased latency, and decreased performance. A number of strategies can be used to lessen the adverse consequences of cohabitation. Configuring Wi-Fi and 802.15.4 devices to run on distinct, non-overlapping channels can help minimise interference because the 2.4 GHz band is divided into many channels. For instance, Wi-Fi channels and 802.15.4 networks' channels usually overlap, therefore channel distribution can be carefully planned to reduce conflict. In order to reduce interference, devices can also use temporal separation, which involves scheduling their communication times to avoid simultaneous broadcasts. Furthermore, some devices detect interference and employ adaptive techniques like dynamic channel switching or frequency hopping to shift to less crowded areas of the spectrum.

Additionally, technological advancements like clear channel assessment (CCA) make coexistence better by lowering the chance of collisions by enabling devices to detect whether the channel is congested before sending data. Cross-technology communication (CTC) approaches are used by some systems to enable 802.11 and 802.15.4 networks avoid overlapping transmissions by exchanging basic information about their transmission schedules.

III. SYSTEM MODEL

To simulate the cross-technology interference model we consider the following scenario in OMNET++ INET simulator. Detailed system model is explained below.

1) Take the 2 Wi-Fi and 4 Zigbee nodes and arrange them in shown in below figure.
2) Configure the applications for Wi-Fi and Zigbee nodes shown in simulation table.
3) Set the power levels of both Wi-Fi and Zigbee nodes.
4) Let them to see the both Wi-Fi and Zigbee nodes get interfere each other by selecting the suitable channel number.
5) Run the simulation for certain time to evaluate the performance
6) Analyse the performance metrics like Throughput, end to end delay and packet delivery ratio.

IEEE 802.11 (Wi-Fi) and IEEE 802.15.4 (Zigbee) are two examples of wireless technologies that frequently use the same frequency band. This can cause cross-technology interference (CTI) between the signals of the two protocols, which can impair both of their performance. Versions of 802.15.4 and 802.11 both utilise the 2.4 GHz Industrial, Scientific, and Medical (ISM) spectrum, which may cause CTI between the two protocols [21].

OMNET++ INET has support for simulating CTI between any of its wireless protocol models, including 802.11 and 802.15.4. This enables users to investigate the ways in which the various protocols interact and impact one another's functionality within a simulated setting [21].

The 2.4 GHz frequency is used for communication between all nodes. While the centre frequencies and bandwidths of the signals for the two wireless protocols differ, there may be overlap in the signal spectra. We will actually employ overlapping channels in this work by configuring the two networks [21].

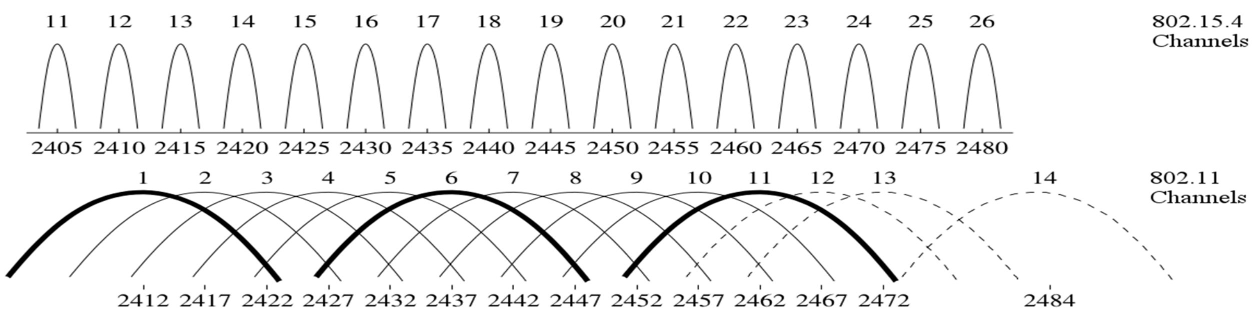

Fig 1: Channels for IEEE 802.11 and IEEE 802.15.4 technologies

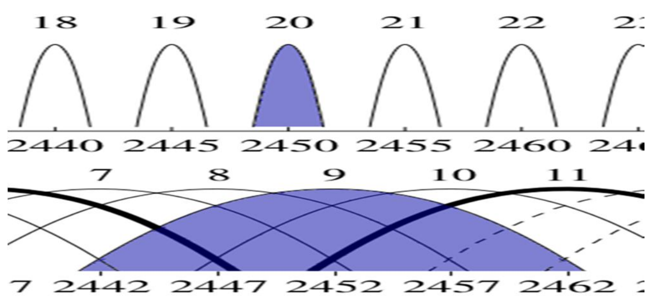

Fig 2: Overlapping of channels number 9 in Wi-Fi and 20 in WPAN

INET's 802.15.4 narrowband version, which has a default bandwidth of 2.8 MHz and a carrier frequency of 2450 MHz, will be used for the WPAN. 802.11g, which has a 20 MHz bandwidth for transmissions, will be used for the Wi-Fi. Wi-fi Channel 9 (centre frequency of 2452 MHz) will be used, while the frequency and bandwidth of 802.15.4 will be left on default, allowing the Wifi and WPAN transmission spectra to overlap [21].

The following system model is considered for simulation of co-existence of IEEE 802.11 and IEEE 802.15.4 cross technology interference.

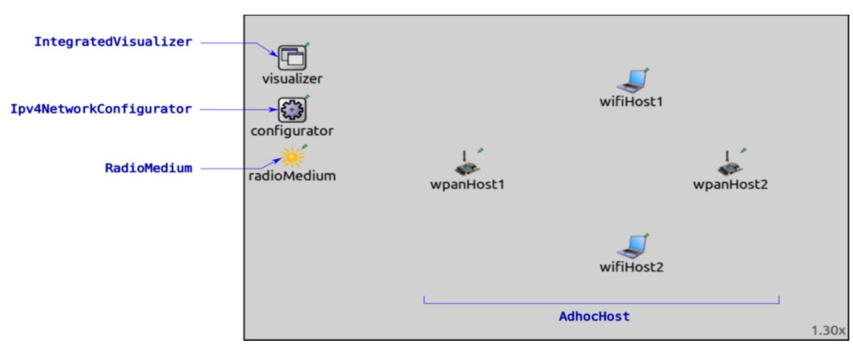

Fig 3: Network Diagram

The above figure describes the network diagram for simulating the coexistence. It contains four Ad hoc hosts. Two hosts are Wi-Fi hosts and another two are WPAN nodes. All are operating at 2.4 GHz band. We will observe the effect this cross-technology interference by configuring applications among the nodes. The simulation parameter table shown below.

S No	Parameter	Value
1	Applications Configured	wi-fi host 1 to wi-fi host2 wpan host 1 to wpan host2
2	Wi-Fi host message Length Wpan host message Length	1000 Byte 88 Byte
3	Application Type	UDP
4	Wi-Fi radio medium	IEEE 80211-Dimensional radio
5	Wpan radio medium	IEEE 802154 Narrowband Dimensional Radio
6	Power applied	20 mW
7	Send interval time	0.4 ms for Wi-Fi hosts 0.1 s for wpan hosts
8	Simulation Time	10 sec

Table 1: Simulation parameters

IV. RESULTS AND DISCUSSION

Here we simulated the above network in OMNET++ INET simulator environment for a simulation time of 10 sec. Performance analysis of cross technology interference is analysed for the following cases.

Case 1: Only Wi-Fi hosts are communicated

Case 2: Only WPAN hosts are communicated

Case 3: Coexistence of both Wi-Fi and WPAN hosts are communicated

Performance analysis carried out for the throughput and packets received parameters.

1) Throughput: Throughput is the rate at which data packets are successfully sent over a network from a source node to a destination node in Mobile Ad Hoc Networks (MANETs). It represents the effectiveness of data transfer in the dynamic and decentralised environment of MANETs and is commonly expressed in bits per second (bps) or packets per second.
2) Packet Delivery Ratio: The Packet Delivery Ratio (PDR) is a crucial performance indicator that assesses the dependability of data transfer in Mobile Ad Hoc Networks (MANETs). It is defined as the ratio of the number of data packets transmitted by the source to the number of data packets that were successfully delivered to the destination.

A. Case 1: Only Wi-Fi hosts are communicated

When only IEEE 802.11 nodes are actively broadcasting in a coexistence scenario, overlapping 2.4 GHz frequency bands are likely to cause interference with IEEE 802.15.4 channels. While IEEE 802.15.4 employs tighter 2 MHz channels, IEEE 802.11 uses bigger channels (about 20 MHz wide), which results in a large amount of channel overlap. Because of this overlap, IEEE 802.11 signals which are usually sent at higher power may obscure IEEE 802.15.4 signals, raising noise levels and possibly causing packet loss. Furthermore, IEEE 802.11 uses an aggressive channel access strategy, which means that it frequently controls shared frequencies and restricts the channel's availability to IEEE 802.15.4 devices.

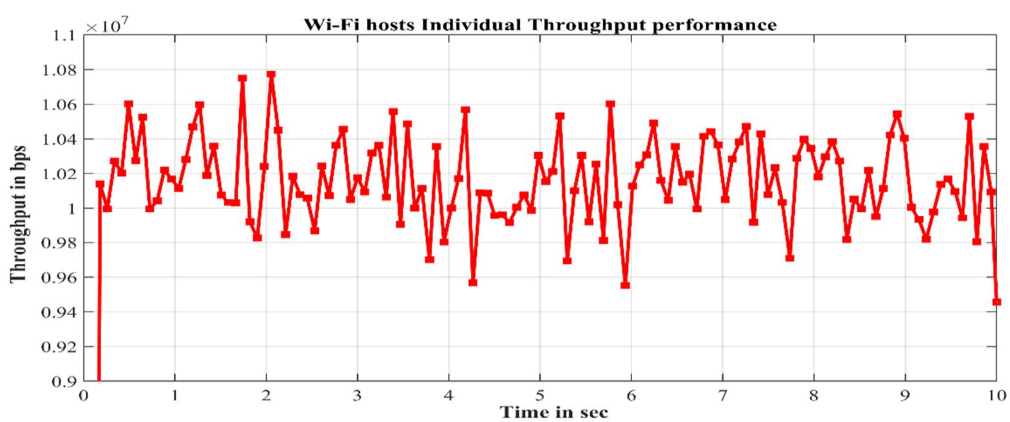

Fig 4: Wi-Fi hosts throughput performance

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As we can observe from the above figure that throughput performance is better throughout the simulation time. The entire channel is available for transmitting their packets. No collisions detected and with proper acknowledgements packets are transmitted. Because of IEEE 802.11's aggressive CSMA/CA access technique and higher transmit power, IEEE 802.15.4 devices back off more often than IEEE 802.11 devices. The performance of IEEE 802.11 is improved by the lower power and data rates of IEEE 802.15.4, which also reduces channel contention and collision rates. More data can be handled per transmission opportunity because to 802.11's increased capacity. When 802.15.4 is used in shared-channel situations, this leads to increased throughput for 802.11.

B. Case 2: Only WPAN hosts are communicated

Due to a number of features that lessen interference, WPAN hosts frequently maintain higher performance in networks with IEEE 802.15.4 (WPAN, like Zigbee) and IEEE 802.11 (Wi-Fi) devices coexisting. Because WPANs employ low-data-rate narrowband channels, they can minimise cross-protocol interference by avoiding significant channel overlap with Wi-Fi's wide channels. WPAN devices also have low duty cycles, meaning they only transmit in brief bursts and seldom. This allows them to identify idle channel periods and avoid Wi-Fi traffic. This infrequent and low-power transmission method keeps WPAN performance consistent even in high-interference situations by reducing collisions and improving channel access possibilities. Throughput can be further stabilised in the presence of Wi-Fi by using adaptive frequency hopping or timing algorithms to dynamically avoid interference-heavy channels.

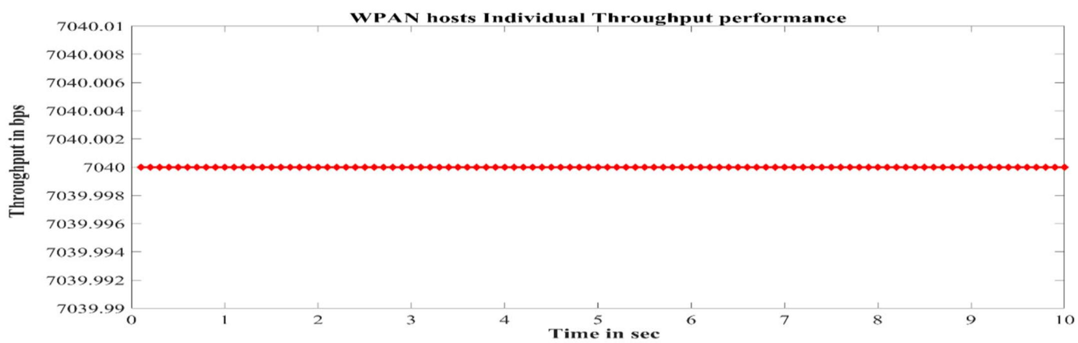

Fig 5: WPAN hosts throughput performance

As we can understand from the above figure WPAN hosts are received packets correctly. Throughput maintains better due to narrowband channels and low power requirements.Overall performance got improved even when Wi-Fi hosts are exists in the network.

C. Case 3: Coexistence of both Wi-Fi and WPAN hosts are communicated

The supporting operational characteristics and interference mitigation methods of IEEE 802.11 and IEEE 802.15.4 hosts result in enhanced packet reception performance in coexistence circumstances. Both protocols employ Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) for channel access, which lowers the likelihood of collisions by having each device "listen" before sending. In contrast to Wi-Fi's wider channels (20 or 40 MHz), IEEE 802.15.4's narrower channels (only 2 MHz) enable WPAN devices to occupy Wi-Fi spectrum segments without directly overlapping, reducing interference and improving packet reception. WPAN and Wi-Fi devices have more free airtime to transmit without congestion because of its low-duty cycle, which involves short and infrequent transmissions and fewer packet collisions.

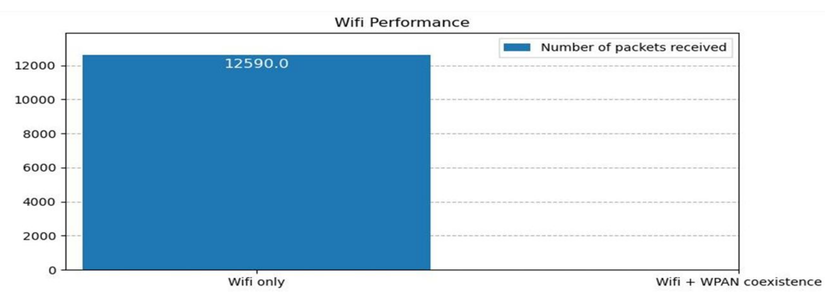

Fig 6: Wi-Fi hosts performance in Co-existence case

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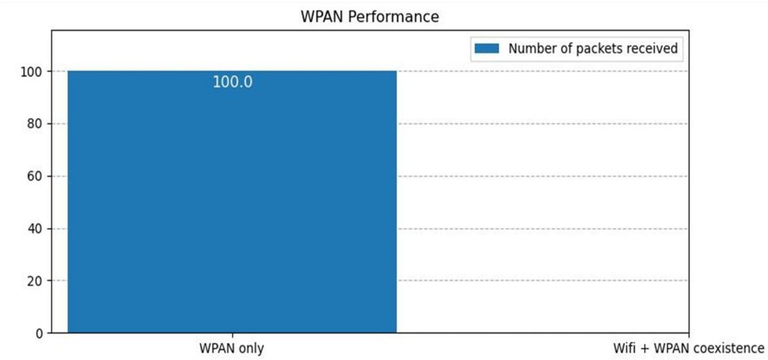

Fig 7: WPAN hosts performance in Co-existence case

Both IEEE 802.15.4 and IEEE 802.11 can also dynamically modify transmission behaviour by selecting less crowded channels and reducing conflicts through adaptive techniques like frequency hopping and clear channel evaluations. Because of this, both systems' adaptive characteristics, restricted channel usage, and complimentary traffic patterns let both device types in shared networks receive more packets and have fewer collisions. We can observe from the above co-existence graphs both Wi-Fi hosts and WPAN hosts performed better in packets receiving. The throughput performance is better due to cooperative channel accessing mechanism.

V. CONCLUSION

The coexistence of IEEE 802.15.4 and IEEE 802.11 networks results in improved packet reception rates and throughput. By reducing collisions, this study demonstrates how their application of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) increases throughput for both systems. IEEE 802.15.4 may efficiently occupy spectrum segments due to its narrower bandwidth, which reduces interference with IEEE 802.11 channels that are more widely used. This results in lower congestion for IEEE 802.11 hosts and fewer packet collisions for WPAN devices, which improves delivery success. By restricting airtime usage, WPAN devices' low-duty cycle promotes coexistence even more. By optimising transmission patterns, adaptive techniques like frequency hopping and clear channel assessments help both standards. The study's findings basically show that these networks supportive properties improve spectrum efficiency and performance. Advanced coexistence techniques, such as machine learning for dynamic channel allocation, should be investigated in future research to improve wireless communication systems even more. These advancements may help meet the growing need for dependable connectivity in a variety of applications.

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