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A Review of Interference Mitigation Approaches for the IEEE 802.15.4 Device Architecture

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Modern health care applications are closely associated with the use of Wireless Body Sensor Network (WBSN) technologies. There is also a lot of on-going research in this area. The usefulness of Wireless Body Sensor Network technologies has a lot of applications in healthcare systems. For instance, WBSN technologies can be used to control and monitor the health status of a patient for a specific period of time, and signal professional care-givers about an abnormal physical health status that otherwise would have been disregarded or remained unnoticed by the patient. This provides enough time for the patient to seek medical attention, and thus help to eliminate a physical alignment before its signs become noticeable or the physical health of the patient becomes acute. WBSNs also make it possible for elderly and chronically ill people to maintain their independence without the need of having the physical presence of caregivers. One of the greatest challenge experienced by WBSNs is: interference caused by other technologies with which they may be sharing the same frequency band. When the closeness between individual IEEE 802.15.4-based WBSNs within the same operating frequency increases, it results in mutual interference, which reduces the performance of the WBSNs. This poses one of the most challenging issues caused by neighboring WBSNs. Also, mutual interference is also known to bring about inefficient channel utilization in WBSNs, leading to significant performance degradation. A lot of research has been undertaking in order to study the impact of internal interference in homogeneous WBSNs and a lot of approaches that can be used to mitigate its effects have been proposed. This research work presents a comprehensive review of studies geared towards mitigating the impacts of internal interference caused by neighboring homogenous WBSNs and how their performance can be taken a step further. The review covers years of studies published up to and including the year 2015, in order to present and evaluate the empirical findings regarding the Impact of Interference in IEEE 802.15.4-based WBSNs.
Keywords: Wireless Body Sensor Networks, Mutual Interference, Performance, Frequency.

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1. INTRODUCTION

Improvements in micro electric devices such as tiny microprocessors has led to the emergence of powerful sensors bringing about the invention of Wireless Body Sensor Networks (WBSNs), which has emerged as an important branch of the Wireless Sensor Network (WSNs).WBSNs focus on offering support to all aspects of people's daily lives. When attached to the body or ingested, they are capable of supporting continuous, real-time, non-contact monitoring of the bodies' physiological conditions at any time and in any place. This makes it possible to provide remote medical monitoring, at the same time, thereby improving the quality of health care. WBSNs find their greatest use in health-related applications, tracking applications and entertainment [7, 9]. They are very reliable in monitoring the health status of individuals who need to be under a regular routine check, such as old people, without physically engaging them.

The sensor nodes attached to them transmits collected information about their health status to care givers, thereby giving these individuals a lot of independence and freedom of movement. The major difference that separates classical WSNs [40, 58] from WBSNs in spite of their similar characteristics is the differences in size of networks that they make up.WBSNs usually form small to medium-sized networks, and sensor nodes are at most one to two hops away from a central unit called the coordinator node [19, 32]. In a WBSN, sensor nodes transmit the collected information to the coordinator node over the wireless network. The most commonly used topology for WBSNs is the single-hop star topology [13, 20].

Amongst the many protocols and standards that work with WSNs and WBSNs, the IEEE 802.15.6 standard is specifically

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designed for WBSNs and has been recently standardized and released [1]. However the author has decided not to consider it, as following a careful search, to the best of the author's knowledge, no sensor nodes following the specifications of this standard is commercially available for carrying out this study. The IEEE 802.15.4 on the other hand is a proven and widely-used standard protocol for WBSNs [27].It describes a Low-Rate Wireless Personal Area Network (LR-WPAN) and is designed to offer simplicity and reduce the network communication costs. The IEEE 802.15.4 supports and is restricted to the Physical (PHY) and Medium Access Control (MAC) layers only. Given the commercial availability of IEEE 802.15.4 component and its simplicity. For a long time, this protocol is likely to remain the choicest protocol used for wireless sensor networks and wireless body sensor networks. Thus for this study, the IEEE 802.15.4 is considered as the standard or benchmark protocol.

The physical layer offered in the IEEE 802.15.4 protocol supports a total of 27 different operating frequencies or channels. Amongst these, 16 channels are in the 2.4 GHz Industrial Scientific and Medical (ISM) band. This frequency band is perhaps the most popular frequency band utilized by IEEE 802.15.4-based technologies. It is also utilized by other technologies such as Wireless Fidelity (WiFi) and Bluetooth. This study is aimed at examining the effect of MAC parameters on several co-existing IEEE 802.15.4-based WBSNs on their performance gain as their number becomes larger in the 2.4 GHz frequency spectrum.

2. LITERATURE REVIEW

The IEEE 802.15.4 standard [58,57] is a widely accepted standard for low-power wireless sensor networks and has been considered as the underlying technology for WBSNs .Despite the recent approval of the IEEE 802.15.6, the IEEE 802.15.4 is likely to remain a serious opponent in the WBSN area for a long time to come. The architecture of this standard is limited to the Physical (PHY) and the Medium Access Control (MAC) layer. Each layer is responsible for accomplishing the tasks related to the specific part of the standard and provides specific services to the layers above it. The physical layer of the IEEE 802.15.4 standard consists of the low-level control structure and the Radio Frequency (RF) transceiver while its MAC layer provides unicast, multicast, or broadcast communication services and the required operating frequency needed for any transmission.

The layers are shown below in Figure 2.1. Both network and application layers The network layer and the application layers are given credence in the upper layer block shown in Figure 2.1 above, except for the upper layers which are not part of the areas to be covered in this study. This research work shall focus on the offset quadrature phase-shift key (PHY) band, because of its compliance with the ChipCon CC2420 transceiver which is generally available and accessible. Also, in the IEEE 802.15.4 standard, various PHY layers were supported in the 2.4GHz band. The physical layer of the IEEE 802.15.4 standard has 27 non-overlapping operating frequencies.

One of the most important challenges in IEEE 802.15.4 is channel co-existence. Several studies have been conducted to evaluate the performance of the wireless systems when the spectrum is utilised homogenously or non-homogenously. The IEEE standard for Local Area Networks (LAN and Metropolitan Networks (MANs) standardised Wireless Body Area Network (WBAN) to in order to met the requirements of applications related to health in the field of wireless body sensor networks. A lot of approaches have been used to examined the challenges concerning the homogenous co existence of IEEE 802.15.4 based WBSNs. These approaches have only been able to solve the problem of channel co-existence to a certain degree. For instance the beacon shifting approach is most useful in assisting WBANs to adjust their beacons in order to avoid kind of overlapping which occurs during the active period at beacon when the number of active WBAN is relatively small.

An adaptable beacon scheduling plan is offered in [24] in which coordinators have to carry out carrier sensing before transmitting the beacon when this approach is then weighed against the beacon-shifting approach offered in IEEE 802.15.6 MAC protocol the outcome shows profound improvements in terms of successful transmission over the beacon – shifting strategy. In the IEEE 802.15.4, beacon transmission will occur weather the channel is busy or not. Moreover, the possibility of the failure of a beacon scheduling increases as the number of users of the channel increases. This happens when the beacon detects that the channel is busy and is being compelled to retreat. A simulation study was also carried out to compare the performance of IEEE 802.15.4 with IEEE 802.15.6 [8]. The simulation carried out revealed that IEEE 802.15.4 performs better than the IEEE 802.15.6 in terms of throughput.

In order to resolve the problems caused by channel coexistence through internal interference as an example, the system must be made to be more flexible with dynamic operating frequency allocation. This is one of the major ways of solving issues caused by channel co existence. The main intension is to reduce packet collision caused by numerous IEEE 802.15.4 based systems, using the same operating frequency at the same time. In resolving interference problems caused by co-existing WSNs the first thing to do, is to use an interference detection technique. For instance one of the techniques that can be used is ED. It is offered in IEEE 802.15.4, it uses the RSSI service and it is done through CCA attempt. Interference caused by WiFi technology can be very well detected by the RSSI measurement since the traffic load is always in existence and various carrier sensing strategies are used. The use of such measurement does not give cogent information about interference that can likely occur in homogenous WSNs with periodic transmission. LQI measurements and Packet Error Rate (PER) can also be said to be two wide used interference detection technique.

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Different studies have been carried out to find out how efficient the above mentioned interference detection techniques are and also to reduce the negative effects of external interference often caused by WiFi technology on the performance gains of WSNs/WBSN [55], [56] and [49]. In this review only the impacts of Internal interference caused by neighbouring homogenous WSNs on their performance gains are considered. Studies have been carried out by Amirhossein et al [41, 42] in evaluating the performance of IEEE 802.15.4 MAC protocol to find the potential white spaces. These studies the channel utilisation is classified into three regions. White, grey and red. These colours indicate when a given channel is idle, under use by user or overlapped with two or more neighbouring WSNs, respectively.

Another strategy for ensuring reliable data packet transmission in the presence of interference is the use of the multi-channel MAC (CMAC). It has been observed that smaller end-to-end delay has resulted from the use and modification of the Request To Send (RTS) and Clear to Send (CTS) in CAP [50]. However, the chances of having collisions are high as the number of active WBSNs grows. Due to advantage such as simplicity and low power consumption single fixed channel approaches are frequently used in WSN applications [14], though these days a lot of low power sensor network nodes are furnished with radio transceivers which are able to operate on multi-channels and multi-bands [51] and [53].

One importance of multi-channel MAC protocols is to improve the quality of the network even while it is experiencing some interference. The shortcoming of protocols like the multi channel MAC protocol is that when they are experiencing light interference they do not save much energy, as compared to single channel protocols. Y-MAC is an example of energy efficient multi-channel MAC protocol for WSNs. The protocol is able to achieve high performance while cutting down energy expense in high and moderate traffic conditions when the performance of a sensor network is seriously affected by internal interference. To improve the total performance gain and reduce energy consumption, using multiple transceivers can be used WSN devices. Although this will increase the cost and the level of complexity of WSNs.
As such reduction in cost and complexity in addition to having smaller sizes of sensor devices are crucial factors that should be focused upon when dealing with WBSNs.

In order to make it possible to increase the number of available channels by managing spectral and temporal resources available, virtual channel strategy was deployed [25]. In the virtual channel strategy an approximation of the IEEE 802.15.4 CSMA/CA is put into a superframe scheduler. What follows after this is the selection of the logical channel accompanied with the superframe scheduling approach which results in the creation of a virtual channel. A management object is required to provide channel information for future WSN. The major problem with the central management method is that when the main object of management fails the whole system is adversely affected.

The Dynamic Channel Allocation (DCA) approach [11] is used to reduce the interference caused by coexisting sensor nodes. Based on techniques used in graph colouring, colour repetition occurs in DCA only if the nodes are separated by more than two hops. This approach is likely to allocate the minimum channels in a distributed fashion. The multi-channel MAC whose link has been cut off takes over responsibility of the standard MAC protocol, once the channel is assigned. The multi-channel MAC plays an important role in the DCA approach in minimizing control overhead, preventing over learning and allowing the maximum possible sleep time.

A review of the most recently proposed approaches and strategies used to combat the adverse effect of internal interference in homogeneous WSNs is provided in Table 2.1. Khanafer et al [23] have concentrated on methods of advertising the effect of interference on performance gains. Carrano et. al [12] have concentrated on reducing the energy consumption of sensor nodes by managing the duty cycle and Sudealayan et. al [47] have focused on the applicability of the energy saving techniques on WBANs using the human body as basis for energy. Tilting away from the studies highlighted studies, this research work is focused on dealing with the internal interference caused by coexistence WBNs. Mainly, the effect of system parameters on WBSNs performance gain is closely being studied from two standpoints: protocol design and MAC parameters. In addition, a broad simulations study shall be conducted to spell out the effects of MAC parameters on WBSNs performance gain while a high level of interference is present.

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Table 2.1: Comparison of Approaches and Offered Strategies to Mitigate Interference Amongst Coexisting WSNs.

	Problem Statement	Proposed solution	Evaluation Methods and Verification Tools
[1]	channel coexistence	beacon-shifting, channel-hopping and active superframe interleaving	Not specified
[24]	channel coexistence	flexible beacon scheduling scheme for IEEE 802.15.6	Castalia 3.2 simulator
[8]	channel coexistence	comparison between IEEE 802.15.6 and IEEE 802.15.6	Castalia 3.2 simulator
[41]	internal interference in homogeneous WBSNs and channel scarcity	initial-choice and idealised schemes (introduced as upper band)	Castalia 3.2 simulator
[42]	internal interference in homogeneous WBSNs and channel scarcity	greedy channel utilization approach	Castalia 3.2 simulator
[36]	internal interference in homogeneous WBSNs and channel scarcity	continuous-hopping approach	Castalia 3.2 simulator
[37]	internal interference in homogeneous WBSNs and channel scarcity	continuous-assessment vs periodic-assessment	Castalia 3.2 simulator
[11]	channel assignment problem	segment-based channel assignment strategy	analytical and simulation
[12]	low performance gains due to channel coexistence	coexistence-aware spectrum sharing protocol	analytical and simulation
[17]	low performance gains due to channel coexistence	coexistence detection and coexistence mitigation strategies	OPNET simulator
[16]	low performance gains due to channel coexistence	dynamic coexistence management (DCM) mechanism	OPNET simulator
[15]	low performance gains due to channel coexistence	dynamic coexistence management (DCM) mechanism	test-bed experiment (Markov model)
[50]	low performance gains due to channel coexistence	multi-channel MAC protocol approach	-
[21]	destructive impacts of internal interference on sensor network performance gains	advantages and disadvantages of various proposed multi-channel communication approaches	analytical modeling (Markov model)
[52]	increasing the nodes density and escalation of internal interference	an energy e□cient multi-channel MAC protocol approach	test-bed experiment
[51]	coexistence with other technologies	multi-radio prototype	test-bed experiments
[37]	coexistence with other technologies	dynamic spectrum access strategy	test-bed experiment (Iris platform)
[6]	performance degradation due to spectrum congestion caused by increasing the popularity of wireless embedded devices	a low-power spectrum agile MAC protocol	analytical analysis and test-bed experiment (TelosB platform)
[32]	the current multi-channel MAC proto- cols are being inflexible to the variation of the environment	Dynamic Multi-radio Multi-channel MAC (DMMAC)	test-bed experiment
[53]	performance degradation due to radio interference	coordinated channel switching and spectral multiplexing	test-bed experiment (Mica2 sensor nodes)
[25]	channel scarcity	Scheduler Using Throughput Estimator (SUTE), Nearest Vacancy Search (NEVS)	ns_2
[29]	internal interference	dynamic channel assignment (DCA) and CMAC	JAVA based discrete event (SimJava)

2.4 International Interference System Parameters Interaction

When the IEEE802.15.4 is in a beacon enabled mode, there is often a competition amongst the sensor nodes gain access to the medium. The time Division Multiple Access method is used by the sensor nodes to compete with each other although CSMA/CA is the most popularity used method in IEEE802.5.4 [27]. The CSMA/CA aids the sensor node in ensuring that the channel is not currently used by other sensor nodes. Parameters such as BE, macMinBE and macMaxBE are CSMA/CA is internal parameters. Some of the investigations that have been conducted to study the effect of CSMA/CA internal parameters on the performance of WSN/WBSN are as follows:

Koubaa et al [26] carried out investigations on the performance of the CSMA/CA algorithm of IEEE802.15.4 while it is in the beacon enabled mode. The study slotted CSMA/CA is inpected for the presence of the configuration of various network parameters. Specifically studies on the effect of SO, BO and BE on the network performance were carried out. The result of the afore-mentioned studies reveal and up-shoot on network efficient as the load (G) varied from 50% to 30% due to two cogent reasons: (1) the overhead of beacon packets is better suited to the lower SO values. This is because the beacon packets are transmitted more often. (2)

The regular clear channel assessment (CCA) in lower so values are likely to cause more collisions at the beginning of each superframe. When the loads increase the network reaches a saturation level of about 62% according to the study being discussed [26] currently. The probability of success however reduced as the load offered increased. The offered G (<50%) has the highest probability of success rate when the SO is greater than or equal to 1. The afore-described study, this research work shall consider changing WBSN density and the impact of interference on network performance gains. In addition, various values for the macMinBE and macMaxBE shall be considered in contrast to the study my Koubaa et al. [26] were the CSMA/CA parameters (i.e. macMinBE and macMaxBE) where constant all through their simulation study. Also the mathematical model they presented did not correspond with the results they obtained.

Hence, Part et. al [43] presented enhanced Marker model to fully characterise the behaviour of CSMA/CA strategy used by the IEEE 802.15.4 standard. The proposed Markov model was tested using analysis gotten with the aid of Network Simulator version 2 (NS-2). The major improvement provided by Part et al's study over the one presented in [26] it takes into account the probability of the channel sensing state instead of the channel assessing state. The channel accessing is not appropriate for analysing the behaviour of the CSMA/CA strategy. The major reason behind this is that in the improved strategy, channel sensing takes place twice before it enters into the channel assessing state. In the study carried out by Park et al [43], it was proved that measuring the channel sensing state rather than the accessing state provide better matching of the simulation results to the mathematical analysis although the improved version of the mathematical model did not appear to correctly represent the CSMA/A behaviour proposed for IEEE 802.15.4.

G. Bianchi [5] carried out on analytical assessment on the performance of the CSMA/CA operated in IEEE 802.15.4 Mac layer. In this study a Markov Model that forecasts the behaviour of the slotted CSMA/CD mechanism being performed by IEEE802.15.4 standard was proposed. The outcome of the simulation results did not match with the propose Markov model.

Hence, Pollin et al [45] presented a Markov model that forecasts the behaviour of the slotted CSMA/CA mechanism being performed by the IEEE802.15.4 standard. The results obtained were then compared with the simulation results to validate their accuracy. Pollin et al [45] also proposed a Markov model that is verified by looking at the simulation results and which also fully portrays the characteristics of the CSMA/CA mechanism for IEEE802.15.4. They conducted an analytical study on the behaviour of CSMA/CA in both saturation and unsaturation networks and concluded that higher macMinBE values are more appropriate for use with saturated networks, while smaller values of macMinBE only improved the energy consumption of unsaturated networks marginally. It was also confirmed that the probability of sending packets over a network with a saturated traffic is higher when no acknowledgement packet is utilised. The quality of the network is however poor due to a higher possibility of collision occurrence. When there is a lower collision probability a high throughput can still be achieved in n saturated traffic where smaller numbers of packets are sent. Also in Pollin et al studied [31] the effect of interference was not considered which a major contrast to this study.

In the preceding mathematical models the analytical model could not fully symbolise the behaviour of the unsaturated WSNs which are characterised by senor nodes not having data packets to transmit. This problem was addressed by Ling et al [30] where other analytical model known as "a renewal analytic model". In this proposed model it is assumed that the probability of beginning to perceive the channel that the probability and all sensor nodes attempt to re-transmit the data packets associated with them until the packets are sent successfully. The outcome showed a drastic decrease in throughput while the average time is surtuated at the head-of-line and the instance of the time that is removed because of either successful transmission, greater than the maximum re-transmission or exceeding the maximum number of concurrent CCA failure, aAS, represents the oppose tendency as the number of sensor nodes increases. This is because the values of macMinBE and macMaxBE are too small (3 and 5 respectively). These stated values are the default values for the macMinBE and macMaxBE according to the IEEE

802.15.4 standard draft. This backoff slots are usually evenly spread out uniformly over a short range of [0-31].

This results in the executive of simultaneous channel sensing by multiple sensor nodes as the size of the network increases. This eventually leads to a higher rate of reduction of the network's throughout.

Lee et al [63] enhanced the renewal model, making it appropriate for use with unsaturated IEEE 802.15.4 – based networks including acknowledgement packets. The study also examined "frame dropping" which occurs as a result of transmission failure. The outcomes of the study indicated that the probability of data packet dropping increases as packet to arrival ratio increases. One other thing the study achieved is that it showed that a longer service time can be achieved when the number of sensor node are increased. The reverse is the case however, for throughput.

For instance, the throughput of a network consisting of 5 nodes drops as the values of the macMinBE and macMaxBE becomes higher. However the throughput increases as the number of nodes in the network increases. (e.g. Number of nodes = 10). This is because unnecessary amount of time is wasted on backoff purposes when the sensor node attempts to transmit a data packet, in the small network size scenario, where as in a larger network it is necessary to spend a larger amount of time in order to avoid collisions. As such the network experiences a higher throughput as the number of sensor nodes increases. The distinction between this research work and that of Lee et al [63] is that it examines the interaction between CSMA/CA internal parameters and other IEEE 802.15.4 system parameters while Lee et al is only indirectly studied the impact internal interference on the performance of CSMA/CA. Feng et al proposed an Markov chain analytical model that takes slotted and unslotted CSMA/CA mechanisms into consideration. In the proposed model, channel model and node model were integrated into one model. Based on the outcome of the study, it was found that the throughput builds up as the number of states become higher while the data transmission is being kept at a constant value of 314 bit. This implies that when there is a constant data transmission, the probability of collision will decrease as the number of states also increases.

Zhu et al proposed the Linear Increase Back-off (LIB) as a modification to the slotted CSMA/CA. LIB is created using an accurate Markov chain model. The main aim of LIB is to examine the performance of an unsaturated and unacknowledged one-hop star network topology based on the IEEE 802.15.4 MAC protocol and operating in a beacon-enable node. Particularly, the LIB aims at identifying the probable congestions in the network and improve the latency and delay while ensuring that the energy and throughput a kept at reasonable levels. Based on the analytical and simulation results obtained, it was established that the chances of detecting the channel in the first CCA attempt increases as the number of the nodes and the unit backoff period increase. However, as for the second CCA attempt the chances of sensing the busy channel is less sensitive to the unit backoff period but increases as the number of nodes increases.
The results from the simulation for throughput reveal that the value of the first backoff counter plays an important role in obtaining the throughput. The sensor nodes begin to sense the channel concurrently due to the small backoff counter. This eventually leads to higher collisions. However, setting a value that is too large as the backoff period will result in a lower throughput due to the collection of a large number of packets at the slot boundary. The infers that the sensor nodes are expected to wait for a longe backoff period before sensing the channel. The study showed that the throughput is highly dependant on the number of active nodes and the unit backoff period. However the interaction between these factors and other system parameters were not considered.

Improving the CSMA/CA mechanism as been thought of as a way of reducing the energy consumption of sensor nodes. As such many analytical models for the CSMA/CD mechanism in IEEE 802.15.4 MAC protocol have been proposed.

Feng Shu and Taka Sakurai proposed a energy conserving models for reducing energy consumption while CSMA/CA is being perform. They evaluated the performance of stochastic model for CSMA/CA based on the collision windows [10]. The result of evaluation showed that the energy consumption of the sensor nodes is scrutinized when the CSMA/CA algorithm is performed. The results obtained revealed that the lifetime of the sensor can be severely reduced for the CCA higher than 30%.

Many studies have also been conducted to ascertain the effectiveness of the role that traffic loads play on CSMA/CA and sensor network performance.

Baz et al [3] have proposed two algorithms to enhance the performance of the CSMA/CA. The CSMA/CA mechanism proposed contains the time based frame aggregation and selective frame strategies. The strategies were implemented based on the network density and size of the data packets. They also proposed an efficient approach for modelling the CSMA/CA protocol for IEEE802.15.4 standard based on the theory of compound probability distributions [4]. The study revealed that the least energy consumption and the lowest service time together with non-stable throughout are the major characteristics of the unacknowledged mode. In addition, they also discovered that "limited" and "unlimited" number of data packet re-transmissions could lead to the improvement and decline in the stability of throughput respectively.

To increase the Quality of Service (QoS) for slotted CSMA/CA mechanism an adaptive algorithm is proposed in [52]. In their study back off exponents are initialised dynamically according to variations in traffic. The simulation results indicated a significant improvement in success rate, effective data rate and average delay. Assigning the length of backoff period without considering the current channel condition could degrade the overall performance gains [31]. This is a major detect of the standardised CSMA/CA.

This current study has previously discussed about the significance of CSMA/CA internal parameters such as the macMinBE and macMaxBE and their effect on the overall performance gain. The ongoing study of related work henceforth takes its turn in examining other system parameters and their effects on the WSN/WBSN performance gains.

Golmie et al [19] have studied internal and external interference as related to the IEEE 802.15.4 standard. Results obtained from the study revealed that although the end-to-end delay of the high data load of 1500 bytes reduced significantly, the “good put” dropped tremendously as the number of transmitters increased. This was as a result of the partitioning of the big data packets into a smaller size and awaiting the opportunity to transmit them to the receiver during the current and upcoming CAPs. This reduced the average end-to-end delay. According to their configuration, if the transmission of a single partition fails, the other partitions will be deleted from the queue. This bring about a lower percentage of success as compared with other traffic loads. The second phase of their study two WPANs with each consisting of four medical applications are considered for each patient. The two WPANs are configured to utilize the same operating frequency. The output results indicated huge packet losses for high traffic loads as the number of transmitters was increased.

In the study carried out in [3], involves a simulated situation, where a patient uses on Electro Cardio Gram (ECG) and blood analysis module to study the protocol parameters for optimisation of the network behaviour as well as reducing consumption of energy. The study also identified the impact of varying values of the BI parameter on packet loss ration, packet transmission retries, medium access delay and energy consumption. In the simulation results it was shown that where BO=SO, the BO values lower than 3 use up more energy in contrast to higher values. This is due to having a high network traffic load such as the 56192 tps load used in their study and a short superframe duration that finally leads to putting off data packets to the next B.I. This could lead to packet collision at the first time slot of the next BI. As such, packets will be lost, a higher rate of re-transmission will be incurred and more energy will be consumed. Although, their study examined the configuration of the commonly used values for some network parameters as in [19], it also did not consider the impacts of interference caused by having multiple coexisting WBSNs together with various values for data packet generation and the internal parameters for CSMA/CA.

The impacts of several, system parameters such as packet butter size, packet size, number of sensors, packet arrival rate and inactive periods on the performance of sensor networks is investigated in [34].The outcome of the study indicated that if the throughput exceeds 50%, the average access delay becomes very large. To achieve a higher throughput, a larger size of buffer is needed. They also examined the impacts of buffer size, arrival rate and the inactive period on IEEE 802.15.4 network performance gains with a different set of performance measures on shown in [35].
The performance measures indicated as the main performance measures where: the probability of access probability that the medium is idle and the blocking probability. The obtained results revealed that a careful evaluation of either the network size or the packet arrival in order to avoid the probability of a packet being blocked due to the device buffer’s lack of adequate capacity during the backoff period. In addition, the study proposes that the packet arrival rate, as well as the number of stations can be increased provided that the buffer size is large enough.

The study in [2] examined the challenges and issues caused by various system parameters such as BI, packet arrival patterns, different values of CSMA/CA parameters, various packet sizes and different offered loads. The outcome of the study indicated that all the nodes compete to gain access to the channel at the start of the active period thereby reducing the delivery ratio. Poisson and periodic patterns were used in this study and it was indicated that all the nodes did not have to contend for channel access at the start of the CAP, where Poisson data arrival pattern is employed. However, there exists a high probability for contention to occur even in a situation where the CAP length much more smaller than the BI in length. This suggest that the IEEE 802.15.4 MAC layer not able to handle the contention effectively. Although the study considered a wide range of system parameters and their effects on the WSN performance gains, it also failed to consider the effect of system parameters under the influence of high levels of internal interference. This differentiates it from my proposed research work.

As seen from previous studies considered, packet delivery ration is directly connected to the size of length of the BI (BO) and CAP (SO). Also, as earlier discussed there is a greater likelihood of contention occurring when the size of the CAP is very small as compared to the length of BI.

Sometimes long BI’s also lead to buffer overflow and finally loss of data packets. Adjusting the value of SO and BO based on the traffic load will thus be a very rewarding step to take. A study was conducted to evaluate the effect of MAC parameters such as BO and SO [101] while examining the performance of the IEEE802.15.4 MAC protocol using the Dynamic Manet On demand (DYMO) protocol. In this study, the values of BO and SO were specifically adjusted based on traffic loads. The results obtained showed that throughput is drastically affected as the data rate per packet becomes larger. In addition, the throughput is found to be low for all values of BO = SO. In order to address the problem of beacon colliding with each other and with data frames, superframe Adjustment and Beacon Transmission (SAB+) is proposed [62].

A cross examination and test of the proposed approach resulted in higher rates of successful transmissions and a reduction in energy consumption. The approach improved the sensor network performance gains to a large extent however is

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it not applicable on random independent co existing WSNs. Figure 2.7 depicts the SAB+ flow process.
A layered model pTune is designed in [126]. The model is useful in handling issues such as poor link quality, traffic lead fluctuation and insufficient bandwidth by adjusting the values of X-MAC parameters. It is designed to receive network requirements and provide improved values for IEE802.15.4 X-MAC parameters. The details of how the proposed model handles the aforementioned issues dose not reflects in their pTune framework.

In studies carried out in [99,100] it was observed that presence and absence of hidden terminals determined the size of traffic loads and the level of interference encountered. The aim of the study was to determine the proper values MAC parameters as to be able to reach compromise between the latency and success rate for the give range of the traffic loads. The researchers showed that by increasing the value of BE lower packet loss rates could be achieved (at lower traffic leads and while hidden terminals are not present). The study examined the impacts of IEEE802.15.4 MAC parameters such as macMaxBE, macMinBE, macMaxCSMA Backoffs and re-transmission of frames on MAC protocol performance. The study also discovered that, for all values of macMaxBE higher probabilitie of collisions occurring and packet less rate will increase as the number of hidden terminals in appearance increases for all value of macMaxBE. The outcome of the re-transmission of frames revealed that there are no observable changes in the rate of loss of packet (in the absence of hidden terminals) for any increase in the value of frame retransmission beyond the value of 1.

To evaluate the performance of IEEE802.15.4 a major hardware-based experiment is conducted in [29]. Direct and indirect data transmission, data payload size, CSMA/CA and the beacon enabled mode where the elements whose effect on the performance gains of IEEE802.15.4. The results of the study revealed that in the non-beacon enabled mode the transmission from the coordinator to the first sensor device is very much below the direct data rate from the first sensor device. The other set of results of the experiment revealed the effect of low macMaxBE and macMinBE values of 4 and3 respectively. The results also revealed that the delivery ratio experienced a decline as a result of data packet collisions, as the number of active devices increases. In addition, the delivery ratio experiences decline as traffic loads transmitted by other devices beacons larger, due to the possibility of collision occurrence.The outcome of the experiment performed observed the effect of the size of the data payload on the performance gain revealed that, the delivery ratio declines due to a higher probability of collisions occurring and also with s the payload increases too. The experiments showed that the value of BO and SO remained at 15. This value represents the non-beacon-enable mode, although in the last experiment (aimed at determining the impact of the beacon-enabled mode, the values of BO and SO was found to be in between 1 and 15. In obtaining the results the delivery ratio of data packets was not taken into account.

The study in [32] examined the “Reinforcement Learning” method in order to determine the best duty cycle of a specific BI. Duty cycle has been considered to have a positive impact on WSN performance gains. In doing this, the Duty Cycle Learning Algorithm (DCLA) was employed to collect network statistics information with the aim of minimising the need for manual re-configuration of the duty cycle in order to meet certain requirements for diverse networks. The outcome suggested that the micro-processor experienced a very high processing overhead while carrying out more regular CCAs.

Even though the Adaptive MAC for Efficient low –power communication (AMPE) [7] used the same duty cycle that DCLA uses. The AMPE algorithm reveals that the period of time for which a channel is busy is related to the occupation of the superframe and is directly linked to the traffic load factor. Hence the period of time for which the channel is busy (during the active period) can be ascertained by using the physical layer Management Entity – Clear Channel Assessment (PLME-CCA) request primitive recommended in the IEEE802.15.4 standard. It is expected the primitive request be reportedly made within the superframe duration. The demerit of the CCA measurement in this aspect is its high expense of energy usage, even though it appears to provide a more precise information rather an strategies based on inaccurate estimations. The Beacon Order Adaptation (BOAA) proposed in [87] uses specific number of messages sent by the sensor devices in order to make a guess of the land offered by the network. After the messages have been received, it their destination, they are put in a matrix form. Having this elements in matrix forms make them to use up more memory space and problematic when dealing with large networks.

The DCA proposed in [22] uses addition information such as end-to-end delay in their duty cycle and transmit queue occupation in order to determine the proper duty cycle. To ascertain the queue occupation (during the active period), the queue indicator is put into all frames, and employed in the determination of the queue occupation during the active period. This study does not take into consideration, the transmission requests occurring throughout the active duration during the period in which the queue occupation in the end devices is decreasing.

Calderral et al [20] considered issues relating to the mobility of hospital patients while they have a WBSN on them They studied the method of used in handling over signals sent and received by the sensor on a patient from one access point to another within the same network domain.

Carran et al [12] studied the energy consumption of the sensor nodes, while managing the duty cycle while Khanafer et al [23] examined different methods used in mitigating the effect of interference on performance gains. Suderalayam et al focused on using the human body as a means of supplying energy to WBANs [46]. Table 2.3 presents details of various system parameters and factors, their performance measures and the evaluation methods and tools.

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Table 2.2: The analogy of State of art in terms of utilised system parameters

Ref No./Column Heading	System parameters and factors	Performance Measures	Evaluation Methods and Verification Tools
[91]	BI and packet transmission retry	energy consumption, packet loss ratio, medium access delay	OPNET simulator
[19]	number of transmitter in homogeneous and heterogeneous networks	end to end delay, goodput	OPNET simulator
[26]	slotted CSMA/CA algorithm, BO and SO	throughput and average delay and probability of success	analytical modeling
[43]	slotted CSMA/CA algorithm	throughput, average delay and probability of success	Markov model and ns_2 simulator
[45]	saturated and unsaturated sensor nodes in beacon-enabled and non- beacon enabled modes	CSMA/CA performance	analytical modeling (Markov model) and (Monte-Carlo simula- tion procedure)
[34]	CSMA/CA internal parameters packet arrival rate, number of stations, the finite size of individual node bu□ers, packet size, inactive period be- tween the beacons and CSMA/CA internal parameters	average access delay and throughput	analytical modeling (Markov model)
[35]	packet arrival rate, number of stations, station bu□er size, packet size and in- active period between the beacons	probability of access, probability that medium is idle, queue length distribution in the device, and probability distribution of the packet service time	analytical modeling (Markov model)
[30]	number of sensor nodes and CSMA/CA algorithm	throughput and MAC service time	analytical modeling (Markov model)
[63]	network size and CSMA/CA internal parameters	packet-arrival ratio, the probability of data packet, average service time, throughput and success rate	analytical modeling and C++ language based simulation code
[115]	slotted and unslotted CSMA/CA mechanisms and integration of the node and the channel	collision probability and throughput	collision probability and throughput
[125]	modified slotted CSMA/CA mechanisms	latency and delay, energy e□ciency and throughput	analytical model (Markov model) and ns_2 simulator
[46, 104]	ack and non-ack mode with both saturated and unsaturated tra□c pattern, CSMA/CA mechanism	Energy e□ciency of CSMA/CA algorithm and throughput	analytical modeling and C++ language based simulation code
[9]	ack and non-ack mode with both saturated and unsaturated tra□c pattern, CSMA/CA mechanism	throughput, average delay, collision rate, bu□er occupancy and o□ered load	bespoke simulation platform
[4]	number of nodes, slotted CSMA/CA algorithm	throughput, average MAC service time, successful transmission	Analytical Model (Markov model)

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[52]	number of sensor devices, di erent pri- ority levels for di erent sensor devices (service di erentiated) and adaptive CSMA/CA internal parameters value	average delay, e ective data rate, and packet loss rate	IEEE 802.15.4 module included in the OM- NeT++ simulator
[31]	number of sensor devices, di erent pri- ority levels for di erent sensor devices (service di erentiated) and adaptive CSMA/CA internal parameters values	collision probability and mean end-to- end delay	IEEE 802.15.4 module included in the OM- NeT++ simulator
[2]	number of sensor devices, power man- agement mechanism (always active or not), periodic or poisson packet arrival patterns, frame re-transmissions, BI, CSMA/CA parameters	delivery ratio, latency, on-time delivery ratio average energy per packet	Gilbert-Elliot model and ns_2 simulator and real test-bed experiment
[99, 100]	macMinBE, macMaxBE, macMaxCSMABacko s, frame re- transmission, tra c loads and in- terference caused by neighboring nodes	packet loss probability and the packet latency	Simulink or NS-2 and the real test-bed experiment
[126]	low and high tra c loads varying link quality and generally MAC parameters	network lifetime, end-to-end latency and end-to-end reliability	test-bed experiment
[29]	the direct and indirect data transmissions, CSMA-CA mechanism, data pay load size, and beacon-enabled mode	data throughput, delivery ratio, and RSSI	real test-bed experi- ments
[62]	inter-arrival time	probability of successful transmission, the probability of collisions, network gudput and energy consumption	Markov model and ns_2 simulator
[32]	network o ered load, number of sensor devices and duty cycle	energy e ciency, end-to-end delay and probability of successful transmission	OPNET simulator
[87]	BO, time scale	the average power consumption to the power consumption in receive mode, service delay and BO	Network Protocol Sim- ulator (NePSing)
[22]	number of sensor devices	energy consumption(sensor and coordinator), SO variance, number of packet dropped, end-to-end delay and successful transmission	ns_2 simulator

3. CONCLUSION

This research work presents a study the IEEE 802.15.4 device architecture in a layered structure. It specifically considers the internal interference caused by coexisting WBSNs. This review can serve a basis for an in-depth investigation into the effect of system parameters on the performance gain of WBSNs with specific interest in MAC parameters and protocol design.
Based on this review, the author suggests a simulation based experiment to examine the effect of MAC parameters on the performance gain of WBSNs in environments where they experience high levels of internal interference, as an additional approach in order to improve the performance of co-existing WBSNs.

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