A Review on ZigBee Based WSNs: Concepts, Infrastructure, Applications, and Challenges

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***Abstract*—Wireless Sensor Networks (WSNs) are one of the most important technical fields that have gained a wide interest by various developers and leading industrial companies to use them in various applications, especially in the applications of monitoring electric power consumption as well as military and medical applications. The quick developments in these networks promise to revolutionize the way people live and thus help to overcome management and control issues as well as reduction of service costs. Although one of the essential features of WSN is its capability to work in a wide area network, the communication in such area could be noisy and present a challenge for the robustness of such systems. In this review paper, the concepts of WSNs are presented and discussed as well as discussing the most popular data transmission technologies used in WSN. The paper focuses on power monitoring applications in building environment and summarizes the recent studies in this field and the enhancements achieved and present the most important challenges faced in such applications. Finally, some conclusions and suggestions are drawn at the end of this paper.**

***Index Terms*—WSN, zigbee, power monitoring, wsn challenges, power consumption, noisy channel**

I. Introduction

WSNs are massive-scale sensor networks that were enabled due to the continuous improvements in wireless networking, embedded microprocessors, and integration and micro-fabrication. These networks can be adjusted to fit appropriately for a series of commercial and military applications [1].

In general, WSNs consist of multifunctional wireless sensing devices positioned over a wide geographical area. These devices form a distributed communication network which is capable of collecting data about the surrounding environment and collaborate effectively to process the collected data [2].

Modern WSNs consist of a large number of sensing devices that are cheap and linked together using low power communications such as IEEE 802.15.4 or ZigBee transceivers [3]. WSNs differentiate functionally from the usual collection of sensing devices by its network capabilities, which enable cooperation, coordination, and collaboration between sensing assets [3]. Additionally, instead of sending the raw data to the nodes responsible for the fusion, sensing nodes use their processing capabilities to perform simple local computations and transfer only the required and partially processed data [4].

In general, WSNs represent an important topic of study where many researchers tried to benefit from it to build various systems where control, tracking, or monitoring are involved such as smart grid [5]–[9], smart buildings [10]–[13], track cycling [14]–[16], localization [17], [18], smart alarm, energy monitoring, control, and management [19]–[27], health care [28], agriculture [29], and many other applications.

This review paper focuses on energy control and management applications in smart buildings due to its importance in the current literature and the pressing societal challenge of climate change and increases in the poverty/income rate.

To reduce the energy cost per household, one of the key solutions is to address the demand response problem via advanced solution techniques such as the implementation of the optimized appliance management models, the usage of available renewable resources, and precise forecasting system for both demands and resources. Also, an efficient fault detection and monitoring system will help to prevent accidental maintenance costs. Hence, an integrated and holistic intelligent solution in the built environment will both reduce the household cost and optimize the usage of grid energy to avoid the peak hours' demands.

Many studies were carried out in the field of electric power monitoring to find the best way of designing and implementing a functional system to reduce energy consumption or monitor the consumption or do both functions at the same time i.e., researchers aimed to reduce energy consumption in order to reduce the overall consumed power cost by implementing different systems capable of performing single or multiple functions such as monitor or control electric appliances power consumption in both houses and buildings. Where to reduce energy consumption and save costs in [30] authors presented an embedded WSN model system by monitoring the

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temperature in a building to use it in air conditioning management. Whereas, to monitor building electrical safety researchers in [13] proposed a cost-effective monitoring system based on ZigBee protocol which was enhanced by the addition of protective mechanisms, self-protection, and built-in temperature control for fire prevention as well as making it capable of dynamically setting the overload limit of the outlets and avoid the effects on other equipment in the same branch circuit when the outlet disconnects the power.

Furthermore, in [23] Valenzuela presented a multi-sensor system for energy consumption awareness in large, existing buildings that offers low-cost and low-installation real-time consumption values of all energy types. The main purpose of the system presented was to educate, motivate, and support people in saving energy and reducing their carbon footprint. Sensor data fusion was used to improve the quality of measurements while maintaining low costs. The presented multi-sensor showed that such a system of visualization does not have to be sophisticated and accurate. It has been demonstrated that the low-cost retroactive installation of real-time energy monitoring for all energy types used in a building is possible. The low cost and simple installation characteristics of the multi-sensor were achieved by integrating many sensors, limiting the electrical measurements to the AC currents of three-phase circuits, and assuming balanced loads and sinusoidal symmetrical voltages. The errors introduced were finally largely removed by combining and analyzing various sensor data.

On the other hand, in [21] and [26] authors aimed to reduce consumers' costs and improve grid stability. Where in [22] Gill *et al*. Authors have studied the design and development of an intelligent power control device that can monitor electrical parameters in households thus, the main function was to detect and control household electrical appliances using a smart sensor module and track different tariff rates. Similarly, in [27] Suryadevara *et al*. designed and developed an intelligent, real-time system that can control and monitor household appliances electrical parameters.

In addition to energy management in houses and buildings, Batista *et al*. [24] defined extensive field tests using ZigBee with open-source instruments to monitor photovoltaic and wind vitality systems. Their experimental results showed ZigBee's capability in dispersed renewable generation and intelligent meter systems. They also specified the infrastructure of the smart grid and the importance of intelligent metering. To address the most appropriate test procedures for the implementation of ZigBee technology, four contextual analyses were carried out. The experimental results collected have demonstrated the ability of ZigBee devices to monitor real-time information in conveyed renewable generation and smart meters, making them important, adaptable and powerful resources within a smart grid.

On the other hand, in [25] a WSN for energy monitoring was developed. The work had three goals. First, design and implementation of a WSN prototype for buildings power monitoring (and temperature). Second, to investigate coverage limits in various building construction materials. Third, to assess the amount of improvement introduced by channel coding methods to the ZigBee transceiver. A fully functional WSN of one BS and six end nodes were built and tested. The system is based on Arduino microcontrollers and ZigBee Transceivers. Many ways of displaying and controlling the system were used such as the GSM platform, onboard control, and GUI. The system proved to be functioning well, and good results were achieved.

Later, in [19] Blanco-Novoa *et al.* presented a smart socket system that records information about the supplied energy cost and makes use of sensors and actuators to rationalize home energy consumption depending on the user preferences. They claimed that the presented hardware prototype is the first to practically manage the price values collected from a public electricity operator in a real-world scenario. The novelty of the system lies in the Wi-Fi based WSN communications protocol, which enables an easy-to-deploy smart plug system that minimizing user intervention by self-organizing and auto-configuring the collected sensed data. They performed different experiments to validate the designed system performance in terms of the initial setup, configuration, access for third-party developers, smart socket scheduling system, and current monitoring features. Furthermore, the system functionality in both plain HTTP and HTTPS was tested and compared in terms of average energy consumption and processing time, showing that there are no significant differences in average energy consumption. However, the processing time required by HTTPS is approximately three times greater than that required by HTTP, which indicates the need for more efficient and lighter IoT device ciphering suites. Finally, the achieved results showed that for an energy-demanding appliance, power saving could be achieved up to 67.41€ per year.

It can be noted from the reviewed researches that two of the most important protocols used in such a monitoring environment are ZigBee and IEEE 802.15.4. However, WSNs used to monitor energy in buildings face different challenges. Some of the most critical challenges are noise and co-channel interference, where many researches tried to either investigate the performance of the WSN systems in such noisy environments or give solutions to these challenges, such as in [9]–[11], [31]–[44]. The aim was to improve the overall performance of WSN in terms of various aspects such as minimizing the power consumption of WSN to increase the lifetime of the battery-powered systems, enhancing the ability of the transmission protocol to handle co-interference and noisy channel environments, and other aspects.

To give the best understanding of the intended subject. Next sections will discuss the WSNs concepts, main infrastructure, transmission protocols and their infrastructure, why ZigBee is preferred over other known protocols, what challenges these systems to face, and finally, some conclusions and suggestions are drawn at the end.

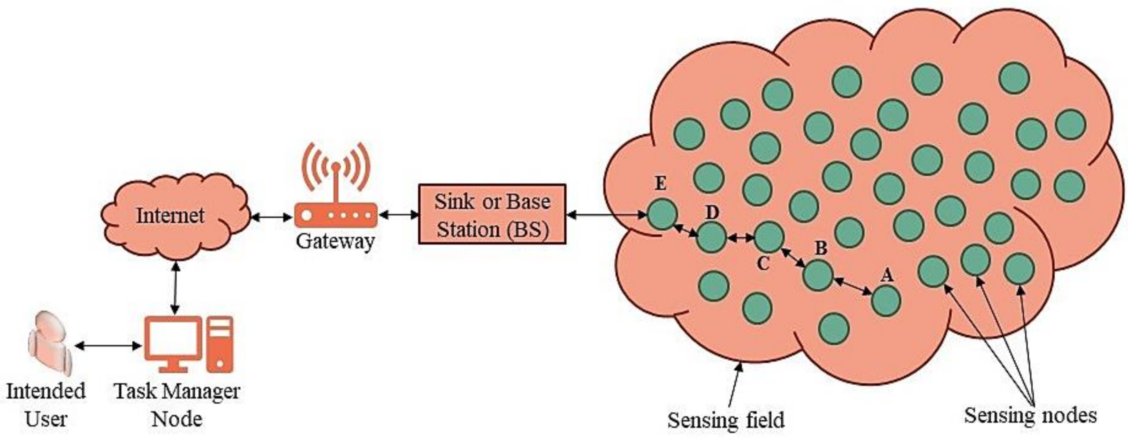

Fig. 1. Basic wireless sensor network.

II. WSN Concepts, Infrastructure, and Transmission Protocols

WSNs have emerged as highly flexible and dynamic facets that are popular for a wide range of applications worldwide. Thus, WSNs are diploid in almost every type of environment, whether rural, suburban or urban in nature, due to their efficiency in minimizing resources, low installation costs, environmental cleanliness, and many benefits, thus contributing to the three dimensions of sustainability: economic, environmental, and social [43], [45].

WSNs usually represent an ad-hoc network consisting of hundreds or thousands of sensor nodes (SNs) that are scattered over a vast geographical region, creating what is known as the sensing field, as shown in Fig. 1. These nodes cooperate to route packets of the sensed data to a particular node (known as the sink node or base station (BS)) [24], [46]. BS functionality is usually higher than basic sensing nodes since complex data must be processed. Thus, BS mainly has workstation/laptop class processors as well as sufficient memory, energy, storage, and computing power to perform its tasks well [25].

The BS is also responsible for communicating between the WSN and an external network, as shown in Fig. 1, e.g., the Internet, through a gateway where data is to be further processed then sent to the intended user. SNs are commonly deployed in hard-to-reach environments having limited processing, storage, transmission, and battery resources. It is painful to replace a SN in such places when it fails or when the battery is over, thus planning the deployment of the WSN is a crucial activity [47]. Also, communication between sensor nodes depends on the combination of various sensors from simple to complex, enabling WSNs to monitor a wide range of environments to obtain accurate field information [48].

Fig. 2 shows the infrastructure of a typical SN in a WSN where it usually contains a sensor (to sense the natural phenomenon in the surrounding environment), a processing unit (microcontroller and memory to collect, process, and store sensed data), a power unit (usually a battery to power the SN components), and a transceiver (to transmit collected data to BS or receive data (commands) from BS). On the other hand, a BS usually contains all parts of a SN except for a sensor where most base stations in a WSN does not have a sensor. Instead, most of the BS include onboard control unit (to control the network) and a data visualization unit (to visualize the collected data from SNs) as shown in Fig. 3.

Wireless protocols (transceivers) are the most important component in a WSN, which specifies how nodes can communicate with each other and defines many unique features that make WSN practical and preferable over other technologies. There are many wireless protocols used in a WSN, and each provides specific features that fit in a wide range of applications. Table I shows a comparison between some of the most popular wireless protocols in terms of frequency of operation, data bit rate, modulation methods, maximum range, power level, applications, key features, and network configuration.

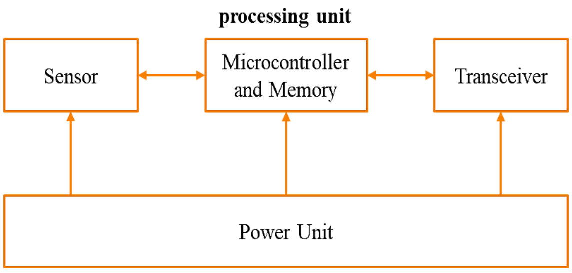

Fig. 2. A typical SN infrastructure in a WSN.

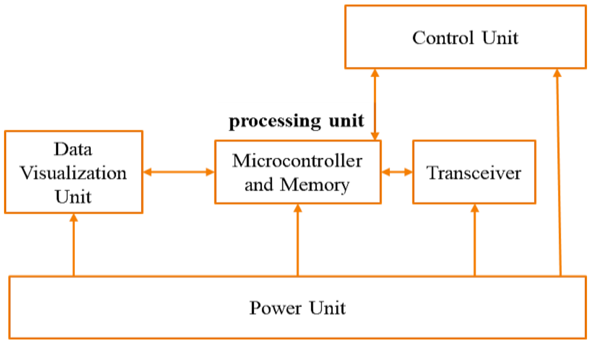

Fig. 3. A typical BS infrastructure in a WSN.

TABLE I: COMPARISON BETWEEN SOME WIRELESS PROTOCOLS [48]-[51].

Feature	ZigBee	Wi-Fi	Bluetooth	802.15.4	Sigfox	LoRa	LTE-M1	NB-IoT
Frequency of Operation	868MHz 915MHz 2.4GHz	2.4GHz 5.8GHz	2.4GHz	868MHz 915MHz 2.4GHz	868MHz 915MHz	915MHz	Cellular Band	Cellular Band
Bit Rate	20, 40, 250Kbps	11Mbps up to 7Gbps	1Mbps up to 3Mbps	20, 40, 250Kbps	600bps	50Kbps	1Mbps	250Kbps
Modulation Method	DSSS with DBPSK or OQPSK	DSSS, OFDM	FHSS with GFSK, π/4-DQPSK, or 8DPSK	DSSS with DBPSK or OQPSK	UNB with GFSK, or DBPSK	SS Chirp	OFDM	OFDM
Range (m)	10-100+	200	10-100	10-100	1000+			
Power Level	0.5, 1 (typically), 100mW	100mW-1000mW+	100, 2.5, 1, and 10mW for class 1, 2, 3, and BT smart respectively	1mW	10uW-100mW	25mW+	100mW	200mW+
Application	Consumer, Industrial	Consumer, Commercial, Industrial	Consumer	Consumer, Industrial	Industrial	Industrial	Industrial	Consumer, Industrial
Key Characteristics	Uses IEEE 802.15.4 for PHY and MAC, Short range, low data rate, Low power consumption, License-free spectrum	Short range, high data rate, license-free spectrum.	Short range, Low power consumption, Single chip implementation, license-free spectrum	Short range, low data rate, Low power consumption, License-free spectrum, represents the basis for many advanced wireless standards	Long Range, Low data rate, Low power consumption	Long Range, Low data rate, Low power consumption	Long Range, Low power consumption	Long Range, Low data rate, Low power consumption
Network Configuration	Point to Point, Star Topology, Mesh Topology	Point to Point, Star Topology	Point to Point, Piconet with up to 7 Nodes, Support Star Topology	Point to Point, Star Topology	Star Topology			

However, for indoor monitoring applications where long-range communication is not a requirement, such as in power monitoring, control, and management, ZigBee is preferred in many carried out researches in the literature. This is due to its unique features as can be seen in Table I where it uses the IEEE 802.15.4 communication protocol as a baseline and adds additional features to it such as mesh networking topology which is perhaps one of the most essential features that make ZigBee preferable where mesh topology makes ZigBee based WSN more robust, scalable, and a self-healing network.

Despite the interesting features and promising solutions provided by WSNs especially ZigBee based WSNs, these networks face different challenges that may affect the performance of the network. Many researches were carried out trying to deal with a specific challenge in WSN. The next section will provide an overview of the most important challenges and studies carried out to solve or deal with some of these challenges.

III. WSN IMPORTANT CHALLENGES

WSNs face several challenges that need to be considered during the design and deployment of WSNs. Most of these challenges are related to communication protocols used in WSNs, especially ZigBee, and the most important challenges are as follows.

A. Limited Battery Power (Limited Power Resources)

Most of the WSNs are battery powered, which limits power resources and thus requires ways to maximize the average lifetime of the nodes in a WSN, especially in those applications where deployed nodes are hard to reach in case of battery failure. Many researches were carried out to find ways to maximize battery powered WSNs and to efficiently manage power resources mainly focusing on how to reduce power consumption of the communication protocol used in the WSN which dissipates most of the power during Tx/Rx of data such as in [15] where Gharghan, Nordin & Ismail proposed an energy-efficient transmission method known as the sleep/wake algorithm for a bicycle torque sensor node. The study aimed to emphasize the trade-off between energy efficiency and the communication range between the cyclist and coach. It conducted two experiments where ZigBee (XBee S2) protocol was utilized in the first experiment, and the Advanced and Adaptive Network Technology (ANT) protocol based on the Nordic nRF24L01 radio transceiver chip was used in the second experiment. Also, ANT current consumption was measured and simulated as well as comparing it to the XBee S2 based torque sensor node.

Furthermore, to correlate the sensor node average current consumption with a crank arm cadence, an analytical model was derived. The results showed that 98% of power savings were achieved for the ANT protocol compared to ZigBee, while 30% power saving was obtained for all components of the sensor node. Also, results showed that for outdoor cycling track a communication range of about 50m and 65m was achieved for ANT and ZigBee protocol, respectively. They concluded that when power consumption is a crucial demand in a torque sensor node, then ANT protocol is preferred over ZigBee protocol whereas the latter is more suitable in ensuring data communication between cyclists and coaches.

On the other hand, in [39], authors designed a new channel access mechanism for the buffer constraint sensor devices in an IEEE 802.15.4e based WSN aiming to reduce the packet drop rate, collision, and power consumption of the node. The achieved results indicated that their scheme significantly improved energy consumption as well as packet drop rate, throughput, reliability, and average delay of nodes.

Similarly, to reduce energy consumption and collisions in IEEE 802.15.4 networks, authors of [33] introduced a network allocation vector (NAV). The NAV data is transmitted within the beacon frame to enable PAN nodes to retain their energy for the remaining NAV period. In saturated traffic, a Markov chain-based analytical model of the fragmentation mechanism and an energy consumption model using the NAV mechanism were given. The results showed that the fragmentation technique simultaneously improves throughput, access delay, and bandwidth occupation. The results obtained also revealed that the use of the NAV significantly reduces the energy consumption in slotted CSMA/CA under saturated traffic conditions.

Furthermore, in [47], the authors presented an integrated evaluation solution for WSNs in terms of power consumption and reliability. The evaluation of the solution proposed included an experimental assessment to validate the models proposed, indicate how the sensitiveness analysis helps in selecting the best WSN configuration, and assess the effect of these suggestions on energy consumption analysis. The proposed solution enables the precise automated estimation of the power consumption of WSN applications and network stacks.

B. Noisy Channels, Co-Interference, and Network Coverage

Wireless protocols operate in different channel environments, which can be noisy and represent a challenge for WSN robustness in such channel conditions, especially in the harsh indoor channel environment where AWGN, Rayleigh, and Rician multipath fading is a critical issue to overcome. Another challenge is the co-channel interference due to other devices operating in the same frequency band, especially the popular 2.4 GHz band which is mostly used by WSNs and other devices. These challenges mainly affect the performance of the WSN and reduce the overall system coverage.

Most of the wireless protocols cannot correct errors, and thus some researches were carried out to solve this problem. In [10] Zhan *et al.* proposed to combine forward error correction (FEC) within the media access control (MAC) layer of the IEEE 802.15.4 standard for packets transmission. They aimed to avoid the time and energy consuming mechanism (namely the automatic repeat request (ARQ) mechanism) used by WSNs in the noisy wireless channel scenarios within the smart building environment. They have investigated the performance of convolutional codes (CCs), Reed-Solomon (RS) codes, and their concatenated codes in terms of bits error rate (BER) and packets error rate (PER) using the developed CPS simulation platform and was applied to different code rates and packet lengths. The achieved results showed that in most cases CCs proved to be superior compared to other codes. They also found that for longer packet RS codes with larger symbol length are preferred. Furthermore, the result also showed that RS and CCs concatenated codes are good candidates. As future work, they suggest considering the non-line-of-sight wireless channel and the pulse interference from other devices.

Also, in [38] Romia, Ali & Abdalla proposed to incorporate a recursive least square (RLS) based adaptive linear equalizer (ALE) to the physical layer of the receiver side aiming to improve the ZigBee performance in harsh transmission channel effects. They investigated the performance of the system for different multipath fading channels, including Rayleigh and Rician. Moreover, they proposed a methodology for deciding design parameters of the RLS based ALE's where these parameters are chosen to obtain the best performance in terms of BER and convergence response time. The design procedure is based on solving multiple objectives optimizing function using genetic algorithms (GAs). Finally, for verification purposes, the designed system was also modeled and tested in MATLAB Simulink as well as comparing the performance of the RLS adaptation algorithm with the least mean square (LMS) one. According to the achieved results, they found that the RLS based ALE was able to remove the inter-symbol interference and recover the original signal efficiently with least BER concluding that the RLS algorithm offers the best ZigBee performance with least BER and fast convergence compared with the LMS technique.

Aiming to reduce the packet drop rate, energy consumption and collisions in the buffer constraint sensor devices in [39] Sahoo, Pattanaik & Wu designed a new channel access mechanism which includes a new frame structure, a new superframe structure, and a modified superframe structure with a new retransmission opportunity. These designs lead to 1) avoiding collision due to the hidden terminal problem, 2) mitigating the problems due to Wi-Fi and ZigBee interference, and 3) reducing the collisions and retransmission delay with high reliability respectively. According to the performance evaluation and validation of their design, they indicated that significant improvements could be achieved in terms of throughput, packet drop rate, energy consumption, reliability, and average delay of the nodes.

Using the Monte Carlo simulation method in [40], Pesovic and Planinsic determined the spatial probability of k-tuple mutually hidden nodes. In the context of the error probability of IEEE 802.15.4 communication, they examined the impact of co-channel interference (CCI) and derived exact analytical models that took into consideration non-ideal popular characteristics of the used spread-sequences. Numerical Monte Carlo simulation for IEEE 802.15.4 communication examined the accuracy of the derived mathematical models and used IEEE 802.15.4 transceivers to create CCI in a real-world experiment. The researchers found consistency with the proposed analysis error models. They also showed numerical results on the likelihood of the occurrence of several mutually hidden nodes, which show that double-hidden node collisions are most common. In the IEEE 802.15.4 CCI networks, a model for the probability of a chip error was also derived for two nodes hidden in an AWGN channel. Moreover, a numerical simulation of the IEEE 802.15.4 CCI Communication was carried out in an AWGN channel, which shows clearly that the analysis models presented in all error probability parameters are very well matched to the results of the simulation. However, some differences were caused by a poor synchronization of the preamble with low SNR.

In [41] authors introduced a simulation model that fully reflects the coexistence of ZigBee and Wi-Fi and proposes a frequency agility-based interference avoidance algorithm. The algorithm detects interference and adapts nodes to a safe channel so that WLAN interference with lower latency and energy consumption is dynamically avoided. They assessed ZigBee performance under Wi-Fi empirically in terms of the packet error rate (PER) and bit error rate (BER). Simulation results using the frequency agility algorithm show that the design guideline can effectively reduce the impact of Wi-Fi interference and to improve ZigBee's performance. The results also show that Wi-Fi can interfere seriously with ZigBee and that the use of ZigBee can be guided by a secure distance and offset frequency. Finally, 8 m from the ZigBee to Wi-Fi was shown to be a safe distance to ensure the reliable performance of ZigBee irrespective of the offset frequency, while 8 MHz is a secure offset frequency even if the distance is only 2 m. The algorithm also enhances ZigBee's performance to provide robust and reliable service in conjunction with Wi-Fi.

In [42] the authors presented a model to analyze the problems of propagation and coexistence in WSN and presented the results of the measurements on indoor propagation, microwave interference (MWO) and its impact on WSN performance. The measurements of propagation show a significant influence of the multipath, i.e., changing the node position with a few centimeters or changing the communication channel can lead to a difference of up to 30 dB in the received power. The power leakage of MWO was observed at 1 m distance to the oven at around-20dBm, leading to additional IEEE 802.15.4 messages retries which match the simulation results, i.e., the success rate of the packet first attempt decreases to 30-40 percent increasing the average active time of the sensor closely located to the MWO. Finally, they noted that the MWO ON/OFF pattern could be used by WSNs to improve performance.

In [43] Kleinschmidt has used the IEEE 802.15.4 ARQ schemes and proposed custom coding with BCH codes. The performance was analyzed by simulation using the parameter of energy efficiency. The results for multihop networks with different channel conditions and packet sizes are obtained, showing that the ARQ scheme and BCH codes are energy efficient for networks with a high hop count and low Signal-to-Noise Ratio (SNR) values. Kleinschmidt also found that the use of FEC or ARQ is not necessary for good channel conditions (SNR above 25 dB) and few hops where under these conditions, the use of CRC code only for error detection is the best option, while retransmission must be used for more hops and SNRs under 20 dB. However, Kleinschmidt concluded that error control coding reduces the probability of packet error, but due to the extra energy consumed it must only be used in adverse channel conditions. Longer packages with more data also benefit from FEC's use compared to smaller packages.

In [44] authors considered a simple block error correction code to be used in IEEE 802.15.4 based sensor nodes such as cyclic and Bose Chaudhuri Hocquenghem (BCH) codes. Simulations were carried out to measure network parameters such as energy spent per bit and BER in Rayleigh fading channel environment. The analysis was performed over an uncoded network for different code rates for both BCH and Cyclic codes. Error control techniques with the same coding gain were selected to determine the optimum choice of FEC for IEEE 802.15.4. Based on the results, it has been found that BCH code with a coding rate of 0.8 gives 1.6 dB coding gain compared to Cyclical and ARQ systems and is an energy efficient code among the codes considered.

In [31] authors have reposted a Bit Error Rate (BER) analysis of the WSN consisting of SNs based on an RF transceiver of IEEE 802.15.4. Closed-form expressions for BER are obtained for WSNs that operated on AWGN, Rayleigh, and Nakagamim fading channels. Furthermore, they derived BER analytical expressions for the connection of sensor nodes as a transmission unit with a base station without the effects of wireless interferes being considered. Numerical results of BER is obtained by changing specific physical layer parameters of the IEEE 802.15.4 standard, such as the number of bits used to represent a Zigbee symbol, the number of levels of modulation used in a modulator of the OQPSK system, and the various fading (α and m) parameters of Rayleigh and Nakagami-m. Based on the results achieved, WSN's error performance analysis showed improvement when less bits are employed as representing a Zigbee symbol under a fading channel specifically Rayleigh that reflects a WSN environment in real time and the network only performs better when running at high SNR values, i.e., BER of order 10^{-2} is achieved when SNR is between 5 and 15 dB. Furthermore, the impact of fading parameters on Network performance also reveals that for higher α and m values for the fading channels of Rayleigh and Nakagami-m, better results are obtained.

WizBee, a single antenna sink coexistence system with no change in the current Wi-Fi and ZigBee design, was introduced in [32]. It was based on the conclusion that the Wi-Fi signal in the symmetrical area is about 5 dB to 20 dB stronger than the ZigBee Signal, which leaves room for interference cancelation to mitigate Wi-Fi interference and to receive ZigBee Signals. However, Wi-Fi interference must be canceled correctly for residual ZigBee signal decoding, which requires a more accurate channel coefficient throughout data transmissions despite cross-technology interference. For sturdy and precise Wi-

Fi decoding, they used soft Viterbi with a weighted confidence value over interfered subcarriers. They also used decoded data to estimate the channel coefficient instead of conventional symbol-based training methods. The key insight is that the opportunity for signal recovery for the coexistence of cross-technology lies in multi-domain information such as power, frequency, and coding differences. Using this information accurately, the coexistence network throughput will improve effectively. They implemented WizBee in the USRP/GNURadio Software Radio Platform and studied interference cancelation technique decoding performance. Extensive evaluations under real wireless conditions have shown that WizBee increases ZigBee throughput to 1:9x with a median throughput increase of 1:2x. WizBee's key insight is that it can use cross-technology to recover the signal effectively. Finally, iterative decoding and cancelation schemes can recover the interfered signals by utilizing multi-domain information such as power, frequency, and coding discrepancy.

In [35] authors proposed to balance the load and prevent ZigBee based WSN congestion a new routing system called SMQP (Statistical Multipath Queue-wise Preemption). That was done with statistical route planning and queue-wise preemption on multiple routes from a source to a target node. NS2 simulations showed that in terms of delivery ratio, end-to-end delay, and packet delivery ratio, QoS was substantially improved with the proposed scheme in comparison with WSN routing schemes such as ad-hoc on-demand distance vector and ad-hoc on-demand multipath distance vector.

In [11] the authors analyzed a home Internet-of-Things system by dividing it into four layers (namely the node, the gateway, the service, and the open layers). The gateway layer, which supports a variety of wireless technologies and is the core of the home wireless network access unit, along with the node layer, forms the home wireless network. A gateway prototype has been implemented following the proposed architecture. A testbed for a wireless interference network, including the gateway prototype, was also created to test its user interaction performance. The experimental results have shown that Wi-Fi and Bluetooth affect ZigBee communication. Given the complex home and building scene, ZigBee multi-hop communications reduce the probability of packet loss. Also, an event-level transmission control strategy is proposed, in which the probability of packet losses on the wireless network is reduced by controlling the transmission priority of different monitoring event levels and optimizing the occupancy of the ZigBee wireless channel.

A new in-band narrow-band interference (NBI) elimination scheme is proposed in [36] to solve in-band interference problems for Ultra-WideBand (UWB) WSN. A new complex-coefficient adaptive notch filter unit with a single, restricted zero-poles pair is used as a basis for the proposed narrowband interference suppression system. Also, it is designed to reduce the computational complexity of the proposed system through an adaptive, complex-coefficient, iterative method based on the two-order Taylor series. Furthermore, to deal with multiple narrowband interferences, a linear cascaded high-order adaptive filter and a cyclic high-order matrix adaptive filter (CCHOMAF) based on the basic Adaptive Notch Filter Unit were also presented. The theoretical analysis and numerical simulation results showed that the proposed CCHOMAF algorithm could improve the average bit error rate performance of UWB WSNs. Also, the proposed NBI removal system can substantially improve the receiving performance of low-cost and low-power UWB wireless systems.

In [37] Ding and Song presented the development and coverage evaluation of a ZigBee-based wireless network application where a stack structure node available for home service integration is proposed, and all data of sensing nodes with an adaptively weighted fusion (AWF) processing are passed to the gateway and through the gateway to re-execute packet processing and then reported to the monitoring center, which effectively optimizes the wireless network to the scale of the data processing efficiency. The linear theory of interpolation is used to evaluate the work status of each node and the entire network coverage case for a background graphical user interface. A testbed for validating the fundamental functions of the proposed ZigBee home network system has been designed. Furthermore, the capabilities of network coverage were tested, and the packet loss and power saving of the proposed system were also verified during long-term wireless network monitoring tasks. Experimental results show that the testbed is sufficiently convenient for the coverage and monitoring of wireline networks and that each node can display its working state visually.

C. Quality of Service (QoS)

QoS is an important parameter that specifies the overall performance in any WSN in terms of different factors such as response time, packet drop rate, packet delivery ratio, transmission delay, and throughput. Thus, analyzing QoS parameters represents a challenging task in WSN design which is directly related to other constraints and challenges that affects the system performance.

Where aiming to analyze the QoS parameters in ZigBee network, authors in [52] implemented a ZigBee Network based on node priority, which demonstrates a method to generate a new priority of devices with respect to their existing priority and zones' priority as well. They analyzed QoS based on the new priority status for task preference purposes. The results were obtained by performing a simulation study. The achieved results showed that the QoS of the network is more conspicuous than the non-priority based network.

Authors in [9] proposed a smart distribution power grid architecture with Cyber-Physical System (CPS) enabled micro-grids that meet almost all smart distribution power grid functional requirements. They have also presented a six-tier communication topology derived from the architecture for a smart distribution power grid for an easy transition to an optimal communication architecture. The optimization formulations for each packet structure in the paper minimize the total cost and consider the QoS requirements for each packet. Based on the results of the simulation, the authors made recommendations for optimal communication technologies for each packet (such as Zigbee, Wi-Fi, Cellular, and Powerline Communication) and developed a heterogeneous microgrid communication architecture.

Also, in [34] the authors propose a Radio Aware Channel Assignment (Ra-CA) mechanism based on a direct graphics model for interference mitigation in multi-channel multi-radio networks. The co-located radio interference is initially identified by classifying non-interference links for simultaneous network transmission. The channel allocation mechanism proposed helps to allocate the minimum number of channels to the network that mitigate co-located radio interference. Compared with other existing techniques such as Breadth First Search-Channel Assignment (BFS-CA) and Maximum Independent Set Channel Assignment (MaIS-CA), the performance analysis of the proposed Ra-CA strategy is carried out in multi-radio networks. The simulation results showed that the proposed channel assignment scheme is more efficient in terms of QoS parameters such as packet drop rate, packet delivery ratio, transmission delay, and throughput compared to existing ones.

D. Localization and Distance Accuracy

For location-based WSN applications, localization accuracy represents a significant challenge that has gained attention from various researchers.

Thus, aiming to improve localization and distance measurement accuracy of WSN used in track cycling applications authors in [17] proposed two soft computing localization techniques (Neural Fuzzy Inference System (ANFIS) and Artificial Neural Network (ANN) which was hybridized individually with three optimization algorithms namely Particle Swarm Optimization (PSO), Gravitational Search Algorithm (GSA), and Back-tracking Search Algorithm (BSA)). These two techniques emphasis on the received signal strength indicator (RSSI) measurement carried out from the three ZigBee anchor nodes scattered throughout the track cycling field. They aimed to estimate the distance between bicycles moving on the cycle track for outdoor and indoor velodromes. The achieved results showed that the hybrid GSA-ANN performance is the best compared to other methods in terms of accuracy localization and distance estimation accuracy as well as achieving a mean absolute distance estimation error of 0.02 m and 0.2 m for outdoor and indoor velodromes respectively. The results indicate that GSA-ANN is appropriate in both indoor and outdoor environments and applicable to any static or mobile WSN node. However, the study has a drawback, which lies in the possibility of implementing such a technique in real time where ANN requires a considerable amount of memory. To solve this issue, a microcontroller with high speed and large memory size like Arduino Due is required which results in high power consumption, large size, and extra weight, all of which are considered critical issues in bicycle sensor nodes. They expect that these challenges can be avoided in the future once quantum computing is in place.

On the other hand, in [18] authors used the Received Signal Strength (RSS) based algorithm for position estimation. The algorithm uses gaussian and averaging filters for distance estimation, whereas it uses trilateration and least square estimation for localization. They used IRIS motes from MEMSIC for the experiments and were configured in real time to record the RSSI. Furthermore, the effect on distance estimation and localization was studied in an indoor environment by conducting several experiments. The achieved simulation results showed that the proposed sensor selection, distance estimation based on RSSI as well as localization method helps in improving the accuracy of position estimation in different environmental conditions.

IV. Conclusions

In this review paper, some of the recent power monitoring, control, and management systems were reviewed and discussed. The review shows the importance of such applications and overviews the development in this field of study. This review aimed to study such monitoring systems and specify the challenges and issues as indicated by many researchers where these challenges need to be avoided during the design and deployment of WSNs.

Communication protocols represent the most important component in any WSN where many researches are carried out to either investigate the performance of these wireless protocols or to enhance their performance in terms of different aspects such as power consumption, error correction capability, QoS, etc.

Through the literature, it can be concluded that noise and co-channel interference represents the most important challenge, especially for ZigBee based WSNs. Although that some researches were carried out to overcome noise, most of these solutions increase the power consumption of the transceiver itself, which represents a critical issue and one of the most important challenges affecting sensor lifetime, especially in those applications where power resources are limited. Also, most of these solutions are simulation-based and have not been validated practically.

Thus, there is a considerable demand to design an improved WSN communication protocol that considers all challenges and improves the overall system performance without affecting the essential features of a WSN such as low power consumption and low cost.

On the other hand, there is also a needs to study ways of improving estimated coverage accuracy for both indoor and outdoor WSN taking into consideration wireless channel characteristics in such an environment for better planning of sensing nodes deployment, especially for long-range communication protocols.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Haider A. H. Alobaidy and J. S. Mandeep initiated the study and prepared the review conception/design; Haider A. H. Alobaidy prepared the literature and wrote the manuscript; J. S. Mandeep, Rosdiadee Nordin, and Nor Fadzilah Abdullah revised the manuscript critically before submission; Haider A. H. Alobaidy and Rosdiadee Nordin revised the manuscript according to reviewers comments and prepared it for final submission; all authors had approved the final version to be published.

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