

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Wireless Sensor Networks: Applications and Challenges

*Kingsley Eghonghon Ukhurebor, Ituabhor Odesanya,
Silas Soo Tyokighir, Rout George Kerry,
Akinola Samson Olayinka and Ayodotun Oluwafemi Bobadoye*

Abstract

Wireless sensor networks (WSNs) allow innovative applications and involve non-conventional models for the design of procedures owing to some limitations. Due to the necessity for low device complication and low consumption of energy, an appropriate equilibrium among communication and signal processing abilities should be instituted. This stimulates an enormous effort in research actions, standardisation procedure, as well as manufacturing investments on this aspect since the preceding years. Therefore, this chapter aims at presenting a summary of WSNs machineries, foremost applications and values, structures in WSNs project, and the developments drawn from some evidence and meta-data-based survey and assessments. Precisely, some applications, such as those based on ecological monitoring, and design approaches that emphasise a real implementation are discussed briefly. The trends and conceivable developments are outlined. Emphasis is given to “the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 technology” that enables several applications of WSNs. Hence, it is anticipated that this chapter would serve as an introductory aspect on the applications and challenges of WSNs for persons interested in WSNs.

Keywords: applications, device, IEEE, models, technology

1. Introduction

Presently, wireless sensor networks (WSNs) have created a growing attention from researchers and other stakeholders both in the industries and governments sectors [1–11]. Generally, WSN could be defined as a small system of nodes which accommodately sense, monitor, capture, process and control situations such as data/signals around an application, supporting dealings between peoples/computer systems and the immediate surrounding [12–14]. Hence, these nodes are resource-deprived and simultaneously very dependent on battery control, storing capacities, multiplication, size of data/signals and available bandwidth [7, 14]. Ordinarily, these nodes are static in a specific way and are left as a sole node in an isolated and human-remote point to implement tracing and recording of data.

The term wireless has turned into a generic and extensively comprehensive term employed to describe communications in which electromagnetic waves (EMWs) are employed in sending signal to several or the entire path of the communication [15].

According to Tiwari et al. [16], wireless networks (WNs) are any category of computer system that applies wireless statistics networks to plug system nodes. They are computer systems which are usually not connected by cables irrespective of the category. The application of a wireless system aids enterprises to avoid the expensive means of making use of cables for buildings or connecting different equipment settings. The basis of any wireless systems is the radio waves/microwaves, and their application that ensues at the physical advanced level of network construction both for radio waves/microwaves, radio communications systems (RCSs) and other relevant EMWs [17–20]. These radio waves/microwaves, RCSs and other relevant EMWs as well as mereological variables are useful in the propagation of the refractivity indices in the atmosphere [21–25].

Even if WSNs have been reported to have all it takes to allow innovative applications and by so doing contribute greatly to the innovative potential markets, there is also some possibility that the design of some WSNs is affected by several limitations which call for innovative models. According to Verdone [13], the action of detecting, processing and communication under restricted quantity of energy, explodes a cross-layer design method that characteristically necessitate the combined contemplation of circulated data/signal processing, intermediate access control and communication procedures.

Wireless machineries vary in several dimensions, most remarkably in what extent is the bandwidth they offer and the extent of the distance between the communicating nodes. Other vital differences which are included are possibly the electromagnetic fields (EMFs) they indicate and precisely the extent of the power they consume; this is greatly significant to mobile nodes [16]. As reported by Tiwari et al. [16], the four prominent wireless technologies are; “third-generation or 3G cellular wireless, Bluetooth (802.15.1), WiMAX (802.16) and Wi-Fi (more formally and generally known as 802.11).”

Presently, one of the utmost conventionally employed WSNs links is typically asymmetric; implying that both endpoints are typically categories of nodes [16]. Occasionally, one endpoint is called the base-station (BS), usually without mobility, but with a wired (or at top high bandwidth) connected to other networks such as internet. The node at the reverse end from the connection since a “client node” could habitually be transportable and employs its link to the BS for its communication with other nodes [11].

WSNs have grown substantially over the years and have a momentous potential in diverse applications in areas of environmental science, medical sciences, telecommunications, education services, agriculture, surveillance, military services, etc. [3, 26–29]. It has been reported that notwithstanding the influential capabilities of WSNs, their effective development is still somehow stimulating and challenging [1–3, 26, 28, 30, 31]. Presently, in deploying WSNs, some programming procedures have been anticipated, which emphasis mostly on issues of low-level-based (LLB) systems. However, for the simplification of the design of WSNs and abstract from technological LLB specifics, high-level-based (HLB) methods have been developed and some advantageous resolutions have been anticipated [3].

Hence, in this chapter an attempt will be made at presenting an overview of WSNs machineries, some of the primary applications and values, structures in WSNs project, developments and challenges drawn from some evidence and meta-data-based survey and assessments, which is anticipated to serve as an introduction on the applications and challenges of WSNs for persons interested in WSNs.

2. Categories of wireless networks

According to Tiwari et al. [16], there are essentially five categories of WNs as illustrated in **Figure 1**.

A brief description of these essentially five categories of WNs are high-lighted below.

2.1 Wireless personal area network (wireless PAN)

This is a WSN that is carried over a low-powered, short-distance WN technology such as Bluetooth network, IrDA, wireless USB or ZigBee. The reach of a wireless PAN differs from a few metres to a few kilometres.

2.2 Wireless local area network (wireless LAN)

This is a WSN or wireless computer network (WCN) that links or connects two or more devices by means of wireless communication (WC) to form a LAN within a restricted location such as a computer research laboratory, household, institution, or workplace. This gives users the capability to move from place to place within the said location and remain connected or linked to the WN. Wireless LAN could also offer a connection to the wider cyberspace (internet) through a gateway. Most contemporary wireless LANs are based on the standards of IEEE 802.11 and are marketed under the Wi-Fi product designation. Wireless LANs have become prevalent for use in the several households, as a result of their ease of installation and use. They are also prevalent in commercial physiognomies that offer wireless access to their workforces and clients.

2.3 Wireless metropolitan area network (wireless MAN)

This is a computer network (CN) that communicates and interconnects users with various computer resources in a geographic location of the size of an urban area. The term MAN is applied to the interconnection of LANs in an urban area into a single greater network which could similarly offer effective connection to a wide area network (WAN). Wireless MAN is also used in describing the interconnection of several LANs in an urban region via the use of “point-to-point connections” between them [32].

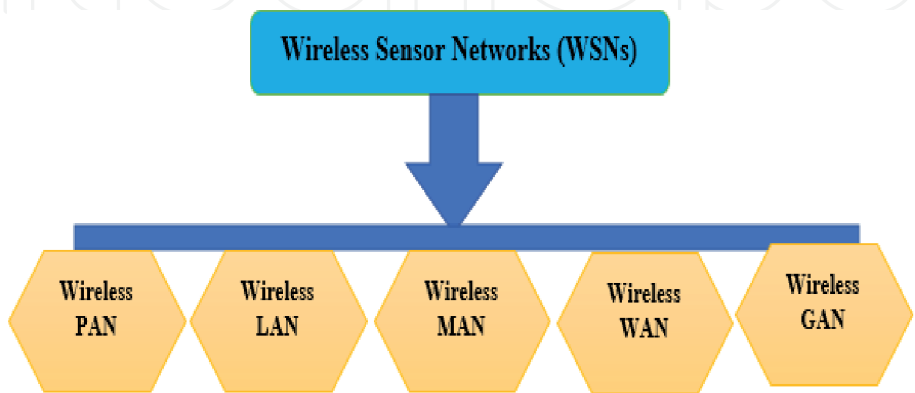


Figure 1.
Categories of WNs.

2.4 Wireless wide area network (wireless WAN)

This is another form of WN. The greater size of a WAN compared to a LAN entails the modifications in technology. WNs of diverse dimensions deliver data in the form of web pages, telephone calls and streaming video. A wireless WAN often differs from wireless LAN by using mobile telecommunication cellular network (MTCN) machineries such as 2G, 3G, 4G LTE, and 5G in transferring data. Wireless WAN is sometime called mobile broadband (MBB). These machineries are existing nationally, regionally, or even globally and are provided by a wireless service provider (WSP). Wireless WAN connectivity permits a user with a CN and a wireless WAN card to surf the network, check electronic mail, or connect to a virtual private network (VPN) from somewhere within the boundaries of WNs. Several CNs could assist in the integration of wireless WAN proficiencies. A wireless WAN could also be a closed network that covers a huge geographic location. For instance, a “mesh network or MANET” with nodes on towers, trucks, planes and buildings. It could also be a “low-power, low-bit-rate (LBR) wireless WAN, (LPWAN),” proposed to carry minor packets of information between things, habitually in the form of battery-operated sensors. Since the RMSs hardly offer a physically protected connection path, the wireless WANs characteristically integrate “encryption and authentication” approaches to make them more protected. Reportedly, several early GSM encryption procedures are imperfect, and security professionals have issued cautions that MTCN, including wireless WAN, is not that secure [32].

2.5 Wireless global area network (wireless GAN)

This refers to any network that is composed of diverse interconnected CNs (WANs) and also covers an unrestricted geographical location. It is apprehensively identical with Internet, which is considered as a GAN. Unlike LANs and WANs, GANs cover a much larger geographical area. Since GANs are used for supporting MTCNs across a number of wireless LANs, one of the main challenges for any wireless GAN is in transferring of the user communications from one LAN to another. One of the utmost popular wireless GAN categories is a broadband (BB) wireless GAN. The BB wireless GAN is a worldwide satellite Internet network (SIN) that employs transferrable terminals for telephony. The terminals connect CNs located in LAN to BB Internet.

3. The IEEE 802.15.4 technology

The “IEEE 802.15.4 wireless technology” is a “short-range communication system” which is planned to offer applications with comfortable throughput and potential necessities in Wireless PAN [4]. The main features of the “IEEE 802.15.4 wireless technology” as reported by Buratti et al. [4] are; inexpensive, truncated complexity, low consumption of power, truncated transmission data rate, to be maintained by inexpensive either fixed or moving means. One of the foremost fields of applications of this technology is the implementation and execution of WSNs.

The “IEEE 802.15.4 Working Group (the IEEE 802.15.4 Working Group) as noted by Buratti et al. [4], emphasizes on the standardization of the lowest two layers of the “ISO/OSI protocol stack” [33]. There are two possibilities for the higher layers characterisation, viz.; Zigbee protocols, specified by “the industrial consortia ZigBee Alliance (the industrial consortia ZigBee Alliance) and 6LowPAN. Some technical specifics interrelated to the “physical and MAC layers” as well-defined in the standard

are would be briefly discussed [34]. Also, some physiognomies interrelated to advanced layers would be presented, bearing in mind the “Zigbee and 6LowPan,” with specific consideration to the former [35].

3.1 The physical layer of the IEEE 802.15.4

Buratti et al. [4] in their study reported that “the IEEE 802.15.4” main system comprises of a “radio frequency (RF) transceiver and the procedure stack,” as illustrated in **Figure 2**.

According to Buratti et al. [4], the “802.15.4 physical layer” functions basically in three diverse unrestricted/unlicensed bands (as well as with the diverse modalities) in respect to the geographical location where the system is positioned or installed. Nevertheless, spread spectrum procedures are somewhere required for the reduction of the interference extent/range in shared unrestricted/unlicensed. The “IEEE 802.15.4” requires a total of “27 half-duplex channels” transversely on the three frequency bands. The organisation is as follows:

- **The 868 MHz band:** This is just a channel with data rate availability of 20 kbps, with -92 dBm RF sensitivity essential and superlative (ideal) transmission extent is roughly 1000 m
- **The 915 MHz band:** This has ten channels with rate availability of 40 kbps; the receiver sensitivity and the superlative transmission extent are also roughly 1000 m;
- **The 2.4 GHz ISM band:** This has sixteen channels with data rate availability of 250 kbps, with minimum -85 dBm RF sensitivity essential and superlative transmission extent of 220 m.

The superlative transmission extent is calculated bearing in mind that, even though any legitimately suitable power is allowed, the “IEEE 802.15.4-compliant devices” ought to be capable of communicating and transmitting at -3 dBm. Giving, the energy efficiency challenges, short rate and short duty cycle are given. The “IEEE

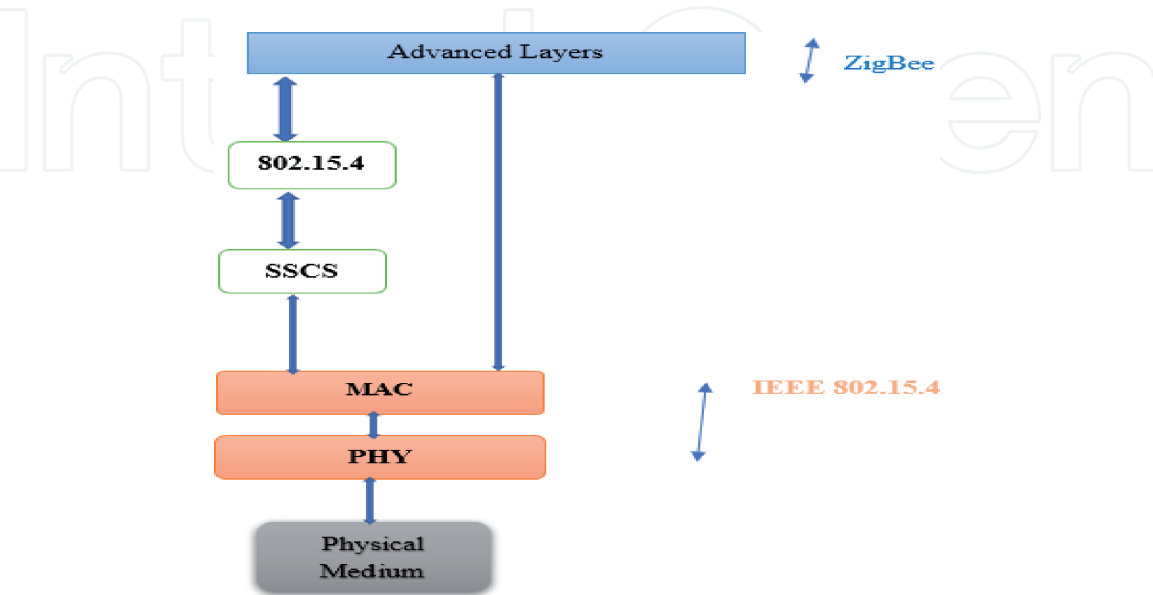


Figure 2.
ZigBee procedure stack.

802.15.4-compliant devices” are dynamic only during a brief period and the standard permits some devices to function with both the transmitter and the receiver inactive for about a duration of 99% [4].

3.2 The IEEE 802.15.4 MAC layer

The “IEEE 802.15.4” employs a procedure built on the CSMA/CA algorithm, which entails compensating attention to the channel before transmission for the reduction of the possibility of collisions with other continuing transmissions. The “IEEE 802.15.4” describes two diverse operational approaches, viz.; the “beacon-enabled (BE) and the non-beacon-enabled (nBE),” which correspond to two diverse channel access machineries.

The nBE approach nodes use an unpetitioned CSMA/CA procedure for the assessment of the channel and transmission of their packets [36]. The algorithm is executed by employing units of time (UT) known as “back off periods (BPs).” Foremost, each node will interrupt any actions for a haphazard number of BPs. Subsequent on this interruption, channel sensing is achieved for one UT. If the channel is discovered free, the node instantly starts the transmission; but if, in its place, the channel is busy the node enters again in the back off situation. There occur an uppermost number of times the node could attempt in accessing the channel. When this uppermost is attained, the algorithm ends and the transmission could hardly occur. According to reports from the IEEE 802.15.4 Standard Part 15.4, in the BE mode (instead, the access to the channel is accomplished through a super frame [SF]), beginning with a packet, known as “beacon,” transmitted by wireless PAN coordinator. The SF could contain an indolent portion, permitting nodes to go in sleeping mode, while the active portion is shared into two portions; “the contention access period (CAP) and the contention free period (CFP),” composed of what is known as the “guaranteed time slots (GTSs),” that could be allocated by the sink to precise nodes. However, the use of the GTSs is discretionary.

4. Applications of wireless sensor networks (WSNs)

According to Buratti et al. [4], the various conceivable applications of WSNs to every sectors globally is essentially boundless, from environmental monitoring and management [37], medical and health care services [38], as well as other aspects such as positioning and tracking [39], localization, logistic. Strappingly, it is imperative to emphasise that the benefits and applications affects the choice of the wireless machinery to be employed.

As soon as the requirements of the application are set, the network designers need to select and choose the machinery which allows the gratification of these requirements. Hence, the knowledge of the structures, benefits and difficulties of the various machineries is fundamental. As a result of the significance of the relationship between the requirements for application and the machineries, this section will attempt to briefly give an outline of the some of the utmost applications of WSNs.

As stated earlier, WSNs have gained substantial admiration as a result of their flexibility in resolving issues in different application fields and have all it takes to change our world in several diverse ways. Reportedly, WSNs have been efficaciously employed in several application domains [1–4, 7, 13, 26–29, 40–44] such as:

Military Applications: Possibly, WSNs is an essential fragment of military intelligence, facility, control, communications, computing, frontline surveillance, investigation and targeting systems.

Applications in Area Monitoring: In the aspect, the sensor nodes are positioned over an area where some display is to be observed. When the sensors notice the occurrence being observed (such as temperature, pressure etc), the occurrence is conveyed to one of the base stations (BSs), which then takes action appropriately.

Transportation Applications: Instantaneous traffic statistics is being composed by WSNs to later forage transportation models and keep the drivers on alert of possible congestion and traffic difficulties.

Medical/Health Applications: Some of the medical/health benefits of WSNs are in the areas of diagnostics, investigative, and drug administration as well as management, supporting interfaces for the incapacitated, integrated patient monitoring and management, tele-monitoring of human physiological information, and tracking and monitoring medical practitioners or patients inside the medical facility. According to Nwankwo et al. [45] nanoinformatics and nanomedicine are now beginning to advance in clinical applications via the use of biosensors.

Environmental Applications: The term “Environmental Sensor Networks (ESNs)” has developed to cover several benefits of WSNs to environmental and earth science study. This comprises of sensing oceans, seas, glaciers, atmosphere, volcanoes, forest, etc. However, there are presently some biosensors that have been developed for use in agricultural and environmental sustainability [29]. Some other key aspects are; air contamination monitoring and management, forest fires discovery/detection, greenhouse (GH) monitoring and management, and Landslide discovery/detection.

Structural Applications: WSNs can be employed for monitoring the movement of diverse structural projects such as buildings and other infrastructural projects like flyovers, bridges, roads, embankments, tunnels etc., allowing manufacturing/engineering practices to monitor possessions remotely without necessarily visiting the sites, and this would reduce expenses that would have been incurred from physical site visitations.

Industrial Applications: WSNs have been advanced for “Technological Condition-based Maintenance (TCBM)” since they could offer momentous cost reductions/investments and allow innovative functionalities. In wired classifications, the installation of adequate sensors is habitually limited by the amount involve in wiring.

Agricultural Applications: The employment of WSNs has been reported assist farmers in various aspects such as the maintenance of wiring in a problematic environment, irrigation mechanisation which aids more resourceful water use and reduction of wastes.

5. Design challenges in WSNs

Reportedly, there are several challenges placed by the disposition of sensor networks [1, 2, 7, 46–49], which are segment of those that are initiated in WSN systems. The sensor nodes interrelate over the wireless, lossy spots without sub-structure. Another projecting challenge is the one that is related to the constrained, customarily non-renewable natural resource; that is the energy basis of the sensor nodes. As reported by Akyildiz et al. [1, 2], so as to enjoy the complete benefit of the generation of the WSNs, the techniques need to be premeditated from the beginning with the aim of efficient monitoring and management of the natural resources (energy source).

According to Matin and Islam [7], the specific design challenges in WSNs are:

Scalability: SNs differ in scale from some nodes to possibly several numbers. Furthermore, the deployment density is correspondingly adjustable. In the process

of gathering data with high resolution, the node density could reach the extent where a node has numerous neighbours in their range of transmission. The protocols positioned in SNs should to be scalable to these extents and should be able to maintain and preserve performance effectively.

Culpability Tolerance: SNs are susceptible and regularly deployed in hazardous environment. The failure in the nodes are supposedly due to hardware complications, physical impairment or through gruelling their energy source. Expectedly, the node failures are much higher than the one generally considered in strengthened or infrastructure-built WNs. The protocols positioned in a SN should be talented in detecting these failures in the nodes instantly and should be strongly robust in handling a comparatively huge quantities of the node failures while maintaining and preserving the complete functionality of the network system. This is particularly relevant to the routing protocol project, which ensure that alternative paths are accessible for redirecting of the packets. However, diverse deployment situations pose diverse culpability tolerance necessities.

Cost of Production: Due to several deployment models consider the SNs to be disposable devices, sensor networks could possibly contend with traditional information gathering methods only if the specific SNs could be produced economically. The target price intended for a NS should preferably be very low in price.

Hardware Limitations: At least, every NS needs to have a detecting component (sensing component), a processing component, a transmission component and a power source component. In some instant, the nodes could possibly have numerous built-in sensors or extra devices like a localization arrangement that assist the location-aware routing. Nevertheless, every extra functionality emanates with extra cost and amplifies the power consumption rate and physical dimensions of the node. Consequently, extra functionality needs to be continuously balanced in contrast to the cost and low-power requirements.

Topology of the Sensor Network: Even though WSNs have advanced in several aspects, the networks incessantly experience some constrained resources in terms of energy resources, computational power, storage (memory) and communications competences. Among all these aforementioned constrictions, energy resource is of utmost significance, and this is confirmed by the huge quantities of algorithms, procedures, and protocols that have been established for saving energy, and by this means encompass the generation of the network. Reportedly, maintenance of the topology is one of the utmost issues that could assist in the reduction of the energy consumption rates in WSNs [22].

The Media of Transmission: The communication and interaction among the nodes is ordinarily implemented by means of the radio communication over the prevalent ISM bands. Nevertheless, some sensor networks employ optical communication or infrared communication, with that of the infrared having the advantage of being strong and effectively free of interference.

The Consumption of Power: As previously stated, most of the challenges of WNSs mainly centred on the inadequate power resources. The magnitude of the nodes restricts the magnitude of the source of power (battery). Hence, in designing the both the software and hardware, there the needs to cautiously contemplate on the issues of resourceful energy use. For example, data compression could possibly reduce the quantity of energy used for radio transmission, but uses extra energy for the manipulation, computation or/and filtering. Also, the energy procedure depends on the application; where in some applications, it could be suitable to turn off a subdivision of nodes so as to preserve and conserve energy whereas other applications need all nodes to operate instantaneously.

According to Puccinelli and Haenggi [28], sensor networks offer an influential combination of disseminated sensing, computing and communication. They offer

themselves to immeasurable applications and simultaneously offer several challenges as a result of their distinctiveness, essentially the rigorous energy limitations to which sensor networks are characteristically subjected. The distinguishing traits of sensor networks have a direct influence on the hardware design (HWD) of the nodes at least four levels namely; “power source, processor, communication hardware, and sensors.” There are several HWD platforms that have been established in testing the innumerable ideas and concepts produced by various researchers and in implementing the applications to effectively suit all fields of study especially the scientific and technological aspects [50].

Presently, in the design and deployment of WSNs, several programming procedures have been projected, of which prominence are habitually on issues of low-level systems. Nevertheless, as stated earlier, for the simplification of the design and deployment of WSNs and abstract from technological LLB specifics, some HLB procedures have been anticipated, developed and established for its resolutions. According to BenSaleh et al. [3], applying the model-driven engineering (MDE) technique is becoming an auspicious solution in particular and these HLB procedures would be of great assistance in easing the design and deployment as well as mitigate some of the challenges of WSNs.

6. Conclusion

This chapter discusses some of the utmost issues of WSNs, ranging from applications to challenges on the technological points of view. Essentially, in designing a WSN it is required to describe the utmost appropriate technology to be employed and the communication procedures (such as signal processing, topology, approaches, etc). These selections are subject to various factors, and most significantly, the application necessities.

The first section of the chapter was keen in discussing the description of some of the limitations that should be fulfilled by the WSN and the various aspects that should be considered for designing a WSN. The proceeding section, was connected to the possibly authentic selections that could be completed, in terms of machineries. The purpose is to assist designer of WSNs in selecting or choosing of the utmost appropriate technology. The consideration was primarily focused on standard of the IEEE 802.15.4, for which also several possible performance levels are make available. Conclusively, it is suggested that a vision on imminent trends of research and prospects such as MDE techniques on WSNs should be put in place.

Acknowledgements

The authors express their appreciation to authors and agencies whose research studies and publications were used for this chapter.

Conflict of interest

There is no conflict to declare.

Notes

This research has not received any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

IntechOpen

Author details

Kingsley Eghonghon Ukhurebor^{1*}, Ituabhor Odesanya², Silas Soo Tyokighir³,
Rout George Kerry⁴, Akinola Samson Olayinka¹
and Ayodotun Oluwafemi Bobadoye⁵

¹ Department of Physics, Edo University Iyamho, Edo State, Nigeria

² Department of Physics, Federal University Lokoja, Kogi State, Nigeria


³ Department of Electrical and Electronics Engineering, Federal University of
Agriculture Makurdi, Makurdi, Nigeria

⁴ Department of Biotechnology, Utkal University, Bhubaneswar, Odisha, India

⁵ Forestry Research Institute of Nigeria (FRIN), Ibadan, Nigeria

*Address all correspondence to: ukeghonghon@gmail.com;
ukhurebor.kingsley@edouniversity.edu.ng

IntechOpen

© 2020 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 

References

- [1] Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E. A survey on sensor networks. *IEEE Communications Magazine*. 2002a;**40**(8):102-114
- [2] Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E. Wireless sensor networks: A survey. *Computer Networks*. 2002b;**38**(4): 393-422
- [3] BenSaleh MS, Saida R, Kacem YH, Abid M. Wireless sensor network design methodologies: A survey. *Journal of Sensors*. 2020;**2020**:9592836
- [4] Buratti C, Conti A, Dardari D, Verdone R. An overview on wireless sensor networks technology and evolution. *Sensors*. 2009;**9**:6869-6896
- [5] Culler D, Estrin D, Srivastava M. Overview of sensor networks. *IEEE Computers*. 2004;**37**:41-49
- [6] Hac A. *Wireless Sensor Network Designs*. Etobicoke, Ontario, Canada: John Wiley & Sons Ltd; 2003. p. 2003
- [7] Matin MA, Islam MM. Overview of wireless sensor network. In: Matin MA, editor. *Wireless Sensor Networks – Technology and Protocols*. London, UK: IntechOpen; 2012. DOI: 10.5772/49376
- [8] Raghavendra C, Sivalingam K, Znati T. *Wireless Sensor Networks*. New York, NY, USA: Springer; 2004
- [9] Rajaravivarma V, Yang Y, Yang T. An overview of wireless sensor network and applications. In: *Proceedings of 35th Southeastern Symposium on System Theory*. Vol. 2003. Morgantown, WV, USA: IEEE; 2003. pp. 432-436
- [10] Sohrabi K, Gao J, Ailawadhi V, Pottie G. Protocols for self-organization of a wireless sensor network. *IEEE Personal Communications*. 2000;**7**:16-27
- [11] Tubaishat M, Madria S. Sensor networks: An overview. *IEEE Potentials*. 2003;**22**:20-30
- [12] Rawat P, Singh KD, Chaouchi H, Bonnin JM. Wireless sensor networks: A survey on recent developments and potential synergies. *The Journal of Supercomputing*. 2014;**68**(1):1-48
- [13] Verdone R, Dardari D, Mazzini G, Conti A. *Wireless Sensor and Actuator Networks*. London, UK: Elsevier; 2008. p. 2008
- [14] Worlu C, Jamal AJ, Mahiddin NA. Wireless sensor networks, internet of things, and their challenges. *International Journal of Innovative Technology and Exploring Engineering*. 2019;**8**(12S2):556-566
- [15] Chen DB, Zhang NL, Zhang MG, Wang ZH, Zhang Y. Study on remote monitoring system of crossing and spanning tangent tower. *IOP Conference Series: Materials Science and Engineering*. 2017;**199**(1):1-6
- [16] Tiwari P, Saxena VP, Mishra RG, Bhavsar D. Wireless sensor networks: Introduction, advantages, applications and research challenges. *HCTL Open International Journal of Technology Innovations and Research*. 2015;**14**:1-11
- [17] Ukhurebor KE, Odesanya I. Relationship between meteorological variables and effective earth radius factor over Auch, Edo state, south-south, Nigeria. *Covenant Journal of Physical & Life Sciences, SE*. 2019;**7**(1):1-10
- [18] Ukhurebor KE, Azi SO, Abiodun IC, Ojiemudia SE. The influence of weather variables on atmospheric refractivity over Auch, south-south, Nigeria. *Journal for Applied Science and Environmental Management*. 2018;**22**(4):471-475

- [19] Ukhurebor KE, Olayinka SA, Nwankwo W, Alhasan C. Evaluation of the effects of some weather variables on UHF and VHF receivers within Benin City, south-south region of Nigeria. *Journal of Physics: IOP Conference Series*. 2019;**1299**:012052
- [20] Ukhurebor KE, Umukoro OJ. Influence of meteorological variables on UHF radio signal: Recent findings for EBS, Benin City, south-south, Nigeria. *IOP Conference Series: Earth & Environment Science*. 2018;**173**:012017
- [21] Nwankwo W, Ukhurebor KE. An x-ray of connectivity between climate change and particulate pollutions. *Journal of Advanced Research in Dynamical and Control Systems*. 2019a;**11**(8) Special Issue:3002-3011
- [22] Nwankwo W, Ukhurebor KE. Investigating the performance of point to multipoint microwave connectivity across undulating landscape during rainfall. *Journal of the Nigerian Society of Physical Sciences*. 2019b;**1**(3):103-115
- [23] Ukhurebor KE, Azi SO, Aigbe UO, Onyancha RB, Emegha JO. Analysing the uncertainties between reanalysis meteorological data and ground measured meteorological data. *Measurement*. 2020;**165**:108110
- [24] Ukhurebor KE, Nwankwo W. Estimation of the refractivity gradient from measured essential climate variables in Iyamho-Auchi, Edo state, south-south region of Nigeria. *Indonesian Journal of Electrical Engineering and Computer Science*. 2020;**19**(1):276-284
- [25] Ukhurebor KE, Azi SO. Review of methodology to obtain parameters for radio wave propagation at low altitudes from meteorological data: New results for Auchi area in Edo state, Nigeria. *Journal of King Saud University – Science*. 2019;**31**(4):1445-1451
- [26] Chong CY, Kumar SP. Sensor networks: Evolution, opportunities, and challenges. *IEEE Proceedings*. 2003;**91**(8):1247-1254
- [27] Haenggi M. Opportunities and challenges in wireless sensor networks. In: Ilyas M, Mahgoub I, editors. *Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems*. Vol. 1. Boca Raton, FL: CRC Press; 2004. pp. 1-1.14
- [28] Puccinelli D, Haenggi M. Wireless sensor networks: Applications and challenges of ubiquitous sensing. *IEEE Circuits and Systems Magazine*. 2005:19-29
- [29] Ukhurebor KE. The role of biosensor in climate smart organic agriculture towards agricultural and environmental sustainability. In: Meena RS, editor. *Agrometeorology*. London, UK: IntechOpen; 2020. DOI: 10.5772/intechopen.93150
- [30] Durisic MP, Tafa Z, Dimic G, Milutinovic V. A survey of military applications of wireless sensor networks. In: *Proceeding from the 2012 Mediterranean Conference on Embedded Computing (MECO)*. Bar, Montenegro, USA: IEEE; 2012, 2012. pp. 196-199
- [31] Furtado H, Trobec R. Applications of wireless sensors in medicine. In: *Proceeding from the 2011 Proceedings of the 34th International Convention MIPRO*. Opatija, Croatia, USA: IEEE; 2011. pp. 257-261
- [32] IEEE Standard 802-2002 at the Wayback Machine, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture, page 1, section 1.2: “Key Concepts”, “Basic Technologies”
- [33] IEEE 802.15.4 Working Group (see also the website: <http://www.ieee802.org/15/pub/TG4.html>)

- [34] The Industrial Consortia ZigBee Alliance (see also the website: <http://www.zigbee.org/en/index.asp>) and 6LowPAN
- [35] Omojokun G. A survey of Zigbee wireless sensor network technology: Topology, applications and challenges. *International Journal of Computer Applications*. 2015;130(9):47-55
- [36] IEEE 802.15.4 Standard. Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs). Piscataway, NJ, USA: IEEE; 2006
- [37] Ong J, You YZ, Mills-Beale J, Tan EL, Pereles B, Ghee K. A wireless, passive embedded sensor for real-time monitoring of water content in civil engineering materials. *IEEE Sensors Journal*. 2008;8:2053-2058
- [38] Lee DS, Lee YD, Chung WY, Myllyla R. Vital sign monitoring system with life emergency event detection using wireless sensor network. In: *Proceedings of IEEE Conference on Sensors*. Daegu, Korea, USA: IEEE; 2006
- [39] Hao J, Brady J, Guenther B, Burchett J, Shankar M, Feller S. Human tracking with wireless distributed pyroelectric sensors. *IEEE Sensors Journal*. 2006;6:1683-1696
- [40] Bharathidasan A, Anand V, Ponduru S. Sensor networks: An overview. Department of Computer Science, University of California, Davis. Technical Report; 2001
- [41] Boukerche A. Algorithms and Protocols for Wireless, Mobile Ad Hoc Networks. USA: John Wiley & Sons, Inc.; 2009
- [42] Nwankwo W, Olayinka AS, Ukhurebor KE. The urban traffic congestion in Benin City and the search for ICT-improved solution. *International Journal of Scientific & Technology Research*. 2019;8(12):65-72
- [43] Sohraby K, Minoli D, Znati T. *Wireless Sensor Networks: Technology, Protocols and Applications*. Hoboken, NJ, USA: John Wiley & Sons, Inc; 2007
- [44] Yick B, Mukherjee DG. Wireless sensor network survey. *Computer Networks*. 2008;2(12):2292-2330
- [45] Nwankwo W, Olayinka AS, Ukhurebor KE. Nanoinformatics: Why design of projects on nanomedicine development and clinical applications may fail? In: *Proceeding of the 2020 International Conference in Mathematics, Computer Engineering and Computer Science (ICMCECS)*. Lagos, Nigeria: IEEE Xplore; 2020. pp. 1-7
- [46] Akkaya K, Younis M. A survey on routing protocols for wireless sensor networks. *Elsevier Journal of Ad Hoc Networks*. 2005;3(3):325-349
- [47] Pan J, Hou Y, Cai L, Shi Y, Shen SX. Topology control for wireless sensor networks. In: *Proc. 9th ACM Int. Conf. on Mobile Computing and Networking*. San Diego, USA: IEEE; 2003. pp. 286-229
- [48] Verdone R. Wireless sensor networks. In: *Proceedings of the 5th European Conference*. Bologna, Italy, Switzerland: Springer Nature; 2008
- [49] Younis O, Fahmy S. HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on Mobile Computing*. 2004;3(4):366-379
- [50] Rodriguez-Zurrunero R, Utrilla R, Rozas A, Araujo A. Process management in IoT operating systems: Cross influence between processing and communication tasks in end-devices. *Sensors*. 2019;19(4):805