Wireless Communication Technologies and Applications for Wireless Sensor Networks: A Survey †

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Submitted: October 10, 2018 — Accepted: April 12, 2019 — Published: April 30, 2019

Abstract—Nowadays, wireless sensor networks (WSNs) appear in numerous applications in both civil and military. The applications focus on either event detection, observation or sensing data collection. With the rapid growth of potential applications, it's believed that the networks support the most promising technologies for the future applications. The sensors have some constraints with saving energy consumption in the networks since they usually have pre-charged batteries while working in a sensing area. So, choosing appropriate technologies for such networks to be able to work well with some application should be considered and advised. In this survey, a presentation of some prominent applications in different fields such as: military, agriculture, healthcare system, environment monitoring, etc. is provided. In addition, an overview of wireless communication technologies used in WSNs will be addressed in the next part of this survey. We tend to specify some highlight wireless technologies that most appropriate for a WSNs like: ZigBee, Bluetooth, Wireless HART, ISA100.11a, and some other wireless technologies wide used to make a comparison among their characteristics. We further provide suggestions for utilizing technologies in different applications for optimal purposes.

Keywords—Wireless Sensor Network (WSN); WSN Applications; Internet of Things (IoT); Wireless Communication; Protocols

I. INTRODUCTION

RECENTLY, wireless sensor networks (WSNs) have proved themselves as the most promising technologies for the future [1]. A wireless sensor network is a network formed by a large number of sensor nodes, embedded CPUs, working together to monitor a region in order to obtain data about the environment. Each node is equipped with a sensor to detect physical phenomena such as light, heat, pressure, etc. and uses one or more specific wireless communication technologies to form a network [2, 3]. WSNs have gained world-wide attention and were much improved in recent years. Today, smart grid [4-6], smart homes [7, 8], smart water networks [9], intelligent transportation [10-12], are infrastructure systems that connect our world more than we ever thought possible, the common vision of such systems is usually associated with one single concept, the internet of things (IoT) [13, 14], where through the use of sensors, the entire physical infrastructure is closely coupled with information and communication technologies. WSNs are regarded as a revolutionary information gathering method to build the information and communication system which will greatly improve the reliability and efficiency of infrastructure systems. Compared with the wired solution, WSNs feature easier deployment and better flexibility of devices. With the rapid technological development of sensors as well as wireless communication technologies, WSNs will become the key technology for IoT.

A lot of research related to WSN or IoT has been released; several wireless technologies have been developed or much enhanced for using in specific WSN applications like Bluetooth Low Energy for wearable devices [15, 16], WirelessHART and ISA100.11a using in industrial automation [17, 18], ZigBee in monitoring, smart grids [19, 20] etc. Many routing methods, transmission topologies also have been developed for minimizing the power consumption and latency in WSN.

With the scope of this survey, we present how WSNs are applied worldwide in some fields like military, smart agriculture, health care, environment monitoring…by giving several specific applications in each fields in first section. The next part provides some highlight WSN topologies, standards and wireless technologies, and a summary about their own specifications, advantages and drawbacks when used in WSNs.

The remainder of this paper is organized as follows. Almost common applications are classified in Section II. Technologies for connections in WSNs are addressed in Section III. There is a discussion in Section IV, and finally, conclusions and future work are in Section IV.

II. WIRELESS SENSOR NETWORK APPLICATIONS

In Table I, different applications are classified in different fields with specific purposes.

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† Review Article

TABLE I
COMMON APPLICATION FIELDS OF WSNS

Fields	Contents	Tasks	References
Agriculture Applications	*-Crops and environmental parameters monitoring*	Minimizes unpremeditated effects on wildlife, real-time information monitoring, analyzing monitored data, applying the control mechanisms	[24-28]
	-Greenhouse monitoring	CO_2, light, temperature, pH, and humidity are measured, calculated, and adjusted	[29,30]
Health Applications	*-Human physiological monitoring*	Early detection, physiological data are collected and stored for long period of time	[31-33]
	-Support healthcare monitoring	Variable resolution wireless body sensor network	[34,35]
Offshore Applications	*-Fish farms*	Monitor temperature, pressure, pH, salinity, turbidity, conductivity, dissolved oxygen, and chlorophyll levels	[36,37]
	-Wind farms	Monitor wind speed and wind direction	[38,39]
	-Resources monitoring	Oil, gas detection and measurement	[40-43]
Military Applications	*-Monitoring friendly forces, equipment and ammunition*	Check status of friendly troops, the quality of equipment and ammunition	[31,44,45]
	-Battlefield surveillance	Actions of the enemy are watched	[31,45-47]
	-Reconnaissance of opposing forces and terrain	Sensor networks are attached to critical positions of the enemy	[31,48-51]
	- Targeting	Guidance and aiming system attached to weapons	[31,50,51]
	-Nuclear biological and chemical attack detection and reconnaissance	Chemical or biological warning system, calculating and detecting harmful agents	[31]
Environmental Applications	*-Air pollution*	Monitor the concentration in air especial CO, CO_2…	[46,47,52]
	-Forest fire detection	Early detection forest fires by fire indexes or image from spatial data	[53-58]
	-Indoor living monitoring	Detect theft, leak of gas and fire, then send an SMS to the users	[59,60]
Industrial Applications		Monitoring, reporting, controlling equipment or processes	[61-63]

A. *Agriculture Applications*

There are several types of sensors used in agricultural applications for wireless sensor networks to measure temperature, humidity, irrigation (energy efficient automated control), soil pH, parameters in precision agriculture and farming, luminance, wind (speed and direction), EC, and CO2 in greenhouse [21].

Some applications of wireless sensor networks include monitoring and collecting meteorological and soil information such as temperature, humidity, wind, air, rainfall, and soil pH; monitoring distributed lands; disposing multiple crops on single piece of land; furnishing farmers with diverse requirements of crops for different weather and soil conditions [22]; providing information for automated adequate irrigation and fertilizer; choosing the best time to harvest crops based on the individual maturity of agricultural products [23]; and collecting environmental data precisely to get the desired crop's environment conditions in greenhouse.

Crops and environmental parameters monitoring in precision agriculture: Smart and precision agriculture is the art and science of using advanced technology to enhance crop production. The development of WSN applications in precision agriculture makes it possible to increase productivity, efficiency, and profitability in diverse agricultural production systems, also minimizes unpremeditated effects on wildlife and the environment. The real-time information collected from the fields can provide a solid base for farmers to adjust strategies at any time [21]. The following three steps are needed for achieving precision control of the production environment: 1) monitoring temperature, humidity, illumination, and other related parameters which affect the quality and product yield; 2) analyzing monitored data and making decision supported by optimization; and 3) applying the control mechanisms. [24]. Since the global climate is seriously changing every day, not only a wide range of study and research of the crop growth is needed, the small scale environment for the growth of crops also needs to be understood. Along with the help of ubiquitous network integration applications of Internet of things (IoT), the development of smart and precision agriculture will be promoted [25]. From all the collected data, farmers can directly download the information via IoT and schedule their own operation plans; automated precision irrigation can be built to save the water usage [26, 27]; and precision agriculture can be applied to greenhouse which helps farmers grow high quality crops [28].

Greenhouse monitoring: Greenhouse monitoring and control is not only necessary to achieve maximal crop productiveness but also to manage greenhouse effect. Several parameters closely related to one another are needed to be measured, calculated, and adjusted such as CO2, light, temperature, pH, and humidity. In [29], some of these elements are controlled by a system of sensors arranged rationally. The system feasibility was verified in a simple star topology setup in a tomato greenhouse. Air temperature, humidity, soil condition, and greenhouse climatic control process is also described in detail in [30]; based on the data collected from sensors, the proper irrigations and fertilizations of the crops are varying as per the type, age, phase and climate.

B. Healthcare Applications

WSN has made a remarkable progress in the field of healthcare and health monitoring. Some of the health applications for sensor networks are cancer detection; glucose level and brain liquid monitoring; cardiovascular diseases, Alzheimer, depression, and elderly people monitoring; stroke and post-stroke monitoring; home monitoring; heart rate monitoring; vital sign monitoring in hospitals; preventing medical accidents; life-shirt; mobile-health; multi-electrophysiological system; e-watch; drug administration; real-time video streaming surgery; and some support applications for healthcare monitoring [30-32].

Human physiological monitoring: By exploiting WSN systems, physiological data can be collected and stored for a long period of time. The data can provide people many healthcare services for medical monitoring, memory enhancement, medical data access, and detecting vital sign in emergency situations. Continuous monitoring with wearable and implantable body sensor networks [32] will increase early detection of emergency conditions and give immediate alerts of changes in patient status. The data can also be relayed to the hospital or correlate with patient records and so on. In [33], the purpose of indoor monitoring and outdoor monitoring is to provide enough sensory data from both body sensor network and home sensor network to make health status decision and report monitoring, including emergency situations. Based on the data, the length of hospital stay can be reduced.

Support applications for healthcare monitoring: In addition to the applications for healthcare, there are some applications that support and increase the monitoring qualities and efficiency. In many devices and sensors, it is difficult to choose between the high resolutions that consequently lead to high-quality monitoring and low power consumption. Users hope both benefits of the long time use and high resolution. But the less power consumption will cause the lower quality and the higher quality will also cost more power consumptions. In [34], a variable resolution wireless body sensor network is presented to allow doctors set the resolutions flexibly in any situation due to the requirement of the high quality or long time use. The concerns for privacy and security issues are also shown in [35].

C. Offshore Monitoring Applications

Some applications of wireless sensor networks for offshore environmental aspects are monitoring and measuring different chemical and physical parameters such as water temperature (MCP9700 sensor), pressure (SBE 39 sensor or YOUNG 61302L sensor), pH, salinity, turbidity, conductivity, dissolved oxygen and chlorophyll levels for fish farms [36, 37]; water quality and coral reef monitoring for environment protection purposes; and wind speed and wind direction for wind farms [38, 39]. Paper [40] also shows application of wireless sensor networks in oil and gas installations. There are two kinds of sensor nodes in any offshore monitoring systems: floating node and anchored node. The data collected from each node is processed in an offshore station. General structure of a sensor node is shown in figure 1. The energy for sensor nodes can alternatively be batteries, capacitors, heat engines, fuel cells, and energy harvesting, generally solar power [41].

D. Military Applications

With the development of the size of sensors and sensor nodes are getting smaller and smaller, also with the rapid deployment, self-organization and the continuous operating ability event failure of some of its components, sensor network become very promising for military application such as monitoring friendly forces, equipment and ammunition, battlefield surveillance, reconnaissance of opposing forces and terrain, targeting, and nuclear biological and chemical attack detection and reconnaissance [42-51]

Monitoring friendly forces, equipment and ammunition: Status of friendly troops, the quality of equipment and ammunition can be easily check and record to the leaders and commanders. Each troop, equipment and particular ammunition are attached with small sensor, the information are assembled to the sink nodes and sent to the troop leaders or can be forwarded to higher level commander.

Battlefield surveillance: The approaching paths, war zones can be rapidly covered with sensor nodes. All actions of the enemy are closely watched, so leaders are ready to prepare their plans early and win easily. [45]

Reconnaissance of opposing forces and terrain: Sensor networks are attached to critical positions of the enemy to monitor the situation, quantity and plan of opposing forces quickly. Then sensor networks collect the information to the upper level for the new operational plans to intercept the approaching routes of the enemy.

Targeting: the aiming programs and guidance systems associate with sensor networks, attached to the modern ammunition for higher efficiency and remote control.

Nuclear biological and chemical attack detection and reconnaissance: In chemical and biological warfare, the ground is important for calculating and detecting harmful agents. Sensor networks are deployed over friendly areas and are used as a chemical or biological warning system that can provide reaction time for friendly forces thereby reducing the number of deaths a significant way.

E. Environmental Applications

There are many environmental applications of wireless sensor network such as: air pollution monitoring, disaster detection, animals living monitoring, agriculture index monitoring, and indoor living monitoring [46, 47, 52-60].

Air pollution: With the fast-growing industrial and the working of heavy machines and vehicles result in the poor air quality for a long time also causes damages to human health. [46] is the air quality monitoring in the urban area which WSN technology is applied to reduce the cost compare to the traditional monitoring station. This system is deployed on a main road to monitor the CO concentration, each sensor nodes real-time collect the data to the database which are viewed by a directly connected software or can be accessed by remote users through internet. Paper [47] provides some sensors for detecting air pollution after survey about market trends. ZigBee technology was applied to this system, the tested experiments found the suitable routing protocol among Flooding, Gossiping, and Modified LEACH. The tradeoff between working range and output power also be considered. And another ideal to monitor air quality is making the mobility nodes by attacked them into car, is present in [52], the system consists of vehicular sensors, GSM base station, and monitoring server. To reduce the communication overhead, a vehicular node can form an ad hoc network with nearby nodes via their wireless interfaces (for example, Wi-Fi), that would allow opportunistic communications among vehicular nodes.

Forest fire detection: Wireless sensor network for early detection of forest fires in [53] is a system detects fire by analyzing the Fire Weather Index (FWI) [54, 55]. The FWI system consists of six components: three fuel codes and three fire indexes. The fuel codes are the moisture value at different layer in soil up to 20 cm depth. The three fire indexes are the rate of fire spread, wind speed, and the total amount of fuel available for combustion. The simple algorism was implied to solve the k-coverage problem, it does not require any specific node deployment schemes, so nodes can be deployed uniformly by threw them out by an aircraft. Paper [56] mentions the forest fire detection system based on ZigBee technology. The structure of this WSN is tree network topology consists of sensing nodes, cluster heads, network coordinators, gateways, satellite network, and host monitoring computer. The sensor node designed hardware comprised of core chip CC2430, sensor SHT11, a unique identifier memory DS2401 chip, power supply, and antenna. When the monitoring computer send an order about temperature and humidity data to router via internet, router scans the order to decide the target coordinator, then the target cluster head is activated and the data are collected by the nodes. Another intelligent system for effective forest fire detection using spatial data [57], the system consists of Color Space Conversion that converts RGB to CIE XYZ color space, an Anisotropic Diffusion Segmentation that enhances the response of edge detection algorithms by a series of operations namely: smoothing the image interiors to emphasize boundaries for segmentation, eliminating the spurious detail and eradicating noise from images efficiently, Artificial Neural Networks (ANN) that possesses the abilities to recognize patterns, manage data and learn like the brain [58]. Firstly, the RGB image from spatial data converted to XYZ color space, and then the converted image is segmented using anisotropic diffusion segmentation to detect the fire region, and then fed as the input to the ANN.

Indoor living monitoring: Security and automation in home and building are promising applications of wireless sensor networks. A remote home security system based on GSM technology [59] can detect theft, leak of gas and fire. Structural system consists of data collecting nodes, center nodes module, MCU-based indoor, GSM module, and user mobile phone. If any error detected, the warning message will be sent to the user via GPRS network. A Home Security and Automation System, presented in [60], use ZigBee for multi-hop communication. Pic18f452 is the main controller that equipped a GSM module to send and receive SMSes. In home security system, the trigger node sends the alert signal to the main controller through multi-hop communication, then the main node sends an SMS to the users via GSM module. In home automation system, the users send the command message to the main node, and then it is forwarded to the destination node via multi-hop communication. The target node will carry out the commanded task by the user.

F. Industrial Applications

Wireless sensor networks have numerous applications for industrial such as: Health monitoring of equipment, Underground resources monitoring, monitoring and control the activities of a specific process to achieve the goal, Autonomous mobile robots…

A smart sensor platform was introduced in [61], each sensor or actuator is equipped reconfigurable generic wireless or smart sensor interface which can read data from sensors, commands the actuator, and provides communication interface to the control unit. Hardware and software design of sensor nodes are considered clearly, real-time control and predictive maintenance are implemented. Also many challenges, design principles, and technical approaches of industrial wireless sensor networks (IWSNs) are presented in [62], the challenges of IWSNs are outlined such as: resource constraints, dynamic topologies and harsh environmental conditions, quality-of-service…, the design goals are followed the challenges to solve it. Following those requirements, the hardware design is the comparisons among many commercial chips and sensors, the trace-off between capacities of battery and data communication performance also be discussed. Some major standardization efforts related to IWSNs among ZigBee, wireless HART, UWB, 6LoWPAN, ISA 100, and Bluetooth. In [63], a Self-Aware Self-Adaptive sensors network (SASA) was introduced. The main functions of SASA are Detecting and Locating collapse hole, Accident reporting, displaced node detection and reconfiguration. The sensor nodes are deployed on the wall and ceiling of the tunnels form a mesh network.

III. WSN STANDARDS AND TECHNOLOGIES

A. *Network Topologies*

Every wireless communication device in a network need to assemble as a "team", WSNs are the same way. In WSNs network, nodes or devices are connected together in several different layouts or topologies to give the network its structure, these topologies define the way the devices are logically connected to each other but their physical arrangement may be different. There are some common topologies used in WSNs network such as: Pair, Star, Mesh or Cluster Tree, each of them is used in specific applications and projects to give the best efficiency [64-71].

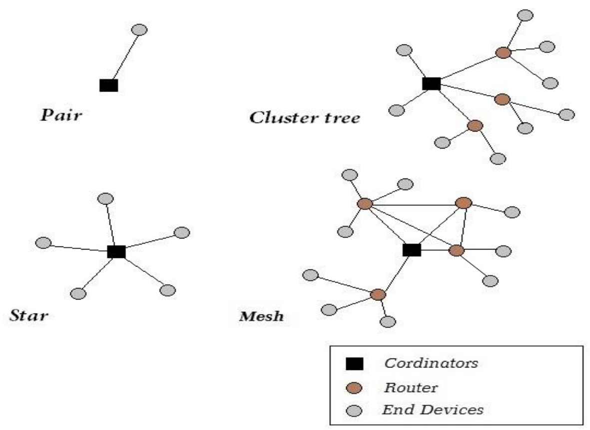

Figure 1. Basic Topologies in Wireless sensor networks

This is the simplest network topology with only two nodes or devices. One node must be a FFD or PAN coordinator to form the network and the other can be configured as an end device or a router [68].

Star topology

The star topology network is formed by a FFD - PAN coordinator placed in the center of the network and surrounded by several RFDs – End devices. Any data packet exchange between ending devices must pass through the coordinator, which routes them as needed between devices. The advantage of star topology is simple and packets go through at most two hops to the destination but it also has some drawbacks such as; there is no alternative path from the source to the destination and the network totally depends too much on the coordinator so that the coordinator may become bottlenecked.

B. *Mesh Topology*

Mesh topology, known as a peer-to-peer network, consists of a PAN coordinator, several router and end device nodes. There is no communications restriction in this topology that means data packets can pass through multiple hops to reach their destination. In addition, a mesh topology is well-known for its self-healing ability, meaning during transmission, if a path fails, the node will find an alternative path to the destination so that it can eliminate dead zones. The other mesh topology advantage is that devices can be close to each other which help to decrease the transmission power in the network. Beyond its advantages, there are also some disadvantages such as: low performance for long-thin networks, larger routing tables that implicitly use more memory, incorporates a low number of nodes and produces a low throughput and compared with star topology, mesh topology requires greater overhead and more complex routing [65-74].

C. *Cluster, Tree Topologies*

In cluster tree topology, the PAN coordinator of the clusters forms a tree structure, and acts as intermediate aggregators and routers of data between different devices. Routers in this topology form a backbone of softs, with end devices clustered around each router and it's nearly the same as a mesh configuration. [68, 75]

Furthermore, several hybrid topologies are being developed and researched for maximizing efficiency of power consumption, routing, gathering data, etc. such as;

Tree-based which was designed for Multi-Sink WSNs aims to maximize the amount of information gathered at the sink (network reachability) [76-80] and integrate with Compressive sensing (CS) for energy-efficient data gathering [81-90].

Cluster-based provides an effective method for prolonging the lifetime of a WSN by distributing the energy consumption among nodes in each cluster [91-95]. Combining with CS in WSNs, cluster-based significantly reduce the energy consumption related to data collection in such networks [96,97].

Random walk (RW) based has been proven to be an energy-efficient method routing for monitoring [98-103] and mobile data gathering problem in large-scale WSNs [104-108]. For more effective, RW-based is integrated with CS in WSNs routing [109-111].

Some methods like neighborhood based or gossip based are being researched for applying in WSNs, with these topologies listed above; they are utilized in wireless communication technologies to form the frame of the network, several common standards and technologies used in WSNs will be provided detail next.

The process of communication technologies has been very active in recent years, some new standards and wireless technologies were published or much improved. According to the distance and data rate transmission speed, four main categories of existing access technologies are classified: Wireless Wide Area Network (WWAN), Wireless Metropolitan Area Network (WMAN), Wireless Local Area Network (WLAN) and Wireless Personal Area Network (WPAN) [64]. However, the overall developing trend of high transmission rates is almost not suitable for the application requirements in a WSN because of the limitation of energy. Hence, most the representative standards and wireless communication technologies that are more effective and noteworthy for a WSN operate on WPAN access technology which has medium distance transmission and low power consumption. This section introduces a detailed overview of some common WSN communication technologies: ZigBee, Bluetooth, WirelessHART, ISA 100.11a, Ultra-wideband (UWB) and some potential synergies from a couple of wireless communication technologies working on WWAN or WLAN access technology that can help a WSN to be easily interfaced through the internet in term of Internet of Things (IoT).

D. ZigBee

ZigBee is a wireless technology developed as an open global standard; it was the original release of ZigBee and defined as ZigBee 1.0 which was publicly released in June 2005 [46, 47]. This technology is built on top of the IEEE 802.15.4 standard [71] which defines the Medium Access Control (MAC) and physical layers, operating in unlicensed bands of 868 MHz for Europe, and 915 MHz, 2.4 GHz for North America with maximum data transfer rate for each band of 20 kbps, 40 kbps and 250 kbps respectively [65-67]. In recent years, ZigBee has found its way into commercial systems for industrial sensing, smart energy systems, consumer electronics, etc. [68] Due to its advantages in low power consumption, simple network deployment, low installation costs, reliable mesh networking [70] and more importantly is that it can automatically forms entire networks that can heal themselves, routing around problem areas without manual intervention, ZigBee make itself outstanding from others common wireless technologies using in WSN [68, 69]. ZigBee networks basically have two different class devices including full-function device (FFD) and reduced-function device (RFD), but propose three different types of devices: Coordinator, Routers and End Devices [49, 52, 53].

A unique FFD Coordinator plays a role in forming the network, handing out the addresses and managing the other functions that define the network and holds a list of neighbors and RFDs [73]. In ZigBee network, a coordinator can communicate with routers and end devices operating in that network.

On the other hand, end devices operating within a limited set of the IEEE 802.15.4 MAC layer have only ability to sense the data (temperature, humidity, light, etc.) then transfer to the coordinator or router; they are not able to communicate or exchange data with others. Consequently, they can power themselves down intermittently, saving energy by going temporarily into a nonresponsive sleep mode.

A router is a FFD and performs all functions like a coordinator except the establishing of a network. It can join existing networks; usually in tree and mesh topologies to expand coverage and play a part in sending, receiving and routing data which means to find the best route to the destination over which to transfer a message [68, 73].

Due to ZigBee's advanced specifications, ZigBee technology is most preferred for a WSN in general. We can find ZigBee standard in various applications in reality such as: Real time tracking in military field, monitoring environment in agriculture, home automation, smart energy, etc.

E. Bluetooth

A few years ago, Bluetooth was positioned as short distance cable substitution alternative interfering with 802.11b, also known as the IEEE 802.15.1 standard, [76] with very short-range, small footprint, low power consumption, reasonable throughput hence suitable for replacing cables for computer peripherals or various small, battery-driven devices [78-80]. Recently, Bluetooth concept has been developed to a protocol suitable to support more complex ad hoc networks with enhanced specifications, particularly WSNs [77].

Nowadays, we are living in a connected world, influenced by the seamless exchange of data between of devices and sensors. As the advance of the Internet of Things (IoT) growing rapidly day by day, Bluetooth technology is enabling a global vision to connect from mobile phones to automobiles, medical equipment to manufacturing plants.

The year of 2016 marked a new era in Bluetooth-powered wireless innovation; many Bluetooth technologies were much improved such as: Bluetooth Core Specification Version 2.1, referred to as Basic Rate/Enhanced Data Rate (BR/EDR), Bluetooth Low Energy (BLE) or Bluetooth 4.0/4.2, Bluetooth High-Speed and most recently released Bluetooth 5.Because the most nearly important of a WSN is that the power consumption need to be optimized into lowest level, in the purpose of expanding the battery lifetime of nodes so the Bluetooth Low Energy (BLE) will be more suitable for a WSN than others listed above.

With the advent of BLE or Smart Bluetooth, now we developers are able to make small sensors that run off tiny coin – cell batteries for months or years in some case due to its ability of ultra-low power utilization with a peak current utilization of just about 15mA and an achievable of under 1 µA for infrequent sampling [37]. BLE is built on a completely new development framework using Genetic Attributes, or called GATT. GATT features are the heart of Bluetooth, making it perfectly suitable for a WSN architecture, and taking advanced over other technologies in the current development of IoT.

Bluetooth Low Energy includes [83]:

- Industry-standard wireless protocol that allows for interoperability across platforms

- Ultra-low peak, average and idle mode power consumption
- Standardized application development architecture eases development and deployment time and cost
- Allows for some of the government-grade security with 128-bit AES data encryption

Bluetooth and ZigBee technology are used extensively for WSNs, however, each of these technologies has its own strengths beyond other, and Table 1 shows that, BLE has very effective power consumption and remarkable data rate, but ZigBee has larger coverage range and very huge number of nodes per Master in a network.

With the launch of Bluetooth 5 on 6 December 2016, Bluetooth technology had much improved its specifications for better fit to the IoT; quadruples the range, doubles the speed, and boost broadcast messaging capacity by 800% [84]. By the estimation of 48 billion connected devices in 2021, we can easily meet Bluetooth technology in various areas, especially in Home Automation, Consumer Electronic, Medical & Health, Sport & Fitness, Wearables, Mobile phones & Smart phones, (etc.).

F. WirelessHART

WirelessHART is an open-standard wireless networking technology extended from the HART protocol to support wireless communication. The standard began in 2014 but first appeared on the market in late 2017. The WirelessHART specification was approved by the International Electro Technical Commission (IEC) unanimously in April, 2010, making it first wireless international standard as IEC 62591 and updated in 2015 [85-87].

Communications in WirelessHART are time synchronized and scheduled based on Time Division Multiple Access (TDMA) for minimizing collisions and reducing the power utilized by the devices. WirelessHART operates based on couple of mechanisms namely Frequency Hopping Spread Spectrum (FHSS), Clear Channel Assessment (CCA) in the purpose of successfully coexisting in the share 2.4 GHz ISM band and ensuring WirelessHART does not interfere with other co-existing wireless system that have real-time constrains to get rid of the influence of interference in the network operation and consequently to increase the communication reliability [86].

A WirelessHART network basically includes some type of devices like: Network manager, network security, gateway, access point, router, field device and handled device. All of these devices are connected to form a mesh-type topology and put the basic mechanisms into action to support network formation, reliability, maintenance, routing, security.

- Field devices – the most basic devices in WirelessHART performs field sensing or actuating functions.
- Handled device are used during the installation, configuration, and maintenance phases of the network carried by mobile users.
- Routers are used for routing purposes, it's not really necessary in the WirelessHART but it can provide redundant paths to the gateway and minimize the power consumption of field devices.
- Gateway, working as sink point for all wireless traffic, provides the connection between the plant automation network and the wireless network.
- Access points connect wireless mesh to the gateway, and increase redundancy and to improve the effective network throughput.
- Network security ensures the security over the network and provides join, network and session key for all devices.
- Network manager is the centralized "brain" of the WirelessHART network. It's logically connected to the gateway and manager the entire network.

WirelessHART protocol stack includes five layers based on the OSI 7-layer communication model; physical layer, data link layer, network layer, transport layer and application layer. In addition, WirelessHART provides redundant paths which allows messages, data to be routed around physical obstacles, broken links and interference, there are two different mechanisms for message routing; Graph routing and Source routing. In graph routing, the network manager determines few redundant parts forming the graph, the parts are stored by each device and then are used to identify the next destination to forward the message. On the other hand, the source routing, the message or packet header contains the list of the devices from the source to the destination [72]. WirelessHART is designed from start to be a robust, reliability, security, energy efficiency and compatibility with existing devices make itself very suitable for industrial applications such as process measurement and control applications [90].

G. ISA100.11a

ISA100.11a is an open-standard wireless networking technology developed by the ISA100 standard committee, part of the non-profit International Society Automation (ISA) organization. The ISA officially released the ISA100.11a standard in September 2009 with wide range of wireless industrial plant needs including process automation, factory automation, and RFID [89, 91].

In a WSN, ISA100.11a can be organized based on different schemes and are formed by two device types; field devices and infrastructure devices. Field devices include some type of devices such as; routing device, I/O device, and portable device, they responsible for sensor data collection and actuator management can also provide routing functionalities [72, 89]. The amount of subnets is not limited; therefore, there is no limitation of the total amount of devices. Nevertheless, up to 30 000 devices can be included in a subnet because of the restriction of addressing space. Infrastructure devices include gateway(s), backbone router, and system, security manager. Gateway(s) is a medium device between control system and backbone router which is the destination of the whole filed devices data, it also supports interoperability with existing standard, such as WirelesssHART by translating and tunneling information between the networks [89, 90]. Basically, ISA100.11a protocol stack includes five layers: physical layer, data link layer, transport layer and application layer. ISA100.11a physical layer is based on 802.15.4 similarly to WirelessHART, but the data link layer is slightly different from WirelessHART in which the slot time has duration of 10ms or 12ms. In addition, the schedule mechanism was designed in a more flexible way than the WirelessHART schedule [92]. ISA100 uses CSMA-CA with OQPSK, which make it efficient at its physical layer. For routing, IPV6 helps ISA100 to coexist with any other legacy network. IPV6 also helps to carry traffic over a network without any routing gateway support [93]. However, ISA100.11a was designed for wireless industrial area similar to WirelessHART then the specifications are nearly the same such as:

- Supporting mesh, star-mesh, star topologies
- Connection to a plant network via a gateway
- Device interoperability
- Data integrity, privacy, authenticity, replay and delay protection
- Coexistence with other wireless networks
- Robustness in the presence of interference

By that means and the fast response time of 100ms of ISA100.11a key feature, ISA100.11a is better than HART and far better than ZigBee protocol thus we can easily find out ISA100.11a in many generally industrial wireless applications and industrial wireless sensor network.

H. Ultra-Wideband

In last few years, the development of Ultra-wideband (UWB) technology has proved itself as a very promising wireless communication technology. Due to its ability in using very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum, it's a solid candidate for the WSN. The US Federal Communications Commission (FCC) defines UWB signals as having an absolute bandwidth larger than 500 MHz or a fractional bandwidth of more than 20% [90, 95]. In Feb 14, 2002 FCC Report and Order authorized the unlicensed use of UWB in the frequency range from 3.1 to 10.6 GHz. Remarkably, China allowed 24 GHz UWB Automotive Short Range Radar in Nov, 2012 [98]. One of the remarkable specifications of UWB is that its bandwidth is over 110 Mbps (up to 480 Mbps) which can satisfy most of the multimedia applications [70]. In addition, UWB has significant advantages with respect to robustness and location accuracy. UWB utilizes very short pulses in impulse radio transmission with signal and architecture design results in very simple transmitters and permits quite low power consumption. An UWB sensor node with a temperature measurement capability consumes 5.31mW, which is lower than the power level of state-of-the-art wireless technologies for smart-home applications [94]. With the efficient power consumption and the simple in circuitry design or transceiver architecture, UWB results an economical solution. By comparing UWB with the other wireless technologies with short distance, UWB has better transport mechanism and spatial capacity per unit area in which UWB Spectrum can give about 1000 kbps/m2 [96]. The experiment in [96] show that the largest observed fading of UWB signal is only 5 dB while the narrowband radio signal exceeds 15-30 dB in multipath case. The interference resistant system for secure radio communication with high data rate is considered in UWB as a result the processing gain is observed high. Data is transmitted by a sequence of short pulses with duration about 1ns, and the modulation is performed by using ON-OFF keying [97]. Because of low density and high data rate application, UWB is very easy to adopt platform for many applications such as; indoor network, military projects, navigation systems and body area networks [96].

I. 6Lo-WPAN

WSN is rapidly growing which arms to participate in the Internet of Things, an IPv6 over low-power wireless personal area network (6Lo-WPAN) originated from the idea that the Internet Protocol could and should be applied even to the smallest devices [99]. The 6Lo-WPAN standard (RFC 4944) has defined by IETF to adapt IPv6 communication on top of IEEE 802.15.4 standard, it allows IPv6 data packets communication over low power and low rate IEEE 802.15.4 links and assures interoperability with other IP devices [90]. Similar to ZigBee, 6Lo-WPAN operates worldwide in 868 MHz, 915MHz and 2.4 GHz ISM band with data rates of 20 kbps, 40 kbps and 250 kbps, respectively. It supports star, mesh, and cluster tree topology with some effective cluster generation algorithms [100], besides several routing protocols have been proposed by 6LoWPAN community such as LOAD [103], DYMO-LOW [104], HI-LOW [105]. 6LoWPAN provides an adaptation layer below IP which performs header compression of IPv6 and transport layer headers, new packet format, enabling the transmission of IPv6 datagrams over IEEE 802.15.4 wireless link [90,101,102]. Due to the variety of reasons such as; uncertain radio connectivity physical tampering, device lookups, (etc.) the devices within 6LoWPANs tend to be unreliable but in many environments or cases, the devices can be on sleep mode for long periods of time with the purpose of saving energy as a result they are unable to communicate during these sleep periods [106]. The 6LoWPAN provides the ability of self-healing, robust and one-to-many or many-to-one routing. Furthermore, it uses not only open IP standard including UDP, HTTP, COAP, MATT and web-sockets, it also offers end-to-end IP addressable node. Using appropriate gateways 6LoWPAN can be integrated into the global IP network that is a big step toward IoT.

J. Wi-Fi

Wireless fidelity (Wi-Fi) is a technology for wireless local area networks (WLAN) with devices mostly based on IEEE 802.11a/b/g standards. 802.11b/g standards use the 2.4 GHz ISM band then 802.11b/g equipment may sometimes suffer

TABLE II
COMMON IEEE 802.11 STANDARDS IN FREQUENCY SPECTRUM AND THROUGHPUT [110]

Version	Released	Frequency	Theoretical PHY Rate	Practical Rate
802.11a	1999	5 GHz	54 Mbps	~24 Mbps
802.11b	1999	2.4 GHz	11 Mbps	~4.4 Mbps
802.11g	2003	2.4 GHz	54 Mbps	~24 Mbps
802.11n	2009	2.4 GHz, 5 GHZ	600 Mbps	~150 Mbps

interference from microwave ovens, cordless telephones, and Bluetooth devices while 802.11a uses 5 GHz U-NII band which offers at least 23 non-overlapping channels [107]. Wi-Fi allows users or devices to connect to internet by an access point (AP) or in ad hoc mode; obviously, it's like a bridge that leads WSN to reach Internet of Things concept. Wi-Fi-based WSN supports high bandwidth and throughput; 802.11n uses double the radio spectrum/bandwidth (40 MHz) compared to 802.11a/g (20 MHz).

Furthermore, Wi-Fi has the features of non-line-transmission ability, large-scare data collection and high cost-effective hence Wi-Fi has the capability of video monitoring or in wireless multimedia sensor network (WMSN) which can't be supported by normal standards. Wi-Fi signal range will vary depending on frequency band, radio power output, antenna gain and antenna type, the modulation technique as well as the environment [108]. 802.11b/g can reach 100 meters in range signal however 802.11n is able to double in the coverage range [109]. During operating, Wi-Fi devices have much more power consumption than other wireless technologies; therefore, they are usually supplied by fixed power supply. In reality, Wi-Fi is usually used with other wireless technologies which have low data rate, effective power consumption, medium distance transmission; ZigBee, BLE, (etc.) in various applications [101-104] forming WSN which can be interfaced though internet toward IoT concept.

IV. DISCUSSION

Due to the fact that WSNs commonly operates in WPAN, thus the power consumption is generally low compared with other types of wireless communication transmission. However, we are still able to classify those transmitting methods into 3 levels of power consumption; ultra-low, medium, high. With ultra-low ones, generally they are used mostly on short-range transmitting applications such as; sport wrist watch, health care system, etc. and BLE and ANT/ANT+ perfectly exemplify this kind of technology. There are a lot of medium kinds namely ZigBee, UWB, WirelessHART, ISA100.11a, etc. This kind are usually utilized in smart home, smart grids, and even IoTs purposes due to its medium transmission distance and power consumption. And to reach to IoT concept, we still need to use some sort of WLAN technology. For example, Wi-Fi could be used in any applications as a bridge connecting a network to the internet, thus the data can be streamed and uploaded to the database on internet. As a trade-off specification, Wi-Fi have to uses direct power supply for high data speed and remarkable distance transmission.

A wide variety of different standards wireless data technologies exist, each designed technology for a specific application. They can be evaluated by a variety of different metrics such as communication range which are discussed in this section.

Standards can be grouped as follows in increasing range order:

Personal Area Network (PAN) systems are intended for short range communication between devices typically controlled by a single person. Some of these technologies include standards such as Bluetooth, ANT, UWB, Z-wave.

- Bluetooth is a wireless technology standard for exchanging data over short distances about 10 meter (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices [76, 78, 79].
- ANT is a proprietary (but open access) multicast wireless sensor network technology designed and marketed by ANT Wireless. It is conceptually similar to Bluetooth low energy (BLE), but is oriented towards usage with sensors. Its physical range is about 30 meter [102, 108].
- Ultra-wideband (UWB) is a radio technology that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum. UWB has traditional applications in non-cooperative radar imaging. Most recent applications target sensor data collection, precision locating and tracking applications. Its physical range is about 10-10 meter [99-102, 106].
- Z-Wave is a wireless communications protocol used primarily for home automation. It is oriented to the residential control and automation market and is intended to provide a simple and reliable method to wirelessly control lighting, HVAC, security systems, home cinema. Its physical range is about 30-40 meter [72, 79].

Wireless Sensor Networks (WSN/WSAN) are, generically, networks of low-power, low-cost devices. While most individual nodes in a WSAN are expected to have limited range (BLE, 6LoWPAN, Bluetooth), particular nodes may be capable of more expansive communications (Wi-Fi, WirelessHART, ISA100.11a, ZigBee) and any individual WSAN can span a wide geographical range.

- Bluetooth Low Energy (BLE) is a wireless personal area network technology aimed at novel applications in the healthcare, fitness, beacons, security, and home entertainment industries. Its physical range is up to 77 meter [80-83].
- 6LoWPAN is an acronym of IPv6 over Low Power Wireless Personal Area Networks. IPv6 is also in use on the smart grid enabling smart meters and other devices to build a micro mesh network before sending the data back to the

billing system using the IPv6 backbone. Its physical range is about 10 meter [90, 102]

- Wi-Fi is a technology for wireless local area networking with devices based on the IEEE 802.11 standards. An access point compliant with either 802.11b or 802.11g, using the stock antenna might have a range of 100 m [107-111].
- WirelessHART an open industrial standard is developed to meet special requirements of wireless communication at field level in the process industry. It consistently fulfills all specific requirements for reliability, security, cost-efficiency and ease of use. Its physical range is 50-250 meter [85-87, 90].
- ISA100.11a is a wireless networking technology standard developed by the International Society of Automation (ISA). The official description is "Wireless Systems for Industrial Automation: Process Control and Related Applications. Its physical range is 50-250 meter [89-93].
- ZigBee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols. Many applications are capable in Smart gird, Smart home, etc. Its physical range can be up to 1500 meter [65, 68, 72].

Based on all of the technologies' properties, the most four types of wireless communication technology for the IoTs and Machine to Machine (M2M) are shown in [110].

- ZigBee is inexpensive to run and doesn't require a lot of power, making it an ideal solution for many industrial applications. The technology has a low latency, and a low duty cycle, allowing products to maximize battery life. It is also used in Mesh networks, which allow nodes to be connected together through multiple pathways. The wireless technology is hoped to ultimately be implemented in things like smart home devices and smart grids.
- Wi-Fi uses radio waves (RF) to allow two devices to communicate with one another. The technology is most commonly used to connect Internet routers to devices like computers, tablets and phones; however, it can be used to connect together any two hardware components. Thus, Wi-Fi is widely used for multimedia.
- Bluetooth and BLE are wireless technologies applied in transferring data over short distances. The technology is frequently used in small consider devices that connect to users' phones and tablets. For instance, the technology is used in many speaker systems. Bluetooth Low Energy uses less power than standard Bluetooth and is used in hardware such as fitness trackers, smart watches and other connected devices in order to wirelessly transmit data without heavily compromising the battery power in a user's phone.

V. CONCLUSIONS AND FUTURE WORK

In this article, the wide range application of wireless sensor network was presented in many different fields, and some major protocols of sensor network were introduced briefly. This make the sensor network in the near future become an integral part of our lives. There are still many constraints that need to be considered, such as fault tolerance, scalability, cost, hardware, topology change, environment and power consumption. Since those constraints are highly specific for certain sensor networks, new wireless networking techniques are required. Many researchers are currently exploring and developing wireless sensor network for betterment of special purposes in our lives.

TABLE III
COMPARISON OF COMMON WIRELESS COMMUNICATION TECHNOLOGIES USED IN WSNS

Specifications / *Standards*	*Working Frequency*	*Range*	*Network Topology*	*IPv6*	*Power Consumption*	*Self Healing*	*Latency*	*Max data rate*	*Application*	*References*
ZigBee	868/915 MHz, 2.4 GHz	Up to 1500m	Star, Mesh, Tree	✓	Low	✓	Low	250 Kbps	Monitoring Smart grids, home	[65, 66, 68,69,71,72]
Bluetooth	2.4 GHz	10m	Piconet, Scatternet	-	Low	-	Medium	720 Kbps	Mobile phone, Wearables	[76,78,79]
BLE	2.4 GHz	77m	Piconet, Mesh Scattermet	-	Ultra Low	-	Low	1Mbps	Smart phone, IoT, Health, Sport & Fitness	[80,81,82,83]
WirelessHART	2.4 GHz	50-250m	Star, Mesh	-	Low	✓	Low	250 Kbps	Industrial automation	[85,86,87,90]
ISA100.11a	2.4 GHz	50-250m	Star, Mesh	✓	Low	✓	Low	250 Kbps	Industrial automation	[89,90,91,92, 93]
6LoWPAN	868/915 MHz, 2.4 GHz	Small	Star, Mesh, Tree	✓	Low	✓	Low	250 Kbps	Automation, Entertainment Applications.	[90,99,101,102]
UWB	3.1 - 10.6 GHz	10-30m	Piconet, Peer-to-Peer	-	Low	-	Low	110Mbps Up to 480Mbps	Navigation systems, WMSN, military	[90,100,101, 102,106]
Wi-Fi	2.4 GHz, 5 GHz	100m	BSS, ESS	✓	High	-	Medium	~150 Mbps	Multimedia, Voice data	[107,108,109,110-114]
ANT/ANT+	2.4 GHz	30m	Star, Mesh, Tree	-	Ultra Low	-	Low	Up to 60 Kbit/s	Fitness monitoring	[127,128]
Z Wave	15 ISM bands	30m-40m	Mesh	-	Low	-	Low	100 Kbit/s	Control and sensor applications	[72,129]

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