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Wireless Sensor Network as a Mesh: Vision and Challenges

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ABSTRACT Nowadays, network technologies are developing very rapidly. The growing volume of transmitted information (video, data, VoIP, etc.), the physical growth of networks, and inter-network traffic are forcing manufacturers to produce more powerful and ''smart'' devices that use new methods of transferring and sorting data. Such connected smart devices (IoT) are used in intelligently controlled traffic for self-driving vehicles in Vehicle Adhoc Networks (VANET), in electricity and water in smart cities, and in-home automation in smart homes. These types of connected Internet of Things (IoT) devices are used to leverage different types of network structures. Such IoT sensor devices can be deployed as a wireless sensor network (WSN) in a mesh topology. Both WSNs and Wireless Mesh Networks (WMNs) are easy to organize as well as to deploy. In this case, there are many reasons for combining these different types of networks. In particular, the detailed sensory capabilities of sensor networks may be improved by increasing bandwidth, reliability and power consumption in the mesh topology. However, there are currently only a handful of studies devoting to integrate these two different types of networks. In addition, there is no systematic review of existing interconnection methods. That is why in this article we explore the existing methods of these two networks and provide an analytical basis for their relationship. We introduce the definition of WSN and WMN and then look at some case studies. Afterward, we present several challenges and opportunities in the area of combined Wireless Mesh Sensor Network (WMSN) followed by a discussion on this interconnection through literature review and hope that this document will attract the attention of the community and inspire further research in this direction.

INDEX TERMS IoT, wireless mesh network, wireless sensor network, wireless mesh sensor network.

I. INTRODUCTION

The Internet of Things (IoT) was first introduced to the community in 1999 for supply chain management [1]. Then the concept of ''making the computer perceive information without human intervention'' was widely adapted to other areas such as healthcare (COVID-19), home, environment, and transportation, as well as education, agriculture, and other areas of IT like Blockchain and others [2]–[22].

According to experts' estimation of the Cisco Annual Internet Report, by 2023 people, machines and things will produce data volume of up to 850 zettabytes, while by that time the IP traffic of the global data center will reach only 21 zettabytes [23]. By 2025, 55% of the data generated by the IoT will be stored, processed, analyzed, and used near or at the edge of the network [24]. According to forecasts of the

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Cisco Internet Business Solutions Group, 60 billion objects will be connected to the Internet by 2021 [25].

However, the technology industry is already fully embraced by the Internet of Things, which brings with it the necessary conditions for connectivity and, in many cases, also for security [26], [27].

Some IoT applications may require very short response times, some may include personal data, and some may produce large amounts of data, which can be a heavy load on networks [28]–[31].

A significant role in the work of wireless networks is assigned to routing protocols. In the last decades, a wide expansion of wireless devices with its mobile networks became novel in the IT sector. This raised concerns about the fact that Mobile Adhoc Networks (MANETs) and their routing algorithms were thought out, and investigated beforehand [32]–[37]. They optimize the use of network resources, such as power consumption, processor time, memory, etc [38]–[41]. This means that the use of effective routing protocols allows maximizing the lifetime of the network. For instance, in [42] authors propose a Multicast protocol using the Fuzzy logic technique [43]–[46] to improve QoS in mobile ad-hoc networks as in Figure 1.

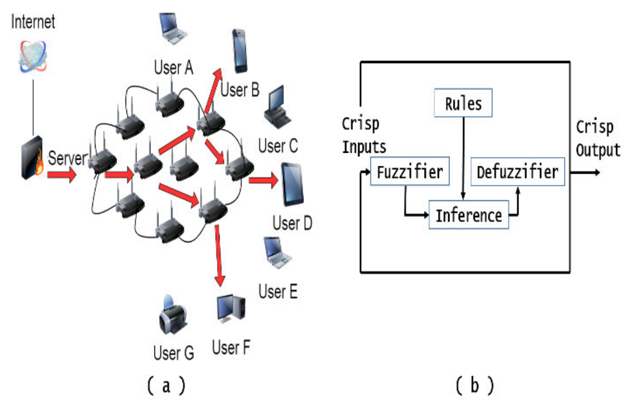

FIGURE 1. (a) Multicast routing protocol in MANET. (b) Fuzzy logic system.

The network architecture, IoT devices can be built of, may be of different topology as well as star, point-to-point, ring or as a mesh or be a composite of them performing various scheduled tasks such as environment sensing, monitoring, etc [47]–[52]. Nevertheless, the hybrid of the above topologies has no longer been observed.

Therefore, the purpose of this article is to identify problems connecting WSN and WMN and explore the different strategies that you can use to implement a connection. Our emphasis is on identifying key significant issues of concern that could then be resolved to fully deploy truly optimized interconnection strategies.

We begin by analyzing why wireless mesh sensor networks are needed. Continuing, we will try to give our own definition and point of view. Moreover, there are several case studies such as smart home, smart city, video analytics, large area monitoring, and artificial intelligence presented to further explain this collaboration in more detail. As well as some challenges and opportunities in energy management, communication reliability, resilience, scalability support, interoperability, self-organization, end-to-end reliability, privacy and security, and support for mobility that deserve further study and research are provided. In addition, related works in this area of research were discussed.

The rest of the article is organized as follows. Section II discusses the need for wireless mesh sensor networks and defines these two networks. In Section III, we investigate several WMSN case studies. Potential challenges and opportunities were presented in Section IV. While in section V we discuss a bunch of related works. Finally, this article concludes with section VI. At last, further research is explained in Section VII.

II. WHAT IS WIRELSS MESH SENSOR NETWORK

Over time, all types of electrical devices such as air quality sensors, LED strips, street lights and even a microwave oven connected to the Internet will become part of the IoT, and they will play the role of data producers as well as consumers [53]–[56]. It is also safe to say that the number of objects at the edge of the network will increase to more than a billion within a few years. This will lead to the fact that the initial data produced by these devices will reach enormous values, which will make traditional sensor networks not efficient enough to process all this data [57]–[62]. This will mean that the information data generated by the IoT will place a colossal load on the network elements trying to transfer data to the end-users of the network.

According to a recent report by market research experts from Mordor Intelligence [63], up to 75% of 216 industrial automation end-users, most of whom are established business communities and manufacturers, have already been installed or are planning to install WSN-based applications to meet their needs. Specifically, 57% of these end-users are currently testing or are already using this WSN system. What's more, 75% of current WSN end-users say that for at least a few of their deployments they are in view of using a composite mesh feature, at the same time 20% of those considered said they want to operate a mesh solution exclusively.

By this section, we try a contribution attempt in the interconnection concept of wireless sensor network with the mesh network. In addition, give our definition and understanding of wireless mesh and sensor networks in separate, as well.

A. WHY DO WE NEED MESH NETWORK

Mesh network is a cellular radio network containing fixed wireless routers creating a wireless highway and a service area to mobile and fixed subscribers, which have access within a zone of radio communication to one of the routers [64]–[68].

Mesh communications have become a very popular networking solution today [69]–[74]. These networks have a decentralized design with multiple switches. These characteristics are of interest to research on functions such as inter-node communication, task distribution, scalability, and connectivity with limited infrastructure support.

In WMN, network nodes are part of the infrastructure they create, and their primary purpose is to perform routing tasks. The mobility of mesh nodes is limited or zero, and their processing capabilities, memory and bandwidth are usually higher than those of traditional dedicated network nodes. In addition, the power requirements of a mesh network are generally less stringent than ad-hoc wireless networks [75]–[81].

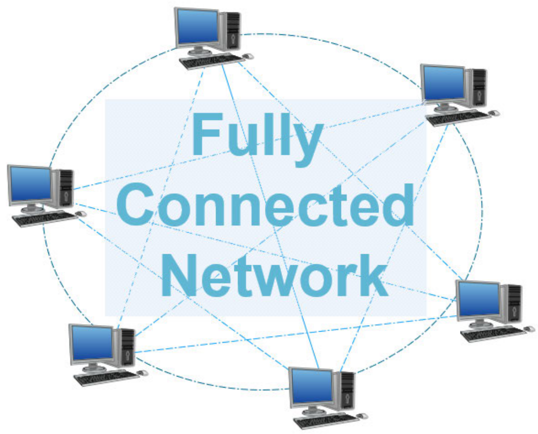

FIGURE 2. Wireless mesh network topology.

When connecting nodes each to each, they can independently create data transmission routes. They are also able to detect failures in neighboring nodes or, conversely, detect the appearance of new nodes, as a result of which the route is automatically rebuilt. Figure 2 illustrates the typical WMN topology.

B. WHAT IS A SENSOR NETWORK

Conversely, wireless sensor networks are built on the principle of interaction of sensor devices. These devices are known for their small size and low cost, but at the same time, they are burdened with relatively low processing power and memory, limited power supply, and relatively low communication bandwidth [82]–[95]. While some sensors are moveless and stationary, other sensors can be very mobile when attached to moving objects. Most studies of this type of network have focused on energy-efficient and low-processing routing [96]–[100].

There are many different types of WSNs, starting from primitive single-hop data collection mechanisms and up to intelligent multi-hop sensor networks. The latter type of network can provide the widest possible range and can allow the use of advanced mechanisms that provide sensory values on-demand or adjust packet routing according to additional needs of the application [101]–[104].

Wireless sensor networks consist of a few hundredths of simple sensors equipped with a radio receiver. They are commonly used to monitor and automate large areas. Because of their simplicity, these networks run out of energy quickly and often have problems with scalability and available bandwidth, and more often, to solve these problems, current research is mainly limited to adding additional receivers to the network [105]–[109].

Currently, in automation systems, monitoring the state of objects, the technology of wireless sensor networks is increasingly being successfully used. For technological and industrial purposes low-power and small sensor equipment may be built into virtually any data acquisition machine [110]–[120].

In practical application, the most widespread are stationary wireless sensor networks, which are characterized by their fixed state during operation. Recently, sensor networks are actively developing a direction associated with the use of autonomous power supplies for them, or totally battery-free WSNs based on alternative energy sources [121]–[133].

The quality of service provided by the WSN depends to a large extent on the battery life of the network, as researched in previous works [82]–[133]. However, frequent replacement of power supplies is not always possible due to network conditions. Thus, reducing energy consumption is becoming a key research problem in sensor network design, and research input in this issue will never be sufficient since the improvement in new technologies will require new solutions.

To solve the problem of energy balancing, it is required to develop a model and an algorithm for the operation of a certain node or device: a ‘‘quality of service manager’’, which, in the process of ensuring the required quality of service of the sensor network, would solve the problem of energy balancing by redistributing loads in the network, taking into account the influence of certain external factors and energy, spent on sending confirmation of data reception from the data collection node. This should reduce the power consumption of the data collection nodes.

C. WHAT IS WIRELESS MESH SENSOR NETWORK

Traditional WSNs consist of a set of sensor nodes, where read data is often collected by one or more central devices called ‘‘sinks’’ [134], while these central devices are connected to an external control server and/or database that authorized users can use to search for interpreted or raw data.

New directions of WSN applications such as intelligent transportation systems [135], urban monitoring [53] or wireless building automation [136] are driving unprecedented demand for large-scale WSNs with many thousands of nodes, unintentionally increasing the number of hops to the destination. This growing problem may be solved by adding additional receiver sink nodes to this network, which consistently gives an increase in scalability, as discussed in previous works by various authors as in [134]. When receiving sink nodes are connected, data is sent to the management server.

However, there is doubt that such a traditional data collection mechanism, such as from node sensors to receivers and from receivers to the backbone, can lead to extraordinary suboptimal routing.

Thus, with its automatic deployment characteristics and strong connectivity at a large scale, a wireless mesh network is a more convenient and suitable option to connect receiver sink nodes.

In other words, Mesh networks can be used in situations where the structure or shape of the network does not allow each node to be within the range of its final destination. That is, the mesh network can be used to connect separate sensor networks, to connect sensor nodes to a monitoring platform, or as a scalable backbone/infrastructure for sensor-to-sensor communication. One of such applications is environmental sensing [137]–[139].

However, when building a large network of sensors, we are often limited by the cost of such sensors. An inexpensive mesh network structure can be envisioned to which any number of different sensors can be connected.

Sensor nodes in the mesh network are mated to microcontroller devices at the deployment point. These devices act as a small computing platform establishing routing algorithms for communication between various sensor packages in an enterprise.

Combining the capabilities of WSN and WMN allows to effectively use the capabilities of each network, and the expected synergistic effect allows us to talk about the creation of a fundamentally new architecture of the combined network [140].

Wireless mesh sensor networks as of Figure 3, which have the potential to improve scalability, reliability, and throughput of sensor nodes, may become more popular in a wide range from industry to academic communities [141].

The solution to the problem of building a combined network is also one of the most relevant at the present stage of development of integrated cellular networks of various standards such as GSM, UMTS, LTE, 5G, 6G and others [142]–[148]. Combined communication networks are focused on the formation of a unified environment for the provision of services.

Self-healing mesh illustrates that the Internet of Things is based more on cost, power, and ease of use than the speeds and flow that the electronics industry has consumed in the past.

Unlike a star network, in which every node communicates with the gateway directly, nodes in a mesh network transmit data among themselves, acting as a repeater for other nodes as needed. When the remote sensor node initiates the transmission of readings, the information data is sent to all intermediate nodes until the data reaches the central collection point. The only requirement for this remote sensing node is that it is within reach of one other node in order to be part of the network. If one node on the network goes down, the surrounding nodes can automatically deliver the sent information around that tarnished node without endangering the rest of the network. This intelligent routing engine would be essential to create a reliable and resilient wireless sensor network.

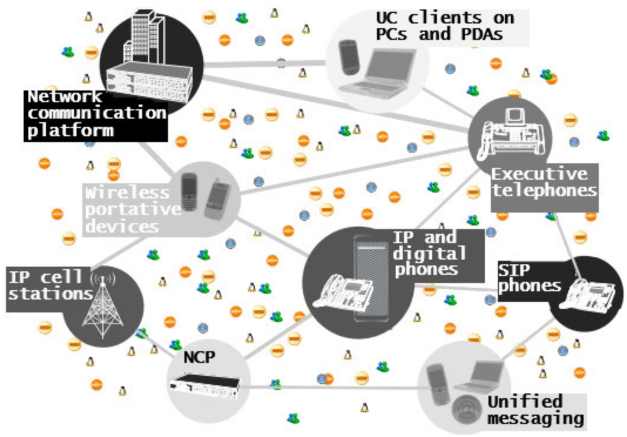

FIGURE 3. Wireless mesh sensor Network.

III. CASE STUDY

Continuing our work, in this section, we present several case studies in which the Wireless Mesh Sensor Network could shine itself to further illustrate our point of view on WMSNs.

A. SMART HOME

Internet of Things will greatly benefit the home environment. Several products have been developed and are available in the market, such as smart lights, smart televisions, and robotic vacuum cleaners [149]–[152]. However, simply adding a Wi-Fi module to your current electrical device and connecting it is not enough for a smart home. In a smart home environment, apart from a connected device, cheap wireless sensors and controllers must be deployed in a room, pipe, and even on the floor and wall. These things will communicate an impressive amount of data, and given the pressure to transport data and protect privacy, this data should be primarily consumed at home. This feature makes the general wireless mesh sensor network infrastructure paradigm suitable for the smart home. Thus, the WMSN topology can be ideal to build a home with a smart environment around with a gateway running a dedicated operating system (OS) in the home, creating better conditions for easily connecting things and managing the home itself. While the data could be processed locally, reducing the load on the bandwidth of the external network, and the service could be deployed to the OS for better management and delivery. Below is the demonstration example of the IoT smart home network as a Figure 4.

B. SMART CITY

According to statistics, more than 41% of all road accidents in a developed country take place at intersections, while 27% of these accidents occur at intersections in the absence of stop signs, traffic lights or road controls, and at the same time, 39% of accidents happen in the presence of stop signs at the intersection [153].

To solve the problem of preventing or monitoring and controlling traffic accidents, a wireless cellular mesh sensor network can be used, the wireless sensor nodes of which can be located between traffic lanes at an intersection for

FIGURE 4. IoT smart home network.

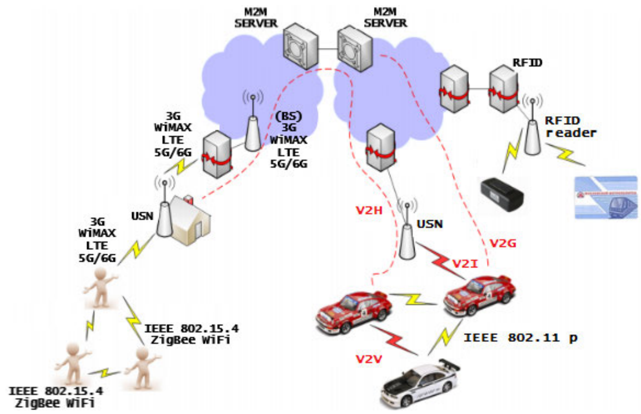

FIGURE 5. Wireless VANET smart transport infrastructure.

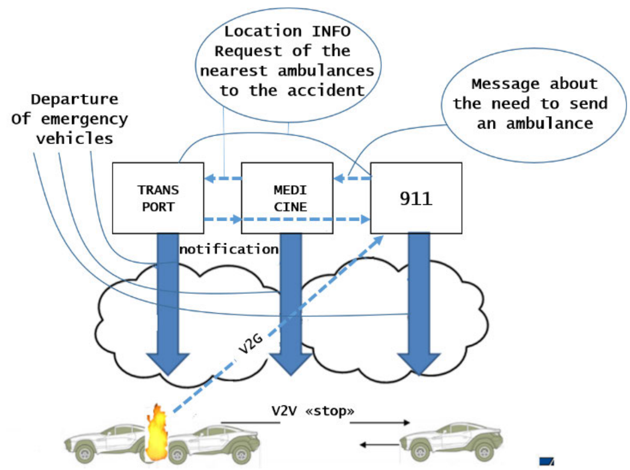

FIGURE 6. Machine-to-machine (M2M) communication in VANET smart transport infrastructure.

the purpose of collecting data. Each such device will consist of an anisotropic magnetoresistance circuit for vehicle detection, a radio module, and a rechargeable lithium-ion battery. When the vehicle moves over the wireless node, detection is recorded, and the sensor device, marking the time stamp, sends this record to the WMSN coordinator. The WMSN coordinator is empowered to register vehicle sightings recorded by each node in the WMSN. Based on these recorded data, a specially designed vehicle tracking algorithm can track the trajectories of vehicles crossing a specific intersection, and also record the total number of vehicles at the intersection [154].

Thus, the WMSN application can be temporary, portable or permanent and work in different weather conditions and environments.

Below is the VANET Smart Transport Infrastructure (Vehicle Adhoc Network) as an example, Figure 5:

Where, for vehicle useful characteristics are:

- Random organization of communication with other nodes.
- Node mobility. Travel speed: up to 120 kmph.
- The number of nodes is random, and generally ranges from 0 to Nmax.

And for the Roadside infrastructure elements (RIE), serving the smart vehicle infrastructure, advantage characteristics are:

- Stationary connections with other objects of the wireless sensor mesh network.
- Immobility of nodes of the wireless sensor mesh network.
- The number of mesh network nodes is fixed.

Figure 6 illustrates the M2M communication in VANET Smart Transport Infrastructure.

In this smart vehicle infrastructure, the road accident detection message initiates the "car stop action" of the behind-approaching vehicle. While the simultaneous message is delivered to RIE to initiate the departure of emergency vehicles.

The implementation of WMSN in smart cities for such a smart vehicle infrastructure may possess an unrestricted amount of nodes in 264, whereupon the distance amongst every node can reach 100 meters or more. As a result, information data can be transmitted over long distances with less delay, thus WMSN can extend over a large area [155].

The same ideology may be implemented in the passenger traffic control in public transport, as illustrated in below Figure 7.

C. VIDEO ANALYTICS

The widespread adoption of mobile phones and network cameras has made video analytics a new technology [156]–[161]. Combined, resilient and reliable network infrastructure can provide good opportunities for applications requiring video analytics, providing low latency and privacy concerns.

Here is a good example of finding a lost child in the city. Today, in urban areas and in every car, you can see the widespread use and use of different types of cameras. When the child goes missing, it is possible that he was captured on camera. However, due to privacy or bandwidth considerations, camera data is usually not uploaded to external storage and processing sources, making it extremely difficult to use the camera's global data. But even if this stored data were uploaded and accessed from an external source, then

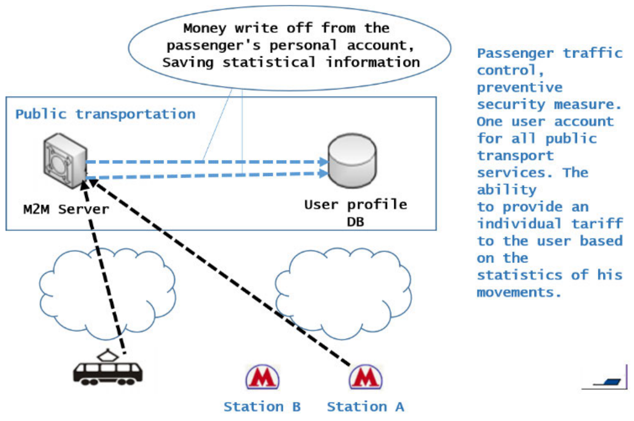

FIGURE 7. Passenger traffic control in public transport.

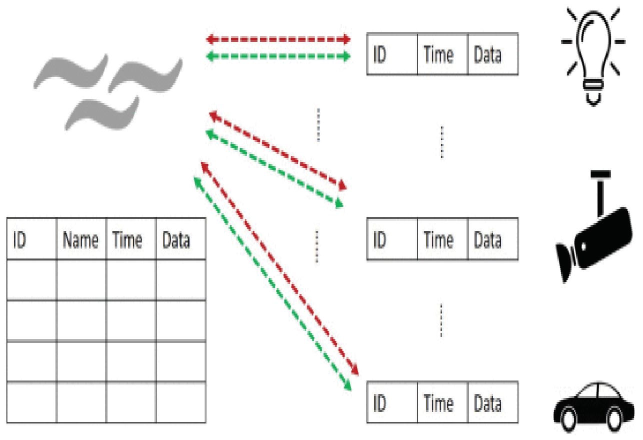

FIGURE 8. Video analytics on RIE.

loading/downloading and further searching in such a huge amount of data could take a long time, making this method unacceptable for implementation.

With an edge computing paradigm integrated into a robust wireless network such as WMSN, a missing child's search query could well be generated from an external source and relayed to all smart devices in that target area, such as roadside infrastructure elements. Any smart thing, such as a smartphone, has the ability to execute a query and search for data from its local camera and report only the results obtained back to an external source. This paradigm makes it possible to use the data and computational power of any thing and get results much faster. Figure 8 is the ideological demonstration of the video analytics on RIE.

As a real-life example, there are models of expensive road cameras on the market that can create a network between similar model variants and require a separate base station or use the camera as a base station. Cameras capable of creating a mesh network between cameras are available from vendors such as Cuddleback Dual [162].

D. LARGE-AREA MONITORING

In recent years, smart and intelligent manufacturing has become widespread in the industry. This technology has many advantages in the industry of electric power, healthcare, construction, logistics, Industry 4.0 and more [163]–[172].

The commonly used networks in the industry have been wireless local area networks (WLANs). The ability of such a stubby diapason of coverage is only to form a local network, a great vertical extent of the expense in deployment and installation of the complex. Moreover, there are network blind points, poor reliability, low transmission rate, and other problems. Therefore, for practical use, it is not the best fit.

A wireless sensor network in a large industrial facility consists of many self-contained sensor devices, which are mainly utilized for observation and inspection. To implement control and transfer of sensor records over a wireless network these nodes combine sensing, distributed information processing, integrated computing and reliable communication technologies. The goal is to coordinate the perception, collection and processing of information about perceived objects in the network coverage area.

A wireless mesh network combines the superior features of WLAN and ad-hoc networks and forces investigators to stump up more attention on it. This network owns features such as high-speed deployment and uncomplicated installation, flexible structure and high bandwidth, non-line-of-sight (NLOS) transmission and reliability, and as more as discussed earlier in Section II. Over and above, WMN is able to connect to the Internet, Wi-Fi LAN, PSTN, and other various networks via appropriate gateways.

The production line of personalized or small-sized products requires extreme precision and high status. This requires production to have high fluidity, fast measurement and precise various manufacturing processes. If there occurs an unwelcome situation with one of the processes, inconceivable consequences may happen. Accuracy of data collection is critical for subsequent workshops.

Thus, based on the foregoing, the creation of a wireless mesh sensor network combining sensing, distributed information processing, integrated computing and reliable communication technologies, gives an extended implementation of control and transmission of sensor information among a wider wireless network. As well as its goal is to jointly sense, gather and deliver information data about sensed objects in the coverage area of an extensive network. See the concept of the WMSN on large-area monitoring as in Figure 9.

E. ARTIFICIAL INTELLIGENCE

Artificial Intelligence (AI) systems as a science appeared in the mid-50s of the last century [173]–[175]. Artificial intelligence systems mean a large number of advanced technologies that provide machines with the ability to learn, adapt to new conditions, make decisions and change behavior. Many of these abilities can be used in sensory systems.

To this day, several powerful tools have been developed such as automatic knowledge collection systems, knowledge base systems, fuzzy logical elements, genetic algorithms, expert systems based on worked out situations, neural

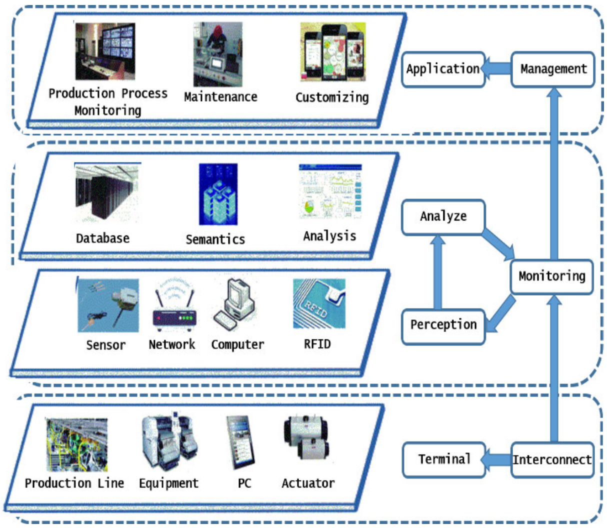

FIGURE 9. WMSN large-area monitoring concept.

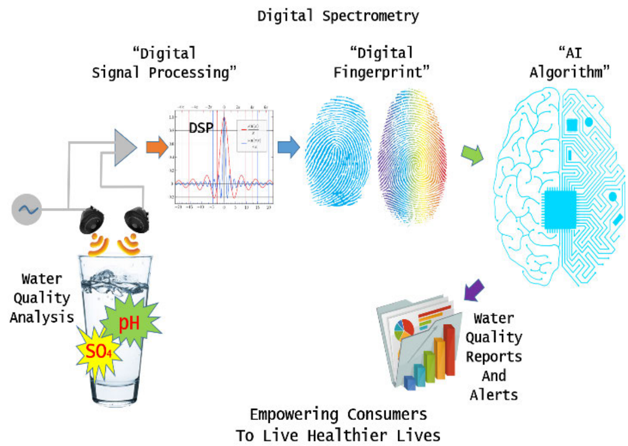

FIGURE 10. AI sensor.

networks, external intelligence technology, etc [176]–[184] that can be used, including in sensor systems for the automatic solution of problems that otherwise would require human participation. These devices or methods have minimal computational complexity and can be implemented in small sensor systems, single sensors, or arrays on simple microcontrollers [185]–[189].

AI systems are constantly improving, and advances in machine intelligence ensure seamless interaction between humans and digital sensory systems. Although the introduction of AI into electronic devices has been slow, it provides flexibility, customization, and high reliability.

This system is increasingly penetrating into everyday life. And over time, many new applications for intelligent sensor systems will emerge. Most likely, preference will be given to hybrid solutions that combine several of the above technologies as illustrated in Figure 10. Other technological developments that are likely to affect sensory systems include data mining techniques, multi-agent systems, and distributed self-organizing systems.

In addition novel AI approaches such as Machine learning, Deep learning, and Reinforcement learning will be investigated to be contributed in new generation sensor networks [219]–[223].

Artificial intelligence can improve communication efficiency, reduce errors and failures, and extend the life of the sensor [225]–[228].

IV. CHALLENGES AND OPPORTUNITIES

In the last section, we have described several potential applications for wireless mesh sensor networks. We would like to argue that systems and network communities must work closer to each other to realize WMSN visions.

Optimum performance for any network can be achieved if the system is capable of responding to challenges and evolving. To achieve the level of effective adaptability of a particular system, the deployment of the network must take into account the placement of the sensors and the possibility of good connectivity.

One of the best approaches to achieve a good network is to make sure that the nodes at the edge of the network have intelligent application software built-in. Individual devices need to be aware that a communication failure is occurring so that the data they collect can persist until a successful link connection is established.

Adding ''intelligence'' at the node level assures more versatility so that the node detecting water leakage can shut the water supply off until the leakage is renovated. And the device will continue to work even if the node is currently out of range. These nodes can work both individually or as a part of a network. Nodes are given some autonomy.

The final feature of a well-built, solid wireless sensor network is the ability to manage and update connected network devices. If the software embedded with the sensor device can be updated, then it can restore or improve the security of the software, or even add new features. The upgrades provide the sensor network with a ''future-proof'' level and ensure a noteworthy grade of versatility over conventional wired systems, which can't evolve.

In this section, we take a closer look at some challenges and suggest some potential solutions and capabilities that deserve further study when developing a WMSN, such as a link reliability, robustness, power management, scalability support, self-organization, interoperability, end-to-end reliability, privacy and security as well as support for mobility.

In addition, we explore some problems arising when connecting WMN and WSN networks as below:

- Backward Compatibility: When adding these two types of networks to each other, the backward compatibility issue must be resolved. Because if the WMN is added to the WSN, sensor nodes do not need any configuration. In addition, using a mesh network to connect sensor networks can reduce deployment costs.
- Radio technology differences: Gateway nodes must have both sensor and mesh technology interfaces. WMN and WSN may operate in similar frequency ranges.

This causes interference in the network. The successful combination of these two different technologies avoids radio communication failures.

- Addressing schemes: WMN and WSN can use different addressing schemes. In this case, they need to map the types of addresses to communicate with each other.
- Routing strategies. Although WMN and WSN use the same version of IP, the routing schemes they use may be different.
- Translation of metrics. By leveraging WMN support to improve sensor network efficiency, sensor nodes need to know alternative ways to route packets through WMN. This means that WMN metrics must be mapped to WSN metrics.
- Synchronization strategies: The WSN sometimes implements a waiting scheme due to power constraints. To send a packet from WMN to WSN, WSN needs to know synchronization strategies.

Bringing mesh capability to traditional WSNs has a huge impact on the mercantile extension of this technology and opens up new opportunities for new applications or markets such as situational awareness and pinpointing assets, protecting firefighter operations, streaming media services, or monitoring environmental security. To achieve this interconnection goal, several important requirements must also be considered during the design phase of a WMSN that affect the performance of a WMSN. They can be briefly described as follows:

A. ENERGY-MANAGEMENT POLICY

The policy in energy management and the energy efficiency design are the requirements that play an important role in the design of WMSN networks and is an issue of high importance. Usually, power supplies for devices are provided by conventional AA/AAA chemical accumulators. This drastically reduces the lifetime of network elements during long and continuous operations. In many cases, using external energy sources such as solar or wind is too expensive or unusable for use or placement.

Mentioned problems are even greater in large-scale mesh networks. This is because the number of hops between source and destination can be very large. This, in turn, in many cases increases the power requirements associated with data transmission/retransmission, thereby minimizing network lifetime.

Obviously, power management mechanisms can solve these problems. This is because they can reduce the power consumption of nodes by temporarily turning off certain facility composites, that of processor or radio module. In addition, other node activities as well as addressing schemes, routing procedures, or security should be cautiously considered to keep away from overloading the nodes. Because it increments the need for energy.

B. LINK RELIABILITY

Ensuring and maintaining a constant connection link between the source and destination nodes throughout the entire operation of the application is one of the most important factors in the design of WMSN networks.

Unlike other network topologies such as tree or star, the mesh topology method can guarantee reliable connectivity by allowing multiple paths to connect source-destination pairs. Which, in turn, in the situation of, for example, deceased intermediary node, will allow the use of alternative routing paths that can be used in the event. In addition, the requirement for reliable communication can be solved by adding and increasing the number of nodes in the limited read area, which implies a large redundancy in the path. This means better connectivity to all of the nodes in the deployed area under consideration since they would have more neighbors in the coverage area.

C. ROBUSTNESS

WMSNs need to be flexible, resilient and self-healing to deal effectively with problems like changes in topology when nodes appear/disappear, under dynamic and aggressive environmental conditions, or radio interference.

Interference, in turn, can be caused by a variety of phenomena such as radio waves reached from elsewhere, from other wireless technologies such as network devices using the same propagation medium as Wi-Fi operating in the same range.

Consequently, this requirement may obviously be covered at the expense of the benefits of the redundancy of network routes and effective mechanisms softening or eliminating such effects as external interference.

D. SCALABILITY SUPPORT

To ensure that network performance does not degrade as the number of devices increases is the requirement for scalability support. One of the next goals of the WMSN is to extend the traditional WSNs to include dozens or even thousands of battery-supplied network elements. Thus, scalability is becoming an important requirement for scalable control applications to ensure reliable communication, robustness and efficient power consumption.

E. INTEROPERABILITY

One of the functions that the WMSN protocols may guarantee is the compatibility and interoperability between heterogeneous networks, including various wireless/wired technologies. For this purpose, it is necessary to provide the ability to interoperate several networks out of influencing the complexity of software and hardware components. A wireless mesh sensor network solution supported by IEEE 802.15.4 protocol stack is an example discussed in a further Section V and is a somehow priori, satisfying interoperability with other solutions. It fully utilizes the same standard and interoperability with different wired/wireless technologies via available commercial gateways.

F. SELF-ORGANIZATION

Wireless mesh sensor networks should be easy to set up and maintain with minimal or no human intervention. For the end-user, such necessity is the most attractive WMSN network aspect, since very little effort is required to perform network maintenance tasks. However, for solution developers, self-organization is not an easy challenge. This is due to the fact that, in order to automatically organize themselves into a mesh network topology, these nodes need to have sufficient intelligence and autonomy with efficient hardware and software modules. Besides, in terms of energy efficiency, this fact must entail a significant trade-off.

G. END-TO-END RELIABILITY

Correct delivery of information to its destination is a necessary guarantee. As discussed earlier, the reliability of the communication channels can be increased due to the redundancy of the path, achieved by increasing the number of nodes in the service square.

Providing this solution can reduce the rate of lost messages in the WMSN, caused, for example, by fading due to a drop of a path in a wireless distribution environment. It is useful to note that there are applications, such as personal health monitoring or the exact location of assets that require transport-level services to transfer their information data, or at least to notify of any significant events, such as the detection of intruders in restricted access zones that arise in the network at the destination. Therefore, applying methods that support data prioritization can also improve the end-to-end network reliability.

H. PRIVACY AND SECURITY

Due to the weakness, vulnerability or non-existence of security mechanisms, wireless networks can be easily intercepted, modified or replaced, destroyed, introduced or damaged by external/internal intruders. For example, a malicious, dishonest fake user may continue to send multiple requests to the network, preventing access to genuine users who are allowed access to touch data. Therefore, security measures are one of the key aspects of WMSN.

One of the main goals of security is to ensure privacy and data inviolability, to ensure the authentication to verify the identity and availability of nodes, to ensure the survivability of applications exposed to attacks disrupting the normal operation of the network.

At the network edge, the most important services to be provided are user privacy and data protection. If an IoT is deployed in the home, a lot of personal information can be obtained from the received usage data. For example, by reading the consumption of electricity or water, one can easily assume whether the house is empty or not. In this case, how to maintain the service without compromising privacy is a daunting challenge.

Some personal information may be removed from the data before processing, such as masking all faces in the video. We think keeping computing at the edge of the data resource, for example, at home, is a worthy method to keep privacy and provide data security. To achieve privacy and data security in the network, several issues remain open:

- The first is public awareness of privacy and security. Take the security of Wi-Fi networks as an example. Among 439 million households using wireless connections, 49% of Wi-Fi networks are unsecured, and 80% of households have default passwords on their routers. For public Wi-Fi hotspots, 89% of them are unsecured [190]. All stakeholders, including the service provider, the system and application developer, and the end-user, should be aware that users' privacy can be violated without notice at the network edge. For example, IP cameras, health monitors, or even some Wi-Fi-enabled toys can be easily connected by others if not properly secured.
- Second, it is the ownership of the data collected from devices/things/nodes at the edge of the network. As with mobile apps, the end-user data collected by things will be stored and analyzed on the side of the service provider. However, leaving the data at the edge where it is collected and letting the user have complete ownership of the data would be the best solution to protect the privacy and the end-user must be able to control whether this data is to be used by service providers or not. As well as during the authorization process, highly confidential data could also be deleted to further protect the privacy of users.
- Third, the lack of effective tools to protect the privacy and data security at the network edge. Some of these things are highly resource-constrained, so current security protections may not be applicable to things because they require resources. Moreover, the highly dynamic environment at the edge of the network also makes the network vulnerable or insecure. To protect privacy, some platforms, such as Open mHealth, are proposed for standardizing and storing health data [191], but tools are still lacking to handle various data attributes for edge computing.

Wireless mesh sensor network aims to provide a clear multi-hop backhaul network capable of handling different types of data as temperature, humidity, etc. coming from the devices. More specifically, in such a context, sensor nodes can use their resources only for discovery and encryption, while mesh routers implement secure encrypted data aggregation and relay the aggregated data to the network sink.

I. MOBILITY SUPPORT

Many WSN or WMSN solutions are originally designed for static devices, and these devices/nodes usually will typically remain in their original destinations. Whereas some applications need the mobility of receivers and/or sources. For example, in large networks, to improve the various indicators, such as transmission latency or to ensure the data delivery from sources-to-recipients, receivers can be moved to different strategic points.

V. DISCUSSION AND TAXONOMY

From this study, we can conclude that the union, emergence, or connection of two different networks and their coexistence can solve and improve the problems received during their separate solitary existence.

TABLE 1. Some studies of network interconnections.

References	Title	Study Purpose	Method	Year	Result Evaluation	Future Work
[55]	Design and Evaluation of an Open-Source Wireless Mesh Networking Module for Environmental Monitoring	To extend the communication range of transceivers to make monitoring applications low-cost by embedding an off-the-shelf wireless design in sensor systems.	Time Division Multiple Access (TDMA) is proposed to communicate with the host processor through UART and GPIO implementation.	2016	Experimental results showed that the proposed algorithm achieves 94.09% in the average package delivery ratio and 5.14% in the standard deviation of the proposed module.	In the future, authors envision further investigating the performance and power consumption of the proposed module.
[192]	A Bluetooth Low Energy real-time protocol for Industrial Wireless mesh Networks	To overcome the limitations of the BLE standard that does not make available for use real-time support for data packets and which is restricted to a star topology.	The offered algorithm utilizes a Time Division Multiple Access (TDMA) method with an optimized transmission allocation, which affords data packets with real-time support for industrial wireless mesh networks that is matured on top of the BLE, which allows for meshed topologies. Authors enable BLE to bring off bounded messages delay, therefore supplying base for real-time communications, by introducing multi-hop data transmission, which allows the creation of meshed networks.	2016	The maximum end-to-end delay that was measured is equal to the connection interval. The packet end-to-end delay is always lower than the connection interval configured. This result provides an evidence of the latency bound on a single hop, which represents the most important condition for the feasibility of the proposed approach.	In the offered method the network is configured offline. A full-fledged version: dynamic configuration composited with load balancing techniques supplying better flexibility and improved reliability and fault-tolerance estimated to explore in the next studying.
[193]	Study on coupling of software-defined networking and wireless sensor networks	To effectively use restricted resources when two algorithms intend to process simultaneously on the same network.	Authors analyze coupling Software-defined networking (SDN) and WSNs, infusing needful of this conjunction to succeed in dealing with imperfections of network such as versatility, flexibility, and easy management.	2016	Researchers fact that the SDN notion could be one of the innovative approaches to efficiently make use of limited network resources, particularly of WSNs, for future networks.	Authors intend to supply a solution of programmable sensor networking that improves the challenges they describe in the study.
[194]	Wireless Sensor Network with Mesh Topology for Carbon Dioxide Monitoring in a Winery	To increase the single-point sensor network to multi-point sensor network addressing the problem of radio frequency connectivity by implementing a mesh topology.	The system implements a low-power architecture designed to increase battery life by completely disconnecting the battery from the microcontroller and sensors in the inactive state within ZigBee mesh network.	2021	Proposed designed network demonstrated increase in the life-time of the network by 2,5 times as compared to star network as not being able to replace the battery of the nodes during 5 months compared to every 2 months.	Researchers envision further investigating the performance of secure, low cost and reconfigurable edge-to-cloud device with open-source edge to cloud software for Industrial Internet of Things (IIoT) application.

TABLE 1. *(Continued.)* **Some studies of network interconnections.**

[38]	Energy-Efficient Receiver-Driven Wireless Mesh Sensor Networks	To construct a robust network against node failure and wireless channel fluctuations.	An implementation of a collision avoidance method for control packets is proposed, where the collision probability is referred as a function of the intermittent interval in which a data aggregation mechanism is reduced in frequency thus preventing collision occurrence.	2011	Simulation results ensured more than 99% in packet collection ratio and an average energy consumption of 90% lower than that the original compared protocol.	Authors assure that the maximum energy consumption that is tightly bounded to the network lifetime, could be minimized further by introducing load balancing.
[53]	Monitoring of Large-Area IoT Sensors Using a LoRa Wireless Mesh Network System: Design and Evaluation	To increase the packet delivery ratio (PDR) as well as communication range with no need for auxiliary gateways installation in the large-area networks in the purpose of dense deployment avoidance.	The paper approaches to deploy a mesh network system based on LoRa PHY rather than LoRaWAN with using the single Lora gateway.	2018	Experiments illustrated IoT mesh-networking system achieved an average of 88.49% PDR, against the star-network topology of 58.7% under the same settings.	The next research on this topic will focus on adjusting the spreading factor/bandwidth parameters dynamically to raise PDR and understand how to minimize the delays in data transmission among the nodes. As well as the security and low power issues will be focused.
[195]	WSN Based Agricultural Bird Pest Control with Buzzer and a Mesh Network	To implement the mesh topology in sensors system to enable the two directional communication of the sensor nodes.	The painless mesh library, WLAN Mesh Standard IEEE 802. 11s, was used to build the wireless sensor network.	2020	The system built shows the overall decrease of bird pests for 2.7% in the morning and 15.5% in the evening. The achievement of the proposed system in bird pests removement during five days is 10.6%.	Future studies focus on increasing the nodes for the maximum detection rate purposes with the ability to monitor the network remotely.
[196]	Comparison of data collecting methods in wireless mesh sensor networks	To compare the routing of communications packets between a centralized star type polling data collection method and a synchronized mesh type broadcast response and aggregated data collection.	IQRF technology based on Time-Division Multiple Access (TDMA) medium access using flooding mesh routing method is used.	2018	In the test application, the time duration of data collection in polling is the shortest and the number of transmissions per device is better in synchronized broadcast response, and the best simultaneous sampling is in merged data collection.	In a fully discovered network the future studies intended to improve the reliability of data collection.
[197]	An efficient hybrid topology construction in ZigBee sensor network	To define the best combination of topologies of different types to design the sensor network to certify the reliability of this communication network.	Scenarios are performed taking into account the specific features and recommendations of the IEEE 802.15.4/ZigBee standard using OPNET Modeler 14.5 with multiple ZigBee coordinators.	2014	The results conclude that the conjunction of mesh and star topologies is better to make an efficient hybrid topology, than the other star-tree and mesh-tree combinations on the network parameters like throughput, packet delivery ratio, delay and network load.	Topology formation with performance parameters such as energy consumption, network lifetime, data delivery delay, and sensor field coverage is a future work study.
[198]	Automated Production Line Monitoring Base on Wireless Mesh Sensor Network	Aiming to expand the intelligent network by covering the wide	Proposed network integrates sensing, distributed information	2020	The system has wide coverage area, flexible structure and high transmission efficiency and advantages as well as simple,	Adequate flexibility and robustness to configure resources and to deal with

TABLE 1. ***(Continued.)*** **Some studies of network interconnections.**

		area, flexible structure, high transmission efficiency and many sampling points demand to monitor and collect the embedded system data from interconnected objects.	processing, embedded computing and reliable communication technologies. Data transmission is done through GPRS module. Digital content is visualized by Augmented Reality.		fast in networking and reliable in data transmission.	disturbances effectively is the next focus area.
[199]	Wireless Sensor Network Configuration—Part I: Mesh Simplification for Centralized Algorithms	To maximize the network coverage in irregular shaped polygonal areas while maintaining a high degree of node connectivity with the centralized algorithms.	A centralized mesh simplification and mesh generation approaches with the Iterative Node Removal with Constrained Delaunay Triangulation and Smoothing (INRCDTS) technique, that may be used for any nonintersecting closed polygonal area is proposed.	2013	The improvement has been proven to increase mesh uniformity in irregular polygonal regions compared to advancing front and MATLAB PDE algorithms by 23% and 41%, respectively.	The second part of this study will compare and contrast centralized algorithms with decentralized algorithms for mobile sensor nodes.
[200]	Wireless Sensor Network Configuration—Part II: Adaptive Coverage for Decentralized Algorithms	To maximize the coverage of irregular shaped polygonal areas and maintain a high degree of node connectivity with the decentralized and distributed approach.	Provided an adaptive coverage and configuration of the mesh network by dynamically adjusting the sensing range of sensor nodes by the Extended Virtual Spring Mesh (EVSM) - Adaptive Coverage Algorithm and Protocol (ACAP) algorithm.	2013	Proposed approach provides a high degree of coverage and formation while minimizing gaps and overlap in coverage with the most optimal distance between nodes for decentralized approach with the spacing within 1.6% of the desired spacing versus 5.75% in centralized algorithmic approach.	The future study aims to explore additional criteria for multi-objective optimization of centralized and decentralized sensor network deployments including minimizing power, maximizing the lifetime of a sensor network, and minimizing the number of nodes while maximizing the coverage and formation by implementing with mobile sensors in a realistic deployment environment.
[201]	A Load-Adaptive Beacon Scheduling algorithm for IEEE 802.15.4 mesh topology improving throughput and QoS in WMSNs	To increase the throughput and lower the delay parameters of the network to transmit the multimedia data, such as voice, image and video by enabling the mesh topology over IEEE 802.15.4 Beacon-Enable mode which supports only Star and Cluster Tree Topologies.	A Load-Adaptive Beacon Scheduling (LABS) method was introduced to enable the mesh topology. As well as MeshMAC and BOP, approaches have been proposed for scheduling of IEEE 802.15.4.	2014	Because of the adaptive scheduling of the studied protocol the LABS protocol throughput showed a significant increase in comparison with MeshMAC algorithm as well as significant decrease in end-to-end delay was observed, because contention periods were eliminated in the network as much as possible.	Energy consumption of LABS in comparison with other methods may be considered. On the other hand, value of RT (periodic time interval) in LABS protocol may be selected adaptively to decrease the delay for real time applications.
[202]	Comparative Analysis of Mesh and Star	To compare the mesh topology,	Both mesh and star topologies are	2019	Based on the results of research the system using Mesh	Methods such as LEACH for the

TABLE 1. *(Continued.)* **Some studies of network interconnections.**

	Topologies in Improving Smart Fire Alarms	because of its fault tolerance nature, with the star topology in wireless sensor network on network parameters such as delay, packet loss and power consumption.	implemented and compared to discover the better topology by the ESP32 microcontroller connected to Thingspeak server. Moreover, this tool is connected to an Android phone that functions as a monitoring system in user application.		topology produces sensor data with lower delay of 43% lower than in star topology; packet loss improvement as 3% against 8% in star topology. But the power consumption compared to star topology is higher in mesh.	more power consumption friendly ecosystem for WSNs in mesh topology can be provided. As well as other topologies can also be evaluated, such as Tree Topology.
[203]	ZigBee Wireless Sensor Network simulation with various topologies	The main goal is to have low power consumption and high channel utilization, and to have the influence of MAC parameters such as beacon order and super frame order for star, tree and mesh topologies in beacon off mode and beacon on mode through different CBR load.	Nodes in the network are connected in upward or uplink direction to the coordinator of one node through IEEE 802.15.4 MAC layer physical devices, such as Full-Function Devices (FFD) and Reduced-Function Devices (RFD), of another node.	2016	It has been shown that the beacon disable mode performs better in star, tree and meshes topologies and has low energy consumption.	The analysis will be made for combination of two topologies and comparative analysis will be made in beacon enable and beacon disable mode.
[204]	The Wireless Sensor Network (WSN) for Meteorological Monitoring in Transmission Lines	To improve the robustness of the wireless sensor network and build a fault-tolerance router mechanism to settle the transmission interruption occurred by the nodes break down and collapse.	Based on the topological structure of the transmission line, a network of wireless sensors with a chain topology and a mesh topology combined for meteorological monitoring in the transmission lines is considered.	2019	In the proposed route mechanism, the router table is extended to two hops through the adjustment of transmission power so that the transmission delay and the packet loss probability is increased a little. In general, the proposed routing mechanism can let the WSN work normally with a little lower performance.	The energy efficiency problem of nodes will be considered futher.
[205]	Mobile Nodes as a Dynamic Management Strategy to Improve Coverage in Wireless Sensor Networks	To maximize the coverage area by avoiding sense on the same place by the event-triggered dynamic network reorganization to different network setups, varying adopted topology (random and mesh).	The mobility against the load balancing state-of-the-art techniques are adopted. Nodes can move itself to maximize the area coverage avoiding sense on the same place based on the force fields approach of mobile robotics.	2016	In random networks configurations, dynamically reorganized mobile nodes increase the coverage in low density networks, increasing the number of sensed events in around 220%. As density is increased, mobile nodes sense around 2% more events in comparison to the static ones.	As part of future work, it is planned to expand the conducted experiments to discuss the impact of mobility on the effectiveness of load balancing methods. Therefore, conduct a joint analysis of these dynamic management strategies.
[206]	Implementation of IoT in development of intelligent campus lighting system using mesh network	To control, to reduce power consumption and diminish power wastage, sensor embedded IoT based network system is actualized utilizing short link Wi-Fi mesh network.	Raspberry pi3, ESP32 Wi-Fi and Real Time Clock (RTC) modules by embedded different type sensors with low bandwidth, lightweight protocol as of MQ Telemetry Transport protocol with Adafruit.IO broker/server is	2018	Proposed network showed the efficiency of the system as improvement by 30%.	As a future scope of work, small size web cameras can be integrated to the system for surveillance purposes.

TABLE 1. *(Continued.)* **Some studies of network interconnections.**

			used.			
[207]	A Raspberry Pi Mesh Sensor Network for Portable Perimeter Security	To deploy cost-effective extendable and expendable sensor nodes.	A data driven approach by an inexpensive battery-operated Raspberry Pi Zero HWs (OHW) nodes with adopted High Speed Multimedia Mesh (HSMM) network is deployed.	2019	By using a wireless mesh network for communication, and implementing a number of sleep states, battery life is extended by 320% and it makes possible to add and remove sensors easily to the system. Proposed system currently supports up to 500% more sensor nodes.	Authors expect the system to only get more inexpensive, extendable, and powerful in the coming years, as the improvements in individual components enable sensor nodes to be improved incrementally and with little cost and begin exploring antennae.
[208]	Wireless sensor network cluster formation at the presence of a Wireless Mesh Network	To monitor quality of life in an infrastructure poor environment using energy-efficient cluster tree reorganization algorithm caused by topology changes.	The presence-advertising algorithm bridging IEEE 802.15.4 to arbitrarily moving nodes existent IEEE 802.11 network protocol is presented.	2010	The solution proposed in the paper focused on leveraging the collaboration of the two networks to achieve less network formation traffic. The presence is defined as a new way of routing identifying the two networks connection. Simulation results identified multiple node hops illustrating the connection.	Testing the implementation of the algorithm and checking the simulation results are the next stages of the study.
[209]	Configuration of Aerial Mesh Networks with Internet of Things	To provide solutions for intermittent link connectivity and mobility with self-configuration ability.	A middleware concept with the Simple Object Access Protocol (SOAP) integrated with Internet of Things (IoT) technology is performed.	2018	Simulation results find that in rural scenario, the Connectivity Index (CI) metric value of proposed network is more, indicating better connectivity performance of the network.	In the future, the authors would like to conduct the same experiment in different scenarios, such as in an urban or suburban environment, and compare their results in corresponding scenarios of Aerial mesh networks configured in a controlled manner using some previously defined protocols.

Table 1 lists some of the studies that have been used to connect different types of networks. From this table, we conclude that studies obtained by combining the two networks show effectiveness on different parameters. Different authors try to merge different technologies as cellular network and Wi-Fi, as well as different topologies like star, tree, ring or mesh types. The most common modern and new interconnected network is a sensor node network in which the mesh network coexists as a backbone/infrastructure. There are also many studies pointing to the use of other types of networks in common. It appears to us that to improve the overall sensor network, its' proposal with mesh topology will lead to high-quality results.

This section of the study aimed to review research papers that focus on bringing together different target networks to collaboratively solve problems that cannot be solved by one type of network alone. Each network with a different purpose and topology is designed for specific purposes. This means that when goals are expanded or upgraded and the network needs to be improved, certain types of networks cannot meet the upcoming improvement requirements. Thus, we assume that the appearance of networks of different purposes in one and a change in their topology can lead to the solution of problems that cannot be solved by a separate network. In this study, we reviewed a number of existing studies that use various networking technologies in their combined form and illustrated it in a taxonomy scheme in Figure 11. Based on the analysis of the conducted research, we concluded that connecting multiple types of networks is a good approach to improve network performance in terms of scalability, bandwidth, energy efficiency, reliability and security.

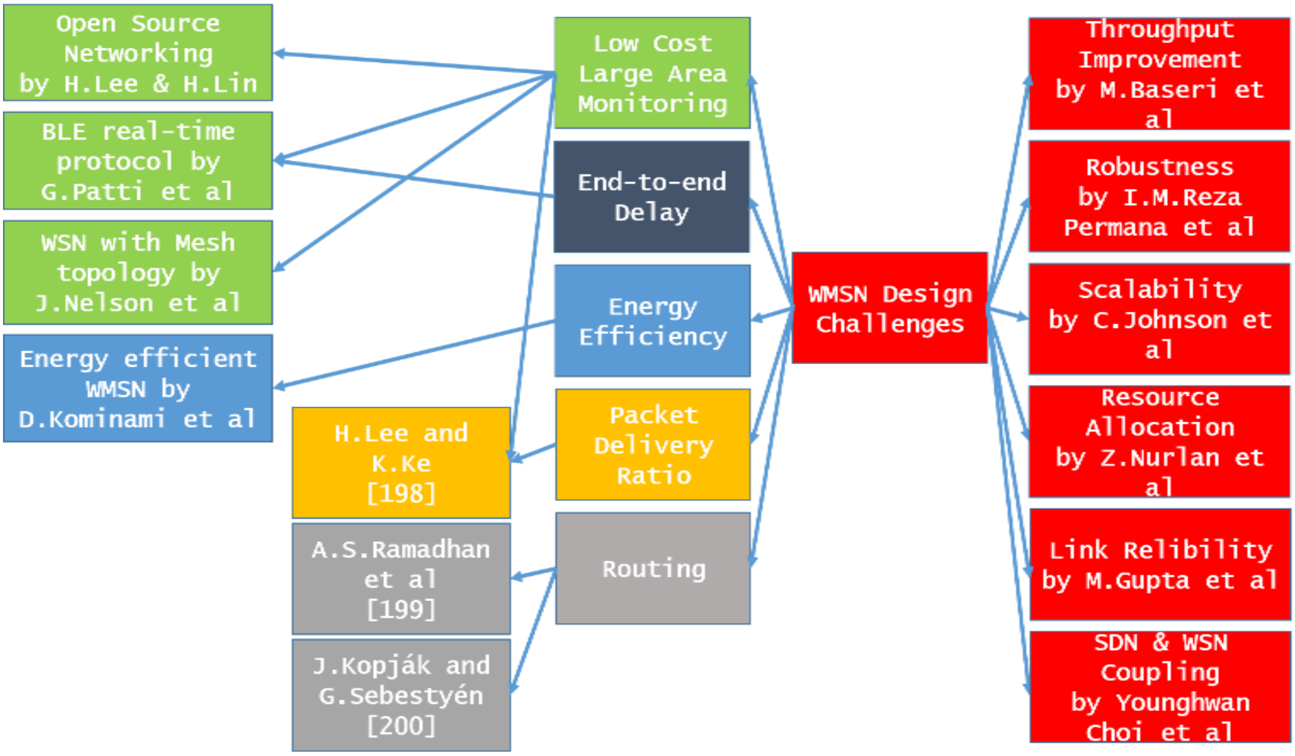

FIGURE 11. Taxonomy of the WMSN design challenges.

VI. CONCLUSION

The combination of cheap, energy-efficient devices provided the possibility to virtually monitor anything from anywhere.

The consistency of sensors brings into existence complex circumstances in which the volume of data gathered can make analysis difficult, while growing demands may rapidly convert the sensor networks no longer in use.

Careful planning and integration of wireless sensor devices with microcontrollers can assist to keep those troubles from happening by affording a platform for the new sensors and updates, as well as for bug fixes needed to keep the sensor network up to date.

However, heterogeneities in transmission technologies, routing protocols, neighbor discovery, performance metrics, and power requirements make the task of integrating technologies such as sensor and mesh channels challenging and trivial. And, unfortunately, because of such difficult problems, many of the above tasks remain unsolved. These tasks are accompanied by questions ranging from the definition of global routing metrics to the development of broadcast protocols. Nevertheless, we can optimistically believe that the listed differences in metrics between these, sensor and mesh networks, will fade out over time. And thus, WSN and WMN will converge over time and will require developers to develop adaptive network protocols usable and suitable for networks with highly heterogeneous nodes.

Furthermore, Mordor Intelligence research indicates that approaches in WMSN technology in the nearest future years will provide severe adoption of this technology in the consumer market. In this value, research by Mordor Intelligence predicts that by 2026, about 48% of wireless devices are going to be used in new services and applications that are exclusively available on mesh networks [63]. Thus, we are seeing a clear shift from traditional networks of just a few nodes to a large-scale deployment, where all of the nodes communicate one-to-another through a standard mesh solution.

It is worth noting that a star, tree, ring, hybrid, or mesh are a variety of distinct network architectures, which a wireless sensor network is able to launch. All of these topologies possess their proper discrete advantages, nevertheless, a mesh network topology is best suited for IoT applications.

In this article, we came to our understanding of joint wireless sensor and wireless mesh networks. We listed several cases where this interconnected WMSN could thrive in intelligent environments such as smart homes and cities, video analytics, large-area monitoring, as well as artificial intelligence. We put forward challenges and opportunities worth working on, including power management, connectivity, reliability, scalability support, interoperability, self-organizing, end-to-end reliability, privacy and security, and mobility support. Discussed research related to this area. And we hope that this study will bring this to the attention of the community.

VII. FUTURE RESEARCH

Implementation of a mesh network of mobile devices can be performed at different layers of the OSI model. A standard mesh solution ("802.11s - the IEEE standard for information technology'', 2011) is implemented at layer 2 (data link layer). There are also implementations at level 2.5 (with additional software between levels 2 and 3), level 3 (network), and level 7 (application).

Many industry alliances and organizations as well as IEEE [210], Internet Engineering Task Force [211], ZigBee [212], HART Remote Sensor Communications Foundation (HCF) [213], IP500® [214] and the International Society for Automation (ISA) [215] have been promoting their own commercial standards. However, unfortunately, most of them lack some important features, such as power-saving mechanisms or the ability to interoperate with other wireless technologies, or they simply have not gone through rigorous and complete testing or evaluation, which means that their true performance is practically unknown.

Although there are research papers comparing many of these proposals [64], [216]–[218], no research work looks at them collectively or focuses specifically on the WMSN domain. However, they are all new WMSN standards that will also need attention in the future.

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ABBREVIATIONS

ABBREVIATION TABLE

VoIP	Voice over IP
IoT	Internet of Things
VANET	Vehicle Adhoc Network
QoS	Quality of Service
WMN	Wireless Mesh Network
WSN	Wireless Sensor Network
WMSN	Wireless Mesh Sensor Network
MANET	Mobile Adhoc Network
M2M	Machine to Machine
LTE	Long Term Evolution
BLE	Bluetooth Low Energy
5G, 6G	5^{th} and 6^{th} Generation
OS	Operating System
RIE	Roadside Infrastructure Elements
WLAN	Wireless Local Area Network
NLOS	Non-Line-Of-Sight

PSTN	Public switched telephone network
IT	Information Technology
AI	Artificial Intelligence
OFDM	Orthogonal Frequency-Division Multiple Access
TDMA	Time Division Multiple Access

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