Wireless Networks
https://doi.org/10.1007/s11276-019-02142-z

A survey on data aggregation techniques in IoT sensor networks

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Abstract

There is a growing interest in using wireless sensor technologies in various Internet of things scenarios. Considering the huge growth of smart objects and their applications, the need to collect and analyze their product data are becoming one of the main challenges. Sensor nodes are powered by batteries, efficient operations in term of energy are critical. Toward that end, it is desirable for a sensor node to eliminate redundancies in the received data from the neighboring nodes before transferring the final data to the central station. Data aggregation is one of the influential techniques in elimination of data redundancy and improvement of energy efficiency; also it increases the lifespan of Wireless Sensor Networks. In addition, the efficient data aggregation protocol can reduce network traffic. When a specific objective takes place in a specific area, it might be detected by more than one sensor. Considering the main challenges and aspects of data aggregation in wireless sensor networks, a review on different types of data aggregation techniques and protocols are presented in this paper. The ultimate objective of this study is to make the basic foundations to develop new advanced designs based on data integration techniques and clustering that have been proposed so far. Major techniques of data integration in wireless sensor networks covering ground, underground and underwater sensor networks are presented in this paper and the applications, advantages and disadvantages of using each technique are described.

Keywords Internet of things (IoT) · Wireless sensor networks (WSN) · Data aggregation · Routing

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1 Introduction

Daily progressive spread in using technologies such as wireless networks and smart devices which are equipped with different sensors, radio frequency identification labels (RFID) and near field communications (NFCs) have led to develop the thought of the new technology concept of internet of things (IoT) for daily human's life [1]. Internet of things describes a world in which everything including inanimate objects have digital identity for themselves and let the smart systems to organize and manage them. The idea of internet of things promotes the potential of communication, data exchange, aggregation and integration among the objects existing in our surrounding [2].Anything in this space has some services which presents them to other things or existences and receives its required services. For simpler and faster communication between these objects and the potentiality to manage them, some models and criteria have been presented that have the capability to receive and present a special service automatically. Given the extent of work in the IoT and the emergence of

Published online: 25 September 2019

categories such as the smart cities, smart factories, intelligent vehicles, smart buildings, smart wearable, care and health, it is required to create a system with lowest challenges. For this purpose, it is needed to remove the existing challenges in order to improve and increase the daily use of this interdisciplinary technology. Many researchers are working in different fields for resolving the challenges existing in smart internet. In the following, some of these challenges in terms of international union of communication are observable:

Connection regarding to the ability of internet of things, everything can be communicated and connected to the infrastructures of information and global communications. Thus, this volume of communication will bring about numerous problems; for instance, how these are connected to each other and how such volume of information are processed and/or stored.

Inconsistency and non-homogeneity in the rest of developing internet of things, it is expected that millions of various devices in whole the world connect to each other through various ways. Thus, organizing all these heterogeneous things will be known as a basic challenge or problem. In this respect, some businesses can be created and developed via the opportunity of market's need to present the required services.

High dynamism of changes in the field of internet of things the situation of tools in the field of internet of things is constantly changing (night, day, work hours, work sessions and etc.) and connection and disconnection to the network; the type of tool connected to network (for example, a tag on the box to moisture sensor in weather station). Thus, the number of tools connected to "Network of everything" is alternatively changing and these changes will make their management very challenging.

Vast scale wide area and vast scale of internet of things which are due to connection places and as well, the number of connected devices will encounter the management of this field with fundamental challenges. Besides the challenges mentioned above, some items such as architecture of internet of things, identification, connection, network technology, network identification, software and algorithm, hardware technology, data and signal analysis, discovery and search engine, network management, energy storage, security, trust, independence and privacy are interactive and the related standards are posed, too. Moreover, another problem stated as challenge in this field is the lack of global standards accepted and agreed by public; this is counted as a very serious problem; since different devices and things need common language to interact and this can be paid attention in comprehensive standards. Among the challenges above, security is much more serious than others. In this respect, Fig. 1 shows the key technologies involved in internet of things.

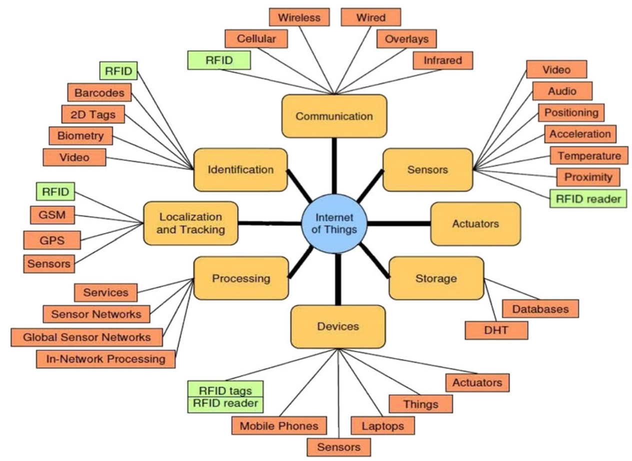

Fig. 1 Tools involved in internet of things

Each of the important technologies in internet of things including sensors, wireless communication devices, RFIDs, storage systems which contain different tools are progressing and updating every day. In this regard, there are some vital pieces that advancement in them; it requires solving the challenges in several areas and they play key role of the IoT in the future. Therefore, we can name two fields of RFID and wireless networks. About wireless systems, we can refer to involvement of some parts such as communications (wireless networks), sensors (wireless sensors), wireless operators, processing (global sensor network), locating (wireless sensors with locating capability) and etc. For this purpose, utility of wireless sensor networks in internet of things are investigated in the following.

Applicability of wireless sensor networks in IOT

With the advancement of technology, using some equipment such as cell phones, messengers, and similar apparatuses have become possible through the wireless networks. If the applicable programs of users or companies demand to have the required data and information dynamically at their disposal, the wireless sensor networks are proper response for them. Advancements of late technologies in developing electronic circuits with low energy consumption in wireless communications have led to emergence of tiny equipment with low energy consumption, low cost and high efficiency in order to be used in measurement applications and remote calculations [3]. This subject helps to raise the efficiency of a wireless sensor network consisted of infinite number of smart sensors and as well, processing, analysis and distribution of worthy information collected from different environments. The data gathered from sensor nodes are shared and next, are sent to the centralized or distributed system to be analyzed. Among the most evident merits of this technology compared to other smart technologies is the diverse range of sensors among which we can refer to mechanical, thermal, environmental, chemical, visual and magnetic sensors. These sensors are attached to things and then, can measure different environmental conditions, while such ability does not exist in other smart-maker technologies. The idea of "every time, every place and every media" was a perspective which greatly contributed to advancement of communication technology for a long time. In this respect, the wireless technology has a key role and today, it plays an important role in communications among people. Decrease in size, weight, energy consumption, and cost of wireless communications has made the human to enter a new period of development in using this technology. Outreach in using this technology allows individuals to add the word "everything" to the phrase stated above and get close to the concept of "internet of things" [4]. In this regard, one of the key elements in internet of things is the radio frequency systems. This technology is the combination of one or more radio frequency single reader apparatuses and several radio frequency labels. From the properties of these labels, we can name the uniqueness of their identity and usability in things and even individuals and animals; thus, the radio frequency systems can be used to control the thing in every moment without any need to direct connection to that thing. This capability permits us to convert the real world to virtual world and this technology can be incredibly used in a vast range of applicable software, transportation, electronic health and security. The wireless sensor network like other radio frequency systems have decisive role in the technology of internet of things. In fact, these networks can provide more and better information of things including place, temperature, displacement and etc. for us by a combination of radio frequency systems. Such networks complete our knowledge of the environment; therefore, it can be supposed as a connection bridge between physical and virtual worlds. Sensor networks can be used in different ways including control of environment, electronic health, smart systems of transportation, military spaces, control of industrial units, crowdsourcing and crowdsensing [5]. Sensor networks have been made of definite number of sensor nodes (may be high number of nodes) and these sensors are connected to each other wirelessly. Sensor nodes usually transfer their obtained information to one or some specific nodes named sinkhole. In recent years, numerous researches have been conducted in recent years regarding the construction of sensor networks and the relevant problems together with presenting the offered solutions for various layers of the protocol connecting among layers. These solutions are about different subjects such as optimal use of energy resources in sensors, scalability, error tolerance, accuracy measurement in high level, low cost and properties of fast makeup of sensor networks . These issues are at priority of researches. These problems include: error tolerance, scalability, cost, hardware, changing network regulation, environment, and energy consumption.

One of the problems usually discussed is the data aggregation in wireless sensor networks. Indeed, in WSNs, the sensor device is said to a device that can sense certain physical parameters of the system or a specific region and converts the sensed data to electrical signals and then transmits signals by means of wireless radio to the base station. Unlike conventional sensors, wireless sensors have limited energy because they work with small batteries that recharging in remote or dangerous environments, is difficult or even impossible. The data aggregation techniques are used for reducing the amount of data sent and increasing network lifetime in a wireless sensor network.

Wireless sensor network includes one or more sensors. They are usually randomly scattered in spaces that have less human intervention in them. The distributed sensors can collect data and send them toward the base station or sink based on multi-hop system architecture. Energy conservation is one of the important factor in this network. Sensors are consumed a lot of energy when data is sent by the transmitter. Thus, manage packets is essential on this network. This is done by merging data by middle sensors through the network as well as data compression [6]. The effects are energy efficiency in sensors utilization, increasing network lifetime and efficient bandwidth. In this context, the data aggregation is known as an effective technique for combining data. Data gathering or aggregation performs the process of collecting data from multi sensors. Another contributing factor that impacts data aggregation is the most essential data delivery using efficient manner with minimal data latency. So for increasing the lifetime of the sensor network, different data aggregation algorithms according to the conditions are produced. Figure 2 demonstrates a general idea of IoT data aggregation in WSN.

Data aggregation in IoT such as wireless sensor network (WSN) is important, because in IoT, we have heterogeneous data collected from different sources and more energy is needed in order to send data [7]. One of the solutions to reduce energy in this case is to process and aggregate data prior to data sending, and this time, to send the aggregated and summarized data.

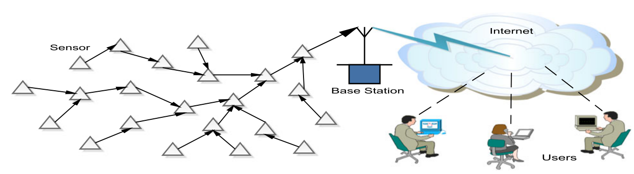

Fig. 2 General idea of IoT data aggregation in WSN

One of the problems with data aggregation in IoT is the heterogeneity of data in this network. For example, data may be in the form of image, audio and sensory data. In this case, the need for data modeling and compressing is discussed.

Due to the extent of the network as well as the large number of nodes in one place, WSN has led to high reliability of data, but on the other hand, data reported by the neighboring nodes have caused a high redundancy. Therefore, sending data separately from each node leads to energy consumption and causes an increase in the bandwidth across the entire sensor network, leading to reduced network life span. To prevent this problem from happening, data aggregation techniques were introduced; the aim of aggregating data is to eliminate excessive data transfer, increase lifespan and energy, reduce traffic and decrease data overlap in the network.

Below some of the internet of things (IoT) applications and the necessity for data aggregation are explained in order to make easier to understand the importance of data aggregation in the real life:

Among the common uses of the IoT are improving the production efficiency of factories, monitoring and controlling individuals' health in a community, the continuous updating of city data, such as car park places, etc., which are done by the IoT platform. This platform brings together and aggregates valuable data and creates a common language for them so that data can interact with each other between various equipment and their applications, and can be sent. Each device has a processor which securely transmits data to the platform after it has been locally processed. The platform receives data from various devices and shares their valuable data with their special applications. Accordingly, by assuming the connection of a vehicle to the IoT, data aggregation becomes more tangible. In this example, assume a vehicle; suppose that after driving a long distance, the driver receives vehicle control messages, for instance, receives a warning message indicating the vehicle should be taken in for repair, but the driver does not know whether the car need to repair shop is urgent or it can be postponed to another time, or even does not know which is the best repair shop and/or where is located the nearest vehicle repair shop relative to the driver situation. If we consider IoT with regard to this application, a set of different units measure the brake line pressure or anything else in that vehicle. These different units are located in different parts of the vehicle, but interact to each other.

The chip which is located in the vehicle calls data from a bass called the fault detection bass of that vehicle, gathers data from different centers and puts them in the transmission gate. In addition, the transmission gate receives data from different sensors and transits them securely in an aggregated way to the platform to consume lower energy. But before sending these organized data, the gate of various vehicles and platform should securely communicate with each other. The platform consistently receives data from thousands of different vehicles during 24 h a day and 12 months of a year and makes a secure database using these data.

The factory adds rules and logics to the platform, indicating what a platform does when an information machine sends a defect to it. Moreover, the factory uses the platform to manage and build applications. For example, the factory adopts system management assistant application. This application receives customers' data in the road, and then uses the received data to send suggestions and messages to the customer. These messages announce the machine repair and service time, the path to reach the nearest repair shop, discounts available for the driver, etc., and when the vehicle and driver reach to the repair shop, the vehicle warranty contract is approved by the factory, and even the factory can suggest to the repair shop what piece is suitable for that vehicle, which part is defective and what to do.

Even the engineers can use these data to develop, improve, or resolve the faults in the vehicle design. Given the data received on the faults of various vehicles, these data also help the factory detect faulty pieces, the series of vehicles with that defective part, the factory which have manufactured the faulty piece, or even that piece manufacturing date using the analysis of data. All of these help to improve factory products safety and efficiency and safer and faster driving.

It may, however, be said that these data transmissions by in-vehicle and factory devices require consuming the vehicle battery energy. To this purpose, the aggregated data causes a reduction in the energy consumption and the number of data sent and received.

To name another use of data aggregation in this type of networks, we can refer to installation of sensors on the patient's body in order to control vital signs. Due to being used inside or on the human body, they are required to be connected to small batteries. Therefore data should be aggregated in order to consume less energy compared to the past so that the batteries need to be recharged later. Another application is putting the sensors in hard conditions such as the reinforcement of buildings because of the possibility of building conditions over several years and the effects of the earthquake on it or putting underground sensors to detect earthquake time that in both cases, it is difficult to access to sensors in difficult locations and must have a long life due to being the sensor in hard locations. Another application of aggregating data is using sensors on the body of fishes and sensing the annual motion of fishes that due to having GPS sensors, consumption of these sensors for a duration of about 6 months to a year is very difficult and important; appropriate methods of collecting data should be used for these sensors. Another application of data aggregation is in connection temperature sensors to soldiers and the transmission of information to ensure soldiers are alive due to special circumstances; such sites must have long lifetimes and require the integration of data to reduce energy consumption. Moreover, the temperature sensor networks is used to report forests temperature or status or location within the forest creatures that in such situations the difficult access to these sites has led to the idea of integration and compression of data and use of data aggregation protocols.

This article aims at dividing networks according to where they are used: networks on the ground, multimedia, undersea, underground and In the human body. A comparison between the data aggregation and not aggregation in the wireless sensor network is presented in Table 1 [8].

In IoT scenarios based on wireless sensors, the cost of communication between consumer nodes is high. Data gathering techniques have been created to reduce the size of additional information and increase the network lifetime.

The rest of this study is organized in four parts which covers data aggregation in four common IoT scenarios based on wireless sensors (shown in Fig. 3): (1) Terrestrial WSN in Sect. 2, (2) Underground Wireless Sensor Networks in Sect. 3, (3) Underwater Wireless Sensor Networks in Sect. 4, (4) Wireless Body Sensor Networks in Sect. 5.

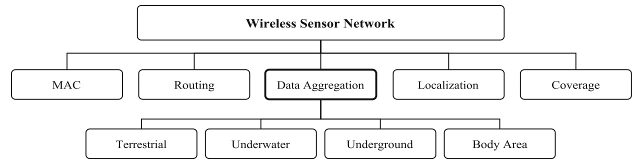

Fig. 3 Data aggregation in WSN

2 Data aggregation in terrestrial WSN

There are various techniques for data aggregation on WSNs. Since energy conservation is one of the most important challenges in the data aggregation, a data aggregation technique to be able amount of energy used by each sensor node data collected at each cycle to reach equilibrium. In addition, a WSN has been often designed with a particular application in mind. Based on the application requirements, you may have some QoS metrics such as packet loss, delay and beam alignment [9] need to be supported. In the following sections, the main techniques of data aggregation in the proposed ground wireless sensor networks are introduced in two main parts, Network Architecture and Computational Intelligence.

2.1 Impact of network architecture data aggregation

Architecture of WSNs is effective in the performance of Data Collection(DC). In this section, we consider several DC protocols that specifically aim architecture of WSNs which is shown in Fig. 4.

Table 1 Advantages, disadvantages and challenges of scenarios with data aggregation versus without data aggregation

Without aggregation	Advantages	For all measurements environment is applicable
		In the event of a routing problem, it can be solved easier with a simple linear program.
	Disadvantages	The amount and size of transmitted data is higher
		The amount of energy consumption from one node to another node is increased for transmission
		Data may be received by multiple nodes alike
	Challenges	The possibility of forming a cavity near the Sink
		Ability to network outages in long distances with high data volume
		Increase in the vain transmitted data due to the taken data by some nodes
With aggregation	Advantages	Reduce the size and amount of data transmission
		Sensors have the ability to integrate multiple aggregation
	Disadvantages	It is not applicable for all measurement environments
		Aggregator or clustering head may be attacked or failed
		In some cases, energy consumption of data aggregation is increased
		Remove duplicate data and improve energy efficiency
	Challenges	Data aggregation in the limited acceptable time intervals should also be carried out
		Due to the application, different compression rate needs to be done
		Energy optimization, Since sensor nodes have limited battery power, timing protocols, in order to fall asleep efficient nodes, unemployed sensor nodes should be used for energy storage

Fig. 4 Data aggregation based on network architecture

2.1.1 Structure-based methods

This method contains two modes namely Flat Method and Hierarchical Method. At first, general comparison of these two methods is observable in Table 2. In the following, each of the intended methods and the protocols existing in each one have been reviewed

Flat methods In this networks, all sensors are playing the same role. These sensors to be affiliated with each other for doing sensing job. For example, in torrential method, a query is broad-casted to all the sensors by the base station. The node which is proportional to the query, transfer the answer to the base station. Multi-hop path through which data is transmitted is used for the implementation of data aggregation. As a result, network delay is very high. One of the drawbacks of flat networks is that data aggregation is accomplished only in the specific area (Sink node) by the data transfer. This increases the overhead calculation on the Sink node and leading to discharge faster. In the placement stage, if Sink node fails, the entire network goes down; this in turn increases the overhead [10].

Hierarchical approach The main goal of this routing is energy efficiency of sensors within a cluster step to engage them in a special secure communications. Cluster information is generally based on stored energy in sensors and proximity of sensors with cluster Head (CHs). Energy storage is improved by using clustering which improve energy consumption, network lifetime and scalability in WSNs. Because only cluster head node for the cluster is required to perform the task of routing, cluster nodes per cluster for the task of routing header is needed, other sensor nodes send their data to the cluster head and data is aggregated in this way [10]. Table 2 presents a comparison of data collection with hierarchical versus flat method.

Hierarchical—cluster-based aggregation In this approach, node dissimilarity, and programming reservation-based uses clustering. In aggregate based on the cluster, the network allocates a cluster head for the implementation of data aggregation. The key purpose of the method is the effective implementation of energy aggregation of data in large networks. This method effectively decreases energy consumption of sensor nodes with limited energy in large networks.

Next, more details on some of the common cluster-based aggregation protocols is provided. LEACH protocol and its descendants: LEACH is a low-power adaptive hierarchical clustering protocol. In LEACH, nodes can arrange themselves to local clusters. LEACH is one of the most popular probabilistic clustering protocols. In LEACH, by finishing the energy of cluster head node, the whole cluster does not fail and life of cluster does not end, cluster nodes with higher energy become cluster head with a random and rotating basis. In addition, the data are locally combined so that the amount of data that must be sent to the base station and therefore network lifetime is increased and energy consumption is reduced [11, 12]. HEED [13], EECS [14], EEUC [15], Max-Min D-Cluster Algorithm [16],LEACH-MAC [17], LiMCA [18] and VAP-E [21] techniques function based on the remaining energy and distance from the neighboring nodes. Some of the clustering techniques select cluster heads based on special criteria such as CFL [22] method based on weighting network nodes, BRAC [11] based on math cluster battery model, FoV, CACC [23] based on cluster selection according to celling and KOCA based on K-step overlap and

Hierarchical—chain based aggregation String-based aggregation is of the hierarchical methods that constitute the architecture of string. By this method, the energy is distributed equally and each sensor node can be associated

Table 2 Comparison of data collection with hierarchical versus flat method

Flat approach	Hierarchical approach
Data collecting by different nodes along with multi-hop path	Data collecting by the head cluster or a head node
Formation of data collection only in areas where there is data to transfer	Clusters or chains involved in the formation of networks.
Certain node death may fails network	The network can continue its work despite the problems in cluster head
Higher delay in data transmission to Sink through a multi-hop route	Low delay in data transmission in low distance
There is an uneven but improving network nodes are not affected	Heterogeneity specific node cluster nodes
Optimal routing overhead	Our simple routing structure is not necessarily optimal

with adjacent nodes. TOKEN exchange method is used to select the leader. When TOKEN is received, the node sends data to the aggregation node and finally to the Sink station.It solves the LEACH problems largely by eliminating the overhead of dynamic cluster and minimizing the number of transmissions and receptions. Efficiently collecting power in information sensor systems (PEGASIS) declares the protocol for string-based routing. Oriented strand sensor network protocol for efficient data collection (COSEN), hierarchical routing protocol based on the string (CHIRON), are other protocols based on the different string networks.

In addition, a summary of these methods and their merits and demerits have been presented in Table 3. For more investigation, you can refer to posed resources.

Location-based approach In this method, the addresses of sensor nodes based on location can be identified [96, 97]. The position of nodes is detected by the power of the input signal or using a global positioning system (GPS) [19]. In order to decrease the consumption of energy , passive nodes are set to sleep mode. Location-based routing protocol is based on the method of SPAN protocol.

2.1.2 Structureless aggregation

The integration of unstructured data does not support structure. This structure is very useful for event-based applications that vary by the region of the event. If a node fails there is no need to rebuild the structure. The main disadvantage of aggregating unstructured data is that creating a routing decision for implementation of data aggregation [10].

2.1.3 Other methods

Tree-based method In this approach, aggregating data is done through creation of data aggregation tree, which can be a spanning tree is minimal. Finding optimum tree aggregation which minimizes number of transmission and maximizes the lifetime of the network is the NP-Hard problems and approximation algorithms have been presented for constructing the tree.

If we compare the tree-based approaches with the cluster-based method approaches, cluster-based approach has average overhead, a low energy uniformity, average strength and flexibility, scalability and low power consumption versus tree-based methods that have high overhead and energy uniformity, strength, flexibility, scalability and energy consumption is the average.

Grid-based In grid-based data aggregation, the array of sensors are like an integrator in the constant region of the sensor network. Sensors within a particular grade send data directly to the integrator of the grid, so the grade sensors do not communicate with each other. The grid-based data aggregation, integration is a constant in every grade and the grade received and aggregated data from all the sensors. This is similar to the cluster-based data aggregation that the cluster head is fixed. Grid-based data aggregation is useful for moving situations like military surveillance, weather

Table 3 Advantages and disadvantages of Chain based methods

Protocol	Brevity	Brief description	Advantages	Disadvantages	References
Power-efficient gathering in sensor information systems	PEGASIS	Each node communicates with its neighboring node and information reaches to cluster head and Sink node	Reducing energy consumption	String leader must shift change—delay in sending information	[24]
Chain oriented sensor network for efficient data collection	COSEN	A protocol for data collection in terms of low energy	Improve energy and delay	Allow the transmission of unnecessary information	[11]
Enhanced power-efficient gathering in sensor information systems	EPEGASIS	Improvement of concentric clustering scheme PEGASIS	Reduce transmission path and increase the lifetime of the network	More consumption—further delay	[11]
Chain-based hierarchical routing protocol	CHIRON	Offer based on the concept of beamstar and divided into smaller areas to create chains	Reduce unnecessary routes and improve energy	Many small chains	[25]
Pegasis Algorithm improving based on double cluster head	PDCH	The algorithm uses clusters of low-level header and the header for improved load balancing	PDCH performs better PEGASIS algorithm and it's also useful for large networks	High overhead in the early installations	[26]

forecast and adaptation to dynamic changes in the network and mobile events [27].

Hybrid methods Hybrid methods are created by the combination of hierarchical data integration techniques, some of which are as follows. PEZCA (Power-Efficient Zoning Clustering Algorithm) method including LEACH and PEGASIS considering zoning closer and small clusters and VoGA (Voting-on-Grid Clustering) which is a combination of voting method and clustering algorithm to reduce costs of calculation [11]. From another viewpoint, iLEACH and PROPOSED-DA are improved LEACH methods that have presented useful solutions with the aim of reducing energy consumption and increasing life span [28, 29]. The three of data integration of structureless aggregation be compared in Table 4

PSO based methods PSO methods are well-known optimizer algorithms that can be used in wireless sensor networks. These methods include (1) Clustering which can be applied only when each node has a multi-directional transfer range; (2) PSO-clustering: Nodes with the energy levels higher than the average energy source will be selected as cluster headers in PSO-clustering which function better than LEACH and LEACH-C methods; and (3) Minimum Spanning Tree-PSO: whose optimized path between the nodes and cluster header are searched for based on energy consumption.

Moreover, it is noteworthy that PSO-based methods regarding to the architecture of network are a combination of artificial intelligence methods and noted protocols of network architecture from the perspective of intelligence.

A general comparison of some of the most prominent and most practical network-based protocols in Table 5 is significant.

Additionally, it should be noted that one of the ways to improve data aggregation is the right data routing toward source, and from there, to the data source and sending it to Internet. A lot of research has been done in that regard; amongst them we can refer to Article [67]. Given the various routing methods based on network architecture, attempts have been made to select and describe the best routing method.Also, one of the best articles in comparing three methods of Tree based, Cluster based and Centralized is described in article [68], A detailed and thorough description of these three methods is described. If you choose one of these methods, it is recommended to read this article.

2.2 Data aggregation based on computational intelligence

Data aggregation is attempting to reduce the number and size of data transmission and the therefore the lifespan of energy of network is stored. Data aggregation is done either by reduction of data transmission to source and data compression or by integration of incoming packets from multiple sources without processing them and sending packets. Computational Intelligence in recent years with advances in computational intelligence have been made that these systems enter wireless sensor networks. To see the performance of the network it is required that environmental parameters are calculated which are lifetime of the network, data accuracy, delay, energy efficiency, bandwidth, capacity and power consumption, hop count and the strength of the signal [69]. The best fit for the data aggregation issues and evolutionary algorithms are Genetic Algorithm (GA) [70, 71] , GA sensor fusion, fuzzy logic and Millimeter Wave Sensor Networks [72]. An outline of existing methods is observable in Fig. 5. In addition, a summary of these methods and their merits and demerits have been presented in Table 6. For more investigation, you can refer to posed resources.

3 Data aggregation in wireless underground sensor networks (WUSNs)

This network consists of underground wireless devices. These devices are either fully in dense underground or in outdoor unearth mines and tunnels such as well as road or subway. WUSNs are used to enable wide and varied applied programs that are not possible with groundwater monitoring techniques.

3.1 Advantages, applications and challenges of WUSNs

The WUSN study requires several unique challenges. In particular, the strong and close interaction between the environment with the soil's properties, temperature, climate, location and communication parameters leads to several challenges, including underground channel dysfunction, antenna design, and the effect of soil properties on communications [73]. In this section we will describe 2 network challenges.

Energy efficiency Depending on the type of intended application, the lifetime of WUSNs should be at least several years in order to make cost effective deployment. These challenges are complicated by underground channel having a lot of wastes, which makes necessary WUSNs have radio with more transmit power than ground-based WSN devices. Long lifetime of the network is vital given that the underground sensors can't be recharged or replaced easily. So energy efficiency is considered as a major concern in the design of WUSNs, such as the underground wireless receiver network, the lifetime of the WUSNs is limited by the energy constraints of each device. In

Table 4 Comparison of tree, grid and hybrid-based data aggregation

Protocol	Brevity	Advantages	Disadvantages	Network type	References
Data aware any cast	DAA	Event-based method, in the case of node failures, restructuring not needed	Making routing decisions and implementing integration is a challenging task	Structure less	[30]
Energy-aware data aggregation tree	EADAT	Broadcast method begins by Sink node	Auxiliary broadcast messages, can not specify a method for determining the power limit	Tree	[32]
Energy-SPAN	E-SPAN	Power consumption is lower in data transmission.	Ease of resources within an area event to perform data aggregation	Tree	[33]
Tiny aggregation	TAG	Query-based approach and multi-casts are supported	An overhead track is formed.	Tree	[34]
Center at nearest	CNS	Faster data transmission	Pitting near Sink	Tree	[35]
Shortest path tree	SPT	Overlapping routes is achieved by combining aggregation tree and Shortest route	Energy problem in nodes	Tree	[35]
Greedy incremental tree	GIT	Shortest route	Energy problem in nodes	Tree	[35]
tree based energy efficient protocol for sensor information	TREEPSI	1. Data transfer with less energy 2. performs better than LEACH and LEACH-C as the tree formation [36]	Constructed path produces additional topology and an alternative routing	Tree	[37]
Power efficient routing with limited latency	PERLA	Avoid the use of unnecessary routes	More energy needs To identify errors and improve it	Tree	[38]
Tree-clustered data gathering protocol	TCDGP	Reducing energy consumption	The way to improve it is needed	Tree	[35]
A grid-clustering routing protocol for wireless sensor networks	GROUP	Sharing the load among the sensors in the network	Periodically aggregation tree and pick the clusters based on the distance of the grid is done	Grid	[39]
Aggregation tree construction based on grid	ATCBG	1. Select the cluster based on energy and distance 2. cluster head with energy less than half the energy needed alternative action is done	Tree construction is only based on energy	Grid	[40]
Tree-clustered data gathering protocol	TCDGP	Reducing energy consumption	Node recovery process is complex	Cluster and tree	[41]
Chain-chain based routing protocol	CCM	Improves network lifetime.	Overhead in cluster head selection	Chain and cluster	[42]
Clustered diffusion with dynamic data aggregation	CLUDDA	The same cluster communication	Urgent memory still needs	Cluster and diffusion	[52]
A cluster-based routing	CBRP	Centralized computing features	The number of non-data messages exchanged between the sensor nodes	Cluster and tree	[54]
Improved LEACH	iLEACH	Reducing energy consumption	Early death of first node because of a hole near the Sink node	Cluster and tree	[28]

addition, accessing to WUSNs devices for establishment of rebuilding construction to recharge or replace damaged ones is difficult. In addition, underground wireless sensor devices can be equipped solar cells completely or even replaced with power sources, which is a non-obvious option for underground devices. Opportunities are restrained for WUSNs such as transforming earthquake vibrations or thermal gradient to energy.

Topology design Designing an appropriate topology for WSNs is critical for network reliability and energy

Table 5 Comparison of data aggregation based on network architecture

Protocol/solution	Brevity	Network type	Consumed energy	Application	References
Sensor protocols for information via negotiation	SPIN	Flat	Limited	Habitat monitoring	[55]
Directed diffusion	DD	Flat	Limited	Environment monitoring	[56]
rumor routing	RR	Flat	Low	Habitat/ environment	[57]
Gradient based routing	GBR	Flat	Low	Health monitoring	[10]
Constrained anisotropic diffusion routing	CADR	Flat	Limited	Environment monitoring	[58]
The cougar approach	COUGAR	Flat	Limited	Environment monitoring	[59]
Mechanism for efficient querying	ACQUIRE	Flat	Low	Environment monitoring	[60]
Low-energy adaptive clustering hierarch	LEACH	Hierarchical/cluster	High	Health and underwater monitoring	[11]
Low-energy adaptive clustering hierarch-C	LEACH-C	Hierarchical/cluster	Limited	Health monitoring	[61]
Hybrid energy efficient distributed protocol	HEED	Hierarchical/cluster	Low	Environment monitoring	[11]
The clustered aggregation	CAG	Hierarchical/cluster	Low	Habitat monitoring, home/office monitoring	[62]
Threshold sensitive energy efficient sensor network	TEEN	Hierarchical/cluster	High	Home/office monitoring	[63]
Power efficient gathering in sensor information systems	PEGASIS	Hierarchical/chain	Max	Disaster monitoring	[11]
Chain oriented sensor network	COSEN	Hierarchical/chain	Low	Battlefield monitoring	[64]
An energy-efficient chain-based hierarchical routing protocol in wireless sensor networks	CHIRON	Hierarchical/chain	Low	Civil/military monitoring	[65]
An energy-efficient coordination algorithm for topology maintenance in Ad Hoc wireless network	SPAN	Hierarchical/ location	High	Civil/military/habitat monitoring	[33]

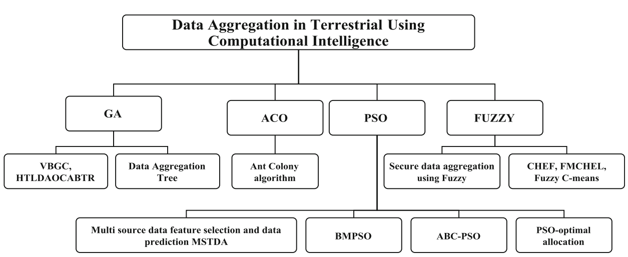

Fig. 5 Data aggregation using computational intelligence techniques

efficiency [74]. The topology of WUSNs is likely to be different from their ground counterparts. For example, the location of a WUSNs device is usually carefully planned due to the drilling effort required to deploy it. Also, the 3-D topologies that are common in WUSNs are dictated by the devices deployed at various depths by the measure software. In topology design, reducing the power used and the cost of deployment should be considered in design. The WUSN topology design is faced with the following considerations:

Intended application Sensor devices should be placed close to a phenomenon that has been deployed to sense it. Some applications may require the very dense deployment of sensors in a small area, while some may are interested in lower density in a larger area. Since communication is considered as a major concern in network deployment, applications that require the deployment of sensors in high depth and mediating sensors for providing communication paths between the sensed phenomenon and the ground surface.

Reducing power consumption Smart design of topology can help maintain power in the WUSNs. Since the damping is minimized proportional to the distance between the transmitter and the receiver, power consumption can be minimized by designing a topology with a large number of short-range hops instead of a smaller number of long-range hops. In addition, wireless underground channels require careful study because they are significantly presented in the air with different characteristics of their counterparts.

Table 6 Artificial Intelligence techniques for data aggregation

CI paradigm	Algorithm	Task of CI approach	Centralized/ distributed	Objective	Summery	References
PSO	PSO-optimal allocation	Allocate optimal transmission power	Centralized	Minimum energy and error probability	The pso is used to determine the optimal power allocation in cases related independent observations with the aim of reducing energy consumption while maintaining specifies the error threshold is required fusion	[46]
	ABC-PSO	Determine Local threshold	Centralized	Minimum decision error	Using combination of PSO and ant protocols that manage the integration by the hierarchy management of the serial sensor networks	[45]
	BMPSO	Determine sensor configuration	Distributed	Minimum decision error and transaction time	In this method for integration have been used multiple sensor fusion making decisions using Bayesian fusion from different sensors	[44]
	Multi source data feature selection and data prediction MSTDA	Data prediction	Distributed	Minimum energy	Remove data replication features using entropy function	[43]
FUZZY	CHEF, FMCHEL, Fuzzy C-means	Cluster head election, event detection	Distributed	Energy optimization	Integration is done by B-MAC protocol and using a weighted average based between the approximation and the new integration value.	[47]
	Secure data aggregation using Fuzzy	Select the secure node	Distributed	Reduced power consumption	Based on the power level and ensure node - phase system and emphasis on three factors: path length, along the way, available power, node credit	[48]
GA	Data aggregation Tree	Aggregation tree generation	Distributed	Increased life time	Create a tree by a chromosome and improve it through the division of parent nodes and improvements in future generations	[49]
	VBGC	Optimal clustering	Distributed	Coverage, energy optimization	The procedure for data aggregation by genetic algorithm prohibits the premature convergence and to search for new solutions instead of the current uses of the search	[50]
ACO	Ant Colony algorithm	Data aggregation tree	Distributed	Energy minimization	Use multi-step routing nodes for aggregating and weighting by ants	[51]

Cost Drilling required for deployment requires cost. Additional costs are needed for replacing or recharging the device when the power supply of each device is degraded, therefore, it should be avoided the deployment of devices at high depths and the number of devices must be minimized.

Condition and type of soil The close and strong interaction between the type of soil and the situation in which the network is deployed is considered as an important characteristic of the underground relationship. The damping properties may change significantly depending on the soil, which have a significant effect on the design of the topology. In addition, for even the same type of soil, the changing conditions due to the humidity and climate introduces the various channels depend on the season; therefore, it is necessary to consider the earth's effects in which the network is used for efficient and reliable communications for the design of the topology.

Antenna design Underground wireless communications are considered as one of the major challenges in the design of WUSNs. There is a significant difference between WUSN and WSN which may lead to a completely different hardware for underground communications. In this regard, the design of the underground transmitters and receivers and, therefore, best antenna selection for WUSNs is considered as the most challenging problem. The design challenges are as follows:

Variable requirements Different communication goals may be met by different devices and therefore, an antenna with different characteristics may be required. For example, devices located at a few centimeters above the ground surface may require special considerations due to reflection of EM radiation, which is experienced at the joint surface of air and soil. In addition, near-surface devices are likely to act as relays between deep devices and surface devices. Deeper devices act as vertical interfaces for data routing towards the surface and may require centralized antennas in both horizontal and vertical directions.

Size Underground receiver/transmitter devices are required to operate at a MHz frequency or lower in order to reach the practical transfer range from several meters. However, reducing the operating frequency requires larger antennas. For example, one quadrant antenna measures a wavelength of 0.75 meters at a frequency of MHZ100. While it contrasts with providing an acceptable transmission range, including an antenna, with the aim of maintaining small underground devices.

Direction detection As mentioned earlier, WUSNs can be deployed at different depths for providing coverage and connectivity in the network. This requires antennas that are able to communicate in three dimensions. However, it is not possible the use of receiver or transmitter antenna in the right direction because the radiation pattern of these antennas contains empty spaces for vertical communication; therefore, in underground sensors, equipment may have been coordinated with both antennas or an smart antenna (also known as adaptive array antennas, digital antenna arrays, multiple antennas and, recently, MIMO) that is capable of dynamic changes of radiation pattern based on communication needs. Design considerations about the design of the antenna have so far been focused on the EM wave.

An extreme environment The underground environment is far from ideal site for electronic equipment. Water, high temperatures, animals, insects and drilling equipment represent a threat to a WUSN device, and should be protected in a proper manner. Processors, radios, power supplies, and other components should represent these factors. In addition, the physical size of the WUSN device should be kept small, so that the cost and time of drilling of the larger devices to be increased [53]. Battery technology must be selected carefully in such a way that is suitable for deployment of the device at ambient temperature, which balances environmental considerations with physical capacity concerns and physical size. Devices should also be under pressure from people or moving objects on top of the head or the inherent pressure of the soil is high for in-depth devices. In addition to physical factors that have a significant effect on the lifespan of an underground sensor, environmental factors affect the performance of the relationship between WUSNs. Especially the composition of soil and water content in soil has a significant effect on the conditions of underground wireless channels. Table 7 provides a summary of advantages, disadvantage and challenges of WUSNs.

3.2 Topology of underground networks

It increases underground interaction features and close interaction between soil content and their performance, network deployment and architecture for efficient performance. According to applications, WUSNs can be established in soil or underground cavities such as mining and road tunnels or subway[73].

In Table 8 a brief explanation of existing protocols coupled with their advantages and disadvantages have been presented. As you observe, few researches have been conducted regarding WUSN networks. And with respect to the challenges stated in previous part, lots of researches can be done in this field.

4 Data aggregation in underwater wireless sensor networks (UWSNs)

Overall, an undersea network has been created of separate and independent sensor nodes that perform data warehousing and transmission (store and forwarding) of routing data that have been collected to a central node. Major challenges for the development of such a network are computing power, cost, memory, communication range and most of all, the life cycle of each individual sensor UWSN is limited. The number of sensor nodes fails since power dissipation increases with long development time. So, the coverage area of wireless sensor network will decreases. Other very important issues are limited battery resources and gaining long operation time without sacrificing system performance that are challenges for researchers [20].

Therefore, many of the leading researchers have studied the proposed aggregation methods to improve protocols efficiency of energy for tasks of UWSN node. In data aggregation of UWSN, master nodes (integrator node) aggregate and process data from nearby nodes, and sends the data to Sink [79]. Therefore the major challenge of aggregating data UWSN is minimizing redundant data until the guarantee of accuracy of data. Aggregating data is one of the main communication methods in which some sources send data into a Sink. Data aggregation has been tested as an indispensable technique for reducing power consumption in wireless sensor networks by minimizing the frequency of the incoming data by sensor nodes. Data aggregation process not only helps the increasing the accuracy of the information that are gained by the whole

Table 7 Advantages, applications and challenges of WUSNs

Advantages	Application	Challenges
Concealment	Environmental monitoring	Energy efficiency
Ease of deployment	Monitor the presence and concentration of various substances	Topology design
Real-time data delivery	Predict earth tremors	Reduce the use of power
Strength	Monitoring of air quality in underground coal mines	cost
Density of coverage	Infrastructure monitoring	Conditions and typeof soil
Acoustic communication	Monitoring of underground piping	Antenna design
Mobility model	Health monitoring of buildings used	Environmental extremism
Layer based design	Border patrol and security monitoring	Underground channel properties

Table 8 WUSNs topologies

Protocol	Brief description	Advantages	Disadvantages	References
Single depth	The mobile Sink (animated) can be used and each sensor can be collected above the ground by a mobile unit	applications in stationary and mobile Sink—simple topology	Can be used in shallow depth	[73]
Different depths	Possible to get a lot of information in-great depth	High overhead for data transfer away—reduction of life expectancy—the problem cavity near the Sink	At great depths is not possible to communicate directly with Sink above the ground. so nodes must be central at less depths to provide multi-hop routes between Sink and nodes located in the depths of the earth	[73]
Hybrid	Reduced losses—Interchangeable Battery—Increased longevity	Complexed topology	Consisting of a mixture of underground and above ground sensing devices.	[73]
AODV (Ad hoc on-demand distance vector routing)	Lowest delay—high throughput (the number of received data within the time specified above)	Low life expectancy	A node that wants to communicate with another node, generates a route request packet and spreads around	[75]
DSR	Medium dealy	Low operating power	Works based on link-state algorithm, i.e. Each node is able to supply the best route to their destination. In addition, if changes occur in the network all network nodes via the issuance of general (flooding) will be informed of these changes	[76, 77]
TORA	Low delay	Low operating power	Based on a distributed routing algorithm and is designed for highly dynamic mobile networks	[78]

networks but also helps to reduce redundant information and prolong the network life cycle.

The main idea of integration is avoiding one by one communication to Sink node and creating an aggregation path on the network. The main goal of data aggregation is reducing the network traffic and store the energy waste in communication. Select a path in aggregation depends on a number of factors such as the type of network, network topology, and so on. Two major security issues in providing data aggregation are confidentiality and integrity of data. The main purpose of data aggregation technique is the accumulation of data to a monitoring network for energy efficiency for a long term. Data aggregation is a key integration process to reduce network usage by eliminating redundant data and reducing the size of the packet that is transmitted to the Sink. Meanwhile, the security issues of underwater sensor networks are complicated and needs suitable security. The main features of UWSNs are highlighted in Table 9.

4.1 Architecture of UWSN network

Network topology is generally an important factor in determining energy efficiency, capacity and reliability of a network. When expanding the sensor network, the formation of a reliable sensor network is greatly important. In order to avoid damage to the nodes, topological expansion plans must be precisely designed. As capacity is limited in sensor nodes, network topology is important as a way that energy remains preserved and is used efficiently. Network topology is a hot topic, which requires more evaluation. Underwater sensor network architecture can be classified based on motion of the sensor. Figure 6 briefly introduce different available architectural design of UWSN.

Static UWSN In that sensors are assumed Fixed or with negligible mobile. This architecture is divided into two-dimensional or three-dimensional.

Mobile UWSN Sensors are assumed free float with ocean currents.

4.1.1 Static UWSN

As previously discussed, static UWSN can be divided into two categories:

Two-dimensional static underwater sensor network In static two-dimensional submarine sensor network, each sensor with wireless voice links is connected to one or more sensor (gate), Sinks of undersea.

These gateways are network appliances that are in charge of relay data from surface stations of a network of ocean bottom. In 2006 to enhance the robustness and energy efficiency, a virtual two-dimensional topology was floating a few rows together, a mesh was formed (suggested by WKGSeah [93]) that network and sensors transfer their data by the internal virtual Sink network inside the cluster to the local Sink. Sinks of underwater sensor network have been equipped with two acoustic transceivers i.e. vertical and horizontal transceivers. Horizontal transceiver is used by Sink to communicate with other sensor nodes and vertical connection that is used by Sink is used to relay data to surface stations.

Table 9 Applications and features of UWSNs

Applications	Ocean prototyping networks
	Pollution monitoring
	Undersea exploration
	Predict and prevent disaster
	Navigation assistant
Features	Dynamic
	Error-prone
	3 dimensional

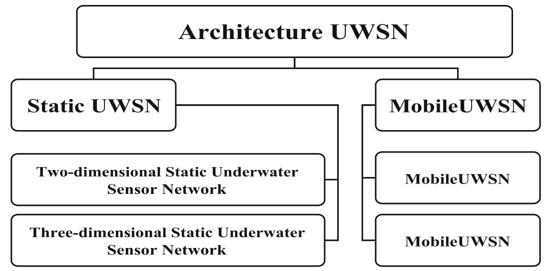

Fig. 6 Architecture of UWSN network

Three-dimensional static underwater sensor network Three-dimensional sensor networks are used to detect submarines and see something that is not enough to be observed by ocean bottom sensor nodes. In UWSN of three-dimensional, sensor nodes are floating at various depths to perceive the given phenomenon. I.F. Akyildiz et al. [94] suggested for the three-dimensional case, a highly inventive method that sensors anchored to the bottom of the ocean with a fleet can be equipped by a windy pump. The depth of sensor can adjust the length of the wire that connects the sensor to the anchor. Three expansion strategies have been proposed: three-dimensional random grid; random lower and lower. The first two strategies sensors randomly spread on the bottom where they were anchored, however, in the strategy of lower grid, sensors must be accompanied by one or more components that extend undersea sensors to acquire expansion of the grid at the lowest part of the ocean. The simulation results show the coverage rate obtained by the lower random strategies and 3D random strategies.

4.1.2 Mobile UWSN

Another type of underwater sensor network is mobile sensor network where the nodes are floating and neither fixed nor static, i.e. it is assumed that nodes are on the move with ocean currents. A mobile UWSN is a self-organizing one. Underwater sensor nodes may be moved by the horizontal displacement of air emissions and move. After submission, the sensor must be maintained and recognized as a network. One aim of creating such a network is relying on local intelligence and less dependency on online communication beaches. In the article Akylidiz [95] introduces two categories for mobile submarine sensor network:

Mobile UWSNS for insensitive long-term water monitoring Applications searches in oceanography, marine biology, archeology, deep sea, earthquake prediction, detection and monitoring pollution Oil / Gas.

Mobile UWSNS for insensitive short-term water monitoring Its applications are in natural resource discovery, hurricane and disaster recovery and *etc.*

4.2 Data aggregation protocols for UWSNs

Data aggregation is a fundamental problem for any network and the protocols of data aggregation are responsible to discover and maintain the efficiency of a sensor network. Submarine sensor network have been studied for decades, submarine networking and plans of data aggregation are still disordered in the research lifetime [66]. If we want to present an outline of plans posed in this respect, we can refer to Fig. 7 which has stated a list of protocols existing for submarine networks. Table 10 explains the number of protocols in UWSNs and Table 11 compares different of clustering schemes of underwater sensor networks and data aggregation protocols.

5 Data aggregation in wireless body sensor networks (WBSNs)

New developments in the field of integrated circuits, wireless communications, technology and science semiconductor miniaturization have been led to the growth of sensor network applications including medical and healthcare organizations. On the other hand, an increase in illness and medical expenses result in the advent of techniques for solving these problems [31]. One of these techniques is the use of physical wireless networks. These systems work by providing different services such as medical monitoring, providing medical, individuals memory improvement, home appliances control and communication in emergency situations and can be a considerable help to people (see Fig. 8).

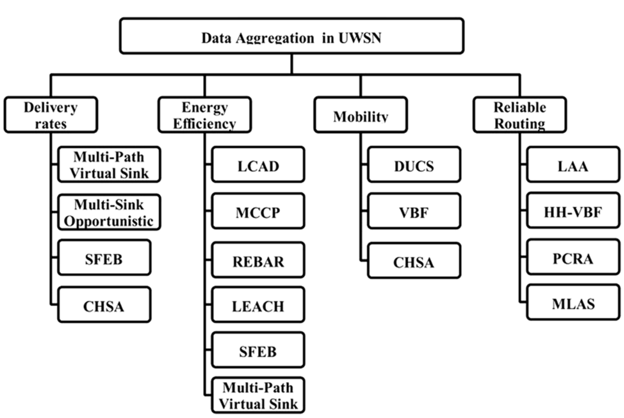

Fig. 7 Classification of UWSN algorithms

5.1 Architecture and components of a physical sensor node

Network architecture is defined according to the source [99] that WBSN is divided into three parts: Tier 1—In the internal WBSN: Biomedical sensor nodes in the body and/or implanted, the sensed data is sent to the coordinator or the base station. Tier 2—Among WBSN: coordinator or base station sends the received data to Sink(s) after processing the necessary data and data density. Tier 3—Additional WBSN: In this row, Sink(s), send collected data in remote medical centers and/or any other destination through specific infrastructure such as the Internet(Fig. 9).

5.2 Data aggregation protocols in WBSN

In this method, grid and cluster-based protocols are conventional methods that can be used for body sensor networks. Below, we describe two types of physical clustering protocol. It is also possible to use grid networks according to data aggregation techniques in physical networks possible.

5.2.1 Hybrid indirect transmission (HIT)

In [100], the authors propose data aggregation protocol called hybrid indirect transmission (HIT) based on a hybrid architecture from one or more clusters that each cluster is capable of a few multi-step transmission. HIT uses parallel processing in both communications between the cluster and inside cluster to minimize energy consumption and network delay.

5.2.2 AnyBody

AnyBody [101, 102] is self-organizing clusters based data aggregation protocol that is designed to reduce direct transmission of sensor nodes with remote stations. AnyBody uses of added LEACH [102] that selects the cluster head at regular intervals to balance energy generation and collects data cluster head and transmits to remote stations. In LEACH, it is assumed that all nodes are in a remote area of the base station. AnyBody encounters to this problem by using density-based cluster head selection and use of the column headers to build a network cluster. Five steps of AnyBody are: Neighbor discovery, compute density, making the cluster head, set up the column and set the routing path.

Table 10 Data aggregation protocols for UWSNs

Protocol	Brevity	Brief description	References
Parametric chain based routing approach	PCRA	It is assumed that all network nodes, such as type of motion sensor are floating underwater	[80]
High level view of vector based forwarding	HH-VBF	All data packets are transmitted using a redundant path that is due to packet loss and damage, and manage sensor nodes from the source Sink	[81]
Structure free and energy balanced data aggregation	SFEB	It is a mechanism for data aggregation and release of energy balance that reduces energy consumption by decreasing the number of transmit and receive	[82]
Low-energy adaptive clustering hierarchy	LEACH	Sensor network is divided into clusters and each cluster is made up of the head and a large cluster nodes. Cluster head is in charge of data communication between clusters	[83]
location-based kACK aggregation	LAA	Instead of transmitting a packet at a time, sends integrated packet with the least cost path	[84]
Reliable and energy balanced routing algorithm	REBAR	Solving problem of Sensor node draining with frequent changes of node locations	[85]
Location based clustering algorithm for data gathering	LCAD	Sensor nodes spread in fixed relative depth of each other. All sensor nodes in their relative positions have been organized with the help of the relevant cluster. Cluster heads are associated with each other by horizontal links audio with a finite length	[86]
Minimum-latency aggregation scheduling	MLAS	Developing an approximation algorithm based on virtual slot time domain, multiplexing to efficiently exploit the opportunities and it provides theoretical range	[87]
Distributed minimum-cost clustering protocol	MCCP	Of a cluster-based approach takes advantage of the energy, remaining energy and the relative position of nodes and Sink are three main parameters for the formation of clusters	[88]
Distributed underwater clustering scheme	DUCS	Supports the mobility of nodes and energy loss	[89]
Self healing clustering head selection algorithm	CHSA	Each node can also act as a resource and as a cluster server role rotates among all nodes in a way that energy consumption is evenly balance	[90]
Multi-sink opportunistic routing protocol	–	Multi-Sink opportunistic routing protocol	[91]
Multipath virtual sink architecture	–	The architecture of the entire network is divided into clusters, each cluster contains one or more aggregation points	[92]

Table 11 Comparison of clustering schemes of underwater sensor networks and data aggregation protocols [80–92]

Protocol	Energy efficiency	Bandwidth efficiency	Performance	Delivery ratio
PCRA	High	Low	Moderate	Moderate
VBF	Moderate	Moderate	Low	Low
HH-VBF	Low	Moderate	Moderate	Moderate
SFEB	High	Moderate	High	High
LEACH	Low	Low	Moderate	Low
LAA	Low	Moderate	Moderate	High
REBAR	High	Moderate	Moderate	Moderate
LCAD	Moderate	Moderate	Low	Moderate
MLAS	Moderate	High	Moderate	High
MCCP	High	Moderate	Moderate	Low
DUCS	Moderate	Moderate	Low	Moderate
CHSA	Moderate	Low	Low	Moderate
MVSA	Low	Moderate	Moderate	Moderate
MSOP	Moderate	Moderate	Moderate	High

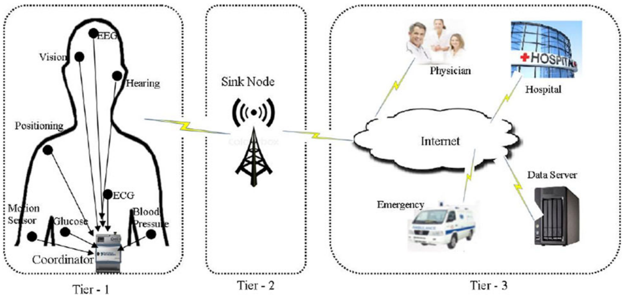

Fig. 8 Architecture of wireless body sensor networks [98]

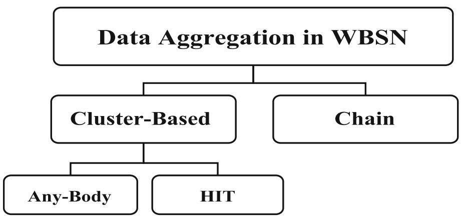

Fig. 9 Data aggregation in WBSN

5.3 A comparative study of cluster-based routing protocols

Energy limitation is the main constraints in WBSN along with other applications of WSN. In WSNs, the cluster mechanism is used to reduce the number of direct communication with the sensor nodes with base station, to reduce power consumption, to increase the quality of the link and thus extending the network lifetime.

It should also be noted that a number of newly introduced data aggregation methods are the Constrained Application Protocol (CoAP) [103] and MQ Telemetry Transport (MQTT) Protocol [103] that are still in the research phase.

6 Conclusion

The aim of this research is to provide a basic platform to develop new advanced designs in the area of internet of things (IoT). The focus is based on the improvement of data aggregation techniques in wireless sensor network (WSN) with regard to four function areas (i.e., terrestrial, underground, underwater, and body). Toward that end, after introducing the problems with the IoT and considering WSN as part of it and determining data aggregation as one of the discussed issues, attempts were made to gather the existing data aggregation methods with a more complete view to facilitate the process of method selection by reader through gathering different data aggregation methods and stating their advantages and disadvantages. As it turns out by studying the paper, due to the extent of the debate and the lack of a comprehensive and coherent approach for data aggregation, a comprehensive and observable approach is required. Several decades after the introduction of WSN, still no comprehensive and coherent approach has been presented in the area of data aggregation which is capable of combining security, communication overhead, energy consumption, and data compression ratio. In other words, perhaps not presenting effective and useful methods for data aggregation in underground and body sensor networks can be considered as an extremely valuable opportunity for researchers to provide useful solutions by conducting research studies on these areas. On the other hand, another problem is the analysis of the applicable methods in the oil and gas industries with regard to the sensitivity of the work and the necessity of stability, continuous function of the network, low errors and high security in relation to access to wireless sensors data. Considering the investigation of different industries, the shortage of such equipment in industries is evident.

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