



WSN Strategies Based on Sensors, Deployment, Sensing Models, Coverage and Energy Efficiency: Review, Approaches and Open Issues

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Abstract

Wireless sensor networks (WSNs) are growing rapidly in various fields of commerce, medicine, industrial, agriculture, research, meteorology, etc. that eases complicated tasks. The most active and recent research areas in wireless sensor networks are deployment strategies, energy efficiency and coverage. Besides energy harvesting, network lifetime of the sensors can be increased by decreasing the consumption of energy. This becomes the most challenging areas of utilizing wireless sensor network in practical applications. Deployment in WSNs directly influence the performance of the networks. The usage of sensor nodes in large quantity in the random deployment improves concerns in reliability and scalability. Coverage in wireless sensor networks measures how long the physical space is monitored by the sensors. Barrier coverage is an issue in wireless sensor networks, which is used for security application aims in intruder detection of the protected area. Several ongoing research work focuses on energy efficiency and coverage in wireless sensor networks and numerous schemes, algorithms, methods and architectures have been proposed. Still, there is no comprehensive solution applicable universally. Hence, this work provides with a state-of-the-art of the classification of wireless sensor networks based on different dimensions, such as, types of sensors, deployment strategies, sensing models, coverage and energy efficiency.

Keywords Wireless sensor networks · Energy efficiency · Coverage · Sensing models · Deployment strategies

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1 Introduction

Wireless Sensor Networks (WSNs) are the networks that are made up of nodes, known as sensors, which perform the task of sensing. Sensing is a technique in which information is gathered about an event or a physical object, etc. A wireless sensor network incorporates these nodes, which are usually deployed in remote areas and communicate information wirelessly using their wireless radios. There are various challenges to be addressed based on the localization, channel access, connectivity, scheduling, security, energy efficiency, quality of service, coverage problems, theoretical modeling etc. Among these, energy-efficiency and coverage problems are considered the most challenging tasks of WSNs.

Coverage is based on how well each individual point in the sensor area is monitored with the sensor nodes deployed [1]. The sensor coverage problem has gained importance due to the integrated and efficient electronic devices, various applications and a variety of sensors [2]. To achieve coverage, sensors are deployed at pre-determined places. The coverage is not guaranteed in many applications when the sensors are randomly deployed at remote and dangerous areas. The failure of sensor nodes is considered as the main cause of coverage problems due to the hardware problem or depletion of the battery. Energy efficiency of nodes is considered as a challenge task [3] because of mainly two reasons (a) resource-limitation in terms of computational capacities and in term of memory, thus preventing the usage of complex algorithms and TCP/IP (Transmission Control Protocol/Internet Protocol) protocol stack is not suited; (b) wireless sensor networks are intended for specific applications like healthcare monitoring system, weather detection, environmental supervision system, military surveillance etc. Deployment of WSN has to satisfy the requirements that changes from application to another application. Hence, this paper deals with a review based on sensors, deployment, sensing models, energy efficiency and coverage in wireless sensor networks along with various approaches and issues.

2 WSN Classifications

Wireless Sensor Networks are categorized into various dimensions like types of sensor nodes, deployment strategies, sensing models, coverage types, coverage algorithms and energy efficiency. The type of sensors are again classified on the basis of environment and node type. Deployment strategies are of two types: Deterministic and Random. The sensing models are divided into Binary Sensing Model and Probabilistic models such as Elfes sensing, Shadow Fading, Log-Normal Shadowing, Rayleigh Fading and Nakagami-m Fading sensing models. Coverage is categorized on the basis of algorithms and coverage types. On the basis of algorithms, it is further divided into centralized, distributed and localized coverage. Also, on the basis of coverage types, it is further divided into Full and Partial coverage. Energy efficiency is categorized into radio module, data reduction, sleep/wakeup schemes and battery repletion. The overall WSN classifications based on different dimensions are depicted in Fig. 1.

3 Categories of Sensors in WSN

WSN consists of various categories of sensors namely, seismic, thermal, acoustic, visual, magnetic, radar, and infrared. These sensors are able to observe a wide range of ambient conditions [4]. The various ambient conditions are temperature, vehicular movement, humidity,

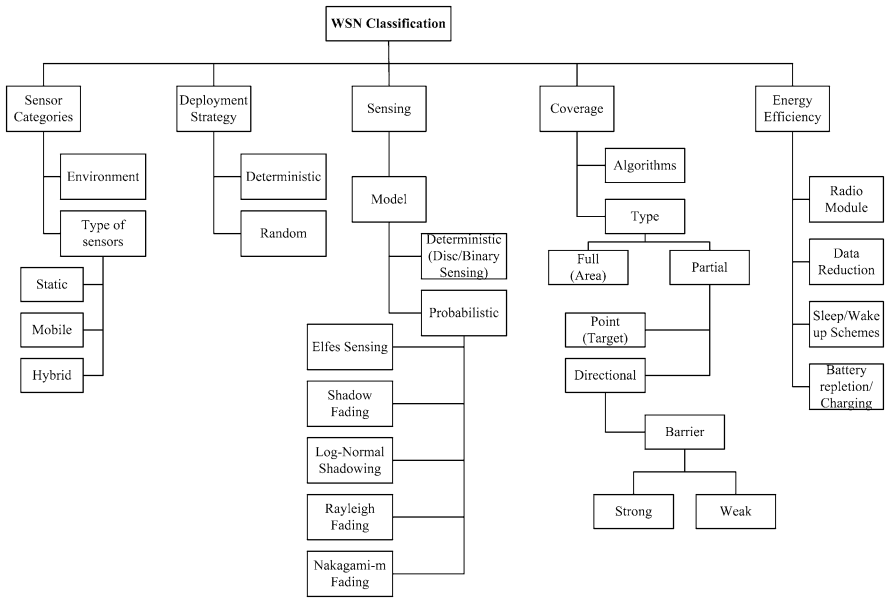


Fig. 1 WSN Classifications based on different dimensions

pressure, lightning condition, noise levels, soil makeup, levels of mechanical stress, the existence or nonexistence of objects, and characteristics of an object like size, speed and direction [5]. Sensor nodes identify and detect the events, and can be used for location sensing and continuous sensing. The nature of the wireless connection and micro sensing of these sensor nodes promises various applications such as health, agriculture, environmental studies, home, military, commercial, chemical processing, disaster relief, space exploration and Internet of Things (IoT) [6, 7].

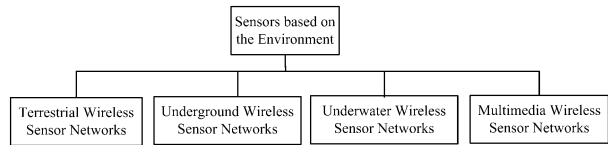
3.1 Sensors Based on the Environment

Depending on the environment, the types of sensors are classified into various categories (Fig. 2) such as (i) Terrestrial Wireless Sensor Networks; (ii) Underwater Wireless Sensor Networks; (iii) Multimedia Wireless Sensor Networks; and (iv) Underground Wireless Sensor Networks.

3.1.1 Terrestrial Wireless Sensor Networks

Terrestrial Wireless Sensor Networks contains hundreds of wireless sensor nodes which are capable of sensing an event in adhoc or preplanned manner. For terrestrial WSN, power consumption and reliable dense environment communication are significant. The energy conservation can be achieved by low duty cycle operations, shorter transmission range, minimizing delays, reduction of data redundancy and optimal routing [6]. Two algorithms, namely, Dir and Omni [8] are used for localizing terrestrial objects precisely by using a drone which is equipped with a Global Positioning System (GPS). To localize the objects, Dir uses directional antennas by a single trilateration to localize precisely the terrestrial sensors. This

Fig. 2 Different categories of sensors based on the environment



approach formulates an Omni algorithm which is based on the omnidirectional antenna. Both algorithms use a static path, in which a set of waypoints are considered within the deployment range. The distance between the terrestrial sensor and the drone are measured by using Impulse-Radio Ultra-WideBand (IR-UWB) technology and at a certain threshold, a guaranteed precision is achieved for each sensor. Even though, simulation results prove that the two algorithms generates a localization precision, Dir algorithm shows a path which is shorter than the Omni algorithm. An Advanced first order Energy Consumption Model (A-ECM) [9] was proposed for terrestrial WSNs which considers the design factors such as wireless communication, sensing and processing.

3.1.2 Underwater Wireless Sensor Networks

In Underwater WSNs, sensor nodes are deployed underwater and they have unique characteristics such as large delay, restricted energy and high error rate [10]. These sensor nodes are expensive in terms of deployment, equipment and maintenance. It is a difficult task to replace them once it has been deployed [6]. Instead of radio signals, acoustic signals are suitable for underwater communication because of low bandwidth and speed. Based on the location information, the protocols used for underwater routing of data are localization based routing protocols and localization free routing protocols. Due to the significance of underwater exploration, sea-life exploration, oils/spills monitoring, tsunami and seismic detection, underwater sensor networks has gained importance in recent years. Designing a routing protocol is a challenging issue in the underwater environment because replacement of batteries is a difficult task. Also, improving the energy efficiency is another issue because of the battery replacement in underwater is heavily expensive.

Wahid and Kim [10] developed an Energy Efficient Depth Based Routing (EEDBR) routing protocol for Underwater WSNs. To forward the data, EEDBR utilizes depth of the sensor nodes, achieve energy efficiency, minimizes the transmission rate of sensor nodes and also uses the residual energy to improve the lifetime of the network. There are two phases concerned with EEDBR: (i) knowledge acquisition, in which each node communicates through the Hello message with its neighbors and also allocates its remaining energy; (ii) data forwarding phase, in which the forwarding nodes holds the packet and the neighboring nodes are chosen based on the depth information. The holding of packets and the suppression techniques are based on the remaining energy and delivery ratio respectively.

A Constraint based Depth Based Routing (CDBR) protocol and Energy Efficient Depth Based Routing (CEEDBR) protocol are proposed by Mahmood et al. [11] which maximizes the network lifetime, results in better performance and energy consumption. This is achieved by minimizing the forwarding number of nodes because all neighboring nodes obtain the data while forwarding. A depth-based routing (DBR) protocol [12] uses the depth sensor to obtain depth information in underwater sensors. The benefit of using DBR protocol is high packet delivery (95%) in case of dense networks, minimum communication cost, multiple-sink architecture for underwater sensor network and efficiently handling

network dynamics even in the absence of localization services. In DBR protocol, once a packet is received by a sensor node, it checks for its depth. When the depth of the sensor is less than the embedded depth of the packet, the routing protocol forwards the packet, else the packet will be discarded.

There is a possibility of disagreement within the sensors, when a common wireless transmission is used by the sensor node. In this situation, the decision is made by the Media Access Control (MAC) protocols of underwater WSN which perform its function at the physical layer. The unique characteristics of MAC protocol are framing, flow control and error correction. MAC protocols for underwater WSN is classified into contention-free MAC protocols and contention based MAC protocols. In contention-free MAC protocols or scheduled based MAC protocols, schedules are maintained by the sensor nodes. Contention-free protocols are not advisable for large scale underwater WSN and the resources are reserved for individual users [13].

Dynamic Sink Mobility (DSM) routing protocol [14] increases the network lifetime, stability period and throughput of the underwater WSN. DSM incorporates a scheme known as dynamic sink mobility. Here the sink node moves towards the dense region of the network, which ensures high data collection. Energy is consumed in each round because more number of sensors send the data directly to the sink. But nodes have to wait for their turn when it is at remote distance from the sink. To overcome this, Autonomous Underwater Vehicles (AUVs) which acts as the relay nodes are used. AUVs gather the data from the sensor nodes in their own regions and send the gathered data to the closest sink node. Underwater Acoustic Sensor Networks (UASNs) employs multi-hop communication to achieve high signal quality and frequency scaling in dense UASNs. The lifetime of the network is increased by Remotely Powered UASN [15].

Link-State-Based [16] and Rounded-Based Clustering [17] routing schemes for energy efficiency are used to minimize the problems related to routing in acoustic sensor networks. These routing schemes take into consideration the conditions of shallow water and the mobility of the sensor nodes. A reactive based routing protocol, known as improved Adaptive Mobility of Courier nodes in Threshold-optimized Depthbased-routing (iAMCTD) [18] minimizes the ratio of packet drop and increases the throughput of the network by using Forwarding Functions (FFs). To minimize the lifetime of the network, underwater WSN are utilized with mobile courier nodes.

3.1.3 Multimedia Wireless Sensor Networks

Multimedia WSN track and monitor events in the multimedia data format such as images, audio, video, etc. These networks involve large data rates, high bandwidth, large data processing, maximum energy consumption, high compression techniques and high Quality of Service (QoS) provisioning. Large data rates and high bandwidth are required for video transmission, which leads to higher consumption of energy. QoS provisioning is another challenging issue which plays a vital role in the reliable content delivery [6]. A cross-layer scheme [19] and a routing protocol were proposed for video streaming in WSN. A multi-path routing protocol, named Efficient Queuing Multimedia transmission over WSNs (EQM), which work together with the application layer transmits data and video efficiently from various sources. A frame aware solution is provided for which the most important frames are assigned with high priority and the least ones with low priority. The queuing

policy reduces the video latency and increases the reliability which involves congestion solving function, enqueueing and dequeuing.

An adaptive cross layer scheme and energy aware scheme [20, 21], are investigated to transmit the content of multimedia over WSNs. At the application layer, an optimal video encoding parameter is chosen with respect to the current status of the wireless channel. Depending on their various packet types, they are scheduled by an adaptive priority video queue. Path scheduling is used to route the packets by different paths. The lifetime of the network is considered when path scheduling happens. Ad-hoc On-demand Multipath Distance Vector (AOMDV) routing protocol is used since the video transfer over WSN happens between the application and network layer.

An energy efficient and high quality video transmission architecture (EQV-Architecture) [22] was developed for transmission of video in WSN with the influence of three protocols stack communication layers. They are application, network and transport layers which perform compression, routing and communication respectively. The dropping scheme discards the packets based on the priority information and the level of energy. Energy efficient Mechanism for Multimedia Streaming over Cognitive Radio Sensor Networks (EMCOS) [23] was proposed for video streaming in multimedia transmission over WSN. A cognitive radio technology ensures energy efficiency by clustering mechanism. EMCOS is used to group the multimedia WSN nodes. EMCOS considers the geographical location and also the availability of the channel to ensure stable clusters. To preserve the energy, a cluster head is selected for individual cluster and a routing mechanism conveys the information to the sink node.

Shift-Advanced Encryption Standard (Shift-AES) [24] algorithm is a security approach used for multimedia data transmission and minimizes the energy consumption with the principle of Shannon. A Real Time Video Streaming Routing Protocol (RTVP) [25] was used with an adaptive traffic shaping for Wireless Multimedia Sensor Networks (WMSN). For the next hop selection of intermediate nodes, it uses multipath forwarding and forwards the packets with high priority. The classification of packet is based on the information of the video content, and the packets are delivered through the reliable path. A new adaptive cross-layer error control protocol (NAC) [26] is used for multimedia streaming in WSN. It is accomplished through algorithms namely, Forward Error Correction (FEC) algorithm, an Unequal Error Protection (UEP) mechanism and a dynamic hybrid FEC/ARQ (Automatic Repeat reQuest) scheme. By dynamic hybrid FEC/ARQ mechanism, the number of retransmission of ARQ is decreased which improves the error control mechanism.

An energy efficient cross layer image transfer protocol [27] was proposed for reliable delivery of image through multi-hop transmission. The cross-layer interactions are made between the application layer, transport layer, network layer and MAC layers. User Datagram Protocol (UDP) and Real Time Transport Protocol (RTP) are used for image streaming. These protocols fails to deal with various issues such as bandwidth variation and error protection which is performed at the transport layer. Hence this layer is extended with other layers, namely, physical layer, transport layer and MAC layer.

3.1.4 Underground Wireless Sensor Networks

In underground WSNs, sensor nodes are deployed underground and are expensive because of achieving reliable communication. The communication in the underground is accomplished through rocks, soils and other minerals [6]. A real time mechanism was proposed for monitoring mining in the underground WSN. The deployment of wireless sensor node

and optical sensors leads to efficient sensing and coverage. It also detects and localizes damages like change in humidity, temperature and strain vibration. In Underground Mining Monitoring System (UMMS), base stations, gateways, mobile and reference nodes are used to monitor miners in underground tunnels via wireless communication. Optical sensors are used to ensure the speed and reliability of the transmission. It includes a signal emitter that converts an electrical signal into optical, one or more laser diodes and a coupler which converts optical waves into electrical signals. To multiplex light waves, an optical multiplexer is used. Various optical sensors are used in underground mining monitoring system such as Fiber Bragg Grating (FBG), Brillouin Raman, and Fabry-Perot. In UMMS system, Fabry-Perot (FP) interferometer sensors are used to measure changes in the pressure or acoustic waves in underground mining. Brillouin Raman sensors are used to detect temperature. The FBG sensor monitors seismic signals and stress variation [28]. The overall review in terms of different WSN environment along with approaches and issues are given in Table 1.

3.2 WSN Classification Depending on the Type of Sensor Nodes

A wireless sensor network can be categorized into three main categories according to the type of the sensor nodes such as static, mobile and hybrid [1]. To support connectivity and full coverage, huge static nodes are needed and organized frequently in most of the WSN applications. All the deployed sensor nodes do not change their position, as they are static. Deployment of this type of nodes leads to increase in the power consumption, increase in cost and complex network management [29]. Mobile sensor nodes are accomplished of moving over a certain distance in a desired direction and also support full coverage. Some of the unique features of mobile sensors are more energy, high sensing power, high communication power, increases the lifetime of the network and other capabilities [30]. In Mobile WSNs, sensor nodes move independently, collect and communicate the sensed phenomenon. The capability of self-organizing, repositioning in the network and dynamic routing makes the mobile nodes different from the static nodes. It also poses various challenges in terms of energy, control, data processing, self-organizing, localization, coverage, deployment, navigation, maintenance, etc. The applications of Mobile WSN include target tracking, real-time monitoring of hazardous materials, monitoring disaster areas and military surveillance [6]. Hybrid wireless sensor networks include both static and mobile sensors. Static sensors monitor the events in the environment, whereas mobile sensors are used to move the locations of the events to achieve advanced analysis [31]. Mobility in sensors overcomes the disadvantages caused by the static WSN. The coverage holes can be eliminated [32], detect certain events by using sophisticated sensors [33], consumption of energy and the issue of path efficiency and load balancing are being addressed [34]. The lifetime of a hybrid WSN depends on the mobile sink node [35].

4 Deployment Strategy

Depending on the deployment strategy, sensor nodes can be deterministic or random. In random deployment, sensors are scattered over the monitoring region to sense the target area of interest. Random deployment is feasible where human intervention is not easily possible and when the information about the region is not known previously such as fire forest, disaster regions, air pollution [36], battlefields etc. Few objects in the sensor

Table 1 Approaches and issues in terms of energy efficiency and different categories of WSN environmental sensors

Ref.	Sensor	Energy efficiency	Approach and analysis	Advantage	Issues/further work
[8]	TWSN	X	2D range localization algorithms, simulation	No need of preprocessing phase, low cost	Modification is made if the orientation is not regular
[9]	TWSN	✓	A-ECM, simulation	Processing of sensors	Energy consumption at MAC and network layer is not possible
[10]	UWWSN	✓	EEDBR protocol, NS-2	Reduces redundant transmissions	Localization of sensor node is not addressed
[11]	UWWSN	✓	CDBR & CEEDBR protocols, simulation	Localization free, improves lifetime	Multiple sinks are not used with dynamic topology & varying locations
[12]	UWWSN	✓	DBR protocol, NS2-AquaSim	Deliver packet to multi-sink, no extra cost	Recovery algorithms in DBR are not investigated
[13]	UWWSN	✓	RMAC, UWAC-MAC, & NS-2 AquaSim	Efficient data transport capabilities	Effect of non environmental factors are not focused
[14]	UWWSN	✓	DSM protocol, and acoustic modem	Prolongs the stability period and throughput	Lack of comparative analysis among protocols
[19]	MMWSN	X	Cross layer solution, NS2	Enhances PDR, QoE and delay	Failed to validate in mobile networks
[20]	MMWSN	X	ACWSN framework, NS2	Broadcasting video contents	Network Lifetime & optimal routing are not addressed
[21]	MMWSN	✓	EA-ACL mechanism, simulation	Transmit video, meet QoS requirements	Optimal routing is not addressed
[22]	MMWSN	✓	EQV architecture, MATLAB	Improve life-time and video quality	Request from multi-sinks are not addressed
[23]	MMWSN	✓	EMCOS scheme, NS2	High video quality, low delay	Compared with only SEARCH & SCEEM mechanisms
[24]	MMWSN	✓	Shift-AES algorithm, MATLAB	Minimum execution time, high security	Cryptanalysis of the Shift-AES is not envisaged
[25]	MMWSN	X	Dynamic traffic shaping, MATLAB	Guarantess QoS	For better VBR streaming, RTVP can be integrated
[26]	MMWSN	✓	NAC protocol, NS2-EvalVid	Better frame loss rate and PSNR	NAC protocol contains firm delay restrictions
[27]	MMWSN	✓	Cross layer scheme, MATLAB	Reliable transfer of images	Only standard test images are used
[28]	UGWSN	X	UMMS scheme, simulation	Efficient sensing & coverage	Only FBG sensors are used to monitor parameters

Ref. reference, TWSN terrestrial WSN, UWWSN underwater WSN, MMWSN multiMedia WSN, UGWSN underground WSN, X energy efficiency not addressed, ✓ energy efficiency addressed, RMAC reservation-based MAC protocol, UWAC underwater acoustic communication, ACWSN adaptive cross layer WSN, EA-ACL energy aware-adaptive cross layer, PSNR peak signal to noise ratio, PDR packet delivery ratio, QoE quality of experience, SEARCH SpEctrum aware routing protocol for cognitive ad-Hoc networks, SCEEM spectrum-aware cluster-based energy-efficient multimedia, VBR variable bit rate

area can be sparsely or densely covered, when there is a random deployment of the sensor nodes. When the sensors are densely covered, issues such as connectivity management and failure detection become more complex [37]. Full connectivity is achieved if each pair of sensor nodes communicate and exchange its information with every other sensor nodes. This condition is achieved in WSN for reliable data transmission through direct or by other nodes [38]. The principle behind WSN deployment is collecting appropriate data for reporting, which is of two types: event-driven and on-demand. The process is activated by the sensor node in an event-driven processing, which detects and reports an event to the monitoring station. Monitoring forest fire is an example of an event-driven reporting system. In on-demand processing, the monitoring station initiates the process and sensor node responses to their request. An inventory control is an on-demand reporting system. A deterministic sensor access friendly environments, whereas a random sensor deployment is deployed in remote areas or military applications or disaster areas [2]. Deployment of deterministic sensor nodes is possible in cases with a limited sensor area. The cost is being reduced greatly because the deployment of nodes is done manually and usage of less sensor nodes [39, 40].

5 Sensing Models

In a WSN, based on its sensing range (R_s), each sensor node contains a sensing coverage. It is an area that a sensor node can monitor its range of sensing as shown in Fig. 3. The coverage of a network can be defined as the combined coverage by all ACTIVE nodes in the WSN. Also the communication range is based on the radio coverage, R_c . The main difference between the sensing coverage and the radio coverage is that the sensing coverage guarantees event monitoring, whereas radio coverage guarantees reliable transmission of data within the WSN [41]. Coverage degree (C_d) is defined as the degree in which the active number of nodes monitoring an area. When there are no active sensors deployed in an area, a sensing hole occurs. To improve the lifetime of the network, the ACTIVE nodes are minimized as well as maximum coverage and sensing are achieved [30]. In WSNs, each and every node has the ability of sensing and detecting an event in the area of interest. The monitoring ability of a sensor node is restricted because of its accuracy and its range of sensing. Hence, a sensor node can sense or monitor only a restricted area of interest. Therefore, sensing models depends on coverage area, lifetime and redundancy of the coverage in a wireless sensor networks. The sensing models are categorized into deterministic sensing models or probabilistic sensing models.

5.1 Deterministic (Binary) Sensing Model

In Deterministic or Binary Sensing Model (BSM), a sensor node only senses the events that lie within the range of sensing. Any point that is present outside the region of interest is not monitored. Assume R_s be the sensing radius of each node which is represented as a uniform circle. An event that takes place within the range of sensing at point (p) is detected as the probability (s) 1, else the probability 0 is assumed. This is represented by the equation (1):

$$s = \begin{cases} 1, & \text{if } d(i, p) \leq R_s \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

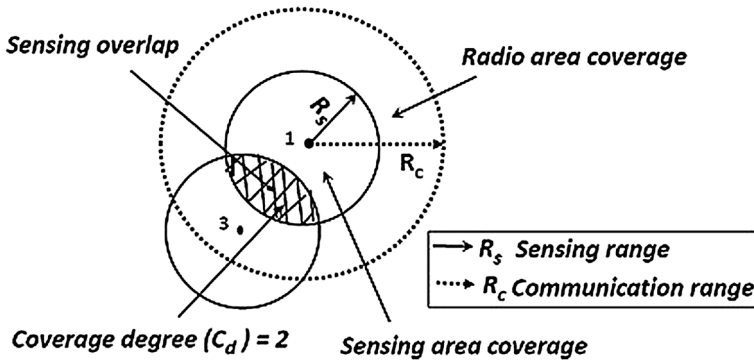


Fig. 3 Sensing range of a node [30]

where, R_s represents the sensing range and $d(i,p)$ represents the Euclidean distance [3]. The deterministic sensing model is also called as a tunable sensing model or variable radii circular sensing model [42]. Binary sensing model is further classified into perfect binary sensing model and imperfect binary sensing models. In the first category, the target is identified by each node if it is within the sensing range. In second category, the target is detected within the inner disk. The Binary sensing model is considered simple, but the uncertainty factor is not considered in the measurement [43].

5.2 Probabilistic Sensing Model

In the probabilistic sensing model, as there is an increase in the distance of the node, the ability of sensing a node decreases. This model is also more realistic than the deterministic sensing model. The probabilistic model reveals the performance of the sensing range devices and is affected by various factors like noise, obstacles, interferences, etc. To explain these various factors, probabilistic sensing models have been defined. For instance, the function of distance can be expressed in exponential, polynomial or staircase [30]. A probabilistic sensing model is considered more practical in terms of an event being sensed, environmental factors and the design of the sensor [43]. The probabilistic sensing models are further categorized into various sensing models such as Elfes, Shadowing fading, Log-normal shadowing, Rayleigh Fading and Nakagami-m Fading model [44].

5.2.1 Elfes Sensing Model

In Elfes sensing model [45, 46], the event detection of a sensor at a distance (x) is calculated by the Eq. (2):

$$p(x) = \begin{cases} 1, & x \leq R_1 \\ e^{-\lambda(x-R_1)^\gamma}, & R_{max} > x > R_1 \\ 0, & x \geq R_{max} \end{cases} \quad (2)$$

where R_1 defines the sensing uncertainty in sensor’s detection capability, λ and γ are various device-oriented parameters and R_{max} defines the maximum sensing range of the node.

Elfas sensing model become Boolean sensing model when $R_1 = R_{\max}$. When $R_1 = 0$, $\gamma = 1$, equation (2) becomes equation (3) as given below:

$$p(x) = \begin{cases} e^{-\lambda x}, R_{\max} > x \geq 0 \\ 0, x \geq R_{\max} \end{cases} \quad (3)$$

5.2.2 Shadow-Fading Sensing Model

In shadow-fading sensing model, the dependency of factors or obstacles have been taken for consideration. In all directions, the sensing node capability is not uniform. In radio wave propagation, this property is close related to the concept of shadowing. In log-normal shadowing path loss model [46], the probability of an event detection at a distance x is calculated as in equation (4):

$$P_{det}(x) = Q\left(\frac{10n \log_{10}(x/r_s)}{\sigma}\right) \quad (4)$$

where n represents the path loss exponent, r_s represent the sensing radius without fading and σ represents the fading parameter.

5.2.3 Rayleigh Fading Sensing Model

Rayleigh model is used for describing the individual multipath envelope component or the statistical time-correlation of the received signal [47]. The fading model arises from the dynamic contexts and probabilistic view. This model is used in scattering environment, where a receiver can be placed in various positions and the received signal in each spot can be calculated. At the receiver, no path will dominate in the absence of line-of-sight path [49]. When there is a presence of dominant path, it will result into a complex Gaussian with non-zero mean. Let x and y denotes the in-phase component and quadrature components of Gaussian respectively. Then, the signal amplitude for this delay is denoted as in equation (5):

$$z = \sqrt{(x^2 + y^2)} \quad (5)$$

If these in-phase and quadrature components have variance σ^2 and zero mean, the resulting distribution become Rayleigh [48, 49], which is given in equation (6):

$$f(z) = \begin{cases} \frac{z}{\sigma^2} \exp\left(-\frac{z^2}{2\sigma^2}\right), \text{ if } z \geq 0 \\ 0, \text{ if } z < 0 \end{cases} \quad (6)$$

5.2.4 Nakagami-m Fading Model

Nakagami-m fading model is used in wireless propagation channel [50] and fading channel. Nakagami-m model are becoming popular because it fits well for empirical data and to model small scale fading in long distance wireless channel. Small scale fading is the variation of the received signal amplitude because of the multiple signal paths [51]. The Nakagami-m fading model is represented in equation (7):

$$f(r^2) = \left(\frac{m}{s}\right)^m \frac{r^{2m-2}}{\Gamma(m)} e^{-mr^2/s} \quad (7)$$

where r^2 indicates the impact of Nakagami- m fading, m is the level of Nakagami- m fading, S is set to constant 1, and $\tau(m)$ represents the Gamma function as shown in equation (8):

$$\tau(m) = \int_0^{\infty} t^{m-1} \exp(-t) dt \quad (8)$$

The review on approaches and issues in terms of sensing models, coverage and deployment strategies are given in Table 2.

6 Coverage

One of the major issues in WSN is the coverage problem which forms diverse point of view over the monitoring constraints and requirements [61]. The main aim of barrier coverage is an intruder detection as they enter the protected area or cross through the border region [62]. The idea of barrier coverage problems was earlier initiated in the robotics field. Then, the barrier coverage is analyzed from the perspective of conventional WSNs [63]. A directional sensing model is used in various applications such as audio, infrared, camera, radar and ultrasound sensors [64]. A sensor network is also called as a Directional Sensor Network (DSN), if all the sensors satisfy the requirements and constraints of the directional sensing model. Now-a-days, the demand for various applications of DSNs such as environmental monitoring, location services, traffic surveillance etc. has been increasing drastically.

6.1 Coverage Algorithms

The coverage algorithms are categorized into centralized, distributed and localized which is shown in Fig. 4. The decision process is centralized in centralized algorithms and decentralized in distributed algorithms. In distributed algorithms and localized algorithms, the information regarding the neighborhood at each node is used to make a decision process. Since WSN has a dynamic topology, distributed and localized algorithms should be designed, so that it can be accommodated in a scalable architecture [2].

6.2 Coverage Types

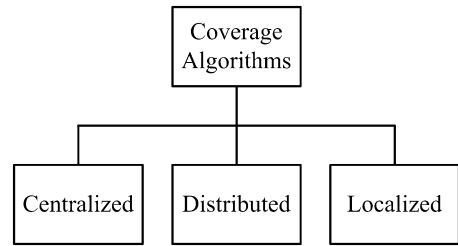
6.2.1 Full (Area) Coverage

The main aim of the area coverage is to examine an area or region in the sensor network [2] and ensures that every point deployed is monitored by at least one node [1]. Figure 5 shows an area coverage in a square-shaped area. The sensing range is represented by a circle. Each point is covered with at least one of the sensor in the sensor area. Active sensors are formed by the connected black nodes [2]. An important objective is the lifetime of the area coverage in the network. The lifetime of the area coverage is the time interval between the start of the network operation and the coverage requirement. To prolong the network life span, the active sensors that are minimum can be selected. Data processing and dissemination also impact the network lifetime and consume more energy. Full coverage is achieved when the ratio of the coverage equals one [1]. The challenge is to decide if the

Table 2 Approaches and issues in terms of sensing models, coverage and deployment strategies

Ref.	Sensing model	Coverage	Dep. strategy	Approach	Issues/further work
[45]	B, E	✓	R	Pattern based strategy	Approach can be analyzed by non-uniformly distributed WSN
[46]	B, E, S	✓	R	Poisson node distribution	Not feasible for all environments
[47]	S, L, RF	X	R	CDMA, CS MAC, SMAC	Not achieved optimized network performance
[48]	RF	X	R	AWGN, Math modeling	Synchronization accuracy chosen from predefined solution sets
[49]	RF	X	D	Multipath fading	Does not applicable in scattering environments
[50]	RF, N	X	R	Connectivity probability	Connectivity is affected by threshold power & path loss
[52]	B	✓	R	Disjoint sets	The sensor model is modeled in an undirected graph
[53]	S, L	X	R	Grid coloring algorithm	Increasing barrier size leads increase in localization error
[54]	B, E, L	✓	D	Square grid based scheme	Misleading result, higher cost, failure happens if not chosen appropriate model, parameters
[55]	B	✓	D	Circular field	Probabilistic Sensing model is not considered
[56]	B	✓	D	Math modeling	Omni directional sensor detection
[57]	RF, N	X	R	Sum-of-low-frequency-oscillators	Decreases the envelope correlations dramatically
[58]	L	✓	R	Grid based deployment scheme	Investigate the scheme under varying node & transmission ranges
[59]	B	✓	R	Uniform load routing algorithm	Due of the limits of the type of energy-block, initial energy is not arbitrary
[60]	B	X	R	Dual beacon discovery protocol	Energy saving in terms of only classical solution

Ref. reference, Dep. strategy deployment strategy, R random, D deterministic, B binary sensing/disc sensing, E Elfes, S shadow fading, L log normal shadow fading, RF Rayleigh fading, N Nakagami-m Fading, X coverage not achieved, ✓ coverage achieved, CDMA code division multiple access, CS MAC CDMA sensor MAC, SMAC sensor MAC, AWGN additive White Gaussian noise

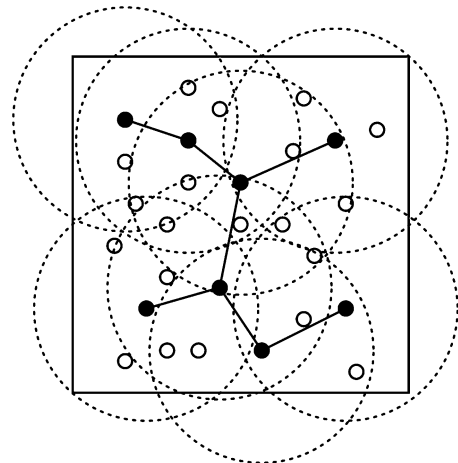
Fig. 4 Coverage algorithms

area deployed by the node can be completely covered by the active neighbor nodes. This node is the redundant node in terms of coverage.

6.2.2 Partial coverage

Since full coverage requires high cost and high complexity, it is not efficient in some applications. In these cases, partial coverage can be used and it guarantees coverage within a certain degree. Partial coverage also known as coverage, p-coverage and q-coverage. Partial coverage is mainly used in WSN to prolong the network lifetime and to save energy [1]. Two types of partial coverage, such as Point coverage and Directional coverage (D-coverage) are discussed below.

Point (Target) Coverage The main goal of point coverage is to cover a set of points. Figure 6 shows the point coverage to examine the set of points in square shaped nodes. Active sensors are formed by the connected black nodes [2]. Target coverage monitors a set of points in which the point coverage problem [65] monitors the known location and deals with a limited number of points or targets. Each point in the point coverage is examined by at least one sensor, so that all sensors within the sensing range monitors all targets. To maximize the sensor lifetime, a method called energy resource preservation is used. This scheme divides the sensors into disjoint sets which enables them to monitor all the targets. The aim is to decide the highest number of disjoint sets. The overall

Fig. 5 Area coverage [2]

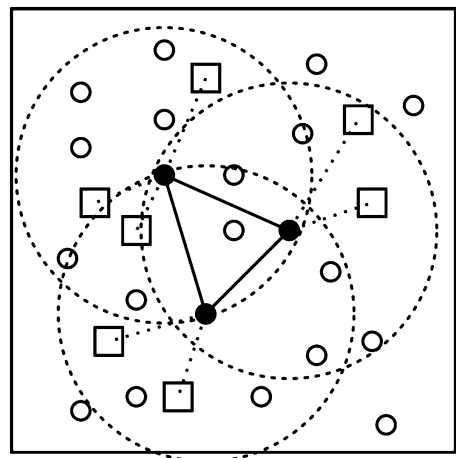
time for all sensors is increased by minimizing the period of time, when there is active number of sensor nodes [2].

Cardei et. al. [52] proposed a solution to this problem by the approximation algorithms like polynomial time and NP-complete. Simulated Annealing (SA) and Particle Swarm Optimization (PSO) [66] approaches are used in the deployment region which contains target nodes. To maximize the network lifetime and to maximize the coverage of WSN, the Simulated Annealing algorithm is used. To obtain the optimal location of the nodes, particle swarm optimization algorithm is used. Also, the scheduling algorithm is used to increase the lifetime of the network and also provides schedules for each time slot.

Directional Coverage In Directional coverage, the aim is to monitor and detect the intruders from passing at the boundary at any point. Directional coverage is used in security, detection of army movements [67] and best suited for tracking applications [68]. The aim of the directional coverage is on the direction of the intruders [2] and approaches like Markov chain and projected based approach was proposed to evaluate the Directional coverage. A Weighted Barrier Graph (WBG) scheme determines the mobile sensors and formulate the barrier coverage formed by the hybrid directional WSN by finding the total length and disjoint paths of k-vertex. A greedy approach and an optimal solution is also used. Barrier coverage is one of the type of Directional Coverage.

Barrier Coverage Barrier Coverage is the sensor node deployment in which the movement of sensors is detected over a predefined border [41]. Barrier coverage is suitable for intrusion detection, military applications and monitoring of boundary surveillance. Depending on the circumstances of various applications, the Region of Interest (ROI) is classified as an open belt region or closed belt region [69]. Barrier coverage is further categorized into strong coverage and weak coverage [68]. Strong barriers assure object detection in whatever path they take, but weak barriers only assure object detection passing through congruent paths [1]. The objective of barrier coverage is to minimize the invisible penetration probability through the barrier [2]. The issue of the barrier coverage lies with the actual deployment. Depending on the environment, a large number of objects can be entered into the deployed zone, which may not be useful or practical in many applications [41].

Fig. 6 Point coverage [2]



Weak k -barrier coverage problem was addressed by Li et al. [70] and a lower bound is derived for the same by considering and by not considering the border effect. An algorithm called mapped calculation algorithm was proposed because it is observed that weak barrier coverage depends on the horizontal deployment direction and not relevant to the vertical direction in belt region. In this way, a two-dimensional plane is converted into a one-dimensional plane in which the problem related to k -coverage can be resolved easier. An attractive feature of the algorithm is that accurate results can be produced in determining the belt region. A success message will be returned by the algorithm if the belt region is covered by weakly k -covered, else a failure message will be returned.

In a graph which is undirected, disjoint dominating sets is being modeled in [52], where the vertex forms the sensors and edge joins the vertices. A graph coloring mechanism is used to calculate disjoint dominating sets and the maximum computation sets are NP-complete. In the graph coloring mechanism, the sequential coloring algorithm is used to color the disjoint sets. On the basis of dominating and non-dominating sets, the uncovered area can be found easily. Local barrier coverage is initiated by Chen et al. [62] which detects the movement of the deployed belt region. For maximizing the network lifetime, a sleep-wakeup algorithm is used. A Localized Barrier Coverage Protocol (LBCP) enhances the network lifetime and guarantees barrier coverage. The quality of the barrier coverage is measured by the local barrier coverage which is provided by the WSN. To achieve k -coverage, mobile sensors were used efficiently by Wang et al. [71].

A belt region is normally formed from the left direction to right direction and the intruder moves from the top to bottom direction of the belt. There are two various schemes known as best and worst case coverage and exposure based coverage. The maximal support path (MSP) and maximal breach path (MBP) [1] represents the best case and worst case coverage respectively. In MSP, the distance is minimized between the deployed node and the penetration path. A Delaunay triangulation diagram is employed to discover the MSP. In MBP, the penetration path contains the distance that is longest from the nodes deployed. A centralized algorithm is used to find the MBP.

A distributed scenario [72] was used to minimize the traveling distance and to preserve the energy. The exposure-based barrier scheme leads to greater sensing ability and minimal exposure path is calculated by using the grid-based approach. There are various algorithms discussed by Meguerdichian et al. [73], which finds the maximal support path. The idea of local barrier is initiated by Chen et al. [74], where the movement of the intruder is to follow a segment of the belt region. In comparison with the weak and the strong barrier coverage, the authors have concluded that strong barrier can be attained in areas having a width larger than the length which has low cost and leads to low delay. Barrier coverage can also be used in the Mobile-WSN (M-WSN) where the mobility forms a barrier [68, 75]. A Genetic Algorithm (GA) known as Modified IGA (MIGA) was proposed by Hanh et al. [7] to maximize the area coverage with different sensing ranges in a wireless sensor networks. MIGA incorporates a heuristic initialization, fitness function and a combination of Laplace Crossover (LX) and Arithmetic Crossover (AMXO) operators. To improve the quality of the final solution, a local search algorithm known as Virtual Force Algorithm (VFA) is being used.

In addition to coverage types, the problems in other fields which corresponds to WSN coverage include Robotic system coverage problem, Art Gallery problem and Circle covering problem. In Robot systems, the types of coverage are blanket coverage, barrier coverage and sweep coverage. In Art Gallery problem, the problem is represented by a 2D plane polygon and can be solved in polynomial time. In Circle covering problem, the goal is to minimize the radius, so that it can cover the whole plane of the given circle [80].

The various coverage types along with the energy efficiency, sensor type, sensing models, deployment strategies are given in Table 3.

7 Energy Efficiency

Energy-efficiency is another issue in WSN because of limited battery resources. In general, the network lifetime is defined as the time interval between the sensing function and the data transmission to the sink in the network. One of the methods used for energy consumption is to minimize the sensing range. Scheduling mechanisms are also used to minimize the utilization of energy in the network [2]. The different mechanisms related to energy efficiency are discussed below.

Radio Module The energy efficiency of the radio module is achieved through one of the four states of the sensor node radio: idle, sleep, transmit or receive. When the sensor radio is off, the state will be of sleep mode. The state will be of idle mode, if the transceiver is not transmitting or receiving [2]. The major source of energy efficiency in the radio component is the idle state [81]. It is the key component that cause depletion of the battery of sensor nodes. The energy consumption of the radio module can be minimized by modulation optimization parameters. The depletion of energy is caused by the circuit and signal power transmission. The information's like the rate of transmission, the transmission time and the distance between the node must be considered for the consumption of energy in the radio module. The transmission time can be minimized by the Bit Error Rate [82].

The distance among the nodes is minimized by the various modulation schemes. The quality of the received signal in the radio module can be improved by cooperative communication methods. This method combines different single antenna receivers to generate a multiple antenna transmitter because due to the channel broadcasting, transmitted information are overheard by the adjacent or the nearest nodes [83]. Cooperative communication can also be used for duty cycling and helps to extend the range of communication [84]. Single Input Single Output (SISO) and Multiple Input Multiple Output (MIMO) [85] systems provide energy consumption, and generates low delays over the transmission range.

To improve energy efficiency, Transmission Power Control strategy [86] is used by the radio power transmission. This strategy is also used to find the delays, interference, quality of the link and connectivity. When delays are increased, more number of hops are needed to forward the packet. Interference occurs in neighbor nodes due to the transmission power. Transmission power also affects the connectivity because of the topology of the network [81].

Cooperative Topology Control with Adaptation (CTCA) [87] consumes energy by decreasing the transmission power. The signals can be broadcast and received only in a single direction at a time in directional antennas. The characteristics of directional antenna are improvement in the throughput and transmission range, requires low power, low interference, contains localization techniques, re-usage of bandwidth, improve network lifetime and network capacity [81]. The limitation of directional antennas are antenna adjustments, signal interference and deafness problems [88].

A cognitive radio is used in the wireless spectrum, contains a communication channel which can be selected dynamically and also contains significant energy consumption. The Software-Defined Radio (SDR) technology in the cognitive radio creates wireless transceivers which adapts their parameters automatically according to the demand of the network [89].

Table 3 Approaches and issues in terms of types of coverage, energy efficiency, sensor types, sensing models and deployment strategies

Ref.	Sen. type	Dep. Str.	Cov. type	Sensing models	Ene. Eff.	Pbl. Obj.	Approach, analysis	Issues/further work
[2]	S	R	A, T	BSM	Rad.	Coverage in terms of efficiency	Comparative analysis	Focus on distributed & localized solutions
[7]	S	R,	A	BSM	X	Maximize area coverage	VFA, Java	Lifetime & connectivity issues are not addressed
[41]	H	R, D	A, T, B, K	BSM & PSM	Rad.	Coverage problems in WSN	Comparative analysis	Deployment needs influence of coverage
[52]	S	R	A	BSM	Bat.	Reducing energy consumption	Heuristic approach, simulation	Only one disjoint set sense the area
[62]	M	R	B	BSM	S/W	Maximize network lifetime	LBCP, Matlab	Quality of barrier is not measured
[63]	S	R	A	BSM & PSM	Bat.	Minimize coverage redundancy	Greedy, algo., C++	Only coverage property of disk model is considered
[65]	S	R	T	BSM	Bat.	Maximize network lifetime	Heuristic approach, simulation	Only one disjoint set sense the area
[66]	H	R	T	BSM	Bat.	Finding optimized location	SA, PSO Matlab	The schedule fulfills the coverage needs high priority
[70]	M	R	B	BSM	X	Impact of border effect	Mapped algo., Matlab	Each sensor is assumed with varying sensing
[71]	M	R	K	BSM	X	To form K-barrier coverage	WBG model, Matlab	Fault tolerant algo. is not considered
[76]	H	R, D	A	BSM & PSM	Rad.	Coverage connectivity problem	Algo. and technique	Non uniformity in sensing & communication range
[77]	M	R, D	P, K	BSM & PSM	S/W	Coverage problems	Comparative study, Survey	Deployment of optimal node, coverage hole
[78]	M	R	A, T, B	BSM	X	Improve network coverage in WSN	Comparative analysis, survey	An integrated movement strategy can be developed
[79]	S	R	A	BSM	Bat.	WSN deployment problem	GA, NSGA-II NS-2	Integrate real sensing models

Ref. reference, *Sen. type* sensor type, *Dep. Str.* deployment strategy, *Cov. type* coverage type, *Ene. eff.* energy efficiency, *Pbl. Obj.* problem objective, *S* static, *M* mobile, *H* hybrid, *R* random, *D* deterministic, *B* barrier, *A* area, *T* target, *K* K-barrier, *P* path, *BSM* binary/disk sensing model, *PSM* probabilistic sensing model, *S/W* sleep/wakeup, *Bat.* battery, *Rad.* radio, *algo.* algorithm, *X* not applicable, *NSGA* non-dominated sorting genetic algorithm

Data Reduction The next category to achieve energy efficiency is data reduction. This implies that the data to be sent to the sink node can be minimized. Data aggregation minimizes the data quantity by forming fusion of the data, and is forwarded to the sink node. It also reduces the rate of traffic and latency. The accuracy and precision of data are lost because of the non-recovery of the original data by the sink [81]. The various aggregation techniques in WSN include [90] aggregation functions, networking protocols and representation of data. A Routing protocol is one of the major ingredients in the aggregation process. It requires forwarding paradigm for routing purposes. Forwarding paradigm aggregates the data to minimize the energy, route packets based on the content of the packet and the next hop is chosen. This type of data forwarding is also known as data-centric routing.

Data compression is another method used for energy efficiency since it minimizes the transmission time. Data compression reduces the number of bits in the packet which represents the initial messages. Various compression algorithms such as distributed compression, coding by ordering, low complexity video compression and pipelined in-network compression are designed specifically for WSN. In coding by ordering compression method, the data is passed from the source node to the sink node. Some nodes operate as a data aggregation node in the data funneling routing. The sensing datas are collected and united together at the aggregation node and is sent to its corresponding parent node. In Distributed Compression scheme, source information is encoded and correlated. The correlation condition can be fulfilled easily because of the densely populated sensor nodes. Low-Complexity Video Compression technique is based on JPEG compression scheme and block changing detection algorithm. Video encoding technologies consumes more power, since it is designed with motion estimation. Pipelined In-Network Compression deals with consumption of low energy for high latency transmission of data. The data from the sensors are collected and stored in the buffer of the aggregation node. The data packets are also gets collected into a single packet and redundancies are removed, which helps to minimize the data transmission [92].

Sleep/Wakeup Schemes Sleep/wakeup scheme consumes energy by setting the sensor radio in sleep mode. To diminish the idle state and to support the sleep mode, duty cycling mechanisms are used [81]. Even though duty cycling scheme is one of the most energy-efficient scheme, they undergo sleep latency. Sleep latency is the latency in which the node waits until the receiver to be awake. It is not possible to broadcast information simultaneously because the neighbors are not active at all times. Duty cycling waste energy because of redundant wakeups. Low duty cycles considerably increase the delay, thus consumption of energy is achieved [93, 94]. Low-powered radios helps to awake a node only when it transmits or receives a packet. An RFID radio which is passive, utilizes the energy to wake-up only the triggered node by the RFID reader. Due to the high cost and power consumption, all sensors cannot contain RFID readers [95]. Topology control [81] dynamically adapts the network topology to minimize the active nodes. By triggering the subset of nodes [96], network coverage can be maintained and energy consumption can be minimized. Selection of active sensors subset is used for data gathering [97] in environmental monitoring. A distributed temperature aware algorithm is proposed by [98] that allows dynamically some nodes to sleep mode while there is low temperature.

Battery Repletion/Charging Several technologies are used to harvest energy from the wind, solar and other categories of energy. Energy prediction mechanisms are required to manage the existing available power. For adapting the consumption of power, various decision parameters such as duty cycling, transmit power and sampling rate must be optimized [81]. In case of designing protocols, nodes with uneven residual distribution of energy must be taken into consideration. The path of routing is done with high residual energy and low

residual energy is assigned with low transmission range and high sleep periods. The network performance is also affected by the leakage or loss or degradation of the battery [99].

In WSN, Wireless charging is done by magnetic resonance coupling and electromagnetic radiation [81]. Electromagnetic radiation technology is used with low sensing and low power requirements, because the waves that is generated by the electromagnetic radiation experiences a rapid drop of efficiency of power over distance and poses human safety [100]. Magnetic resonant coupling addresses energy efficiency within the range of several meters. The technology related with wireless power charging must overcome the energy constraint, because now it is possible to deplete the elements of the network in a controlled manner. A challenge in wireless charging technology is the energy cooperation, because of the energy sharing between neighbor nodes. Hence, in future WSN, nodes will have the capacity to predict the energy harvesting from the environment and transfer of energy to other nodes, leads to self-sustaining network [101].

Recent progress used in wireless technologies to charge the WSN sensor node batteries were illustrated by Prakash et al. [103]. The sensor network is partitioned into two clusters, each own its charging vehicle. The travelling path makes a decision based on the awareness of energy and the initial point decides the energy of the sensor node. A framework named wirelessly energy-charged WSN (WINCH), [104] is used for recharging the batteries of a sensor via mobile robots. This model also calculates the quantity of the harvested energy by each sensor.

The energy controlled in a multi-access network was considered by Sarikaya et al. [106] with concurrent information and wireless transfer of energy. The aim is to increase the energy of the receiver and to determine the collision probability. The samples are taken from the Radio Frequency (RF) signal. A dynamic control algorithm which is asymptotic decodes the decision and formulates an energy harvesting with respect to the battery level and computations of the current channel.

A multi-node wireless energy transfer technology and a Wireless Charging Vehicle (WCV) was proposed by Xie et al. [107]. Based on the WCV range of charging, a cellular arrangement divides the 2-D plane into hexagonal cells. A technique known as Reformulation-Linearization Technique (RLT), is used to generate the solution for any desired accuracy level. The different energy efficiency mechanisms along with approaches, techniques used, advantages and issues are given in Table 4.

8 Conclusion and Further Work

In this paper, various approaches and open issues were analyzed based on sensors, deployment strategies, sensing models, energy efficiency and coverage in wireless sensor networks. The review is based on four different perspectives such as (i) energy efficiency and different categories of WSN environmental sensors; (ii) sensing models, coverage and deployment strategies; (iii) types of coverage, energy efficiency, sensor type, sensing models and deployment strategies; and (iv) energy efficiency mechanisms. The approaches and issues in terms of different perceptions are clearly presented in the respective tables. This work can also be used as an initiative for researchers in the field of wireless sensor networks. Various open issues in research which ranges from the types of sensors to coverage, energy efficiency, etc., are the recent areas for the future study in WSNs.

From this study, it was identified that (i) Network connectivity and security are critical issues that can be devised in building future systems, (ii) Guaranteeing coverage

Table 4 Approaches and issues in terms of energy efficiency mechanisms

Ref.	Energy Eff. Mech.	Approach, technique	Communication	Advantage	Issues/further work
[82]	Radio module	Cooperative transmission	Point-to-Point	Bandwidth, energy efficient	Transmission energy depends on transmission time
[83]	Radio module	Cooperative communication	SISO, MIMO	Improved channel stability	Mobility of nodes are not addressed
[90]	Data Red.	Aggregation cluster, multipath approach	Multi-hop routing, aggregation points	Consumption of energy	Mobility not addressed
[91]	Radio module	Cognitive Radio	Multi-channel	Efficient power allocation	Decrease in energy efficiency with increase in users
[92]	Data Red.	Data compression algorithms	Peer-to-peer	Minimizing power consumption	Diminishes the resource constraint of nodes
[93]	Sleep/wake-up	Duty Cycling	Multi-hop	Ensures a longer network lifetime	Can focus on practical implementation
[95]	Sleep/wake-up	Passive wake-up radios	Broadcast	Improve energy efficiency	Collision happens if there is large number of nodes
[102]	Radio model	GA-ANFIS, cluster head selection	Symmetric communication	Improve energy efficiency	Only static number of nodes are used
[104]	Battery Charging Model	WINCH, charging via robotic vehicle	Intra-cluster communication	Improve energy transfer via robot positioning	No guarantee of maximum power harvesting
[105]	Battery Charging Model	Maximum power transfer & efficiency approach	Multiple receivers	Optimum load range leads to maximum power transfer	Compensation of elements to load series
[106]	Battery	Optimization framework	Multi-access	Harvesting energy with collision model	Recharging battery from RF signals only
[107]	Battery	Reformulation linearization approach	Multi-mode charging	Energy transfer helps charging batteries	Based on charging range

Ref. reference, *Energy eff. mech.* energy efficiency mechanism, *Data red.* data reduction, *GA-ANFIS* genetic algorithm-adaptive neuro-fuzzy inference system

constantly due to the mobility of sensor nodes can form the basis for further research, (iii) Although the coverage schemes of WSN are considered, routing concepts can also be focused, (iv) The irregularity of the WSN sensing ranges can be taken into account for designing future solutions (v) Energy efficient mechanisms like sleep/wake schemes, radio model and battery charging can be analysed in a heterogeneous environment. These challenges can form the basis for further research.

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