An Overview of Energy Efficient Routing Protocols

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Abstract - Wireless Sensor Networks are networks of sensor nodes that monitor the region of interest and collect data to be analyzed and stored. WSNs have many industrial applications in the fields of environmental monitoring, healthcare and diagnosis, industrial process and control, military surveillance, monitoring agriculture, monitoring of air pressure, noise level, temperature and more and the latest being IoT and home automation. There is a need for energy conservation in WSNs as they are largely battery operated and are remotely deployed making them non rechargeable and non replaceable. This paper gives an overview of the WSNs and the various energy efficient protocols used for it.

Key Words - WSNs , LEACH, PEGASIS, TEEN, APTEEN, SEAD, EAQRP

I. INTRODUCTION

The growing demand for all things digital is paving the way for smart gadgets that are connected to the internet. These gadgets offer comfort and ease of use and hence are becoming popular. Internet of Things (IoT) is the umbrella term for such a product where our regular appliances are made such that they can communicate over the internet using sensors, actuators, controllers, etc. Sensors are devices that detect and respond to the sensed change in environment and send it to controllers or processors for further action. It takes change in its physical environment as an input and sends an electric impulse as its output. The change can be in anything from heat, humidity, pressure to motion, light and more.

Wireless sensor networks (WSNs) have garnered global recognition in recent years, in particular with the upsurge in Micro-Electro-Mechanical Systems (MEMS) technology which has led to the development of smart sensors [1]. WSN are networks of interconnected sensor nodes that supervise and record modification in their monitoring field and send it to a central module for processing. The data is communicated through numerous nodes, and with a gateway, the data is connected to other networks like wireless Ethernet.

Routing is the mechanism of determining a path across a network to convey packets from source to a destination host or hosts done via routers. Routing in the context of WSN is required for transmitting the data across the sensor nodes and the base stations, for the purpose of implementing communication [2].

Energy efficiency alludes to a method of reducing energy consumption by using less energy to achieve the identical proportion of usable output.

As part of the IoT, WSNs embody helpful networks which help in the monitoring, tracking and sensing of different environmental events. These activities require energy. Energy assessment in WSNs is of utmost necessity for the remotely dispersed energy demanding sensor nodes. These nodes are usually powered by affixed batteries and hence the need arises to conserve energy for achieving long network lifetime.

This paper focuses on various energy efficient routing protocols that can be applied to WSNs so as to minimize power consumption. Section II discusses WSNs briefly, Section III illustrates classification of routing protocols in WSN and Section IV gives an overview on energy efficient routing protocol (EERP).

II. WIRELESS SENSOR NETWORKS (WSN)

Wireless sensor network is a multi-hop wireless network consisting of a number of small-size, low-priced and low-power, low memory, communication restricted sensor nodes which are proficient in sensing, computation and communication. A WSN comprises geographically dispersed sensors, and one or more sink nodes also known as base stations which collect the data gathered by sensor nodes and communicate it to applications via the gateway. A sensor node can act as data initiator and data router while a sink gathers data from sensors. These sensor nodes consist of sensor, communication, microcontroller, memory, radio and power. Considering the application requirements, other units could be considered such as: GPS, locomotory, energy harvesting, etc [4]. The sensor nodes are deployed in locations which are not easily accessible and hence require radio for communicating with base stations. Fig. 1 depicts the basic architecture of a WSN [3].

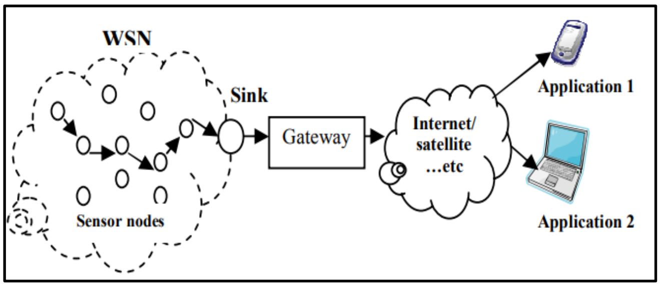

Figure 1: Basic WSN architecture

Implementing WSNs have certain challenges such as Scalability, Quality of Service (QoS), Security, fault tolerance, data fidelity, network lifetime, network connectivity and energy efficiency [4].

Based on the sensors' capabilities and application requirements WSN models and architectures are applied [4]. They are as follows:

A. *Small, medium or large-scale*

The scale of the WSN depends upon factors like the system requirement, region of interest, etc. Sensor nodes present in a WSN can be in the range of tens to thousands or even more.

B. *Homogeneous or heterogeneous*

A homogeneous WSN has sensor nodes with the same functioning capabilities like same processing power, battery, etc. whereas a heterogeneous WSN has sensor nodes with differing functioning capabilities

C. *Stationary, mobile or hybrid WSN*

The term "stationary WSN " refers to a network whose sensors cannot move once installed while a mobile WSN comprises sensor nodes attached to a mobile platform that enables them to move even after deployment. A hybrid WSN contains both stationary and mobile sensors.

D. *Single-hop or multi-hop WSNs*

A single -hop WSN consists of sensor nodes that directly send their data to the base station while multi- hop WSNs take multiple hops meaning they traverse a route through sensor nodes to the base station.

III. ROUTING IN WIRELESS SENSOR NETWORKS

Routing is needed in WSN as strategies required for transferring data between the sensors and the base station while Energy efficient routing protocols (EERP) are required to minimize the utilization of the power resource and prolong the network lifetime path while transferring the data. Routing in WSNs varies from traditional routing in fixed networks in several aspects such as no infrastructure, unreliable wireless links, sensor nodes may fail, and routing protocols have to meet strict energy saving demands [5].

Because of the limited amount of energy supply, resources and computing WSNs face the challenge of providing scalability, data resilience, adapting fault tolerant data delivery models, adapting to operating environments, low cost sensor nodes, handling data redundancy by data aggregation for traffic optimization and trade off between power consumption and accuracy of collected data [6,7].

Routing techniques for WSNs have been introduced by researchers in the field and hence they are categorized on the basis of various criteria. Fig. 2 illustrates the classification of routing protocols on the basis of their functioning mode, participation style and network structure.

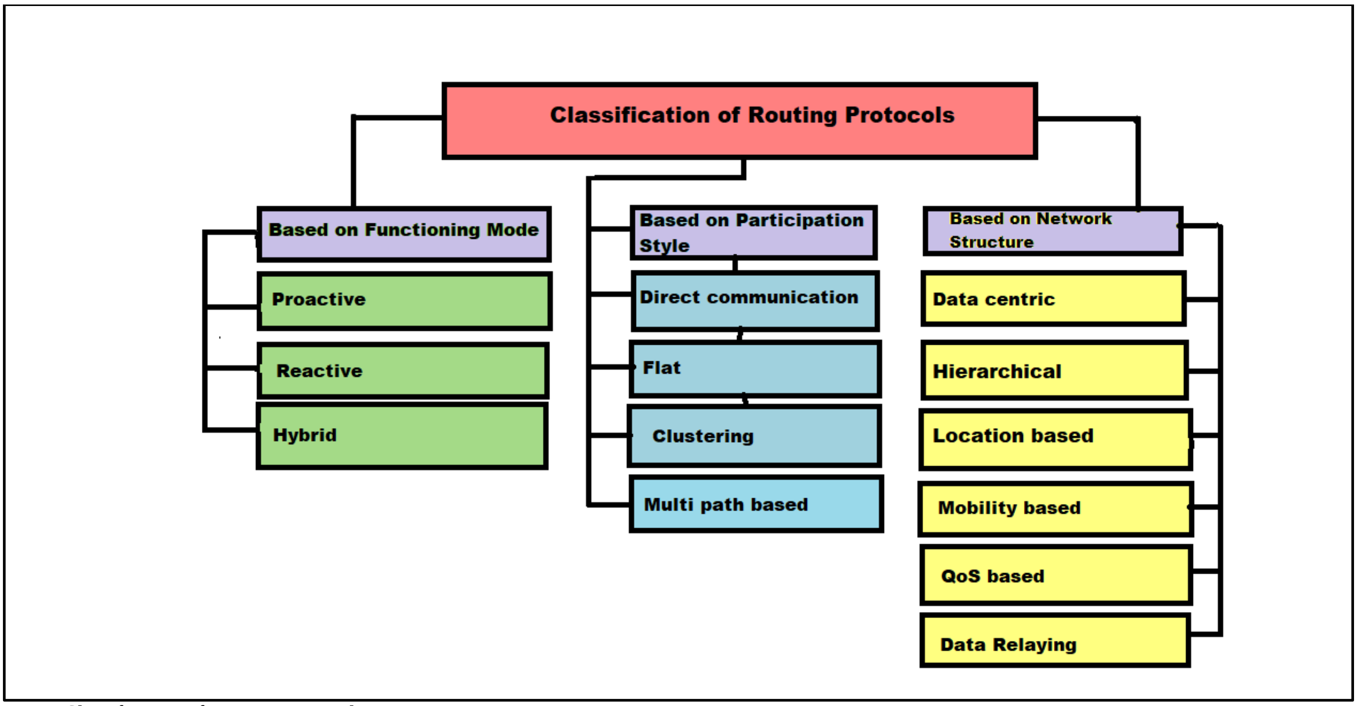

Fig. 2: Classification of Routing Protocol

A. *Based on Functioning Mode:*

The routing protocols can be characterized based on the operation utilized to conform to a WSN function or type of application in three categories;

1) *Proactive:* In a proactive protocol the sensor nodes turn on their sensors and transmitters, perceive the environment and transmit the data to a base station through the predetermined route.

2) *Reactive:* The nodes react instantly only when a sudden change in the monitoring field is detected. This type of protocol is utilized in time critical applications. Reactive protocols only maintain the routes which are currently in use.

3) *Hybrid:* As the name suggests it uses both a proactive and reactive approach. This is done by taking into

account all available routes (as in proactive) and then select the ones that are currently in use.

B. Based on the Participation Style:

WSNs can include homogeneous nodes or heterogeneous nodes or both and these nodes partake diversely in every network. Based on this concept of participation protocols can be classified as:

1) *Direct Communication:* As the name implies here the nodes can transmit data to the sink directly. But it is deficient for energy when applied in large networks as the sensor nodes are drained quickly.

2) *Flat:* For sending the data to the Base station a valid path is searched by the transmitting node and then the data is transmitted.

3) *Clustering:* Here, the overall area is partitioned into a number of clusters. All clusters have a cluster head (CH). Every node belonging to a particular cluster sends their data to their respective CH and the CH directly connects with the base station.

4) *Multi-path based:* In multi-path routing every sensor that sends data, ascertains the first shortest route to the base station and partitions its load evenly among these paths [8].

C. Based on Network Structure:

Network-based routing protocols depend on how the structure of the network is planned. Such protocols fall under three categories:

1) *Data Centric :* These are query based and they rely on the naming of the required data, thereby eliminating most of redundant transmissions. The base station transmits queries to a specific area for data and awaits the reply from the nodes belonging to that area. Attribute based naming is needed to clarify the properties of the data. Depending on the query, sensors gather the data from the region of interest and transmit it to the base station thus reducing the number of transmissions.

2) *Hierarchical protocols:* These protocols are utilized to execute energy efficient routing. It is done by utilizing higher energy nodes to process and transmit the data while low energy nodes are used to conduct the sensing in the region of interest.

3) *Location based :* Sensor nodes are identified by means of their locations. Location oriented routing protocols require the location information of the sensor nodes. Location information is necessary to compute the distance between two specific nodes for measuring energy consumption. It can be acquired from GPS (Global Positioning System) signals, received radio signal strength, etc. by employing location information, an optimal route can be conceived without applying flooding techniques.

4) *Mobility based:* Mobility based protocols have mobile sinks that are responsible for data collection from the network [9]. Here base station mobility necessitates energy efficient protocols to assure data delivery emanating from originating sensors toward mobile base stations [8].

5) *QoS based:* Quality of Service (QoS) prerequisites like delay, reliability and fault tolerance are as crucial in routing in WSNs as energy efficiency but QoS based protocols can also provide energy efficiency [8,9].

6) *Data relaying:* Data relaying protocols are very simplified in nature and easy to enforce as they do not need to maintain a routing table or topology information regarding the network [10]. They simply relay data.

IV. ENERGY EFFICIENT ROUTING PROTOCOLS

In WSN, sensors recede energy mainly for communicating and receiving data as opposed to data sensing and processing, while a substantial quantity of energy is wasted in activities like data collision where a node receives a number of packets simultaneously the packets collide and have to be retransmitted; data overhearing where nodes listen to other nodes who are transmitting data; idle listening in which nodes keep listening to an idle channel for data packets; interference is where each node within a transmission range receives a packet but are unable to decrypt it [10]. All these activities lead to severe energy loss. Consequently, appling EERP becomes a beneficial task that increases the network longevity.

Based on the classifications in Section III we can observe various EERP. They are discussed below:

A. LEACH (Low-Energy Adaptive Clustering Hierarchy):

LEACH [11] is a proactive hierarchical clustering based protocol. It is utilized when a node in the network flunks or its battery ceases functioning [6]. It is self organizing as it partitions all the nodes into clusters and elects a cluster head (CH). Since it is proactive transmission of data takes place routinely and every round a new cluster head is elected. All the nodes in a cluster send their data to the CH which uses the data aggregation method to combine and compress the data and transmit it to the base station. The CH is selected from the sensor nodes at a time with a certain probability. Each node generates a random number from 0 to 1. If this number is lower than the threshold node [T(n)] then this particular node becomes a CH. T(n) is given as follows:

$$T(n) = \frac{p}{1-p}\,[r mod(1/p)]\,, n \epsilon G, \text{otherwise}$$

where p is the percentage of nodes that are CHs, r is the present round and G is the set of nodes that have not acted as CH in the previous 1/p rounds [13]. Every round consists of two phases viz. Setup phase and steady phase [12, 13].

- *Setup phase:* In this phase, the clusters are ordered and the CH is selected, advertisement of nodes is taken care of and schedule establishment takes place.

- *Steady phase:* In this phase, the data is communicated to the base station. This step has a longer duration to compensate for overhead.

LEACH incorporates a TDMA/code-division multiple access (CDMA) to allot time slots to the nodes so that they can minimize inter cluster and intra cluster collisions [6]. This type of selection of CH ensures energy conservation as different nodes are utilized as CH in every round and only CH has to select the route to the base station reducing the number of packets to be sent. However, LEACH is not appropriate for vast networks and cannot ascertain genuine load balancing [14].

B. PEGASIS (Power-Efficient Gathering in Sensor Information Systems):

PEGASIS [15] is a proactive, hierarchical based protocol. It is a near optimal chain-based protocol that serves as an extension of LEACH [7, 13]. Simulation results show that PEGASIS can outperform LEACH [9,10]. Here, instead of forming clusters the nodes form a chain. The chains are formed using greedy algorithm as all nodes have global information about the network. All the nodes have information about all the other nodes. Each node in the chain sends and receives data from its neighbor. Every node receives the aggregated data and adds to it. It is assumed that each node is capable of transmitting the data to the base station and hence a leader is chosen at random to send the aggregated data to the base station [7]. The chain formation starts from a remote node and consists of the nodes that are nearer to each other and pave a path towards the base station. If a node dies the chain is reformed through a greedy algorithm.

Compared with LEACH, this algorithm eliminates the overhead of forming clusters but needs dynamic topology adjustment which causes overhead. Furthermore, it does not take the energy consumption of the next hop into consideration when choosing a routing path and since the delay in transmission is high it does not scale well so it is not suitable for a heavily loaded network.

C. HEED (Hybrid, Energy-Efficient Distributed Clustering):

HEED [16] is a hierarchical clustering based protocol. It is an extension of LEACH. Designed for homogeneous WSNs it employs residual energy and node density for cluster selection to obtain energy balancing [9]. It is a totally distributed clustering method where transmissions can happen in multi-hop mode between CHs and the sink. HEED has the following characteristics:

1. It improves network lifetime by distributing energy usage;
2. It stops clustering procedure within a fixed number of iterations;
3. It minimizes control overhead and
4. Create well distributed CHs and concise clusters.

HEED selects CHs based on the remnant energy of the nodes and intra-cluster transmissions cost as a function of cluster density. HEED clustering provides better network lifetime than LEACH clustering.

D. TEEN (Threshold sensitive Energy Efficient sensor Network protocol):

TEEN [17] is a reactive, hierarchical, clustering based protocol. It was the first reactive network to be developed and was utilized for temperature sensing application [6, 12]. It is modeled on LEACH and is applied in time critical conditions. It is used for sensing the sudden change in the monitoring field. Considering they are largely in sleep mode, the number of transmissions is minimized, thereby reducing the energy consumed. It uses two cluster levels. The CHs senses two types of data viz. hard threshold and soft threshold.

1. *Hard threshold:* Here the nodes send data if the sensed trait is in the scope of interest thereby reducing the number of transmissions.
2. *Soft threshold:* Whilst here, any minuscule alteration in the value of the sensed trait is transmitted.

The nodes sense the monitoring field and stack away the sensed value for transmission. These sensed values are transmitted if one of the following conditions is satisfied [13]:

1. $Sensed\ value > hard\ threshold\ (HT)$.
2. $Sensed\ value \sim HT >= soft\ threshold\ (ST)$.

E. APTEEN (Adaptive Threshold sensitive Energy Efficient sensor Network protocol):

APTEEN [18] is an enhanced version of TEEN protocol. Hence it has similar features to it. It was conceived for hybrid networks so it can gather periodic data and react to time critical occurrences. APTEEN supports queries such as analysis of past data value, a glimpse of the present network condition and continual surveillance of an event for a given timeframe. In APTEEN like LEACH cluster head are elected for every round but unlike TEEN and LEACH here the CH broadcasts elements such as attributes (the trait of interest), threshold (hard and soft thresholds), schedule (allotment of time slots using TDMA) and count time (max time span between two consecutive transmissions done by a node) to all nodes [7, 13].

The energy intake can be governed by the count time and the threshold. The key drawback of the both TEEN and APTEEN algorithms are the overhead and complexity of creating clusters.

F. Directed Diffusion (DD):

DD is a data-centric, energy conserving diffusion technique [19] and application-aware protocol in which data garnered by sensor nodes is identified by attribute-value pairs. It uses meta-data. It is aimed at providing energy efficiency, scalability and robustness which is done by caching. Here data is aggregated by each node. DD involves four parameters:

1. *Interests:* These are the list of attribute value pairs which defines a task.

2. *Data messages:* Data messages are named via attribute value pairs.
3. *Gradients:* It prescribes data rate along with the direction of event.
4. *Reinforcements:* It elects a specific path from a plethora of paths.

In DD, a sink diffuses a query in the direction of the nodes in the interested region. Each node receives the interest and sets the gradient (direction) towards the sensor nodes on the multi hop path and the reverse of this route is traversed towards the sink. This algorithm reduces energy consumption by choosing optimal paths and handling data within the network. The key drawback here is the overhead engaged in capturing information therefore upsurging the cost of a sensor node.

G. *Rumor Routing (RR):*

RR [20] is based on a flat participation style and data centric network structure. It is similar to directed diffusion and is utilized for applications where location routing is infeasible. Rumor routing is a logical combination of query flooding and event flooding [5]. The rumor routing algorithm uses long-lived packets called agents to flood events across the network. An agent is created by a node when it discovers an event and this event is added to the event table of the node. The agent traverses the path randomly along with the event relevant information. A gradient is formed for the event. If a node wants to initiate a query, it routes the query to the starting source. RR only retains one path between source and destination. RR is only feasible for a small number of events. Key drawback is the overhead of being controlled by parameters like time to live, pertaining to queries and agents [13].

H. *SPIN (Sensor Protocols for Information via Negotiation):*

SPIN protocols [21] are a family of negotiation based information diffusion protocols utilized in WSN. Negotiation tackles the problems faced by Flooding algorithm. Here the data is stored in conjunction with its meta-data. Meta-data is used to prevent redundant data from being sent. The transmission of the data from a node is based on application specific knowledge of the data and the knowledge of the resources accessible to them. This permits the sensors to utilize their energy and bandwidth efficiently. Here it is assumed that all nodes are base stations and hence information is broadcasted to every node in the network.

Meta-data is swapped among sensor nodes (meta-data negotiation) ahead of transmission, through a data advertisement mechanism. SPIN uses three types of messages [13]: ADV, REQ, and DATA for communication with each other. ADV is utilized for advertising new data, REQ is employed for requesting the data and DATA is the real message. So, a node obtains new data and it intends to disseminate that data across the network, hence it broadcasts an ADV message comprising meta-data. The interested nodes send a REQ message requesting data and the data is sent to the requesting nodes. This is a classic solution to the problem of flooding and thus it achieves energy efficiency. SPIN accomplishes high performance at low cost in terms of complexity, energy, computation and communication [7].

I. *GAF (Geographic Adaptive Fidelity):*

GAF [22] is an energy aware routing protocol proposed for Mobile Ad hoc Networks (MANETs) but can also be employed for WSNs because it aims at energy conservation. It is a location based EERP. Here the nodes are dappled in a virtual grid covering the area of interest. Nodes utilize their locations to associate themselves to a point on the grid. The location is indicated by GPS. If the nodes are affiliated with the same point on the virtual grid the cost of packet routing is deemed tantamount for those nodes. This helps in energy preservation by allowing some of the nodes present on the same point to sleep. Consequently it can be said that in GAF context if the number of nodes upsurge so does the network lifetime. The state transition diagram in GAF has three states [7, 9, 13]:

1. *Discovery:* Here the nodes swap messages with their neighbors to ascertain them on the grid.
2. *Active :* An active node participates in the routing process. A sensor periodically broadcasts its discovery message to inform other sensors about its state. At least one node in the same grid must remain active to ensure routing fidelity while other equivalent nodes can be in sleep state.
3. *Sleep:* In this state the routers suspend their radios and enter sleep mode.

GAF strives to enhance the network lifetime by attaining a state where each grid has only one active sensor based on sensor ranking rules. The residual energy levels help in ranking the sensors. A sensor with a higher rank conducts routing within their associated grids.

J. *GEAR (Geographic and Energy Aware Routing):*

GEAR [23] is a location based routing protocol which sends queries to region of interest using a geographical and energy aware neighbor selection heuristic. The heuristic helps in minimizing the cost to route the packet over the target region. In this protocol, every node stores two kinds of cost of approaching the destination viz. estimated cost and learning cost. The estimated cost is a blend of residual energy and distance to destination. The learned cost is a reconfigured estimated cost and it records the routing of holes in the network [13]. A hole is developed when there are no next hop nodes immediately near to the current hop node. There are two stages in this protocol:

1. *Stage 1:* Here, the packets are sent in the direction of the target region. When a packet is received, the receiving node searches for a neighbor that is nearer to the target region than its own area; this neighbor is selected as the next hop. If more than one suitable node exists, then a hole exists, and in this case one node is picked to forward the packet based on the learning cost function.
2. *Stage 2:* Here, the packets are transmitted within a region, and if the packet reaches the region, it is

dispersed there either by recursive geographic forwarding or restricted flooding. restricted flooding is employed if the sensors are not densely distributed, and recursive geographic flooding is employed when the node density is high. In recursive geographic flooding, the region is segmented into four sub regions and four replicas of the packet are formed. This process persists till the regions with only one node are remaining.

K. SEAD (Scalable Energy - Efficient Asynchronous Dissemination):

SEAD [24] can be regarded as an overlay network that resides on top of a location-aware mobility based routing protocol. It was proposed to trade-off between reducing the forwarding delay to a movable base station and energy conserving. The origin sensor forwards sensed data to several mobile base stations and the protocol comprises three main elements viz. dissemination tree (d-tree) construction, data dissemination and maintaining links to mobile base stations.

SEAD infers that sensor sensors have knowledge of their own geographical locations. A dissemination tree is constructed for each sensor that routes itself to itself, and all the dissemination trees for other sensor nodes are constructed separately.

L. EAQRP (Energy-Aware QoS Routing Protocol):

EAQRP [22] is a QoS based energy aware routing protocol in which imaging sensors generate real-time traffic. It determines the least cost and energy efficient path and the link cost is a function that catches the nodes' energy reserve, transmission energy, error rate and some communication parametric quantities. A class-based queuing model is employed for supporting best effort and real-time traffic simultaneously. This algorithm accomplishes better performance with respect to both QoS and energy metrics. Table 1 summarizes the features of all the discussed protocols.

TABLE I. COMPARISON BETWEEN DISCUSSED EERPS

Protocols	**Features**										
	Classification	***Power Usage***	***Network Lifetime***	***Data fusion***	***Scalability***	***Multi path***	***Query oriented***	***Mobility***	***Resource awareness***	***QoS***	***Localization***
LEACH	Hierarchical	Maximum	Very Good	No	Good	No	No	Fixed BS	Yes	No	Yes
PEGASIS	Hierarchical	Maximum	Very Good	Yes	Good	No	No	Fixed BS	Yes	No	Yes
HEED	Hierarchical	Good	Good	Yes	Medium	Yes	No	No	Yes	No	Yes
TEEN	Hierarchical	Maximum	Very Good	Yes	Good	No	No	Fixed BS	Yes	No	Yes
APTEEN	Hybrid	Maximum	Very Good	Yes	Good	No	No	Fixed BS	Yes	No	Yes
DD	Data centric	Limited	Good	Yes	Limited	Yes	Yes	Limited	Yes	No	Yes
RR	Data centric	Not supported	Very Good	Yes	Good	No	Yes	Very limited	Yes	No	No
SPIN	Data centric	Limited	Good	Yes	Limited	Yes	Yes	Support	Yes	No	No
GAF	Location based	Limited	Good	No	Limited	No	No	Limited	Yes	No	Yes
GEAR	Location based	Limited	Good	No	Limited	No	No	Limited	Yes	No	Yes
SEAD	Mobility based	Limited	Average	N/A	Yes	No	No	N/A	Yes	No	N/A
EAQRP	QoS based	Good	Good	N/A	Yes	No	No	N/A	Yes	Yes	N/A

CONCLUSION

In conclusion, WSN is a huge and growing industry and is prominent for the implementation of IoT. There are a large number of researchers studying this field to gain an edge in the "smart world". Energy efficiency is a huge undertaking that is beneficial to the industry as it grows network lifetime. A lot of research has been conducted on the matter yet a completely feasible and cost effective protocol is yet to be found as the majority of these protocols have some overhead and drawbacks.

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