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A Survey on Energy-Aware Wireless Sensor Routing Protocols

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Abstract

A technological evolution in digital electronics gives birth to micro-electro-mechanical systems (MEMS). This evolution generates drastic change in the field of micro-sensors. Micro-sensors are advanced in capabilities of low-cost, less energy consumption, self-configurable, work on heterogeneous environment and highly reliable. A way to work efficiently automated systems are relying on sensor backbone known as routing protocols. The routing protocols is key whose functionality provides a better usability of a system in effective and efficient way. In this paper, we have focused on categories of routing protocols based on required applications. The main idea of this survey to present the applicability of sensor routing protocols in various indoor and outdoor applications.

Keywords: energy efficient, sensor routing protocols, clustered sensor routing, fuzzy logic sensor routing, swarm intelligence sensor routing

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1. Introduction

Sensor nodes communicate via wireless technology. Packets are passed to one another after connection has been established. Sensor network faced many challenges. The main constraints of network stability are energy supply and limited bandwidth. Some other quality of service (QoS) challenges is also come under consideration if better quality data is required. The actual issues are common for every type of sensor applications. Therefore, main focus of research is on system level power awareness, radio communication, duty cycle issues, energy aware MAC protocols [12-16]. If we talk about network layer, the main attention is set up a route to channelize the data packets with minimum amount energy consumption and other central requirement is reliable relaying of data towards BS. In-addition to this the overall requirement is to maximize network lifetime.

We now look at some routing challenges. Firstly, there is no likelihood of global addressing scheme usage. Consequently, classical IP-based routing cannot be implemented. Secondly, in most of the sensor applications require flow of data stream from source nodes to BS. Thirdly, redundancy of sensed data required, as due to multi sensors generates the same data value in the territory of the phenomenon. Hence, it improves bandwidth utilization and energy efficiency of the network. At the last, there is a fine requirement of resource management.

After above discussion over routing challenges, many new routing protocols have been proposed in sensor network. The routing procedures have considered the characteristics as well as needs of sensor nodes according to specific application and architecture. Most of the proposed routing algorithms can be categorized as data-centric, hierarchical and location-based protocols along with this some of protocols based on QoS. Data-centric protocols are basically query-based. They are totally depending on naming of desired data, ultimately helps in data redundancy during transmissions. Hierarchical protocol's main prospect is to create the clusters, performs data aggregation from non-cluster nodes to cluster head nodes in various cluster's vicinity. They are mostly based saving energy during execution and transmission of data. Location based protocol as name suggests are based on position oriented information transmission from source to sink node. QoS-based protocols are considering various QoS parameters to get better quality of data at the BS. Now we will discuss routing protocols in some more detail.

2. Flat Network Protocols

If we look into sensor network applications, it is not viable to allot global identifier to every sensor node as due to presence of huge number of nodes. It becomes very difficult to select a distinct set of sensor nodes to be queried as due to lack of global identification. Therefore, data is broadcast in the sensing field from sensor nodes to the destination node (or BS). The routing protocols are selecting a set of sensor nodes and perform the data aggregation to collect sensed data during relaying of data. The data should be redundant and overall network lifetime should be efficient. To address these considerations, flat routing works efficiently in comparison to classical routing techniques.

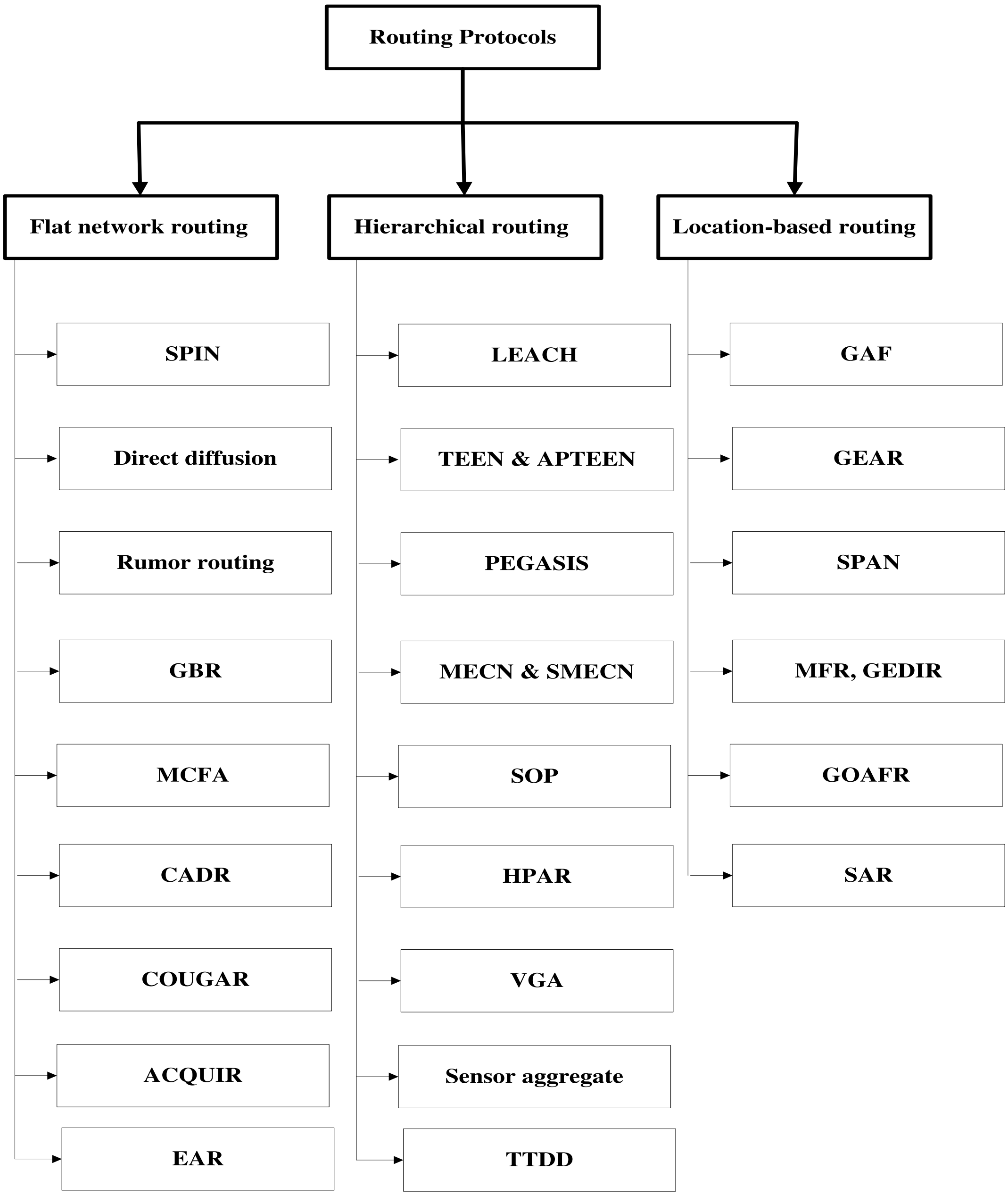

Figure 1. Taxonomy of routing protocols in WSNs

In flat routing, base station (BS) send queries to particular region and remain in waiting state for data from sensors placed in the selected regions. Attribute-based naming is must for representation the properties of data as due to data is requested via queries. SPIN [17] protocol is very first flat network protocol which incorporates with data redundancy and energy efficient properties. Then after Direct Diffusion or other protocols has been proposed. We will see in detail one by one.

Joanna Kulik et al in [17, 18] has proposed a data centric protocol called Sensor Protocol for Information via Negotiation (SPIN). Authors have main focused on efficient dissemination of single sensor node reading to all other sensor nodes which are acting as potential sink nodes. This procedure will give a better effect on the network. Firstly, the whole network view can be replicated, on account of it if some of sensor nodes diffuse due to low battery then we can get reading from other live sensor nodes, as a result of it we get fault tolerant network. Secondly, we can judge from requested sink node Id's whether there is presence of intruder or node. So it provides secure data dissemination.

The decision to design the SPIN protocol has been taken while considering the classical approaches (flooding and gossiping) for data dissemination.

2.1. Flooding and gossiping [19]

These are two classical approaches for data dissemination within every sensor node. In flooding, every sensor node broadcasts the packets that are received from their neighboring node. It continues this packets broadcasting process till the packets have been received to destination node or the packets reach to the maximum number hop transmission condition. In gossiping, there is slightly different scenario then flooding. Data has been disseminated to randomly selected neighbor nodes, further another randomly selected neighbor send data and so on.

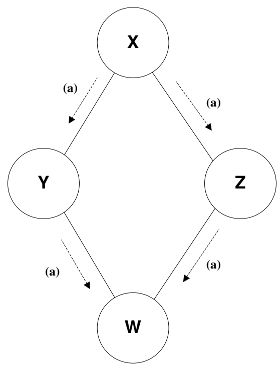

Figure 2. The implosion problem. Node X starts transferring of data (a) to their respected neighboring nodes (Y & Z). Further, data (a) is forwarded from node Y and Z to Node W. At node W, the replicated copy of data (a) has been received which is not required.

Considering flooding approach, there exist some drawbacks in it like implosion, overlapping and resource blindness.

Implosion: it is generated while duplicated message has been received by a node; it does not matter whether is present in the one-hop distance or multi-hop distance. There may exist different intermediate node but at the receiving end it receives the multiple copies same packet shown in figure 2.

Overlapping: when the two neighboring nodes sensing the data and send it to the third node which present in vicinity of two nodes. There exists an overlapping while sensing the range of two sensors i.e. common region exists. Due to this an overlapping has done, therefore same the common region data has been also received at the other receiving node shown in figure 3.

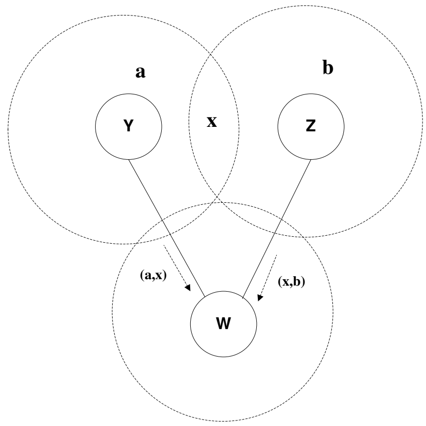

Figure 3. The overlap problem. Y & Z sensor nodes are overlapping geographic region (at x). Node W gets same of copy of overlapped region.

Resource blindness: huge amount of energy consumption by the sensor nodes without consideration energy constraints [17]. Now we will the SPIN in detail.

2.2. SPIN

This approach is purely data-centric based. The whole sensor network is communicating to their corresponding sensor nodes only. The sensor nodes are broadcasting a small descriptor message to their neighboring nodes. This descriptor message is also known as meta-data. After receiving of meta-data, all receiving sensor nodes match to their already received messages. If that particular message is present, then it discards the meta-data message otherwise it generates the request for complete data packets linked to that meta-data. Then source node forwards the requested data on the basis of meta-data. Similarly, this process is continuing till the whole network consists the data. If we look into logical view then, when the source node broadcasts the meta-data then it is known as advertisement of data or ADV in short. Those sensor nodes are interested in the complete data then it generates request message or REQ. And in the end, DATA message is used to transfer the requested data. We can see in the figure 4 from I to VI how the whole process proceeds.

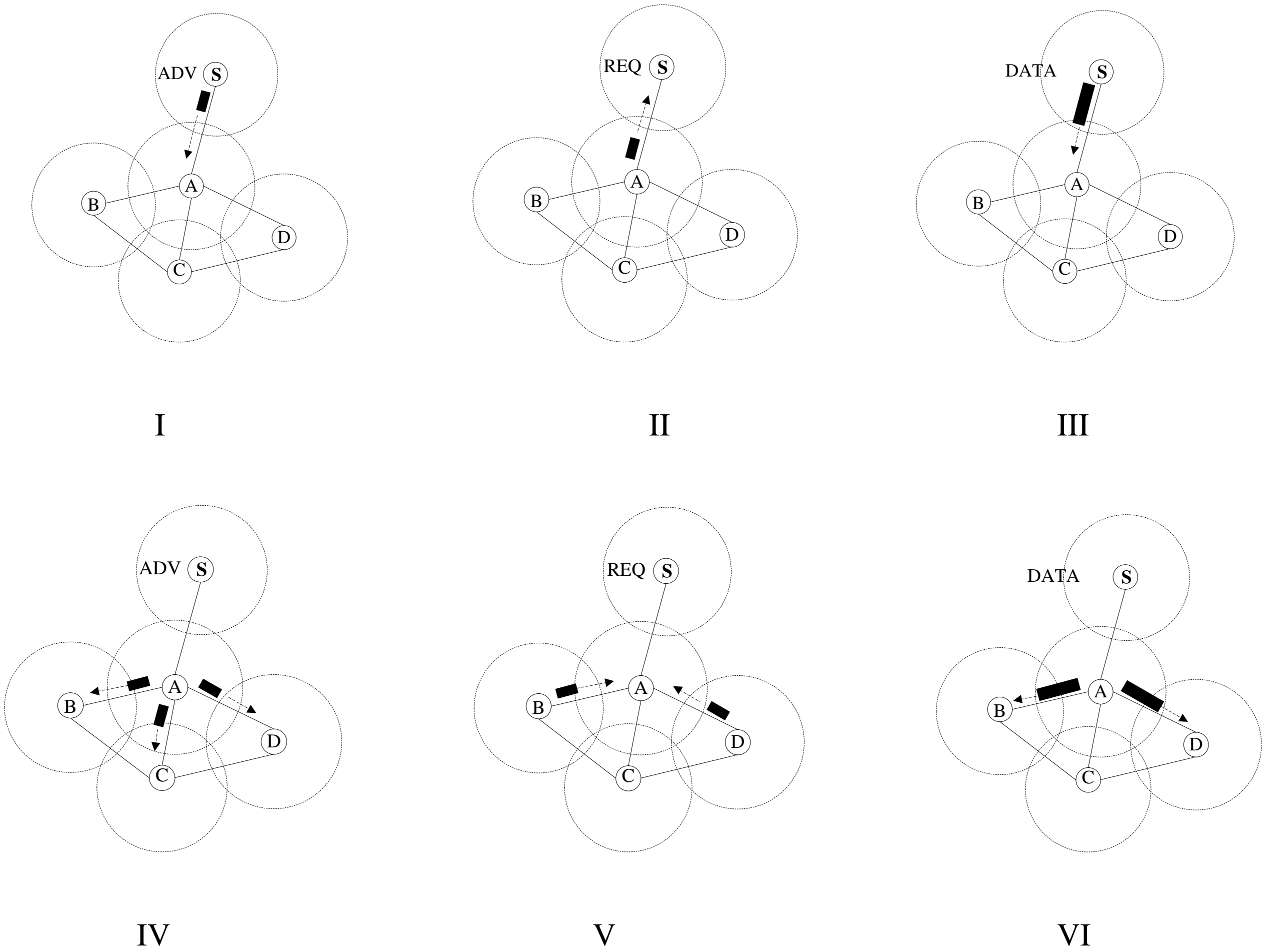

Figure 4. SPIN protocol. Node S begins the advertising its meta-data to node A (I). Node A is requesting the complete data in response of meta-data (II). Actual data is transferred from node S to node A (III). Similar process continues as advertisement of meta-data by node A to their neighbors (B, C & D) in (IV), requesting complete data by only node B & node D (V), and actual data transfer in response of request to node B & node D(VI).

2.3. Direct Diffusion

From [20], this approach relates to data centric paradigm in wireless sensor network. It senses the data values by sensor nodes which are named by attribute-value pairs. The main criteria of Direct Diffusion are to eliminate redundancy and maximize the network lifetime. We look into this approach; sink node induces an interest message for data starting from their neighboring nodes. An interest diffuses to whole network hop by hop and is broadcast to their neighboring nodes in addition to this, gradients (In brief, a gradient relates to attribute value and direction) are set up to draw satisfying the query towards BS or sink node. A gradient is defined by each node direct toward to node from it receives the interest. This very process remains in continuation until gradients have been setup from source back to sink node or BS. The strengths of specified gradients are varying depends on the neighbors as resultant different amount of information flows.

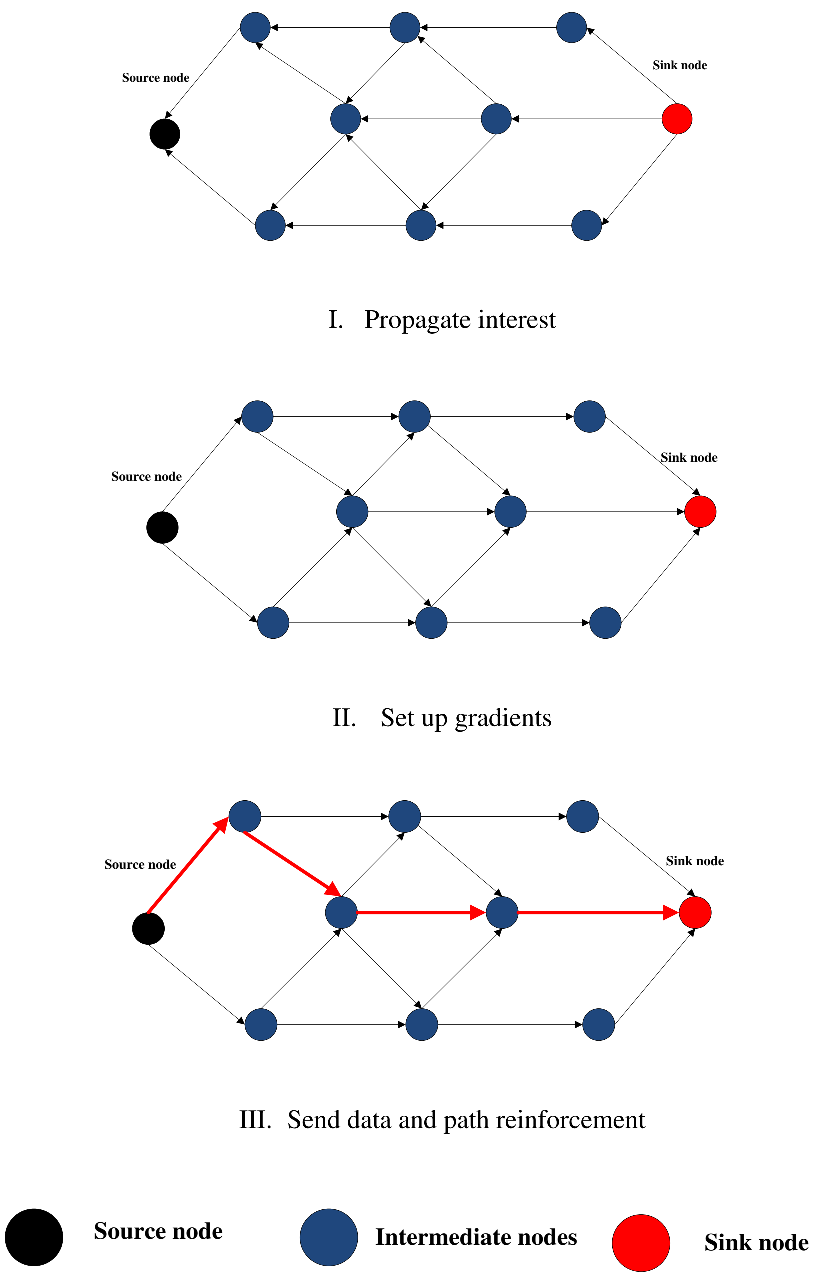

Figure 5. Direct diffusion example from source to sink displayed in I, II and III.

From figure 5, represents the process of direct diffusion. An interest message generates from sink node to source node via multi-hoping, start initializing from its 1-hop neighboring nodes. Nodes are flooded by interest simultaneously a gradient is set. On the basis of gradient, information flows are formed from multiple paths and then best path is selected to prevent further flooding. To get an energy efficient network, here we can reduce communication cost by aggregation of data in the network. The main objective is to search a best cost-effective aggregation tree. After a particular span of time, BS refreshes and resends the interest when it starts to receive data from source. It process is must because interests are not providing reliable transmission throughout the network. This is how we got a cost-effective data flows in direct diffusion technique.

Table 1. Comparison between SPIN, LEACH and Direct Diffusion

S. No	Parameters	SPIN	LEACH	Direct Diffusion
1	Optimal route	×	×	✓
2	Network lifetime	Good	Very good	Good
3	Resource awareness	✓	✓	✓
4	Use of meta-data	✓	×	✓

2.4. Rumor Routing

In contrast to direct diffusion [20], it is totally based on applications where a geographical routing is not feasible. In direct diffusion, a query is induced to the network by a BS, therefore interest message is propagated hop-by-hop and gradient is evaluated towards the BS, hence in the end a best path is selected. Here, in particular cases, sometimes a small amount of data is requested from the nodes, and then in that case flooding process is done which is unnecessary. In another scenario, a node needs to flood the events, if the number of events is less and the number of queries is large. The center idea is to route the queries to nodes that have observed a specific event in spite of flooding the whole network to retrieve information about the occurring event. For the flooding on the basis of events, rumor routing algorithm specifies long –lived packets known as agents. Whenever any node detects an event, it adds up into a table known as event-table and generates an agent. Agents visit throughout the network for information about local events to distant nodes. When a node originates a query for an event, the nodes that have information about the path may respond to the query by looked into event table. Hence, we need to flood the entire network, which reduces the communication cost. On other hand, rumor routing consist a single path only from source to sink as compare to direct diffusion where data can be routed through multiple paths at low rates. On the basis simulation result, rumor routing considered as more energy saving protocol as compare to flooding. Moreover, rumor routing executes good when number events are considered as small but for large number of events, maintaining the event tables by each node in the network become inefficient.

2.5. Minimum Cost Forwarding Algorithm (MCFA)

The vital role of this protocol is that we need not to find out the direction of routing towards BS. Neither unique ID nor formulating of routing table is needed in MCFA [22]. Therefore, only task required is cost estimation from current node to BS. Whenever, BS starts broadcast then cost set to zero, but if any node initiates then cost set to infinite. After setup over, messages are started to broadcast to their adjacent nodes. After receiving these messages by adjacent nodes, then evaluation of cost path takes place and check whether the cost path is minimum or not, between the node and BS. If yes, then rebroadcast to their adjacent nodes again. This process continues so on till it reach to the BS. Now in MCFA, during evaluation of cost estimation on a node is done; check to see if the estimate in the message plus the link on which it is received is less than the current estimated value. If yes, update the current cost estimate value and broadcast updated cost message to their adjacent node again. However, more multiple updates are received by nodes which are placed far apart. To eliminate this problem, MCFA has done modifications in its algorithm. A back-off algorithm is coded in the setup phase. This modification restricts a node to send update message until $a * l_c$ time have elapsed from the time at which message is updated. Here, a represents a constant and l_c represents link cost at which message was received.

2.6. Gradient Based Routing (GBR) [23]

This protocol is originated by inspiration from direct diffusion protocol [20]. The major focus of this protocol is on controlled distribution of traffic in the sensor network which leads to enhancement in network lifetime. To achieve this goal in contrast to direct diffusion, GBR saves the number of hop counts when interest triggered from source node throughout the whole network. Therefore, during interest message disseminate to the network, number of hop counts is also known as height of node. This parametric value should be least to reach the BS to get best network. Calculating difference between a node's height and that of its neighbor node is taken in account as gradient on that link. A message is forwarded towards a link having largest gradient. GBR considers data-aggregation and traffic spreading to optimize the traffic load in the network. When there exist multiple paths through a node then it acts as relay node which combines data according to some specific function. In GBR, three different data dissemination techniques considered:

A stochastic scheme: if there exist same gradient value then node picks on gradient randomly.

An energy-based scheme: as height of a node increases, there will be need for more energy to send data from source to BS. By this, increase more chance for energy drop i.e. energy drains at high range, reaches to below certain threshold.

A stream-based scheme: no new routed has been selected by the nodes which already selected a different path.

2.7. Information-driven sensor querying (IDSQ) and constrained anisotropic diffusion routing (CADR)

In paper [24] has proposed two types of protocols: IDSQ and CADR. CADR is most promising protocol inspired from direct diffusion. It is query-based protocol. CADR diffuses the queries with the help of a set of information criteria which used to select sensor nodes. In contrast to direct diffusion, it considers information gain additionally. The main objective of this protocol information gain is maximized and both latency and bandwidth are minimized. CADR protocol diffuses queries on the basis of a set of information criteria that select, which of the sensor nodes can able to get data? This is only possible by activating the sensor nodes near to the event and also adjustment of data route. In CADR, all sensor nodes in the network evaluate the information/cost objectives and route data based on local information/cost gradients and end user requirements. In IDSQ, node with diffuses query can capable of search which node give information in addition to this balancing the energy cost. It does not provide implementation steps that how query as well as information are routed between sensors and BS. IDSQ is just a complementary optimized procedure.

2.8. COUGAR

Y. Yao et al. in [25] have worked on flat network protocol and proposed a COUGAR protocol. This protocol represents sensor network in the form of big distributed database system. The key stroke point of this protocol is to work over abstraction of query processing i.e. using declarative queries have taken from network layer function such as selection of relevant sensors and so on. If we look more into query abstraction than a query layer is situated between network and application layers. The architecture is depicted in figure 6, which is redrawn from [25]. COUGAR protocol is coded into database system of sensor nodes where these nodes select a head node (or leader node) whose actual work is data-aggregation and forwards the data to BS. A query plan has been generated by BS, that defines data flow and in-network computation from incoming query and then after forward it to a most relevant node. This query plan gives the information about how a head or leader is selected from a query. The main objective of COUGAR protocol is to utilize in-network data aggregation to get an energy efficient network. It provides network-layer-independent solutions for querying the sensor nodes.

Some drawbacks are there in the protocol: firstly, as embedding additional query layer on all sensor nodes will generate the extra overhead to sensor nodes according to energy consumption and memory usage. Secondly, in-network data computation from several nodes will require synchronization, i.e. a relaying node should wait every packet from each incoming source, before sending the data to the head node. Thirdly, the head nodes should be dynamically maintained to prevent them from hotspot.

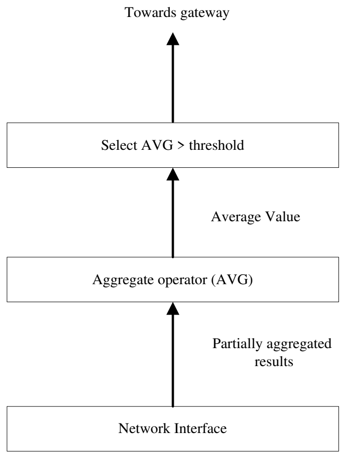

Figure 6. Query plan at a head node: the head node collects all the readings, calculates the average. Checks whether it is greater than a threshold or not, if condition satisfies then sends it to BS.

2.9. ACtive QUery forwarding In sensoR nEtworks (ACQUIRE)

N. Sadogopan et al. in [26] have worked on data-centric protocol and proposed a new query-based mechanism. This approach inspired from COUGAR protocol. The perception of sensor network as distributed database system. It works very efficiently on complex queries which are further divisible to several sub-queries. Now, we will look into querying mechanism of ACQUIRE protocol. The query diffuses by BS into the network with the help of broadcasting approach to their neighboring nodes. Whenever the query disseminates at the receiving end, node tries to response to these query. In initial response it would be done partially with the help of pre-cached information and forward it to another sensor node. If the required pre-cached information is not up-to date, then the node aggregates the information from their neighboring nodes within look ahead of d hops. After solving of query completely, it reverts back or by using shortest path to BS. ACQUIRE approach work efficiently on query processing by adjusting the value of d parameter. Considering, d is equal to the network size, then protocol runs similar to flooding approach. On the other hand, if the value of d is too small then query has to travel more hops.

2.10. Energy-Aware Routing (EAR)

R. C. Shah et al. in paper [27] proposed a destination-initiated protocol. The key idea of this protocol is to enhance the network lifetime. This protocol is similar to direct diffusion. It consists a slight difference regarding a set of path selection based on energy consumption. The optimal path has been selected by the value of probability depends on which of path consumes less energy. Energy of any of single path will not be reduce so quickly, therefore path may be choosing at different time span. This can obtain a better network lifetime as energy is dissipated more equally among all the nodes. The metric for evaluation of network life is network survivability. Now, we will look into detail, how this protocol perform communication. In this protocol, each node presumes as they are addressable via class-based addressing that includes information about locations and the type of the nodes. In the initial stage, protocol starts a connection through localized flooding as a result of it find out all routes between source/destination pairs and cost, inserting these entries in a routing table. From the entries of routing table, high cost paths are rejected and forwarding table is built by selecting the neighboring nodes in such a way that is proportional to their cost. Then after forwarding tables entries used to send data to respective destination nodes with the probability inversely proportional to the cost. In contrast to direct diffusion, simulation result gives 44 % increase in the network lifetime for EAR protocol.

Table 2. Classification of flat network based routing protocols

S. No	Routing Protocols	Mobility	Power usage	Scalability	Position awareness	Negotiation -based	Data aggregation	Localization	Multi -path	Query -based
1.	SPIN[19]	Poss.	Ltd.	Ltd.	×	✓	✓	×	✓	✓
2.	Direct diffusion[20]	Ltd.	Ltd.	Ltd.	×	✓	✓	✓	✓	✓
3.	Rumor routing[21]	Very ltd.	N/A	Good	×	×	✓	×	×	✓
4.	GBR[23]	Ltd.	N/A	Ltd.	×	×	✓	×	×	✓
5.	MCFA[22]	×	N/A	Good	×	×	×	×	×	×
6.	CADR[24]	×	Ltd.	Ltd.	×	×	✓	×	×	✓
7.	COUGAR[25]	×	Ltd.	Ltd.	×	×	✓	×	×	✓
8.	ACQUIRE[26]	Ltd.	N/A	Ltd.	×	×	✓	×	×	✓
9.	EAR[27]	Ltd.	N/A	Ltd.	×	×	×	✓	×	✓

3. Hierarchical Protocols

In routing, the prime objective is energy efficient routing. It is cluster-based routing methods, in which nodes remaining with higher energy perform as cluster head nodes as well as relay nodes and nodes remaining with low energy perform sensing task during occurrence of event. Generally, hierarchical routing is two-layer routing architecture. In the first layer, it consists a setup phase where selection of cluster head nodes is done. In second layer, it is a steady phase where routing is done. Non-cluster head nodes send sensed data to cluster head nodes perform data-aggregation. Instead of directly sending data to BS, nodes with remaining energy high will be selected and also aggregation of data will be within the network to the cluster heads as result of it reduce the data traffic. So, the overall network lifetime increases. Due to clustering scheme, it contributes scalability, enhance network lifetime and improves individual node energy efficiency.

3.1. Low Energy Adaptive Clustering Hierarchy (LEACH) protocol

In paper [28] W. Heinzelman et al. have proposed a LEACH protocol. In LEACH, the whole process of communication depends upon sensor nodes. Each sensor node is involved in the communication till the node’s energy crosses the minimum required limit. The end user does not need the whole sensed data. They only require a high level function of data that describes the occurrence of the event in the acquired sensing field. So, the data processing plays a major role in improving the battery life as it reduces the huge amount of data to a small extent. This is done by the strong correlation between data signals of sensor nodes, which are deployed close to each other. Thus, it emerged the concept of clustering. In this clustering procedure, the nodes themselves announce as cluster head nodes. The cluster head nodes are limited in amount as per given sensor nodes. All the other nodes are called as non-cluster nodes. These nodes must transmit their data to the concerning cluster head nodes. And the cluster head node must receive the data from cluster members and performs the data aggregation process. The aggregated data are afterwards transmitted to the base stations. The cluster head nodes should have more battery life as compared to non-cluster head nodes. Once, after the process of whole data communication procedure executed, the energy level of cluster head nodes is reduced, if they will again choose for the cluster head for the next round of transmission than their energy will be reduced to the greatest extent or node may die (i.e. not able to perform communication further). For this LEACH protocol performs a randomized rotation of selection of cluster heads, not including the past selected cluster head nodes. This will help in sustaining the battery life of the sensor nodes in the network. The whole process of LEACH protocol is divided into the rounds. There exist two phases in each round. The first phase is setup phase and the second is the steady state phase. All the nodes must time synchronized with respect to start the setup phase at the same time. To reduce setup overheads, the steady state phase is long as compared to setup phase.

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

S. Lindsey et al. in paper [29], studied in detail LEACH protocol and represent a new chain-based protocol which is known as PEGASIS. This protocol is another good step forward towards energy efficiency criteria. This protocol main emphasized on analysis of overall network life time. PEGASIS protocol majorly worked on two aims: collaborative technique and communication of nearest neighbor sensor nodes. Collaborative techniques specify the enhancing the lifetime of individual sensor whereas communication with nearest neighbor effects the bandwidth consumption. The key idea authors tried to build is chain, let's see how it works. In the protocol, sensor nodes find the nearest neighboring sensor nodes by using signal strength for calculating the distance of neighboring nodes. After getting the details, sensor nodes adjust their signal strength so that only single node able to hear the information. The creates a chain connected the sensor node with one another and end up with BS. The sensed data is then transferred via this chain formed. The formation of chain is greedy fashion. As PEGASIS protocol does not follow clustering techniques still perform two time better than LEACH protocol.

3.3. TEEN & APTEEN Routing Protocols

A. Manjeshwar et al. have proposed two protocols in paper [30] [31] called TEEN and APTEEN respectively. These protocols are designed to focus over time-critical applications. In TEEN protocol, sensors are deployed in a sensing field and they are continuously sensing the area but data transmission is not at the same rate. A cluster head (CH) node send data to their members of cluster based on hard threshold value i.e. threshold value of sensed attribute otherwise based on soft threshold value i.e. if a small change occurs in a sensed attribute then only procedure executes to switch on the transmitter and transmit the data. The hard threshold eliminates the unnecessary transmission by giving consent to nodes to transmit interest. On the other hand, in soft threshold, it further reduces transmission. It may agree to transmit if there is little change or no change in sensed attribute. It gives more precise and accurate value. The major drawback of TEEN protocol is that if threshold values are not received, then the nodes will never communicate. Therefore, user will not able to get any data. TEEN protocol performed well for time critical applications. During transmission of data consumes more battery power as compare to data sensing the energy consumption is the TEEN is less than in proactive network. APTEEN is a hybrid protocol that changes threshold values used in TEEN protocol as per requirements of users and application specifications. In APTEEN, it is similar to TEEN with little differences. The sensor nodes sense the physical parameters convert into signal form. It is restricted to only those nodes which are able to send sensed value whose values are either equal to or more than HT transmit. After this, further transmission will be possible, if a change happens in attribute value by an amount of equal to or greater than ST. If in case any node is not send data within a time span equal to CT. It is forced to sense and retransmit the data. A TDMA schedule is used for assigning a slot for transmission in a cluster to every node in it. APTEEN uses a modified TDMA; it combines both proactive and reactive policies. On effect of this, APTEEN also provides flexibility at a greater extent by allowing the user to set CT interval, and the threshold values for energy consumption can be controlled by changing the CT as well as threshold values. Simulation result shows that TEEN and APTEEN performed excellent in comparison to LEACH.

3.4. Minimum Energy Communication Network (MECN) and Small Minimum Energy Communication Network (SMECN)

V. Rodoplu et al. in paper [32] have proposed protocol and discussed in detail view of utilization of low power GPS to get an energy efficient sensor network. MECN protocol mainly considers the relay nodes for transmission, if they are more energy efficient as compare to direct transmission. The key idea for MECN protocol is to search for a sub-network that consist of less number of nodes and probably takes less energy transmission between any of two particular nodes. As a result of it, global minimum power paths can be figure out in the absence of all nodes in the network. This whole process is done with the help of localized search for each nodes considering under relay region. MECN protocol is works in efficient way during any node failure due to its self-reconfiguring property. SMECN is proposed by L.li et al. in paper [33]. It is extended version of MECN protocol. SMECN follows the same criteria for construction of sub-network for search out energy efficient paths in relay region as in MECN but SMECN work more effective way due to it provides small sub-network in terms of number of edges even though network is fully connected to each other.

3.5. Self-Organizing Protocol (SOP)

Subramanian et al. in paper [34] have discussed the scenario of hierarchical routing in heterogeneous sensor network. In SOP, sensors are considered either mobile or stationary. Some of sensors in network work only for sensing the physical environment parameters and transmits to the energy efficient node that can be enclosed in a group of sensors takes as hierarchical clustering. Some of nodes act as routers that relay the data from the nodes and transmit to BS. Each sensor node has addressing induced in it. Therefore, they can be identifiable via address of router node to which they are connected. Considering, local Markov Loops (LML) algorithm was used to find out spanning trees of a graph to get paths that can fault tolerant. During transmission, routing tables are maintained by each sensor nodes and balance routing hierarchy. It was more energy efficient protocol as compare to SPIN in terms of broadcasting of messages.

3.6. Sensor aggregates routing

In paper [34], three algorithms have been discussed whose main objective is to aggregate the monitored data. These algorithms will be discussed later one by one. Now, we will see the concept that has been used for aggregation process. The key idea is to manage the huge amount of data to some nodes rather than directly send the whole data to BS. This is done due to limited battery life of sensor nodes. Now, in algorithms it is preferred to select some leader nodes according to some criteria (like remaining battery life) for aggregation of data. Non-leader nodes clubbed to a particular leader node. No non-leader node can be clubbed to more than one leader node. This is how the clusters are formed in a network and data is aggregated by some scheduling process. All leader nodes forward aggregated sensed data to BS directly or by using some relay nodes. Now we will look into first sensor aggregate protocol. Distributed Aggregate Management (DAM) protocol was a lightweight protocol. In this protocol, routing process starts on the basis of decision predicate (P) that can be done by every individual sensor node to decide whether it should participate in an aggregation process or not. In addition to this, message exchange scheme (M) considered that defines how grouping predicate is applied to node. A node determines if it relates to an aggregate which based on result of applying predicates to the data of the node as well as information of the other nodes. Aggregates are formed when the process eventually converges. Now, second sensor aggregate protocol is EBAM which is briefly discussed. Energy Based Activity Monitoring (EBAM): it determines the energy level at each sensor node by processing the signal impact area, adding directed target energy at each impacted sensor in weighted form, assuming that each target sensor has equal or constant energy level.

3.7. Virtual Grid Architecture (VGA) routing

This protocol is proposed by Al-karaki et al. in paper [35]. This energy efficient protocol is based on data-aggregation and in-network. VGA protocol considers two level of aggregation to perform routing of sensed data from sensor nodes to BS. In many WSN applications, sensor nodes are chosen as fixed and extremely low mobility. In VGA, whole network is divided into zones in which may or may not be same amount of sensor node are present. Here, square clusters were used to obtain a fixed rectilinear virtual topology. In each zone, a cluster head (CH) is selected which also called local aggregators. These CHs aggregate the monitored data and send to Master Aggregator nodes (MAs) which are subset of local aggregators. It is second level of aggregation of data. These MAs proceeds the processing of further aggregation of data and transmit to BS.

3.8. Hierarchical power-aware routing (HPAR)

Li et al. have proposed HPAR protocol in paper [36]. In this proposed scheme, whole network disunites into groups of sensors. Based on geographic proximity, groups are clustered together form a zone and further these zones are treated as entity. Each zone configures and performs routing performs routing process hierarchically within a zone. Each entity must decide on how it will route a message across other entity such that battery power of nodes should remain maximized. Messages are chosen to route distinct path that has maximum over all minimum of the remaining power called max-min path. Node with high residual power may be expensive in comparison to path with minimal power consumption. A max-min zPmin algorithm has been discussed in the paper [36]. The key idea behind this algorithm is to minimize the total network power consumption and maximize the minimal residual power of the network. For solution of the above mentioned problem is divided in two parts. In first part of solution, the algorithm determines the path with least power consumption using dijkstra algorithm. In second part of solution, the algorithm determines a path that maximizing the minimal residual power in the network. The algorithm consumes at most zPmin while maximizing the minimal residual power fraction. The proposed algorithm tries to optimize both solution criteria.

3.9. Two-Tier Data Dissemination (TTDD)

Ye et al. in paper [37] have proposed TTDD protocol; the protocol based on mobility based base stations. Basically, sensor nodes stick to one place where there are deployed and base stations will change their position. Base stations change their location in dynamic manner. Therefore, data source should have to work proactively; wherever any event occurs, neighboring sensor nodes actively sense the signal and process it. From neighboring nodes, one of them becomes a source node who generates data reports. The data dissemination process executes in grid structural fashion. Data sources make formation of grid and all neighboring data sources are at crossing point of the grid. Based on greedy geographical forwarding technique the data sources disseminated the data to all crossing point places data sources. When it reaches nearby crossing point it stops. In this process, every intermediator node collects the information regarding the incoming data sources and forward to adjacent node except the income one. The source node which store all information act as dissemination point. With this, base station floods a query that help to nearest dissemination points to receive data in the local cell. As we look into the results of comparison between TTDD and direct diffusion which showed that TTDD outperforms in terms of overall lifetime.

Table 3. Classification of hierarchical network based routing protocols

S.No	Routing Protocols	Mobility	Power usage	Scalability	Position awareness	Negotiation-based	Data aggregation	Localization	Multi-path	Query-based
1.	LEACH[28]	Fixed BS	Max.	Good	×	×	✓	✓	×	×
2.	TEEN[30] & APTEEN[31]	Fixed BS	Max.	Good	×	×	✓	✓	×	×
3.	PEGASIS[29]	Fixed BS	Max.	Good	×	×	×	✓	×	×
4.	MECN & SMECN	×	N/A	Low	×	×	×	×	×	×
5.	OP[32]	×	N/A	Low	×	×	×	×	×	×
6.	HPAR[36]	×	N/A	Good	×	×	×	×	×	×
7.	VGA[35]	×	N/A	Good	×	✓	✓	✓	✓	×
8.	Sensor aggregate[34]	Ltd.	N/A	Good	×	×	✓	×	×	Poss.
9.	TTDD[37]	✓	Ltd.	Low	✓	×	×	×	Poss.	Poss.

4. Location-Based Protocols

Routing the information from source to destination based on their location criteria is called location based routing. In this protocol, all the sensor nodes calculate the distances from it and their neighboring nodes based on incoming signal strength. Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI) are parameters which are generally used for finding out distance. Another option to get location information of sensor nodes may be available directly by communication with a satellite using Global Positioning Systems (GPS). GPS receivers are attached to nodes. To improve the routing performance, we need to emphasize over network lifetime. So, in some protocols, nodes should go to sleep while they are not any activity occurring and only few nodes are active. Now we look some of location based protocols in detail.

4.1. Geographic Adaptive Fidelity (GAF)

Xu et al. have proposed a location-based routing algorithm named GAF in paper [38] for mobile ad hoc networks. But it can also be implemented in sensor networks. Now, we will look into more detailed view of this protocol. The sensor network area is separated into fixed zones and creates a virtual grid. Inside every zone, nodes can communicate with each other and performs different roles. In a particular zone, one node has been elected from all present nodes which will stay awake for a specified time-span and after that go to sleep. During wakeup state of a selected node, it sensed the data and generated a report on behalf of zone by the node and sends the sensed data to BS. GAF conserves a lot of battery of sensor nodes by turning off unnecessary nodes. Sensor nodes are equipped with GPS for finding out location information in a virtual grid. GAF improves the network lifetime as number of nodes increases.

4.2. Geographic and Energy Aware Routing (GEAR)

Ye et al. discussed protocol in paper [39] about data dissemination with the help of geographic information in an appropriate region. This protocol also considers energy parameter to enhance the network lifetime. In GEAR, use of geographic information is to inform the neighboring nodes for packet forwarding scheme towards destination. The main focus of this protocol is to consider only a specified region for sending the interest rather than disseminating to the whole network by doing restriction on sending the number of interests. This protocol mainly estimates cost and learning cost of reaching the destination via its neighbors.

GEAR algorithm divide into two phases: first phase is forwarding packets towards the target region. In this phase, whenever a packets receives by a node it checks their neighbors whether it is present nearest to the target region than itself or not. In case, there exists more than one nearest neighbor to the target region is selected as the next hop. If there are far apart than the node itself, it termed as a hole exists. Then packet is forward based on estimated learning cost. In second phase, packets are forwarded within the specified region. Whenever packets have arrived near the region, it forwards relies on two criteria either on geographical forwarding or restricted flooding.

4.3. MFR, DIR and GEDIR

Stojmenovic and Lin in paper [40] have described location based algorithms. The main issues they are focused are forward and backward direction as the routing progress in direction based. A source or an intermediate node selects one of its neighbors according to certain criteria. Geographic Distance Routing (GDR) is a greedy algorithm that disseminates the packet to the neighbor of current vertex whose distance to the destination is minimized. In DIR, the best situation emerged whenever neighbor has closest direction towards the destination. In Most Forward within Radius (MFR), the best neighbor A will minimize the dot product $\overline{DA}.\overline{DS}$, where S and D are the source and destination nodes, respectively, and $\overline{SD}$ represent the Euclidian distance between the two nodes S, D. GEDIR and MFRs are loop-free, while DIR may create loops unless past traffic is memorized or a time-stamp is enforced.

4.4. Greedy Other Adaptive Face Routing (GOAFR)

Kuhn et al. in paper [41] have proposed a geometric ad hoc routing algorithm combining greedy and face routing. Face routing (FR) algorithm confirms first the connection between the source and destination. FR algorithm directly related to the number of nodes in worst conditions. Adaptive Face Routing (AFR) represent the best route in worst case and it not efficient average cases. Other Face Routing (OFR) is variant of Face Routing. It works on planar graph techniques through which it traverses a series of face boundaries. The aim it achieved when it finds best node on boundary by using geometric planes.

4.5. SPAN

Chen et al. have discussed another location-based algorithm called SPAN in paper [42]. It selects some of nodes as coordinators based on their locations. The coordinators are main building block of network used to forward messages. A node should become coordinator if two neighbors of a non-coordinator node cannot reach each other directly or through one or more coordinators nodes. New and existing coordinators are not essential neighbors in [42], which in effect makes the design less energy-efficient because of the need to maintain the positions of two or three- hop neighbors in the complicated SPAN algorithm.

Table 4. Classification of location based routing protocols

S.No	Routing Protocols	Mobility	Power usage	Scalability	Position awareness	Negotiation-based	Data aggregation	Localization	Multi-path	Query-based
1.	GAF[38]	Ltd.	Ltd.	Good	×	×	×	×	×	×
2.	GEAR[39]	Ltd.	Ltd.	Ltd.	×	×	×	×	×	×
3.	SPAN[42]	Ltd.	N/A	Ltd.	×	✓	×	×	×	×
4.	MFR[40] GEDIR[40]	×	N/A	Ltd.	×	×	×	×	×	×
5.	GOAFR[41]	×	N/A	×	×	×	×	×	×	×

5. Artificial Intelligence Based Protocols

Artificial Intelligence is one of popular computing techniques. It consists of many efficient approaches that can be implemented in sensor network to make them more energy efficient. The key idea of artificial intelligence is nature-inspired approaches are available. A large list of techniques has been developed for solving complex problems. Many researchers have implemented these techniques over sensor routing protocols and provide better results.

5.1 Swarm intelligence based routing protocols

Table 5. Classification of swarm intelligence based routing protocols

S.No	Routing Protocols	Energy Efficiency	Scalability	Load balance	Fault tolerance	Data aggregation	Localization	Multi-path	Query-based	QoS
1	EPMS[43]	✓	Ltd.	✓	×	×	✓	×	×	×
2	AFSA[44]	✓	Good	✓	×	✓	✓	×	×	×
3	QoS-PSO[45]	✓	Very Good	✓	✓	×	×	✓	×	✓
4	PSO[46]	✓	Good	✓	×	✓	×	×	×	×
5	PSO-ECHS[47]	✓	Good	✓	×	✓	×	×	×	×
6	HSA-PSO[48]	✓	Moderate	✓	×	✓	×	×	×	×
7	SIF[49]	✓	Ltd.	✓	×	✓	✓	×	×	×
8	PECE[50]	✓	Ltd.	✓	✓	×	×	✓	×	×
9	IHSBEER[51]	✓	Moderate	✓	×	×	×	×	×	×
10	PDORP[52]	✓	Very Good	✓	×	✓	×	×	×	✓
11	LWTC-BMA[53]	✓	Good	✓	×	✓	×	×	×	×
12	ABC-SD[54]	✓	Good	✓	×	✓	×	×	×	✓
13	FAMACROW[55]	✓	Very Good	✓	×	✓	×	×	×	×
14	BeeSwarm[56]	✓	Ltd.	✓	×	✓	×	×	×	×
15	BeeSensor[57]	✓	Moderate	✓	✓	✓	×	✓	×	×

5.2 Fuzzy logic based routing protocols

Table 6. Classification of fuzzy logic based routing protocols

S.No	Routing Protocols	Energy Efficiency	Scalability	Delay Delivery	Algorithm Complexity	CH Stability
1	CHEF [58]	×	×	×	✓	✓
2	Fuzzy Multi constraint Routing [59]	✓	✓	✓	✓	✓✓
3	Improved Fuzzy Unequal Clustering [60]	✓	×	✓✓	✓✓	✓
4	FCM [61]	✓	×	×	✓✓	✓✓
5	NECHS[62]	✓	✓✓	×	✓	✓
6	FSCA [63]	✓✓	✓	×	✓	✓
7	EEUCF[64]	✓✓	✓	✓	×	✓✓
8	Neuro-fuzzy technique [65]	✓	✓✓	✓	×	✓✓
9	Cluster adaption method[66]	✓	✓	✓✓	✓	✓

6. Conclusion

Routing protocols are the backbone for communication in wireless sensor network. The whole communication is depending on routing algorithms. Routing protocol specifies the whole process of communication i.e. sensing the data and transfer of the sensed data to the base station. The whole communication consumes battery life of every sensor node. Different routing protocols manages the communication differently and evaluation of energy consumption is also different. High performance of network means better the network lifetime. There is still need to generate new routing algorithms for specified applications of sensor network which consumes lesser amount of energy.

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