

# A Comparative Study on Energy Efficient Routing Protocols in Wireless Sensor Networks

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## Abstract

Due to recent development in technology, the implementation of wireless sensor networks becomes technically feasible. Wireless Sensor network consist of sensory nodes having the capacity of sense the environment, perform the computation and communication. Wireless sensor network plays a crucial role in monitoring of both area and object. Several routing protocols have been developed for wireless sensor network during the past few years. Routing protocol differs from other protocols depending on the required practical application and network architecture. Energy efficiency is an essential and primary design issue for the routing protocols. This paper focused on all the categories of the routing protocols. We categorized the routing protocols into three main classes path establishment, network structure and protocol operation. The routing protocols belonging to path establishment can be further classified as proactive, reactive and hybrid. The routing protocols belonging to network structure can be further classified as data centric/attribute based, hierarchical and location based. The routing protocols belonging to protocol operation can be further classified as query, bio-inspired, negotiation, coherent, non coherent, QoS, multipath and mobility. The pros and cons of the routing protocols along with the applications are also discussed.

**Keywords:** clustering, energy efficiency, network lifetime, routing protocol, WSN

## 1. Introduction

### 1.1 Introduction to Wireless Sensor Networks

During the past decades, computers have exponentially magnified in processing power and also decreased in size. This rapid advancement led to a very fast market in which computer would participate in more of our daily activities. Due to recent advancement in technology, the implementation of low cost sensors has become economically and technically feasible. Wireless sensor network is produced by grouping together large number of sensors. Wireless Sensor Networks consist of sensors which are distributed in

specific manner. Sensors work with each other to sense some physical phenomenon and then the information collected is processed to get relevant results. Wireless sensor network (WSN) consist of sensor nodes and these sensor nodes communicate with other nodes or directly with the base station to transmit the data packets. The sensor nodes consist of sensing, processing, power and transmission units and position finding system and the mobilizer. Figure 1, illustrates the general representation of the wireless sensor network. Applications of wireless sensor network can be divided into three categories monitoring of object, monitoring of an area, monitoring of both area and object. Wireless sensor network has been used in several areas like military applications, mobile tracking applications, hospitals etc. The lifetime of wireless sensor network is limited because the sensor nodes work on the battery life [43] and it is very hard to recharge the battery at regular basis because of the deployment of wireless sensor networks in remote and hostile places. That's why in wireless sensor network the research is mostly focused towards energy efficient communications and extending the lifetime of the network. Routing protocol in wireless sensor networks might differ depending on the network architecture and required application. In order to prolong network lifetime, routing protocol with high energy efficiency is required.

### 1.2 Key Contribution

- a. The pros and cons of the routing protocols along with the applications are also discussed.
- b. We focused on all the categories of the wireless sensor network routing protocols.
- c. The comparison among all the categories of energy efficient routing protocols has also been discussed.

This paper is categorized as follows: Section 2 describes the main design challenges of routing protocols for wireless sensor network. Section 3,

discuss the routing protocols and their classification into three main classes namely Path

Establishment, Network Structure and Protocol operation and section 5 concludes the paper.

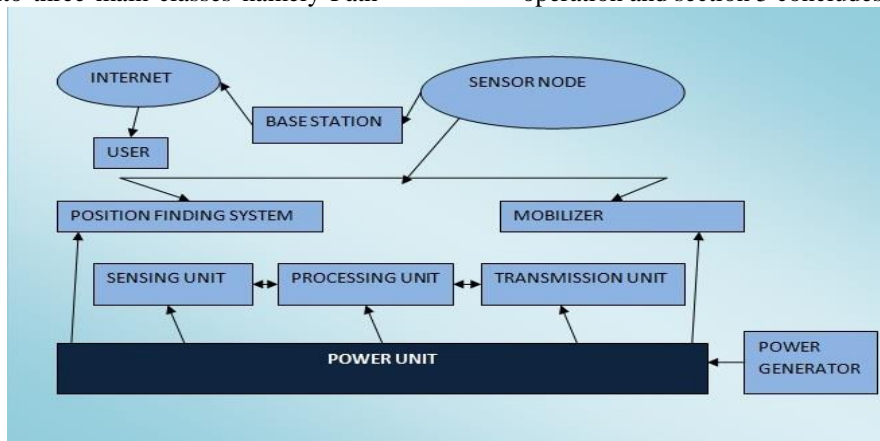


Fig 1: General Representation of Wireless Sensor Network[8]

## 2. Related Work

There are large numbers of research works that focus on the development of routing protocols in wireless sensor networks. These protocols are developed on the basis of architecture of the network and the application. There are so many factors which should be taken into consideration for the development of routing protocols. Energy efficiency is the most important factor that directly affect the lifetime, stability, throughput of the network. There are several surveys in the literature

on routing protocols in wireless sensor network as discussed in table 1. Our survey is focused on the comparative study of energy efficient routing protocols in wireless sensor networks that include all the categories of routing protocols in wireless sensor networks and it can provide directions to the user on how to choose the most appropriate energy efficient routing protocol. The advantages and disadvantages of routing protocols along with the applications are discussed.

Table 1: Summary of previous surveys of routing protocols for wireless sensor networks

S.no	Author Name	Protocols Discussed	Pros	Cons
1	Jamal N.Al-karaki [8]	It classified the routing protocols on the basis of network structure and protocol operation.	Give a complete review of all the protocols.	Exclude classification on the basis of path establishment.
2	K.Akkaya et al. [10]	The routing protocols are classified as data-centric, hierarchical, location based, network flow and QoS aware protocols.	Give a good description of the protocols described in the paper.	Not focused on the classification on the basis of path establishment and protocol operation.
3	G.H. Raghunandan et al [6]	It focused on the three categories of classification namely data centric, hierarchical and location based routing protocols.	Give a good comparison of all the protocols discussed in the paper	Only focused on three categories.
4	M. Masdari et al. [14]	It classified the multipath routing in four category alternative path routing, load balancing, energy efficient and data transmission reliability.	Give a good description of multipath routing protocols	Exclude all other categories.
5	Parul Khurana et al. [17]	It classified the routing protocols on the basis of path establishment, network structure, protocol operation and the initiator of communication.	Good review of all the protocols.	Not explore the classification on the basis of path establishment.
6	N.A. Pantazis et al. [15]	It classified the routing protocol into four main categories network structure, communication model, topology based and reliable routing.	Great work on the energy efficient routing protocols.	Not explore all the categories. Exclude location based routing in network structure.
7	S. Tanwar et al. [22]	It focused on the two level and three level heterogeneity routing protocols.	Great work on the heterogeneity based routing protocols.	Not explore all the categories of the protocols.

## 3. Design Challenges For Wireless Sensor Networks

The wireless sensor networks have several design issues, such as bandwidth, energy supply etc. The main characteristic of wireless sensor network is to

carry out effective data communication and also increase the network lifetime. In spite of lots of advancement in technology, the design of routing protocols for wireless sensor networks is still challenging due to various sensor network parameters and requirements. Due to the limitation

of network resources such as bandwidth, storage and energy, the design issues of wireless sensor network include the following aspects:

- a) Limited energy resources.
- b) Location of the sensor.
- c) Hardware resources.
- d) Massive sensor deployment.
- e) Network characteristics.
- f) Data collection.
- g) Scalability.
- h) Fault tolerance.

- i) Node heterogeneity.
- j) Network dynamics.
- k) Transmission media.
- l) Quality of service.
- m) Connectivity.

#### 4. Performance Metrics Of The Routing Protocols

In wireless sensor network the performance of the routing protocol is evaluated on the basis of following measures discussed below in table 2.

Table 2: Performance metrics for the energy efficient routing protocols

S.no.	Author Name	Parameters	Description
1	G.Smargdakis et al.[7]	Stability period	It is the time period from the start of the sensor network operation until the death of first sensor node. It is also referred as stable region.
		Instability Period	It is the time period from the death of first sensor node until the death of last sensor node. It is also referred as unstable region.
2	Z. Khan et al. [37]	Number of cluster heads per round	It reflects the number of nodes which would send directly to the sink (destination) information aggregated from their cluster members.
		Network Lifetime	It is the time period from the start of the operation of the sensor network until the death of last alive node.
3	G.Smargdakis et al. [7]	Throughput	It is the number of packets sends per round from cluster head to base station
4	Z. Khan et al. [37]	Number of alive nodes per round	It reflects the number of nodes that have not yet expended all of their energy.
5	L.Alazzawi et al. [28]	Energy Per Packet	It is referred to the amount of energy used while sending a packet from source to destination (sink).
6	N.A. Pantazis et al. [15]	Energy and reliability	It is a tradeoff between different application requirements.
		Average Energy Dissipated	It gives the average energy dissipated per node over time in network as it performs functions such as receiving, sending and aggregation of data.
7	L.Alazzawi et al. [28]	Average packet delay	It is calculated as the average one way latency between the receiving and sending of the data at the sink.
		Packet delivery ratio	It is calculated as the ratio of the number of data packets received at the sink (destination) to the number of packets originally sent from the source. This measure indicates the reliability of data delivery.
8	Z. Khan et al. [37]	Energy spent per round	It is defined as the total amount of energy spent in routing message (data) in one round.
		Distance	The distance between the receiver and transmitter can affect the energy that is required to send and receive packets. The routing protocols can select the shortest path between sensor nodes and reduce energy consumption.
		Total number of data signals received at the base station	This is equivalent to the energy saved by the routing protocols by not sending continuously data packets, which are not required.
9	S.Sendra et al. [38]	Energy Consumption	The sensor nodes work on the battery life and it is very hard to recharge the battery at regular basis, therefore energy saving technique is required.

#### 5. Classification Of Wsn Routing Protocols

We classified the routing protocols into three classes namely path establishment, network structure and protocol operation. The routing protocols belong to path establishment can be further classified as proactive, reactive and hybrid. The routing protocols belong to network structure can be further classified as flat or data centric,

hierarchical and location based. The routing protocols belong to protocol operation can be further classified as multipath, query, bio-inspired, QoS, coherent, non-coherent, mobility and negotiation based. Routing protocols can be fallen into more than one category. All the categories of routing protocols are discussed in details in the further section. Classification of wireless sensor network routing protocols is illustrated in figure 2.

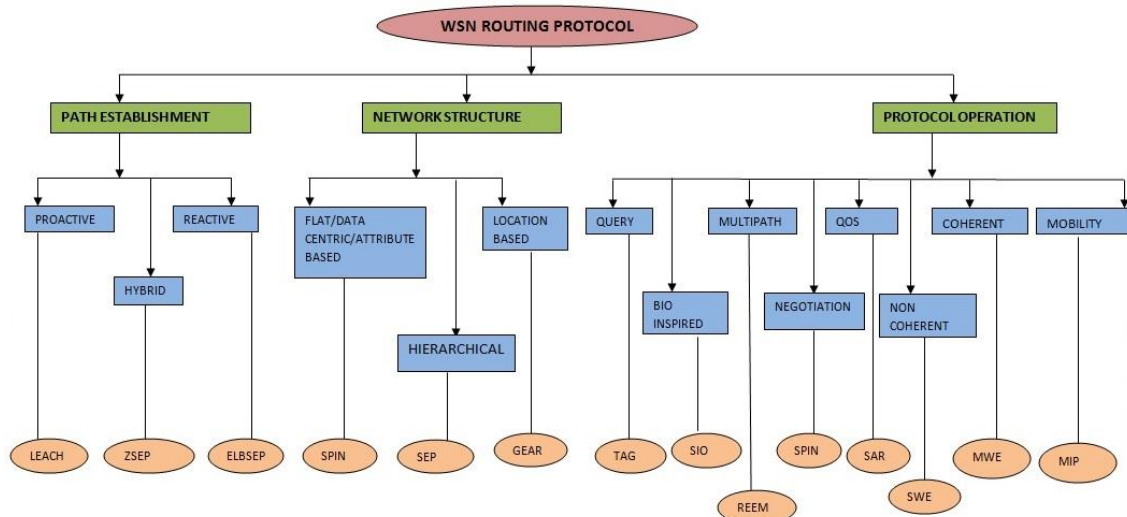


Fig 2: Classification of Energy Efficient Routing Protocol

### 5.1 Path Establishment

On the basis of path establishment the routing protocols are classified as proactive reactive and hybrid [28]. All the three types of routing protocol are discussed in detail below:

#### a. Proactive Routing

All routes are calculated before they are required. In proactive routing, the nodes of the wireless sensor network regularly switch between sensors and transmitters, sense the environment and broadcast the required data. LEACH is one of the examples of proactive routing.

**LEACH-** Leach is a low energy adaptive clustering protocol proposed by W.Heinzelman et al. [24] in the year 2000 in MIT for wireless sensor network. LEACH uses randomization to distribute the energy equally among the sensor nodes in the network [25]. All the sensor nodes in a LEACH routing protocol consist of equal amount of energy, that's why LEACH is considered as a homogeneous routing protocol [19]. The main feature of LEACH protocol is the formation of clusters of the sensor nodes based on the incurred signal intensity. LEACH works in two phase initial phase and stable phase. During the initial phase cluster head is selected on the basis on random number, the nodes in the network generates a random number between 0 and 1, if it is less than the threshold value, the node selected as a cluster head for the current round.

During the stable phase the nodes of the network can begin sensing and broadcasting data to the cluster head, after receiving all the data, cluster head aggregates the data then forward it to the base station. Duration of stable phase is longer than initial phase. LEACH protocol uses data fusion to reduce the amount of data transmission.

#### b. Reactive Routing

Reactive routing is known as on demand routing. In this, routes are computed only when required. The nodes in the network react immediately to the sudden and drastic change in the value of sensed attribute [29]. ELBSEP is one of the examples of reactive routing.

**ELBSEP-** ELBSEP is Energy Level Based Stable Election Protocol proposed by Y.Mishra et al. [41] in the year 2014. This protocol uses the concept of residual energy. Cluster head is selected on the basis of energy level instead of probability basis. This protocol effectively uses the threshold values with the concept of residual energy [41].

#### c. Hybrid Routing

These routing protocols use two or more than two type of routing protocols in efficient manner. ZSEP is one of the examples of hybrid routing.

**Z-SEP-** Z-SEP is a Zonal Stable Election protocol proposed by S.Faisal et al. [2] in the year 2013. It is a hybrid routing protocol. It improves the SEP protocol by using two techniques. In this normal node sends data using direct communication and advanced nodes (nodes having more energy than normal nodes) sends data using clustering approach [2].

### 5.2 Network Structure

On the basis of network structure routing protocol is classified into three category flat, hierarchical and location based. All the categories are discussed in detail below:

#### a. Data Centric or Flat Based or Attribute Based

In data centric protocols when the source node sends data to the base station, intermediate nodes perform some process on the data and send the processed data to the base station. In flat based routing, all nodes of the network perform same functions. Data is being requested through query, therefore attribute-based naming is necessary to mention the characteristic of data. SPIN is one of the examples of data centric or flat based routing.

*SPIN*- SPIN is a Sensor Protocol for Information via Negotiation proposed by W. Heinzelman et al. [9] in the year 1999. SPIN is an adaptive and data centric routing protocol. The key feature of SPIN protocol is that data is specified by using a high level descriptor called Meta data [33]. SPIN uses three types of messages namely ADV, REQ and DATA. ADV is used to advertise a new data or

Meta data to the sensor nodes. REQ is used to request the new data and DATA is a message that carries the actual data [35].

### b. Hierarchical Routing

In hierarchical routing sensor nodes perform different functions in the network. Hierarchical routing is based on clustering mechanism. Clustering is the prominent technique for the enhancement of network lifetime by efficient utilization of the energy of the sensor nodes [42]. Hierarchical clustering is classified in two ways homogeneous and heterogeneous. Heterogeneous clustering is further classified as communication (energy), computation and link heterogeneity [22]. Figure 3 describe the concept of clustering.

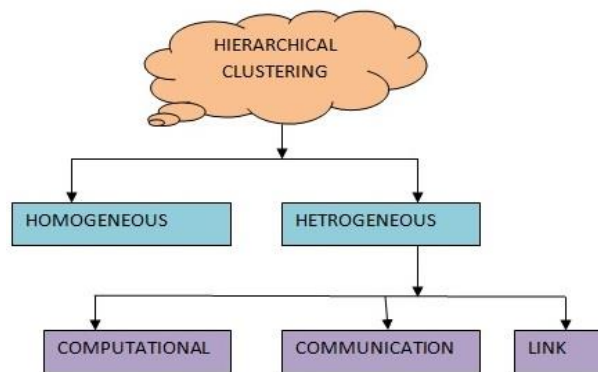


Fig 3:Classification of Hierarchical Clustering

*Energy heterogeneity* means that the battery of sensor node is replaceable. *Computational heterogeneity* defines that the heterogeneous node consist of a powerful microprocessor and memory as compared to the normal node, complex data processing and more data storage is provided by the heterogeneous node processing the powerful computational resources. *Link heterogeneity* is focused on the distance between two sensor nodes, for long distance wireless sensor network, transceiver of heterogeneous environment must have high bandwidth to achieve reliable data transmission [22]. SEP is one of the examples of hierarchical routing.

*SEP*- SEP is a stable election protocol proposed by G. Smaragdakis et al. [7] in the year 2004. It was an improvement over LEACH protocol. SEP is a heterogeneous clustering protocol. There are some nodes which are having higher energy than the normal nodes. The selection of cluster head in SEP is done randomly on the basis of probability of each type (normal and advanced) of node. Nodes in the network sense the data and broadcast it to the associated cluster head, and then, cluster head forward it to the base station.

### c. Location Based Routing

Location based routing also termed as geographic routing. As the name suggest in location based routing, the location of sensor nodes have the primary role. The locations of sensor nodes are used to route the data in the network. The distance between two nodes can be calculated on the basis of incoming signal intensity [6]. GEAR is one of the examples of location based routing

*GEAR*- GEAR is a geographic and energy aware routing protocol proposed by Ya Xu et al. [27] in the year 2001. It uses geographically and energy aware heuristic for neighbor selection to route a data packet to the sink (destination). GEAR routing consist of two phases first forward the packet towards the destination region and second, forward the packet within the region [10, 37].

### 5.3 Protocol Operation

On the basis of protocol operation routing protocols are classified into seven categories namely Query, Multipath, Bio Inspired, Negotiation, QoS, Coherent and Noh Coherent. All the categories are discussed in detail below.

#### a. Query Based Routing



In query based routing, a node initiate a query for the data within the network and a node which contains that data sends the reply to the node which request for the data. The queries can be generated either in natural languages or in high level languages [30]. TAG is one of the examples of query based routing.

*TAG-TAG* is a Tiny aggregation Services proposed by S Madden et al. [21] in the year 2002. TAG routing protocol allows user to express simple, declarative queries and have them distributed and executed efficiently in a wireless sensor network. In TAG routing time is divided into epochs for queries. The intermediate nodes set their parent nodes as the response sending nodes when the sensor node initiates the query. In standard database query execution, a central node or processor collects and process the data, when a query gets executed. In, TAG routing, the query executed in a distributed fashion and therefore decrease the data traffic transmitted in the sensor network.

#### b. Multipath Routing

As the name suggest these routing protocols uses more than one path to send the data packet from source to destination [14, 42]. If one path fails in a network, alternate path can be used to send the data this lead to reliability and fault tolerance of the protocol. In these routing protocols overhead cost and energy consumption cost may increase because of several paths [17, 34]. REEM is one of the examples of multipath routing.

*REEM-* REEM is Reliable and Energy efficient multiple path routing protocol proposed by Xin Hua et al. [26] in the year 2010 to increase the node reliability and energy level of the network. In the REEM routing multiple path are generated from source to sink. The routing path is generated by the sink or base station through message broadcasting and each receiving node will keep the neighboring node information and store it in the routing table. It increases the life time of the network.

#### c. Negotiation Based Routing

These routing protocols use Meta data or high level data descriptors for decimating redundant data transmission through negotiation [8]. In wireless sensor networks, the key feature of negotiation based routing is to prevent redundancy of data. *SPIN* [35] as discussed before in Data centric routing, is also the example of negotiation based routing.

#### d. QoS Based Routing

In QoS based routing, the routing protocol has to satisfy certain QoS metrics (like energy,

bandwidth, and delay). Energy consumption and Data Quality are to be balanced such that quality of service is maintained in the routing protocol. SAR is one of the examples of QoS based routing.

*SAR-* SAR is Sequential Assignment Routing proposed by K. Sohrabi et al [11] in the year 2000. SAR is the first QoS based routing protocol. SAR is a table driven multi path protocol that increases energy efficiency. It creates trees by considering QoS metric, and energy resource on every path, then; these trees are used to form multiple paths from source to destination which makes the routing fault tolerant. SAR provides low energy consumption.

#### e. Non-Coherent Routing

In non coherent routing, node firstly collects and processes the raw data, then send it to aggregators. Non coherent routing has low data traffic loading. In non coherent routing, data can be processed in three phases. First, data collection and preprocessing, second is membership declaration that means when a sensor node decide to participate in routing, then, node send this information to all its neighbors and last is Central node election [31]. SWE is one of the examples of non-coherent routing.

*SWE-* SWE is Single Winner algorithm proposed by K Sohrabi et al [11] in the year 2000. In SWE routing aggregator node performs complex data processing. In SWE the node selection is based on energy consumes and node computational capability. So, when SWE routing process ends, a minimum hop spanning tree will completely covered the network [32].

#### f. Coherent Routing

These routing protocols after minimal processing (like data suppression, time stamping etc.) forward data to the aggregators. In coherent routing energy efficiency must be achieved by path optimality. MWE is one of the examples of coherent routing.

*MWE-* MWE is Multiple Winner Algorithm proposed by K.Sohrabi et al. [11] in the year 2000. It is the extension of Single Winner Algorithm. When every sensor node acts as sources and send the data to the central node, large amount of energy will be consumed. To lower the energy consumption, minimize the number of sources that can send data to the central node. When MWE routing completes its execution, each node in the network has a set of minimum energy path to each source node [32].

#### g. Bio Inspired Routing

These routing protocols are developed by the inspiration of insect sensory system for computing and communication paradigm. These routing are guided by pheromone trails and heuristic information [4, 5]. SIO is one of the examples of bio inspired routing.

*SIO*- SIO is Swarm Intelligence Optimization proposed by Chao Wang et al. [3] in the year 2008. SIO routing balances the energy consumption. In SIO routing, the energy is consumed early in some nodes due to high concentrated routes among the nodes. The main idea of SIO routing is taking less hop numbers into consideration and choosing the next node with less pheromone. This routing is better than directed diffusion protocol when end to end delay and energy balancing factors are primarily concerned.

### h. Mobility Based Routing

It is also a topology based routing. Mobility based protocol contains mobile agent as a main component which may be a software or a program. MIP is one of the examples of mobility based protocol [12, 15, 23].

*MIP*- MIP is a Multi agent based Itinerary protocol proposed by M.Chen et al. [13] in the year 2009. MIP protocol is used in large scale networks, because in large scale sensor networks single agent based itinerary protocols cause high delay rates and unbalanced loads. Energy consumption of MIP protocols is much less.

Table 3 describes the advantages, disadvantages along with the applications of all the energy efficient routing protocols discussed in this paper.

Table 3: Comparison of Energy Efficient Routing Protocol in WSN

<i>Protocol</i>	<i>Pros</i>	<i>Cons</i>	<i>Applications</i>
<i>LEACH</i>	Data collection is centralized	LEACH ignores residual energy LEACH is not suitable for large networks [23] [16]	It can be used to supervise machinery.
<i>ELBSEP</i>	It reduces the transmission time [1].	if the thresholds values are not attained, the sensor nodes will never communicate [1].	It is most applicable for the time critical applications.
<i>Z-SEP</i>	Low energy consumption [2].	Additional complexity & long delay [2].	It can be used in both time critical applications and time non critical applications.
<i>SPIN</i>	Eliminates the redundancy of data [17] [20]	It cannot guarantee the delivery of data [15].	It can be used to supervise machinery for fault detection and diagnosis.
<i>SEP</i>	It increases the network lifetime, stability period, and throughput of the network [22]	does not support multi level heterogeneity of nodes [22]	It can be used to supervise machinery for fault detection and diagnosis.
<i>GEAR</i>	Energy consumption is balanced. [15]	The routing table exchange periodically [15]	It can be used for large scale networks.
<i>TAG</i>	It reduces the amount of traffic transmitted in the sensor network [17]	Overhead increases [17].	It can be used to supervise machine.
<i>REEM</i>	Reliable and Fault tolerant [17].	Due to multiple path overhead cost and energy consumption cost may increase [17].	It can be used where reliability and security is highly needed.
<i>SAR</i>	It maintains multiple paths to destination. [15]	Large overhead in maintaining the tables and states at each sensor node [15]	It can be used where quality of service is the major concern.
<i>SWE</i>	It builds a minimum hop spanning tree [15]	It is a complex protocol[15]	It can be used to supervise machine
<i>MWE</i>	Each sensor node in the network has a set of minimum energy path to each source node. [15]	More delay Larger overhead Less scalability [15]	It can be used to supervise machine
<i>SIO</i>	It prolongs the network lifetime	More Delay [15]	can be used in medical field.
<i>MIP</i>	Consume less energy	More Delay [15]	Used in large Scale networks

## 6. Conclusion

Routing in wireless sensor network is a new area of research. This paper presents a comparative study

of the energy efficient routing techniques in the wireless sensor network. The main categories of routing protocols discussed in this paper are path

establishment, network structure based and protocol operation. We also discussed the advantages and disadvantages of the routing protocol in this paper.

A summarized form of routing protocol is discussed in table 4.

Table 4: Classification of Energy Efficient Routing Protocols in WSN

Protocol	Classification	Power Usage	Mobility	Localization	State Complexity	Scalability
SPIN	Flat/Negotiation	Limited	Limited	No	Low	Limited
LEACH	Proactive/Hierarchical	Maximum	Fixed Base Station	Yes	Cluster Heads	Good
ELBSEP	Reactive/Hierarchical	Maximum	Fixed Base Station	Yes	Cluster Heads	Good
Z-SEP	Hybrid/Hierarchical	Maximum	Fixed Base Station	Yes	Cluster Heads	Good
SEP	Hierarchical	Maximum	Fixed Base Station	Yes	Cluster Heads	Good
GEAR	Location	Limited	Limited	No	Low	Limited
SWE	Non Coherent	Not Available	No	No	Low	Good
MWE	Coherent	Not Available	No	No	Low	Low
REEM	Multipath	Limited	Limited	Yes	Low	Limited
SAR	QoS	Not Available	No	No	Moderate	Limited
MIP	Topology /Mobility	Limited	Good	Yes	Moderate	Limited

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