A Review of Power Efficient Hierarchical Routing Protocols in Wireless Sensor Networks

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Abstract

The area of wireless sensor networks is one of the emerging and fast growing fields in the scientific world. This has brought about developing low cost, low-power and multi-function sensor nodes. However, the major fact that sensor nodes run out of energy quickly. In the research area of wireless sensor networks the power efficient time is a major issue. There are various routing protocols in which optimal routing can be achieved in the context of power. In this paper we intend to discuss some of the major power-efficient hierarchical routing protocols for wireless sensor networks. First we will discuss the some of power-efficient Hierarchical routing protocols in brief .We also highlight the important features, Drawbacks and area of application of each routing technique . Finally, we provide a comparative study on these various protocols.

Keywords – Base Station, Cluster-based routing, Cluster Head, Hierarchical clustering, Wireless Sensor Networks.

1. INTRODUCTION

Wireless sensor networks usually consists of a large number of nodes called sensor node that bring themselves together to form a wireless network. These sensor nodes are scattered in sensor field situated far from the user which consist of sensor nodes, BS and monitored events[2] . A typical sensor node is made of four building blocks: power unit, communication unit, processing unit and sensing unit [1] . The fig.(1) shows the component of sensor nodes. The sensing component in a node measures certain physical characteristic like temperature or detects soil moisture of a location in which it is placed. The processing component is responsible for collection and processing captured data from its surrounding. The wireless communication component of a sensor node is responsible for transmission or reception of captured data from one sensor node to another node or to an end user through the cluster head to the base station (BS). The sensor node, its processing and communication component requires energy to function as expected, and the power component, which is of limited amount, is solely responsible for provision of energy to the three other components[1].

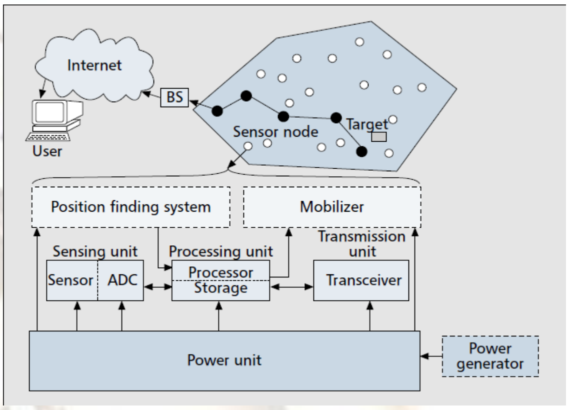

Figure 1. The components of a sensor node

WSN creates a local network hierarchy on one or more levels represented by nodes chosen by certain criteria that are aggregating and sending data to a central base station (BS).Most times it is not necessary to identify the exact location of the node and it's ID. Communication is done mostly from node to BS, the BS sends requests to obtain data from nodes. the answer of a particular node is not important, but the area of origin is. All data has to be aggregated by the cluster-head before reaching the BS.This data aggregation in the head nodes greatly reduces energy consumption in the network by minimizing the total data messages to be sent to BS. The less the energy consumption, the more the network life time. The main idea of developing cluster-based routing protocols is to reduce the network traffic toward the sink. This method of clustering may introduce overhead due to the cluster configuration and maintenance, but it has been demonstrated that cluster-based protocols exhibit better energy consumption and performance when compared to flat network topologies for large-scale WSNs.

The paper is organized in the following way. In Section 1 introduction to WSNs. In Section 2, describe the cluster based Hierarchical model. In Section 3, various power-efficient hierarchical cluster routing protocols are briefly explained .In section 4, we compare Hierarchical routing protocols using some parameters. Finally, Section 5 concludes the paper .

2. HIERARCHICAL ROUTING MODEL

As shown in Fig.(2), a hierarchical approach breaks the network into clustered layers [3]. Nodes are grouped into clusters with a cluster head that has the responsibility of routing from the cluster to the other cluster heads or base stations. Data travel from a lower clustered layer to a higher one. Although, it hops from one node to another, but as it hops from one layer to another it covers larger distances. This moves the data faster to the base station.In the cluster-based hierarchical model, data is first aggregated in the cluster then sent to a higher-level cluster-head. As it moves from a lower level to a higher one, it travels greater distances, thus reducing the travel time and latency. This model is better than the one hop or multi-hop model.

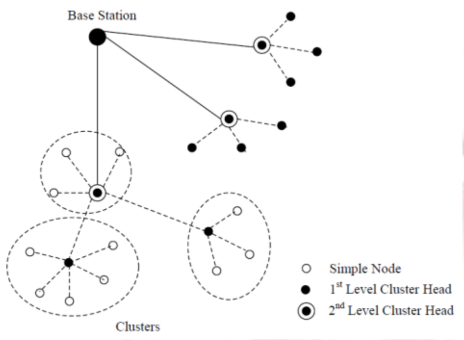

Figure 2. Cluster-based Hierarchical Model

Further, in cluster-based model only cluster-heads performs data aggregation whereas in the multi-hop model every intermediate node performs data aggregation. As a result, the cluster-based model is more suitable for time-critical applications than the multi-hop model.

However, it has one drawback, namely, as the distance between clustering level increases, the energy spent is proportional to the square of the distance. This increases energy expenditure. Despite this drawback, the benefits of this model are more important than drawback. A cluster-based hierarchical model offers a better approach to routing for WSNs.

3. Power-Efficient Hierarchical Cluster Routing Protocols

Clustering algorithms for traditional wireless ad hoc networks are not well suited for WSNs . Some of the special features of WSNs are as follows:

- Sensor nodes are densely deployed.
- Sensor nodes are prone to failure.
- The large number of sensors nodes in a WSN and are limited in power, computational capacities, and storage memory.
- The topology of a WSN may change rather frequently because a sensor node may alternate between the active and sleep states.
- Sensor nodes may not have global identification (ID) because of the large amount of overhead and the large number of sensors.

Sensor network requires certain protocol for efficient performance. For instance, protocol can come in form of a specific application with a defined order to aggregate data and optimizing energy consumption. This kind of protocol is referred to as hierarchical routing. Hierarchical routing have special advantages related to scalability and efficient communication. As such, the concept of hierarchical routing is also utilized to perform energy-efficient routing in WSNs. In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used for routing. A variety of protocols have been proposed for prolonging the life of WSN and for routing the correct data to the base station. Some of the hierarchical protocols are LEACH, PEGASIS, HPIGASIS, TEEN, APTEEN, HEED and EARP.

3.1. Low Energy Adaptive Clustering Hierarchy protocol (LEACH)

LEACH [2],[4],[5] is a kind of cluster-based routing protocols, which includes distributed cluster formation. LEACH randomly selects a few sensor nodes as cluster heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. In LEACH, the CH nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the BS in order to reduce the amount of information that must be transmitted to the BS. LEACH uses a TDMA/code-division multiple access (CDMA) MAC to reduce inter-cluster and intra-cluster collisions. All the data processing such as data fusion and aggregation are local to the cluster. The operation of LEACH is done into two phases, the setup phase and the steady state phase. In setup phase the clusters are organized and CHs are selected. Cluster heads change randomly over time in order to balance the energy dissipation of nodes. This decision is made by the node choosing a random number between 0 and 1. The node becomes a cluster head for the current round if the number is less than the following threshold value $T(n)$,

$$T(n) = \begin{cases} \frac{P}{1-P(r\text{mode}(1/p))}, & \text{if } n \in G, \\ 0, & \text{otherwise.} \end{cases}$$

Where G is the set of nodes that are involved in the CH election. LEACH clustering is shown in Fig. (3).

In the steady state phase, the actual data transfer to the BS takes place. The duration of the steady state phase is longer than the duration of the setup phase in order to minimize overhead. During the steady state phase, the sensor nodes can begin sensing and transmitting data to the CHs. The CH node, after receiving all the data, aggregates it before sending it to the BS. After a certain time, which is determined a priori, the network goes back into the setup phase again and enters another round of selecting new CHs. Each cluster communicates using different CDMA codes to reduce interference from nodes belonging to other clusters.

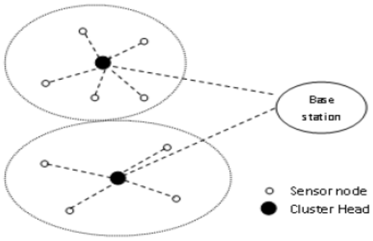

Figure 3. Clustering in LEACH Protocol

LEACH achieves over a factor of 7x and 8x reduction in energy dissipation compared to direct communication and a factor of 4x and 8x compared to the minimum transmission energy (MTE) routing protocol.

The major characteristics of this Protocol are as follow:

- It rotates the cluster heads in a randomized fashion to achieve balanced energy consumption,
- Sensors have synchronized clocks so that they know the beginning of a new cycle,
- Sensors do not need to know location or distance information.

There are some drawbacks of this protocol such as:

- LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions.
- The idea of dynamic clustering brings extra overhead, e.g. head changes, advertisements etc., which may decrease the gain in energy consumption.
- Random election of CH, hence there is Possibility that all CHs will be concentrated in same area.
- The protocol assumes that all nodes begin with the same amount of energy capacity in each election round, assuming that being a CH consumes approximately the same amount of energy for each node.

This protocol is most suited for constant monitoring such as monitor machinery for fault detection and diagnosis.

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

PEGASIS [6], an enhancement over the LEACH protocol and it is a near optimal chain-based protocol. The basic idea of the protocol is that in order to extend network lifetime, nodes need only communicate with their closest neighbors, and they take turns in communicating with the BS as shown in fig.(4) [12] .

When the round of all nodes communicating with the BS ends, a new round starts, and so on. The chain in PEGASIS will consist of those nodes that are closest to each other and form a path to the BS. The aggregated form of the data will be sent to the BS by any node in the chain, and the nodes in the chain will take turns sending to the BS. The chain construction is performed in a greedy fashion. To locate the closest neighbor node in PEGASIS, each node uses the signal strength to measure the distance to all neighboring nodes and then adjusts the signal strength so that only one node can be heard.

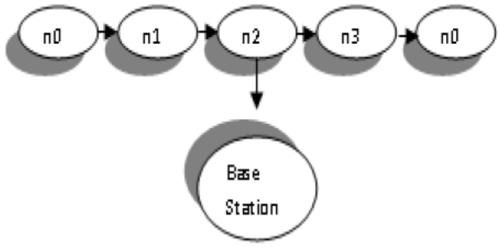

Figure 4. Chaining in PEGASIS

PEGASIS achieves energy conservation in two ways:
1. The number of data messages received by the head node is at most two.
2. The distance over which the data are transmitted to one-hop neighbor is much less
So, PEGASIS conserves energy by reducing the number of data messages gathering at head node [7].

The important features of this protocol are as follows:

- PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS instead of multiple nodes.
- PEGASIS increase the lifetime of each node by using collaborative techniques.
- PEGASIS reduces the power required to transmit data per round as the power draining is spread uniformly over all nodes.

An extension to PEGASIS, called Hierarchical-PEGASIS was introduced in [8] with the objective of decreasing the delay incurred for packets during transmission to the BS.

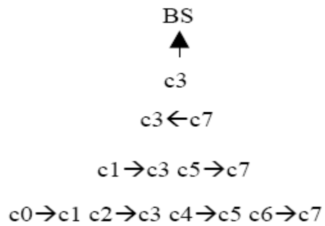

Figure 5. Hierarchical PEGASIS

H-PEGASIS proposes a solution to the data gathering problem by considering energy X delay metric. In order to reduce the delay in PEGASIS, simultaneous transmissions of data messages are pursued. To avoid collisions and possible signal interference among the sensors, two approaches have been investigated.

- The first approach incorporates signal coding, e.g. CDMA.
- In the second approach only spatially separated nodes are allowed to transmit at the same time.

The chain-based protocol with CDMA capable nodes, constructs a chain of nodes, that forms a tree like hierarchy as shown in fig.(5) [12], and each selected node in a particular level transmits data to the node in the upper level of the hierarchy.

There are some drawbacks of this protocol such as:

- PEGASIS assumes that each sensor node is able to communicate with the BS directly. In practical cases, sensor nodes use multi-hop communication to reach the BS.
- PEGASIS assumes that all sensor nodes have the same level of energy and are likely to die at the same time.
- PEGASIS introduces excessive delay for distant nodes on the chain.
- The single leader can become a bottleneck.

This protocol is most suited for surveillance application such as motion detection, motion characteristic detection etc.

3.3 Threshold-Sensitive Energy Efficient Sensor Network Protocol (TEEN)

TEEN [2],[9], is a hybrid of hierarchical clustering and data-centric protocols, which groups sensors into clusters with each led by a CH. The sensor network architecture in TEEN is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until the BS is reached. The model is similar to the architecture as depicted in Fig. (2). In this protocol, nodes sense the medium continuously, but the data transmission is done less frequently. The network consists of simple nodes, first-level cluster heads and second-level cluster heads. TEEN uses LEACH's strategy to form cluster. First level CHs are formed away from the BS and second level cluster heads are formed near to the BS.

A CH sends two types of data to its neighbors—one is the hard threshold (HT) and other is soft threshold (ST). In the hard threshold, the nodes transmit data if the sensed attribute is in the range of interest and thus it reduces the number of transmissions. On the other hand, in soft threshold mode, any small change in the value of the sensed attribute is transmitted. The nodes sense their environment continuously and store the sensed value for transmission. Thereafter the node transmits the sensed value if one of the following conditions satisfied:

a. Sensed value > hard threshold (HT).
b. Sensed value ~ hard threshold >= soft threshold (ST).

Which indicates a small change in the value of the sensed attribute and triggers a sensor to turn ON its transmitter and send its sensed data to the CH. As a consequence, soft threshold will further reduce the number of transmissions for sensed data if there is little or no change in the value of sensed attribute. Thus, the sensors will send only sensed data that are of interest to the end user based on the hard threshold value and the change with respect to the previously reported data, thus yielding more energy savings. When cluster-heads are to change , new values for the above parameters are broadcast. The time line for TEEN is as shown in fig.(6).

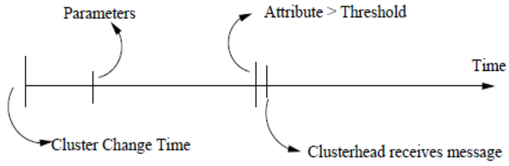

Figure 6. Time Line for TEEN

The main features of this protocol are as follows:

- Time critical data reaches the user almost instant-neously.
- The soft threshold can be varied, depending on the criticality of the sensed attribute and the target application.
- A smaller value of the soft threshold gives a more accurate picture of the network, at the expense of increased energy consumption.
- At every cluster change time, the attributes are broadcast afresh and so, the user can change them as required.

There are some drawbacks of this protocol such as:

- A node may wait for their time slot for data transmission. Again time slot may be wasted if a node has no data for transmission.
- Cluster heads always wait for data from nodes by keeping its transmitter on.

TEEN is best suited for time critical applications where the users can control a trade-off between energy efficiency, data accuracy, and response time dynamically such as intrusion detection, explosion detection etc.

3.4. Adaptive Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN)

APTEEN [2],[10] is an improvement to TEEN to overcome its short comings and aims at both capturing periodic data collections (LEACH) and reacting to time-critical events (TEEN). Thus, APTEEN is a hybrid clustering-based routing protocol. APTEEN allows the sensor to send their sensed data periodically and react to any sudden change in the value of the sensed attribute by reporting the corresponding values to their CHs. The architecture of APTEEN is same as in TEEN, which uses the concept hierarchical clustering for energy efficient communication between source sensors and the sink. CHs also perform data aggregation in order to save energy. When the base station forms the clusters, the CHs broadcast the following parameters. The time line for APTEEN is as shown in fig. (7).

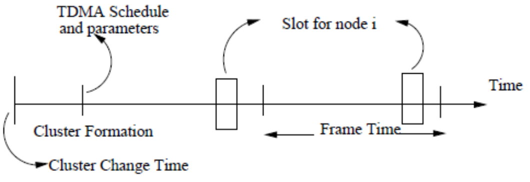

Figure 7. Time Line for APTEEN

- Attributes (A): a set of physical parameters about which the user is interested in obtaining information
- Thresholds: consists of the hard threshold (HT) and soft threshold (ST)
- Schedule: a TDMA schedule, assigning a slot to each node
- Count time (CT): the maximum time period between two successive reports sent by a node.

The node senses the environment continuously, and only those nodes which sense a data value at or beyond the hard threshold transmit. Once a node senses a value beyond HT, it transmits data only when the value of that attribute changes by an amount equal to or greater than the ST. If a node does not send data for a time period equal to the count time, it is forced to sense and retransmit the data. A TDMA schedule is used and each node in the cluster is assigned a transmission slot. Hence, APTEEN uses a modified TDMA schedule to implement the hybrid network.

APTEEN supports three different query types namely
(i)Historical query: To analyze past data values,
(ii)One-time query: To take a snapshot view of the network; and
(iii)Persistent queries: To monitor an event for a period of time.

The main features of this scheme are as follows:

- It combines both proactive and reactive policies.
- It offers a lot of flexibility by allowing the user to set the count-time interval (CT), and the threshold values for energy consumption.
- The energy consumption can be controlled by changing the count time as well as the threshold values.

There are some drawbacks of this protocol such as:

- The overhead and complexity of forming clusters in multiple levels.
- The complexity increases to implementing threshold based functions, Count Time (CT) and dealing with attribute-based naming of queries.

APTEEN is best suited for both periodic sensing & reacting to time critical events such as habitat monitoring for example animal monitoring in the forest etc.

3.5. Hybrid, Energy-Efficient Distributed Clustering (HEED)

HEED [11] excellent cluster-based protocol it elect CHs based on residual energy and node degree or density of nodes as a metric for cluster selection to achieve power balancing, which is a rational improvement compared with LEACH. In HEED, the proposed algorithm periodically selects CHs according to a combination of two clustering parameters. The primary parameter is their residual energy of each sensor node and the secondary parameter is the intra-cluster communication cost as a function of cluster density. The primary parameter is used to probabilistically select an initial set of CHs while the secondary parameter is used for breaking ties. HEED was proposed with four primary goals namely,

(i) Prolonging network lifetime by distributing energy consumption,
(ii) terminating the clustering process within a constant number of iterations,
(iii) minimizing control overhead,
(iv) producing well-distributed CHs and compact clusters.

In HEED, the clustering process at each sensor node requires several rounds. Every round is long enough to receive messages from any neighbor within the cluster range. The parameter C_{prob} is only used to limit the initial CH announcements and has no direct impact on the final cluster structure. In HEED, each sensor node sets the probability CH_{prob} of becoming a CH as follows.

$$CH_{prob} = C_{prob} \cdot \frac{E_{residual}}{E_{\max}}$$

Where $E_{residual}$ is the estimated current residual energy in this sensor node and E_{max} is the maximum energy corresponding to a fully charged battery, which is typically identical for homogeneous sensor nodes.

The CH_{prob} value must be greater than a minimum threshold *pmin*. A CH is either a tentative CH, if its CH_{prob} is <1, or a final CH, if its CH_{prob} has reached 1.During each round of HEED, every sensor node that never heard from a CH elects itself to become a CH with probability CH_{prob}. The newly selected CHs are added to the current set of CHs. If a sensor node is selected to become a CH, it broadcasts an announcement message as a tentative CH or a final CH. A sensor node hearing the CH list selects the CH with the lowest cost from this set of CHs. Every node then doubles its CH_{prob} and goes to the next step. If a node completes the HEED execution without electing itself to become a CH or joining a cluster, it announces itself as a final CH. A tentative CH node can become a regular node at a later iteration if it hears from a lower cost CH. Here, a node can be selected as a CH at consecutive clustering intervals if it has higher residual energy with lower cost.

The important features of this protocol are as follows:

- HEED distribution of energy extends the lifetime of the nodes within the network thus stabilizing the neighboring node.
- HEED does not require special node capabilities, such as location-awareness
- HEED does not make assumptions about node distribution
- The nodes also automatically update their neighbor sets in multi-hop networks by periodically sending and receiving messages.
- It operates correctly even when nodes are not synchronized.
- The nodes only require local (neighborhood) information to form the clusters

There are some disadvantages of this protocol such as:

- The random selection of the cluster heads, may cause higher communication overhead for: The ordinary member nodes in communicating with their corresponding cluster head, the cluster heads in establishing the communication among them, or between a cluster head and a base station.
- The periodic cluster head rotation or election needs extra energy to rebuild clusters.

This protocol is most suitable for prolonging the network lifetime rather than for the entire needs of WSN.

3.6. Energy-aware routing protocol for cluster-based sensor networks (EARP)

EARP [13] is mainly designed for cluster-based sensor networks, based on a three-tier architecture. There are some assumptions such as: Sensors are grouped into clusters prior to network operation. The algorithm employs cluster heads, namely gateways, which are less energy constrained than sensors and assumed to know the location of sensor nodes. Gateways maintain the states of the sensors and sets up multi-hop routes for collecting sensors data. The sink communicates only with the gateways. The sensor is assumed to be capable of operating in an active mode or a low-power stand-by mode.

A TDMA based MAC is used for nodes to send data to the gateway. The gateway informs each node about slots in which it should listen to other nodes' transmission and slots, which the node can use for its own transmission The sensing and processing circuits can be powered on and off. The sensor nodes in a cluster can be in one of four main states:

- *Sensing state*: The node probes the environment and generates data at a constant rate.
- *Relaying state*: The node does not sense the target but its communications circuitry is on to relay the data from other active nodes.
- *sensing-relaying state* : The node is both sensing and relaying messages from other nodes,
- *Inactive state:* The node neither sensing nor relaying messages from other nodes, the node is considered as in inactive state and can turn off its sensing and communication circuitry.

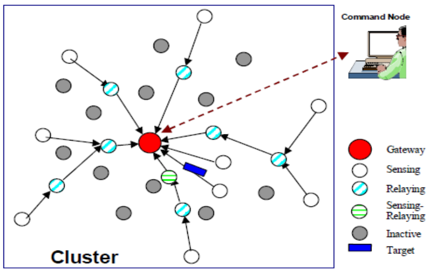

Figure 8.A Typical Cluster in a Sensor Network

The results also have indicated that combining the routing approach with the time-based medium arbitration can further increase the life of the network by an order of magnitude. However, such approach assumes simple propagation model, which might require the deployment of many gateways to ensure high sensor coverage. The nodes that are not reachable are assigned an agent sensor to convey commands from the gateway and pass nodes status back to the gateway.

This protocol performs well for to both energy-based metrics, e.g. network lifetime, as well as contemporary metrics, e.g. throughput and end-to-end delay. This protocol is most suitable for a target-tracking application as shown in Fig. (8).

4 Comparative Study Of Routing Protocols

Table 1 gives comparison of various above mentioned power efficient routing protocols for wireless sensor networks. PEGASIS increases network lifetime two-fold compared to the LEACH protocol. The performance of APTEEN lies between TEEN and LEACH with respect to energy consumption and lifetime of the network. The HEED clustering improves network lifetime over LEACH clustering because LEACH randomly selects CHs, which may result in faster death of some nodes. The final CHs selected in HEED are well distributed across the network and the communication cost is minimized as compared to other routing protocols. Simulation results shows that both modes of TEEN is more efficient than LEACH in terms of energy consumption and response time[19].

Table 1. Comparison of different Hierarchical routing protocol

Protocols / Parameters	LEACH	PEGASIS	TEEN	APTEEN	HEED	EARP
Routing	Cluster Based	Chain Based	Hybrid	Hybrid	Cluster Based	Cluster Based
Node Mobility	Fixed BS	Fixed BS	Fixed BS	Fixed BS	Stationary	Stationary
Data Aggregation	No	No	Yes	Yes	Yes	Yes
Energy efficient	No	Yes	Yes	Yes	Yes	Yes
Balanced clustering	OK	N/A	Good	Good	Good	Very Good
Cluster stability	Moderate	N/A	High	High	High	High
Multi-hop	No	No	Yes	Yes	Yes	Yes

5. CONCLUSION

In this article we provide descriptions of several power efficient Hierarchical routing schemes proposed for wireless sensor networks .We have highlighting their important features, drawbacks and application where they particularly used. They have the common objective of trying to extend the lifetime of the sensor network, while not compromising data delivery. All above mentioned protocols have some advantages and some limitations. So we can select an effective protocol, depending up on the network, applications and other conditions.

Quality of services (QoS) related to video and imaging sensors, factors affecting cluster formation and the communication between CHs or CH to BS are open issues for future research.

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