

Routing Protocols to provide Quality of Service in Wireless Sensor Networks

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Abstract: Wireless Sensor Networks consist of small, low-power, low-energy nodes used for monitoring environmental parameters such as temperature, humidity and motion. Routing is a critical issue in WSN and hence the WSNs are required to provide different levels of Quality of Services (QoS) based on the type of applications. Due to resource constraints like processing power, memory, bandwidth and power sources in sensor networks, QoS support in WSNs is a challenging task. In this paper, we discuss the QoS requirements in WSNs and present a review on some of the QoS aware routing protocols in WSNs. In the end, we have done the comparison of QoS aware routing protocols in WSNs.

Index Terms:- Wireless Sensor Networks(WSN), Quality-of-Service(QoS), LEACH, Routing Protocols.

1. INTRODUCTION

Wireless Sensor Network (WSN) is used for many applications like environmental monitoring and habitat study, over a battle field for military surveillance and reconnaissance, in emergent environments for search and rescue, in factories for condition based maintenance, in buildings for infrastructure health monitoring, in homes to realize smart homes, or even in bodies for patient monitoring. It is one of the most growing fields and it will become the part of human life like mobile phones in a near future due to its growing application. Nodes in WSN sense the physical phenomena like temperature, pressure, humidity or location of objects and transfer the sensed data to the Base Station. In the WSNs, each node has limited energy because they operate on a battery power and this battery power is limited. Lifetime of the wireless sensor network depends upon its battery power and maximizing the lifetime of wireless sensor network is one of the major research areas currently.

A sensor node is made up of four basic components: a sensing unit, a processing unit, a transceiver unit and a power unit [15]. They may also have application dependent additional components such as a location finding system, a power generator and a mobilizer.

2. QoS Requirements in WSN

The characteristics of WSNs are different from other networks. Such a network requires to sense data from

the surrounding environment and finally forwards the sensed data towards a remote and resourceful node

called sink or base station. Therefore, QoS provisioning in WSN has some significant challenges. Different applications may have different QoS requirements as follows:

i). Packet delivery ratio (PDR): It is the ratio of number of data packets successfully received by the receiver to the total number of data packets sent by sensor node.

ii). Average End-to-End delay: It indicates the length of time taken for a packet to travel from the CBR (Constant Bit Rate) source to the destination. It represents the average data delay an application experiences when transmitting data.

iii). Throughput: It is the number of bits passed through a network in one second. It is the measurement of how fast data can pass through an entity (such as a point or a network).

iv). Energy Consumption: This is amount of energy consumed by sensor node devices during the periods of transmitting, receiving, idle and sleep. The unit of energy consumption used in the simulations is m Joule.

v). Energy per goodput bit: It is the ratio of total energy consumed to total bits received. It is used as a figure of merit to compare the performance of various network methods based on battery powered devices.

vi). Network Lifetime: This is defined as the minimum time at which maximum numbers of sensor nodes are dead or shut down during a long run of simulations.

3. Classification of Routing Protocols in WSN

The routing protocols of Wireless Sensor Networks are classified into various categories such as Flat routing, Hierarchical routing, Location based routing, Negotiation based routing, Multipath based routing, Quality of Service (QoS) routing and Mobility based routing.

In flat-based routing, all nodes are typically assigned equal roles or functionality. Flat routing protocols and Hierarchical routing protocol supports good quality of service. In location-based routing, sensor nodes positions are exploited to route data in the network [2,14].

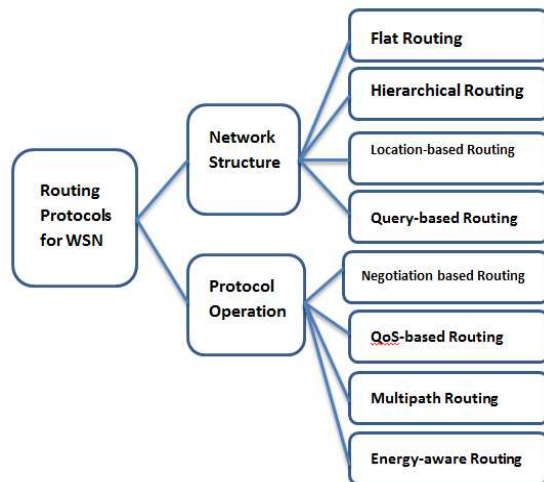


Fig 1: Classification of Routing Protocols in WSN

3.1.1 Network Structure Based Protocols:

The underlying network structure can play significant role in the operation of the routing protocol in WSNs. In this section, we identify in details most of the protocols.

(A) Flat Routing Protocols:

This class of protocols performs data centric routing, where the end nodes and the sensors themselves are less significant than the data itself. In flat networks, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task. Early works on data centric routing, e.g., SPIN and directed diffusion was shown to save energy through data negotiation and elimination of redundant data. These two protocols motivated the design of many other protocols which follow a similar concept [14]. In the rest of this subsection, we

summarize these protocols and highlight their advantages and their performance issues.

Sensor Protocols for Information via Negotiation (SPIN)

SPIN is a family of Flat protocols that use data negotiation and resource-adaptive algorithms. SPIN is a data centric routing protocol. It assumes: A. all nodes in the network are base stations. B. nodes in close proximity have similar data.

The key idea behind SPIN is to name the data using high-level descriptors or meta-data. Since all nodes can be assumed as base stations all information is broadcasted to each node in the network. So user can query to any node and can get the information immediately. Nodes in this network use a high level name to describe their collected data called meta-data.

Before transmission, meta-data are exchanged among sensors nodes (meta-data negotiation) via a data advertisement procedure, thus avoiding transmission of redundant data in the network. After receiving the data each node advertises it to its neighbors and interested neighbors get this data by sending a request message. The format of this meta-data is not specified in SPIN and it depends on the used applications. This meta-data negotiation solves the classic problem of flooding and thus it achieves energy efficiency. SPIN uses three types of messages: ADV, REQ, and DATA for communication with each other. ADV is used for adverting new data, REQ is used for requesting for data and DATA is the actual message. According to this protocol first a node gets some new data and the node wants to distribute that data throughout the network, so it broadcasts an ADV message containing meta-data. The interested nodes request that data by sending a REQ message and the data is sent to the requesting nodes. The neighboring node repeats this process until the entire network gets the new data.

Advantages: -

- SPIN protocol is that each node only knows its single-hop neighbors therefore topological changes in network localized, i.e. does not affect whole network.
- Significantly reduce energy consumption compared to flooding.

Disadvantages: -

- SPIN protocol does not guarantee delivery of data Large overhead (Data broadcasting).
- Not good for applications requiring reliable data delivery, e.g., intrusion detection.

Directed Diffusion (DD):

In spite of SPIN, where availability of data is advertised, in directed diffusion the BS broadcasts interest which describes a task required to be done by the network. Upon receiving the interest, each sensor node then stores the interest entry in its cache and sets up a gradient toward itself to the nodes from which it receives the interest. When a node has data for broadcasted interest, it sends data through the interest's gradient choosing only best paths to avoid further flooding. First, directed diffusion issues on demand data queries as the BS send queries to the sensor nodes by flooding some tasks. All communication in directed diffusion is neighbor-to-neighbor with each node having the capability of performing data aggregation and caching. There is no need to maintain global network topology in directed diffusion.

Advantages: -

- Better energy efficiency, especially in highly dynamic network.
- It can reduce the bandwidth needed for sensor networks.
- Robust to failed path.

Disadvantages:-

- Matching data to queries might require some extra overhead at the sensor nodes.
- There is limit memory storage for data caching inside the sensor node.
- Directed diffusion may not be applied to applications (e.g., environmental monitoring) that require continuous data delivery to the BS.

(B) Cluster-based Routing /Hierarchical Routing Protocols:

Hierarchical or cluster-based routing, originally proposed in wireline networks, are well-known techniques with special advantages related to scalability and efficient communication. 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. 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.

LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol:

LEACH [8] is a cluster-based protocol, which includes distributed cluster formation. The purpose of LEACH is to randomly select sensor nodes as cluster-heads, so the high energy dissipation in communicating with the base station is spread to all sensor nodes in the sensor network. In LEACH the role of the cluster head is periodically transferred among the nodes in the network in order to distribute the energy consumption.

The operation of LEACH is separated into two phases, the set-up phase and the steady phase. The duration of the steady phase is longer than the duration of the set-up phase in order to minimize the overhead. During the set-up phase, a sensor node chooses a random number between 0 and 1. If this random number is less than the threshold $T(n)$, the sensor node is a cluster-head. $T(n)$ is calculated as:

$$T(n) = \begin{cases} \frac{P}{1 - P * [r \bmod (1/p)]} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

Where P is the desired percentage to become a cluster-head, r is the current round and G is the set of nodes that have not being selected as a cluster-head in the last $1/P$ rounds. After the cluster-heads are selected, the cluster-heads advertise to all sensor nodes in the network that they are the new cluster-heads. Once the sensor nodes receive the advertisement, they determine the cluster that they want to belong based on the signal strength of the advertisement from the cluster-heads to the sensor nodes[10].

The sensor nodes inform the appropriate cluster-heads that they will be a member of the cluster. Afterwards, the cluster-heads assign the time on which the sensor nodes can send data to the cluster-heads based on a Time Division Multiple Access (TDMA) approach.

During the steady phase, the sensor nodes can begin sensing and transmitting data to the cluster-heads. The cluster-heads also aggregate data from the nodes in their cluster before sending these data to the base station. After a certain period of time spent on the steady phase, the network goes into the set-up phase again and entering into another round of selecting the cluster-heads.

The cluster head is the router to the sink and it is also responsible for the data aggregation. A centralized version of this protocol is LEACH-C. This scheme is also based on time rounds which are

divided into the set-up phase and the steady-phase. In the set-up phase, sensors inform the base station about their positions and about their energy level. With this information, the base station decides the structure of clusters and their corresponding cluster heads. Since the base station possesses a complete knowledge of the status of the network, the cluster structure resulting from LEACH-C is considered an optimization of the results of LEACH.

Advantages:-

- Completely distributed
- No global knowledge of the network
- Increases the lifetime of the network

Disadvantages:-

- It is not applicable to networks deployed in large regions and no use of meta data.

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

PEGASIS is an enhancement over LEACH protocol was proposed. The protocol 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 base-station. When the round of all nodes communicating with the base-station ends, a new round will start and so on. This reduces the power required to transmit data per round as the power draining is spread uniformly over all nodes. PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS instead of using multiple nodes. Simulation results showed that PEGASIS is able to increase the lifetime of the network twice as much the lifetime of the network under the LEACH protocol. PEGASIS assumes that each sensor node can be able to communicate with the BS directly. In addition, PEGASIS assumes that all sensor nodes have the same level of energy and they are likely to die at the same time.

Advantages: -

- Extend network lifetime.
- Bandwidth consumed in communication is reduced.

Disadvantages: -

- Delay incurred for packets during transmission to the BS.
- To obtain a global knowledge is difficult.
- Very long delay.

Threshold-sensitive Energy Efficient Protocols (TEEN and APTEEN):

It is a LEACH based routing protocol for reactive network, having a smart data transmission which saves power. Here nodes have dynamically reconfiguring capability. At any cluster change time, the cluster-head broadcasts the following parameters: Attributes and Threshold values (Hard threshold and Soft threshold). The nodes transmit only if the perceived value is greater than the Hard Threshold (HT), or value differs from the last transmitted value (SV i.e. sensed value) by more than the Soft Threshold (ST). After transmission SV is set to the currently transmitted value. Here the time-critical data reaches the user almost instantaneously. In APTEEN cluster-heads are decided in each cluster period and the cluster-heads have to broadcast the following parameters: Attributes, Thresholds (Hard Threshold and Soft threshold), Schedule and Count-Time (TC). Nodes transmit in time slot only if the sensed value is greater than the Hard Threshold (HT), or value differ from the last transmitted value (SV) by more than the Soft Threshold. If a node transmits for a maximum time TC, or if required by some sink, it transmits and after transmission SV is set to the current transmitted value. By sending periodic data it gives user a complete picture of the network. It can also respond immediately to drastic change, thus making it responsive for time-critical situations. Energy consumption can be controlled by the Count-Time and Thresholds.

Advantages:-

- Suitability for time critical sensing applications.
- Offers a lot of flexibility.

Disadvantages:-

- If the thresholds are not received, the nodes will never communicate, and the user will not get any data from the network at all.
- Energy consumption in this scheme is less.
- The additional complexity required to implement the threshold functions and the count time.

(C) Location-based Routing Protocols:

In this kind of routing, sensor nodes are addressed by means of their locations. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths. Relative coordinates of neighboring nodes can be obtained by exchanging such information between neighbors. Alternatively, the location of nodes may be available directly by communicating with a satellite, using GPS (Global Positioning System), if nodes are equipped with a small low power GPS receiver. To save energy, some

location based schemes demand that nodes should go to sleep if there is no activity. More energy savings can be obtained by having as many sleeping nodes in the network as possible.

Geographic and Energy Aware Routing (GEAR):

The key idea is to restrict the number of interests in directed diffusion by only considering a certain region rather than sending the interests to the whole network. Each node in GEAR keeps an estimated cost and a learning cost of reaching the destination through its neighbors. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a refinement of the estimated cost that accounts for routing around holes in the network. A hole occurs when a node does not have any closer neighbor to the target region than itself. If there are no holes, the estimated cost is equal to the learned cost. The learned cost is propagated one hop back every time a packet reaches the destination so that route setup for next packet will be adjusted.

There are two phases in the algorithm:

(1) Forwarding packets towards the target region: Upon receiving a packet, a node checks its neighbors to see if there is one neighbor, which is closer to the target region than itself. If there is more than one, the nearest neighbor to the target region is selected as the next hop.

(2) Forwarding the packets within the region: If the packet has reached the region, it can be diffused in that region by either recursive geographic forwarding or restricted flooding. In that case, the region is divided into four sub regions and four copies of the packet are created. This splitting and forwarding process continues until the regions with only one node are left.

Advantages: -

- This protocol conserves more energy and delivers more packets.
- Increases the lifetime of the nodes.
- The transmission power is considerably reduced because the clusters are not too far away from each other.
- The clusters can cross check the information and aid in the distributed processing.

Disadvantages:-

- GEAR faces a problem of limited scalability.
- Difficulty in utilizing the route cache.

Small Minimum Energy Communication Network (SMECN):

MECN identifies a relay region for every node. The relay region consists of nodes in a surrounding area where transmitting through those nodes is more energy efficient than direct transmission. The main idea of MECN is to find a sub-network, which will have less number of nodes and require less power for transmission between any two particular nodes. In this way, global minimum power paths are found without considering all the nodes in the network. The small minimum energy communication network (SMECN) is an extension to MECN. In MECN, it is assumed that every node can transmit to every other node, which is not possible every time. In SMECN possible obstacles between any pair of nodes are considered. The energy required to transmit data from node u to all its neighbors in sub graph G is less than the energy required to transmit to all its neighbors in graph G' .

Advantages: -

- Simulation results show that SMECN uses less energy than MECN and maintenance cost of the links is less.

Disadvantages: -

- Finding a sub-network with smaller number of edges introduces more overhead in the algorithm.

(D) Query based Routing:

In this kind of routing, the destination nodes propagate a query for data (sensing task) from a node through the network and a node having this data sends the data which matches the query back to the node, which initiates the query. Usually these queries are described in natural language, or in high-level query languages [1]. Directed diffusion is an example of this type of routing. To lower energy consumption, data aggregation (e.g., duplicate suppression) is performed en-route.

Advantages: -

- Better energy efficiency and robust to failed path.
- It can reduce the bandwidth needed for sensor networks.

Disadvantages:-

- Matching data to queries might require some extra overhead at the sensor nodes.
- There is limit memory storage for data caching inside the sensor node.

3.1.2 Routing Protocols based on Protocol Operation:

In this section, we review routing protocols that different routing functionality. It should be noted that

some of these protocols may fall below one or more of the above routing categories.

(E) Negotiation based Routing Protocols:

These protocols use high level data descriptors in order to eliminate redundant data transmissions through negotiation. Communication decisions are also taken based on the resources that are available to them. The SPIN family protocols are examples of negotiation based routing protocols. The motivation is that the use of flooding to disseminate data will produce implosion and overlap between the sent data; hence nodes will receive duplicate copies of the same data. This operation consumes more energy and more processing by sending the same data by different sensors. Hence, the main idea of negotiation based routing in WSNs is to suppress duplicate information and prevent redundant data from being sent to the next sensor or the base-station by conducting a series of negotiation messages before the real data transmission begins.

Advantages:-

- SPIN protocol is that each node only knows its single-hop neighbors therefore topological changes in network localized.

Disadvantages: -

- SPIN protocol does not guarantee delivery of data.
- Large overhead (Data broadcasting).

(F) QoS-based Routing Protocols:

In QoS-based routing protocols, the network has to balance between energy consumption and data quality. In particular, the network has to satisfy certain QoS metrics, e.g., delay, energy, bandwidth, etc. when delivering data to the BS.

Sequential Assignment Routing (SAR)

Sequential assignment routing (SAR) is the first protocol for sensor networks that includes the notion of QoS in its routing decisions. Routing decision in SAR is dependent on three factors: energy resources, QoS on each path, and the priority level of each packet. To avoid single route failure, a multi-path approach is used and localized path restoration schemes are used. To create multiple paths from a source node, a tree rooted at the source node to the destination nodes (i.e., the set of base-stations (BSs)) is built. The paths of the tree are built while avoiding nodes with low energy or QoS guarantees. At the end of this process, each sensor node will be part of multi-path tree. For each packet in network, SAR calculates

weighted QoS metric, which is the product of the additive QoS metric and a weight coefficient associated with the priority level of that packet. Lower the average weighted QoS metric, higher the levels of QoS achieved. The objective of SAR algorithm is to minimize the average weighted QoS metric throughout the lifetime of the network and make the network energy-efficient and fault tolerant. If topology changes due to node failures, a path re-computation is needed.[14]

Advantages: -

- Less power consumption.
- Fault-tolerance and easy recovery.
- Minimize the average weighted QoS metric throughout the lifetime of the network.
- SAR maintains multiple paths from nodes to BS.

Disadvantages: -

- The main disadvantage of this protocol is the overhead involved in maintaining tables and states at each node.

SPEED (Stateless Protocol for Real-Time Communication in Sensor Networks)

Another QoS routing protocol for WSNs that provides soft real-time end-to-end guarantees was introduced. The protocol requires each node to maintain information about its neighbors and uses geographic forwarding to find the paths.[11] SPEED strive to ensure a certain speed for each packet in the network so that each application can estimate the end-to-end delay for the packets by dividing the distance to the BS by the speed of the packet before making the admission decision. The routing module in SPEED is called Stateless Geographic Non-Deterministic forwarding and works with four other modules at the network layer. Delay estimation at each node is basically made by calculating the elapsed time when an ACK is received from a neighbor as a response to a transmitted data packet. By looking at the delay values, SNGF selects the node, which meets the speed requirement. If it fails, the relay ratio of the node is checked, which is calculated by looking at the miss ratios of the neighbors of a node (the nodes which could not provide the desired speed) and is fed to the SNGF module.

Advantages: -

- Less power consumption.
- SPEED can provide congestion avoidance when the network is congested.

Disadvantages: -

- It does not consider the metric of energy in routing decisions.

(G) Multipath Routing Protocols:

In this subsection, we study the routing protocols that use multiple paths rather than a single path in order to enhance the network performance. The fault tolerance (resilience) of a protocol is measured by the likelihood that an alternate path exists between a source and a destination when the primary path fails. This can be increased by maintaining multiple paths between the source and the destination at the expense of an increased energy consumption and traffic generation. These alternate paths are kept alive by sending periodic messages. Hence, network reliability can be increased at the expense of increased overhead of maintaining the alternate paths. Multipath routing was used to enhance the reliability of WSNs. It is known that network reliability can be increased by providing several paths from source to destination and by sending the same packet on each path. The idea is to split the original data packet into subpackets and then send each subpacket through one of the available multipath. It has been found that even if some of these subpackets were lost, the original message can still be reconstructed. .

Advantages:-

- Multipath routing was used to enhance the reliability of WSNs.
- Decrease the cost of network.

Disadvantages: -

- Traffic will increase significantly.

(H) Energy-aware Routing Protocol:

This protocol finds least-cost, delay-constrained path for real time data based on node's energy reserve, transmission energy, error rate and other communication parameters. Moreover, the throughput of non real-time traffic is maximized. This protocol ensures guaranteed bandwidth through the duration of connection while providing the use of most energy efficient path. The protocol consists of two steps. The first step consists of calculating candidate paths in ascending order of least costs using an extended version of Dijkstra's algorithm without considering end-to-end delay [1,5]. In second step, it is checked which path fulfills the end-to-end QoS constraints and the one that provides maximum throughput is selected. Simulation results have shown that the proposed protocol consistently performs well with respect to QoS and energy metrics.

Advantages: -

- Least cost and delay constrained and energy efficient path.

Disadvantages: -

- Maximize Traffic.

4. Comparison of routing protocols in Wireless Sensor Networks

Hierarchical and geographic routing protocols are considered scalable solutions. Keeping a hierarchical structure demands the coordination of nodes by means of transmitted messages. In dense networks, the use of the cluster-based structure makes up for this cost. However, this benefit does not hold in small networks. When the network is composed of a significant number of nodes in an extended area, the exchange of messages to establish the location of neighbors becomes negligible compared to the reduction of transmissions that the geographic algorithm achieves. In these two approaches, the topology of the network must be stable. On the contrary, the cluster structure and the geographic information must be frequently updated which leads to additional costs.

The performance of APTEEN lies between TEEN and LEACH with respect to energy consumption and longevity of the network. TEEN only transmits time-critical data, while APTEEN performs periodic data transmissions. In this respect APTEEN is also better than LEACH because APTEEN transmits data based on a threshold value whereas LEACH transmits data continuously. Again PEGASIS avoids the formation of clustering overhead of LEACH, but it requires dynamic topology adjustment since sensor energy is not tracked. PEGASIS introduces excessive delay for distant nodes on the chain. The single leader can become a bottleneck in PEGASIS. PEGASIS increases network lifetime two-fold compared to the LEACH protocol. In directed diffusion the base station sends queries to sensor nodes by the flooding technique but in SPIN the sensor nodes advertise the availability of data so that interested nodes can query that data. In Directed diffusion each node can communicate with its neighbors, so it does not need the total network information, but SPIN maintains a global network topology. SPIN halves the redundant data in comparison to flooding. Since SPIN cannot guarantee data delivery, it is not suitable for applications that need reliable data delivery. SPIN,

directed diffusion and rumor routing use meta-data whereas the other protocols don't use it. Since they are flat routing protocols routes are formed in regions that have data for transmission, but for the others, as they are hierarchical routing methods they form clusters throughout the network. GEAR limits the number of interests in Directed Diffusion by considering only a certain region rather than sending the interests to the whole network. GEAR thus

complements Directed Diffusion and conserves more energy. Therefore, they are not appropriate for networks critically constrained by their reduced batteries. However, they become necessary when reliability is a strong requirement in the application business.

Routing Protocols	Routing Structure	Scalability	Mobility	Network Lifetime	QoS	Energy Aware	Data Aggregation	Multipath
SPIN	Flat	Limited	No	Good	No	No	Yes	Yes
DD	Flat	Limited	No	Good	No	No	Yes	Yes
LEACH	Hierarchical	Good	Yes	Very good	Yes	Yes	Yes	No
PEGASIS	Hierarchical	Good	Yes	Very good	Yes	Yes	Yes	No
TEEN & APTEEN	Hierarchical	Good	Yes	Very good	Yes	Yes	Yes	No
GEAR	Location	Limited	No	Very good	Yes	Yes	No	No
SAR	QoS	Limited	Yes	Good	Yes	No	Yes	Yes
SPEED	QoS	Limited	Yes	Good	Yes	No	No	No

Table 1. Comparison of QoS aware routing protocols in WSN

5. Conclusions

In this paper we have studied the QoS requirement in WSNs and highlighted some of the challenges posed by the unique characteristics of wireless sensor network. We have reviewed some of the QoS aware routing protocols for WSNs. A comparative study of some of the QoS aware routing protocols, taking few important parameters in context of WSNs is done. Finally, we are convinced that the QoS support in WSNs should also include QoS control besides QoS assurance mechanisms. Since the sensor networks are application specific, we can't say any particular protocol is better than other. We can compare these protocols with respect to some parameters only. Future perspectives of this work are focused towards modifying one of the above routing protocol such that the modified protocol could minimize more energy for the entire system.

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