International Journal of Energy, Information and Communications
Vol.6, Issue 5 (2015), pp.1-14
http://dx.doi.org/10.14257/ijeic.2015.6.5.01

A Systematic Review on Energy Aware QoS Routing in Wireless Sensor Networks

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Abstract

Wireless Sensor Networks consist of many small devices that can sense the environment and communicate the data as required. WSNs provides a large number of applications like gathering meteorological variables (such as temperature, pressure), disaster management situations such as earthquakes, military situations (real time target tracking in battle environment), surveillance applications etc. The most critical requirement for widespread sensor networks is power efficiency since battery replacement is not viable. Many protocols have been proposed to minimize the power consumption by using complex algorithms. On the other hand, sensor nodes need to send this sensed real time traffic generated in such applications to the base station or gateway, so that controller can take the appropriate actions. So, here we need to deal with real time traffic with minimum delay constraint and with certain bandwidth. Hence energy aware QoS Routing is required to deliver the data with certain bandwidth and delay constrained to the base station in an energy efficient manner.

In this paper, an introduction of WSNs is presented with a deep insight into the various routing protocols for sensor networks. The various energy aware QoS energy aware routing techniques have been presented along with a comparison of these protocols. Tradeoffs among energy savings, delay, robustness and tradeoff between traffic overhead and reliability is also presented.

Keywords: *Wireless Sensor Networks, energy efficient routing, QoS routing, life time*

1. Introduction

A Wireless Sensor Network (WSN) consists of a large number of low-cost, low–power sensor nodes deployed in an area of interest. Sensors have computation, communication, sensing capabilities. Sensor generally communicates via a short range radio signals and collaborates to accomplish the common tasks as shown in Figure 1 and have limited bandwidth, power, memory, processing resources and limited lifetime [1].

There are larger number of applications of a WSN, such as medical diagnostics, industrial process control, traffic monitoring, security and surveillance, environment monitoring, mining, home intelligence, inventory management and military applications *etc*.

Figure 1. WSNs [2]

ISSN: 2093-9655 IJEIC

The objectives which are to be kept in mind while proposing any WSN solution are small size, power efficiency, scalability, secure network design, adaptability, self-configurability, reliability, fault-tolerance, bandwidth utilization, low cost and QoS support.

1.1. Network Architectures

There can be two types of architectures for WSNs which are classified [7] as shown in *Figure 2*. The sink acts as a gateway to outside world. The base controller/station sends the query to the sensor nodes regarding a physical phenomenon. The deployed sensor nodes are responsible for sensing the occurrence of an event and send the event information back to the sink node. The base station aggregates the data and sends the same to the user as a response to his/her query.

- **Single Hop Architecture**

In this architecture, the sensor node directly sends the data to the sink in single hop without forwarding it to any intermediate node. But energy consumption and transmission power grows exponentially with the increase in distance.

- **Multi-Hop Architecture**

In densely deployed networks, all the nodes are so close that the data can travel from one hop to other by covering a short distance. It is preferred over the single-hop architecture. It can further be classified as:

- **Flat Architecture:** In this, all nodes act as peers rather than acting as master slaves. Due to high node density, address centric routing is not possible. In this case, we have to maintain global identification information, so data centric routing is more suitable. Sink sends a query to all nodes and the node which has the required data, will only respond via multi-hop path using peers just as relays.

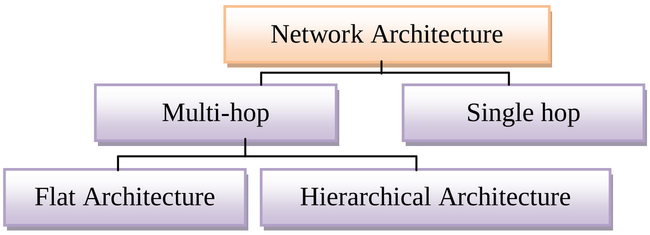

Figure 2. Classification of Network Architecture

- **Hierarchical Architecture:** A network field is divided into number of clusters and in each cluster one cluster head is elected to which all the nodes of that cluster send their data. Cluster head forwards that data to the sink as a response to the query. The node which have high energy act as a cluster head and nodes having low energy simply perform the task of sensing. But the problem with this architecture is this that how we can choose the cluster head and organize them.

1.2. Key Research Areas in Wireless Sensor Networks

- **Modulation Schemes [8]:** There is a need to develop low-power and simple modulation schemes for WSNs. There can be various modulation schemes like baseband, Ultra Wide-Band (UWB) or pass band.
- **Strategies to Overcome Signal Propagation Effects:** There are many problems with the signal transmission like signal fading, selective fading and absorptive fading *etc*. A lot of research has been done in this area but still it is not completely successful.
- **Hardware Design**: Power is a scarce resource in WSNs, so designing a small size, power efficient, low cost hardware units is necessary. Predicting the workload in

processors, reducing the switching power between various modes of operations and frequency of operations are some power management strategies.

- **Computation Methods to Compute the Residual Energy for Self-organization in WSN [9]:** Depending upon energy available, several methods have been proposed to determine the residual energy of the network for their self-organization.
- **Error Control Coding Schemes**: Sending the data error free from source to destination is one of the most important and critical issue in some applications like mobile target tracking, machine monitoring etc. The new ideas, implementation scenarios of various error control methods still need to be explored.
- **Power-saving Modes of Operation:** A sensor node enters into a sleep mode, when there is reduced or no activity running at all. This will save the energy and can prolong the network lifetime. The transition management for these nodes is open to research.
- **Sensor Query and Reporting Protocols:** Sensor Query Task Language (SQTL) has been widely used for data dissemination but due to long delays, its performance is not that good as required.

1.3. Routing in WSNs

The routing protocols are used to decide the best route to send data from the sensor node to host controller. The routing protocols can be classified on the basis of network structure and protocol operation point of view. Such classification is illustrated in *Figure 3*. From network structure point of view, protocols can be classified into three categories namely flat routing, hierarchical routing and location based routing. In *flat routing*, a network consists of homogenous nodes. Each node has same processing power, energy level and has same data transmission capability. In *hierarchical routing*, a network is divided into number of clusters and within each cluster, a cluster head is elected whose main task is to gather the data from other nodes in its cluster, aggregate the data and report that data to the base station. In *location based routing*, the exact position of the nodes is gathered via GPS and then routing decision is made.

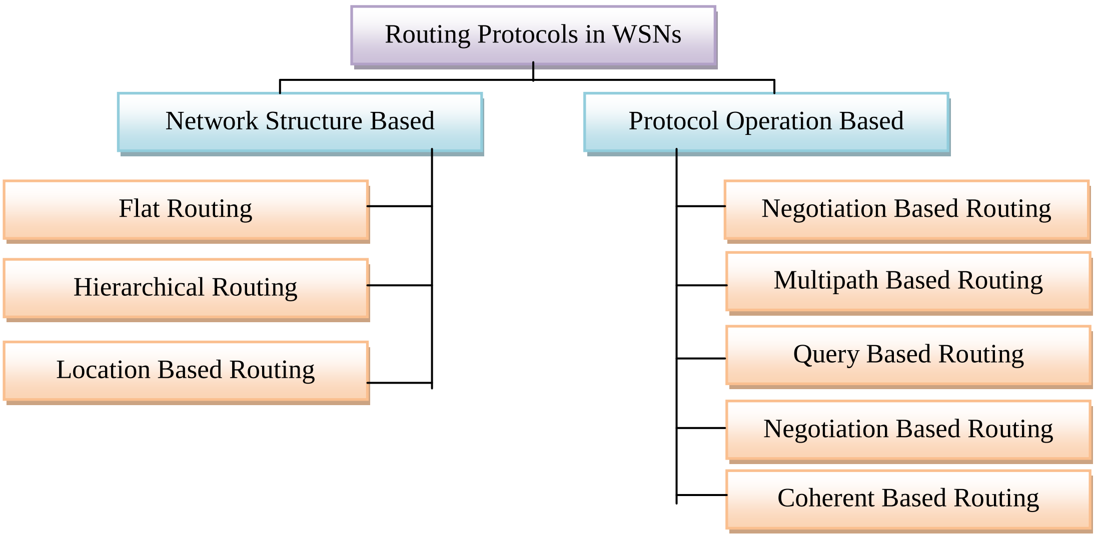

Figure 3. Classification of Routing Protocols

From protocol operation point of view, protocols are classified into five categories namely negotiation based routing, multipath based routing, query based routing, QoS based routing, coherent based routing [2]. In *negotiation based routing*, the data redundancy is reduced by providing high level description to the gathered data and by performing negotiations. In *multipath routing*, each node constructs multiple paths towards the destination, so that fault tolerance and reliability can be increased, which the major drawback of single path is routing. In *query based routing*, interest is propagated in the network by the base station. The node which has the required data sends back the data to the base station. In *QoS based routing*, the desired QoS level such as throughput, delay and jitter is maintained depending upon the applications. In *coherent based routing*, data is aggregated first to reduce the data redundancy and to enhance the energy efficiency. This is helpful because it is possible that same event is reported by multiple nodes in a network due to which a lot of energy will be wasted. In this paper, our main focus is on *energy aware QoS routing.*

1.4. Energy Aware QoS Routing in WSNs

WSNs provide a large number of applications like gathering meteorological variables (such as temperature, pressure), disaster management situations such as earthquakes, military situations (real time target tracking in battle environment), surveillance applications etc. So in such applications, we need energy aware QoS routing. For e.g., in battlefield environment, we need to locate, detect and identify the target. To identify the target, imaging sensors are needed which can send the sensed information to the base station or gateway, so that it can take the appropriate actions. So, here we need to deal with real time traffic with minimum delay constraint. Energy aware QoS Routing is required in such applications to deliver the data with certain bandwidth and delay constrained to the base station in an energy efficient manner.

Chen and Varshney [10] proposed some *non end-to-end parameters* for QoS routing. QoS refers to the set of quality services such as bandwidth, end-to-end delay, jitter and packet loss etc provided by the network to deliver the packet from source to the destination. It is the responsibility of the network, not only to provide quality of service but should also be concerned with the resource utilization. QoS requirements of WSNs are entirely different from the traditional data networks due to the dynamic nature of the WSNs. The main difference is that packet loss can be tolerated in WSNs to some extent depending upon the criticality of the application and redundancy of the sensor nodes. So end-to-end parameters are not appropriate in case of WSNs application. Some new non-end-to-end parameters are proposed by the author such as end to end latency, packet loss, end to end bandwidth and information throughput.

In traditional data networks, QoS is guaranteed using *over provisioning of resources* and *traffic engineering.* In the first approach i.e. over-provisioning of resources, the performance of the network can't be predicted especially at peak load as the service rate for all the users is same. In traffic engineering, services are provided depending upon the type of the traffic i.e. real time traffic or non-real time traffic. According to the requirements of the applications, various classes of traffic are defined. It can be implemented using two approaches namely *reservation based approach* and *reservation less approach*.

In reservation based approach, resources are reserved depending upon the requirements of the application domain. Example: Asynchronous Transfer Mode provides the desired QoS to its users based on this approach. In WSNs, QoS parameters vary according to the application needs. Example, if coverage is an important factor in some WSN application, then number of sensors covering an event may define a QoS parameter.

There are two perspectives of QoS in dynamic WSNs namely *application based QoS* and *network specific QoS*. In *application based QoS*, each application may have its own QoS requirements like reliability, error rate, coverage, jitter and bandwidth etc. In *network specific QoS*, QoS parameters are balanced along with efficient resource utilization. How the data to the sink is effectively transmitted depends on the data delivery model *i.e.*, event driven, query based, continuous delivery model which can be described in terms of application requirements and characterized by some factors such as end-to-end, interactivity, characteristics and criticality of the application as shown in Table 1.

Table 1. Delivery Models based on Application Requirements

Class	Continuous	Query Driven	Event driven
Criticality	Yes	Yes	Yes
Delay Tolerance	Yes	Query Specific	No
Interactivity	No	Yes	Yes
End-to-end	No	No	No

There are various challenges for QoS support in WSNs such as data redundancy (lot of energy is wasted due to redundancy of data), energy balance (some nodes drain out very soon as compared to the other nodes), network dynamics, scalability, resource constraints (memory, buffer, bandwidth, energy), unbalanced traffic, multiple sinks and packet criticality depending upon the application. Several algorithms have been proposed for QoS routing such as Sequential Assignment Routing (SAR), SPEED *etc*.

Akkaya and Younis [11] proposed an energy aware QoS routing protocol, in which a *class based queuing model* is used to classify the traffic. There are two types of queues for *real time traffic* and *non-real time traffic*. In real time traffic end-to-end delay is an important factor and in non-real time traffic throughput is more important. As bandwidth and other resource requirements for both type of traffic are different, so this classification is done. The parameter bandwidth ratio, is set by controller determines the bandwidth reserved for two types of traffic as shown in Figure 4.

The goal of this approach is to find the least-cost, delay constrained path. Several performance metrics are considered such as time to first node to die, average delay per packet, network throughput and average lifetime of a node.

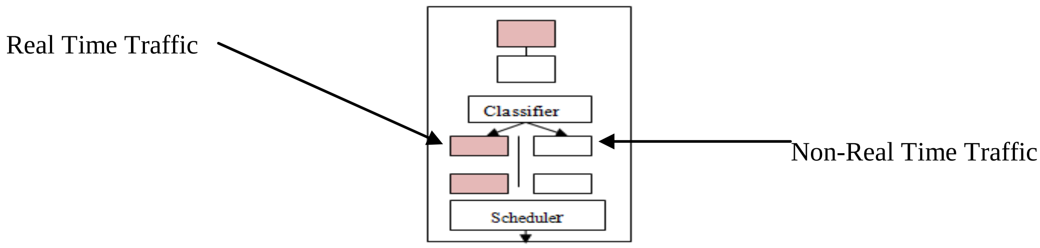

Figure 4. Queuing Model on a Particular Node

Topology control means to calculate and adjust the communication range of the sensor nodes to prolong the node lifetime by saving the energy and bandwidth while maintaining the connectivity. The energy needed for a packet transmission can be decreased by varying the transmission range of a node. But this will lengthens the process of route delivery and can hamper the end-to-end reliability.

Li and Sinha [12] developed a topology control framework for networks to evaluate the performance and scenarios in which these approaches can be beneficial. The various factors which are considered are energy efficiency, throughput etc. Author proposed that in heavily loaded traffic patterns, the performance metric throughput can be improved by k^2 by using topology control, where k is reduction factor in transmission range. The performance of throughput can be increased up to k^4 in unicast traffic scenario. All packets are assumed to be of equal length and transmission range.

It is assumed that all the nodes in the network have uniform transmission range, but if topology control mechanism is considered, then each and every node can calculate its own transmission range (due to which the standard IEEE 802.11 does not work well in this scenario). In this scenario, only User Datagram Protocol (UDP) traffic is considered, but we can consider the various types of Transmission Control Protocol (TCP) traffic patterns and can analyze their behavior affected by variable transmission ranges.

For the sake of throughput analysis and underlying MAC layer traffic load, networks are classified into two categories namely *saturated* and *unsaturated networks*. In *saturated networks*, extra traffic cannot be handled by the MAC layer beyond the current load. So end-to-end throughput is based on the capacity of the network, but in case of *unsaturated networks*, channel capacity is not fully utilized. In later case, channel error rate and retransmission frequency hampers the throughput.

Branislav *et al.* [13] proposed a *predictive QoS routing* in which a mobility graph is introduced which predicts the mobility patterns in a network. This mobility graph can be used to predict the intermediate nodes for the mobile sink nodes and can pre-compute the possible paths and routing states in a network. The network is assumed to be semi static. Mobile nodes will act as sink nodes and are not used for forwarding the information. A path is computed to a relay node that is in the range of destination sink node. Packet loss, high latency must be avoided in such a scenario, so there must be some reliability mechanism. New paths can be computed before the old paths become useless due to energy drain. The proposed algorithms have two components: *prediction of mobility* and *routing to mobile sinks*. For predicting the mobility patterns, several methods have been suggested like Markov style predictor, clustering and path matching etc. to find the future relay node based on the past information.

Ma and Yang [14] proposed a *battery aware routing* approach, which presents the discharging behavior of a sensor node is modeled and an effort has been made to maximize the network lifetime especially in case of large volume streaming traffic as shown in Figure 5.

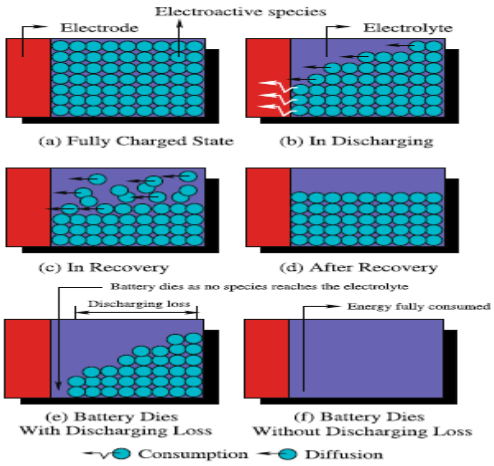

Figure 5. Battery Operation at Different States [14]

Battery Aware Routing (BAR) protocol schedules the node by considering the residual battery status of node. An online computable battery model has been proposed. Energy dissipated is not equivalent to the energy consumed in a node and battery consumes more power than required during discharging phase. A battery discharge behavior model is assumed in which electrochemical reaction, analysis of discharging loss (due to difference between reaction and diffusion rates) has been considered. The main idea behind this BAR protocol is that," *well recovered*" nodes are used for routing between source and destination pairs. Fatigue nodes are left for recovery. The online computable model reduces the complex computations. This algorithm can be used for other energy schemes.

Jeong, Sharafkandi and Du [15] proposed an energy efficient routing mechanism where sensors are deployed for mobile target tracking and road surveillance as shown in Figure 6. There is an important relationship between the average detection time of a target and energy consumed. Quality of surveillance is defined as reciprocal of the average detection time. This algorithm ensures the required Quality of Surveillance. It minimizes the energy consumption to enhance the network lifetime and make sure that no target will go undetected. QoSv metric can be derived from two parameters: number of sensor nodes deployed and working time for each sensor. Nodes must be kept in sleeping mode most of the time and sleeping time should be adapted in such a way that turn-on time does not incur any extra overhead.

This algorithms work in two phases: In first phase *i.e.*, *surveillance phase*, the sensor nodes are selected to satisfy the required QoSv level. In second phase *i.e.*, tracking phase, sensors wake up and track the target. Every node knows its location and is synchronized with its neighbors. This work can be extended to two dimensional planes.

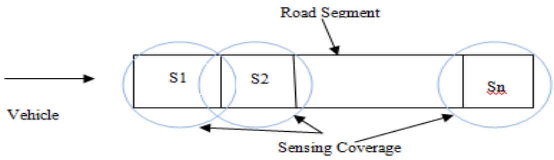

Figure 6. Sensor Network Model for Road Segment

In hierarchical routing, the whole network area is partitioned into clusters and from each cluster; one cluster head is elected to which all other nodes send the data. The task of cluster head is to aggregate the data received from other nodes and transmit that data to the base station. The huge amount of energy will be consumed, if data is being sent directly from the cluster head to the base station.

Anisi and Abdullah [16] proposed a reliable, energy efficient multi hop routing protocol to transmit the data between cluster heads and the base station rather than having the direct transmission to the base station. Various link quality parameters considered are buffer size, number of hops to BS and residual energy as defined below (1-3).

$$C_1 = \left(1 - \frac{E_{res}(x)}{E_{init}(x)}\right)^2 \left(1 - \frac{B_{ava}(x)}{E_{total}(x)}\right)^2 \quad (1)$$

$$C_2 = \frac{(dx+dy)+1}{dx} \quad (2)$$

$$C = \alpha\,(C_1 + \ C_2) \quad (3)$$

where C_1 is cost in terms of residual energy and buffer size. $E_{res}(x)$ is the residual energy, $E_{initial}(x)$ is the initial energy of node x. $B_{ava}(x)$ is the available buffer, and Btotal (x) is the total buffer size.C_2 is the distance cost of selecting the next node. C is the total cost of sending the packet from node x to y, α is the adjustment factor to minimize the link cost.

In the proposed approach, a combination of flat, hierarchical and QoS routing is used. Like hierarchical routing, network is divided into number of clusters in which data is aggregated within the clusters themselves. Flat routing is used to route the data between the cluster heads and base station to reduce the amount of energy. Several approaches have been proposed in this context like hierarchical Geographic Multicast Routing, S-Energy Efficient Routing Protocol (S-EERP), Reliable Energy Efficient Routing Protocol (R-EERP) based on Low Energy Adaptive Clustering Hierarchy (LEACH), M-SPIN based on SPIN, Data Query Protocol with Restriction Flooding (DQPRF) *etc*.

2. Tradeoffs among Various Qos Parameters

This section presents the tradeoffs among various Qos parameters: tradeoff between energy savings and delay, tradeoff between energy savings and robustness, trade-off between traffic overhead and reliability.

2.1. Tradeoff between Energy Savings and Delay

In WSNs, the delay in the transmission of sensed data depends on the transmission time because there is no queuing delay. As compared to the transmission time, the propagation and processing delays are negligible. If N sensors nodes are deployed, then transmitting sensed data directly to the base station requires a total delay of N units, if the sensors transmit one unit at a time to the sink. This delay can be lowered to log N units if the sensors are allowed to transmit their sensed data simultaneously to the sink using a binary scheme. However, the energy being consumed in data transmission is proportional to the square of the transmission distance between the sending and receiving sensors. For this reason, direct transmission will incur significant energy consumption. On the other hand, minimizing energy introduces longer delay if sensed data have to be sent over short distances. Hence, there is a tradeoff between energy consumption and transmission delay.

To account for the delay cost per round of data gathering, Lindsey *et al*. [18,19] proposed a metric which is product of energy and delay and two data gathering schemes to trade - off between energy and delay. By minimizing energy × delay, it is possible to achieve acceptable delay for those time-critical applications while reducing energy consumption in sensors, thus extending the network lifetime. Simultaneous wireless communications among pairs of sensors is possible if the sensors are CDMA capable, but low interference between those transmissions will occur. In this case, a binary chain based scheme, which is an updated version of the PEGASIS protocol, can be used. However, the energy × delay cost depends on the sensor distribution in the sensor field. PEGASIS constructs a chain of sensors in which each sensor receives sensed data from its neighbor in the chain, fuses them with its own data, and forwards them to its neighbor. Assume that the neighboring sensors are equidistant from each other and this distance is equal to d. Then, there are N/2 sensors transmitting their sensed data at distance d. According to PEGASIS, the receiving sensors will fuse their own sensed data with the data they have received and become active in the next level of the tree as shown in Figure 7. Therefore, only N /4 sensors will be transmitting their sensed data, but at distance 2 d. The same process is repeated until repeats until the last sensor receives the fused data, which performs the task of data fusion with its own data and transmits the fused data to the sink. Therefore, the total energy cost for this binary chain - based scheme is proportional to

$$\frac{N}{2} \times (\mathrm{d})^2 + \frac{N}{4} \times (2\mathrm{d})^2 + \frac{N}{8} \times (4\mathrm{d})^2 + \ldots\ldots\ldots\ldots + 1 \times \left(\frac{N}{2} \times \mathrm{d}\right)^2 \quad (4)$$

which is approximated by $N^2/2 \times d^2$ provided that we consider energy consumption in data transmission to the sink.

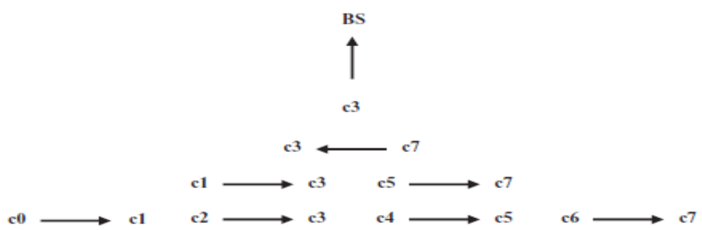

Figure 7. Data gathering in a Chain based Binary Scheme

If the sensors are not CDMA capable, the use of the binary chain based scheme would introduce a considerable amount of interference. In order to solve this problem, Lindsey *et al*. [18, 19] proposed *a three-level chain-based scheme*, in which simultaneous transmissions among pairs of spatially separated sensors are possible. As its name indicates, this scheme constructs a three level hierarchy where each level contains a few groups and each group promotes one sensor to the next level. Figure 8 illustrates an example of this scheme. In this example, a set of N sensors is split into G groups, each of which has N / G successive sensors. The value of G is computed based on the number of sensors in the network and the size of the sensor field. Each group will promote one sensor to be active in the next level. Thus, the selected G sensors from the first level will be split into two groups in the second level and a sensor is promoted from each group to have two sensors in the third level. One of these two sensors will be promoted to the last level from which it will transmit the fused data to the sink.

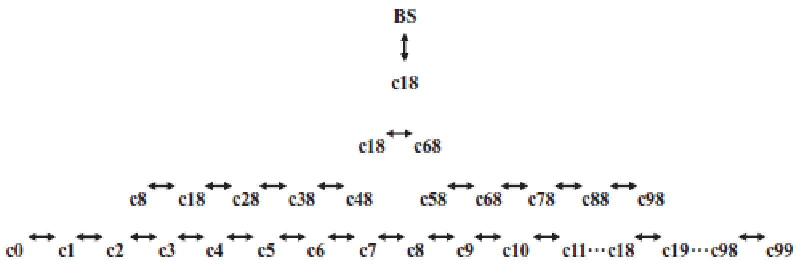

Figure 8. Chain-based three Level Scheme for non-CDMA Sensors

Figure 8 shows a chain of 100 non CDMA sensors in the first level of the three - level hierarchy. It was found that for a 100 m × 100 m sensor field and a network with 100 sensors the best balance between energy and delay is obtained for a value of G = 10. This means that only 10 simultaneous transmissions can take place and data fusion occurs at each sensor except the end ones in each level. Note that the leader that will transmit to the sink changes from one round to another in order to balance the load among the sensors.

2.2. Tradeoff between Energy Consumption and Robustness

One of the main requirements of a network for some applications is the network should remain functional in spite of the occurrence of sensor failures. For this purpose, it is necessary for routing protocols to be fault tolerant (or robust) and at the same time guarantee energy efficiency. To provide robustness, conventional approaches attempt to control the transmission power while maintaining connectivity between sensors and use multipath routing, in which multiple disjoint or partially disjoint communication paths between source sensors and the sink are used. Different from these approaches, Krishnamachari *et al*. [20] proposed an approach that uses a single - path routing scheme with higher transmission power, but can achieve robustness against sensor failures.

Using this approach, for each routing scheme Z that routes information from a source node to a receiver, an energy metric equal to $Z_H L_H^{\alpha}$ α is assigned, where L_H is transmission radius required for this routing scheme, m_H is the number of transmissions required for the information to reach the receiver, and α stands for the path loss exponent. The approach assumes that any intermediate sensor can fail independently of other sensors with probability p while the source and the destination are perfectly reliable. The robustness metric Π_H associated with the routing scheme H is equal to the probability that a message initiated by a source sensor reaches the sink. Figure 9 shows different routing schemes for routing information from the source sensor S to the destination sensor D.

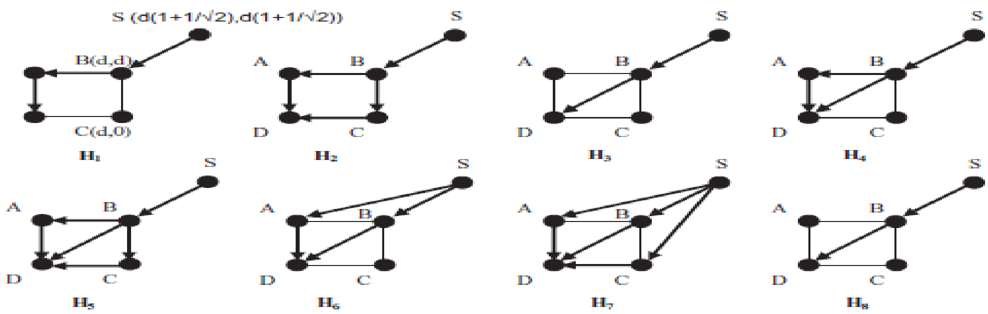

Figure 9. Alternate Routing Configurations

Given the above assumption that the source and destination sensors are perfectly reliable, the routing scheme H_8 is the most robust one. However, direct transmission between the source and destination is highly costly in terms of energy consumption. Thus, there must be a trade-off between robustness, which has to be maximized, and energy consumption, which has to be minimized.

Let H_i and H_j be two routing schemes. H_i dominates H_j if ($\Pi_{Hi} \geq \Pi_{Hj}$ and $E_{Hi} < E_{Hj}$) or ($E_{Hi} \leq E_{Hj} \leq$ and $\Pi_{Hi} > \Pi_{Hi}$). The routing schemes that are not dominated by any other routing scheme form the Pareto set and are called Pareto optimal. It is clear that {H_1, H_3, H_8} is the Pareto set. Pareto optimal routing schemes provide single path routes. Moreover, although the routing scheme H_8 uses direct transmission, it consumes less energy than multipath routing schemes H_6 and H_7. This result means that when robustness and energy efficiency are the main concerns, single path routing outperforms multipath routing under the assumption of perfectly reliable source and destination sensors.

2.3.Tradeoff between Traffic Overhead and Reliability

While single path routing routes a sensed data packet from a source sensor to the sink through a sequence of intermediate sensors acting as forwarders, multipath routing routes the same data packet via multiple paths between source and destination sensors. The former scheme is sensitive to the failure of intermediate sensors whereas the later increases the reliability of data transmission, but yields much overhead. Dulman *et al.* [21] suggested that a variant of multipath routing be used, where a data packet is split into k sub packets of equal size with added redundancy and sent over k available disjoint paths. In order to construct the original data packet at the destination sensor, only a smaller number of sub packets are needed. The amount of redundancy that should be added for the split message transmission is determined based on the number of successful paths. Let S_k be a random variable representing the number of successfully delivering paths. S_k is upper bounded by k, that is, $S_k \leq k$. In fact, all the generated paths are disjoint and the experiment corresponding to transmit a data packet from a source sensor to a destination sensor can be viewed as a repeated Bernoulli experiment. For the i^{th} path, if the transmission succeeds, this subrun is assigned 1; otherwise, it is assigned 0. The value of S_k is the sum of the values assigned to the k subruns as there are k disjoint paths. Thus, the expected number of successful delivering paths can be calculated as (5)

$$E\ (S_k) = \sum_{i=1}^{k} P_i \tag{5}$$

where p_i is the probability of successfully delivering a message to a destination using the i th path. In order to compute a good estimation for the value of E_k for a given bound representing the overall probability of successfully reconstructing the transmitted message at the destination such that $P\ (\ S_k \geq E_k\ ) \geq \alpha$. Dulman *et al*. [21] approximated the repeated Bernoulli experiment by a standard distribution $N\ (\ \mu\ ,\ \sigma\ )$, where the mean is given by (6)

$$\mu = E(S_k) = \sum_{i=1}^{k} P_i \quad (6)$$

and the standard deviation is calculated as (7):

$$\sigma^2 = \sum_{i=1}^{k} P_i \ (1 - P_i) \quad (7)$$

Given that the total number of sub packets depends on the degree k of multipath routing, a given pair (k , { p_1 , … , p_k }) produces a different normal distribution, N (μ (k), σ (k)). To solve this problem, the random variable S_k is transformed into $S_k^* = (S_k - \mu)/\sigma$, which is N (0, 1) distributed. However, the values of the bound x_α are known for any given α such that $P(Sk^* \geq x\alpha) \geq \alpha$ is satisfied. As a result, $S_k^* = (S_k - \mu)/\sigma \geq x_\epsilon$ implies that $S_k \geq x\,\alpha \times \sigma + \mu$ and hence we have the following probability

$$P(S_K \geq x_\alpha \times \sigma + \mu) \geq \alpha \quad (8)$$

By equating this probability with $P(S_k \geq E_k) \geq \alpha$, we obtain an approximation of E_k for a given bound α ; that is,

$$E_k = \max(\lfloor x_\alpha \times \sigma + \boldsymbol{\mu} \rfloor , 1) \quad (9)$$

By using the previously computed values of μ and σ, the value of E_k is given by (10)

$$E_k = \max(\lfloor x_\alpha \times \sqrt{\sum_{i=1}^{k} P_i \ (1 - P_i)} + \sum_{i=1}^{k} P_i \rfloor \ 1) \quad (10)$$

which gives a good estimation of the number of successfully delivering paths for a given bound α .

3. Comparison of QoS Aware Routing Protocols

In this section, an overview of various QoS aware protocols is presented along with their comparison.

SPEED: Tian He *et al*. [22] presented a real-time communication protocol for sensor networks, called SPEED. It provides three types of real-time communication services, namely, *real-time area-anycast*, *real-time unicast* and *real-time area-multicast*. SPEED is a stateless, localized algorithm which incurs minimal control overhead. By using a novel combination of feedback control and non-deterministic geographic forwarding, a desired delivery speed across the sensor network is maintained.

MMSPEED: Emad Felemban *et al*. [23] proposed a novel packet delivery mechanism called Multi-Path and Multi-SPEED Routing Protocol (MMSPEED) for probabilistic QoS guarantee in WSNs. The QoS provisioning is performed in two quality domains, namely, *timeliness* and *reliability*. Multiple QoS levels are provided in the timeliness domain by guaranteeing multiple packet delivery speed options. In the reliability domain, various reliability requirements are supported by probabilistic multipath forwarding. These mechanisms for QoS provisioning are realized in a localized way without global network information by employing localized geographic packet forwarding augmented with dynamic compensation. It compensates for local decision inaccuracies as a packet travels towards its destination.

Energy Aware MMSPEED: The time sensitive nature of the traffic, along with the amount of energy left for each sensor should be considered while taking any routing decisions in WSNs. S. Sanati *et al*. [24] presented Multi-Path and Multi-Speed Routing Protocol (MMSPEED)which is an energy aware packet delivery mechanism for probabilistic Quality of Service (QoS) guarantee. Each node takes routing decisions based on geographic progress towards the destination sink, required end-to-end total reaching probability, delay at the candidate forwarding node and residual energy.

Multimedia Aware MMSPEED: S. Darabi *et al.* [25] presented a Multipath Multi-Speed (MMSPEED) protocol as a Wireless Multimedia Sensor Network (WMSN) routing protocol. MMSPEED protocol has significant potential in video applications but it does not compatible with special features of multimedia traffic such as high video frame rate, packet's information dependency and frames different reliability. Awareness of MMSPEED about of embedded information in the received packet can lead to better resource utilization in network and MAC layers.

Table 2 presents a comparison among various energy aware QoS routing protocols based on various parameters such scalability, service differentiation, QoS metric, location awareness and energy awareness.

Table 2. Comparison of Energy Aware QoS Routing

Energy QoS routing protocols					
Parameters	***SPEED***	***Energy aware QoS routing protocol***	***MMSPEED***	***Energy-aware MMSPEED***	***Multimedia aware MMSPEED***
QoS Metric	End-to-end delay	End-to-end delay	Delay and reliability	Delay and reliability	Delay and reliability
Energy aware	No	Limited	No	Yes	No
Location aware	Yes	No	Yes	Yes	Yes
Scalability	No	Limited	Yes	Yes	Yes
Service Differentiation	No	No	Yes	Yes	Yes

4. Research Issues in QoS Routing

- **Types of Services:** Which type of services a network must provide like whether it should provides best effort, guaranteed or differentiated services or must apply a hybrid approach is an open research issue.
- **QoS Control Mechanisms:** In some application, excessive amount of data is generated due to which a lot of energy gets exhausted. If lesser amount of data is generated then quality of service will not be met. So a balanced, distributed or centralized approach is required.
- **QoS aware data dissemination protocols:** These protocols must support data diffusion as well as QoS support under highly dynamic environment and high traffic while keeping the energy minimized.
- **Service Differentiation:** The services provided by the underlying network can be differentiation based on various parameters such as data delivery models, sensor types, content of packets, traffic types.
- **End-to-end energy-aware QoS support:** End-to-end energy aware QoS parameters are not applicable in WSNs, so in this case, local QoS parameters are required.

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