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A Comparison of Different Routing Protocols in WSNs

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Abstract: *WSNs differ from traditional wireless communication networks in several of their characteristics. Few of them are power awareness and security, due to the fact that the batteries of sensor nodes have a restricted lifetime and are difficult to be replaced and sensitive data communication. Therefore, all protocols must be designed in such a way as to minimize energy consumption and preserve the longevity of the network. That is why, routing protocols in WSNs aim mainly to accomplish power conservation while in traditional networks they focus primarily on the quality of service (qos).*

Keywords: *WSN's (wireless sensor networks)*

1. INTRODUCTION

A sensor network is composed of tens to thousands of sensor nodes which are distributed in a wide area. These nodes form a network by communicating with each other either directly or through other nodes. One or more nodes among them will serve as sink(s) that are capable of communicating with the user either directly or through the existing wired networks.

Each node typically consists of the five components: sensor unit, analog digital convertor (ADC), central processing unit (CPU), power unit, and communication unit. The sensor unit is responsible for collecting information as the ADC requests, and returning the analog data it sensed. ADC is a translator that tells the CPU what the sensor unit has sensed, and also informs the sensor unit what to do. Communication unit is tasked to receive command or query from, and transmit the data from CPU to the outside world. CPU is the most complex unit. It interprets the command or query to ADC, monitors and controls power if necessary, processes received data, computes the next hop to the sink, etc. With a sensor network, a user should be able to task some sensors to monitor specific events, and know when interested events happen in the interested field. Thus, the sensor network builds a bridge between the real world and computation world.

Many Routing protocols are existent in the wireless sensor network. Depending on how the sender of a message gains a route to the receiver, routing protocols can be classified into three categories, namely, proactive [1], [2], reactive [3], [4], and hybrid protocols [5], [6]. In proactive protocols, all routes are computed before they are really needed, while in reactive protocols, routes are computed on demand. Hybrid protocols use a combination of these two ideas. Since sensor nodes are resource poor, and the number of nodes in the network could be very large, sensor nodes cannot afford the storage space for "huge" routing tables. Therefore reactive and hybrid routing protocols are attractive in sensor networks. According to nodes' participating style, routing protocols can be classified into three categories, namely, direct communication [7], flat [2], [8]–[9], and clustering protocols [1], [3], [9] In direct communication protocols, a sensor node sends data directly to the sink. Under this protocol, if the diameter of the network is large, the power of sensor nodes will be drained very quickly. Furthermore, as the number of sensor nodes increases, collision becomes a significant factor which defeats the purpose of data transmission. Under flat protocols, all nodes in the network are treated equally. When a node needs to send data, it may find a route consisting of several hops to the sink. Normally, the probability of participating in the data transmission process is higher for the nodes around the sink than those nodes far away from the sink. So, the nodes around the sink could run out of their power soon. In the clustered routing architecture, nodes are grouped into clusters, and a dedicated cluster head node collects, processes, and forwards the data from all the sensor nodes within its cluster.

2. WIRELESS SENSOR NETWORK ROUTING PROTOCOLS

The routing protocols developed for WSNs can be classified in several categories [11]-[15]. Flat routing

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architecture, hierarchical routing architecture, and location based architecture are one of those.

Flat routing architecture: In flat routing, each node typically plays the same role and sensor nodes collaborate to perform the sensing task. Due to the large number of such nodes, it is not feasible to assign a global identifier to each node. This consideration has led to data-centric routing.

Hierarchical routing architecture: Hierarchical or cluster-based routing methods, originally proposed in wire line networks, are well-known techniques with 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.

Location based routing architecture: 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. Alternatively, the location of nodes may be available directly by communicating with a satellite using GPS 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 any sleeping nodes in the network as possible. In the rest of this section, we review most of the location or geographic-based routing protocols.

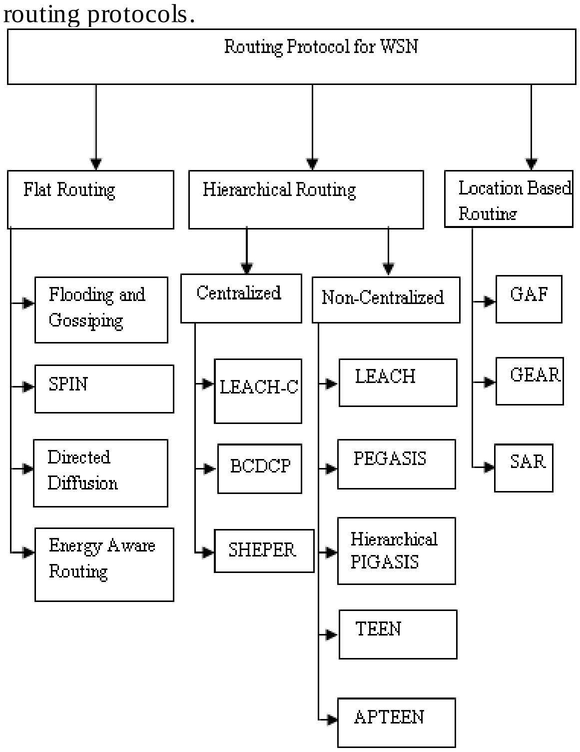

Figure 2.1: Classification of routing protocols in WSNs

2.1 Flat Routing Architecture

Flooding and Gossiping: Two of the original protocols designed for WSNs, Flooding and Gossiping [17] do not require any routing algorithms or topology maintenance. In Flooding, each sensor node will broadcast its information. Each receiving node will then pass the message on, until the message reaches the sink node or the TTL value is exceeded. Gossiping is an altered version of Flooding. The sending node will select a neighbor at random to send its data to. Some of the problems that are faced by these protocols are implosion as shown in Figure 2.2 and overlap as shown in Figure 2.3. Implosion is caused by duplicate message being sent to the same node, and overlap deals with two nodes sensing the same region and both reporting their values. By sending its data to one random neighbor Gossiping is immune to implosion.

In Gossiping, the gathered data is not broadcasted but sent to randomly chosen neighbor node until the specified maximum number of hops for packet is reached or the packet delivered to the destination. In this way it avoids the problem of implosion. But, the delivery of the data takes so much time. Both of these protocols suffer from resource blindness [17].

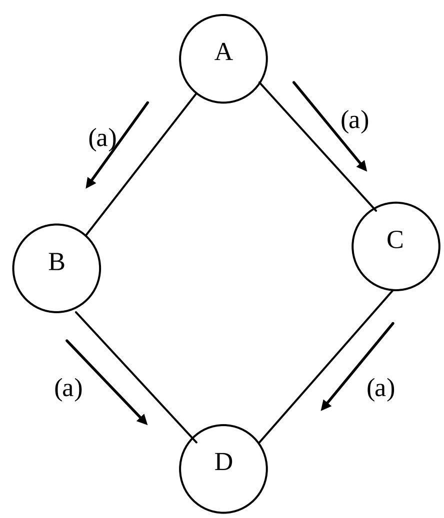

Figure 2.2: Implosion problem. Node A floods its data to node B and C. After that B and C sends this data to D and so D receives redundant data.

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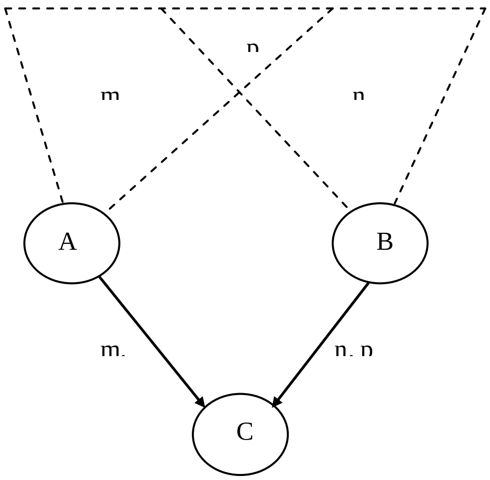

Figure 2.3: Overlap problem. Two sensors cover an overlapping geographic region and C gets same copy of data from these sensors.

Sensor Protocol for Information via Negotiation (SPIN): Sensor Protocol for Information via Negotiation is the network layer protocol based on data centric routing. This protocol is also termed as three phase routing protocol, in the sense that it makes the use of three messages ADV, REQ, and DATA. ADV is used to advertise the data, REQ for request the data and DATA is the actual data itself. In this protocol, the node that have data to send broadcasts an advertise message as ADV to its neighbors. If the neighbor is interested in the data, it sends an REQ message to the node from where ADV has received. Then, the data is send to those nodes only from where REQ has come. The advantage of this process is that implosion, overlap and resource blindness are not a factor, giving SPIN a significant energy saving.

Directed Diffusion: Directed Diffusion [18] is recognized as being an important milestone for routing in WSNs. Many other protocols are built on its foundation [19]. An interest for specific data is “diffused” through the network, where a naming scheme is used for the data.
For receiving data messages the Directed Diffusion protocol is divided in to three phases; interest propagation, initial gradients setup, and data delivery.

Interest propagation: the interest, defined using a list of attribute-values pairs, is broadcast by the sink node. Caching of the interest can be done by the receiving node for later use. Each node maintains an interest table, where all received messages are cached. The interest in then compared to the data received from other sensor nodes.

Initial gradient setup: Directed Diffusion makes use of gradient values (data value, duration and expiration time) that are located in the interest message to the establish paths between the sink node and the sources of the data. Several paths can be established, but one will be reinforced by the sink sending the interest (with the lower interval) again.

Data delivery: Data aggregation is performed by the nodes, thereby increasing energy efficiency. A sensor node will generate the traffic at the required rate; will transmit this data to the sink via the established path. The duration and the expiration values received from the interest will control the flow of the traffic from the sensor node.

Directed Diffusion differs from SPIN since it uses on demand data querying mechanism. Whereas, in SPIN the nodes itself advertises about its data when it have and then interested node sends and request message to node from advertisement has come, in order to retrieve the data. Also this is highly energy efficient because it use on demand data query mechanism.

Energy Aware Routing: Energy- Aware Routing [20] is designed to choose sub optimal paths using a probability function, which depends on the energy consumption of each path. By doing this, the hope is that the network lifetime will be extended to its fullest.

The three phases of the protocol are briefly defined; as they are appear in [20].

Setup phase: localized flooding occurs to find the routes and create the routing tables. While doing this, the total energy cost is calculated in each node.

Data communication phase: each node forwards the packet by randomly choosing a node from its forwarding table using the probabilities.

Route maintenance phase: Localized flooding is performed infrequently to keep all paths alive.

The problem with this protocol is two-fold. Firstly, the protocol assumes that the nodes are aware of their location and there is an addressing scheme being used to address the individual nodes. This complicates the initial set up phase for the network using these protocols. Secondly, only a path is used for sending information to the sink. By using this

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method the protocol would struggle to recuperate from a path failure.

2.2 Hierarchical Architecture

Although the data-centric routing approach provides a reliable and robust solution to wireless sensor networks, there are still some shortcomings associated with protocols utilizing this technique. In the worst case, both SPIN and directed diffusion suffer from the amount of overhead energy spent in activities such as advertising, requesting, and gradient setup. Furthermore, the excessive time spent in such activities might not suit some applications that require the sensor nodes to respond quickly to an emergency situation. A more optimal solution for such scenarios is a clustering-based protocol. Hierarchical Routing can be of two types.

Non – Centralized Hierarchical Routing

In non-centralized type of routing, the sensor nodes self configures for the cluster head.

Low Energy Adaptive Cluster Hierarchy (LEACH): Low Energy Adaptive Clustering Hierarchy is one of the first hierarchical routing protocols for sensor network. The conventional clustering technique used in wireless sensor networks does not improve network lifetime since this scheme assumes the cluster heads to be fixed, and thus requires them to be high-energy nodes. Low-Energy Adaptive Clustering Hierarchy (LEACH) presented in [10-11], provides a hierarchical protocol that makes the use of local coordination among the nodes to enable scalability and robustness for sensor networks. So, LEACH is an energy conserving communication protocol where all the nodes in the network are uniform and energy constrained. An end user can access the remotely monitored operation, where large numbers of nodes are involved. The nodes organize themselves into local clusters, with one node acting as the randomly selected local cluster head. If the allocated cluster heads are always fixed, then they would die quickly, ending the useful lifetime of all nodes belonging to those clusters. LEACH includes random alternation of the high-energy cluster head nodes to enable the sensors to uniformly sustain the power. Sensors nominate themselves to be local cluster heads at any given time with some probability. These cluster head nodes relay their status to the other sensors in the network. Each sensor node resolves which cluster to follow by choosing the cluster head that requires the minimum communication energy. This allows the transceiver of each unassigned node to be turned off at all times except during it's transmit time, thus minimizing the energy dissipated in each sensor. LEACH divides the operation of the entire network into many rounds. Further, each round has set-up phase or initializing phase and steady state (data transmission) phase. During the set-up phase some sensor nodes project themselves as potential cluster heads and announce their cluster head position to the rest of the nodes in the network, and then other nodes organize themselves into local clusters by choosing the most appropriate cluster head (normally the closest cluster head). During the steady-state phase the cluster heads receive sensed data from cluster members, and then transfer the aggregated data to the BS.

PEGASIS and Hierarchical PEGASIS: S. Lindsey et. al. have been proposed a protocol, called Power Efficient Gathering in Sensor Information Systems (PEGASIS)[11], which was enhanced over LEACH protocol. In PEGASIS [21], each sensor node forms a pattern so that each node will receive from and transmit to a close neighbor. Each node takes turn being the leader for transmission to the base station so that the average energy spent by each node per round is reduced. PEGASIS outdoes LEACH'S performance by (1) purging the over head of dynamic cluster formation, (2) decreasing the distance non leader-nodes must transmit, (3) reducing the number of transmissions among all nodes, and (4) using only one transmission to the base station per round. Principal goals in the operation PEGASIS are (a) augment the lifetime of each sensor node by using collaborative techniques (b) reducing the bandwidth of communication by allowing the local coordination among neighboring sensor nodes. The idea in nodes dying at random places is to make the sensor network robust to failures. In a given round, the author is using a simple control token passing approach initiated by the leader to start the data transmission from the ends of the chain. The cost is very small since the token size is very small. In Figure 3.7, node N_2 is the leader, and it will pass the token along the chain to node N_0. Node N_0 will pass its data towards node N_2. After node N_2 receives data from node N_1, it will pass the token to node N_4, and node N_4 will pass its data towards node N_2. PEGASIS performs data fusion at every node except the end nodes in the chain. Each node will fuses its neighbor's data with its own to generate a single packet of the same length and then transmit that to its other neighbor (if it has two neighbors). As shown in Figure 3, node N_0 will pass its data to node N_1. Node N_1 fuses node N_0*'s* data with its own and then transmits to the leader N_2. After node N_2 passes the token to node N_4, node N_4 transmits its data to node N_3. Node N_3 fuses node N_4*'s* data with its own and then transmits to the leader. Node N_2 waits to receive data from both neighbors and then fuses its data with its neighbors' data. Finally, node N_2 transmits one message to the SINK. However, one of the major drawbacks of PEGASIS is that it introduces excessive delay for distant node on the chain. Moreover, the single node acting as a leader of the chain can sometimes become a bottleneck. Hierarchical-PEGASIS [22] is an extension to PEGASIS, which decreases the delay during transmission from the designated node to the sink. In order to improve the performance by reducing the delay in PEGASIS, messages are transmitted simultaneously.

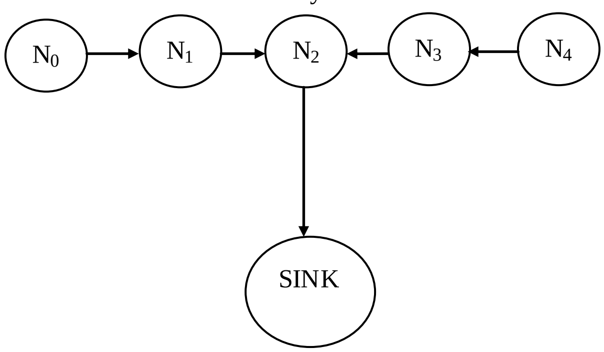

Figure 2.4: Chaining in PEGASIS

Threshold sensitive Energy Efficient Network (TEEN): The Threshold sensitive Energy Efficient Network (TEEN) and Adaptive Threshold sensitive Energy Efficient Network protocol as proposed in [23-24] are both hierarchical protocols. This protocol is basically proposed for time critical applications *i.e.* it is designed to be responsive to abrupt variations in the sensed physical attributes such as temperature, pressure etc. In TEEN, physical phenomenon is sensed constantly, but the actual data transmission is done sparingly. Nodes that are closer together form clusters and this process continues throughout the network until the sink node is reached. An example of this is shown in figure.

Basically, TEEN [23] protocol has been developed for reactive networks so that to respond for the sudden changes in the sensed attributes. This makes it appropriate for the time critical application. However, TEEN is not suitable for applications where periodic reports are needed, because if the thresholds are not received, the nodes will never communicate with each other, and the user will not get any data at all from the network. APTEEN (Adaptive Threshold sensitive Energy Efficient sensor Network protocol) [24] is an augmentation to TEEN. It is intended to acquire periodic data collections and is more receptive to time-critical events depending on the type of the application. It works similar to that of TEEN. In this routing protocol, cluster head broadcasts transmission schedule in addition to thresholds values as in TEEN. In this way, it becomes feasible to capture data on periodic manner and if a node does not send data for a time period equal to the count time. In APTEEN, the count time is the maximum time period between two successive reports sent by the sensor node. If the sensor node does not send data beyond the count time, TDMA schedule is used and each node in the cluster is assigned a transmission slot. The performance evaluation of TEEN and APTEEN shows that both of them outperform LEACH.

Centralized Hierarchical Routing

In centralized routing, the base station is responsible for formation of cluster head.

LEACH-C: A centralized version of LEACH, LEACH-C, is proposed in [10]. Unlike LEACH, where nodes self-configure themselves into clusters, LEACH-C utilizes the base station for cluster formation. During the setup phase of LEACH-C, the base station receives information regarding the location and energy level of each node in the network. Using this information, the base station finds a predetermined number of cluster heads and configures the network into clusters. The cluster groupings are chosen to minimize the energy. Although the other operations of LEACH-C are identical to those of LEACH, results presented in [10] indicate a definite improvement over LEACH. The authors of [10] cite two key reasons for the improvement:

• The base station utilizes its global knowledge of the network to produce better clusters that require less energy for data transmission.

• The number of cluster heads in each round of LEACH-C equals a predetermined optimal value, whereas for LEACH the number of cluster heads varies from round to round due to the lack of global coordination among nodes.

Base station Controlled Dynamic Clustering Protocol (BCDCP): A centralized routing protocol called Base-Station Controlled Dynamic Clustering Protocol (BCDCP), which distributes the energy dissipation evenly among all sensor nodes to improve network lifetime and average energy savings. This protocol utilizes a high-energy base station to set up clusters and routing paths, perform randomized rotation of cluster heads, and carry out other energy-intensive tasks. The key ideas in BCDCP are the formation of balanced clusters where each cluster head serves an approximately equal number of member nodes to avoid cluster head overload,

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uniform placement of cluster heads throughout the whole sensor field, and utilization of cluster-head-to-

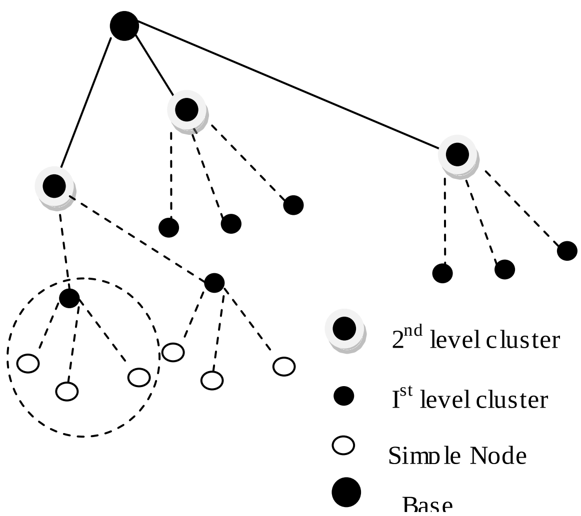

Figure 2.5: Hierarchical Clustering in TEEN and APTEEN

cluster head (CH-to-CH) routing to transfer the data to the base station. BCDCP operates in two major phases: *setup* and *data communication*.

Setup phase: Activities involved in this phase are cluster setup, cluster head selection, CH-to-CH routing path formation, and schedule creation for each cluster.

The Data Communication Phase: The data communication phase consists of three major activities:

• Data gathering
• Data fusion
• Data routing

Scaling Hierarchical Power Efficient Routing (SHPER): A hierarchical scheme used in SHPER [25] protocol in a similar way as in other protocols discussed earlier. However, contrary to other non-centralized routing protocols, the election of the cluster heads is not randomized rather it is based on the residual energy of the nodes. Cluster head selection is done by the base station itself. Base station asks each node to send their residual energy initially. And based on the energy of each node and the predefined percentage of cluster heads, base station selects the cluster head. The operation of SHPER protocol may be divided in two phases: *Initialization phase,* and *Steady state phase.*

3. COMPARISON

Advantages of the Flat Architecture

Scalability: with each node knowing as much about the network as the next node, this allows the network to be extremely scalable. This is the advantageous should be network need to be redeployed or new nodes added. Some protocols are more scalable than others depending on the process of path discovery and the time taken to each convergence.

Simplicity: From a computational perspective flat protocols are easier to implement than a hierarchical as cluster head calculations and network setup is kept to a minimum. Protocol operation though can affect the ease with which a flat protocol can be deployed.

Disadvantages of a flat architecture

Hotspots: Sensor nodes surrounding a sink node, one to two hops away, will consume their energy at a quicker pace. This is due to the amount of messages that have to be routed to the sink. This will eventually lead to the possibility of a single node handling all the traffic for the network. A way around this would to be increasing the number of sink nodes which in turn limits the distance the message has to travel.

Dis-connectivity: with node failures a prominent feature in WSNs, it is possible for certain sections of the network to become unreachable. If a specific node, located at a critical junction should fail, the section would be cut off from the rest of the network and unable to reach the sink node.

Advantages of a Hierarchical Architecture

Data Aggregation: With all the messages for a cluster going through a central location, the cluster head is able to perform data aggregation on the information before sending the data to the sink.

Localized Power Consumption: The power consumed in a cluster is less than in a whole network, as there is a smaller amount of overhead when setting up the network. Only a small portion of the network (a cluster) is set up, pointing to a cluster head. Once this has been done, all messages travel a smaller number of hops to reach the cluster head, thereby saving on their available energy resources.

Disadvantages of a Hierarchical Architecture

Hotspots: Cluster heads perform more functions that the average sensor node and this consumes their energy at a greater rate. To alleviate this problem, some protocols rotate the cluster head amongst all the nodes in the cluster or network. The possiblity of a section getting seperated from the network still exists.

Hardware Requirements: Some protocols require specific hardware, usually a high power transmitter that is capable of reaching the sink node directly. As soon as this happens, the clusterhead position can no longer be rotated amongst the other nodes, unless of course all the nodes have this facility. As with all features, the cost of the development and production of the nodes will increase.

Complexity: To maintain a hierarchical network is more computationally intensive. The algorithms for clusterhead selection and routing decisions are usually more complex. To provide the initial information for these algorithms to be used and calculated usually requires more knowledge about the network. The only way to learn more is to send and receive more transmissions, increasing the power consumption.

Scalability: Networks that employ nodes with specific hardware requirements decrease their ability to scale to a larger size. As the network would grow so too would the number of clusterheads and they would have to be placed in specific spots so that new clusters could be formed from the additional nodes.A further comparison between the two types of routing architectures can be viewed in Table 3.1.

Hierarchical routing	Flat routing
Reservation-based scheduling	Contention-based scheduling
Collisions avoided	Collision overhead present
Reduced duty cycle due to periodic sleeping	Variable duty cycle by controlling sleep time of nodes
Data aggregation by cluster head	Nodes on multi hop path aggregates incoming data from neighbors
Simple but not-optimal routing	Routing can be made optimal but with an added complexity
Requires global and local synchronization	Requires global and local synchronization
Overhead of cluster formation throughout the network	Routes formed only in regions that have data for transmission
Lower latency as multiple hop network formed by cluster heads always available	Latency in waking up intermediate nodes and setting up the multipath
Energy dissipation is uniform	Energy dissipation depends on traffic patterns
Energy dissipation cannot be controlled	Energy dissipation adapts to traffic patterns
Fair channel allocation	Fairness not guaranteed

Table 3.1: Comparison between Hierarchical and Flat Routing.

4. CONCLUSION

Through this paper we"ve tried to present the most common WSNs routing protocols in various layers. We have demonstrated that currently proposed routing protocols for these networks are insecure. We leave it as an open problem to design a sensor network routing protocol. Link layer encryption and authentication mechanisms may be a logical first approximation for guard against mote-class outsiders, but cryptography alone is not enough.

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