Volume 3, Issue 2April2014

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X

Comparative analysis of WSN Routing Protocols

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ABSTRACT

The era is rapidly updated by the revolutionary technological growth every day specifically in the field of wireless communication. Wireless Sensor Network (WSN) is promising candidates for both the contemporary industrial development and the end user market demand. This paper presents the comparative analysis of WSN routing protocols. Routing in WSN network is different than the routing in the traditional data networks. Most of the attention has been given to the routing protocols. Currently various routing protocol have been designed and developed for WSN. In this work we have done a deep survey of routing protocols and have made their comparison based on their pitfalls and benefits. We have compared two routing protocols of WSN. We have considered Battle field scenario. The two protocols have been compared in terms of power, network lifetime, delay and redundant

Keywords:*WSN, nodes, Rumor protocol , SPIN routing*

1. INTRODUCTION

Wireless Sensor Networks (WSN) has proven to be an emerging field in the area of Computer Science and Computer communication. The recent enhancement and development of electronic devices has now reached a level of integration that offers high capacity for sensing, processing, "Storing and communicating data than previous decades. The first decade of 21st century is labeled by the experts as the "Sensor Decade" because of dramatic increase in sensor Research and Development (R and D) and applications over the past 15 years [1]

There are three stages of advancement in sensor technology.

Stage 1:In late 70's, the sensor controller and the technology of Point to Point transmission was adopted for the traditional sensors. It is called the first generation of sensor network.

Stage 2: The technology development in this field has contributed the advanced version of sensor network- The second generation which is capable to synthesize and process various types of data.

Stage 3: Since the late 20th century, the development of the intelligent sensor network and widely application of multifunctional sensors with wireless connection, contribute to the formation of WSN. The motivation behind WSN development was military applications such as Battle field but WSN has found its application in the scientific, medical, commercial and social life areas. It also finds its application in biomedical field. WSN is a wireless ad-hoc network of billions of tiny nodes performing sensing that jointly monitor environmental and physical status with partial processing and exchange their data cooperatively. WSN are typically used in hostile and dynamic environment with no human existence and therefore they must be tolerant to the failure and loss of connectivity of individual nodes [2].WSN applications are numerous and growing and range from indoor deployment scenario in the home and office to the outdoor deployment scenario in natural, military and embedded settings [3].

2. WSN COMMUNICATION PROTOTYPE

The applications of WSN require the integration and interaction of various components that performs different assignment and forming a communication prototype. The general components of any WSN networks are source, intermediate nodes and sink.

1) Source that generate data for the task
2) Intermediate nodes that make additional processing to forward data
3) Sinks are the points which provide information reception

The interaction of these components has some patterns which are known as

1) Event Detection: Source should report the sinks once they have events matching their required task or when the alarm threshold crossed. In this interaction pattern generally more than one sensor node is required.
2) Function Approximation: The sensor nodes are used to approximate a function of location that estimates the physical value changes from one point to another. The sinks required to have approximation mapping of the area defined in the application.
3) Periodic Measurement: Sources can be tasked to report measured values periodically to a defined interval, according to the application requirements.
4) Tracking: The task of the network is to obtain information of an object of interest that represents a mobile behavior. In order to generate meaningful information various sensors nodes must interact.

3.THE GENERIC WSN NODE ARCHITECTURE

The implementation and development of the WSN nodes must consider a design, according to a very well-studied and analyzed application. This is required to specify and define profile of the elements as well as the characteristics and methods which offers the best flexibility and efficiency during the operation. Besides it has to be taken in consideration that sensor node in WSN must be

small, cheap, energy efficient, equipped with sensors, good computation performance, adequate size storage and suitable communication facilities

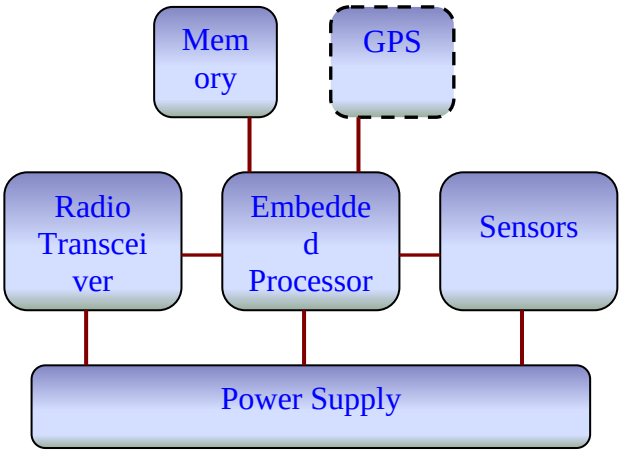


Fig 1 WSN node Architecture

Embedded Processor. The task of WSN nodes include the processing of information. At present, due to economic constraints the embedded processor is often significantly constrained in terms of computational power. Due to the constraint of such processor, devices typically run specialized component-based embedded operation systems, such as Tiny OS [4].

3.2 Memory/Storage. Storage in the form of random access and read only memory includes both program memory and data memory. The quantities of memory and storage on board a WSN device are often limited primarily by economic considerations and are also likely to improve over time [4]

3.3 Radio Transceiver. WSN devices include a low rate, short range wireless radio. While currently quite limited in capability too, these radios are likely to improve in sophistication over time-including improvement in cost spectral efficiency, tenability and immunity to noise, fading and interference. Radio communication is often the most power intensive operation in a WSN and hence the radio must incorporate energy-efficient sleep and wake-up, modes [4]

3.4 Sensors. Due to bandwidth and power constraints, WSN devices primarily support only low data rates sensing. The specific sensor used is highly dependent on the application.

4. WSN PROTOCOL STACK

Wireless Sensor Network (WSN) is a new class of networking technology that is increasingly becoming popular today. Huge strides taken in sensing technology, Low power microcontrollers and communications radio have spurred the mass production of relatively inexpensive sensor nodes. Such large scale sensor networks far outweigh use of conventional networks in situations where terrain, climate and other environmental constraints hinder the deployment and setting up of regular networks [8].

Although the sensor nodes communicate through the wireless medium, protocols and algorithms proposed for traditional wireless ad hoe networks may not be well suited for sensor networks. As sensor networks are application specific and the sensor nodes work collaboratively together, in addition to that sensor nodes are very energy constrained compared to traditional wireless ad-devices [6].

A rapid increase in the number of very application specific sensor networks has definitely been a great boost in terms of protocols and techniques developed; it has created two basic impediments to more growth:

- Lack of interoperability between individual components of different systems.
- Lack of a common framework on which new developers can build.

Because most all of these applications are custom built with no standardization in the protocols used for communication, there can be no interoperability between two components developed separately by different research groups. With interoperability, there will be a unification of various efforts in sensor networks

Also, there is no basic architecture which everyone can use to build on, forcing each developer to build each component in their application from scratch. If there is a common framework of integral components to be used, it would help save greatly in development and testing time since not everything has to be built from scratch every time [8].

The protocol Architecture for the Wireless Sensor network (WSN) is still not decide, different approaches are currently begins used with different applications requirement

.

4.1 TRADITIONALLAYERED ARCHITECTURES

The traditional layered architecture used for communications networks are based on OSI reference model. The TCP/IP protocol suite, a layered architecture consists of different layers namely the application layer, transport layer, network layer, data link and physical layer. Each layer is built on top of the one below it. Reduce Complexity: each layer offers service to the respective higher layer. It encapsulates the implementation specific details and provides an abstract interface for its service. For implementation such architecture it is assumed that this protocol is used on each sensor node of WSN.

4.2 Cross Layer Design Approach

The cross layer design can be observed as a way to loosen the strict limitations in the stack layerd approach. The objective of this is to obtain approach that is flexible and efficient for implementing communication protocols. The idea consists of breaking monolithic layer into small, self-contained components or modules. These modules must have one well – defined function interacting with other module in a clear interface and the interaction are not confined to immediate neighbors in an up/down relationship, but can be with any other component. This

approach expects to offer big protocol optimization, nevertheless it is also argued that the imprudent use of this cross layer design can compromise functionally and performance of the entire system.

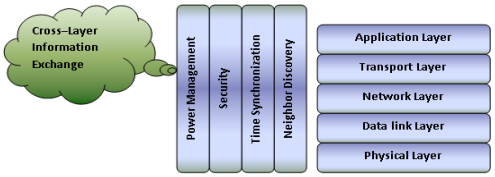


Fig 2 cross layer design for WSN [2]

With application layer different types of application software can be built depending on the task. The transport layer helps in maintaining the flow of data wherever the application requires it. The network layer is on charge of routing the data supplied by the transport layer. In the data link layer the MAC protocol must be energy aware and must minimize possible collision with the broadcast of the neighbor. Finally the physical layer is required to be efficient and robust with the transmission and reception of packets.

There are also many Verticals like security, Power Management, Neighbor Discovery and time Synchronization. These verticals provide cross- layer functionalities as a set of interface, which can be used by all of the network layers [8].

5. NETWORK LAYER

The Network layer of OSI is responsible to provide network service to exchange data between two transport entities over a network connection. The Network layer routes packets and controls operation of the network. It also addresses flow control. There is little concern of flow control in most WSN due to their very low offered data through put and stated lack of quality of service provisions. The routing operation in a WSN network represents significant challenges to network designers because of the need for low duty cycle operation of network nodes. This low duty cycle requirement limits the allowable overload for synchronization, negotiation and other Network layer activities. [3]

The network layer is the lowest layer that deals with end to end transmission and it is concerned with getting packets from the source all the way to the destination. This network layer must get to know topology to achieve its goals. Network layers is based on routing algorithms which are responsible for deciding which output route an incoming packet should be transmitted. The main objective of network layer is to find best energy efficient route to transmit data over destination to maximize the life time of the network.

5.1 Network Layer Function

There are two basic function of Network layer

1) Addressing
2) Routing

5.1.1 Addressing

5.1.1.1 Traditional network Addressing

The traditional network addressing scheme assign fixed address to each node such as the case of Internet. The addresses can be unique is its advantage. It requires very high cost and maintenance of such addresses. It is a problem if node address does not provide a clue to which direction the packet is to be routed. Two approaches offer a solution.

1) One is to maintain a central server that keeps up to date information on the position of every node
2) The other is to take the mobile IP approach: every node has a home agent that handles all the requests for the node and redirects them to the present position of the node [6]

5.1.1.2 Addressing in WSN network

In WSN, addresses and names refer to individual nodes as well as to data items stored in them. This is critical issue to represent size of this data in WSN. Content based addressing is an important aspect in WSN in which no node or network interface but the data itself is addressed. To enable in-network processing content based aspect can be integrated with data centric routing. Therefore WSN nodes are not independent when performing a task. They need collaborate to find a solution. Mostly content based addressing is used for communication in WSN.

It is a common practice of user in WSN to specify his query containing not only the data type expected but also the region from where the data should be generated. This is illustrated in figure

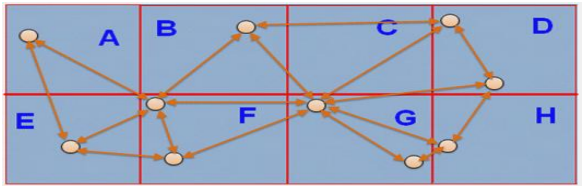


Fig 3 Area of interest for specific region

The region can be specified in different shapes like circle, rectangle and square. When the nodes know their position they can identify themselves that they belong to which area of interest. [18]

5.1.2 Routing

Routing means to find best path to which data is to be send. Routing makes use of information on the topology to find out which node is connected to which node. If the nodes are not physically connected it cannot route any data.

Routing scheme of WSN sometimes use routing tables that dictates the next node to be routed to given current destination. Larger network have large routing tables and routing tables cannot take into account real-time effects such as failure of links, congestion on a link and nodes with back up queues. Routing may also depend on the current network status and can take into account various performance measures including cost of transmission over a given link, congestion of a given link, reliability of a path

and time of transmission. They can also account for a link or node failure [19]

5.1.2.1 Routing challenges and design issues

Routing in a WSN face many challenges and e design issues. One of the main design goals of WSN is to prolong the lifetime of the network and present connectivity degradation by employing aggressive energy management techniques. The life time of energy sources in WSN is limited. The position of nodes in WSN environment is not predetermined. It can be random. This implies that the nodes are expected to perform sensing and communication with no continual maintenance or human attendance and battery replenishment which limits the amount of energy available to the sensor nodes. The design of routing protocols in WSN is influenced by many challenging factors. And these factors must be overcome to achieve best communication. In the following we have summarized some routing challenges and design issues that affect routing process in WSN [20]

1) Energy consumption without losing accuracy: To transmit information in wireless medium sensor nodes can use their supply of energy. As such energy conserving form of communication and computation are essential, sensor node life time shows a strong dependence on a the battery life time [6]
2) Node deployment: Node deployment in WSN is depend on application on and affects the performance of the routing protocol. This deployment can be either random or deterministic.
3) Data reporting model: Data sensing and reporting in WSN is application dependent on the application and the time criticality of the data reporting. Data reporting can be categorized as either
   a) Time-Driven
   b) Event Driven
   c) Query-Driven
   d) Hybrid
4) Fault tolerance: Some sensor nodes may fail or be blocked due to lack of power, physical damage or environmental interference. The failure of sensor nodes should not affect the overall task of the network.

6. ROUTING PROTOCOLS OF WSN

Routing means to find best path to the destination along which data is to be sent. Network layer in WSN is usually used to implement routing function. In WSN source node can't reach sink node directly and rely on intermediate nodes. The implementation of routing tables provides the routing mechanism. These routing table contains list of node options for any given packet and destination. The distinguish features of WSN from other traditional wireless network are as follows

1) It is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes. Therefore, classical IP-Based protocols cannot be applied to sensors networks.
2) In contrary to typical communication networks almost all applications of sensor networks require the flow of sensed data from multiple sources to a particular sink.
3) Generated data traffic has significant redundancy in it, since multiple sensors may generate same data with in the vicinity of a phenomenon. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization

Due to such differences, many new algorithms have been proposed for routing data in sensor networks. Routing in WSN can be achieved by different approaches like in general it can be divided into flat-base routing, hierarchical-based routing and adaptive-based routing [20].

6.1 Taxonomy of WSN Routing Protocols

Recently, routing protocols in WSN have been extensively studies by several researchers and lots of work on this field is still in progress. A variety of approaches exist for making taxonomy of protocols, those classification are made by considering different aspects of routing data in the network. On basis of our analysis we have classified the routing protocol in two basic classes.

1) Based on network structure

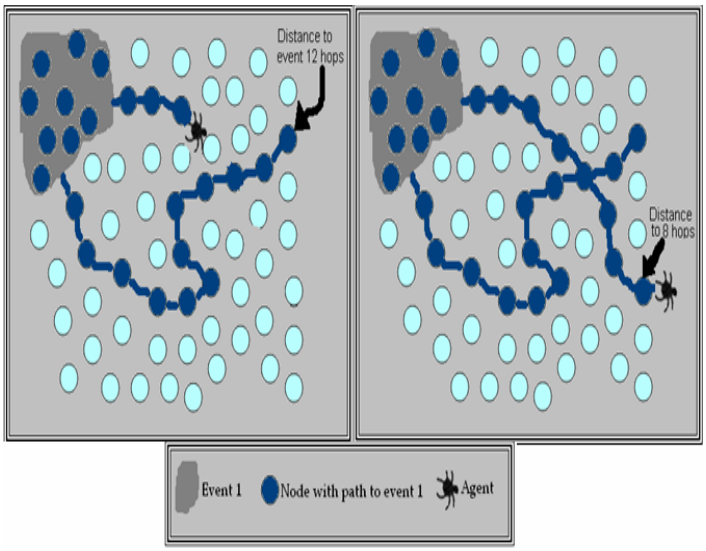


Fig4 Rumor Routing

2) Based on protocol operation

Based on network structure are further divided into two classes

   a) Flat based routing
   b) Clustered based routing

In our project, we have worked on two protocols of flat based routing which are Rumor routing protocol and SPIN routing protocol.

6.1.1 Flat-based routing protocol

In flat based routing protocol all nodes are assigned equal roles. Each node performs similar operations. Rumor and SPIN are most popular routing protocol of Flat-based routing.

6.1.1.1 Rumor routing protocol

Rumor routing is a modification of Directed Diffusion. Usually Directed Diffusion floods the query to the whole network but in few cases there is only a small amount of data requested from the nodes and thus the use of flooding is not necessary. Another approach is to flood the events if number of events is too small and number of queries is too large. Rumor routing is somewhat in between event flooding and query flooding. The main concept is to route the queries to the nodes that have observed a specific event rather than flooding the whole network to retrieve information regarding the occurring events.

The Rumor routing proposed approach does not flood the network with information regarding an event occurrence but it only installs a fewer paths in the network by employing and sending out one or many long-lived packets, called agents. When a node discovers an event, it put such event to its local table and generates an agent. The agent moves from node to node and installs routing information regarding the event in every node that it visited. When a node create a query for an event, the nodes that know the route, can reply the query by referring its event table. Hence, the cost of flooding the entire network is avoided. Rumor routing maintains only one route between source and destination as compared to Directed Diffusion where data can be sent via multiple paths at low rates.

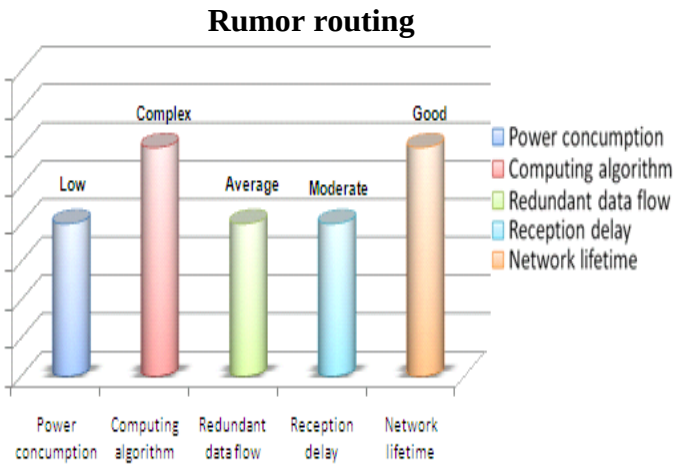


Fig.5 Routing Parameters of Rumor Routing

Rumor routing's performance is better only when the number of events is small. If number of events is large, the cost of maintaining agents and event tables at every node may not be amortized if there is not sufficient interest on those events from the sink. In figure 4, the mechanism of Rumor routing algorithm is illustrated.

Figure 5 illustrate the power consumption, computing algorithm, reception delay, redundant data and network lifetime for Rumor routing.

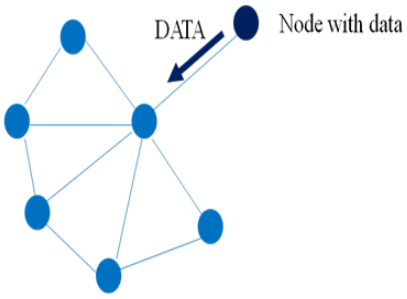
6.1.1.2 SPIN routing protocol

SPIN is the Sensor Protocols for Information via Negotiation. The protocol disseminates all the information at each node to all nodes in the network, considering that all nodes in the network are potential base stations. This helps a user to query any node and gather the required information immediately. The protocol uses of the property that close by nodes have similar data and thus it only distributes the data that the other nodes do not have.

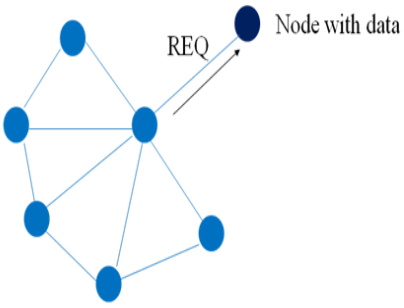
The SPIN family of protocols is based upon data negotiation and resource-adaptive algorithms. Nodes running SPIN assign a high-level name to define their collected data (called metadata) completely and carry out metadata negotiations before any data is transmitted. In addition, SPIN has access to the current energy level of node and adjusts the protocol it is running based on how much energy is left. This family of protocols is designed based on the concept that sensor nodes works more efficiently and conserve more energy by sending data that defines the sensor data instead of sending all the data. Sensor nodes use three types of messages in SPIN ADV, DATA, and REQ to communicate. Where ADV advertises new data, DATA is the actual message and REQ requests data.

1. The protocol begins when a SPIN node has new data that it is intended to share. It does so by broadcasting an ADV message having metadata.

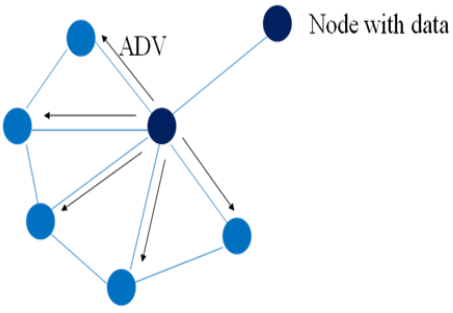
2. If a adjacent is interested in the data, it sends a REQ message for the DATA and the DATA is sent to this adjacent node.
3. The adjacent sensor node then repeats this process with its neighbors. As a result, the whole sensor area will receive a copy.



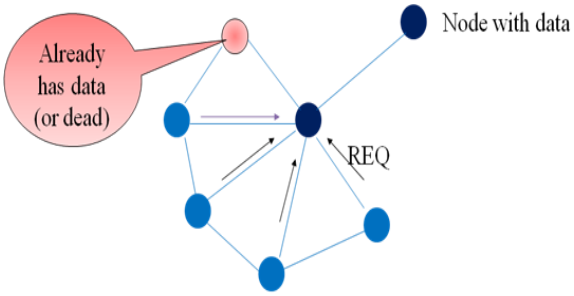
Node with data advertises to all its neighbors



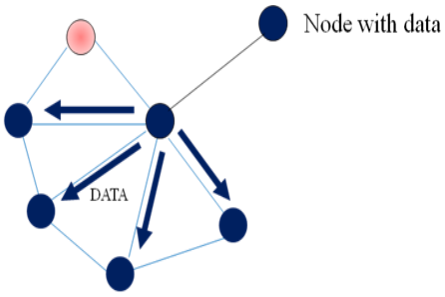
Neighbor requests for data and it is sent



Receiving node sends ADV to neighbors



Receiving neighbors requests for data.



Receiving node sends ADV to neighbors

Fig 6. SPIN Operation

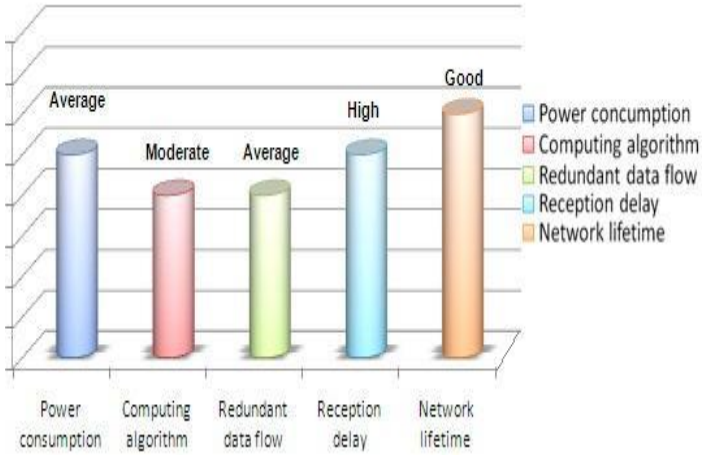


Fig 7 Routing Parameters of SPIN

The power consumption, computing algorithm, redundant data, and reception delay and network lifetime for SPIN protocol is illustrates in figure 7.

6.1.1.3 Comparison

The comparison of these flat based protocols can be made by taking some critical routing parameters into account. Here a theoretical comparison of these protocols is presented based on network life time, reception delay and computing algorithm.

1. **Network Life Time**

The network life time gives information that for how long a network can be operable, and it is highly dependent on the energy consumed by the individual nodes in transmitting a packet from source to destination. Flooding broadcasts data

to all neighbors without thinking about the energy constraints of next node, exhibits a poor network life time. The gossiping by random selection substantially reduces the energy consumption and therefore has much better life of network than flooding. Direct Diffusion being demand driven sends data only when requested by using gradient path and thus have better life of network. In contrast, Rumor routing has slightly less life time as there are few more consumption of energy in spreading the rumor occurs and it may possible in the area where rumor reached and

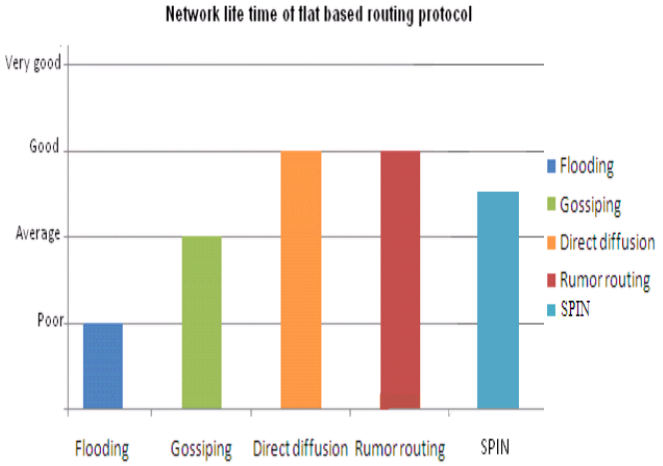


Fig 8.Network life time of Flat based Protocol

that may not need such type of data. SPIN utilizing ADV, REQ and DATA propagation have better network life time but have few extra wastage as every node in the network have to transmit, receive and store the information related to all events in the network.

2. Computing Algorithm

It requires very simple routing algorithms to make less energy consumption and less memory usage in WSN. The Flooding simply utilize broadcasting method and thus is simplest from all, where as gossiping is a little complicated in selecting a random neighbor. In Direct diffusion interest propagation and selection of gradient path for data increases complexity in the algorithm, while in rumor routing spreading of rumor, source search for rumor, build path by flooding and then following the predefined route further increases complexity and is the most complex among all flat based protocols discussed. SPIN, however, reduces the complexity by simply sending the data only to its adjacent nodes after exchanging few negotiation messages.

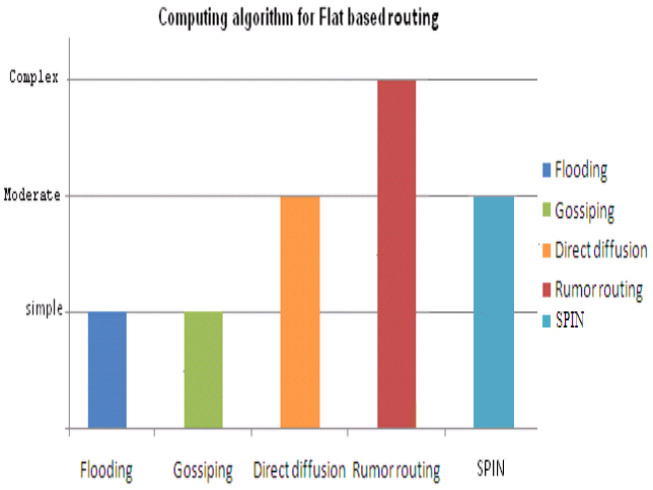


Fig 9. Computing algorithm of Flat based Protocols

3. Reception Delay

The reception delay is related with delay, which is occurred in a packet when it received at the sink (BS). In flooding, as data floods through all the possible paths to the sink therefore it also chooses the shortest path and therefore reception delay of flooding is minimum.

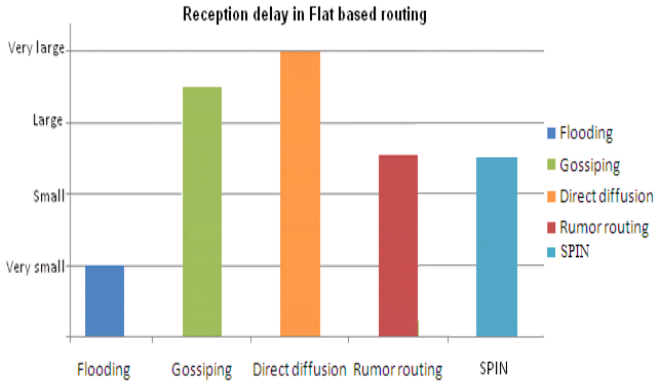


Fig 10. Reception delay of Flat based Protocols

Gossiping with random selection has greater delay as the selected random path might not be the shortest path and therefore it offer more delay than flooding. Direct diffusion and rumor routing algorithm have higher delays as extra time is taken by the interest or rumor to expand in the network and then data travel from source to sink. In SPIN delay occur due to first exchanging negotiation messages and then actual transmission of data is started.

6.1.1 Clustered-Based Routing Protocols

In clustered-based routing, nodes play many different roles in the network. Clustered based routing is also called hierarchical routing. It was originally intended for wire line networks, which consists of well-known techniques with some special advantages related to scalability and efficient communication. The idea of clustered routing is to carry out energy-efficient routing in WSN. In a clustered architecture, nodes with higher energy can be used to process and send the information where as low energy nodes can be used to carry out the sensing in the proximity of the target. This means that creation of clusters and assigning special functions to cluster heads can significantly contribute to overall system lifetime, scalability, and energy efficiency.

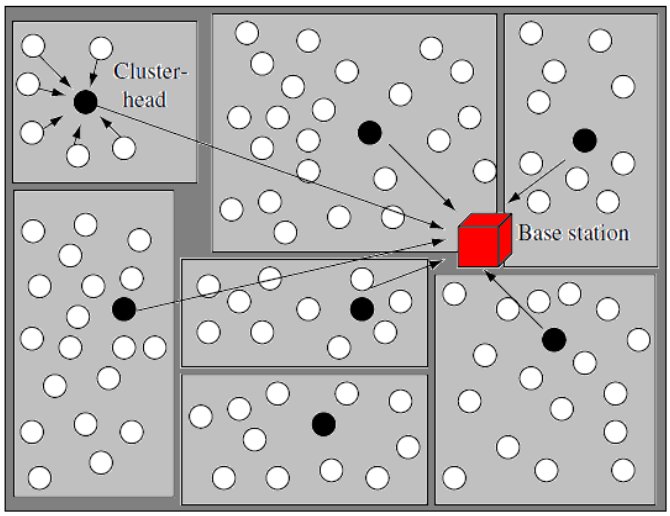


Fig 11. LEACH clustered based Protocol

Clusters can be formed by dynamically choosing nodes in a cluster or it can also be formed via considering the geographic location of nodes using GPS. The cluster formation via geographic location of nodes is also known as the location based routing.

Some of the clustered based routing protocols include:

i. LEACH
ii. PEGASIS
iii. TEEN
iv. APTEEN
v. GAF

6.1.1.1 LEACH

One of the most popular hierarchical routing algorithms for sensor networks is Low-Energy Adaptive Clustering Hierarchy (LEACH). The idea is to create clusters of the sensor nodes based on the received signal strength and utilize local cluster heads as routers to the sink. This will save energy since the transmissions will only be done by these cluster heads in spite of all sensor nodes.

It is shown in Fig 11. that there are several clusters and each has a head of the cluster. Head of the clusters collect all the data from nodes which are present in their respective cluster and sends that collected data to the base station.

LEACH utilizes localized coordination to enable scalability and robustness for dynamic networks and incorporates data fusion into the routing protocol to reduce the total amount of information that must be transmitted to the base station. As data collection is centralized and is performed periodically, this protocol is most appropriate when constant monitoring by the sensor network is required. LEACH introduced adaptive clustering i.e. re-clustering after a given interval with randomized rotation of the energy-constrained cluster head so that energy dissipation in the sensor network is constant.

The operation of LEACH is divided into two phases: the steady state phase and the setup phase. In the setup phase, the clusters are organized and cluster heads are chosen. In the steady state phase, the actual data transfer to the base station occurs. The interval of the steady state phase is longer than the interval of the setup phase in order to reduce overhead.

- **Setup Phase**

During the setup phase, a predetermined fraction of nodes p, select themselves as cluster heads as follows. Each sensor node elect a random number between 0 and 1, if this random number is smaller than a threshold value T (n), the node becomes a cluster head for the current round. The threshold value is derived based on an equation that incorporates the required percentage to become a cluster head, the current round, and the set of nodes not elected as a cluster head in the last (1/P) rounds, denoted by G. This is given by:

$$T(n) = \begin{cases} \dfrac{p}{1 - p*(r \bmod (1/p))} & .....if..n \in .G \\ 0.....Otherwise \end{cases}$$

Where p is the required percentage of cluster heads (e.g. 0.05), r is the current round, and G is the set of nodes that have not been cluster heads during the last 1/p rounds.

After the cluster heads have been elected, they broadcast an advertisement message to the rest of the nodes within the network that they are the new cluster heads. As they receive this advertisement, all the node on cluster head nodes decide on the cluster to which they want to belong, on the bases of the signal strength of the advertisement. The non-cluster head nodes let the appropriate cluster heads know that they will be members of their cluster.

After receiving all the messages from the node that would like to be a part of the cluster and based upon the number of nodes in the cluster, the cluster head node build a TDMA schedule and assigns a time slot to each node when it can transmit. This is the schedule to broadcast to all the nodes in the cluster.

- **Steady Phase**

During the steady state phase, the sensor nodes can start sensing and transmitting data to the cluster heads. After receiving all the data, the cluster head node aggregates them before sending them to the base station. After a specific time, which determine a prior; the network goes back into the setup phase again and starts another round of selecting new cluster heads. Each cluster communicates using different CDMA codes to minimize interference from nodes belonging to other clusters.

Although LEACH can increase the network lifetime, a number of issues regarding the assumptions used in this protocol remain.

1. LEACH assumes that all nodes are able transmit with enough power to reach the base station if required and that each node has computational power to support various MAC protocols.
2. It also assumes that nodes have data to send all the time, and adjacent nodes have correlated data.
3. LEACH utilizes single hop routing each node should transmit directly to the cluster-head and sink.
4. The concept of dynamic clustering add extra overhead, e.g. head changes, advertises etc., which may lessen the gain in energy consumption.

Fig. 12 illustrates the power consumption, computing algorithm, reception delay, redundant data, and network lifetime for LEACH.

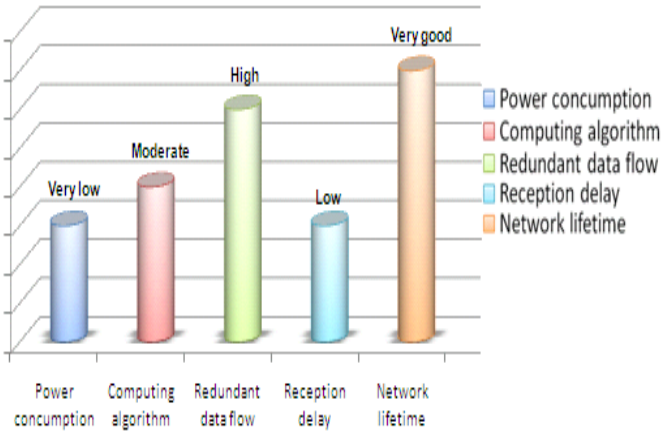


Fig 12. Routing Parameters of LEACH

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