Routing Techniques in Wireless Sensor Networks: Review and Survey

Muhammad Paend Bakht[1], Aftab Ahmed Shaikh[2]

[1]Department of Telecom Engineering, [2]Department of Computer Science, Faculty of Information and Communication Technology Balochistan University of Information Technology, Engineering and Management Sciences, Quetta, Pakistan

Abstract

Wireless Sensor Networks utilize their energy resources for data sensing, processing and communication purposes. Sensor nodes have limited energy resources due to small size and are usually deployed in large quantity at remote locations. Such situations limit the frequent access of human to small sensor nodes. Therefore recharging and replacing batteries of sensors is difficult. For this reason researchers have invested their inclination to design intelligent routing protocols that may efficiently manage energy resources to extend network lifetime. This paper presents a review of the state of art routing protocols of WSNs. It first explains optimization goals which may be considered while designing WSNs routing protocols followed by a detailed survey of different routing techniques. Finally it concludes by suggesting some directions for future research work in the field of WSNs.

Key words: Wireless sensor networks; Cluster; Multi Hop transmission

Corresponding author's email: *Paend1@hotmail.com*

INTRODUCTION

Sensor Networks are composed of small size, large number of sensor nodes used in computing and communication applications of 21st century (Pantazis et al., 2013). At times Wireless communication nature of these networks demands their deployment at such harsh locations where small nodes are physically inaccessible. Large size and unreachable qualities of sensor networks makes sensor nodes rely on their own resources without any attention from the outside world. Sensor nodes have built in battery which they utilize for data sensing, processing and communication purposes. But small size of sensor nodes limits the size and power of battery (Feng et al., 2013). Therefore the Battery of sensor nodes should be efficiently used to extend the network lifetime. Energy consumption is specifically focused while designing WSNs. Energy efficient routing protocols contribute to the network lifetime (Spachos et al., 2012).

WSNs routing challenges

While designing routing algorithms, WSNs researchers face many challenges due to limited resources of these networks. Some routing challenges are listed below which are focused while designing WSNs (Al-Karaki et al., 2004).

Node Deployment

Nodes can be deployed in manual (predefined) order or in random manner depending upon the application. When nodes are manually deployed, data is sent through predetermined routing paths. But for randomly deploying the nodes an ad-hoc routing infrastructure is created, however this type of routing can introduce overheads for MAC protocols (Qayyum et al., 2015).

Energy Consumption

Among sensing, processing and communication maximum energy is used in communicating the data (Pantazis et al., 2013; Feng et al., 2013). The process of formation of routes is directly linked with energy considerations (Spachos et al., 2012). There can be directed or multi hop routing depending upon the distance between source and sink. Directed routing consumes less energy if the distance between source and sink is less. However when sink is far away from sensing nodes then multi hop routing performs better because it balances load and network resources. Routing protocols should effectively manage energy in order to enhance network lifetime (Al-Karaki et al., 2004).

Scalability

Normally sensor nodes are deployed in huge quantity for monitoring an area. Therefore routing schemes should respond to huge number of events sensed through sensors in the environment. If the event does not occur for specific time then sensors should go to sleep mode to minimize energy usage.

Network dynamics

Sensor nodes and BS can be fixed as well as mobile. In case when nodes are moving, routing data from/to such mobile nodes is challenging task because there arise important issues like stability of routing data, energy and bandwidth consumption

etc. However network dynamics purely depend upon application.

Time Delay

Also called as latency means how much time a data packet requires reaching from sensing node to BS or vice versa. It can be measured in either direction or round way fashion. Multi-hop and Data aggregation process can affect time delay (Qayyum et al., 2015).

Data Collection and Aggregation

Data reporting after gathering is related to any physical event sensed by sensor node. Based on this there can be event driven algorithms, query driven and automated time driven algorithms (Qayyum et al., 2015). Data collection methods are very important while designing routing algorithms to avoid the collection and aggregation of same data from multiple nodes to optimize energy consumption.

Connectivity

While designing routing algorithms high connectivity is required in order to avoid isolations in the Wireless sensor networks. Network should be fault tolerant so that connectivity amongst nodes is not affected. In case of the failure of particular node, routing protocols should be intelligent enough to route the data to the data collection point or sink via different paths (Meguerdichian et al., 2001).

Security

Security is very important in applications like surveillance and vigilance (Pathan ASK., 2006). It is obvious that Data fusion process helps reduce communication, but security assurance becomes more complex while fusing data packets. Sometimes, intermediate nodes can copy, modify or even loose data packets. In addition, data encryption from source to sink may not be required but the intermediate nodes cannot perform data fusion without understanding the data. Researchers intend to provide secure aggregation while developing routing protocols to make them resilient to intruder devices.

Transmission media

Sensor nodes communicate over wireless medium. So wireless channel may face problems like higher rate of error and fading which can disturb the operation of network. As a result, the bandwidth is affected and not received as required. So the design of MAC needs to resolve such issues. One way to MAC design is to assign time division multiple access (TDMA) based protocols instead of contention based protocols like carrier sense multiple access (CSMA) (e.g. IEEE 802.11). There is other option to use Bluetooth technology because these protocols conserve more energy.

WSNs Routing Protocols

Routing decides to send the data directly from source to the destination or through intermediate nodes. Routing protocols strongly affect the efficiency of network. Although there are many routing protocols for WSNs but we analyze network structure based protocols which are classified mainly into flat routing and Hierarchical routing WSNs (Al-Karaki et al., 2004). These routing protocols are discussed in detail in the next section.

Flat Routing Protocols

In these routing schemes, all nodes perform same role in the network. When a node requires to transmit data to the Base station (BS), it investigates valid route and then transmits under multi hop fashion. Some important protocols are: Sensor Protocols for Information via Negotiation (SPIN), Reliable and energy efficient protocol (REEP), Sequential Assignment Routing (SAR), Energy Aware routing (EAR) and Directed Diffusion (DD) etc.

Sensor Protocols for Information via Negotiation (SPIN)

Heinzelmanet.al. suggested this adaptive protocol WSNs (Al-Karaki et al., 2004), Here all the information is spread to complete network because it considers all nodes as potential base stations in the network. Users can find their required information by making a query to any node in the network directly. Here data negotiation and resource-adaptive algorithms are used by SPIN protocols. Nodes allocate a high-level name (called meta-data) to explain their gathered data and execute meta-data negotiations to transmit the data. Which can assure that no redundant data is spread to network. The protocols of SPIN family are designed on two essential thoughts:

1. Sensors save energy by sending the required data instead of all the data.
2. Sensors utilize their energy by not sending the needles and unnecessary data.

SPIN is 3-layered protocol because sensor nodes communicate using three sorts of messages ADV, REQ and DATA. For advertising about new data ADV is used, while to request data REQ is used, and original message is DATA. When a SPIN node finds a new data and wants to share, then the protocol is started by sending an ADV message that has meta-data. If other node at neighbor wants the same data then it initiates a REQ message and DATA is transferred to neighbor node. This process is repeated from neighbor to neighbor in the sensor node and entire area of sensor nodes receives data. Some other SPIN family protocols are:

SPIN-BC: protocol for broadcast channels.
SPIN-PP: protocol for point to point communication.
SPIN-EC: SPIN–PP protocol with an addition of energy heuristic.
SPIN-RL: SPIN-PP protocol for a lossy channel

Sequential Assignment Routing (SAR)

This was the first protocol to implement the QOS concept for WSN routing. SAR protocol takes routing decisions according to packet traffic type; it plans the energy resources and QoS for each path. It also resolves different reliability issues. SAR uses localized path restoration process and multipath approach. The protocol creates multipath table for getting energy efficiency, recovery and fault tolerance. But the disadvantage with SAR is that it can suffer with the problem of overhead, However table states needs to be refreshed continuously. The problem gets severe as the number of nodes increase.

Reliable and energy efficient protocol (REEP)

A renowned protocol which transmits data through energy efficient and reliable paths. The protocol is formed of following essential parts: which are sensing event, information event, request event, request priority queue event and an event of energy threshold value. “Sensing event” is a request produced at sink node which is considered by network for obtaining information. Response to this request is the “Information event” is the request produced at sensor node. Then the "Request events" are created at base station node for setting path. While “Request priority queue” is a queue with first-in-first-out order which selects a neighbor node for path selection through highest importance. Then the “Energy threshold value” checks the nodes conditions for participation in path setup process (Zabin et al., 2008).

Cluster Based Routing

Clustering is an approach to divide the sensor network into clusters (groups) assigning one of the sensor the role of cluster-head (CH). Routing based on the concept of clustering is called cluster based routing (Al-Karaki et al., 2004). Cluster based routing is also called hierarchical based routing because here different nodes play different role in the network. This routing is very helpful to effectively manage network resources within the cluster contributing to improve the lifetime of sensor networks. Recent studies have developed that clustering algorithms play an important role to produce energy efficient networks by reducing the communication among nodes and therefore minimizing the energy consumption. Some protocols of cluster based routing are discussed below (Boyinbode et al., 2011; Heinzelman et al., 2000; Rajeshwari et al., 2015).

Threshold sensitive energy efficient sensor network (TEEN)

TEEN is designed to perform in critical applications. The protocol has the key factor which is the value of the attribute measured. TEEN is sensitive protocol that responds to abrupt changes in attributes such as pressure and temperature. Responsiveness is necessary for applications where network operates in a reactive mode. Here the network architecture of sensors is hierarchical from cluster formation to ordinary nodes and process of cluster formation repeat itself with in rounds until the base station is achieved.

Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN)

APTEEN is an extension to TEEN that makes both the collection of Periodical data and responds to critical events. TEEN cannot be applied to periodic reports because it depends upon thresholds

APTEEN has advantages to examine past data values by taking snapshot view of the entire network. It can also observe an event for a specific time interval. In APTEEN the clusters head announce attributes to threshold values and the transmission schedule to the all nodes. This protocol saves energy because data aggregation is performed at cluster-head. TEEN and APTEEN perform better than LEACH but TEEN /APTEEN has overhead and complex formation of cluster as compared to LEACH.

Low Energy Adaptive Clustering Hierarchy (LEACH)

Heinzelman et al. proposed low energy adaptive clustering hierarchy (LEACH) specifically enhancing network lifetime (Heinzelman et al., 2000). This algorithm selects nodes randomly and they act like “local base-stations” for some group of regular nodes. Sensor nodes transmit their data to their cluster head instead of sending to sink. Main idea of LEACH is to:

1) Balance network load by changing cluster head position at every round.
2) Reduce communication load by performing data aggregation and fusion locally at cluster head.

LEACH protocol works in two rounds. First round is set-up phase which forms clusters and next round is steady state phase.

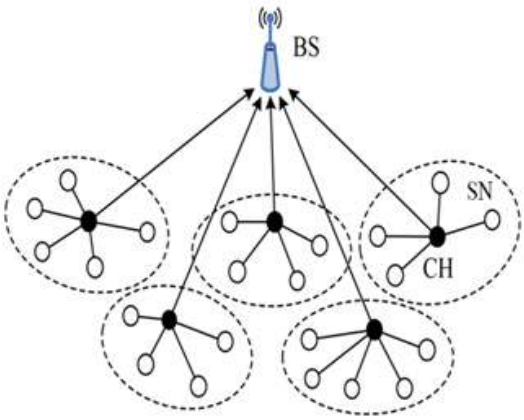

Figure 1: LEACH Network Topology

Interval of steady state phase is long because this is regular working environment of the network.

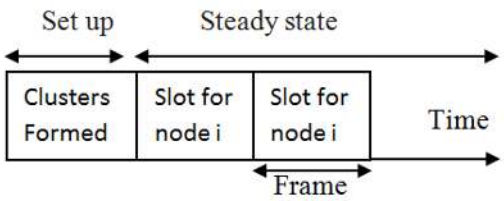

Figure 2: LEACH Protocol

Simulation results prove that nodes were able to communicate longer by using LEACH algorithm. As the CHs consume more energy than other remaining nodes, therefore CHs role should be frequently rotated among all nodes in order not to die the CHs nodes. Furthermore, rotating the role of cluster head decreases the network energy consumption as compared to fixed role. After cluster formation in Setup phase, Cluster heads (CH) are selected based on the recommended percentage P and previous position as CH. Nodes which have not been cluster head in the previous 1/p rounds now produce a random number from 0 to 1. Random number is compared with threshold T (n) value. If the generated value becomes less than threshold T (n), then the nodes are selected as CHs. Following formula is used to set threshold value as described in (Heinzelmen et al., 2000).

$$T(n) = \begin{cases} \frac{P}{1 - P * (r \bmod \frac{1}{P})} & \text{if } n \in G \\ 0 & \text{if } n \notin G \end{cases} \quad (1)$$

Here p is the recommended percentage for CHs; While G is the set of those nodes which have not performed the role of CHs in the previous 1/p rounds. r represents the current round. Nodes becoming CH in the existing round will be able to become CH after 1/p rounds. After becoming CH, each CH announces its status by broadcasting through CSMA /CA protocol. Sensor nodes other than CHs form clusters by selecting their CHs on the basis of received signal strength indication (RSSI) of different CHs which have advertised their status. Nodes send the message of join-request containing their CHs IDs. This way clusters are created; now CHs sends TDMA schedule to their cluster members. This way setup phase is completed after the formation of clusters and all cluster members get their time slots. Now Steady state phase begins and sensor nodes communicate to their CH during allocated time slots only and remain in sleep mode otherwise. These sensor nodes send all the data to their CHs where CH sends the data to the BS after aggregating the data. First-order wireless transmission model which gives us the values of transmitted Energy (E_{Tx}) and received energy (E_{Rx}) is given in figure 3 (Vallalba et al., 2009).

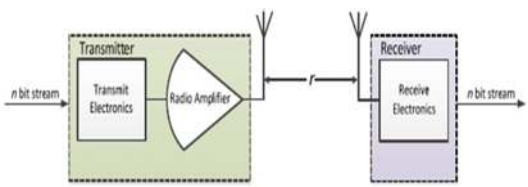

Figure 3: Radio Model [13]

$$E_{Tx}(l, d) = \begin{cases} lE_{elect} + l\epsilon_{fs} d^2 & d \le d_o \\ lE_{elect} + l\epsilon_{mp} d^4 & d \ge d_o \end{cases} \quad (2)$$

$$E_{Rx} = L.E_{elect} \quad (3)$$

Where E_{elect} is the energy dissipated for transmitting or receiving *l* bit message; is the amplification coefficient of free-space signal and ε_{mp} is the multi-path fading signal amplification coefficient, their value depend on the distance (d) between transmitter and receiver.

Simulation

Matlab7.0 is used as simulation platform to Emulate LEACH protocol. Following network parameters are defined in the MATLAB environment. These network parameters can be adjusted according to WSNs application.

Table 1: Network Parameters

Parameter	Definition
A	Area of Sensor Network
N	Number of Sensor Nodes
R	transmission radius
L	Message Length
BS	Base station
d	Distance between source and sink node

Following Radio parameters are considered while emulating protocol.

Table 2: Radio parameters

Parameter	Definition	Value
E_{elec}	Energy Dissipation	*50nJ/bit*
Efs	Free space model	$10pJ/bit/m^2$
E_{mp}	Multi-path model	$0:0013pJ/bit/m^4$
l	Data length	*2000 bits*

Following view gives us MATLAB environment showing randomly placed sensor nodes. There are two different forms of nodes shown in the figure 4. Circle dots are those nodes which start dying with the passage of the time, while plus sign nodes show alive nodes

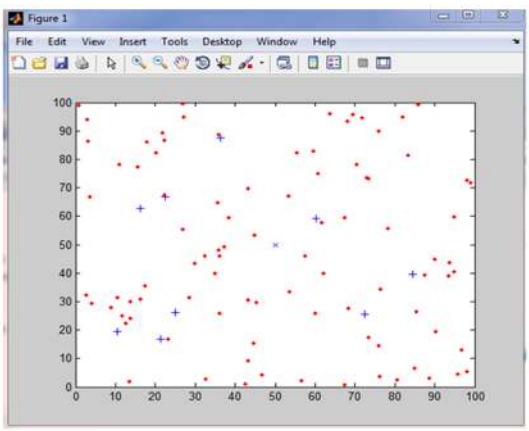

Figure 4: 100 Nodes randomly deployed in the MATLAB Environment

Sensor nodes try to retain their energy for maximum period of time whereas entire network dies after a long period as compared to flat routing protocols. This Paper gives some advantages and disadvantages of LEACH protocol in the next section.

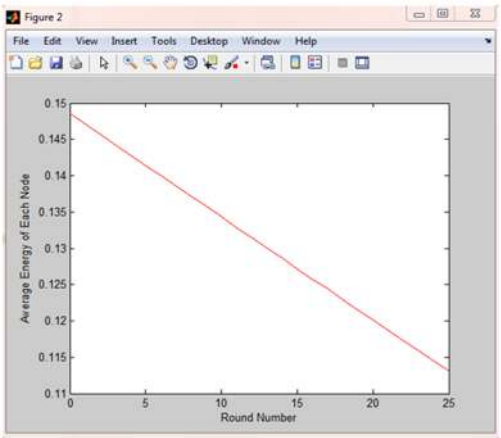

Figure 5: Number of rounds vs average cumulative energy of node

LEACH Advantages

-It performs data aggregation at CHs node by reducing number of data transmission to base station.

-It introduces communications to CHs by reducing the number of direct transmission to BS.

-It increases the lifetime of the nodes by rotating the role of CHs randomly.

-It reduces energy consumption by allowing the sensor nodes that are not CHs to sleep till their time slot comes.

-LEACH helps network to be scalable and robust.

LEACH Disadvantages

-Radom selection of Cluster heads (CHs) does not ensure optimal number and proper distribution of cluster.

-Low and high remaining energy nodes have same probability to become CH. Therefore CH formation from low energy node causes the network to die early.

CONCLUSION

After analyzing Flat and Hierarchical routing protocols, this paper concludes by comparing the two routing schemes given in table 3.

Table 3: Comparison between Flat and Hierarchical routing

Flat routing	Hierarchical routing
Scheduling due to Contention	Scheduling due to Reservation
Collisions present	Avoid Collisions
Duty cycle is variable as sleep time of nodes is controlled.	Duty cycle is reduced as sleeping is periodic.
Adding complexity contributes to Optimal Routing.	Routing is not optimal ,Simple routing
No synchronization on links	Synchronization at global and local level
Routes exist in regions of interest having data	Cluster formation causes overhead
Latency exists in forming multipath path	Relatively low latency due to parallel cluster-heads availability
Traffic pattern cause Energy dissipation	Same controllable Energy dissipation , No effect of traffic pattern
Fairness may not be assured	Channel allocation is fair.

It is obvious that hierarchical routing protocols extend network lifetime by decreasing energy consumption but flat routing protocols are also preferred in the time critical applications and the application having short communication distance. Query-driven and event-driven data delivery models are not comfortable with hierarchical routing protocols.

REFERENCES

- Pantazis, Nikolaos, Nikolidakis SA and Vergados DD. (2013). Energy-efficient routing protocols in wireless sensor networks: A survey. *Communications Surveys & Tutorials, IEEE.* 15(2): 551-591.
- Feng, Daquan, Jiang C, Lim G, Cimini LJ, Feng G and Li GY. (2013). A survey of energy efficient wireless communications. *Communications Surveys & Tutorials, IEEE.* 15(1):167-178.
- Spachos, Petros, Periklis Chatzimisios, and Dimitrios Hatzinakos.(2012). Energy aware opportunistic routing in wireless sensor networks. In *Globecom Workshops (GC Wkshps), IEEE*. 405-409.
- Al-Karaki, Jamal N, and KamalAE. (2004). Routing techniques in wireless sensor networks: a survey. *Wireless communications, IEEE.* 11(6): 6-28.
- Qayyum, Bushra, Mohammed Saeed and Roberts JA. (2015). Data aggregation in wireless sensor networks with minimum delay and minimum use of energy: A comparative study. In Electronic Workshops in computing (eWiC) BCS International IT Conference papers. British Computer Society.
- Meguerdichian S, Koushanfar F, Potkonjak M and Srivastava MB. (2001). Coverage Problems in Wireless Ad-hoc Sensor Networks, IEEE INFOCOM.
- Pathan AK, lee HW and Hong CS. (2006) Security in wireless sensor networks: Issues and challenges, IEEE ICACT.
- Zabin F, Misra S, Woungang I, Rashvand HF, Ma NW, Ali MA. (2008). REEP:data centric, energy efficient and reliable routing protocol for wireless sensor networks. *IET Communications.* 2(8):995-1008.
- Boyinbode, Olutayo, Le H and Takizawa M. (2011). A survey on clustering algorithms for wireless sensor networks. *International Journal of Space-Based and Situated Computing*. 1(2-3) :130-136.
- Heinzelman W, Chandrakasan A and Balakrishnan H. (2000). Energy-efficient communication protocol for wireless sensor networks. *Proc. of Hawaii Int. Conference System Sciences,* Hawaii.
- Rajeshwari P, Shanthini B and Prince M. (2015). Hierarchical Energy Efficient Clustering Algorithm for WSN.
- Biradar, Rajashree V, Patil VC, Sawant SR and Mudholkar RR. Classification and comparison of routing protocols in wireless sensor networks. (2009). *Special Issue on Ubiquitous Computing Security Systems.* 4(2): 704-711.
- Villalba LJG, Orozco ALS, Cabrera AT and Abbas CJB. (2009). Routing protocols in wireless sensor networks. *Sensors.* 9(11):8399-8421.