Study of Different Communication Protocols for Wireless Sensor Networks

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ABSTRACT
In Wireless Sensor Network (WSN) the sensor nodes are very much sensitive to the energy consumption. The success of the wireless sensor network applications highly depends on the reliable communication among the sensor nodes. One of the major problems in WSN environments is the limitation of the physical resource that is energy resources. More energy is consumed in transmission of data from sensor nodes to the destination that is the base node. Due to change in environmental conditions and energy available with nodes there may be change in network structure; therefore dynamic clustering is essential. Apart from existing protocol, improved protocols are needed so that energy consumption can be reduced and overall performance can be improved. This paper considers various protocols for energy efficient data gathering in WSN. The performance of WSN with respect to various parameters is studied.

Keywords
Wireless sensor network, dynamic clustering, cluster head, energy efficiency, routing.

1. INTRODUCTION
Sensor nodes are used for the monitoring/detection of different events in environment Data is collected from these nodes and sent to a base station (BS) which is further connected to internet. Base station give commands to these nodes and gather the sensed data from the nodes, which is then accessible through the internet. To avoid redundancy smart sensor nodes sense the physical phenomenon, do the local data aggregation, some local processing and transmit the sensed data to the base station.

WSN's have been used for many applications like military surveillance, disaster management, forest fire detection, seismic detection, habitat monitoring, biomedical health monitoring, inventory tracking, animal tracking, hazardous environment sensing and smart spaces [5]. Recent advances in MEMS-based sensor technology, low-power analog and digital electronics, and low-power RF design have enabled the development of relatively inexpensive and low-power wireless sensors. But still senor nodes have very limited battery power and random deployment in difficult terrain; make it almost impossible to recharge/replace the dead battery. So, battery power in WSN is considered as scarce resource and should be used efficiently [1].

Sensor node consumes battery in sensing data, receiving data, sending data and processing data. The most energy-consuming component is the R/F module that provides wireless communications. Consequently, Out of all sensor node operation, sending/receiving data consumes more energy than any other operation. The energy consumption when transmitting 1 bit of data on the wireless channel is similar to energy required to execute thousands of cycles of CPU instructions [2]. Therefore, the energy efficiency of the wireless communication protocol largely affects the energy consumption and network lifetime of wireless sensor networks.

In clustering, the whole sensor network is divided into small regions known as cluster. In each cluster, one node is elected as Cluster Head (CH). Elected CH is responsible for aggregating sensed data from its cluster member node(s) and propagate/forward it to base station or to the next CH. As CH has to relay the data of all member node(s), and will deplete energy if continuously selected as a CH. So, the phenomenon of CH selection is periodically divided in rounds [8]. In each round, responsibility of CH is alternatively taken by different cluster member node(s) in a cluster. New CH is selected randomly or based on the parameters like residual energy, distance from base station, connected nodes, topology etc [4]. For forwarding data to the BS, CH is multi-hop CH communication. In which every CH sends sensed data to other CH in its neighborhood which near to the BS. In this way sensed data is forwarded by CH's using multi-hop communication and ultimately it reaches the BS.

2. NON CLUSTER BASED PROTOCOLS
When the sink node is far away from the source node multi-hop communication is needed. For determining the path and updating the path in case of discovery of a better path or loss of current path various techniques are used. Following are some commonly used protocols with their benefits and drawbacks.

2.1 AODV (Ad-hoc on-Demand Distance Vector)
AODV is a method of routing messages between mobile computers. It allows these mobile computers, or nodes, to pass messages through their neighbors to nodes with which they cannot directly communicate. AODV does this by discovering the routes along which messages can be passed. AODV makes sure these routes do not contain loops and tries to find the shortest route possible [2]. AODV is also able to handle changes in routes and can create new routes if there is an error. The diagram to the left shows a set up of four nodes on a wireless network. The circles illustrate the range of communication for each node. Because of the limited range, each node can only communicate with the nodes next to it [3]. AODV is one of the most efficient routing protocols in terms of establishing the shortest path and lowest power consumption. It is mainly used for ad-hoc networks but also in wireless sensor networks. It uses the concepts of path discovery and maintenance. However, AODV builds routes between nodes on demand i.e. only as needed. So, AODVs' primary objectives are:

1. To broadcast discovery packets only when necessary,
2. To distinguish between local connectivity management (neighborhood detection) and general topology maintenance,
3. To disseminate information about changes in local connectivity to those neighboring mobile nodes that are likely to need the information.

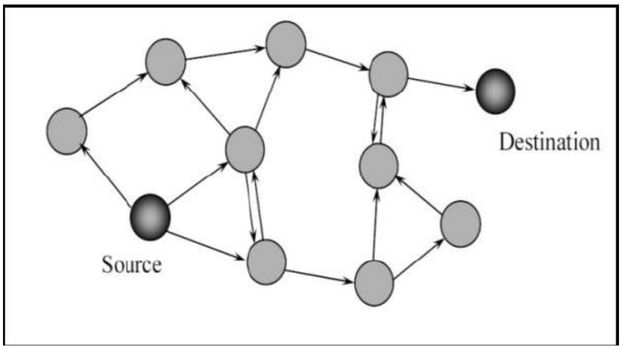

Figure 1: Route Request (RREQ) broadcast flood

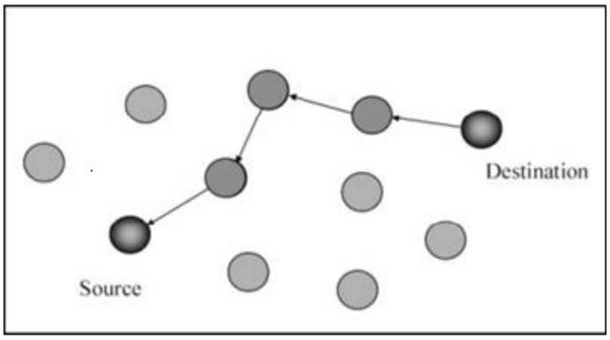

Figure 2: Route Reply (RREP) propagation

AODV Characteristics

- Will find routes only as needed.
- Use of Sequence numbers to track accuracy of information.
- Only keeps track of next hop for a route instead of the entire route.
- Use of periodic HELLO messages to track Neighbors.

Pros

- The AODV routing protocol does not need any central administrative system to control the routing process.
- Reactive protocols like AODV tend to reduce the control traffic messages overhead at the cost of increased latency in finding new routes.

Cons

- It is possible that a valid route is expired.
- The performance of the AODV protocol without any misbehaving nodes is poor in larger networks.
- There is lot of energy wastage in finding the route

2.2 DSDV (Destination-sequenced Distance Vector)

Destination-Sequenced Distance Vector routing protocol (DSDV) is a typical routing protocol is based on the Distributed Bellman-Ford algorithm [2]. In DSDV, each route is tagged with a sequence number which is originated by the destination, indicating how old the route is. Each node manages its own sequence number by assigning it two greater than the old one (call an even sequence number) every time. When a route update with a higher sequence number is received, the old route is replaced. In case of different routes with the same sequence number, the route with better metric is used. Updates are transmitted periodically or immediately when any significant topology change is detected. There are two ways of performing routing update: “full dump”, in which a node transmits the complete routing table, and “incremental update”, in which a node sends only those entries that have changed since last update. To avoid fluctuations in route updates, DSDV employs a "settling time" data, which is used to predict the time when route becomes stable. In DSDV, broken link may be detected by the layer-2 protocol or it may instead be inferred if no broadcasts have been received for a while from a former neighboring node.

DSDV Characteristics

- Proactive - based on Bellman – Ford.
- Packets transmitted according to the routing table.
- Each node maintains routing table with entry for each node in the network.
- Each node maintains its own sequence number.
- Updates at each change in neighborhood information.
- Used for freedom from loops.
- To distinguish stale routes from new ones.

Pros

- Proactive Routes maintained through periodic and event triggered routing table exchanges.
- All available information is transmitted.

Cons

- Frequency of transmitting full updates is reduced if the volume of data begins to consume significant bandwidth.

2.3 Sensor Protocols for Information via Negotiation (SPIN)

This protocol uses the idea of distributing only the data that other nodes do not have, assuming the nodes in close proximity have similar data. Thus nodes avoid sending redundant data. Protocol starts when SPIN node gathers new data. Node broadcasts an ADV message containing metadata of newly obtained data. Any neighbor interested in that data sends a REQ message. After that the actual DATA is sent to neighbor node. Operation of SPIN network is illustrated in figure 2. SPIN has access to the current energy level of the node and adapts the protocol it is running based on how much energy is remaining.

SPIN is more energy-efficient than flooding or gossiping while distributing data at the same rate or faster than either of these protocols.

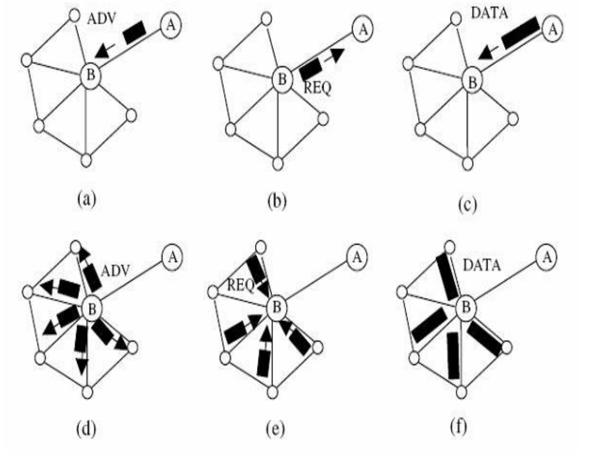

Figure 3: The SPIN protocol.

Important advantage of SPIN protocol is that each node only knows its single-hop neighbors therefore topological changes in network localized, i.e. does not affect whole network. On the other hand, SPIN protocol does not guarantee delivery of data because intermediate nodes between source and destination nodes may not be interested in advertised data, therefore such data may not be forwarded to destination.

Pros:

- Topological changes in network does not affect whole network due to single hop transmission.
- Only interested nodes participate in the communication.
- More energy-efficient than flooding or gossiping.

Cons:

- Does not guarantee delivery of data because intermediate nodes between source and destination nodes may not participate in communication.

2.4 Reliable and energy efficient protocol (REEP)

Data centric routing can be categorized as a query based routing protocol which relies on the query given by the sink(Base Station) [1]. In sensor network environment, the identification of each participant is difficult since the large number of nodes can be deployed in the sensor field. Hence, selection on specific node for any queries will be difficult. Nevertheless, requesting data from specific node in wireless sensor network can be achieved using region method. The sink will send queries to the target location and nodes in the selected location will reply with the information needed. Reliable and energy efficient protocol (REEP) has been proposed to provide path selection with energy saving in data centric protocol. Basically, REEP was designed based on existing routing protocol for sensor network which is directed diffusion (DD) where the data requested by the sink is based on interest on named data which is called attribute-value pairs.

REEP consists of 5 important elements where each of the elements plays an important role whether on the sink node or source/intermediate nodes. REEP assumes the network topology as each network communicates between their neighbors and is only considered as multi-hop communication. The elements are:

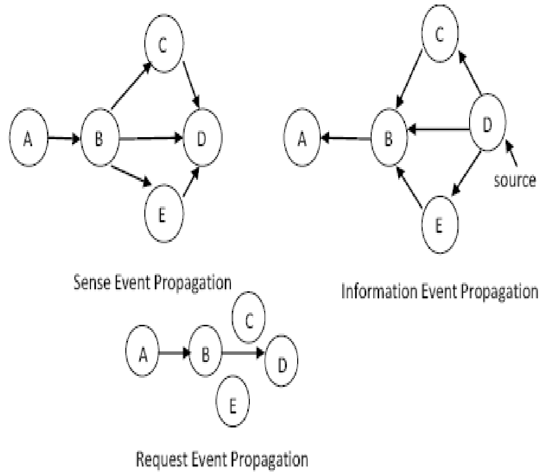

Figure 4: Phases in constructing routing path for data transmission

Sense event: A query which is executed by the sink node to initiate sensing process to all nodes.
Information event: In responding to the sense event, the source node will generate the information which contains the location of source node and the type of object data.
Request event: Sink node will generate request event once it receives the information from the source node. A path will be created by this event to send the real data from source node.
Energy threshold value: To select which node is to participate on transmitting the real data. If the node energy is below the threshold value, the node will simply reject it.
Request priority queue (RPQ): The element in each node which is responsible to establish a path setup where it needs to select their neighbor based on the information event list.

Using these five elements, REEP consists of three phases in constructing routing path for data transmission from the source to the sink node. Figure 4 illustrates the phase processes which are the sense event propagation, information event propagation and request event propagation. In sense event propagation, the sink node will be initiated with a query from the user to request specific data. Each sense event initiation will include the location of sink node, timestamp and the duration. Sink node generates the sense event and broadcasts to all its neighbors where node A acts as a sink node and broadcasts its sense event information to the neighboring nodes. Node B receives the sense event and activates its sense device to collect data from its sensing range. The received sense event by node B is checked with its cache to confirm whether the sense event is new based on the timestamp given by sink node. Each node will save the current sense event and overwrites the previous sense event. Node B will also send the sense event to all its neighbors which are C, D and E. Information event propagation is to send information to the sink node which consist the node sensing information. Node D sends its information event to the sink node where node D broadcasts to all its neighbors. Request event propagation will create a path for routing where in request event propagation; each node will be evaluated of their energy threshold to validate whether the node is ready to participate in routing path. REEP considers the energy in energy threshold value where each node is examined whether the energy value is less than the threshold or not. If the result shows the value is lower than the threshold, the nodes will be exempted from taking place as a route path in routing selection. The problem arisen from this scenario is the energy problem which is only considered on the current status energy value in sensor nodes. Thus it does not focus on how to reduce the energy consumption by each sensor node.

Pros:

- It considers the energy status of the nodes and selects nodes with sufficient energy for transmission.
- Guarantees proper transmission along the route.

Cons:

- It does not concentrate on how to reduce the energy consumption by a node.

3. CLUSTERING PROTOCOLS

In case of non-clustering protocols more energy is needed finding the path from source to sink in multi-hop communication since the WSN consist of large number of nodes and more energy is consumed in transmitting and receiving the data as compared to other processing done. Therefore we can use cluster based (Hierarchical) protocols in which the set of nodes are divided into different groups called clusters. For each cluster a cluster head is selected which is responsible for all the communication between the nodes in the cluster and the base station. The nodes in the cluster send their data to CH and CH sends it to the base station. Thus in two hops data can be communicated to the sink node. This concept helps in reducing the energy consumption during transmission of data thereby increasing the life of the overall network. Following are the major hierarchical routing approaches.

3.1 LEACH (Low-energy Adaptive Clustering Hierarchy)

LEACH is hierarchical routing approach for sensors networks. The idea proposed in LEACH has been an inspiration for many hierarchical routing protocols, although some protocols have been independently developed [2].

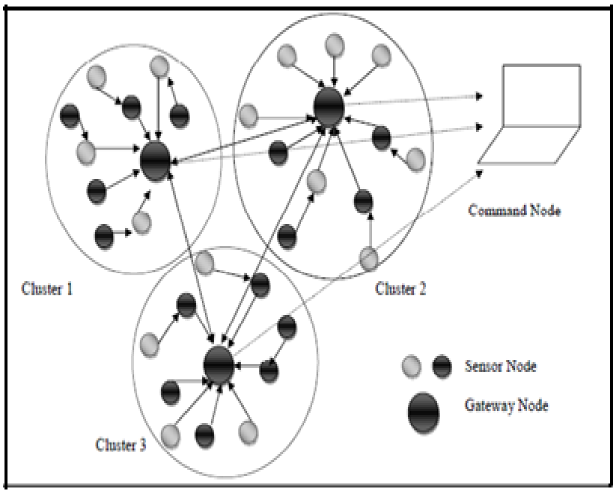

Figure 5: Hierarchical or cluster-based routing

The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. Cluster formation is typically based on the energy reserve of sensors and sensor's proximity to the cluster head.

Hierarchical or cluster-based routing, 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. In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used for routing. LEACH randomly selects a few sensor nodes as cluster heads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network [2]. In LEACH, the cluster head (CH) nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the base station in order to reduce the amount of information that must be transmitted to the base station. LEACH uses a TDMA/CDMA MAC to reduce inter-cluster and intra-cluster collisions. However, data collection is centralized and is performed periodically. Therefore, this protocol is most appropriate when there is a need for constant monitoring by the sensor network. A user may not need all the data immediately. Hence, periodic data transmissions are unnecessary which may drain the limited energy of the sensor nodes. After a given interval of time, a randomized rotation of the role of the CH is conducted so that uniform energy dissipation in the sensor network is obtained. The operation of LEACH is separated into two phases, the setup phase and the steady state phase [4]. In the setup phase, the clusters are organized and CHs are selected. In the steady state phase, the actual data transfer to the base station takes place. The duration of the steady state phase is longer than the duration of the setup phase in order to minimize overhead.

During the setup phase, a predetermined fraction of nodes, p, elect themselves as CHs as follows. A sensor node chooses a random number, r, between 0 and 1. If this random number is less than a threshold value, T(n), the node becomes a cluster head for the current round. The threshold value is calculated based on an equation that incorporates the desired percentage to become a cluster-head, the current round, and the set of nodes that have not been selected as a cluster-head in the last (1/P) rounds, denoted by G. It is given by:

$$T(n) = \frac{p}{1-p\left(r \bmod \left(\frac{1}{p}\right)\right)} \quad \text{if } n \in G$$

Where G is the set of nodes that are involved in the CH election. Each elected CH broadcast an advertisement message to the rest of the nodes in the network that they are the new cluster-heads.

All the non-cluster head nodes, after receiving this advertisement, decide on the cluster to which they want to belong to. This decision is based on the signal strength of the advertisement. The non cluster-head nodes inform the appropriate cluster-heads that they will be a member of the cluster. After receiving all the messages from the nodes that would like to be included in the cluster and based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule and assigns each node a time slot when it can transmit. This schedule is broadcast to all the nodes in the cluster. During the steady state phase, the sensor nodes can begin sensing and transmitting data to the cluster-heads. The cluster head node, after receiving all the data, aggregates it before sending it to the base-station. After a certain time, which is determined a priori, the network goes back into the setup phase again and enters another round of selecting new CH. Each cluster communicates using different CDMA codes to reduce interference from nodes belonging to other clusters.

Pros

- Distributed and no global knowledge of network required.

Cons

- Extra overhead to do dynamic clustering.

3.2 Energy Efficient Multi Hierarchy Clustering Protocol (EMHC)

In most of the currently algorithm in cluster head selection algorithm optimization is done on single parameter which can be residual energy, distance from the BS, connected nodes, coverage etc. But optimization of one parameter results in the performance degradation in other parameter, as the other parameter(s) are not considered. For instance, if in cluster head selection residual energy is considered as optimization parameter, it may optimize the life time of the network, but it will compromise the coverage of the network and vice versa. To address these problems Energy Efficient Multi Hierarchy Clustering Protocol for Wireless Sensor Network (EMHC) is used [5]. It proposes the use and effectiveness of introducing extra capability nodes in the network to cater hotspot problem and to increase the lifetime of a sensor. It also proposes the use of coverage along with energy as selection parameter for CH. It tackles energy efficiency problem and two algorithms for CH selection and sleep wakeup scheduling are used.

It uses 7 phases for the operation of the network. Some are for setup and others are for actual communication. They are as follows:

- **Setup Phase Initialization:** Each node determines its residual energy i.e. battery power left and location in which it lies after random deployment. Residual energy and distance to the BS are used for cost calculation in cluster formation.
- **Setup phase Route Update:** maintains the route information which is used in later phases for inter clustering communication.
- **Setup Phase Cluster Head Selection:** *R*esidual energy as well as coverage are used as CH selection parameter. Nodes are classified in two types i. e. normal nodes and critical nodes. During CH selection the critical nodes do not participate so that coverage problem will not arise.
- **Steady Phase Sensor Activation:** Once CH is selected for a specific cluster and all the node in the cluster are already known to the CH. Now based upon energy efficiency and coverage, CH define sleep/wakeup schedule for nodes in each round. The sensor nodes which are redundantly covering the same area are alternatively made to sleep and wakeup.
- **Setup Phase TDMA Schedule:** After CH has done the sleep/wakeup scheduling, then, selected CH assign the time slots to all the nodes in cluster i.e. slots when the member cluster nodes can send the sensed data to the CH. CH gives fixed TDMA slots to the member cluster nodes.
- **Steady Phase Intra-cluster Communication (Forwarding to cluster head):** It involves how a sensor node should send a sensed data to its CH. It uses single hop communication.
- **Steady Phase Inter-cluster Communication (Forwarding to sink):** For forwarding data to the sink/base station (BS), it uses the technique in which each cluster head send data to the next cluster head and so on. Ultimately nodes nearest to the base station send data directly to the base station.

Using two algorithms for CH selection and sleep wakeup scheduling these phases tackles energy efficiency problem and coverage problem. It also increases the life time of the network.

4. CONCLUSION

For small sized WSNs the use of non cluster based algorithms can be used. AODV protocol has better results than the DSDV protocol. AODV will find routes only as needed and keeps track of only next hop for a route instead of the entire route. DSDV maintains the entire set of routes in the routing tables which are dynamically updated. In case of SPIN protocol topological changes in network does not affect whole network due to single hop transmission and its more energy-efficient than flooding or gossiping. In REEP protocol it considers the energy status of the nodes and selects nodes with sufficient energy for transmission. It guarantees proper transmission along the route but does not concentrate on how to reduce the energy consumption by a node. For large networks hierarchical protocols will be more suitable. Out of the LEACH and EHMC protocols EHMC has better throughput and lower energy requirement for packet transmission as compared to LEACH protocol.

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