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Energy Efficient and Scalable Routing Protocols for WSN: A Survey

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***Abstract* - Routing is a process of selecting a path between two or more communicating devices. Routing in terms of Wireless Sensor Networks (WSN) is to make communication possible between autonomous sensor nodes. Many routing protocols are designed and implemented for WSNs. The design of these routing protocols is influenced by many factors like performance, accuracy, lifetime, Quality of Services, Security, synchronization and scalability. In this paper, we represent a survey of different cluster based routing techniques which focus on Energy Efficiency and Scalability. Energy efficiency is important factor of many WSN protocols as motes are coming with limited battery. Power consumption depends on routing techniques, number of nodes and area of network. The scalability factor is also considered as one of these important factors. Scalability is defined as ability to handle growing number of users in a network .The sensor networks scalability is the ability to support network expansion for including more nodes.**

Key words - WSN, Wierless Sensor Networks, WSN Protocols, Energy Efficient Protocols, Scalable Protocols

I. INTRODUCTION

A wireless sensor network is an ad-hoc network consisting of geographically distributed autonomous sensor nodes which are equipped with a radio transceiver, a microcontroller, an energy source and a sensor, to co-operatively monitor physical or environmental conditions. Each sensor node has sensing, computing, and wireless communication capability. A wireless sensor network consists of a large number of sensor nodes. These nodes have the ability to communicate with each other. Sensor nodes are required to communicate with one another to aggregate information about physical environment like temperature, sound, pressure and pollutants. Sensor nodes are deployed in the sensing area to monitor specific targets and collect data. Then, the sensor nodes send the data to sink or base station (BS) by using the wireless transmission technique.

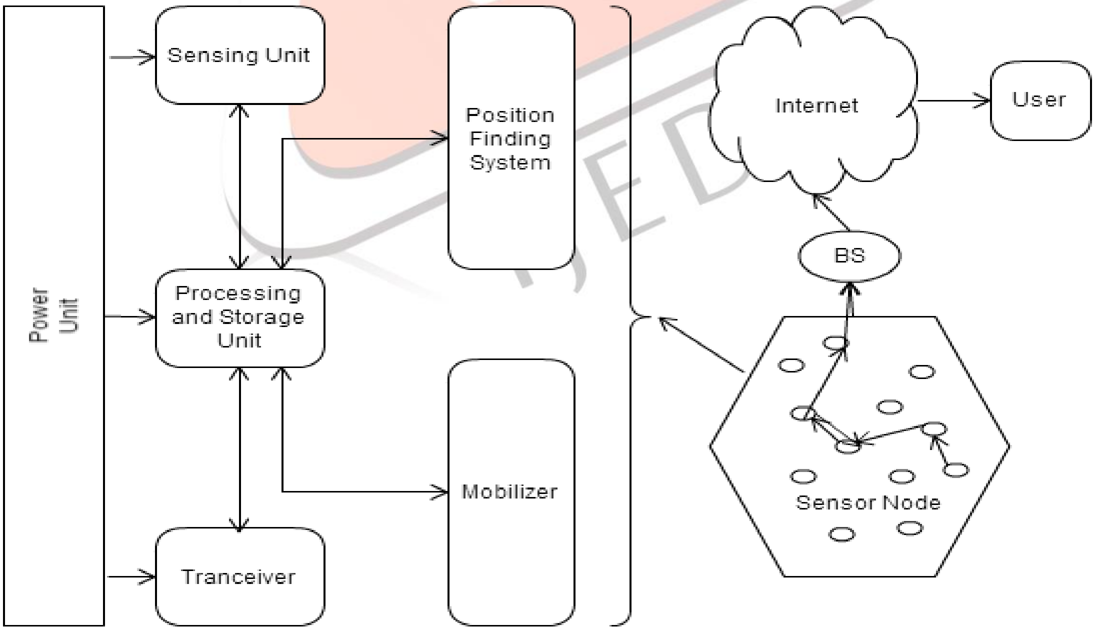

Figure 1: The components of a sensor node

Now-a-days there is a rapid growth in the wireless communication technique. Many protocols and techniques have been implemented and still research is going on. These techniques are described on the basis of different parameters like low energy adaptive, shortest path, good routing techniques and many more. Routing protocols should provide the scheme which avoid degrading the performance of the wireless sensor networks as the network expands. The evaluation of the scalability issue with wireless sensor networks is a real challenge due to the variety of routing protocols, the large nodes number, and the wide range of sensor networks applications.

Routing is a process of determining a path between source and destination upon request of data transmission. In WSNs, the network layer is mostly used to implement the routing of the incoming data. It is known that generally in multi-hop networks the source node cannot reach the sink directly. So, intermediate sensor nodes have to relay the packets on behalf of them. The implementation of routing tables gives the solution. These contain the lists of next hop node option for any given packet destination. Constructing the routing table is the task of the routing algorithm.

This paper contains three sections, First section includes Energy efficient protocols overview, Second phase contains Scalable algorithms and Third phase gives comparison parameters of protocols included in first two phases.

II. Energy Efficient and Scalable Routing Protocols

To make communication and data transfer possible in WSN, there is plenty of algorithm, techniques and methods are implemented. Here some of the energy efficient and scalable routing protocols are discussed. Some of them are to be used in scalable and energy efficient protocol development.

III. Low Energy Adaptive Clustering Hierarchy

Heinzelman, et.al [6] introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH arranges the nodes in the network into small clusters and chooses one of them as the cluster-head. Node first senses its target and then sends the relevant information to its cluster-head. Then the cluster head aggregates and compresses the information received from all the nodes and sends it to the base station. The nodes chosen as the cluster head drain out more energy as compared to the other nodes as it is required to send data to the base station which may be far located. Hence LEACH uses random rotation of the nodes required to be the cluster-heads to evenly distribute energy consumption in the network. After a number of simulations by the author, it was found that only 5% of the total number of nodes needs to act as the cluster-heads.

LEACH Operation

LEACH operations can be divided into two phases:-

1. Setup phase
2. Steady phase

In the setup phase, the clusters are formed and a cluster-head (CH) is chosen for each cluster. While in the steady phase, data is sensed and sent to the central base station. The steady phase is longer than the setup phase. This is done in order to minimize the overhead cost.

1. Setup phase - During the setup phase, a fixed part of nodes, p, choose themselves as cluster-heads. This is done according to a threshold value, T(n). The threshold value depends upon the desired percentage to become a cluster-head- p, the current round r, and the set of nodes that have not become the cluster-head in the last 1/p rounds, which is denoted by G. The formula is as follows:

$$T(n) = \frac{p}{1-p\times(r\times mod\frac{1}{p})} \;\forall n \in G$$

2. Steady phase - During the steady phase, the sensor nodes i.e. the non-cluster head nodes starts sensing data and sends it to their cluster head according to the TDMA schedule. The cluster head node, after receiving data from all the member nodes, aggregates it and then sends it to the base-station.

After a specific time, which is determined a priori, the network again goes back into the setup phase and new cluster-heads are chosen. Each cluster communicates using different CDMA codes in order to reduce interference from nodes belonging to other clusters.

Divide and Rule Scheme

DR scheme is based on static clustering and minimum distance based CH selection. Network area is logically divided into small regions (clusters). These regions are abbreviated as NCR1, NCR2, NCR3, etc. as shown in figure 2 [3].

Nodes in each region select a Cluster Head (CH) except the region closest to the BS, that is, region R1. Nodes whose coordinates lie within the perimeter of R1, communicates directly with BS. Selection of CHs in rest of the regions is based on reference point in each region; reference point is the mid-point of each region. Node closest to reference point is selected as CH first, then next closest node and so on till least close node. In each round only one CH is selected in each region furthermore, we uses multi-hop technique for inter region communication to reduce communication distance. DR scheme has the ability to select CH independent of random number and minimize communication distance to almost less than or equal to reference distance. DR scheme uses hybrid theme of static clustering and dynamic CH selection. [3]

Regions

In first step, network is divided into **n** equal distant concentric squares. For simplicity, we take **n = 3** here therefore, network is divided into three equal distance concentric squares: Internal square **(Is)**, Middle square **(Ms)** and Outer square **(Os)**. BS is located in the centre of network field; therefore its coordinates are taken as reference point for formation of concentric squares. Division of network field into concentric squares can be shown by following figure 2 .

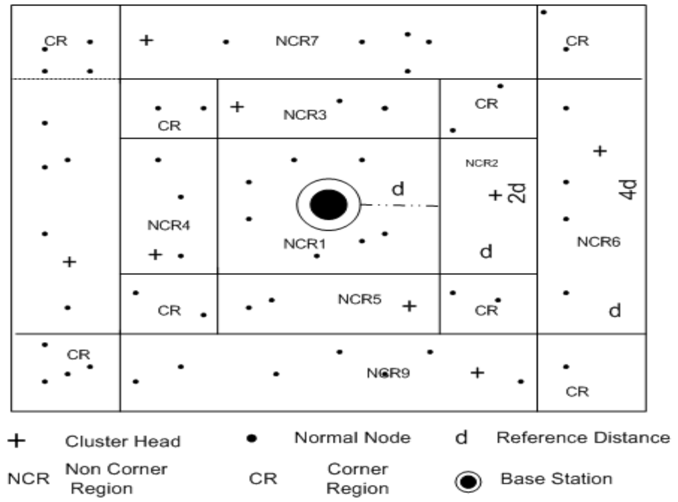

Figure 2: Formation of Regions[3]

Protocol Operation in Setup Phase

BS divides the network field into small regions, on the bases of their co-ordinates. Is nodes send data directly to BS. In each region one CH is selected per round. CHs of Os regions, select front neighboring CHs of MS regions as their next hop CH. Nodes of CR selects, BS or neighbouring CHs as their CH, based on minimum distance. If a tie occurs, for a node of CR, in selection of CH from its neighbouring regions than, it is resolved by selecting the CH with greater residual energy. In steady state phase each node send its data to CH in its allocated time slot. Primary level CHs send aggregated data to their respective secondary level CHs. Secondary level CHs then, aggregate all collected data and forward it to BS.

Directed Diffusion LEACH

The user's query is passed by the BS to each of the nodes in the WSN. The user’s query travels all through and the same is compared with the event record stored in the node. If the event record matches with the query, then the data is sent to the BS otherwise the same query is passed onto its neighbouring nodes. The query for which data is to be collected from a sensor network is diffused (broadcast, geographically routed) in the entire network.

When a node in that region receives a query, it activates its sensors which begin collecting data about the specified task. When the nodes detect the specific data, the same is reported back by following the reverse path of query propagation. Directed diffusion consists of several elements: interests, data messages, gradients, and reinforcements. An interest message is a query which specifies what a user wants. Each interest message contains a description of a specific sensing task that is supported by the WSN. Data in WSN's is collected or processed information of a physical phenomenon. Such data can be an event which is a short description of the sensed data. The specific task description, the interest or the query is usually injected into the WSN via its BS [4].

Two - Level LEACH (TL-LEACH)

In LEACH, every CH node needs to communicate to the BS directly. Only very few CH nodes can be in close proximity to the BS. The distant CH nodes need to increase their power levels so as to reach the BS causing further energy drain. In order to extend the lifetime of the WSN, it is needed to reduce the number of nodes communicating to the BS directly. The CH's elected during the setup phase of LEACH do not communicate directly. Another level of CH among the first level CH's is introduced. One among the first level CH’s is elected as the second-level CH and this second-level CH communicates to the BS directly. Thus a two-level structure consists of leaf nodes, first level CH's and second level CH’s [4]. The first-level CH's gather data from their respective cluster members, aggregate and transmit the same to their respective second level CH's, which also aggregate the received data again and send the same to the BS directly.

IV. ROUTING PROTOCOLS FOR SCALABILITY EVALUATION

The many proposals from point to point routing in ad-hoc wireless networks can broadly divide into four very different categories.

The BVR (Beacon Vector Routing) Algorithm

To provide scalable greedy forwarding BVR defines a set of coordinates and a distance function. These coordinates are lies in reference to a set of beacons. Which are a small set of random nodes; using a fairly standard reverse path tree construction algorithm every node learns its distance, in hops, to each of the beacons. A node's coordinates is a vector of these distances. On the occasion that greedy routing with these coordinates fails, we use a correction mechanism that guarantees delivery.

Consider **qi** denote the distance in hops from node **q** to beacon **i**. Let **r** be the total number of beacon nodes. We define a position **P(q)** of a node **q** as being the vector of these beacon distances: **P(q) = (q1,q2,..,qr).** Two nodes can have the same coordinates, so we always maintain a node identifier to disambiguate nodes in such cases. Neighbour’s positions must be known to each node to make routing decisions, so nodes periodically send local broadcast messages announcing their coordinates [5].

To route a packet through **p**, we need a distance function **δ(p,d)** on these vectors that measures how good **p** would be as a next hop to reach a destination **d**. The main goal is to route greedily using a function usually results in successful packet delivery. The metric should favor neighbors whose coordinates are more similar to the destination. Minimizing the absolute difference component wise is the simplest such metric. The main importance of implementing this design is that it is more important to move ***towards*** beacons than to move ***away*** from beacons. When trying to match the destination's coordinates, move towards a beacon when the destination is closer to the beacon than the current node; move away from a beacon when the destination is further from the beacon than the current node. Moving towards beacons is always moving in the right direction, while moving away from a beacon might be going in the wrong direction (in that the destination might be on the other side of the beacon). To embody this intuition, we use the following two sums:

$$\delta_k^+(p,d) = \sum_{i \in C_k(d)} \max(p_i - d_i, 0) \quad \text{and}$$

$$\delta_k^-(p,d) = \sum_{i \in C_k(d)} \max(d_i - p_i, 0),$$

Advantages

BVR is procedure to make scalable point-to-point routing possible in wireless sensornets. Its main advantages are; easy to implement on resource constrained nodes like motes, simple and wide range of settings are possible in simulation, at times significantly exceeding that of geographic routing. Implementation results suggest that BVR can survive a testbed environment and thus might be suitable for real deployments.

Scalable Coordination for Wireless Sensor Networks: Self-Configuring Localization Systems

When deployed in large numbers and embedded deeply within large scale physical systems, motes gain the ability to measure aspects of the physical environment in unprecedented detail. Through distributed coordination, pervasive networks of micro-sensors and actuators will revolutionize the ways in which we understand and construct complex physical systems [7].

Explore coordination in wireless sensor networks based on adaptive localized algorithms that exploit both the local processing available at each node as well as the redundancy available in densely distributed sensor networks. We introduce the design themes of density, multiple sensor modalities and adaptation to fixed environments, and show how they can be applied to build self-configuring localization systems will need to determine their relative positions and self-organize into a spatial coordinate system without relying on remote infrastructures such as GPS.

Proximity-based Localization

Such nodes can act as beacons for smaller devices such as the UCB motes that may not have the hardware capability for acoustic ranging. A beacon would periodically broadcast its position. By listening to broadcasts from a collection of nearby beacons and inferring proximity to those beacons with low message loss, each node could estimate its position to be the centroid of its proximate beacons.

Localization is andvantageous as a key building block for sensor network applications and is a sensor network in and of itself. We exemplified three design themes that will be important in wireless sensor networks generally density, multiple sensor modalities for robust measurements and adapting to fixed environmental features.

Improvement in LEACH Protocol for Large-scale Wireless Sensor Networks

Improvement in pre-existing LEACH protocol is known as Far-Zone LEACH (FZ-LEACH). A zone is formed within the cluster based on minimum reachability power (MRP), known as Far-Zone. The idea of MRP is borrowed from HEED. MRP can be considered as communication cost from a node to base station (BS). If MRP from a node to BS is greater than the average minimum reachability power (AMRP), then this node will be considered in Far-Zone. Formation of the Far-Zone can be done only after the process of cluster formation is over. Once Far-Zone is formed, nodes within the Far-Zone select a zone head (ZH) of highest energy. ZH role will be rotated in every round. All nodes within the Far-Zone can directly communicate to the ZH rather than CH. ZH collects and aggregates data from all zone members and forwards to the CH. CH then collects sense data from rest of the nodes (nodes within the cluster but not in Far-Zone) and ZH, aggregates it and transmits to the BS [8].

For large real life deployments of WSNs, it may be the situation that there exist large size clusters. This improvement is well suited for such type of scenarios. One point is also worth mentioning that Far-Zone is formed only when nodes have MRP less than AMRP.

FZ-LEACH Protocol

Vivek Katiyar, Narottam Chand, Gopal Chand Gautam and Anil Kumar proposed a solution to the above mentioned problem by introducing the concept of Far-Zone. The working of algorithm can be divided into two phases.

Far-Zone Formation Algorithm

During the set-up phase, when clusters are being created, each node decides whether or not to become a cluster head for the current round.

Once the cluster head formation is complete, proposed algorithm searches for eligible clusters to form Far-Zone. For formation of Far-Zone each node of the cluster sends its power level to CH. Based on the power levels, CH selects the members for Far-Zone. There are four clusters (A, B, C and D) as shown. In cluster D, nodes residing at distant locations form Far-Zone.

As it is clear that sensor network performs longer with FZ-LEACH in comparison to LEACH. This is due to energy saving in transmission by the sensor nodes in Far Zone LEACH.

Proposed FZ-LEACH algorithm, which is based on the original protocol and considers a Far-Zone inside a large cluster. Simulation results prove the improvement in the performance in the original LEACH protocol in terms of energy dissipation rate and network lifetime. It is found that FZ-LEACH protocol saves around 30% energy of sensor network in comparison to LEACH [8].

Comparison of Energy Efficient and Scalable Routing Protocols

By analyzing and comparing protocols mentioned in table shown below we figured out the energy efficiency and scalability. Parameters like Energy efficiency, sclability and robustness are taken into consideration. Energy Efficiency is a measure of the battery consumpion and how longer network stays alive. Scalability is measure of the size of network and fesible expansion of network. Robustness defines the capability of network to stay fit with changes in environment.

Table 1: Comparison of Energy efficient and Scalable protocols of WSN

Protocols	Enegry Efficiency	Scalability	Robustness	Type
DR Scheme	High	Low	High	Static Clustering
TL-LEACH	High	Mid	Mid	Location Based
DD-LEACH	Mid	Mid	Mid	Location Based
BVR	Mid	Very High	Low	Location Based
Localization	High	Very High	High	Location Based
FZ-LEACH	High	Very High	High	Dynamic Clustering

Table 1 shows that Cluster based protocols like DR scheme and FZ LEACH gives high energy efficiency and robustness, where scalability is low in DR scheme. Location Based protocols like TL-LEACH, DD-LEACH gives mid level robustness and scalability, where TL-LEACH is little more energy efficient than DD-LEACH. Beacon Vector Routing (BVR) and Localizaion gives very high scalability tha other cluster based routing protocols mensioned in the table 1. But Energy efficiency and robustness of BVR is little lower than Localization.

V. Conclusion

In this paper, different clustering protocols/methods are discussed with special emphasis on their cluster head selection and routing strategies. They are compared with respect to their parameters like Energy Efficiency, Scalability and Robustness. The use of these parameters for this comparison is justified by reasoning the effects of cluster head selection and its role rotation on the energy efficiency of the network. Finally it is concluded from the survey that, still it is needed to find and implement more scalable, energy efficient and robust routing scheme for wireless sensor networks.

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