Sensor Network Model for Information Dissemination in Ad Hoc Environment

Shantanu Panwar
IEEE Computer Society
IEEE Member
New Delhi, India
shantanu.panwar.in@ieee.org

Broto Rauth Bhardwaj
Head,Research and Entrepreneurship Cell
Bharati Vidyapeeth University
New Delhi, India
brotobhardwaj@gmail.com

***Abstract*—The random deployments of sensors in remote location have direct impact on the performance, power, connectivity and coverage leading to heavy constraints on design and management of sensors. Therefore the research has earnest proclivity towards the system architecture design issues for wireless ad hoc networks. In this paper, we deal with the reliable and quick information dissemination sensor grid which efficiently manages connectivity and coverage in a location-based scenario has been proposed.[4] Nodes within each other's radio range communicate to form a grid network while the cluster head has to store and process the information of only a few nodes in its grid.[3] The paper analyzes the deployment of sensors and dispensation of data within the autonomous system in a sensor field.**

Keywords—Efficient Coverage Area; Faster Connectivity; Autonomous System; Reflection Power Coefficient; Grid-Based Sensor Network.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) comprises small and low cost sensors with sensing, computation and wireless communication capabilities. A sensor network is a static ad-hoc network where sensor nodes are scattered across sensor fields.[5] These sensors have the ability to communicate either among each other or directly to an external base-station (BS).

Each sensor node comprises sensing, processing, transmission, position finding systems, and power units. Sensors coordinate among themselves to produce high-quality information about the physical environment.[4] Sensor nodes are tightly constrained in terms of energy, processing, and storage capacities and they require efficient resource management.[3] Position awareness of sensor nodes is important since data collection is normally based on the location.

Networking unattended sensor nodes may have great significance on the efficiency in diverse strategically sensitive areas; military and civil applications such as target field imaging, intrusion detection, weather monitoring, security and tactical surveillance, distributed computing, detecting ambient conditions such as temperature, movement, or the presence of certain objects, inventory control, and disaster management.[6] Deployment of the sensor networks in the above applications can be in random fashion (e.g. dropped from an airplane). Networking these sensors can assist in identifying risk prone areas, enabling the security team to adopt proper and timely action to avert any untoward incident.

An intensive research that addresses the potential of collaboration among sensors in gathering, processing, coordination and management of the sensing activity has been conducted.[12] Innovative techniques that eliminate energy inefficiencies that are likely to shorten the lifetime of the network is a necessary requirement.[7]

Each sensor node has transmission power, processing capacity, on-board energy, and memory storage. One of the most active areas of research in WSNs is coverage. Coverage in WSNs is usually defined as a measure of how well and for how long the sensors are able to measure the physical domain of interest. It can be thought of as a measure of quality as a service.[9] In addition to coverage, it is necessary to manage connectivity. Connectivity can be defined as ability of sensor nodes to reach the base station directly or Multihop communication. If there is no available route from a sensor node to the BS then the data collected by that node cannot be processed. For any node to receive data packet from any other node it must lie within the communication range of transmitting sensor.[19] The chief function of sensor is to sense the environment for any occurrence of the event in the zone of interest. Generally, coverage and connectivity problems occur by the limited communication and sensing range. In order to optimize the coverage sensors need to be placed not too close to each other so that the sensing capability of the network is fully utilized and at the same time they must not be positioned too far from each other to eliminate the possibility of communication among neighboring nodes (beyond the range of operation). On the other hand from connectivity point of view, the sensors need to be placed close enough so that they are within each other's communication range.[20] This paper divides the sub-networks within the '*Areas*' into grids and each grid has its specific location so as to optimally examine each and every cluster efficiently and accurately.

This paper largely focuses upon utilization of reflection power coefficient to easily detect the other sensor nodes in the network and using this information to transmit the data packet to the nearest available nodes, enabling better connectivity among different nodes within the network.[14] The prescribed algorithm leverages centralized visibility and control of network to realize secure, and bandwidth efficient minimum spanning tree (MST) spread out across the entire network and tree is spread across different paths. Mathematically, the point-to-multipoint routing is devised as minimal tree problem where a tree of minimal total length is searched which connects the source node to all the destination nodes.[18]

II. CONSTRAINTS

The design of routing protocols in WSNs is influenced by many challenging factors depending upon the application. The performance of a network model is associated with its routing approaches. Sensors are typically incapable of long range communication.[13] Various factors need to be overcome before efficient communication can be achieved.

- *Node deployment*: The sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner. If the resultant distribution of nodes is haphazard, optimal clustering becomes necessary to allow connectivity and enable energy-efficient network operation. Inter-sensor communication is normally within short transmission ranges due to energy and bandwidth confinement.
- *Energy consumption without losing accuracy:* Sensor nodes can use up infinitesimal fraction of energy performing computations and transmitting information in a dynamic environment. As such, energy-conserving forms of communication and computation are essential.[17] The malfunctioning of certain sensor nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of the network.
- *Connectivity:* High node density in sensor networks obviates the possibility of them being completely isolated from each other. Therefore, sensor nodes are expected to be perfectly connected. Each node has a communication range which defines the domain in which another node can be located in order to receive data packet which is separate from sensing range which defines the area a node can experience. The two ranges may be equal but are often different.
- *Coverage:* In WSNs, each sensor node perceives view of the environment both in range and in accuracy; it can only cover a limited physical area of the environment. Hence, area coverage is an indispensable parameter in WSNs.
- *Scalability:* The number of sensor nodes deployed in the sensing area may be in the order of hundreds or thousands, and even more. Any routing scheme must be able to work with this huge number of sensor nodes. In addition, sensor network routing protocols should be scalable enough to respond to events in the environment.[14] Until an event occurs, most of the sensors can remain in the dormant state; with data from remaining sensors lying on the active pathway provide somewhat inferior quality.
- *Data Aggregation:* Since sensor nodes may generate significant redundant data, similar data packets from multiple nodes can be aggregated so that the number of transmissions can be minimized.[9] Data aggregation is the combination of data from different sources according to certain aggregation function, e.g. duplicate suppression. Various signal process can be employed for data aggregation.
- *Fault Acceptability:* 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 sensor network. If many nodes fail, MAC and routing protocols must accommodate formation of new links and routes to the data collection base stations.[3] This may require actively adjusting transmit powers and signaling rates on the existing links to reduce energy consumption, or rerouting packets through regions of the network where more energy is available. So, multiple levels of redundancy may be needed in a fault-tolerant sensor networks.

III. ROUTING STRATEGIES

It is not feasible to allocate global identification along with random deployment of sensor nodes. So, data is usually transmitted from every sensor node within the deployment region with significant redundancy.

Various protocols have been taken into consideration while designing the framework for sensor based network. Different protocols do not inherently support multiple grid communication.[9] Some of the network structure based protocols have been described briefly:

- Hierarchical Power-aware Routing (HPAR): In, a hierarchical power-aware routing the network is divided into groups of sensors.[2] Sensors in each group of sensors in geographic proximity are clustered together as a zone and a zone is treated as an entity. To perform routing each zone is allowed to decide how it will route a message hierarchically across the other zones such that the battery lives of the nodes in the system are maximized.
- Avalanche Routing Algorithm (AvRA): It is a polynomial time algorithm that builds a routing tree by attempting to attach each new group member to the existing tree at the nearest intersection. Instead of trying to find the shortest path from new node to a specific node, AvRA tries to find the shortest path to the existing tree. This can be trivially accomplished by computing the shortest path from new member to each node on the existing tree. However, it is computationally prohibitive.[1] AvRA performs this attachment using a unique method which completes in polynomial time. It is possible that AvRA may not always be able to find the best attachment point for all topologies; it does so with high probability in practice for most topologies.

AvRA first assigns a level to all nodes in the network. This level classifies the node's distance, in number of hops, from a physical server. Thus, all physical servers are assigned level 0, all top-of-racks (ToRs) are assigned level 1, and so on.[1] While creating the routing tree for a group, AvRA iterates through the group members one by one and attaches them to the tree. Once the group reaches a steady state in terms of the number of subscribers, a steady state tree can be constructed. The steady state tree can be chosen as the smallest tree obtained from all possible orderings.[1] In our proposed algorithm, we have not implemented steady state tree reconstruction because the trees created in the first attempt efficiently satisfy all design goals.

IV. MOTIVATION

The motivation for this paper is that using reflection power coefficient of the closest neighboring node so as to determine the shortest pathway to the cluster head.[14] The main aim to use this approach is that using nodes with high residual power may be expensive as compared to the path with minimal power consumption and setting up a pathway for multipoint to point communication in dynamic networks. Hence, the algorithm finds the path with least possible power consumption (P_{min}) from each event sensor node to its cluster head. The proposed routing heuristic finds the path with least power consumption using Dijkstra's Algorithm.

V. RELATED WORK

The use of minimal power consumption and maximizing the minimal residual power in the network are the techniques usually employed in Wireless Sensor Networks (WSNs) with a number of essential differences. In the case of sensor-to-base station communications, only outdoor measurements were considered. Multihop operation can be realized between sensor nodes (which are generally identical sensors) or between sensor nodes and the base station.[8] This type of system maintains continuous connections by means of reconfiguration around blocked paths, hopping from node to node until a connection is set up between sub-cluster network and base station. Mesh networks incorporate self-healing capability that enables reliable operation even when a node breaks down or a connection goes bad.[7] Our literature analysis is with respect to reflection power coefficient as a metric: the quality of spanning tree produced by Prim's algorithm considering only the active paths, and the message, time and work required by algorithm to construct the tree. It has been theoretically observed that the number of nodes whose outgoing edges must change, as a result of a node insertion and deletion is *O(ln n)*. This dynamic algorithm does not require any complicated data structures or severe constraints on the sensors. The dynamic aspect of this algorithm makes them very useful in a sensor network setting, where it is very common for nodes to fail, or become alive asynchronously.

VI. PROPOSED ALGORITHM

An autonomous system is the largest entity in a simple distributed mesh network involving communication between the sensors and the base station. As sensors have limited radio communication range, a field sensor would establish a connection with the base station (sink) either directly or through a data aggregation center (gateway), especially in a rough terrain with strong attenuation.

The autonomous system is subdivided into various '*Areas*'. An area within an autonomous system consists of a myriad of network grids and each grid is subdivided into hierarchical structures consisting of clusters.[15] As we require efficient coverage in the remote locations of sensor deployment to optimize the proximity to the ROI (Region Of Interest), we adopt a grid-based strategy enabling the grid network i.e. dividing the ROI into grids.

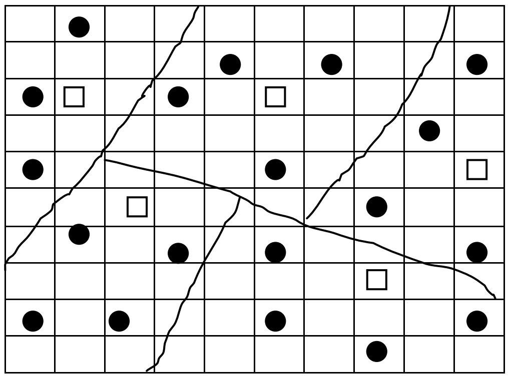

Fig. 1 Grid-Based Sensor Network

— ● EVENT NODE
— □ CLUSTER HEAD

Here the entire grid is sub-divided into sub-cluster networks. Each cluster head uses the local parameters to send discovery packets in order to decide independently its sub-cluster (event) nodes and subsequently the cluster head results in random formation of clusters within the network.[14] When the node has information about its cluster head, a new discovery packet containing information about different cluster will be dropped. So every sensor node is a part of exactly one cluster.

Consider a small sub-cluster network. The design is illustrated in Fig. 1. This consists of event nodes and the cluster head. Initially, each cluster head has information about the sensor nodes in its network. As each node has a limited radio communication range. We exploit the short range communication capabilities of a network susceptible to military applications and provide an efficient mechanism to manage coverage and connectivity. The reflected power coefficient of a node will be communicated by the sensor to its neighboring nodes within the same cluster using radio communication hardware. The transmitting sensor will also store the value of all neighboring sensor's reflected power coefficient including the ones with different cluster IDs. Since the receiver sensitivity of a wireless radio node is inversely proportional to the square of distance between sensors in case of electro-magnetic field. Sensors use the reflection power coefficient as a metric to compute the distance between event nodes.[14] The sensors implement SPF (Shortest Path First) Algorithm, also referred to as Dijkstra's algorithm for dynamically discovering the shortest paths to the cluster head. The cluster head acts as a source vertex.

Relationship of Power:

Here the Reflection Power Coefficient (Γ) is calculated by friis free-space formula:

$$R_s = \frac{\lambda}{4\pi}\sqrt{\frac{P_t\, G_t\, G_r(1-|\Gamma|^2)}{P_r}}$$

P_t - Transmitted Power

P_r- Receiver Sensitivity

G_t -Transmitted Sensor Gain

G_r- Receiver Sensor Gain

λ- Wavelength

R_s- Distance between sensors

Γ- Reflection Power Coefficient

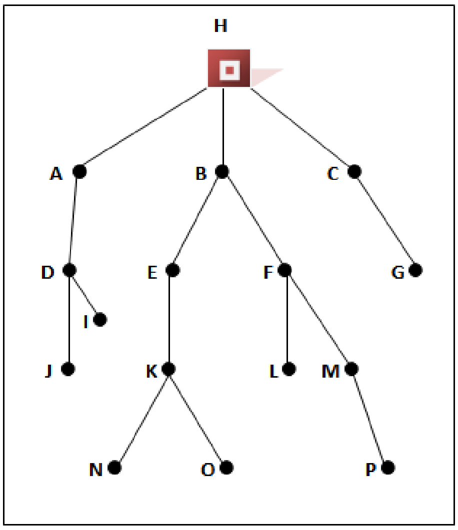

Fig. 2 Complete Spanning Tree

SPF ALGORITHM FOR WSN

1. *dist[H]* ⟵ *0*
2. *for all v ε V-{s}*
3. *do dist[v]* ⟵ *∞*
4. S ⟵ ϕ
5. Q ⟵ v
6. while Q≠ϕ
7. do u ⟵ min_dist(Q,dist)
8. S ⟵ S∪{u}
9. hopcount++
10. for all v ε neighbors[u]
11. do
12. if dist[v] >dist[u]+w(u,v)
13. then dist[v] ⟵ dist[u]+w(u,v)

We assign level to each node present in the cluster. To implement the concept of levels in the sensor we use the function of 'Rev_Hopcount( )' which would enable us to perform easier routing.

REV HOPCOUNT ALGORITHM

1. Rev_Hopcount (G,v)
2. for all v_i ε V
3. rev_hopcount[i]=0
4. for all v_i ε V-{H}
5. shortest_path(node[i],node[H])
6. j=i+1
7. for all j ε active_path_nodes
8. if(rev_hopcount[j]<packet_rev_hopcount[i])
9. rev_hopcount[j]=packet_rev_hopcount[i]+1
10. packet_rev_hopcount[i]=packet_rev_h opcount[i]+1

Here we don't bother about the scenario where an intermediate sensor would be assigned two different hop counts as it can lie in the pathway of more than one nodes. Such a situation may occur when two event node packets having a specific packet_rev_hopcount value reach a sensor higher in the hierarchy while traversing the active known path. Whenever a node's packet arrives at an intermediary node on its active path to cluster head, the receiving sensor performs 2 main operations: Firstly, comparing the rev_hopcount value of sensor with packet_rev_hopcount value, if the rev_hopcount value is less than packet_rev_hopcount value, we update as shown in line 9. Secondly, update the packet_rev_hopcount value before sending it out to the next node in the path. Finally the leaf nodes are dropped to obtain the pruned tree.

PRUNED TREE ALGORITHM

For each u ε G.V*

1. u.key=dist[u]
2. u.π= NIL
3. H.key=0
4. Q=G.V*
5. while Q≠ϕ
6. u=Extract-Min(Q)
7. for each v ε G.adj[u]
8. if v ε Q and w(u,v)=v.key-u.key
9. v.π=u
10. v.key=dist(u,v) // for leaf nodes
11. if node.rev_hopcount=0
12. node ⟵ Upper_Neigh(member)
13. tree ⟵ Hook (tree, node)
14. if tree ≠ Null then
15. tree.add(edge(node, member))
16. else
17. return Null

Here we have implemented Prim's approach and V* consists of all the nodes in the tree excluding leaf nodes. As we have already calculated the distance of each sensor from the cluster head we have used the key attribute to assign the distance of active path nodes in line-2. The for loop of lines 8-11 updates the key and π attributes of those vertices adjacent to Q which uses *'u'* as the intermediate sensor in transmitting data packets to the root/cluster head.

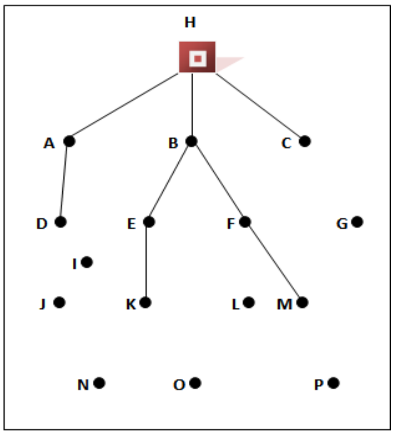

Fig. 3 Pruned Tree

VII. PRUNED TREE

As we can see the pruned tree has reduced the graph to a tree with few branches. Generally in dynamic routing approach when we construct a pruned tree eliminating the initial and terminating nodes then the pruned tree is known as the minimum Steiner tree.

All leaf nodes present in the tree have their rev_hopcount =0; if any new sensor tries to be the part of cluster network, it will be assigned rev_hopcount =0. The leaf node will always try to access the same node which lies on immediately next to it on its active path to the cluster head. In case a new node sends a request to join the cluster, the cluster head can either modify the rules for introduction of new member or deny admission to it based on pre-defined policies.

The 'Upper_Neigh' function will try to find the nearest member of the pruned tree and will make a selection of active path with lower hop count that is higher rev_hopcount value. Once the new sensor or the existing leaf sensors have discovered the tree, they will follow the active nodes' pathway to reach the cluster head in minimum time, instead of discovering their routes repeatedly.[1] When a particular node is sending data packet to the cluster head, all the nodes on its pathway will be active while the other nodes can remain in hibernation thereby reducing their power consumption.

VIII. COMPLEXITY

The cluster-based algorithm calculates the shortest path from event sensor to the sink/cluster head. It takes the running time of order O ($V\log|E|+ E\log|E|$). The running time of this algorithm depends on the implementation of min- priority queue. Each EXTRACT-MIN operation takes $O(\lg\ V)$ time. Dijkstra's algorithm is like Prim's algorithm as both make use of minimum priority queue. EXTRACT-MIN yields an asymptotically faster algorithm than binary heaps. The additional step involved in the prim's algorithm introduces a polynomial time function that attaches new nodes to the existing routing tree.

The running time of Prim's Algorithm and Dijkstra's algorithm are $O(E\ \log\ V)$ as all the sensors are reachable from source. So the total time taken is $2O(E\ \log\ V) + \Theta(1)$ as insertion of new node into the tree will take order $\Theta(1)$ time.

IX. SIMULATION RESULTS

In order to evaluate the performance of the proposed algorithm in the broadcasting mode, the simulation was done in Java JDK 8 based environment. As a primary phase we considered a stationary network in which sensor nodes and targets were scattered randomly in a square hostile field 750m x 750m. Location of Base Station was defined as (500,500). In simulation the statistical link status of the nodes were continuously monitored. For better performance the Node Power Radius was set to a comparatively lower value i.e. the transmission range of node was small throughout the simulation. The proposed algorithm resulted into a longer Average Link Length which means the ratio between the summations of all links and link counts after topology Control increases. The simulation parameters included 500 sensors, 1 Base Station as target, Sensing Energy Consumption in a range of 10m 5mW/s and Communication Energy Consumption in a range of 100m is 75mW/s. The performance of Proposed Algorithm has been compared with that of Protocol Independent Multicast-Sparse Mode in terms of Average Leaf Node Packet Loss %, Cumulative Network Traffic and Average Link Utilization.

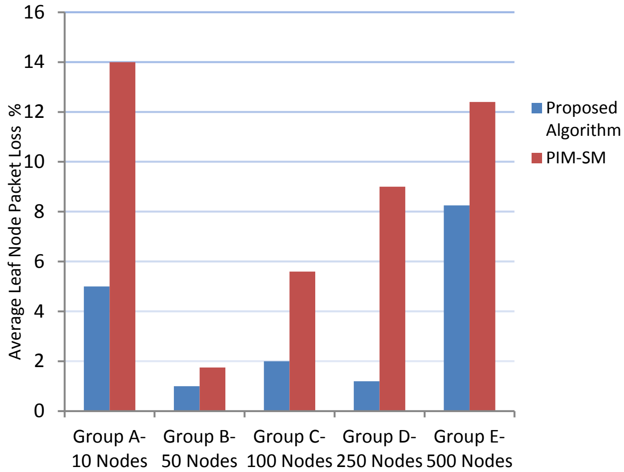

Fig.4 Average Leaf Node Packet Loss %

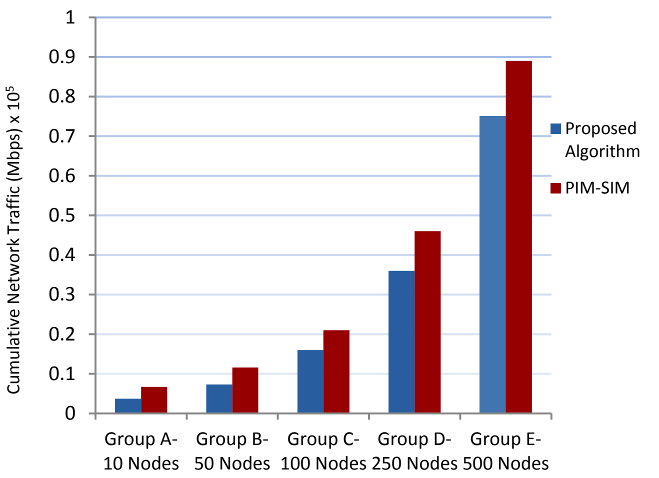

Fig.5 Cumulative Network Traffic

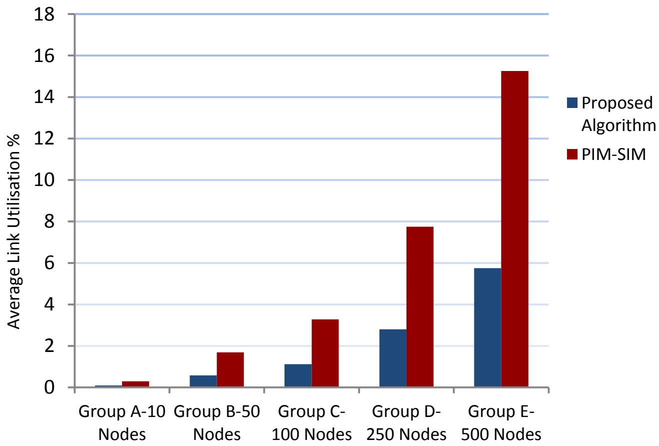

Fig.6 Average Link Utilization %

X. CONCLUSION

Many remote sensor field routing techniques introduce new design challenges such as path diversity utilization.[3] The simulation results suggest that our approach minimizes power consumption and delivers data faster and more efficiently than other routing protocols analyzed. The latency is correlated with sensor refresh rate and rendering ubiquitous coverage are the basic challenging issues in heterogeneous wireless networks, meeting the reliability requirements.

The future work considers the better coverage with minimized constraints, optimization of power consumption, heterogeneous networks and development of weight concepts, to name a few.

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