Distributed Grid based Robust Clustering Protocol for Mobile Sensor Networks

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Abstract: *This paper presents a distributed grid based robust clustering protocol for mobile wireless sensor networks. An overwhelming majority of current research on sensor network routing protocols considers static networks only, while we consider mobile environment. grid based robust clustering is a distributed location based, energy aware clustering protocol designed for mobile sensor networks. grid based robust clustering utilizes node's location information during cluster head selection and introduces a new parameter called center-ness. It also has a recovery mechanism to decrease packet loss during inter-cluster communication. Simulation results show that grid based robust clustering incurs less packet loss, results in high packet delivery ratio, and exhibits robustness against moderate to high mobility of nodes.*

Keywords: *Wireless sensor networks, mobility, clustering, routing protocols, and ad hoc networks.*

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1. Introduction

Wireless Sensor Networks (WSNs) are a new class of ad hoc networks and consist of a large number of sensor nodes and a Base Station (BS). WSNs are used to monitor certain physical phenomenon across a geographic area. The BS is comparatively resourceful [15] as compared to normal sensor nodes and typically acts as a gateway to other networks. Small size sensor nodes are limited in power, processing, and memory [6]. Sensor nodes have sensing circuitry to measure ambient conditions from the environment [23]. Current research on sensor networks considers static networks while evaluating routing protocols. In such networks, nodes do not move after deployment; but there are varieties of applications in which nodes can be mobile, for instance, habitat monitoring, battlefield surveillance, container monitoring [17], and moving object tracking. Rapidly changing topology and frequent path failures make sensor networks more challenging. Mobility and rapidly changing topology causes frequent path breakage, consequently, it results in large packet delay and packet loss. A few routing protocols [1, 5, and 29] make an assumption that each sensor node can directly communicate with the base station which is not a valid assumption because it is constrained by limited energy, regulatory authorities, and scalability issues. The solution to this is to use multi hop routing for communication. But using multi hoping in mobile environments will result in frequent path breakage. As a result packet delay and packet loss will be substantially large as compared to static networks. Such environments demand a routing protocol that minimizes packet loss, shows robustness against moderate to high mobility of nodes, and exhibits energy aware operation. Hierarchical routing has been widely investigated for ad hoc networks [1, 3, 7, 9, 13, 16, 24, 25] due to their energy efficiency and scalability. The main theme of hierarchical routing is to perform clustering. Clustering starts with selecting a set of cluster heads from a set of nodes in the network, and then grouping the remaining nodes with these cluster heads. A cluster head is responsible for collection and aggregation of data from other ordinary nodes in that cluster. Sensor field is divided into regions called clusters and each cluster has a cluster head. All the ordinary nodes within one cluster communicate and send data to cluster head. Cluster head aggregates the data and sends them to base station. Our proposed protocol, GRC, is a distributed, location based energy aware clustering protocol. It shows robustness against packet loss due to node mobility because it makes better use of location information during cluster head selection. Furthermore, it also reduces packet loss because it uses a recovery strategy during inter-cluster communication, and it achieves robustness against packet loss due to node mobility. The remainder of this paper is organized as follows: section 2 describes the related work, section 3 describes the problem statement, section 4 describes operation of GRC, and in section 5 simulation and results are presented. The paper is concluded in section 6.

2. Related Work

In sensor networks, users are usually concerned with monitoring certain physical phenomena associated with some geographic region. Therefore, a sensor node must know its absolute or relative location information. For getting the location, a node can either be equipped with GPS or may use some distributed localization scheme [23] or manual registration techniques. If the location information of a node is available, it can be used to compute the network connectivity [15]. Location based routing protocols use geographic information for taking routing decisions. For mobile sensor networks, Mobile Ad Hoc routing protocols like Ad hoc On-Demand Distance Vector (AODV) Routing [20], Location Aided Routing (LAR) [11], and On Demand Multi path Distance Vector Routing in Ad Hoc Networks (AOMDV) [18] cannot be directly applied because of unique characteristics of WSNs [6]. Also, they require end to end path recovery mechanisms in case of path breakage which is energy consuming. Furthermore, these protocols do not provide the support for data aggregation which can reduce number of transmissions and subsequently reduce network resource and energy utilization. Distance Routing Effect Algorithm for Mobility (DREAM) [2] uses directional forwarding approach. DREAM maintains routing tables to hold information about all the other nodes in the network, therefore, it suffers from scalability issues. For instance, large number of nodes in a network will result in large routing tables and routing table maintenance overhead. In Compass routing [12], a node forwards the packet to the neighbor that is located within the closest direction to the destination. Compass routing does not guarantee to find a path if one exists [25]. Greedy Parameter Stateless Routing (GPSR) [10] uses a combination of greedy and face routing. The location of destination is embedded into the packet and packet is forwarded using greedy forwarding until greedy forwarding fails due to local maximum problem. Face routing is used to route around dead-ends until some closer nodes to the destination are found. Geographical Adaptive Fidelity (GAF) [28] uses the location information of nodes for energy conservation by building a geographical grid. Only a single node needs to be turned on in each cell of the grid while other nodes can be turned off [15]. All the above mentioned routing protocols were primarily designed for mobile ad hoc networks with resourceful devices in mind. Therefore they do not normally fit in for sensor networks where resources are very limited.

In directed diffusion data are named as attribute-value pair and the nodes interested in certain data disseminate their interests to other nodes [16]. The major benefit that Directed Diffusion provides is data aggregation and reducing the number of transmissions. Geographical Energy Aware Routing (GEAR) [30] is an energy aware geographic protocol. The main goal of GEAR is to increase the network lifetime. GEAR uses energy aware metrics for neighbor selection, and each node tries to balance the energy consumption among its neighbors by maintaining a cost function for each neighbor based on its location and energy consumed for reaching that neighbor. Hierarchical routing protocols are proven to be energy efficient and scalable [8, 15]. The main theme of hierarchical routing is to select a set of cluster heads from a set of nodes in the network, and then group the remaining nodes with these cluster heads. Hierarchical routing reduces the number of transmissions and also supports data aggregation. Both of these features make hierarchical routing scalable and energy efficient.

In [14], Mobility Aware Routing protocol (MAR) is presented. It is a hierarchal protocol in which the sensing field is divided into a geographic grid, and cluster heads are selected on the basis of mobility factor of the nodes. Mobility factor refers to the number of times a node has moved from one zone to the other. The objective of selecting cluster heads on the basis of mobility factor is to select a node as a cluster head that has minimum mobility. Selecting such a node will improve the connectivity of cluster head with other corresponding nodes associated with that cluster head. But the major issue with this protocol is that it does not consider node residual energy while selecting cluster head, therefore, it is not energy aware, and it also does not make full use of location information of the nodes; therefore, it incurs more packet loss. During inter-cluster communication, it incurs packet loss because due to mobility it is more likely that cluster heads are not in transmission range of each other. Unable to send data to neighboring cluster head means losing information of whole round. Therefore, a recovery mechanism is required in order to decrease packet loss during inter-cluster communication.

Unlike MAR, our proposed protocol GRC is not only energy aware but also it makes a better use of location information during selection of cluster head. In addition, our protocol also has a recovery strategy for reducing packet loss during inter-cluster communication. By utilizing these strategies our proposed protocol shows resilience against packet loss and improvement in packet delivery ratio under moderate to high mobility of nodes.

3. Problem Statement

A wireless mobile sensor network can be modeled as set '*V*' nodes that are interconnected by a set of full-duplex '*E'* communication links. Each node is identified by a unique identifier. We assume that nodes know their positions (with GPS or some other localization mechanism [19]). Two nodes are neighbors if they are within the transmission range of each other. Nodes in such a network may move at any time, without any notice, so node mobility results in rapidly changing topology. The problem of clustering can be defined as follows. For a multi-hop wireless network with node set '*V'*, the goal of clustering is to select a set of cluster heads that cover the whole network. Each and every node '*v'* in set '*V'* located in zone 'z_l' where 'l' is the number of zones, must be mapped to one and only one cluster head located in that zone (if it is not cluster head). After cluster head selection, every normal node in the cluster must be able to directly communicate with the cluster head of that zone. The clustering protocol must be completely distributed without centralized authority and each node independently makes its decisions based only on location information. Further, the clustering algorithm must consider moderate to high mobility of nodes.

3.1. Network Model

We consider that sensor nodes are randomly dispersed over the field with following assumptions:

- The sensor nodes are mobile and they move randomly in the sensor field.
- Sensor field is organized into a logical grid, which is divided into zones.
- Links between sensor nodes are symmetric, i.e., two nodes 'X_1' and 'X_2' can communicate with each other using the same transmission power level.
- The base station is static.
- Nodes are location aware, i.e., either they are equipped with GPS module or they use some localization mechanism [1] for finding location.
- All the nodes have identical processing and communication capabilities.

3.2. The Clustering Problem

Assume that there are '*n*' nodes dispersed in a field. The goal of clustering is to identify exactly one cluster head for each zone. Another requirement for clustering is that each node must be mapped to one and only one cluster head that is located in its own zone. Each mobile node 'm_i' where $1 \le i \le n$ must be mapped to exactly one cluster head 'ch_j' where $1 \le j \le k$, where '*k*' is the number of cluster heads and 'ch_j' belongs to the same zone as 'm_i' belongs to. Let 'T_c' be the time required for clustering. After time 'T_c', a node can have two roles, either it is a cluster head or it is a normal node that is associated with some cluster head. The following conditions must be satisfied during clustering process.

- The clustering process is completely distributed. The decision of each node is based on local information.
- The clustering process must terminate after 'T_c' After 'T_c' a node is either a cluster head or a normal node associated with some cluster head.
- Cluster heads should be well distributed over the whole sensor field.
- Each zone should have no more than one cluster head.
- Cluster heads should have higher weight as compare to other nodes within that cluster.

4. GRC Protocol

GRC consist of three phases. The first phase is cluster head selection. The second phase is intra-cluster communication, and the third and final phase is inter-cluster communication. During cluster head selection, each node calculates weight based on its residual energy and center-ness. The weight is given by the following equation;

$$weight = w_1 \times E - w2 \times C \quad (1)$$

where $\sum_{i=1}^{2} w_i = 1$ and $0 < w_2 < w_1$, '*E*' is the residual energy of sensor node and '*C*' is the center-ness of that node. Center-ness is calculated as follows.

Let (x,y)be the location of a mobile node 'm_i' where $1 \le i \le n$. Let (x_c, y_c) be the center point of the zone in which 'm_i' is located. Then

$$C = |x_c - x| + |y_c - y| \quad (2)$$

The main objective of introducing center-ness in calculation of weight is to select a node as a cluster head that is located either at the center or close to center of the zone, and has higher residual energy. Selection of such a node serves two purposes.

1. Cluster head located either at the center or close to center of a zone having transmission range of 'r' where size of each cell (zone) is $r/\sqrt{2} \times r/\sqrt{2}$ provides better coverage for mobile nodes during intra-cluster communication.
2. During inter-cluster communication, such a cluster head can reduce the number of packets lost, because there is more possibility that both the cluster heads are within transmission range of each other.
3. If both cluster heads are not within transmission range of each other, then recovery strategy is applied to avoid packet loss.

4.1. Cluster Head Selection

During initialization, each node assumes that it is the cluster head for the zone in which it is located, therefore it sets the flag 'isclusterhead=1'. After calculating the weight, a node broadcasts a message CH_Announcment(myID,myweight,myzone) within its transmission range.

Upon receiving cluster head announcement messages, a node that receives CH_Announcment checks to see whether it belongs to the same zone or not. If it does not belong to the same zone then it simply discards the received CH_Announcment. Else if it belongs to the same zone and its own computed weight is lower as compared to weight received from CH_Announcment of neighboring node and if the flag isclusterhead=1, it will set the flag isclusterhead=0 and mark down the advertising node as its cluster head and for the current round it will not broadcast its own CH_Announcment. As it is communication that consumes far more energy in sensor nodes as compared to sensing and computation [27], so reducing number of messages during formation of clusters leads to lower energy consumption. The cluster head selection algorithm is given below.

Cluster Head Selection Algorithm

```
Start_CH_SelectionAlgorithm()
    myweight=w1×E-w2×C
    isclusterhead=1
    maxweight=myweight
    myzone=getmyzone()
    CH_Announcment(myID,myweight,myzone)

Receive_CH_Announcment
(SendingNodeID,weight,zone)
    If (myzone==zone){
    If (isclusterhead==1){
    If(ownweight<weight){
      isclusterhead=0
      Myclusterhead=SendingNodeID
      maxweight=weight}}
    else if(isclusterhead==0){
      If(maxweight<weight){
        Myclusterhead=SendingNodeID
        maxweight=weight}}}

Send_Final_CH_Announcment()
    If (isclusterhead==1)
    Final_CH_Announcment(myID,myzone)
```

After final selection of cluster head, each cluster head sends a 'Final_CH_Announcment', so that all the nodes within its vicinity know about the final cluster head.

4.2. Intra-Cluster Communication

During intra-cluster communication, each normal node sends information to its cluster head. During this phase each cluster heads collects information from its surrounding nodes that are associated with that cluster head, and then the cluster head performs data aggregation.

4.3. Inter-Cluster Communication

During inter-cluster communication cluster heads send the aggregated information to their neighboring cluster heads. During inter-cluster communication, cluster heads sends the aggregated information of the whole round. Therefore, in case of path breakage if this information is lost, the information of the whole round is lost. In MAR [14], like other sensor networks routing protocols, there is no recovery mechanism available and during simulations it was observed that most of the times cluster heads were not able to communicate with there neighboring cluster heads, because they were not in the transmission range of each other. In absence of any recovery mechanism MAR results in heavy packet loss.

There are two approaches for packet recovery. The first one is hop-by-hop and the second one is end-to-end [10]. Hop-by-hop recovery is energy efficient since retransmission distance is shorter. In the proposed work hop-by-hop recovery strategy is applied because it is more energy efficient as compared to end-to-end recovery strategy and it also causes less end-to-end packet delay. In the proposed protocol, we use a modified version of recovery strategy that was proposed in [7].

In GRC, recovery strategy is applied between two cluster heads during inter-cluster communication. Recovery strategy is based on Wireless Broadcast Advantage (WBA) [7]. WBA is based on the concept that as wireless transmissions are broadcast in nature, therefore, the neighboring nodes of the receiving node also receive the transmissions, and those neighboring nodes can cooperate to transmit that packet to the receiving node in case of a packet loss due to path breakage.

In Figure 1, the transmission ranges of 'A' and 'B' are shown by large circles. 'A' and 'B' are located in zone 1 and zone 2 respectively. In this case, a cluster head (A) wants to send data to other cluster head (B). But it is obvious from figure that both are not within the transmission range of one another and this can be due to mobility if 'B' has moved away from the transmission range of 'A' or vice versa. When such a situation occurs, a recovery strategy is required. The recovery mechanism that we are using is based on the concept of Wireless Broadcast Advantage (WBA). In WBA, a set of guard nodes are selected. In our approach a node is a guard node if it is in the transmission range of two cluster heads. In this case nodes 2 and 3 are guard nodes and they can cooperate, and help in sending the data to cluster head 'B'. When one or more guard nodes receive a message that is sent to neighboring cluster head, they wait for an acknowledgment from the destination cluster head. If guard nodes do not receive acknowledgment then they assume that packet has been lost. They set timers based on their residual energies. The timer of the guard node whose residual energy is more as compared to other guard nodes expires first and that guard node sends a copy of that data to destination. All the other guard nodes receiving a copy of data kill their timers. So in this way, using multiple guard nodes can increase robustness of the routing protocol in case of moderate to high speed mobility.

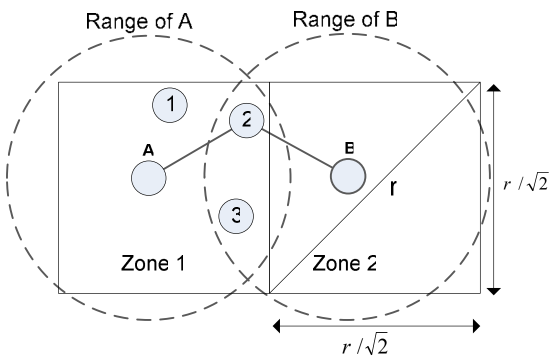

Figure 1. Wireless broadcast advantage.

5. Simulation and Results

All the simulations are carried out in the OMNET++ based simulation framework called INET [26]. INET framework supports various mobility models [4] and is well suited for simulations of wireless sensor networks. For all the communication links unit disk graph model is used, which means that if a node 'X' can reach node 'Y' then node 'Y' can also reach 'X'. The energy consumption model that was proposed in [5] is used for energy calculations. According to this model, in order to transmit a *'k'* bit message over a distance 'd', the energy consumed is

$$E_{Tx}(k,d) = E_{Tx} - elec(k) + E_{Tx} - amp(k,d) \quad (3)$$

$$E_{Tx}(k,d) = E_{elec} \times k + E_{amp} \times k \times d^2 \quad (4)$$

And the energy consumed to receive a packet is given by

$$E_{Rx}(k) = E_{Rx} - elec(k) \quad (5)$$

$$E_{Rx}(k) = E_{elec} \times k \quad (6)$$

where $E_{Tx}(k,d)$ is the energy required to transmit a '*k*' bit message over a distance of 'd' meters and $E_{Rx}(k)$ is the energy required to receive a *'k'* bit message. E_{elec} is the energy consumed for running the transceiver circuitry, E_{amp} is the energy consumed by the amplifier to achieve an acceptable signal to noise ratio. The MAC and physical layer of 802.11 are used. Simulation parameters are shown in Table 1. For simulations initially 100 nodes are randomly distributed in the network field with dimensions 1000m × 1000m. Then both of protocols MAR and GRC are tested with respect to different node speeds and densities. The mobility model that is used during simulations is Mass Mobility. It is a variant of random waypoint mobility model and is provided by INET framework. This mobility model has been built to model nodes movement during which nodes have mass and momentum, and therefore they do not start, stop, or turn abruptly.

Table 1. Simulation parameters.

Type	Parameter	Value
Network	Field dimensions Initial energy of each node Location of each node Number of zones	1000×1000 3 J/battery Randomly deployed 16
Application	Data packet size Broadcast packet size Packet header size	100 bytes 25 bytes 25 bytes
Radio Model	E_{elec} E_{amp}	50nJ/bit 0.0013 pJ/bit/m ^{4}

Figure 2 shows the percentage connectivity of cluster heads with respect to different node speeds. It is evident from the Figure 2 that MAR does not provide good connectivity. The reasons behind this are following; Firstly, in cluster heads selection criteria, the location of nodes is not considered. As a result the probability that selected cluster heads would be within the transmission range of each other is very less. Secondly, there is no recovery mechanism in MAR when cluster heads are disconnected. On the other hand GRC provides better connectivity as compared to MAR firstly by better utilization of location information. Secondly, in case of disconnected cluster heads, recovery strategy is used which results in good connectivity. It is observed during simulations that by using recovery strategy, the connectivity with respect to different speeds remains between 90 and 98%.

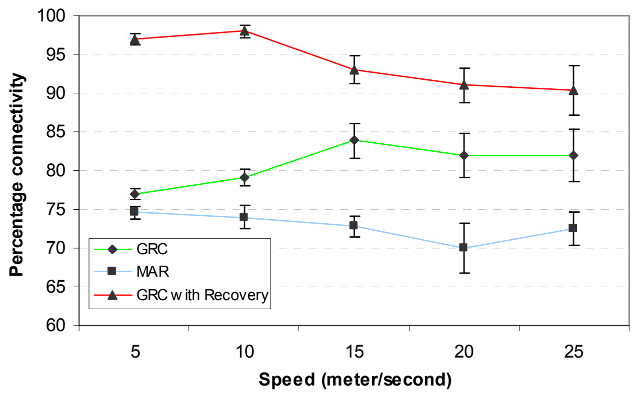

Figure 2. Percentage connectivity with respect to different node speeds.

Figure 3 shows number of packets that are lost with respect to different node speeds. It is observed that the majority of packet loss occurs during intra-cluster communications when normal nodes tries to send information to their respective cluster heads and due to node mobility either cluster head moves away from the transmission range of normal node or normal node moves out of transmission range of cluster head. It is evident from Figure 3 that as the speed increases the number of packets that are lost also increases for all the protocols. In figure 3 two versions of GRC are given. One is having no recovery mechanism and the other one has a recovery mechanism. As MAR and simple GRC have no recovery mechanisms therefore number of packets that are lost are on the higher side. But as compared to this, for GRC with recovery, number of packets lost is lesser as compared to other two protocols. It has been observed that using WBA as recovery strategy can minimize the packet loss and it reduces the packet loss to about 75 to 90% during inter-cluster communication.

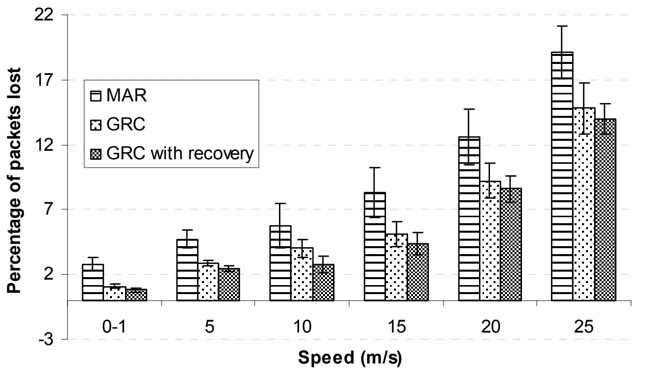

Figure 3. Packets lost with respect to different node speeds.

Figure 4 shows percentage of packets lost with respect to different number of nodes. It can be seen from the results that both versions of GRC incur less packet loss as compared to MAR.

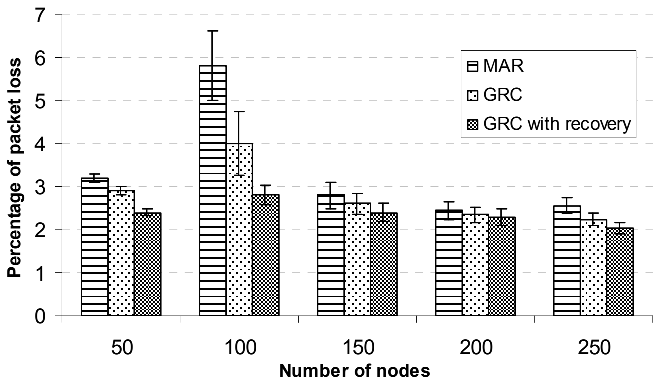

Figure 4. Percentage of packets lost with respect to different number of nodes.

Figure 5 shows packet delivery ratio with respect to different node speeds. It can be seen from the figure that as the node speed increases the packet delivery ratio for all the protocols decreases. Both versions of GRC give higher packet delivery ratio under different node speeds as compared to MAR. The reasons for this are center-ness and recovery strategy used in these protocols, which make these protocols more resilient against packet loss.

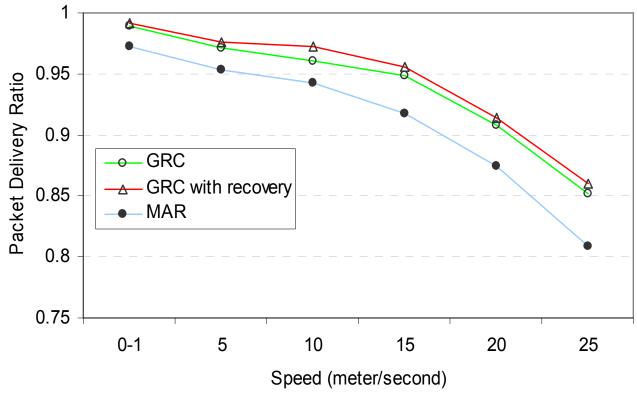

Figure 5. Packet delivery ratio with respect to different node speeds.

Figure 6 shows packet delivery ratio with respect to different number of nodes. It can be seen from the figure that as the number of nodes increases, the packet delivery ratio for all the protocols increases. Both versions of GRC give higher packet delivery ratio as compared to MAR. The reasons for this are better cluster head selection technique and using recovery strategy during inter-cluster communication in these protocols.

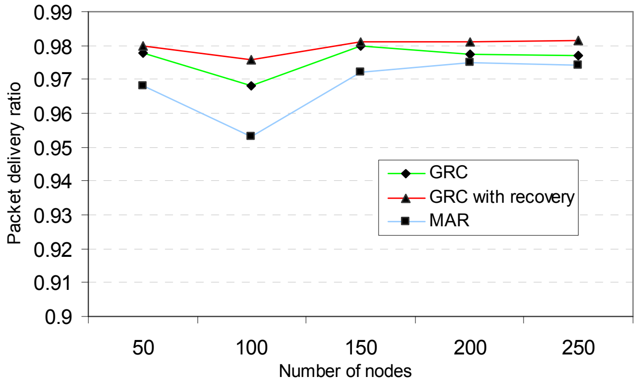

Figure 6. Packet delivery ratio with respect to different number of nodes.

From all the simulation results discussed above, it is evident that our proposed protocols perform well in terms of cluster head connectivity, packet loss, and packet delivery ratio.

6. Conclusions

In this paper we presented a distributed Grid based Robust Clustering (GRC) protocol for mobile wireless sensor networks. This protocol makes better use of location information and it also shows resilience against node mobility. Due to its recovery mechanism, it also minimizes packet loss and enhances packet delivery ratio to 0.99 under moderate mobility and to 0.85 under high mobility of nodes. Our approach is applicable to both static networks as well as networks having moderate to high node mobility, and it can be applied to variety of application in which nodes are mobile.

Future work includes implementing cross layer design and optimization in order to achieve more energy efficiency and robustness, and more extensive simulations by using other power and mobility models, and comparison with other protocols that deal with mobility.

References

[1] Ali S. and Bilal S ., "An Intelligent Routing protocol for VANETs in City Environments," *in Proceedings of 2nd International Conference on Computer, Control and Communication, IC4 2009*, pp. 1-5, 2009.

[2] Basagni S., Chlamtac I., Syrotiuk V., and Woodward B., "A Distance Routing Effect Algorithm for Mobility (DREAM)," *in Proceedings of 4th Annual ACM/IEEE International Conference on Mobile Computing and Networking*, pp. 76 - 84, 1998.

[3] Chan K., PishroNik H., and Fekri F., "Analysis of Hierarchical Algorithms for Wireless Sensor Net-work Routing Protocols," *in Proceedings of Wireless Communications and Networking Conference, 2005 IEEE*, pp. 1830 - 1835, 2005.

[4] Drytkiewicz W., Sroka S., Handziski V., and Koepke A., "A Mobility Framework for OMNeT++," *3rd International OMNeT++*, 2003.

[5] Heinzelman W., Chandrakasan A., and Balakrishnan H., "An Application-Specific Protocol Architecture for Wireless Microsensor Net-works," *Computer Journal of IEEE Transactions on Wireless Communications*, vol. 1, no. 4, pp. 660-670, 2002.

[6] Hou J., Li N., and Stojmenovic I., *Handbook of Sensor Networks: Algorithms and Architectures*, Wiley, 2005.

[7] Huang X., Zhai H., and Fang Y., "Lightweight Robust Routing in Mobile Wireless Sensor Networks," *in Proceedings of Military Communications Conference,* pp. 1-6, 2006.

[8] Jin Z., Jian-Ping Y., Si-Wang Z., Ya-Ping L., and Guang L., "A Survey on Position-Based Routing Algorithms in Wireless Sensor Networks," *Computer Journal of Algorithms*, vol. 2, no. 1, pp. 158-182, 2009.

[9] Karl H. and Willig A, "A Short Survey of Wireless Sensor Networks," *Technical Report TKN-03-018,* Berlin, 2003.

[10] Karp B. and Kung H., "Gpsr: Greedy Perimeter Stateless Routing for Wireless Networks," *in Proceedings of 6th Annual International Conference on Mobile Computing and Networking*, New York, NY, USA, ACM Press, pp. 243-254, 2000.

[11] Ko Y. and Vaidya N., *Location-Aided Routing (LAR) in Mobile Ad Hoc Networks*, *Wireless Networks*, Springer, 2000.

[12] Kranakis E., Singh H., and Urrutia J., "Compass Routing on Geometric Networks," *in Proceedings of 11th Canadian Conference on Computational Geometry*, pp. 51-54,1999.

[13] Li J., Yu M., Levy R., and Teittinen A., "A Mobility-Resistant Efficient Clustering Approach for Ad Hoc and Sensor Networks," *Journal of Mobile Computing and Communications Review*, vol. 10, no. 2, pp. 1-12, 2006.

[14] Liliana M., Arboleda C., and Nasser N., "Cluster-Based Routing Protocol for Mobile Sensor Networks," *in Proceedings of 3rd International Conference on Quality of Service in Heterogeneous Wired/wireless Networks*, Waterloo, Ontario, Canada, 2006.

[15] Lindsey S. and Raghavendra C., "PEGASIS: Power-Efficient Gathering in Sensor Information Systems," *in Proceedings of International Conference on Communications*, 2001.

[16] Madani S., Weber D., and Mahlknecht S., "A Hierarchical Position Based Routing Protocol for Data Centric Wireless Sensor Networks," *in Proceedings of Industrial Informatics International IEEE INDIN*, Korea, pp. 985-990, 2008.

[17] Mahlknecht S., Madani S., "On Architecture of Low Power Wireless Sensor Networks for Con-Tainer Tracking and Monitoring Applications," *in Proceedings of Industrial Informatics International IEEE INDIN*, Vienna, Austria, pp. 353-358, 2007.

[18] Marina M. and Das S., "On Demand Multipath Distance Vector Routing in Ad Hoc Networks," *in Proceedings of International Conference on Network Protocols*, pp. 14-23, 2001.

[19] Moses R., Krishnamurthy D., and Patterson R., "A Self Localization Method for Wireless Sensor Networks," *EURASIP Journal on Applied Signal Processing*, vol. 2003, no. 4, pp. 348-358, 2002.

[20] Perkins C., Belding E., and Das S., "Ad Hoc On-Demand Distance Vector (AODV) Routing," *IETF RFC 3561*, 2003.

[21] Sajjad M. and Ulieru M., "An Application of Industrial Agents to Concrete Bridge Monitoring," *in Proceedings of IEEE International Conference of Informatics in Control*, *Automation and Robotics*, Portugal, pp. 43-50, 2006.

[22] Seada K. and Helmy A., "Geographic Protocols in Sensor Networks," *Encyclopedia of Sensors*, American Scientific Publishers, 2006.

[23] Srinivasan A. and Wu J., "A Survey on Secure Localization in Wireless Sensor Networks," *Wireless and Mobile Communications*, CRC Press/Taylor and Francis Group, Boca Raton/London, 2007.

[24] Tashtarian F., Haghighat A., Honary M., and Shokrzadeh H., "A New Energy-Efficient Clustering Algorithm for Wireless Sensor Networks," *in Proceedings of 15th International Conference SoftCOM on Software, Telecommunications, and Computer Networks*, pp. 1-6, 2007.

[25] Urrutia J., *Handbook of Wireless Networks and Mobile Computing*, John Wiley and Sons, Inc., New York, NY, 2002

[26] Varga A., "The OMNeT++ Discrete Event Simulation System," *in Proceedings of European Simulation Multiconference*, Prague, Czech Republic, 2001.

[27] Wang Q. and Yang W., "Energy Consumption Model for Power Management in Wireless Sensor Networks," *in Proceedings of 4th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks*, pp. 142-151, 2007.

[28] Xu Y., Heidemann J., and Estrin D., "Geography Informed Energy Conservation for Ad Hoc Routing," *in Proceedings of Annual International Conference on Mobile Computing and Networking*, pp. 70-84, 2001.

[29] Yick J., Mukherjee B., and Ghosal D., "Wireless Sensor Network Survey," *Journal of Computer Networks*, vol. 52, no. 12, pp. 2292-2330, 2008.

[30] Yu Y., Govindan R., and Estrin D., "Geographical and Energy Aware Routing: A Recursive Data Dissemination Protocol for Wireless Sensor Networks," *USC Technical Report*, 2001.

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