Distributed Efficient Multi Hop Clustering Protocol for Mobile Sensor Networks

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Abstract: *This paper presents a Distributed Efficient Multi hop Clustering (DEMC) protocol for mobile wireless sensor networks. An overwhelming majority of current research on sensor networks considers static networks only, while we consider mobile environment. DEMC is distributed, works well with mobile nodes, and has a recovery mechanism that is used to reduce the packet loss during inter cluster communication. The recovery mechanism also improves the connectivity between cluster heads during inter cluster communication. On average, each node sends less than one message during clustering, and does not rely on periodic hello messages. As a result reducing number of transmissions leads to energy efficiency. Simulation results show that DEMC is energy efficient, incurs less packet loss, increases packet delivery ratio, and exhibits robustness against moderate to high mobility of nodes.*

Keywords: *Distributed routing protocol, mobile wireless sensor networks, mobility, and clustering.*

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1. Introduction

In many cases, sensor nodes in a sensor network are considered static, but there are many applications [1, 12, 15, 21] in which nodes can be mobile like habitat monitoring, battlefield surveillance, patient monitoring, container monitoring, and target tracking. Link failures due to node mobility pose serious issues in routing of ad hoc networks [26]. Rapidly changing topology and frequent path failures make sensor network more challenging. Path breakage results in large packet delay and packet loss, hence more energy consumption. Mobile Ad Hoc routing protocols like Ad hoc On-Demand Distance Vector (AODV) Routing [18] and On Demand Multi path Distance Vector Routing (AOMDV) in Ad Hoc Networks [16] work well in conventional networks but perform poorly in sensor networks because of constrained resources. Secondly, frequent path failures drive recovery mechanisms that are energy consuming. Some routing protocols assume that each sensor node can directly send data to base station [7, 10, 19], which is not a realistic assumption because it is restricted by limited energy, regulatory authorities, and scalability issues. Therefore, multi hop communication paradigm is used. But multi-hop strategy result in frequent path breakage in mobile environments. As a result packet delay and packet loss are larger as compared to static networks. Hierarchical routing has been widely investigated for ad hoc networks [2, 4, 7, 18, 19, 21, 25] due to their energy efficiency and scalability. The essential operation in 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. Sensor field is divided into regions called clusters and each cluster has a cluster head. All the nodes within one cluster communicate and send data to cluster head. Cluster head aggregates the data and sends them to the base station. Our proposed strategy, DEMC, is a distributed clustering based routing algorithm. It is energy efficient because it does not require periodic hello messages by nodes, and during cluster head selection, it requires lesser number of protocol messages. It also incurs less packet loss because it uses a recovery strategy during inter cluster communication, and it achieves robustness against packet loss due to node mobility by using concept of guard nodes. The remainder of this paper is organized as follows. Section 2 describes the related work, section 3 briefly outlines the problem statement, section 4 presents operation of DEMC, and in Section 5 simulation and results are discussed. The paper is concluded in Section 6.

2. Related Work

A wireless sensor network consists of a large number of sensor nodes and a Base Station (BS) and is used to monitor certain physical phenomenon. The BS typically acts as a gateway to other networks and is comparatively resourceful [21]. While small size sensor nodes are limited in power, processing, and memory [23].

Mobile Ad Hoc routing protocols like Ad hoc On-Demand Distance Vector (AODV) Routing [18], Location Aided Routing (LAR) [6], and On Demand Multi path Distance Vector Routing in Ad Hoc Networks (AOMDV) does not work well in wireless sensor networks because of limited resources [6]. Also the path recovery mechanism used by such protocols consumes enough energy. *Distance Routing Effect Algorithm for Mobility* also known as DREAM [3] uses directional forwarding approach. DREAM maintains routing tables to hold information about all the other nodes in the network. For large scale networks, DREAM is restricted by scalability issues. Hierarchical routing protocols have been widely investigated for sensor networks [13, 23]. In such schemes, clusters are formed and each cluster is headed by a cluster head. Normal nodes send their data to cluster heads and cluster heads relay them to sink node [10]. Low Energy Adaptive Clustering Hierarchy (LEACH) [19] is one of early cluster based hierarchical routing protocol. It assumes a fixed base station and the cluster heads are selected in such a way that energy utilization is evenly distributed. Cluster heads are rotated continuously over period of time. LEACH assumes that nodes are static and they do not move. Furthermore it assumes that each node can reach the sink node directly thus restricting geographic scalability.

A lot of modifications of LEACH have also been proposed. One of such modification is TB-LEACH proposed in [9]. In TB-LEACH, the cluster head selection is based on random time interval instead of complex probabilistic methods. TB-LEACH increases the network life time by reducing the number of control messages during cluster head selection. But TB-LEACH, also is designed for static networks, and do not take into account node mobility. Power-Efficient GAthering in Sensor Information Systems (PEGASIS) [20] is an enhanced form of the LEACH protocol. In PEGASIS instead of forming multiple clusters, different chains are formed. Each node transmits and receives data from its neighbor and only one node is selected from the chain to transmit to the base station. Gathered data moves from one node to other using aggregation and eventually sent to the base station. But PEGASIS also consider static network and does not talk about node mobility. It also assumes that the chain head will reach the BS, which is not a valid assumption. In [25], a Hybrid Energy Efficient Distributed (HEED) clustering approach has been presented. HEED prolongs the network lifetime by selecting cluster heads based on residual energy.

To further enhance performance, intra-cluster communication cost is considered as a secondary clustering parameter. Simulation results have shown that HEED has outperformed many of clustering protocols [19]. But there are a few issues with this protocol. Firstly, HEED considers static networks. Secondly, it is complex because cluster heads are selected on the basis of complex probabilistic methods. One of the protocols that consider node mobility is Distributed Efficient Clustering Approach (DECA) [26]. For each node, a weight is computed on the basis of node residual energy, node connectivity, and node identifier. For clustering, every node only transmits one message, rather than going through rounds of iterations of probabilistic message announcement like in LEACH and HEED. As communication consumes more energy in sensor nodes compared to sensing and computation [11]; reducing the number of messages during formation of clusters lead to better energy efficiency. Every node in the network periodically transmits *Hello* messages to tell its neighboring nodes about itself, and based on these messages, each node maintains a neighbor list. Upon receiving clustering messages, a node decides whether it should select some cluster head or should become the cluster head itself. Simulation results have shown that DECA has outperformed many of clustering protocols including HEED and LEACH. But one of the major issues with DECA is periodic hello messages for table maintenance of the neighboring nodes. Periodic hello messages for maintaining neighbor list will consume a lot of energy.

Secondly, in highly mobile environment, nodes may move at any time, without any notice, therefore, as a result the topology changes frequently and thus requires frequent routing table updates. This results in processing overhead and hence more energy consumption. Therefore, it is not a good approach to maintain table in highly mobile environments. Our protocol, DEMC, does not maintain neighbor list, therefore there is no need for periodic *Hello* messages. By doing so our protocol reduces the number of transmissions (*Hello* messages) per node, resulting in better energy efficiency. It also removes the processing overhead of maintaining neighbor list.

3. Problem Statement

A wireless mobile sensor network is modeled as set of *'V'* nodes that are interconnected by a set of full-duplex *'E'* communication links. Each node is identified by a unique identifier. Two nodes are neighbors if they are in transmission range of each other. Nodes may move at any time, without any notice, hence a continuously changing topology. The problem of clustering is 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'*, if it is not a cluster head must be mapped to one and only one cluster head. After cluster head selection, every normal node in the cluster must be able to directly communicate to its cluster head. The clustering protocol must operate in completely distributed manner, which means that, each node independently makes its decisions based only on local information. Further, the clustering process must terminate fast and execute efficiently in terms of processing complexity, and message exchange. Finally, the clustering algorithm must be resistant from moderate to high node mobility in ad hoc networks and at the same time it must be energy efficient because of limited available energy.

3.1. Network Model

We consider that sensor nodes are distributed over the sensing field under the following assumptions:

- Sensor nodes are mobile and they move randomly in the sensor field by using mass mobility model [5].
- Unit disk model is considered. Links between sensor nodes are symmetric, i.e., two nodes 'x' and 'y' can communicate with each other using the same transmission power level.
- The base station is static.
- Nodes are location-unaware, i.e., they are not equipped with GPS module or they do not use any localization mechanism.
- All the nodes are homogenous.

3.2. The Clustering Problem

Assume that there are *'n'* nodes dispersed in a field. The goal of clustering is to identify a set of cluster heads which cover the entire field. Furthermore, each node must be mapped to one and only one cluster head. 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. Let 'T_c' be the time required for clustering, then, after time 'T_c', a node can have one of the 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 only 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.
- Clustering process must be efficient in terms of message exchanges, processing, and energy.
- Cluster heads should have higher residual energy as compare to other nodes within its vicinity.

4. DEMC Protocol

DEMC, the proposed protocol, is based on DECA [26] protocol. DEMC is different from DECA in many ways. Firstly, DEMC nodes do not send periodic hello messages. The second difference lies in how the weights for nodes are calculated during cluster head selection phase and how the nodes act after receiving these cluster head announcement messages. During cluster head selection each node calculates weight based on its residual energy and unique node identifier.

$$weight = w_1 \times E + w2 \times I \quad (1)$$

where $\sum_{i=1}^{2} w_i = 1$ and $0 < w_2 < w_1$, *'E'* is the residual energy of sensor node and *'I'* is node identifier and it is used to break the tie in case if residual energy of two nodes is same.

4.1. Cluster Head Selection

During initialization each node assumes that it is the cluster head, therefore, it sets the flag *'isclusterhead=1'*. After calculating the weight each node computes a delay for sending *CH_Announcment* on the basis of its weight. On the basis of delay each node sets a timer.

Cluster Head Selection Algorithm

```
Start_CH_SelectionAlgorithm()
    myweight=w1×E+w2×I
    isclusterhead=1
    maxweight=myweight
    timer=1/myweight
    if      (timer<0)
    CH_Announcment(myID,myweight)

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

Send_Finalized_CH_Announcment()
    If (isclusterhead==1)
    Final_CHAnnouncment(myID,myweight)
```

The nodes whose timer expires first, sends a broadcasts message *'CH_Announcment(myID,weight)'* to its neighbor nodes. Upon receiving cluster head announcement messages, a node that receives *'CH_Announcment'* checks to see that whether its own weight is lower as compared to weight received from *'CH_Announcment'* of neighboring node or not. If its weight is lower as compared to the advertised weight and if the flag *'isclusterhead=1'*, then 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 *'CH_Announcment'*. In this way it is different as compared to DECA because in DECA each node sends exactly one cluster head announcement during cluster head selection phase. As it is communication that consumes far more energy in sensor nodes as compared to sensing and computation [23], reducing number of messages during formation of clusters lead to better energy efficiency. If the receiving node currently belongs to some other cluster and it receives a *'CH_Announcment'* from a node whose weight is higher than the maximum received weight then this node needs to switch to the other cluster. This technique will serve two purposes. Firstly, a node receiving a better weight *'CH_Announcment'* message will not transmit its own *'CH_Announcment'*. Secondly it will also avoid wrong cluster head selection that is one of the limitations of DECA. 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. It is observed during the simulations that the majority of packet loss occurs during intra-cluster communications when normal nodes try 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 vice versa. During this phase, each cluster head collects information from its surrounding nodes that are associated with that cluster head and then sends the aggregated data to the final destination discussed in the next section.

4.3. Inter-cluster Communication

During inter-cluster communication cluster head sends the aggregated information to their neighboring cluster heads. During the simulations it is observed that in most cases two cluster heads are not within transmission range of each other. So in this case they can not send information to each other and it results in path breakage. As 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, it will mean that the information of the whole round is lost. Therefore it is very important for any routing protocol to apply a recovery strategy. In DECA, 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. In absence of any recovery mechanism, DECA suffers heavily.

There are two approaches for recovery strategy. The first one is hop-by-hop and the second end-to-end [24]. Hop-by-hop recovery is more energy efficient since retransmission distance is shorter. In the proposed work, we use hop-by-hop recovery strategy motivated from wireless broad cast advantage (WBA) that was proposed in [8]. The basic mechanism in WBA is selection of guard nodes. WBA is based on the following 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 packet loss due to path breakage.

In Figure 1, the transmission ranges of 'Source' and 'Destination' are shown by large circles. In this case, a cluster head (Source) wants to send data to other cluster head (Destination). But it is obvious from Figure that both are not in the transmission range of one another and this can be due to mobility if 'Destination' has moved away from the transmission range of 'Source'. When such a situation occurs, a recovery strategy is required. In our approach, guard nodes are those nodes that are in the 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 'D'. 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 send 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.

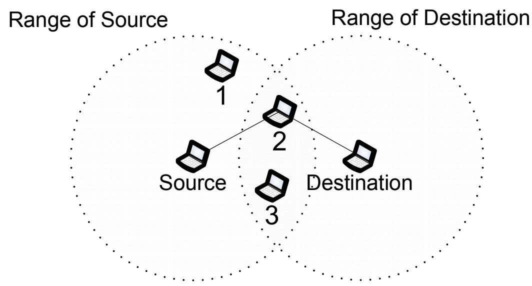

Figure 1. Wireless Broadcast Advantage.

5. Simulation and Results

All the simulations are carried out in the OMNET++ based simulation framework called INET [22]. INET comes with various mobility models [17], and it is well suited for simulations for 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 [7] has been used. According to this model in order to transmit a *'k'* bit message over a distance 'd' the energy required is

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

$$E_{Tx}(k,d) = E_{elec} \times k + E_{amp} \times k \times d^2 \quad (3)$$

And the energy consumed to receive a packet is given by:

$$E_{Rx}(k) = E_{Rx} - elec(k) \quad (4)$$

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

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 (SNR). IEEE 802.11 is implemented on MAC and physical layer. A more energy efficient MAC scheme such as CSMA-MPS [14] or some other similar schemes could be used to enhance efficiency but the major focus in this work is on the network layer.

Table 1. Simulation parameters.

Type	Parameter	Value
Network	Field dimensions Initial energy of each node Location of each node	1000×1000 3 J/battery Randomly deployed
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}

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, DECA and DEMC are tested with respect to different node speeds and transmission ranges. The mobility model that is used during simulations is Mass Mobility [5]. 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 do not start, stop, or turn abruptly.

The Figure 2 shows number of packets that are lost with respect to different node speeds. It is evident from the figure that as the speed increases the number of packets that are lost also increases for all the protocols. In Figure 2 two versions of DEMC are given. One is having no recovery mechanism and the other one has a recovery mechanism. As DECA and simple DEMC have no recovery mechanisms therefore number of packets that are lost are on the higher side. But as compared to this DEMC with recovery has a recovery mechanism as discussed in section IV, therefore number of packets lost is less as compared to other two.

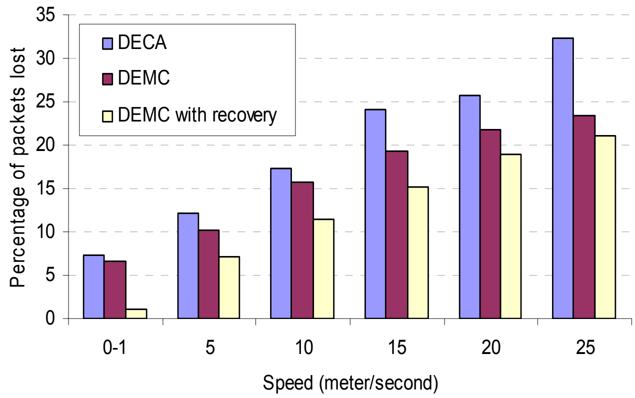

Figure 2. Number of packets lost with respect to different node speeds.

The Figure 3 shows packet delivery ratio with respect to different node speeds. It is evident from the figure that as the speed increases the packet delivery ratio decreases for all the protocols. DEMC with recovery out performs other two protocols in terms of packet delivery ratio. 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.

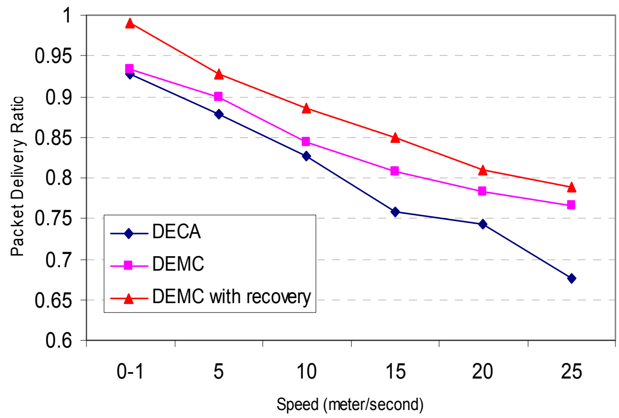

Figure 3. Packet delivery ratio with respect to different node speeds.

Figure 4 shows network life time with respect to different number of nodes at node speed of 5 m/s. Network life time is defined as the number of rounds until the first node dies. It can be seen from the figure that for both versions of DEMC, the network lifetime is more as compared to DECA. The reason behind this is less number of protocol messages per node transmitted during cluster head selection, secondly no periodic hello messages in DEMC. As transmitting and receiving consumes most of energy therefore reducing the number of transmissions decreases the energy consumption and increases the network life time. So in terms of network life time Figure 4 clearly shows that DEMC out performs DECA.

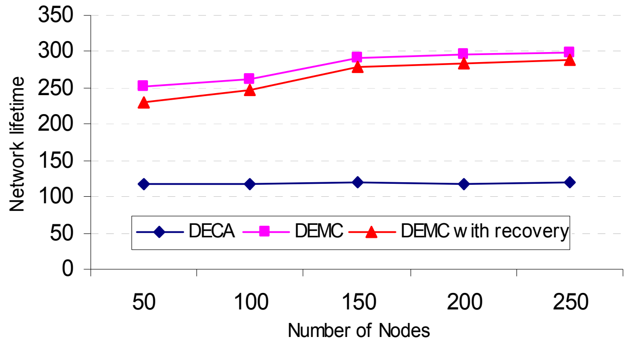

Figure 4. Network life time with respect to number of nodes.

Figure 5 shows network lifetime with respect to different node speeds. As discussed earlier, due to less number of transmissions during operation of DEMC, the network life time of DEMC is more as compared to DECA. As the speed of the node increases, for DEMC with recovery, the number of times the recovery mechanism should be applied also increases; therefore it results in some additional transmission, therefore the network life time of DEMC decreases as the speed of nodes increases. On the other hand the network life time of DEMC without recovery and DECA almost remains constant with respect to different node speeds.

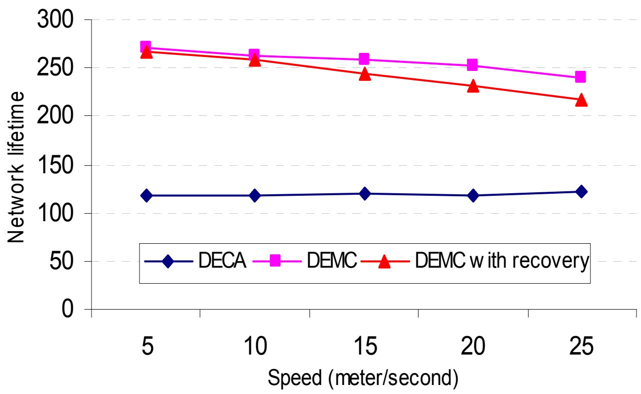

Figure 5. Network lifetime with respect to different node speeds

Figure 6 shows that number of protocol messages required for clustering for DECA with respect to transmission range of nodes at node speed of 5 m/s. It is evident from the Figure that as the transmission range increases the number of protocol messages required for clustering decreases. The reason for this is as the transmission range increases the number of nodes hearing that protocol message also increases and as a result if some or all the receiving nodes have a weight less than the advertised 'CH_Announcment', then in future these nodes will not send their 'CH_Announcment'. So average number of protocol messages sent by each node decreases. As compared to DECA, DEMC has less number of protocol messages per node with respect to different transmission ranges as average number of protocol messages per node in DECA remains 1. This is because every node sends one CH_Announcment (myID, weight) in DECA.

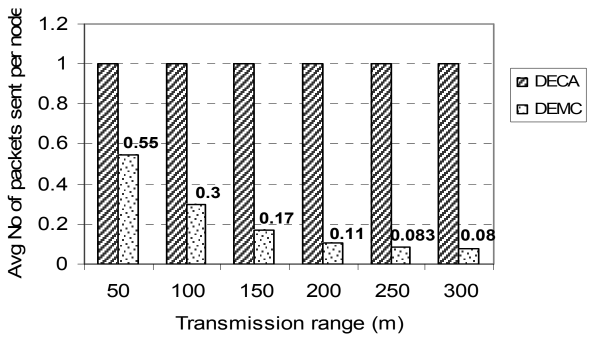

Figure 6. Average number of packet sent per node with respect to different transmission ranges.

The Figure 7 shows number of packets that are lost with respect to different number of nodes. It is evident from the Figure that both versions of DEMC result in less packet loss as the node density in the networks increases as compared to DECA. Therefore, it can be concluded from Figure 7 that both versions of proposed protocol perform well as the number of nodes in the network increases.

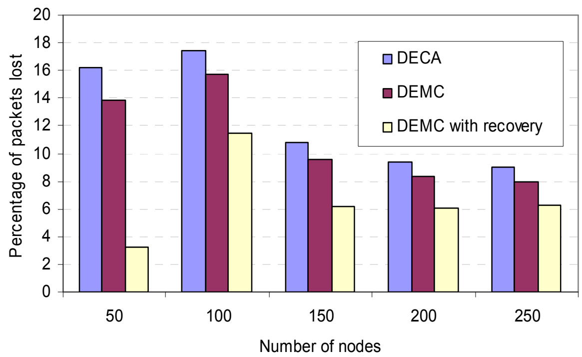

Figure 7. Number of packets lost with respect to different number of nodes.

By all the simulation results it can be concluded that DEMC is energy efficient, robust and resilient against packet loss, and deliver high packet delivery ratio with respect to moderate to high mobility of nodes.

6. Conclusions

In this paper we presented a Distributed Efficient Multi hop Clustering (DEMC) protocol for mobile wireless sensor networks. This protocol is energy efficient, resilient against node mobility and due to its recovery mechanism it also reduces packet loss. It incurs less messages exchanges during cluster head selection. It gives high packet delivery ratio and network lifetime. Our approach is applicable to both static networks and networks having node mobility.

Our future work includes implementing cross layer design 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.

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