

[8] offers a limited support by virtue of their operation [9] and not that they are specifically designed.

A little effort has been made to address the issues of routing in MSNs. A location based routing protocol for MSN has been proposed by L. Zou, M. Lu and Z. Xiong in [10]. This protocol uses the concept of greedy forwarding on the basis of a cost function of each node. This cost is close to the Euclidean length of the shortest path from sensor node to the base station. Whenever the greedy routing is not possible after a number of hops, the packet is forwarded using the high-cost-to-low-cost rule.

Routing protocols developed for MANET are strong candidates to be considered for MSN because of both being somewhat similar except the resource scarcity of MSN. This restriction prevents MANET protocols to be used in sensor networks without modification. The most studied algorithm for MANETs, Adhoc On-demand Distance Vector (AODV) routing protocol has been proposed in [11]. Different variants of AODV have been proposed for wireless sensor networks assuming static nodes among which TinyAODV [12] is the most popular. In TinyAODV the routes are static when they are created for the first time. There is no mechanism for the route expiry and the route are accumulated in route cache and deleted on first in first out basis.

The original AODV [11] protocol performs well in static environment but suffers from performance degradation in mobile environment. Also there is no mechanism in AODV protocol to derive the cost and willingness of a node to be a part of data transmission [1], which is critically imperative in case of low power environments such as sensor networks.

III. NETWORK SETUP

This section explains the network setup and assumptions related to the proposed routing protocol. The network consists of mobile nodes and a static Sink node. The node movement may be either application specific or completely mobile. Our protocol put no restriction on mobility of nodes.

The nodes in the network are aware of their location which is continuously updated even in case of mobility. For location awareness either GPS enabled [13] or non-GPS [14] scheme can be used, details of which is out of scope of this research. The entire network is divided into fixed size $m \times n$ square zones. The zone creation takes places at the start of the network when Sink broadcasts the zone size ' S_z ' to the network. At any point in time, the Sink may vary the zone size depending on a number of factors, such as increasing zone size for reducing hops towards the Sink. This research only focuses on fixed zone size broadcasted by Sink.

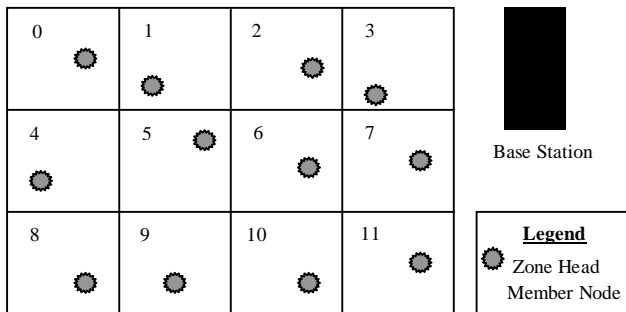


Figure 1. An example of zone based architecture

Each zone is governed by a zone head which is responsible for aggregating and routing the data to the base station. Each node is aware of its zone identifier and hence the identity of its zone head. Initial zone setup and zone head selection is out of scope of this research paper.

IV. PROTOCOL OPERATION

This section describes the operation of our proposed Zone Based Routing (ZBR) protocol that is a modified version of Adhoc On-Demand Distance Vector (AODV) routing protocol. This modified version is used as the underlying routing protocol in the zone based network infrastructure.

The sensor nodes deployed within the phenomena report the event as soon as any activity is observed in the respective region. The data flow depends on the specification of application being used. However, it can be broadly divided into three categories when a node is static, partially static and at times it becomes mobile, or fully mobile in the case of target tracking application. As the ZBR has no limitations regarding the movement of nodes, it is equally efficient in dealing with highly mobile and dense environments.

In ZBR, whatever the case may be, the member nodes transmit data to their respective zone head, which is always one hop neighbor of all member nodes. Zone head performs the aggregation depending on the type of application and transmit the aggregated or individual data to the base station. Route discovery, maintenance and consistent availability of route for reliable data delivery are the core responsibility of the zone head. The protocol is divided into three phases which are individually addressed in the following sections.

A. Mobility Factor and Zone Head Selection

This section introduces the concept of mobility factor which is the core aspect of our proposed protocol. Each node keeps track of its mobility and records the number of movements it has made and the energy spent in these movements. Here, a move is considered as the change in location of node without a pause, irrespective of the distance, destination and direction. A node may change its zone as a result of a movement and joins a new zone as a member. The number of times a node has moved and the number of times that move has resulted into a zone change, along with the remaining energy is used to calculate the mobility factor for the node. The mobility factor (M.F) is given as under

$$M.F = \frac{Z_t}{M_t} \cdot \frac{1}{e'} \quad e' > 0$$

Where e' is the remaining energy, Z_t is the total number of Zone changes and M_t is the total number of moves made during time ' t ' seconds. Each node keeps a record of its mobility factor. A lower value of mobility factor means that the node is less mobile and more of a candidate for being the zone head. On the contrary, a higher value depicts frequent movements and renders a node inconsistent as a zone head.

The zone head selection procedure starts with each node broadcasting its M.F. This broadcast is intended for the members of the same zone and is discarded by others. Initially each node keeps its own M.F as the zone head M.F. Once a broadcast is received, the node compares the zone

head M.F with the one received. If the received value is lower than the value already kept, the zone head M.F and zone head identifier are appropriately updated.

At the end of the broadcast phase, each node has the knowledge of the node with least mobility factor and hence the node is considered the zone head. The lowest values of M.F ensures that the node will serve as zone head for longer duration and if participating in the route towards the base station the route will be stable for maximum period of time.

B. Route Maintenance

This section describes the format of enhanced route request, route reply and the process of route creation and preservation for ZBR protocol.

1) *Route Request*: A zone head disseminates a RREQ when it determines that it needs a route to the base station and does not have one available. The format of the RREQ message is shown in the fig. 2.

Each node in the network, including zone head and base station possesses a unique identifier and is named as Node ID. The Destination ID is always the ID of the base station. The Destination Sequence Number field is the last known sequence number for the Base Station. The Originator ID is the identifier belonging to the source of the RREQ and is in fact the Node ID of the originator zone head in ZBR. The Originator Sequence Number is the zone head's own sequence number, which is incremented prior to insertion in a RREQ to avoid routing loops [11]. The Originator Zone ID is the zone in which the originator of the RREQ exists. The RREQ ID field is incremented by one from the last RREQ ID used by the current zone head. The Hop Count field is set to zero and the RREQ is then broadcasted. The broadcast continues in the network until the request reaches the base station.

The inclusion of zone ID in addition to the node ID itself gives us more control over the dissemination of control information across the path. In fact, each zone is always governed by a zone head, unless the zone is empty. A zone may either be empty due to the movement of all nodes to different location or in case the nodes have their energy depleted. There may also be a case that the node that originated the request is no longer available in the zone and the zone is now governed by a different node. The reply generated by the base station will traverse the intermediate zones to the originator zone. This is because the packet contains the Originator Zone ID. The zone head will receive the reply packet and caches the route in its routing table regardless of Node ID.

Type	RREQ ID	Hop count
Originator ID	Originator Zone ID	Originator Sequence Number
Destination ID	Destination Sequence Number	

Figure 2. RREQ packet format

Type	Hop Count	Originator Zone ID
Originator ID	Originator Sequence Number	
Destination ID	Destination Sequence Number	

Figure 3. RREP packet format

2) *Route Reply*: When a node in the neighborhood receives a RREQ, it silently discards the RREQ if it is not the zone head. However, the zone head of the respective zone upon receiving the RREQ verifies that it has not received the same RREQ before. It then creates a reverse route to the sender of RREQ and rebroadcast the RREQ or otherwise unicast a route for the destination back to the originator if it has a route to the destination that is not expired. The established reverse route contains the sender node and its zone ID beside other necessary information.

If no intermediate node has provided the route to the destination, the RREQ eventually reaches the base station. The base station creates a reverse route with the sender and then generates a RREP and unicast it toward the originator zone. All the intermediate nodes that receive this RREP caches the sender in the forward path table that is, in fact the routing table.

The format of RREP is shown in fig. 3. The destination ID and Destination Sequence number is the base station identifier and its sequence number respectively. The type field identifies that it is a RREP message. Originator Zone ID, Originator Node ID and Originator Sequence number is the node and zone identity and the sequence number respectively associated with originator of the RREQ.

3) *Route Creation*: This section describes the working of our proposed protocol taking into account a model network. The dissemination of route request, the reply generated in response and the routing table is described in this section. Our network consists of mobile nodes and a static base station. The nodes represented by N_i are arranged in square zones represented by Z_i and a zone head represented by ZH_i is elected for each zone.

Suppose the network consists of twelve zones naming Z_0 to Z_{11} as shown in fig. 1. Each zone consists of random number of mobile nodes governed by a zone head. Zone head from Z_0 denoted by ZH_0 has aggregated the data from its member nodes and is ready to transmit it to the base station. ZH_0 broadcast a RREQ to its neighboring zones setting hop count to zero. Neighboring zone heads ZH_1 , ZH_4 and ZH_5 receives the RREQ, establish the reverse route with ZH_0 , increment the hop count and rebroadcast the RREQ as they have no route to the base station. Fig. 4 shows the reverse route for ZH_1 , ZH_4 and ZH_5 .

Orig. ID	Orig. Zone ID	Destination	Previous Hop
ZH_0	Z_0	BS	Z_0

Figure 4. Reverse Route Table for ZH_1 , ZH_4 and ZH_5

Orig. ID	Orig. Zone ID	Destination	Previous Hop
ZH_0	Z_0	BS	Z_2

Figure 5. Reverse Route Table for ZH_3

Type	Node ID	Zone ID
INQUIRY	N_5	Z_1

Figure 6. Beacon message for zone head inquiry

Type	Node ID	Status	Zone ID
BYE	N_3	ZH_0	Z_0

Figure 7. Beacon message from zone head leaving a zone

The RREQ is broadcasted in the entire network. Contrary to the normal operation of AODV, this RREQ is of no concern to the member nodes. Only zone head are the one responsible for receiving and replaying the RREQ making sure that same RREQ is not accepted more than once. This reduces the amount of route requests produced in the entire network. The RREQ reaches the base station through Z_3 which is the closest to the base station. The reverse route for ZH_3 is shown in fig. 5. The base station in turn caches Z_3 as the next hop in reverse route for Z_0 . RREP is generated by the base station and sent to zone Z_3 . ZH_3 receive the RREP and forward it to Z_2 along the reverse path. ZH_2 adhere to the same principle and forward it to Z_1 and ZH_1 in turn forward it to Z_0 . ZH_0 upon receiving the RREP starts transmitting the data.

In case the zone head from any zone had moved out to a different zone, it had immediately been replaced by another node which had the least mobility factor at that time. So as long as there is only one node in the zone, it is the zone head and it is responsible for responding to the control packet. This fact concludes that the movement in zone has no effect on the underlying routing information. This scheme also helps in efficient topology maintenance. Since the zone head is responsible for routing and route management, few zone members can turn-wise be in sleep state to conserve energy.

C. Node Mobility

This sub-section discusses the various scenarios that may result in case of mobility in a sensor network with respect to the proposed zone based architecture.

1) *Node Joining and leaving*: Whenever a new node enters a zone it always joins as a member node. The node broadcast a beacon as depicted in fig. 6 to search for the zone head only in case when it has an event to report. The zone head adds the node into its member list that contains the information about nodes currently sending data for aggregation. Local connectivity between zone head and nodes can be made through hello packets or layer 2 protocols such as 802.11. Nodes when leaving the zone does not send any beacon to the zone head.

2) *Zone Head Leaving or Joining*: When a zone head moves out of a zone it broadcasts a beacon as shown in fig. 7 to notify its members about its status. The nodes after receiving the broadcast re-elects the new zone head following the same procedure as defined in section A. If the zone is currently an intermediate hop in the path of data the new zone head upon receiving the packets will generate a beacon message to its neighbors demanding the next hop towards the base station. In normal operation, intermediate node movement result in path breakage, a RERR message and a RREQ re-broadcast by the originator. This results in

the over head of control traffic and latency for data traffic. This is not the case with ZBR protocol as it is prompt and efficient in rebuilding the route to the destination. The zone head that has moved to join a new zone is revoked from its role of zone head. It joins the new zone as a member node and attach itself to the current zone head regardless of its mobility factor. The same beacon message as shown in fig. 7 can be broadcasted by a zone head to start a zone head re-election process in a zone if the energy level of the current zone head has gone below a certain threshold. Afterwards the entire process of selecting new zone head is the same as in case of zone head leaving the zone.

V. SIMULATION RESULTS

This section presents the comparison of ZBR with AODV protocol. As ZBR is a refinement of AODV protocol, therefore a better approach is to compare it with the same. We can analyze and evaluate both protocols on the basis of same performance metrics which is not possible in case of other protocols designed to address different set of problems.

We have considered three different types of networks with varying number of nodes. The network types are categorized as static, partial and fully mobile. The static network is assumed to be an environment monitoring network where nodes are static and sense data as per requirement broadcasted by sink. The mobile network whether partial or full is assumed to be composed of target tracking sensor nodes that detect any moving targets and follow it across the network while continuously transmitting the sensed data to the sink.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Simulation Time	100 sec
Field Size	100m x 100m
Zone Size	10m x 10m
MAC Layer	IEEE 802.11
Data Packet Length	40 bytes
Data Interval	0.25 sec
Routing Protocol	ZBR, AODV
Radio Range	20 m
Node Velocity	10 km/h
Mobility	0%, 50%, 100%

Number of CBR flows is taken to be 10, 20 and 50 in each network. The first 5 seconds are to calculate mobility factors and construction of zones in case of ZBR protocol followed by data transmission. The nodes generating CBR flow in each scenario are mobile except the case of static network. The simulation is based on ns-2 version 2.33. The simulation settings described in table 1 depicts the settings that are common to all scenarios in the simulation.

Figure 8. Comparison of routing overhead generated in various network scenarios

The performance metrics measured in this simulation includes packet delivery ratio, routing overhead, and scalability.

1) *Packet Delivery Ratio*: The measured end-to-end successful transmission probability. This ratio is calculated by the number of data packets recieved by the sink divided by number of data packets produced by the source.

2) *Routing overhead*: the number of RREQs generated across the network in each case.

3) *Scalability*: the effect of increase in node density on the routing overhead.

B. Simulation results

The three scenarios in our simulation are described in the proceeding section.

1) Static network

The first simulation test was a baseline experiment to evaluate and compare the performance of our ZBR protocol with AODV in case of static nodes. The network is composed of 100, 200, and 300 nodes with 10, 25, and 50 nodes sending data to the sink. Fig. 8 to fig. 10 depicts the results of the simulation. In fig. 8 ZBR and AODV are compared in terms of route requests generated across the network. Fig. 9 depicts the total network energy consumption of both ZBR and AODV protocol. Energy consumed is dependant on the amount of control packets and data packets successfully delivered at destination in addition to the energy used in the creation of zones in ZBR protocol. Finally the fig. 10 shows the comparison of packet delivery ratio for both the protocols.

2) Partially mobile network

In this scenario the network is composed of a mix of static and mobile nodes in equal proportion. For example in a network of 100 nodes, 50 nodes are static and 50 are mobile. The data sending nodes are 10, 25, and 50 in each scenario.

All data-sending nodes whether scattered or in a group, move in a definite pattern along the target while other remaining mobile nodes are randomly moving without any specific pattern or destination. Fig. 8 to fig. 10 depicts the comparison of both the AODV and ZBR protocol for partially mobile network in terms of number of routing overhead, energy and packet delivery ratio.

3) Fully mobile network

The fully mobile network for our simulation is a network with all mobile nodes in the network. The nodes move randomly in the network without any fixed destination. The data sending nodes are 10, 25, and 50 in each case. The data sending nodes whether grouped or scattered move in a definite direction across the network following the target. Fig 8 to fig. 10 also depicts the comparison of both protocols in terms of routing overhead, energy and packet delivery ratio.

Fig. 10 depicts the scalability of ZBR protocol. It is evident from the figures that the performance of AODV protocol exponentially deteriorates as the node density increases, whereas our ZBR protocol is consistent and performs best in dense networks. This owes to the fact that ZBR protocol routes data to the zones and not to the nodes in network so the increase in the number nodes has no effect on the performance of ZBR protocol.

VI. CONCLUSION

In this paper we have proposed an efficient and scalable zone based routing protocol for routing in MSNs. The results have shown that ZBR protocol has reduced the routing overhead caused due to frequent link breaks due to mobility. The zone based network structure and implicit derivation of path cost in terms of mobility factor has resulted in reliable and consistent routes towards the sink. In this research we have assumed a fixed zone size. Our future work will extend our proposed research to support varying zone sizes.

Figure 9. Energy consumption in a network with 100, 200 and 300 nodes respectively

Figure 10. Throughput comparison of ZBR and AODV with varying node density

Figure 11. Scalability comparison for 25 data sending nodes

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