A Reliable Multi-Grid Routing Protocol for Tactical MANETs

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ABSTRACT

We propose a reliable multi-grid based routing protocol with the purpose of attaining high percentage of data delivery in the tactical mobile ad hoc networks. In grid-based protocols, deployment region is divided into small patches called 'cells,' which are the units of routing. Our routing protocol for tactical MANETs employs multi-grid routing scheme adaptively uses varying cell sizes, unlike single-grid based protocols. In a dense network, a small-cell grid is employed to serve more alternative cells for a path. Meanwhile, a large-cell can be used to allow the probability of seamless data forwarding when the network is sparse. Moreover, we propose two reliability metrics for the grid-based protocol based on packet delivery rate between the cells and the status of the mobile nodes that enables relay node selection in the cell for forwarding data. The results from the performance evaluation in network simulator (*ns-2.33*) shows that our scheme shows high reliability over 90% of data delivery ratio, low-latency and better overhead compared to the existing routing protocols.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols âĂŞ Routing Protocols

General Terms

Performance

Keywords

tactical ad hoc networks, routing, grid

1. INTRODUCTION

Reliability of routing protocols is important in carrying out successful network centric warfare (NCW) operations in the tactical mobile ad hoc networking (T-MANETs) environment [1]. T-MANETs are deployed in several challenging situations such as high node mobility, presence of compromised nodes upon enemy attacks, and the difficult terrain features with physical barriers etc. Traffic in this type of network mostly include situational awareness (SA) data and urgent commands to be transmitted to and from the command center (CC) [2]. SA data are generally collected and transmitted by the mobile nodes, *e.g.*, mobile devices carried by army personnel and the armored vehicles deployed in the different regions. CC is typically situated in a fixed location, which collects data sent by the deployed nodes and replies with urgent commands for them to execute.

Traditional routing protocols designed for general purpose mobile ad hoc networks (MANETs) focus on the availability of the individual nodes and their status while computing a routing path. In T-MANETs, these protocols often display poor performance whenever any node in a selected path is affected [3]. Some of the recent works in grid based routing protocols [3], [4] are proposed with the aim to address the challenges of the effective routing in T-MANETs. Since information about the network region is inevitable for reliable data transmission, these protocols construct a grid representing the reliability of the deployment region. The grid comprises of equal sized cells that can be mapped to the group of mobile nodes located in the corresponding network regions. Each cell of the grid is a unit of routing, hence also of measures such as reliability, energy etc., which can be computed depending upon the network application requirement. Such measures are then disseminated to the nodes in the network to select the most suitable list of cells to transmit data from the cell containing the source node to the destination node.

Computing reliability metrics in a grid-based routing should consider the information about the cells represented in the grid. [5] and [6] propose a node-density based metrics, which selects cells that has higher number of nodes. In high mobility, node density of a cell changes frequently, especially when small cell size is considered. [3] presents a metric as a probability of finding a relay node in a cell. It is computed based on the arrival and departure rate of the mobile nodes within the cell boundary and considers only those cells for routing that ensures the availability of at least one node while data traffic is being forwarded. However, this metric does not guarantee the connectivity between the nodes in different cells, especially when the larger cell size is considered. Assurance about the connectivity between the cells requires verification through other means. To alleviate this problem, we propose reliability metric based on HELLO delivery ratio (HDR) between cells that are periodically exchanged

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between the nodes of the neighboring cells. In addition, the location and mobility information of the nodes are used to compute and ensure the existence of relay nodes that has a higher lifetime inside the cell.

In grid-based routing schemes, the size of cells is another important factor deciding the performance. Grid-based schemes use cells to represent the deployment region. However it is difficult to select appropriate cell size due to dynamic nature of the network. In case, when the size of the cell is small, reliability can be achieved with better granularity, however, their state changes frequently due to high node mobility. Total number of cells in the grid will also be more compared to having larger cell size, which increases the complexity of the protocol. Moreover, due to same reason, number of hops in the path might become very high causing delay in the data delivery. In the other-hand, with the larger cell size, it might be difficult to obtain the desired connectivity in the routing path. This happens when the nodes in the neighboring cells goes outside the transmission range from each other, giving false perception of connectivity between the cells. Many papers consider cell size for a single grid network to be $1/2\sqrt{2}$R, where R is the transmission range of the node [7]. This mechanism considers nodes in eight surrounding cells, excluding other that might have sufficient reachable neighbors.

To benefit from the trade-off, we propose a mechanism to maintain multiple grids with different cell sizes, called 'multi-grid reliable routing' (MGRR). Any one grid can be adaptively used, depending upon the condition of the network. To manage MGRR, we propose a new metric based on a periodic HELLO messages sent by the nodes that comprises of node id, location and mobility information, sequence number and a local grid-view of the network. This set of information is used to determine the reliability of the network regions associated with the grids to determine the path of reliable cells. Data packets are then forwarded through these cells in an on-demand fashion by appropriately selecting a relay node. MGRR takes advantage of both smaller and larger cell sizes in multiple grids, along with a simple routing and data forwarding metrics that supports grid based routing protocols. We implemented and evaluated this scheme using network simulator (*ns2.33*) [8] and compared with [3] and [9] in terms of packet delivery ratio (PDR), latency and the overhead.

2. RELATED WORK

Majority of the routing protocols for MANETs can be either classified as a "node-centric" or "space-centric" [3]. The node-centric protocols such as AODV [10], DSR [9] and OLSR [11] discovers a set of nodes as a designated routing path between the source and the destination. They are sensitive to a single node failure, since entire route fails if any node in the set moves out of the range during data transmission. The space-centric protocols in the other-hand select any relay node that satisfies condition to forward data towards the destination. Geographical routing protocols such as [12], [13] use euclidian distances between the sender, destination and eventually selects the relay node that is closer to the destination. Other metrics such as reliability, energy, throughput etc., cannot be incorporated directly. Alternatively, a grid based approached have been proposed in [4] and [3].

[4] presents an on-demand location-aware routing protocol named "GRID". It uses similar approach to construct cells that divides the deployment region equally as shown in Fig. 1(a). The main purpose of the cell however, is to reduce the overhead of reactive route discovery process. To limit such overhead, a leader election is performed in each cell, which selects a particular node as a cluster head. It is used for broadcasting route request packets and data forwarding after the routing path of cells is discovered. Unlike this scheme, our proposed routing protocol maintain cell as a representative of network region similar to [3].

[3] presents a reliability-map based routing protocol named "RMR". It also constructs a grid of equal sized cells. A reliability measure as a weight is computed for each neighboring cell based on the arrival and the departure rate of nodes. These weights are assigned to the edges of the local graph with vertices designated by the cells. It is then merged with other local graphs to construct a global graph of a complete grid. When there is data to send, a route discovery module runs Dijkstra's algorithm on this global graph to find reliable path of cells to the destination. After the path is determined, each node selects a relay neighbor node from the specified cell to forward data. In RMR, single grid formed with non-overlapping square cells is used to represent the network region. In contrast to that, we construct multiple grids of different cell sizes, which are estimated according to the transmission range. When the property of cells changes frequently due to mobility, multiple grids allow better representation of these network regions. This is expected to enhance the reliability and the performance of the proposed routing protocol. Moreover, we use PDR of periodic HELLO packets and a node lifetime in cells as a routing metric as opposed to what is used in [3]. While PDR metric helps in selecting neighbor cells with high delivery ratio, selecting a node with longer lifetime in a cell provides opportunity for seamless forwarding of the data.

3. PROPOSED ROUTING METRICS

A reliable routing protocol needs to discover a route that has the highest probability of successfully delivering data to the destination. In a grid based routing, information from the set of nodes within the cell is quantified as a metric instead of looking at the state of individual nodes. In T-MANETs, such a metric has a distinct advantage of providing the routing protocol with views on reliable areas enabling the selection of reliable path by avoiding compromised and sparse regions that does not have any relaying nodes. Moreover, it is helpful in selecting a forwarding node with a high relay potential from the designated cell to forward data ensures faster delivery. In what follows, we describe our proposed reliability metrics used for constructing a graph of cells and for selecting a forwarding node.

The first routing metric is computed from the proactive HELLO packets and the data packets obtained from the nodes of the neighbor cells, and thus called HELLO delivery ratio (HDR). Neighbor cells are those cells that have nodes from where the HELLO packets are received. Each packet is embedded with the sequence number prior to the transmission. Receiver keeps track of the number of packets and the time-stamp (t_{rs}) of the last received packet from the corresponding neighbor. The update threshold (u_{th}) it set such that if the difference between *current_time* and t_{rs} is lesser than the u_{th}, the information from the sender node is considered fresh and reliable. The reliability metric is thus computed as the ratio of the total number of received packets to the latest available sequence number from the neighbor node. The sum of reliability metric obtained from all the nodes belonging to the same neighbor cell provides the latest connectivity information between two cells. In other case if the u_{th} is smaller, the corresponding node weight is not considered while computing the reliability metric. We note that the selection of appropriate u_{th} is important to the performance of the routing protocol and is defined on the basis of the cell length and the average speed of the nodes. For our simulation, u_{th} is set to 6.0 and 12.0seconds for the grids of 50m and 100m cells, respectively, considering the average node speed to be 5m/s.

The second part of a reliable routing metric is defined as the maximum lifetime of a node in the neighbor cell. It is computed based on the current and predicted position of the mobile nodes. At any time instant t, the predicted location ($x(\Delta t)$, $y(\Delta t)$) of the node at Δt can be computed from its current location $(x(t), y(t))$, heading (θ) and its speed (s) from the following Eq.(1) and (2).

$$x(\Delta t) = x(t) + s \times sin(\theta) \times \Delta t \tag{1}$$

$$y(\Delta t) = y(t) + s \times cos(\theta) \times \Delta t \tag{2}$$

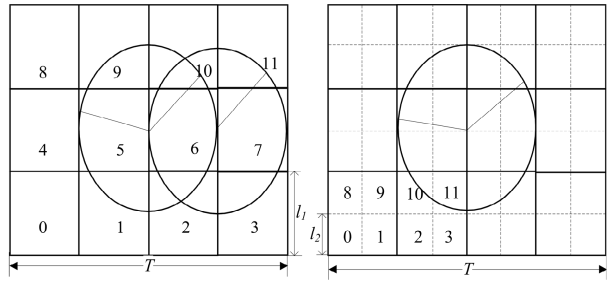
A node receiving the HELLO packet from the nodes of the neighboring cell computes the predicted location ($x(\Delta t)$, $y(\Delta t)$) at Δt. By computing the difference between the current location at time t and the Δt, the speed s of the mobile node and the locations of the neighbor cell, it can compute how long a neighbor node will stay within the boundary of the cell. This value is defined as the maximum lifetime of a node in the cell. While forwarding the data, a sender can thus select a relay node with a maximum lifetime from the designated cell.

4. MULTI-GRID RELIABLE ROUTING PROTOCOL

In this section, first we describe how multiple grids are constructed followed by the operational details about the functionality of our proposed scheme, MGRR. The multiple grids in our routing protocol are mapped with each other for selecting varying size of reliable regions for constructing path of cells. The reliability metric of such regions are based on the HDR metric, which shows availability of the forwarding nodes with high delivery rate. Further, maximum lifetime metric is used to select a relay node in the cell for forwarding data.

4.1 Grid Construction and Cell Mapping

The construction of the grids in our proposed routing protocol is based on the geographical knowledge about the deployment region. Each node is provided with the information that includes the end coordinates of the deployment region and the number of multiple grids required to be constructed with the associated cell sizes. The parameters such as transmission range and node-mobility are the key to determine



(a) $l = t_r$ (grid1) b) $l = t_r/2$ (grid2)

Figure 1: Cell Size *versus* Transmission Range.

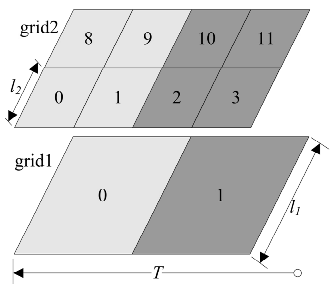


Figure 2: Mapping of grid1 and grid2 from the relative location of cells and their respective cIds

the appropriate cell sizes for the grids, which can affect the performance of the routing protocol. If the cell size is greater than the transmission range, neighbor cells might not successfully exchange packets, resulting in disconnected cells. With a very small cell size, construction of a graph becomes complex due to large number of cells. Moreover, the state of the cell changes frequently due to mobility of the nodes. Thus, the computation of weights associated to the cell becomes frequently outdated, giving result to inconsistent and unreliable path.

Fig. 1 illustrates the coverage of network region and formation of the grid network with respect to the transmission range (t_r). When cell length (l) is equal to t_r as shown in Fig. 1(a), a node located in the center of the fifth cell will have following neighbor cells: 1, 2, 6, 9 and 10. However, other nodes in this cell might not be able to receive packets from some of the nodes in the neighbor cells such as 1, 2, 9 and 10. This might result into inconsistent construction of a local graph with varying weights assigned to the similar edges between cells allowing disparate views in the different nodes. With small sized cells as shown in Fig. 1(b) and l set to half the size of transmission range (i.e. $t_r/2$), the weight assigned to cell fluctuates quickly due to mobility. For e.g., in 50x50sqm cell size, and a transmission range of 150m, a node moving in 25m/s in one direction goes beyond the cell boundary in less than 2 seconds. Thus, it requires a frequent update of a network state (i.e. less than 2 seconds) for having consistent neighbor information. Moreover, a large number of cells add complexity and possibility of more hops to traverse for the data packets to reach the destination.

Based on this discussion, in this paper, we construct two grids of size l set to $t_r/3$ and $t_r/1.5$ for smaller and larger grids, respectively. Transmission of periodic HELLO packet is performed by each node at the interval of randomly selected t_p seconds to avoid the collision. This packet includes its node identifier, location co-ordinates, global view of grids and the latest sequence number for the packet that it has generated. To reduce the packet overhead, the global grid structure is included only when the change in the edge set of is observed. To construct the snapshot of a local graph, each node computes the cell identification number (cId) for a neighbor node and itself. cId is a unique identification number assigned to each cell on a grid. Since cId is a function of a point co-ordinate within the cell boundary, total length T_l and cell length l, it can be computed by Eq. (3) as shown below.

$$cId = \lfloor \frac{x}{l} \rfloor + \lfloor \frac{T_l}{l} \rfloor \times \lfloor \frac{y}{l} \rfloor \quad (3)$$

Thus, any node can compute a cId of a cell of grid that it belongs to, including its neighbors from the available location and grid parameters. The $cIds$ are used as the identifiers for the vertices for the local graph. The HDR metric as a weight is assigned to the edge-set of the local graph, which is computed as described in the previous section. This local graph is subsequently merged with the global grid and propagated in the network through the HELLO packets.

Note that since the cId is a function of a common location co-ordinate between multiple grids, they can be mapped with each other. As shown in Fig. 2, any cell in grid1 can map four cells in the grid2. I.e, cid 0, 1, 8, and 9 of grid2 can be directly mapped to cid0 of grid1. To find the cId of a grid1 related to the cId of grid2, first Eq. 4 and 5 is used to compute the relative location of cId for grid2.

$$y = \lceil \frac{cId}{\lfloor \frac{T_l}{l} \rfloor} \rceil \times l \quad (4)$$

$$x = T_l + (cId \times l) - \lfloor \frac{T_l}{l} \rfloor \times y \quad (5)$$

Replacing this location in the Eq. (3) and the grid parameters T_l and l of grid1 gives us its corresponding cId. This mapping is utilized in our proposed multi-grid routing protocol while forwarding the data packet.

4.2 Multi-Grid Reliable Routing

The edges of the local graphs for each grid constructed in our multi-grid based routing are weighted with our proposed reliability metrics. These graphs at each node are merged to form a global graph. When a source node has a data to send, the routing protocol attempts to discover a connected path of reliable cells in the global graph of the small grid. The source node runs Dijkstra's algorithm on the snapshot of the global graph to compute such path towards the cell where the destination is located. The motivation to initiate a route discovery in a grid of smallest cell is because it provides a representation of network region at a higher resolution. However, if the local graph of this grid is found disconnected, the grid with the larger cell size is utilized. This is because it might be difficult to discover a connected set of cells in a graph when the network is sparse and the node mobility is high. The subsequent grid formed by larger cells increases the probability of generating a reliable connected path of cells. A path, if discovered in the source node is cached and used to forward data until it observes the changes in the grid. The corresponding $cIds$ of the cells are inserted in the header of the data packet, along with the cell length of the selected grid and forwarded towards the next hop cell using a neighbor selection protocol. Whenever the source route is modified due to change in the grid, forwarding nodes use the cell length embedded in the header to identify the cId of a particular grid.

Neighbor selection uses multiple grids as notified from the source to select a node from the neighboring cell that can forward the packet toward the destination. A neighbor lookup table is maintained based on the periodic HELLO information to update the list of neighbors belonging to the cells. The potential relay nodes of the neighbor cell for each grid are ordered according to their maximum lifetime in the designated cell and the validity of the node. A forwarding node first checks the cId and the grid corresponding to the cell length provided in the packet header. Then the look-up table is fetched to find a best relay node in the next reliable cell. If the selected neighbor is non-existent due to mobility or other reasons, the cell of larger grid that maps to the current cId is selected. The probability of finding potential forwarding neighbor increases with the larger area of the grid. The selection of a cell in the larger grid is done by finding the x, y location of a smaller cell using Eq. (4) and (5). Again, using the location information, cId for the larger grid can be computed by using Eq. (3). Another relay node in the larger neighborhood is thus selected to forward data towards the destination. Further, even if the larger grid is empty or forwarding data fail, sender node refreshes the global graph and re-runs Dijkstra's algorithm to find a new path towards the destination.

4.3 Path Re-construction and Routing Loop

In our proposed scheme, we compute a path as a sequence of cells and thus routing loop does not exist. However, when the cells in the path do not have neighbor for forwarding data, path reconstruction might induce loop formation. New path selection from the failure point onward might create a path with the cells that already exist in the previous path. Two measures are taken to avoid routing loop: First, the neighbor information about the failure is immediately refreshed through the HELLO packets. However, this information is not immediately carried throughout the network. The newly re-constructed path is compared with the existing in the data packet. If the path length in the data packet is smaller than the new path, we wait for w_h seconds before creating the new path for the data. The w_h seconds is equal to the product of HELLO packet interval and the number of hops the data packet has traversed. The disadvantage of this method is that it adds the delay at the cost of successfully delivering the data.

5. PERFORMANCE EVALUATION

To evaluate our proposed scheme, we randomly deployed 200 mobile nodes in the network region of 1000x1000m^2. The nodes move in the network region with the maximum speed of 0 to 30m/s based on the random way-point mobility model. The maximum transmission range is 150m and the rate is set to 54Mbps, similar to RMR [3]. Each node sends periodic HELLO packets at a random interval between 0.5 to 1.5 seconds. Data traffic is generated by 50 source nodes towards a fixed CC located in the center of the network. Each source node generates a constant bit rate (CBR) traffic, with 512 bytes packet and the inter-arrival rate set to 0.5seconds. The time-to-live (TTL) for the data packet is set to 32 hops. The total simulation time is set to 300 seconds.

We measured packet delivery ratio (PDR), path length,

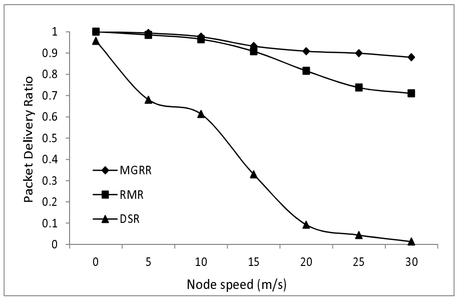


Figure 3: PDR *Vs.* Mobility

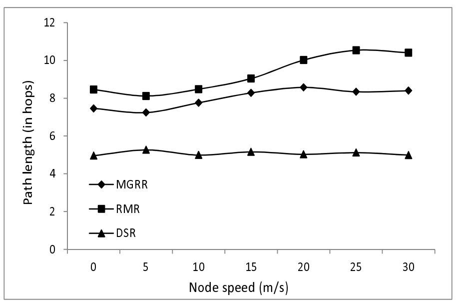


Figure 4: Avg. path length *Vs.* Mobility

network overhead and delay to evaluate our scheme. PDR is a ratio of the number of packets received at the CC to the packets sent by the sources. Average path length is the number of hops traversed by the packets that successfully arrive at the destination node. Average network overhead is defined as the number of control packets generated by each protocol per second throughout the duration of the simulation. Average latency is defined as the average time packets take to arrive at the CC after generated at the source nodes. For comparison DSR routing protocol and single grid based routing scheme similar to RMR is used. The reliability metric for RMR is computed as the $-ln(1-e^{\Sigma(X(t))})$ [3], where, $\Sigma(X(t))$ is the mean number of nodes inside the cell at given time t. Results are obtained from averaged value of five different topologies generated for each speed from 0 to 30m/s.

First, we describe the effect of mobility in tactical network scenarios. Fig. 3 shows the PDR when mobility increases from 0m/s to 30m/s. Our proposed scheme MGRR maintains above 90% of PDR over all speed, while RMR maintains around 85%. Owing to path selection metric HDR, which incorporates node-density and the latest availability of reliable nodes for forwarding data, this protocol maintains the highest reliability. DSR drops fast primarily due to node-centric failure with average of around 40% PDR over all speeds. Whenever the "no route" error is reported, the packet is dropped and the source node is notified to discover a new route. For RMR, node mobility has a considerable effect likewise, when the designated cell in the path has no nodes available to forward data. This lowers the PDR and

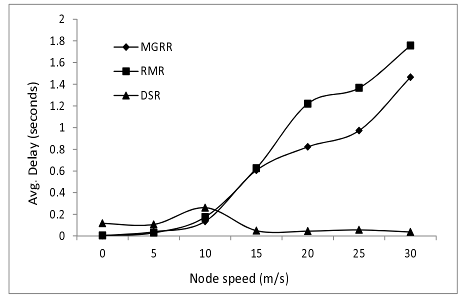


Figure 5: Avg. Delay Vs. Mobility

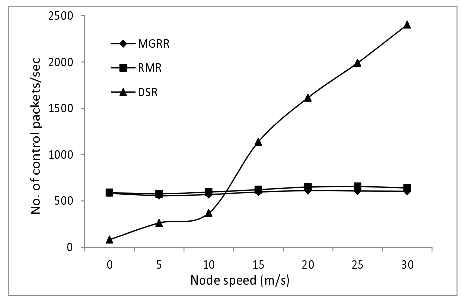


Figure 6: Avg. overhead *Vs.* Mobility

hence the reliability. In MGRR, if sender does not find a forwarding node in the neighbor cell, it looks up in the corresponding larger cell. Instead in RMR, path reconstruction upon failure increases the chance of packet drop both due to restricted TTL and when the router queue is full. We also diagnose that, RMR might go into temporary routing loop when path is reconstructed, at times causing TTL to reach zero before packet reaches the destination.

Fig. 4 shows the average path length required by the packets to reach the destination. Since DSR uses shortest hop count metrics, its average path length is around 5 hops. RMR shows the longest average path length for the delivered packets of about 10 hops at the maximum node mobility of 30m/s. Our proposed scheme, MGRR as expected has an average path length between DSR and RMR owing to the usage of larger cell to select shorter hops whenever the small sized cells fails to forward the data. As opposed to the previous result, in Fig. 5 despite of shortest path length, DSR shows high latency until 10 m/s. Firstly, a route discovery process in the DSR takes initial amount of time to discover the path. For MGRR and RMR, path computation is equivalent only to the processing time required in the source routing agent. Again in DSR, mobility affects the performance of the network. The low delay after 10m/s node speed in DSR is because very few packets reach the destination.

From the results shown in Fig. 6, we compare the network overhead due to generated control packets with the reactive DSR routing protocol and the grid-based routing protocols such as MGRR and RMR. The amount of overhead of DSR routing protocol shows remarkable increase across the in-

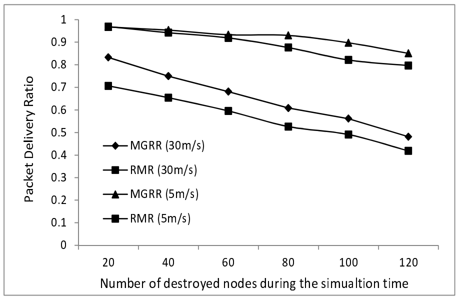


Figure 7: PDR *Vs.* node failure

creasing mobility. As mentioned above, failure of any node in the path causes DSR to reconstruct again by generating additional route request, route reply and route error packets. This causes increase in overhead almost linearly, which also effects the transmission of data packets in the network. Compared to DSR, both grid-based routing protocol has a constant overhead generated by the HELLO packets.

In a next set of results, we show the tolerance of grid-based routing protocols against the faulty nodes that might occur in the T-MANET scenarios. For this purpose we choose low and high mobility scenarios with 5m/s and 30m/s, respectively. For each scenario, 20 to 120 out of 200 nodes are disabled in a random interval during the simulation time as shown in the x-axis of Fig. 7. Since in this case we measure the ability of a routing protocol, 50 source nodes generating CBR data of 512 bytes and the destination node are not disabled. Fig. 7 shows the PDR averaged from five different topologies. Comparing with Fig. 3, we see that the effect of node failure on the routing protocol have a significant impact irrespective to the mobility. Results show that the decrease in PDR is more rapid when the node failure occurs in high mobility for both grid-based routing protocols. Our proposed scheme maintains above 50% of PDR even in high mobility with more than half of the nodes not participating in routing process. Interestingly in multi-grid routing, advantage from the mobility effect can be exploited automatically for better data forwarding. Whenever a node fails in the cell from where the relay node is expected to forward data, opportunity of finding another mobile node in the corresponding larger cell is very high. In RMR, due to small cell size, duration of a mobile node spending time in a cell is much less causing sharper reduction in PDR.

6. CONCLUSION

This paper presents a multi-grid based reliable routing protocol for tactical mobile ad hoc networks. Based on the information about the deployment region and the geographical information about the nodes, the protocols construct multiple grids with different cell sizes for routing. Cells in the grid are mapped to the reliability values enabling a selection of reliable regions for data transmission from the deployed nodes to the CC. Our proposed scheme, MGRR thus, uses these regions to construct a network graph, in which cells are vertices. The edges in the graph are weighted by the reliability metrics that considers packet delivery between links and its availability within the certain time. The formation of multiple grids represents the network region with better granularity depending upon the mobility. Such kind of cell formation for the network can help in finding shorter and reliable path when available. From the performance results, we show that the PDR, average latency and overhead of our proposed scheme MGRR is better across increasing mobility in tactical networks scenarios. In future, we shall study the reliability of our multi-grid routing in presence of compromised regions and its ability to support tactical quality of service based traffic.

7. ACKNOWLEDGMENTS

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