HMS: Holistic MPR Selection and Network Connectivity for Tactical Edge Networks

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***Abstract*—MANET is seen as a promising technology that helps facilitate range extension in tactical edge networks (TENs) where both realtime broadcast and unicast are critical communications. These services are usually provided by proactive routing protocols with Multipoint Relay (MPR) technology. The standardized MPR selection method produces redundant MPR nodes which can cause repeated transmissions of broadcast traffic in TENs where bandwidth and power are scarce. Efficient minimum MPR set optimization remains a challenge. In addition to MPR selection, network connectivity is another important feature for how to best deploy connected MANETs at the tactical edge and ensure its reliable connectivity. To the best of our knowledge, little research has been done on this front. In this paper, we propose a holistic MPR selection (HMS) strategy that selects nearly-optimized MPR sets for a MANET in a pre-defined area at varying radio transmission ranges. We show through simulations that HMS is very close to the lower bound of the optimal MPR number and reduces over 50% MPRs compared to the greedy heuristic method in most tactical edge scenarios. We introduce a method to arrive at the minimum MPR size for fully covering a pre-defined area with different radio transmission ranges and investigate the relationship of MPR set with network connectivity. We developed the algorithm with simple geometry and found that our MPR comparison results among HMS, the minimum MPR size, and the lower bound of the optimal MPR number deliver radio range boundaries that differentiate three different grades of connectivity. The range boundaries can be used as an advanced feature for how to best deploy a MANET at the tactical edge for reliable connectivity.**

I. Introduction

Mobile Ad Hoc Network (MANET) can help facilitate range extension at the tactical edge where dismounted soldiers operate. MANETs allow multi-hop network connectivity to remote nodes as well as self-organization to support on-the-fly network configuration. Both realtime broadcast and unicast are critical communications in a tactical edge mobile ad hoc network (TEN). It remains a sizeable challenge to efficiently disseminate both realtime broadcast and unicast messages among nodes in TENs, especially while considering broadcast messages would account for the majority of total traffic in a TEN (of roughly the size of a platoon) according to the information sharing patterns given by Thomas Hammel [1].

Using a proactive routing protocol such as Multicast Optimized Link State Routing Protocol (MOLSR) [2] with Multipoint Relay (MPR) technology [3] is one of the solutions to reduce repeated broadcast packet transmissions in a TEN while providing realtime unicast service, i.e., selecting only a few nodes to be MPRs (an MPR set) to retransmit all broadcast packets while forwarding realtime unicast packets based on the routing table pre-calculated by each MPR node. The smaller the MPR set, the smaller the volume of broadcast packet transmissions in the network, which could translate to a reduction in node interference, bandwidth usage, and energy savings for the non-MPR nodes.

The minimum MPR set selection is an NP-complete problem as proved by Qayyum et al. [3]. The current implementation of MPR selection uses the greedy heuristic method which is applied to the Optimized Link State Routing Protocol (OLSR) [4] and its multicast variant MOLSR. The greedy heuristic method can create a large number of redundant MPR nodes that can be removed from the MPR set without affecting network coverage and connectivity. The MPR set computed by the greedy heuristic method is at most $log(n)$ times the optimal MPR set [3], where n is the number of nodes in the network. Selecting an MPR set that is close to the lower bound of the optimal MPR set efficiently, without affecting other characteristics of the network (such as performance of routing convergence), is an open problem.

In addition to MPR set selection and optimization, radio transmission range is another very important attribute on how to best deploy a TEN and ensure its reliable connectivity at the tactical edge; however, there is little research investigating the relationship between MPR set selection and radio range in this context. If we consider TEN connectedness is paramount in a given area, then we question what is the minimum MPR nodes and each with what radio transmission range required to ensure all nodes are connected if they are randomly distributed in a predefined area.

In this paper, we propose a holistic MPR selection (HMS) method that reduces the number of MPRs selected by the greedy heuristic method in a TEN with nodes whose radio transmission range can be varied. HMS verifies the redundant MPRs based on the whole view of network topology, and disables the redundant MPRs iteratively from the set by checking the MPR with the smallest number of MPR connections and working up towards the MPR with largest number of MPR connections until all MPRs have been checked. We present MATLAB simulation results demonstrating that our proposed HMS performs close to the lower bound (inf$\{MPR\}$) MPR number given by Qayyum et al. [3]. We will show that the HMS method, on average, can reduce over 50% of MPRs that would be selected by the greedy heuristic method in a TEN with 40 to 60 nodes randomly placed in a (2km X 2km) square area and a wide span of radio transmission range for each node. The processing of HMS may not be scalable for large size MANETs but it is practical for TENs with less than 60 nodes. The delay caused by HMS is less than one second for these practical TENs.

To investigate the relationship among MPR set, radio transmission range, and network connectivity, we developed the

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algorithm to compute the minimum MPR size (min$\{MPR\}$) for full network coverage using simple geometry in a pre-defined area with nodes whose radio transmission range can be varied. We compared the results produced by HMS to those of the minimum method (min$\{MPR\}$) and of the lower bound method (inf$\{MPR\}$) where nodes are randomly distributed in the pre-defined area. We submit evidence, from our simulations in MATLAB and EXata [5], that the cross points of an MPR set graph of the three methods (HMS$\{MPR\}$, min$\{MPR\}$, and inf$\{MPR\}$) for varying radio transmission ranges could indicate three grades of connectivity in a TEN. The boundaries could help imply how to best deploy a TEN and ensure a grade of network connectivity based on number of nodes and radio transmission range.

The rest of the paper is organized as follows. The holistic MPR selection is discussed in the next Section. In Section III, the performance of HMS is simulated and compared with the greedy heuristic method and the lower bound of the optimal MPR numbers (inf$\{MPR\}$). In Section IV, the minimum MPR size (min$\{MPR\}$) for fully covering a pre-defined area is studied, and the network connectivity is investigated based on HMS$\{MPR\}$, min$\{MPR\}$, and inf$\{MPR\}$. Finally, concluding remarks are given in Section V.

II. Holistic MPR Selection

The greedy heuristic MPR selection used in proactive routings such as OLSR and MOLSR can cause a lot of redundant MPR nodes based on the research done by Qayyum et al. in [3]. Fig.1. depicts the MPR set computed based on the greedy heuristic MPR selection method with different node radio transmission range under MATLAB simulation, and compared with the lower bound of the optimal MPR number in a network with 50 nodes randomly distributed in a square field (2km X 2km). However, the minimum optimal MPR set selection has been proved as NP-complete problem in [3]. Several MPR set minimization solutions have been proposed [6–8]. For instance, Li et al. [6] proposed a necessary first algorithm (NFA), which can reduce the number of MPR nodes in the network by 0.7% up to 11.2% under different scenarios compared with the original greedy algorithm [3]. Bai et al. [7] proposed a method based on node density, which can reduce approximately 10% of MPR nodes.

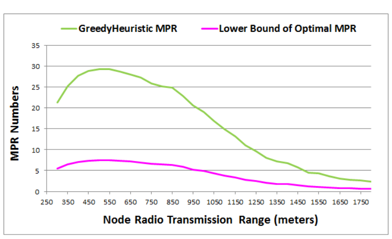

Fig. 1. The greedy heuristic MPR set and the lower bound of the optimal MPR number with different node radio transmission ranges.

In this paper, we propose a holistic MPR selection (HMS) method to reduce the redundant MPR nodes computed by the greedy heuristic method. Unlike the above solutions, which reduce MPR nodes from the point of view of each source node, the proposed HMS uses the entire network topology and reduces the MPR set using a "holistic" algorithm. First, HMS automatically selects a unique MPR node (we call it MPR reduction processing node, i.e., MR) for HMS processing. With network topology information, MR verifies and disables the redundant MPRs based on the number of their MPR connections. HMS can be easily integrated into OLSR and MOLSR, and triggered by certain time interval (e.g., every 30 seconds). The detailed HMS procedure is described below.

In OLSR or MOLSR protocol, once all MPR nodes get the network topology information after the network is initiated, the following HMS process is triggered periodically based on the HMS time interval.

(1) Each MPR node creates an ordered list of all MPR nodes, sorted by the number of their MPR connections;

(2) The MPR node with the highest number of MPR connections and ID number becomes the MR node. All MPR nodes in the network can correctly identify this node based on (1). The MR node carries out the following MPR reduction procedure. Other MPR nodes continue operating as normal until they receive further instructions from the MR node;
   - i Check the MPR node with the smallest number of MPR connections;
   - ii Delete the MPR node in Step i if this deletion would neither reduce the coverage of the network nor break network connectivity by the remaining MPRs;
   - iii Repeat Steps i and ii for each MPR in the network, working up towards the MPR with largest number of connections until all MPRs have been checked;
   - iv The MR node creates a list of MPRs whose MPR function should be retained based on Step i, ii, iii;
   - v The MR node broadcasts the following MPR retain message throughout the network. $\{F_{MPR_r}, M_1, ..., M_n\}$, where F_{MPR_r} is the MPR retain message flag that indicates this is an MPR retain message. $\{M_1, ..., M_n\}$ are the MPRs that should be retained after HMS processing.

(3) An MPR node disables its MPR function if it receives the MPR retain message and it is not on the MPR retain list;

(4) Each node (including both MPR and non-MPR) deletes the MPR nodes (who are not on the MPR retain list) from its 1-hop MPR set when it receives the MPR retain message;

(5) To account for mobility, each node re-selects MPRs based on the following rules:
   - i It would not re-select MPRs if it has at least one 1-hop MPR available;
   - ii It triggers the greedy heuristic MPR selection based on its current 1-hop and 2-hop information if it loses all its 1-hop MPR connections;

As will be discussed in section III, simulations in MATLAB show that the HMS MPR selection can reduce the number of MPRs in the network by over 50% in a wide radio transmission range at TENs when compared with the greedy heuristic method. Even though HMS reduces over 50% MPRs, it still provides certain redundant MPRs for providing the redundancy, diversity, and connectivity of TENs.

III. HMS Performance

In order to evaluate the performance of the HMS method, we conducted simulations in both MATLAB and NS-2 [9].

MATLAB was used to examine the percentage of reduction in the number of MPR nodes that could be achieved using the HMS algorithm presented in Section II as opposed to a local greedy heuristic algorithm for MPR selection. NS-2 simulations were used to evaluate the bandwidth usage, node forwarding load, and delivery ratio of HMS and to compare with the MOLSR routing protocol.

A. HMS MPR Reduction Performance

We simulated the HMS algorithm in MATLAB based on different node radio transmission range, where networks with 50 nodes were created with nodes randomly distributed in a square field (2km X 2km). Simulations of networks configuration were run 100 times for each radio transmission range and the results were averaged (note that each run with different network topology created by random algorithm). Fig.2. depicts the MPR numbers computed by HMS, greedy heuristic, and lower bound of the optimal MPR number (inf$\{MPR\}$).

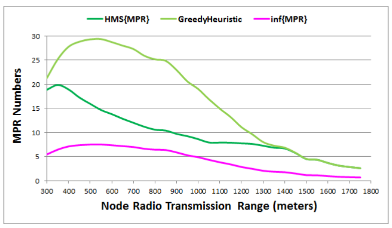

Fig. 2. The MPR numbers computed by HMS, greedy heuristic, and lower bound of the optimal MPR number under different radio transmission ranges using MATLAB simulation.

The simulation shows that the proposed HMS method reduces over 40% redundant MPR nodes when compared with the greedy heuristic method with the node radio transmission range from 450 meters to 1150 meters in the above TEN scenario. The MPR number computed by HMS is closer to the lower bound of the optimal MPR number.

We then simulated the HMS method in MATLAB with different network sizes (nodes) that were created under the same scenario as above and calculated the percentage of MPR reduction when compared with the greedy heuristic method. Fig.3. depicts the percentage of MPR reduction by HMS under different network sizes (i.e., 40, 50, 60, 80, and 100 nodes).

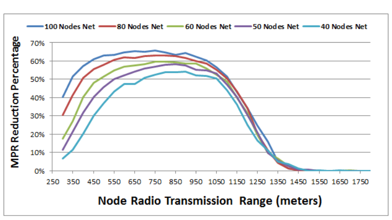

Fig. 3. The HMS MPR reduction percentage over greedy heuristic algorithm under different node radio transmission ranges and their related network size.

Fig.3. shows that HMS can reduce over 40% redundant MPR nodes within a wide radio transmission range under different network size (e.g., over 50% MPR reduction in a TEN with 60 nodes within radio transmission range from 450m to 1150m). The bigger the network size, the larger the radio transmission range can span to reach greater MPR reduction.

B. HMS Bandwidth Usage, Traffic Forwarding Load, and Traffic Delivery Performance

We simulated the performance of HMS under the NS-2 with mixed traffic conditions, i.e., the traffic used in the simulation contains 80% broadcast messages and 20% unicast messages as described in [1]. We were interested in the bandwidth usage, traffic forwarding load, and traffic delivery ratio of HMS, and compared them to MOLSR. All simulations use the same scenarios as that in MATLAB simulation for node radio transmission range and node distribution. The simulation setup is described below.

- Simulation Platform: NS-2 version 2.35;
- Communication Channel: 802.11b with 5.5Mb data rate and 900 meters transmission range;
- Node Distribution: 50 nodes are randomly distributed in a (2km X 2km) square field in NS-2;
- Broadcast Message: Each node periodically sent a broadcast message every 5 seconds. Each broadcast message was 256 Bytes. The first broadcast message sent out at 10 second and the simulation stopped at 310 second;
- Unicast Message: We randomly chose eight source and destination nodes for generating unicast traffic. The total unicast payload traffic occupied 20% of the total traffic in the network based on [1].

The performance metrics include bandwidth usage, traffic forwarding load, MPR set, and traffic delivery ratio which are defined below.

- Bandwidth Usage: is the amount of data transmitted and received by a node including all inbound and outbound traffic. It is calculated as the total inbound and outbound traffic by each node divided by the simulation time. Note that the bandwidth usage is calculated in network layer only in this paper. It does not include the lower layer overhead such as MAC layer frame, etc.;
- Traffic Forwarding Load: is the average load for forwarding the mixed traffic by each node during a simulation period. It is calculated as the total forwarded traffic (in Bytes) by each node divided by the simulation time;
- MPR set: is a set of all MPR nodes selected by nodes in a network;
- Traffic Delivery Ratio: is the ratio of total received traffic by each node to the total traffic sent to the node.

B.1) Bandwidth Usage

Fig.4. depicts the bandwidth usage of each node in the HMS and MOLSR protocols for delivering the mixed traffic. Fig.4. shows that the HMS protocol can save 40% bandwidth on average for delivering the mix traffic compared with using the MOLSR protocol.

B.2) Traffic Forwarding Load

The more nodes involve forwarding traffic, the more nodes consume their energy. The forwarding traffic also causes node interference and occupies bandwidth in the network. Fig.5. depicts the forwarding load of each MPR node in the HMS and MOLSR protocols for delivering the mixed traffic. Although MOLSR selects 40 nodes as MPRs, majority traffic (over 10kbps) are only forwarded by 20 MPRs. HMS selects 9 MPRs and uses 8 MPRs for majority traffic forwarding.

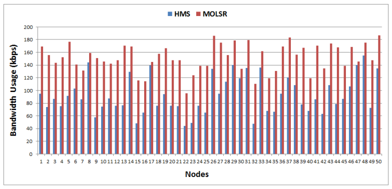

Fig. 4. The bandwidth usage of each node in the HMS and MOLSR protocols for delivering the mix traffic using NS-2 simulation.

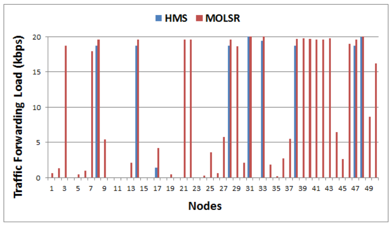

Fig. 5. The forwarding load of each MPR node in the HMS and MOLSR protocols for delivering the mixed traffic using NS2 simulation.

B.3) MPR Set

The more MPRs selected, the more routing messages will be created, the more node interference can be caused, and the more bandwidth will be occupied in the network. Our goal is to reduce the MPR set without degrading traffic delivery ratio. Fig.6. depicts the number of MPR nodes computed by the greedy-heuristic method under MATLAB (M_GH_MPR), and selected by MOLSR and HMS under NS-2.

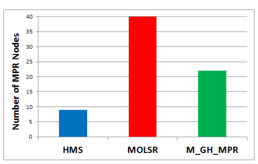

Fig. 6. The number of MPR nodes computed by the different MPR selection methods and under the different simulation platforms.

In Fig.6., M_GH_MPR under MATLAB selects 22 nodes as MPR nodes, and MOLSR under NS-2 selects 40 MPR nodes. HMS only selects 9 MPR nodes under the same simulation scenario. Even though HMS reduces the MPR nodes by over 59% compared with both M_GH_MPR and MOLSR, it still provides 2-4 redundant MPRs for providing the redundancy, diversity, and connectivity of TENs.

B.4) Traffic Delivery Ratio

Reducing MPR set may degrade the traffic delivery ratio if the MPR reduction method is not well designed. Fig.7. depicts the traffic delivery ratio of each node in the HMS and MOLSR protocols for delivering the mixed traffic. Fig.7. shows that HMS has a little lower delivery ratio (less than 3%) compared with MOLSR but HMS reduces over 76% MPRs and saves 40% bandwidth. Both HMS and MOLSR have very good delivery ratio on delivering mixed traffic (over 94%) which is much better than reactive protocols such as MAODV [10, 11].

In general, HMS can reduce redundant MPR nodes in the network and save bandwidth without degrading the traffic delivery ratio. For TENs, this could translate to a reduction

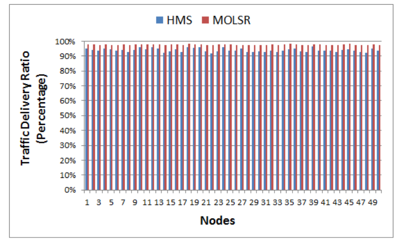

Fig. 7. The mixed traffic delivery ratio of the HMS and MOLSR protocols for each node.

in node interference and energy savings for the removed MPR nodes. The MPR reduction may affect the work of other MPRs on forwarding unicast traffic. However, TENs have a different traffic pattern where broadcast messages occupy the majority of total traffic. That means the redundant MPRs if not reduced can cause more congestion for forwarding broadcast traffic.

IV. HMS Network Connectivity

The network connectivity with respect to transmission range is one of the important features with which we concern in TENs. Here, we investigate the minimum MPR size for fully covering a pre-defined area and its relationship with HMS network connectivity in the following sections.

A. Minimum MPR Size for fully Covering a Pre-defined Rectangle Area

The minimum MPR set selection for fully covering a pre-defined rectangle area is similar to the connected single-cover relay node placement problem which has been proved as NP-hard problem in [12]. In this paper, we discuss how to calculate the minimum MPR size (min$\{MPR\}$) for fully covering a pre-defined rectangle area but will not discuss how to select the minimum MPR set based on the distributed nodes. We focus on calculating minimum number of connected nodes are required in order to fully cover a rectangle area with varying radio transmission range. The network is not fully connected if the selected MPR size is lower than the minimum MPR size.

To make our min$\{MPR\}$ calculation simple, we place the first node in the lower left corner of the rectangle area and let it cover a square area in that corner. Fig.8.(a) depicts our first node placement. We then place the second node in the upper right corner of the square covered by the first node to keep connected. The third node is placed in the lower right corner of the square covered by the second node. We place the rest of the nodes based on this pattern. Fig.8.(b) depicts the rest of the node placement pattern. Fig.8.(c) depicts all nodes in a rectangle area and their connections. Note that some extra nodes may be required in order to cover a corner in this placement pattern.

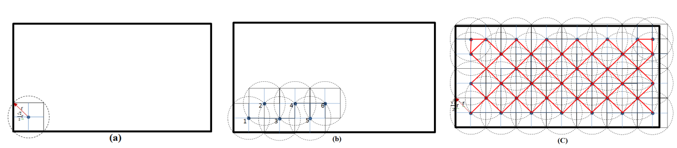

Fig. 8. The node placement for minimum MPR size: (a) the first node placement, (b) the node placement order, (c) all nodes placement.

Now we calculate how many nodes are required in order to fully cover a rectangle area based on the above node placement. Given a rectangle area with length (l) and width (w), and the radio transmission range (r) of the node, we have the following formula (1) to calculate the minimum MPR size ($min\{MPR\}$) for fully covering the rectangle area (l x w) with the radio transmission range (r) of the node, where $L = \frac{l}{\frac{\sqrt{2}}{2}r}$, $W = \frac{w}{\frac{\sqrt{2}}{2}r}$, $\overline{L} = \lceil L \rceil$ is the ceiling value of L (i.e., the smallest integer not less than L), and $\overline{W} = \lceil W \rceil$ is the ceiling value of W.

$$min\{MPR\} = \begin{cases} \frac{\overline{L}*\overline{W}-\overline{L}-\overline{W}+2}{2}, & \text{if } \overline{L} \equiv \overline{W} \equiv 0 \text{ (mod 2)} \\ \frac{\overline{L}*\overline{W}-\overline{L}-\overline{W}+5}{2}, & \text{otherwise} \end{cases} \qquad (1)$$

Fig.9. depicts the minimum MPR size (min$\{MPR\}$) calculated by the formula (1) and the lower bound (inf$\{MPR\}$) of the optimal MPR number given by Qayyum [3] with 50 nodes randomly distributed in a square field (2km X 2km) and different radio transmission ranges.

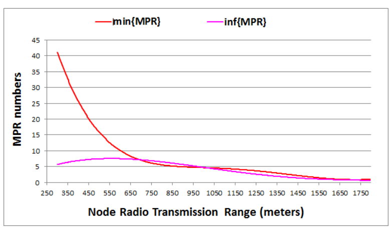

Fig. 9. The minimum MPR size and the lower bound of the optimal MPR number with different radio transmission ranges.

Fig.9. shows the two lines of (min$\{MPR\}$ and inf$\{MPR\}$) almost merge together when the node radio transmission range is over 700 meters in this scenario. That means the optimal MPR nodes could cover the whole area and keep all nodes connected in the network when the node radio transmission range is over 700 meters. However, when the node radio transmission range is less than 700 meters the minimum MPR size is bigger than the lower bound of the optimal MPR number. That means the optimal MPR nodes cannot cover the whole square field once the node radio transmission range is less than 700 meters and may cause some nodes to be disconnected from the network.

In order to compare the minimum MPR size under different covering patterns, we examined another covering pattern with hexagons. We followed the same placement pattern as that with squares. Fig.10.(a) depicts our first node placement with hexagon. We then placed the second node in the upper right corner of the first hexagon to keep connected. The third node is placed in the lower right corner of the second hexagon. We placed the rest of the nodes based on this pattern. Fig.10.(b) depicts the node placement pattern with hexagons. Fig.10.(c) depicts all nodes placed with hexagon pattern in a rectangle area and their connections.

Given a rectangle area with the same length (l), width (w), and same radio transmission range (r) of each node as that in the formula (1), we present the following formula (2) to calculate the minimum MPR size ($min\{MPR_h\}$) for fully covering the rectangle area (l x w) with the hexagons, where $L_h = \frac{l}{r}$, $W_h = \frac{w}{r\sqrt{3}}$, $\overline{L_h} = \lceil L_h \rceil$, $\overline{W_h} = \lceil W_h \rceil$, $\lfloor \frac{\overline{L_h}+1}{2} \rfloor$ is the floor value of $\frac{\overline{L_h}+1}{2}$ (i.e., the largest integer not greater than $\frac{\overline{L_h}+1}{2}$), and $\delta = \overline{W_h} - W_h$.

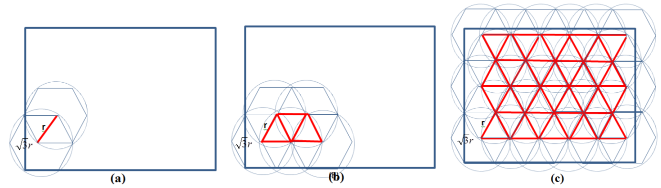

Fig. 10. The node placement with hexagon pattern for minimum MPR size: (a) the first node placement, (b) the node placement order, (c) the nodes placed with hexagon pattern.

$$min\{MPR_h\} = \begin{cases} 2\overline{L_h}*\overline{W_h} - \overline{L_h} - \overline{W_h} + 1, & \text{if } \delta < \frac{1}{2} \\ (2\overline{L_h}-1)(\overline{W_h}-1) + \lfloor \frac{\overline{L_h}+1}{2} \rfloor, & \text{otherwise} \end{cases} \qquad (2)$$

Fig.11. depicts the minimum MPR size (min$\{MPR\}$ and min$\{MPR_h\}$) calculated by the formula (1) and (2) respectively for a square field (2km X 2km) and different radio transmission ranges.

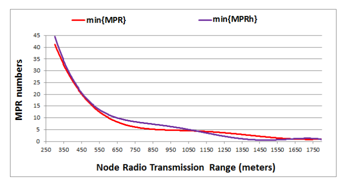

Fig. 11. The minimum MPR size (min$\{MPR\}$ and min$\{MPR_h\}$) calculated based on square and hexagon covering patterns.

Fig.11. shows the two lines of min$\{MPR\}$ and min$\{MPR_h\}$ are very close. For simplicity, we will use the minimum MPR size calculated based on the square covering pattern for the rest of the investigation and estimation of the network connectivity from this point forward.

B. HMS Network Connectivity Estimation

With the results from HMS, minimum MPR size, and lower bound of the optimal MPR number, we submit that one can deduce practical solutions based on the cross sections of the three lines. Fig.12. depicts the network connectivity status with different radio transmission ranges for a network with 50 nodes randomly distributed in a (2km X 2km) square field.

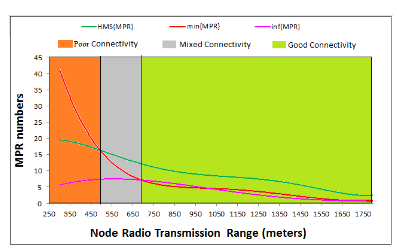

Fig. 12. The network connectivity status estimation based on HMS$\{MPR\}$, min$\{MPR\}$, and inf$\{MPR\}$.

Fig.12. indicates that the network has poor connectivity (i.e., some nodes are disconnected) when the node radio transmission range is less than 500 meters. That is because

the HMS MPR numbers are less than the required minimum MPR size, which means some nodes cannot be covered by the HMS MPRs when the nodes are randomly or uniformly distributed in that area.

The network has connectivity when node radio transmission range is longer than 700 meters (i.e., the lower bound of the optimal MPR number is very close to the minimum MPR size). It means the MPRs could cover the whole area when the lower bound of the optimal MPR number is close to the minimum MPR size. Note, as we mentioned before, the MPR reduction shouldn't change the network connectivity, i.e., the HMS MPRs, greedy-heuristic MPRs, and the optimal MPRs should cover the same network although they may choose different nodes as MPRs and have different MPR set. We submit that cross section of the lower bound of the optimal MPR number and the minimum MPR size can better represent the network connectivity because both of HMS and the greedy-heuristic MPRs have redundant MPRs and can cause more errors for network connectivity estimation. For instance, in Fig.12., where the network has poor connectivity (when the node radio transmission range is 500 meters), even the greedy-heuristic MPR size is much larger than the minimum MPR size (see Fig.1.); we demonstrated it with our simulation results in MATLAB.

The network has mixed connectivity (i.e., it may have connectivity or poor connectivity) when the node radio transmission range is between 500 and 700 meters. That is because the nodes are randomly distributed in the area. It might still have connectivity if the lower bound of optimal MPR number is not less than the minimum MPR size too much but the connectivity is not guaranteed even when the HMS MPRs are larger than the minimum MPR size. This conclusion has been demonstrated with our simulation in MATLAB and EXata.

Based on this research, we can estimate whether or not a network could have good connectivity, based on its network size, radio transmission range, and the value of HMS$\{MPR\}$, min$\{MPR\}$, and inf$\{MPR\}$. We can also predefine how many nodes and how much radio transmission range should be provisioned to ensure a distributed network in a battle field will have good connectivity. Fig.13. depicts the network connectivity cross points related to different network sizes based on the lines of the lower bound of the optimal MPR number (inf{MPR}) and the minimum MPR size (min{MPR}). For instance, if one wants to randomly distribute 50 nodes in a (2km X 2km) square area and keep them connected, one needs to set their radio transmission range over 700 meters based on results presented in Fig.13. On the other hand, if the node radio transmission range is fixed (e.g., 650 meters) and one wants to keep all nodes connected once they are randomly distributed in a square area (e.g., 2km X 2km), one needs at least 60 nodes.

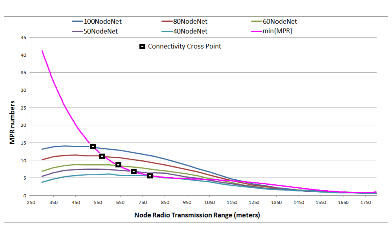

Fig. 13. The network connectivity cross points of different network sizes.

V. Conclusion

In order to provide efficient broadcast technology for disseminating both broadcast and unicast messages such as situational awareness sharing and commander orders in mobile tactical edge networks, we propose the HMS protocol, which uses a holistic method for MPR node selection, reduces MPR nodes and broadcast traffic retransmissions on the network. With fewer MPR nodes, HMS reduces the node forwarding load and node interference for broadcast traffic, and saves the network bandwidth and node energy while providing unicast services. In addition, with HMS, minimum MPR size, and lower bound of optimal MPR number, we can estimate network connectivity. We have presented a simple method establishing radio transmission range to ensure the connectivity of a tactical edge network in a battle field area.

We believe that HMS has great potential for increased efficiency for broadcast traffic in tactical edge networks when considering TENs with slow moving speed (e.g., less than 10 m/s as solders' running speed), larger radio coverage (e.g., 1 km radio transmission range of each solder device), and limited nodes (e.g., less than 50 in general) compared to traditional MANET research. We will continue to enhance the protocol and study its performance, examining the impact of mobility and other features.

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