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Article

Enhancing Reliability of Tactical MANETs by Improving Routing Decisions

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Abstract: Mobile ad-hoc networks (MANETs) have been primarily designed to enhance tactical communications in a battlefield. They provide dynamic connectivity without requiring any pre-existing infrastructure. Their multi-hop capabilities can improve radio coverage significantly. The nature of tactical MANET operations requires more specialized routing protocols compared to the ones which are used in commercial MANET. Routing decisions in MANETs are usually conditioned on signal-to-interference-plus-noise ratio (SINR) measurements. In order to improve routing decisions for use in highly dynamic tactical MANETs, this paper proposes to combine two different metrics to achieve reliable multicast in multi-hop ad hoc networks. The resulting protocol combining received signal strength (RSS) with SINR to make routing decisions is referred to as Link Quality Aware Ad-hoc On-Demand Distance Vector (LQA-AODV) routing. The proposed routing protocol can quickly adapt to dynamic changes in network topology and link quality variations often encountered in tactical field operations. Using computer simulations, the performance of proposed protocol is shown to outperform other widely used reactive routing protocols assuming several performance metrics.

Keywords: connectivity; link quality; network metric; routing decision; tactical MANET

1. Introduction

In the early 1970s, the first generation of MANETs called packet radio network (PRNET) were designed to provide reliable coverage, especially for voice services [1]. MANETs then gradually evolved to focus on improving their range, survivability and security. Tactical MANETs have become the core technology in digitalized battlefields. The distributed nature of application and connectivity management in MANETs make these networks to be more robust than their centralized counterparts. However, tactical MANETs are usually deployed in environments and conditions which are harsh for radio propagation while they have to cope with the relatively large mobility of network nodes.

Link quality is one of the main concerns to achieve reliable communications in wireless networks. Typical non-line of sight (NLOS) multipath propagation with shadowing and fading may disrupt all connectivity in infrastructure-less wireless networks, whereas LOS connectivity may still suffer significantly from path loss attenuations. Maintaining sufficient link quality is critical for achieving an effective transmission range of terrestrial radios [2]. Long range military radios operating in very/ultra high frequency (VHF/UHF) bands require a minimum level of SINR in order to achieve the target bit error rate (BER) or packet error rate (PER). Typical minimum SINR values for the target link reliability range from 6 to 23 dBm [3]. Furthermore, tactical communication networks usually exploit link margins as large as 40 dB in order to guarantee connectivity at all times [4]. The minimum required SINR or RSS values are determined by the receiver sensitivity. Unfortunately, sensitivity and selectivity of legacy VHF and UHF receivers is usually poor while also having limited data rates. Consequently, shorter range LOS radios are now being developed for the UHF band 1350–2690 MHz and a new

4.4–5 GHz band. This enables having links with much higher capacity and enough gain from small size antennas.

Modern tactical MANETs carry mostly broadcast and multicast traffic with small proportion of unicast transmissions. Availability of reliable and efficient packet flooding with small protocol overhead is one of the most fundamental services provided in these networks. Several flooding algorithms have been introduced in the literature for general MANETs. Among these algorithms, reactive routing protocols can offer flooding as a route discovery process when searching for feasible routes. The main drawback of such a mechanism is excessive flooding, which can lead to network clogging. A variety of flooding optimization techniques have been proposed to reduce the overhead of route discovery [5]. However, these solutions do not scale well to embrace large scale networks which are often encountered in tactical MANETs. An alternative approach to overcome scaling problem relies on clustering protocols. Hierarchical routing protocols can reduce the impact of excessive or unnecessarily flooding [6]. Proactive routing protocols utilize flooding to advertise routing information. In general, network flooding is a rather common practice in table driven routing protocols where the neighbor information is gathered and propagated throughout the network [7].

The rest of this paper is organized as follows. Section 2 addresses the issue of connectivity in mobile tactical networks. In Section 3, suitable metrics to make routing decisions are identified, and how these metrics are selected and used is discussed. Section 4 presents a new routing protocol referred to as LQA-AODV. The performance of this protocol is assessed by extensive computer simulations in Section 5. Finally, Section 6 concludes the paper.

2. Connectivity in Tactical MANETs

Network connectivity can never be fully guaranteed for any type of wireless technology unless network topology and radio propagation environment are carefully analyzed. One of the design goals of tactical MANETs is to provide robust connectivity at the network edges. Currently, there is a serious shortfall of providing robust connectivity to the lowest-level combat units represented by dismounted troops at the squad and platoon level in order to provide their access to the command information center. Another challenge is that tactical MANETs operate in different types of terrains with very diverse radio propagation conditions. In addition to RSS, the link quality also depends on the level of interference which is quantified by SINR measure [8]. It is important to consider the following issues to address connectivity in tactical MANETs: Nodes mobility, transmission range and routing protocols.

2.1. Nodes Mobility

The nodes mobile patterns and parameters have a significant impact on network connectivity including average speed, prevailing direction, pausing time distribution, and initial locations [9]. In many cases, real-world mobility traces are not available, so we have to resort to mathematical models to reproduce realistic nodes trajectories. If the mobility model is not carefully selected and configured, evaluation of network protocols may lead to misleading conclusions, either overestimating or underestimating the performance in tactical scenarios. For example, it is generally accepted to assume group mobility as the most suitable model for tactical MANETs. Such model is constrained by assuming permanent group affiliations, homogeneous group velocities or acceleration which is not always satisfied in real-world situations during tactical missions [10]. Thus, there are still many opportunities for developing realistic mobility models for tactical MANETs.

2.2. Transmission Range

It is important to determine the transmission ranges into order to obtain a connected network with given transmission powers. Connectivity and coverage of MANETs with different power control strategies have been well studied in the literature. In these studies, transmission range is either determined for given transmission power, or the minimum SINR threshold. However, the existing studies do not focus on specific context of managing tactical MANETs, and rarely consider typical

networking problems such as hidden and exposed terminal problem, and congestion issues [11]. In order to more precisely determine transmission ranges for specific conditions encountered in tactical MANETs, average network connectivity can be evaluated assuming ratio of the expected number of paths between pairs of nodes over the total number of possible paths [12]:

$$C_N(k) = \frac{2 \sum_{i=1}^{N} \sum_{j=i+1}^{N} \varphi^{(ij)}(k)}{N \times (N-1)} \qquad (1)$$

where N is total number of network nodes, $\varphi^{(ij)}(k)$ is the largest probability of route between nodes *i* and *j* computed over all possible paths, and *k* denotes the time instant. We note that this expression assumes LOS connectivity. Since tactical MANETs are often deployed in harsh terrains with where LOS connectivity is not available, the network connectivity must be sustained via intermediary relay or re-transmission nodes, and also by using aerial platforms such as balloons and drones.

2.3. Routing Schemes

The ultimate goal in mission critical tactical MANETs is to maintain connectivity between all nodes. Tactical MANETs are usually larger than commercial MANETs including the number of hops the data need to pass from the source to a destination. The problem can be formulated as determining the maximum size of MANET which can be sustained for given mobility and routing strategy. Proactive routing protocols preserve the route information for all paths which can be critical to maintain network topology in bandwidth-constrained environments. Proactive routing protocols can also better address security vulnerabilities [13]. In contrast, reactive routing protocols are better suited for smaller networks, for example, at battalion level in tactical MANETs with rapid movements [14]. In addition, MANETs containing several hundred nodes suffer from latency constrains [15]. Another concern is to limit data exchange through the network, particularly during some phase of tactical missions.

Minimum hop-count is the most common metric used for route selection in many existing routing protocols. There are also other metrics used for finding the optimum path in MANETs with other objectives [16]. Routing protocols can also assume geographical distances, channel availability, traffic load and link error rates as metrics to make routing decisions and select end-to-end path. In tactical context, the main concern is to provide robust routing for reliable delivery of mission-critical information within ad-hoc network topology. It is then not sufficient to only consider only the number of hops without regard for the quality of each link along the path. In order to determine the optimum network path in tactical MANETs, it is important to incorporate link-quality into routing metrics to make reliable selection of links and of the end-to-end path under all circumstances. This leads to cross-layer protocol design with improved efficiency and reliability of data delivery [17,18].

3. Link Quality Based Routing Metrics for Tactical MANETs

Selection of good routing metric plays a key role in achieving data transmission efficiency with power savings and rate adaptation. Different link-quality assessment strategies have been suggested [19]. For example, channel quality can be estimated at the receiver with the help of known pilot symbols or training sequences. Blind and semi-blind channel estimation methods have been also considered [20]. Our intention is to explore commonly used link-quality metrics which can be used to make reliable routing decisions over dynamic topology of tactical MANETs [21]. In particular, physical-layer reports can be used to estimate the instantaneous or average link quality over certain time period. Such metrics are attractive, since they are readily available without any additional costs or modification of existing protocols, and they can be used for continuous monitoring of link quality. The key measurements readily available at different stages of the receiver are outlined in Figure 1 [22]. Next, we will review these metrics in more detail.
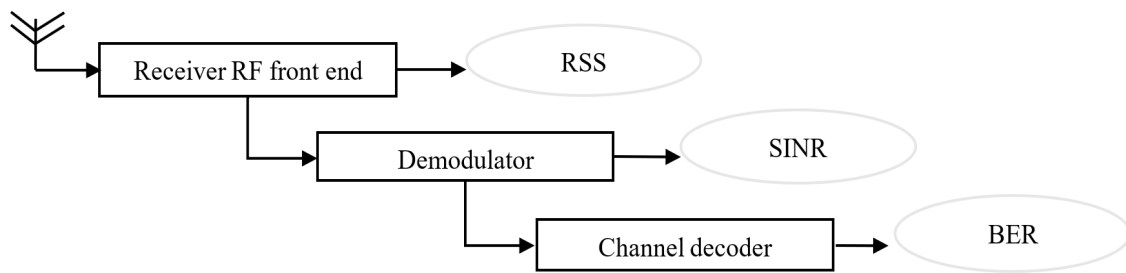
Figure 1. The key metrics for estimating link quality at the receiver.

3.1. RSS Metric

The advantage of using RSS metric is that it can be measured directly, and possibly averaged over time. It reflects relative link quality. Many commercial transceivers have in-build sensor specifically for continuous monitoring and reporting RSS values to upper protocol layers as RSS indicator (RSSI) reports. RSSI mapping can be obtained analytically or using empirical techniques. The analytical approach assumes a mathematical model to estimate the received power level for given channel conditions. Empirical calculation translates RSS into perceived distance. In tactical scenarios, hand-held and man-pack soldier equipment normally operates close to the ground, so ground influence cannot be neglected for more realistic range estimation. For instance, we can assume a 2-ray ground reflection model having a LOS and a multipath component. Since fast fading effects can be suppressed by physical layer techniques such as channel coding and frequency hopping spread spectrum (FHSS) [23], we assume that fast multipath fading will not cause loss of connectivity, and therefore, will not trigger topology changes.

The receiver sensitivity corresponds to the minimum acceptable RSS because the actual transmission range of nodes is environment-specific and often unknown [24]. Specifically, the node i and j are connected if both of them experiences RSS above a certain threshold X_{th} (in dBm), and they are disconnected otherwise. The connectivity is then defined as a random variable:

$$\mathbb{C}_{ij} = \begin{cases} 1, & min\text{RSS} = \frac{P_t\ G_t\ G_r\ H_t^2\ H_r^2}{R^4\ L} \geq X_{th}\ [\text{dBm}] \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

where H is the transmitter and receiver antenna height, G is the antenna gain, L represents propagation and system losses, and R is the distance between nodes. However, RSS values are known to be sensitive to environmental factors such as noise and interference. Therefore, RSS alone is insufficient to be used as a metric for accurately characterizing quality of the wireless link [25]. It is well known that the link connectivity ultimately depends on SINR. The reason why to consider RSS in addition to SINR is that RSS is easier to measure, so it can be used for fast routing decisions in highly dynamic propagation environments with highly mobile nodes. Moreover, SINR is usually estimated over longer time periods where some packets could have been received correctly despite the low value of SINR [26].

3.2. SINR Metric

Tactical MANETs are more likely to be subject to intentional or unintentional interference. The packet delivery rate depends on average SINR being above a certain threshold δ_{th} (in dB). The nodes i and j are connected if both of them experiences SINR above such threshold, and they are disconnected otherwise. Assuming the SINR metric, the connectivity between two nodes is defined by a random variable:

$$\mathbb{C}_{ij} = \begin{cases} 1, & min(\text{SINR}_i,\ \text{SINR}_j) = \frac{P(d_{ij})}{N_0 + max\ (I_i - P(d_{ij}),\ I_j - P(d_{ij}))} \geq \delta_{th}\ [\text{dB}] \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

where N_0 is power spectral density of additive noise (AWGN), P is the received power, I is the interference level, and d_{ij} is the distance between nodes i and j. The field measurements for tactical MANETs suggest the SINR threshold of at least 20 dB to achieve acceptable BER performance [11]. In order to maintain the required SINR thresholds, the VHF/UHF terrestrial radios are limited to link ranges of 20 to 30 km. Whilst it is straightforward to measure RSS at the receiver, and to also estimate the long-term power spectral density of background noise, determining the interference level is rather problematic. The reason for difficulty in estimating the interference is that it usually changes completely unpredictably, and there are no known (pilot) symbols to exploit. We can at least assume that the background noise in all receivers is approximately the same. The interference can be modeled as another zero-mean additive noise with non-stationary changes in the variance given by the transmit powers, distances and path-loss attenuations. We can use hardware testbeds to accurately measure or set the interference levels for experiments [27]. In summary, even though SINR can provide better routing decisions, it is difficult to be measured in practice, especially when changes in interference level are frequent. This motivates us to exploit both RSS and possibly also estimated SNR values (without interference) to assess link quality and make routing decisions.

3.3. BER Metric

Digital communications allow using BER measurements to estimate link quality. BER can be also used as objective metric to asses quality of service (QoS) for applications. Similarly to SINR, it is the average measure determined over longer time periods. Usually, there is a one-to-one mapping between SINR and BER, however, unlike SINR, measuring BER from pilot symbols circumvents the need for estimating the level of interference. However, BER as a link quality metric is rarely assumed in the literature [28]. One reason for not using the BER metric in practical networks is the lack of pilot symbols to make the BER estimates sufficiently reliable [22].

We can conclude that to assess the performance of link between two nodes, both RSS and SINR measurements are useful. RSS is more readily measurable, however, SINR provides more accurate prediction of the link quality [2]. In the sequel, we combine benefits of RSS and SINR to design a new routing protocol for use in tactical MANETs.

4. LQA-AODV Routing Protocol

In this section, a multipath routing protocol utilizing both RSS and SINR metrics is presented. The protocol is labeled as Link Quality Aware Ad-hoc On-Demand Distance Vector (LQA-AODV). In other words, designing energy-efficient algorithms that uses SINR to derive the performance (e.g., packet error rate, PER), and RSSI can be used to make decisions about dynamic communication radius when establishing network connectivity. However, incorporating these metrics into the existing routing protocols would require some modifications as explained in the following subsections.

4.1. Overview of AODV

AODV is a on-demand reactive routing protocol. Thus, AODV does not start route discovery process until a network node requests such service in order to transmit its data. Specifically, when source node (S) wants to transmit data to destination node (D), it first checks its routing table to determine whether there is already a route to node D. If no such path is available, AODV protocol starts a route discovery process to determine an up-to-date path to destination. A route request (RREQ) packet is initiated by S, and it is forwarded to all node S neighbors who forward the packet further until the intended destination is reached. The RREQ packet contains the information fields listed in Figure 2 (see reference [15] for more details).

Bits:		1	1	1	1	1	11	8
Type		J	R	G	D	U	Reserved	Hop Count

RREQ ID (RREQ$_{ID}$)
Source node address (S$_{ID}$)
Source node sequence number (SEQ$_S$)
Destination node sequence number (SEQ$_D$)
Destination node address (D$_{ID}$)
The broadcast identifier (B$_{ID}$)

Figure 2. The RREQ packet format used in basic AODV routing protocol.

4.2. Packet Forwarding Across 2-hop Clusters

Due to limited transmission capacity of tactical MANETs, the number of hops for data transmission must be limited. Usually, the maximum number of hops from a sending node is allowed to be at most 4 hops away. Therefore, we extend AODV protocol to incorporate a hierarchical cluster-based routing. Hierarchical MANETs with clusters assign each node to one of the following functions: gateway node (GN), cluster member (CM), and cluster head (CH). The CHs should always be able to reach nodes in other clusters via their respective CHs or via GNs. The CM nodes within the same cluster can communicate either via their CH, or they communicate directly in a peer-to-peer (P2P) manner with possibly up to 2-hops. In our proposed protocol, we assume energy efficient clustering of nodes where CHs are selected to have the largest remaining energy level. In addition, the CHs need to have sufficient connectivity to nearby nodes, so there is a trade-off between CH connectivity and its residual energy. If either the energy level drops below a threshold or the number of known neighbors decreases, a CH rediscovery mechanism is initiated by the current CH to possibly find its replacement.

4.3. Multicast Extensions

The routing protocols in tactical MANETs need to efficiently support multicast traffic. For instance, a tree-based multicast AODV (MAODV) is extension of AODV protocol to extend its support for unicast communications while modifying the existing RREQ and RREP (route reply) messages. Our proposed routing protocol exploits the same idea. Thus, we assume that multicast routing tables contain extra fields such as address of multicast group, leader node address, multicast leader group HELLO message, and the sequence number of the multicast group [15].

### 4.4. Multipath Route Selection Mechanism

Multipath routing algorithms increase network robustness against unstable links by offering multiple paths. The main design goal of multipath routing is to find several paths towards the destination and then select one of these paths using some metrics. Thus, one primary path is selected with several other alternatives. Such a routing strategy yields many benefits such as increased network lifetime, better load balancing, fault tolerance, and reduction of packet losses. Our proposed protocol exploits reserved or unused 11-bit field and add one extra byte to report link quality (LQ) in the first 4 bytes of RREQ packet. The LQ field contains information on SNR and RSSI threshold as indicated in Figure 3. Other fields in RREQ remains unchanged, and they are used the same way as in conventional AODV [15].

The multiple RREP packets are sent back over the reverse path. Unlike the case of AODV, every RREP is considered by the source in order to discover multiple paths in one route discovery. The route with the highest quality is then selected as the primary path. If the primary path fails, the second discovered path is activated and so on. Overhead management in multipath routing is an important issue [29], but it is outside the scope of our paper.

Bits:	1	1	1	1	1	19		8
						3	16	
Type	J	R	G	D	U	Reserved	**Link-Quality**	Hop-Count

Figure 3. The first 4 bytes of RREQ packet in proposed LQA-AODV protocol containing new Link Quality field.

The complete process of new route discovery process in the proposed LQA-AODV protocol yielding multiple routes is depicted in Figure 4. Note that, the Request for Comment (RFC) of AODV suggests a default value of RREQ_WAIT_TIME_destination to be 300 msec [30].
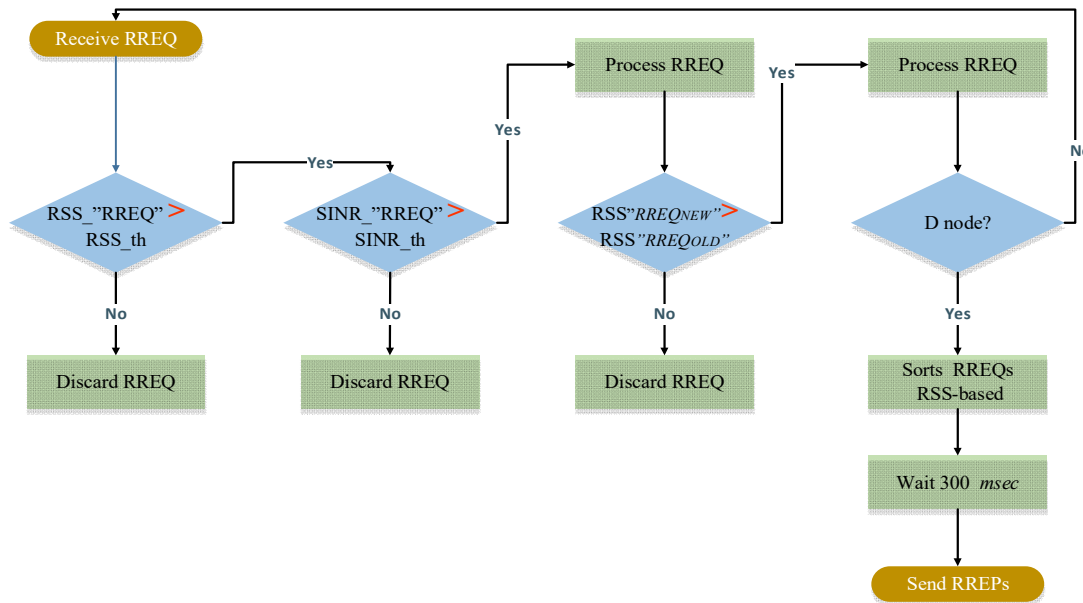
Figure 4. Route discovery with RREQ and RREP messages in the proposed LQA-AODV protocol.

5. Performance Evaluation

We use computer simulations to evaluate the performance of proposed routing protocol and compare it with other similar protocols, namely with AODV, H-AODV and AOMDV routing protocols. These protocols are all extensions of original AODV protocol, and they are described in [29]. All simulations were carried out in ns-2 network simulator. This software was chosen since it is easy to use, and it still has extensive support in the research community. We note that ultimate verification of any network protocol requires to use field tests. However, such tests are not up to scale, they may not be run in realistic conditions, and are also time consuming and rather costly, so they are rarely assumed in the academic community.

5.1. Simulation Environment

The node density in tactical MANETs changes continuously as the mission evolves. However, the number of nodes in tactical MANETs can research up to several hundred (say, 300) nodes. Typically, the largest traffic volumes flow to small combat units in the front-line including squads, platoon or company formations. The network scalability issue involving as much as 300 nodes is resolved by assuming a 3-level hierarchy network clustering at battalion and company, and then a platoon is formed over the whole tactical MANET. The battalion tactical operations center (TOC) is normally located at rear of tactical operations area where the command post is able to monitor events and assist commanders and subordinate units in mission planning. A unique hierarchical architecture of a tactical MANET comprising different communication links with different maximum ranges is shown in Figure 5.
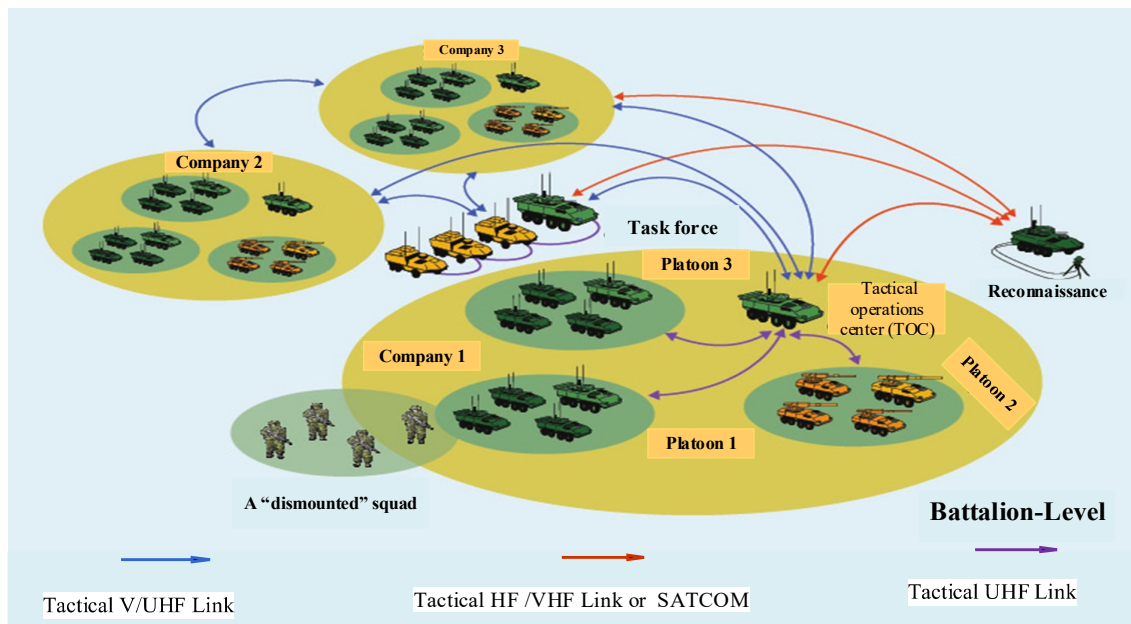
Figure 5. Hierarchical architecture of tactical MANETs.

In tactical MANETs, units and troops often move in tactical formations. The specific (high resolution) position of a unit may have limited impact on connectivity, however, group mobility must be considered. In addition, nodes in tactical MANETs are usually diverging from their initially clustered position. The nodes may move partly in the direction of the leader node, and also partly in their own independent direction when fulfilling the mission objectives. A reference point group mobility (RPGM) model is suitable for such scenarios where a group's individual units and their commander form natural clusters [10].

The parameters and other setting of a tactical MANET assumed in our simulations is summarized in Table 1.

Table 1. Simulation parameters and other settings.

Object	Parameter	Value
Network node	Medium	Wireless channel
	The traffic model	Constant bit rate
	Network interface	WirelessPhy
	MAC	802.11 TDMA
	Antenna	Omni-directional
	Routing protocol	AODV, AOMDV, H-AODV, LQA-AODV
	Number of nodes	300 (100 vehicle, 200 soldiers)
	Packet size	512 bytes
	Number of nodes	300 nodes (100 vehicles, 200 soldiers)
Network scenario	Simulation time	1 h
	Simulation area size	$15{,}000 \times 15{,}000$ m^2
	Pause time	60 s
	Maximum Speed	25 m/s soldiers: 5 km/h vehicles: 90 km/h
	Transmit power	46 dBm (vehicles) 30 dBm (man-pack)
	Receiver sensitivity (RSS threshold X_{th})	-97 dBm
	SINR threshold values (δ_{th})	20 dB

## 5.2. Performance Metrics and Simulation Results

The choice of appropriate performance metrics is important for effective design process. The ns-2 simulator allows choosing from a large set of available performance metrics. For our simulations, we have assumed throughout, packet delivery rate (PDR) and end-to-end delay metrics to analyze the performance of our proposed protocol, and compare it with other similar protocols. Furthermore, each performance metric is simulated assuming the following 3 key parameters: network diameter, node speed, and the number of network nodes.

The throughput metric is defined as the average number of successfully delivered bits per unit of time. Modern tactical MANETs in digitalized battlefield need to support high throughput applications utilizing services such as real-time video. The throughput is affected by the use of heterogeneous network components, and often by jamming and interference. Figure 6a compares the average throughput and the node speed. We observe that AOMDV and LQA-AODV protocols have similar performance, however, when the speed is increased (i.e., over 20 m/s) in a tactical mission scenario, the throughput of AOMDV becomes inferior to LQA-AODV. Figure 6b shows the throughput with different values of the network diameter. Link quality-based routing allows the LQA-AODV protocol to differentiate between strong and weak links, even when the network is large. Even better throughput is observed in Figure 6c, especially when the number of nodes is again increased.
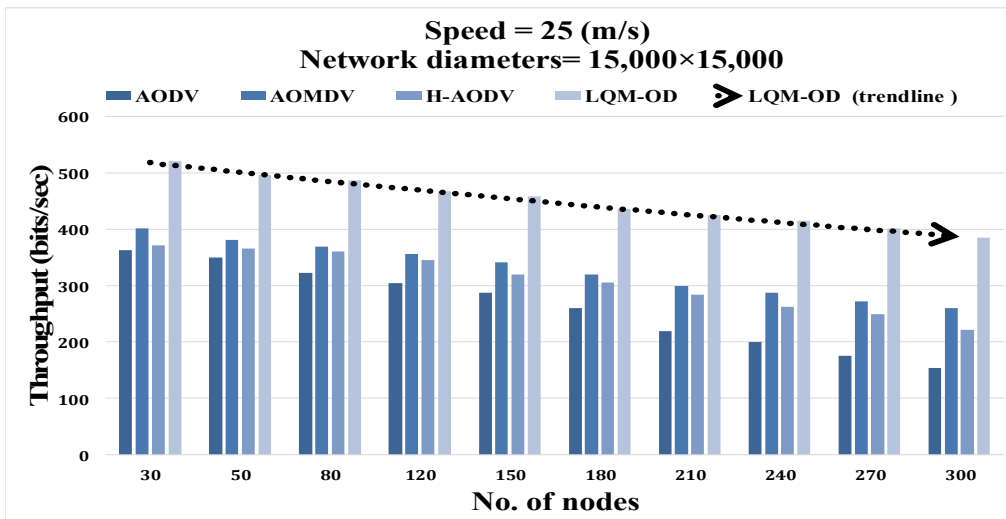

(a)

Figure 6. *Cont.*

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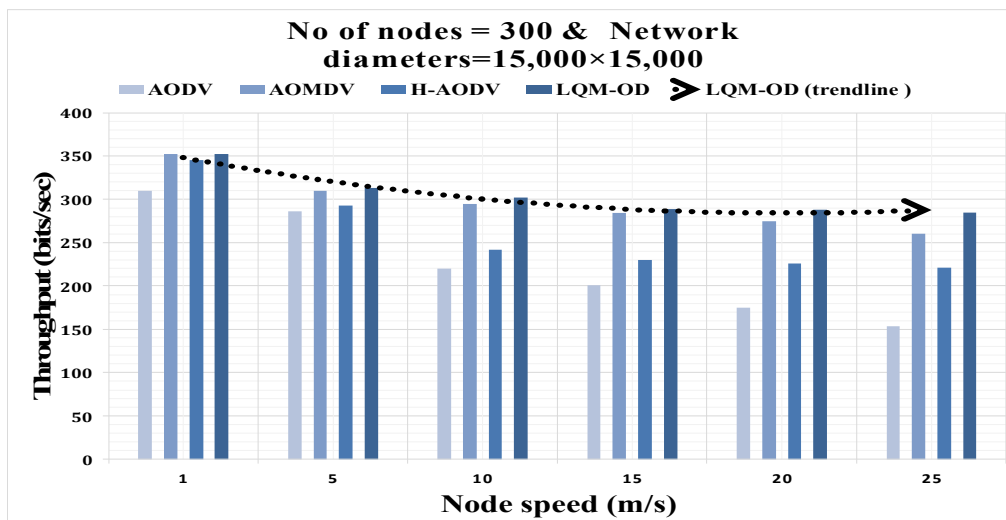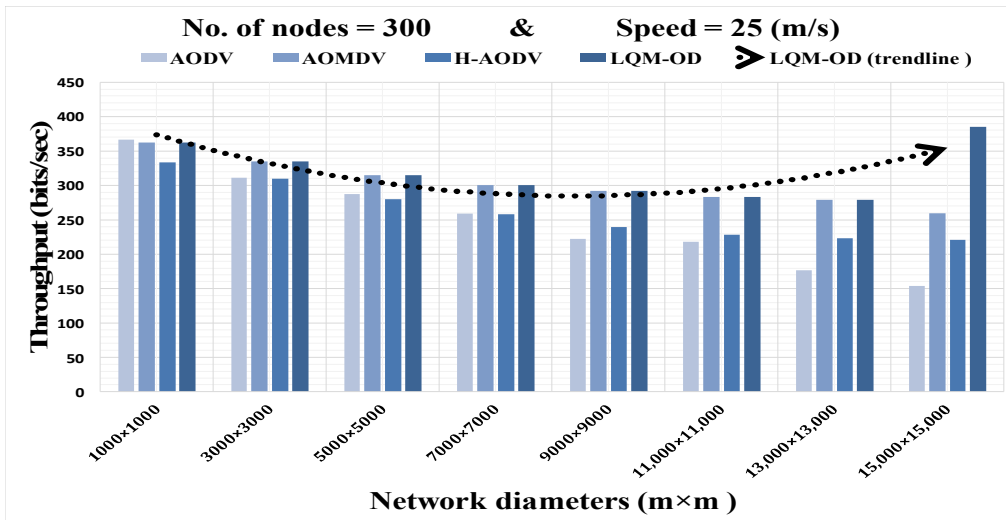
(b)

(c)

Figure 6. (**a**) Throughput vs. node speed. (**b**) Throughput vs. network diameter. (**c**) Throughput vs. node density.

Packet Delivery Ratio (PDR) is a fraction of successfully delivered packets. This metric is often used to estimate link quality small tactical MANETs where network load is a vital QoS constraint to consider. The performance for PDR is evaluated similarly as for the throughput. All results in Figure 7a,b demonstrate that the proposed LQA-AODV protocol can effectively improve the PDR at the destination node. Figure 7c shows that network loads can differ significantly when the network deployment area is larger than 3000 m^2. Clearly, the maximum capacity of MANET as well as PDR are directly related to the achievable RSS or SINR.
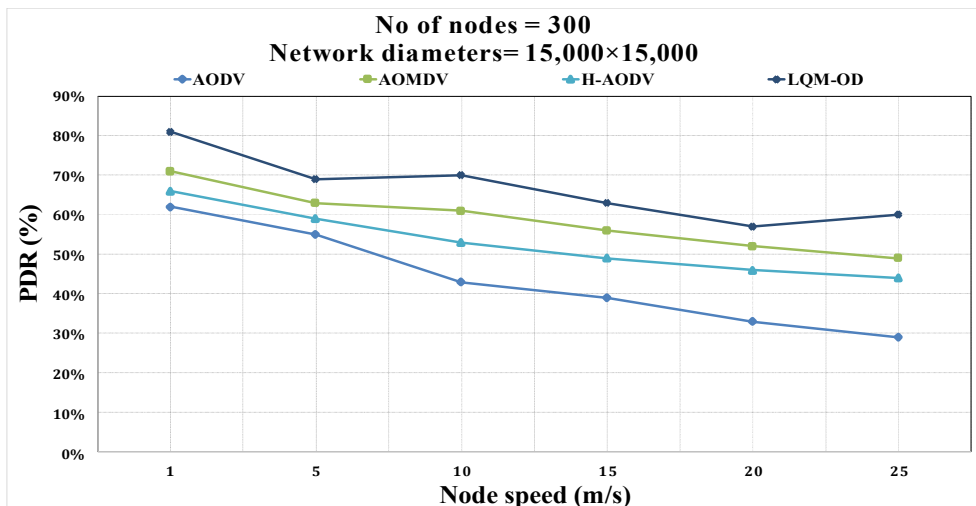
(a)
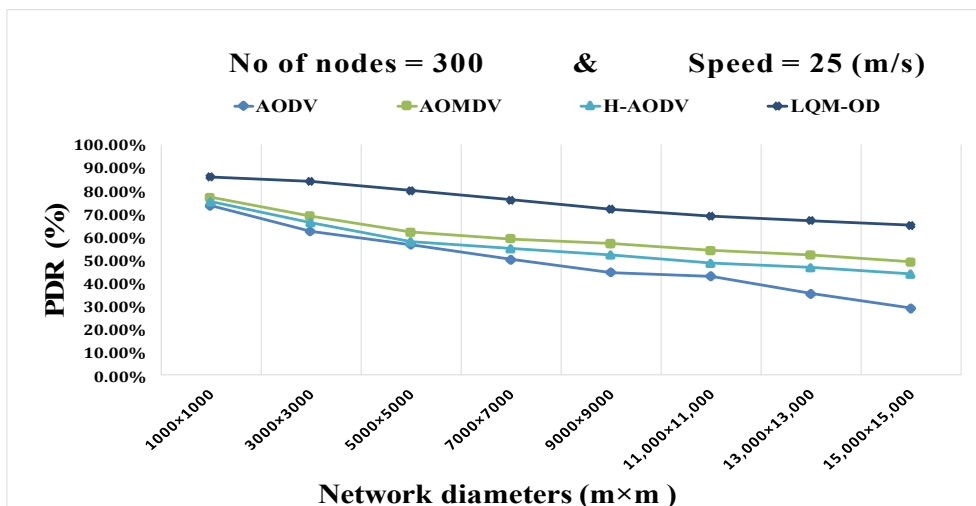
(b)
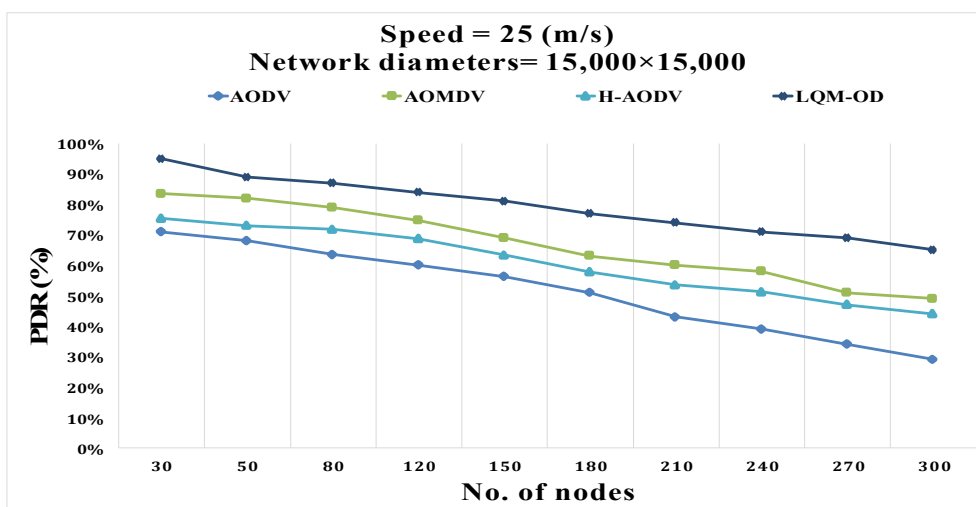
(c)

Figure 7. (**a**) PDR vs. node speed. (**b**) PDR vs. network diameter. (**c**) PDR vs. node density.

Finally, the end-to-end delay is defined as the time required for the packet to be fully received at the destination. It is another important QoS performance metric often considered in tactical MANETs, especially for time-sensitive and mission-critical applications such as remote drone operations. The simulations were carried out assuming varying node speeds, densities and the network deployment area size. The obtained results are presented in Figure 8a,c. The proposed LQA-AODV protocol always outperforms all other AODV based protocols considered. Interestingly, the LQA-AODV protocol yields the best performance improvement over other protocols when used for large area coverage. This shows that link quality measurements are beneficial for routing, especially over large areas.
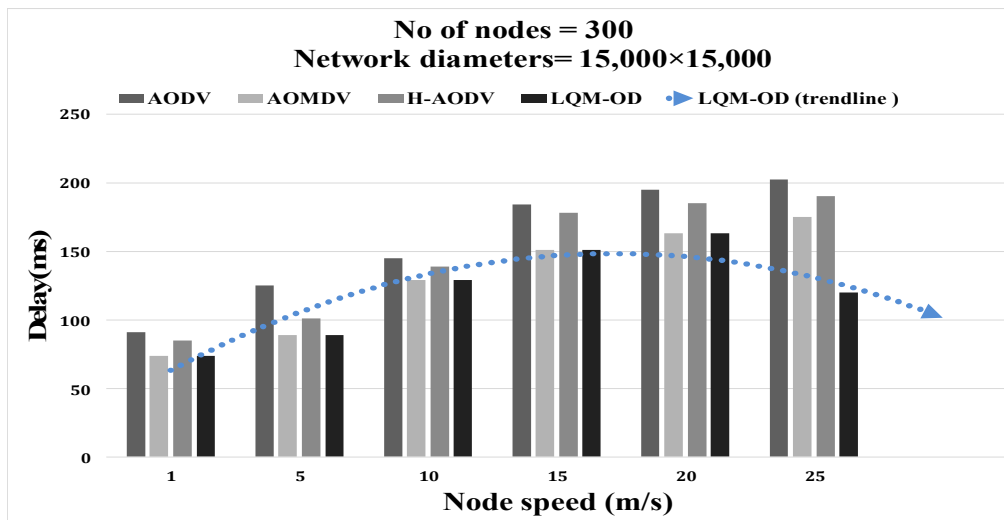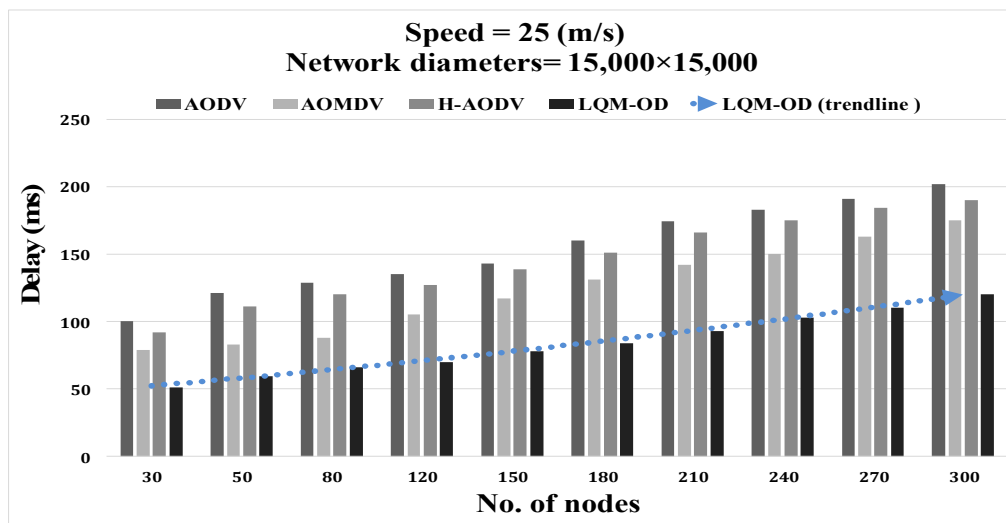

(a)
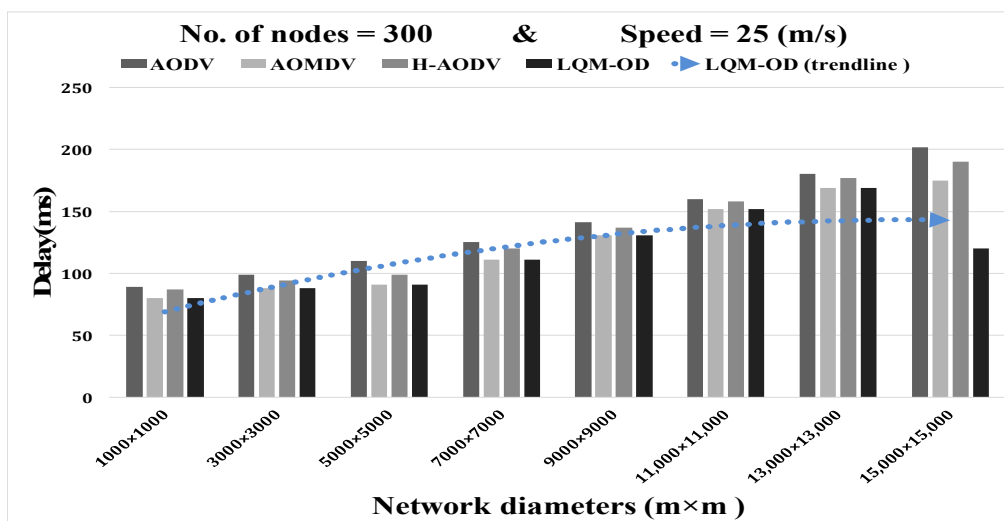
(b)

Figure 8. *Cont.*

(c)

Figure 8. (**a**) End-to-end delay vs. node speed. (**b**) End-to-end delay vs. network diameters. (**c**) End-to-end delay vs. node density.

6. Discussion

In tactical MANETs, the responsiveness, reliability and robustness are more important than scalability. These networks are often deployed in terrains where obstructions weaken transmitted signals and shorten transmission ranges. Limited link budget, constrained bandwidth, unwanted interference (jamming) and multipath propagation conditions are main contributors constraining communication capabilities. In addition, connectivity in tactical MANETs is highly dynamic and multi-hop routes may not be stable enough for on-time delivery of mission critical messages.

The primary goal of this paper was to propose and evaluate a suitable routing protocol which can meet requirements of tactical MANETs. Effective design of such protocol needs to assume militarily-realistic scenario with mobility in order to capture dynamic network behavior. This requires significant background knowledge on tactical mission planning and deployment of tactical MANETs including realistic modeling of the radio propagation environment, mobility patterns, radio equipment type, and antennas which are used to maintain connectivity. In the proposed reactive routing protocol, termed LQA-AODV, RSS and SINR measurements were combined to make routing decisions. RSS is used for initial fast decisions whereas SINR can provide more refined decisions. The proposed protocol was simulated in ns-2 to evaluate its performance against other AODV protocols, namely AODV, H-AODV and AOMDV. The performance comparisons were done assuming 3 metrics: Throughput, PDR and end-to-end delay. For conditions encountered in typical tactical missions, the proposed protocol was found to clearly outperform the other routing protocols. We can conjecture that combining multiple network measurements to improve the protocol performance in wireless networks is an important and largely unexplored problem to consider.

Conflicts of Interest: The authors declare no conflict of interest.

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