Multi-path Routing with Load-aware Metric for Tactical Ad Hoc Networks

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Abstract—To support reliable communication in tactical area networks, multi-path routing protocols can be utilized. Multipath routing protocol makes decisions to select primary route and alternative path by using routing metrics. Link quality routing metrics are popularly used for route selection but it may cause bottleneck and congestion problems. To overcome these problems, we can consider the traffic loads or congestion level into routing metric. In this paper we propose a load-aware routing metric which is based on Airtime link cost metric and combines traffic loads measured from MAC layer. To maximize load balancing effect, we utilize our proposed load-aware routing metric into a multipath routing protocol. The performance of the proposed metric is evaluated with the OPNET simulator and compared with other routing metrics.

Keywords-Tactical Ad Hoc Networks, Multi-path Routing, Load-aware Routing, Load-balancing, Airtime link cost

I. INTRODUCTION

The Network-Centric Warfare (NCW) paradigm represents the future military vision. In this paradigm, ubiquitous network access to enabling “anytime, anywhere” communications is necessary on the battlefield. This potentiality will be provided by the Global Information Grid (GIG), a collection of various networks and more particularly the tactical networks. For the tactical networks, Mobile Ad hoc Network (MANET) technology is very attractive. In order to complete an assigned mission, a MANET is constructed from a different set of participants who must interact. In MANET, a group of mobile nodes is able to communicate with each other through multi-hop wireless communications without any predefined infrastructure, therefore, establishing and connectivity autonomously. The characteristics of MANET are very interest for a lot of situations which are needs of communications without infrastructure or may be used in disaster recovery, automated battlefield and etc. The challenges related to the use of MANET in the field of military tactical network has been described [1].

The tactical networks are designed to support military missions in the battlefield. In this paper, we focus on tactical wireless network which has no wired connections between the network members likely tactical MANETs. Tactical wireless networks may experience difficulties of communication in mission-critical applications because of many different types of environmental conditions, such as obstacles and severe weathers, low signal strength, node mobility, interference, jamming attacks, etc. Considering these environments, reliable communications are actively discussed among researchers and have become one of the most prominent issues in tactical ad hoc networks.

To enhance the reliability of a routing protocol, multi-path routing protocols can be utilized. In single path routing, the discovered routes may have problems in that they could be easily broken due to node mobility or unpredictable link conditions. This problem may cause transmission failures and delay in the network, which makes the protocol unreliable. Also, the single path routing takes time to recover or re-discover the broken routes. To overcome the limitation of the single path routes, methods that discover multiple multi-hop routes between the source node and destination node have been suggested instead.

The multipath routing protocols can use multiple paths simultaneously on a communication. Also, it can use one route at a time. Utilizing alternative paths, a multipath routing protocol makes the decision of which path will be the primary path or alternative route by using routing metrics. When a link quality routing metric is used for route selection, it may cause bottleneck problem which means that many routes pass through a particular link while the link has good quality. To solve this problem, we can consider traffic loads or congestion level into the routing metric. Load-balancing in this case is important in determining the amount of traffic on each path while minimizing the cost function. In this paper, we propose a load-aware routing metric that combines the link quality and load balancing features.

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The remainder of this paper is organized as follows. In Section 2, we discuss the related works on routing metrics, load-aware routing and multipath routing protocols. We present our proposed load-aware routing metric in Section 3 and give a brief introduction of the RHMR [2] protocol. In Section 4, we discuss the simulation experiments that the comparison of the proposed metric and other metrics. We conclude our paper and discuss the potential future works in Section 5.

II. RELATED WORKS

Routing metrics are an important method in routing protocols because routes are discovered or selected by routing metrics. It means that routes are depending on routing metrics. Therefore, routing metrics are very critical for determining the performance of the networks. A good routing metric should find paths with links that have high data rate, low loss ratio, low level of interference and less congestion. Recently many routing metrics have been proposed for multi-hop mobile ad hoc networks (MANETs) and wireless mesh networks (WMNs). Some of them include: (1) Hop-count, (2) Expected Transmission Count (ETX), (3) Expected Transmission Time (ETT), (4) Weighted Cumulative Expected Transmission Time (WCETT), (5) Metric of Interference and Channel switching (MIC), (6) Interference Aware routing metric (iAWARE), and (7) Airtime link cost. Comprehensive surveys on routing metrics can be found in [3] and details of airtime link cost metric can be found in [4]. (2) ~ (7) are considered the link quality for routing metrics and widely use. Link quality routing metrics are popularly used for route selection but it may cause bottleneck and congestion problems. To overcome these problems, we can consider the traffic loads or congestion level into routing metric.

Various load-aware routing protocols and metrics have already been proposed for both MANETs and WMNs. These load-aware routing protocols incorporate the load factor into their routing metrics. The dynamic load-aware routing (DLAR) [5] uses the number of packets buffered at an interface as the load metric. However, the interface queue length by itself does not reflect the correct status of the actual load in 802.11 MAC-based protocols. The load-balanced ad hoc routing (LBAR) [6] also uses the queue length at an interface as the load metric, which sums up node’s average queue length and the neighbor node’s average queue length. This load metric can be considered more accurate than the one used in DLAR. Both the DLAR and LBAR are designed for the mobile ad hoc network, and aim to reduce the packet delay and the packet loss ratio. However, those protocols do not consider link quality. Link quality metrics help to find the route that has low loss ratio and stable links.

LAETT [7] provides a path satisfying the bandwidth request of the flow and combines wireless access characteristics and load estimates. LAETT depends on the estimation of the effective bit rate (EBR). For a node, the EBR of its access link represents the amount of traffic that can be successfully delivered over the access link in unit time. WCETT load balancing (WCETT-LB) [8] is the WCETT augmented by the load factor consisting of the average queue length and the degree of traffic concentration. LARM [9] captures not only differences in data rate, link loss ratio, intra/inter-flow interference but also traffic load. Specifically, it captures traffic load which is the sum of the node’s average queue length and the neighbor node’s average queue length. LARM is incorporated into load balancing routing protocol LBM to provide load balancing in multi-radio wireless mesh network. LAETT, WCETT-LB and LARM capture link quality and traffic load features unlike DLAR, LBAR. However, existing load-aware routing metrics, which combined with link quality features, are highly complex to measure such as LAETT, WCETT-LB, etc.

In order to balance load in Tactical Ad Hoc Networks, routing metrics need to accurately capture the load in various locations of the network. Furthermore, routing protocol needs to distribute traffic among mobile nodes to avoid creating congested areas. Different from existing routing metrics, our routing metric, Load-aware Airtime Link Cost captures traffic load which is the maximum value of the node’s average queue length and the number of neighbor nodes which shares a same channel.

Utilizing multipath routing is one of the ways to provide load balancing because multipath routing can distribute traffic from a source to a destination by using multiple paths. Numerous multipath routing protocols have been proposed based on the popular reactive routing protocols, such as Dynamic Source Routing (DSR) and AODV (Ad hoc On-demand Distance Vector). MP-DSR and Split Multipath Routing (SMR) are based on DSR. AODVM is a multipath design over the AODV that can discover multiple node-disjoint paths. The AODVM-PSP protocol is an extension of AODVM protocol. The difference between AODVM-PSP and AODVM is that AODVM-PSP considers delays along a path while making a routing decision. Since the route discovery process of AODVM-PSP is not as frequent as that of AODVM, there is always a probability of not finding a route, but this reduces the overhead. The detailed surveys on aforementioned multipath routing protocols and other multipath routing protocols can be found in [10].

Recently, as the proactive mechanism for multipath routing, MP-OLSR [11] was proposed over the OLSR protocol. In MP-OLSR, the node uses the Multi-path Dijkstra algorithm to find the multiple paths with node-
disjoint or path-disjoint properties based on the entire topology information. If a link or node failure occurs, the node detecting the failure re-computes the alternative path based on the topology information in the node and then forwards the packet through the new route. In [12], the authors propose Adaptive State-based Multi-path Routing Protocol (ASMRP) to increase reliability of data transmission, allowing adequate fault tolerance in WMNs. The ASMRP is opportunistically exploits multiple paths to synergistically improve the overall performance of WMNs. This algorithm is effectively discovers multiple paths and employs an elegant traffic splitting algorithm for balancing traffic over these multiple paths.

For a tactical environment where reliability and real-time data service is essential, these works may have some problems such as frequent control message exchanges, high node mobility, etc. However, hybrid multipath routing protocols by fusing the characteristics of reactive routing and proactive routing can alleviate some of the problems of these protocols may have. In [2], the authors proposed hybrid routing that called Reliable Hybrid Multipath Routing (RHMR). The hybrid routing designs can reduce data transmission delay and also be more resilient to node mobility and errors. In order to this, we utilize our proposed routing metric into RHMR to provide and maximize load balancing in tactical mobile ad hoc networks.

III. MULTI-PATH ROUTING WITH LOAD-AWARE METRIC FOR TACTICAL AD HOC NETWORKS

The proposed routing metric, load-aware airtime link cost, is based on calculation of airtime link cost specified in the IEEE 802.11s standardization [4]. Load-aware Airtime Link Cost introduces load factor measured from MAC Layer at the mobile nodes and supports load-aware routing. The integration of the load balancing feature to the airtime link cost calculation and the congestion aware routing scheme can provide reliable communications at the view point of the entire network.

A. Load-aware Airtime Link Cost Metric

As mentioned before, we utilize airtime link cost as the link quality feature in Load-aware Airtime Link Cost. Instead of well-known link quality metrics such as ETT (Expected Transmission Time), we utilize airtime link cost because it can support multiple radio environments. In tactical ad hoc networks, they may use multiple radios to communicate between various types of devices.

The airtime link cost metric defines the amount of channel resources consumed by transmitting the frame over a particular link. This measure is approximate and designed for ease of implementation and interoperability. The airtime link cost for each link is calculated as:

$$C_a = \left[ O + \frac{B_t}{r} \right] \frac{1}{1 - e_f}$$

(1)

where $O$ and $B_t$ are constants listed in Table 1 (airtime link cost constants), and the input parameters $r$ and $e_f$ are the data rate in Mbps and the frame error rate for the test frame size $B_t$, respectively. The rate $r$ represents the data rate at which the mobile node would transmit a frame of standard size $B_t$, based on current conditions and its estimation is dependent on local implementation of rate adaptation. The frame error rate $e_f$ is the probability when a frame of standard size $B_t$ is transmitted at the current transmission bit rate $r$, the frame is corrupted due to transmission error. The details of airtime link cost can be found in [4].

The load balancing feature in Load-aware Airtime Link Cost which we define as traffic load ($TL$) is measured by the node’s average queue length and the number of neighbor nodes which shares same channel. The traffic load for each interface at a node is calculated as:

$$TL = Ca_t \times \frac{O_x \times N}{r}$$

(2)

where $Ca_t$ is the existing airtime link cost that measured at a node in a particular link $l$, $O_x$ is the average queue length which represents the average number of bits in the queue that measured at the interface $x$ in a node, $r$ is the data rate in Mbps which is similar to the usage in airtime link cost calculation. We take the fraction of the average queue length over the data rate to get the actual time needed for transmission. We consider the traffic concentration of each node by using $N$ which represents the number of nodes that shares same channel. So, if more neighbor nodes choose $l$ as their next-hop for packet transmission, the traffic at the node increases. Therefore, such a node has higher probability to become congested in the network.

In the proposed approach, we integrate load balancing component which we called traffic load into Airtime link...
cost metric. The proposed Load-aware Airtime Link Cost metric calculated as:

\[
Metric = (1 - \alpha) \times \sum_{j=1}^{k} Ca_j + \alpha \times \max_{1 \leq j \leq k}(TL_j)
\]  

(3)

where \(TL_j\) is the calculated value of traffic load on node \(j\). We consider the maximum value of traffic load on a route because the bottleneck node may have high traffic load. The total path throughput will be dominated by the congested node or link, which has the largest value of \(TL_j\), \(k\) is the number of hops in a route.

Therefore, \(\alpha\) (alpha) is a tunable parameter subject to \(0 \leq \alpha \leq 1\). The proposed metric is incorporated into load balancing routing protocol RHMR to provide load balancing in tactical mobile ad hoc networks.

B. RHMR Protocol and Simple Modification

The Reliable Hybrid Multi-path Routing (RHMR) [2] is a hybrid routing protocol which has both proactive and reactive routing characteristics. RHMR basically provides proactive-like routing with route discovery and maintenance mechanism of the reactive routing protocols. In order to tactical wireless networks have characteristic of long-distance, RHMR periodically discovers multiple routes toward every node in the network with long time intervals by Periodic Route Discovery Message (PRDM). The interval can be dynamically re-configured depending on the node mobility or the link quality. Then, it maintains routing table with multiple routes for entire network like traditional proactive routing protocol and selects the best route among them. This route will be defined as the master route.

To avoid route loop, RHMR finds node-channel-disjoint routes. The node-channel-disjoint routes can be discovered by PRDM forwarding rule. The PRDM is only processed if the sequence number is new or there is no entry in the routing table which has the route information such as the previous hop and the channel index toward the source node. In other cases, the node just updates the route information about the source node and previous node without forwarding PRDM. When the master route failure detected, RHMR firstly switches master route to second highest alternative route. However, if no route to switch or new route request occurs (new destination that has not been discovered yet), this protocol re-discovers or finds new route with reactive routing manner that using On-demand Route Recovery Message (ORRM).

In RHMR, route selection is depending on multiple routing metrics which are Link Quality (LQ) and Channel Trigger Count (CTC). The LQ is the accumulative value that the link quality of every hop in a path. The CTC is the number of channel changes between the current hop and previous hop. This protocol compares the accumulative LQ of existing master route in the routing table with the newly updated route and marks the route with better LQ as the master route. If the link quality of comparing routes is equal, the hop count and CTC will be considered respectively. The priority among the metrics selects the route with less accumulative link quality and fewer hop count as the master route.

In this paper, we have modified control messages of RHMR to utilize our proposed load-aware routing metric. We simply add traffic load field to the control messages. To find the maximum value of TL on a route, it compares with TL value of current node. Only if the value on a current node is higher than the value contained in TL field, the node changes the value in TL field to the value of current node. This process has been added to message handling process of PRDM and ORRM in RHMR. With this process, each node can calculate the proposed load-aware airtime link cost metric independently.

IV. SIMULATION AND RESULTS

Using OPNET simulator [13], we compare the performance of the proposed metric and WCETT-LB, LARM, and airtime link cost defined in IEEE 802.11s. These metrics are utilized on RHMR.

A. Simulation Environments

We use two evaluation metrics: packet delivery ratio and average end-to-end delay. The packet delivery ratio (PDR) represents the count of successful data reception compared to the total number of generated data. The average end-to-end delay is defined as average value of the delay between the time which the data packet generated at the source and the time of the data packet reaches the destination. Otherwise, it includes the queue

<table>
<thead>
<tr>
<th>Environment Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium Access Control Protocol</td>
<td>IEEE 802.11g</td>
</tr>
<tr>
<td>Area Size of Environment</td>
<td>12.5 Km x 12.5 Km</td>
</tr>
<tr>
<td>Number of Nodes (N)</td>
<td>10</td>
</tr>
<tr>
<td>Number of Traffic (T)</td>
<td>100 per 1 second (each 100 Kbps, 200 Kbps)</td>
</tr>
<tr>
<td>Interval of PRDM</td>
<td>50 seconds</td>
</tr>
<tr>
<td>Node Transmission Range</td>
<td>5 Km</td>
</tr>
<tr>
<td>Mobility Speed (M)</td>
<td>0, 10, 20, 30 m/s</td>
</tr>
<tr>
<td>Mobility Model</td>
<td>Random Waypoint</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>300 seconds</td>
</tr>
</tbody>
</table>
delay in every node and the propagation delay from the source to the destination.

A wide variety of system parameters is used for evaluation in tactical MANET. The detailed network parameters are as shown in Table 2. In our simulation, the node has three IEEE 802.11g interfaces with orthogonal channels in each interface, such as channel 1, 7, and 13. The data traffic generates a packet with the payload size of 1 Kbits at every 10 millisecond (100 Kbps) and 2 Kbits at every 10 millisecond (200 Kbps) after 10 seconds have elapsed in the simulation. The amount of data traffic will be various. The PRDM interval of 50 seconds has been configured as a default value in RHMR. Therefore, the tunable parameter \( \alpha \) is set to 0.5 as generally used in most routing metrics [3]. In tactical wireless networks, the transmission range is generally considered between 5~10 Km. IEEE 802.11 links are being used in long-distance setting that is up to several tens of kilometers [14].

B. Simulation Results

The simulations are carried out more than 10 times and simulation results are calculated to average values of all the combined results. Two types of simulation were conducted. First case is 100 Kbps of data packets generated per node. The other case is 200 Kbps of data packets generated on each node. Also, the simulations are carried out with different mobility speeds that are no mobility (0 m/s), 10 m/s, 20 m/s and 30 m/s.

Fig. 1 and Fig. 2 show the simulation results with 100 Kbps data traffic scenario. Fig. 1 shows the simulation results of average end-to-end delay in 100 Kbps scenario. As we can see from the figure, compared with the other metrics, the proposed metric reduces end-to-end delay by considering traffic load feature even though nodes have high mobility speed. In the static case (no mobility), the proposed metric reduces more than 30% compared with airtime link cost. This result came from avoiding congested node. Fig. 2 shows the packet delivery ratio of
the simulation results. In the figure, we can see little improvement of *proposed metric* in PDR results.

The simulation results of 200 Kbps data packets scenario are shown in Fig. 3 and Fig. 4. In Fig. 3, we can see the average end-to-end delay of simulation results. Although, there were more traffic loads than 100 Kbps scenarios, Fig. 3 shows the similar simulation results with Fig. 1 that the *proposed metric* has better performance than the other metrics. Fig. 4 shows the packet delivery ratio of this scenario. In this figure, we can see different result with Fig. 2. This result shows that the *proposed metric* has better packet delivery ratio than other routing metrics specially compared with *airtime link cost* improved 2 ~ 6 %. It looks a small enhancement but throughput results tell us that improved 5 ~ 34 Mbps. We didn’t put the throughput results in this paper because of not enough space.

In the figures, *proposed metric* improves the performance of packet delivery ratio and reduces the average end-to-end delay. As a result, *proposed metric* can be thought superior compared to its counterparts. The *proposed metric* is able to discover routes that avoiding bottleneck links by considering traffic load. This is why the *proposed metric* has better performance than *airtime link cost*. Therefore, the *proposed metric* has enhanced performance comparing with WCETT-LB, LARM by considering number of neighboring nodes.

V. CONCLUSION AND FUTURE WORKS

In tactical ad hoc networks, reliability and real-time data service is essential. With this tactical characteristic, the load-aware routing metric is able to be an effective method to support the load balancing and the reliable communication with redundant paths in tactical wireless networks. In this paper, we propose a *Load-aware Airtime Link Cost* metric and utilize it to RHMR for supporting load balancing and reliable communications in tactical mobile ad hoc networks. Simulation results from OPNET simulator have shown performance enhancement in packet delivery ratio and end-to-end delay. We will focus on the researches that the various data traffic type with load balancing. This parameter effects by more comprehensive simulation study and analysis to enhance the reliability of tactical communication. Also, our simulation includes various environments, such as node density, multiple radios, different network sizes. Therefore, one another study, this metric with other routing protocols will be carried out.

REFERENCES