RELIABLE DUAL-PATH GEOCASTING FOR TACTICAL AD HOC NETWORKS

Sun-Joong Yoon, Sung-Hee Lee and Young-Bae Ko
Graduate School of Information and Communication,
Ajou University, Suwon, Republic of Korea
Email: {sun2015, sunghee, youngko}@ajou.ac.kr

ABSTRACT

Geocasting is a mechanism to disseminate data messages within a certain geographical region. Since packet forwarding is based on the location information of nodes, it is known to reduce the path maintenance cost significantly. The geocasting can be suitable for several applications in tactical ad hoc networks, such as an event to alarm enemy's missile attack, guerilla appearance, or local weathercast. However, previous geocast protocols proposed for general ad hoc networks are not satisfactory for the high demands of the reliability in such military applications. In this paper, we propose more reliable geocasting protocol which utilizes dual paths to improve the possibility of the successful message delivery. Moreover the proposed scheme provides two different acknowledge mechanisms, by which a source node can be confirmed of the destined nodes' message reception. Our simulation study using ns-2 shows that the proposed protocol results in high delivery ratio with reasonable packet overhead and latency.

I. INTRODUCTION

Recently, many countries have been trying to apply the concept of Network-Centric Warfare (NCW) [1] in their national defense area. Tactical ad hoc network is a core technology to realize the NCW because it provides the instantaneous information exchange services such as command control and situation awareness below brigade level. This information tends to be meaningful in the restricted geographical area. For example, when a special area was attacked by hostile chemical weapons in brigade, the command control center (CCC) should send situation awareness messages to all nodes in that area.

Geocasting [2], a mechanism to deliver a message to all nodes within a certain geographical region, can be an appropriate solution. There are many geocasting applications in the military area such as nuclear attack, air strike or missile attack alarms, and weathercast services for each combat unit in a specific area. In general, geocasting does not require any path discovery process and periodic path maintenance. The routing path is immediately decided based on the location information of the node whenever a packet is forwarded in the network. Therefore the path maintenance cost could be significantly reduced. We observe that most of the existing geocast protocols for mobile ad hoc networks (MANETs) are not satisfactory for the high demand of the reliability in tactical military applications. For example, previous geocast protocols do not provide acknowledgement (ACK) of the receipt. This is because the geocast member is decided instantly when a message reaches in the geocast region based on the location of the node. Therefore the source node is hard to aware who the geocast group member is and whether it receives a message successfully.

In this paper, we propose a reliable geocast protocol which utilizes dual path diversity to improve the successful message delivery ratio. In our proposed scheme, the source node selects two different locations within the targeting geocast region, and sends a message twice towards each location separately. Two packets will be forwarded through different paths. Even if one packet fails to be delivered due to obstacles or the topology hole, another packet may still have a chance to be delivered in the target region. Consequently, a delivery ratio increases compared to the traditional single path geocasting.

We also propose two ACK schemes which are useful for the source node to ensure which node receives packets in the geocast region successfully. When a node does not receive a packet, its neighboring node recognizes it based on the ACK mechanism and retransmits a packet. The proposed ACK schemes are named as *Fast-Ack-before-Assurance (FAA)* and *Delayed-Ack-after-Assurance (DAA),* respectively. With the FAA scheme, any node in the geocast region immediately sends the ACK packet back to the source node after receiving a geocast message. Then, this node is responsible for the successful packet delivery within the region by controlling retransmissions. In other words, the ACK towards the source only guarantees the delivery

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of the packet up to the geocast region. On the other hand, the DAA scheme fully guarantees the packet receptions. Multiple ACK packets from each geocast member are aggregated in one node, and then the list of the nodes which successfully receives the packet is transmitted to the source node. Therefore, the source node can obtain the list of the geocast receivers.

The rest of the paper is organized as follows. A brief overview of the related work is presented in Section II. Section III introduces our proposed reliable geocast protocol in details followed by performance evaluation in Section IV. Finally, Section V concludes the paper.

II. RELATED WORKS

Several geocast protocols have been proposed for pure MANETs [3 - 11, 13 - 16] and they can be broadly categorized into two: *flooding-based* and *anycasting-based*. Flooding-based geocast protocols [3, 5, 14, 15] are simple and easy to implement. They first set up a packet forwarding zone to broadcast packets within a certain geographical area including a target region. A packet delivery ratio and overhead can be affected by the size of the forwarding zone. Thus, as the zone size grows, both packet delivery ratio and transmission overhead tend to increase. Basically, since a node within the forwarding zone repeatedly receives a packet whenever a neighboring node broadcasts, this high redundancy ensures the successful packet delivery. However, these protocols consume a lot of network bandwidth due to a broadcast storm problem. Even in Tactical Internet (TI) [1] with limited bandwidth such as 56 kbps, the delivery ratio would decrease because of the high probability of contention.

In order to alleviate this network overhead problem, anycasting-based geocast protocols [4, 6, 7, 13] have been proposed. Here, a geocast message is forwarded up to the geocast region by the greedy forwarding scheme [12]. With the greedy forwarding, the next hop is decided based on the location information of the neighboring nodes [20, 21]. Therefore, it does not generate additional control packets to construct a routing path, resulting in the low network overhead. However, in the tactical MANET environments, route failures frequently occur due to unstable wireless channel condition, dynamic topology change, some physical attacks like jamming, and so on. Therefore, more reliable geocast protocol to fulfill the high demands of the reliable communication is required.

Disjoint path routing protocols have been proposed for ad hoc networks [22 - 23]. These protocols are based on IP address and require control messages such as Route Request (RREQ) and Route Reply (RREP) to find several disjoint paths. However, our scheme does not require additional control messages without the location information of the neighboring nodes. Moreover we consider low link capacity and unreliable radio environment in a battlefield to improve reliability and survivability as well as throughput.

There are several acknowledge schemes to ensure the successful packet delivery in multicast protocols [16, 17, 18]. In the sender initiated protocol (SIP), when destination nodes receive a packet, they reply ACK packets back to the source node individually. This protocol increases packet overhead when many destination nodes exist. In the other hand, the receiver-initiated protocol (RIP) works in a way that the destination nodes send NAK (negative ACK) if they fail to receive a packet or incorrectly receive it. As mentioned earlier, in geocasting, destination nodes are not predefined as in multicasting but decided based on the location information of the node when a geocast message is generated. Therefore there is no way for each node to recognize if it is included in the geocast region until receiving an actual message. Consequently, the NAK approach is not applicable for geocasting.

Whereas, in the tree-based ACK approach, a parent node aggregates several ACKs from its child nodes and finally, an aggregated ACK packet is transmitted from the root node (highest parent node) to the source node. The packet aggregation time is required and it increases as the number of child nodes increases. Therefore, delay reduction is the challenge in this approach.

III. DUAL-PATH GEOCAST PROTOCOL

In this section, we explain the proposed dual-path geocast protocol (DPGP), which consists of the dual path greedy forwarding and ACK schemes. Before sending geocast messages, a source node needs to decide the shape and the size of the targeting geocast region. There could be different shapes of a geocast region such as rectangle, circle, oval, triangle, polygon, etc, depending on the type of messages. The DPGP simplifies a geocast region shape to a circle one.

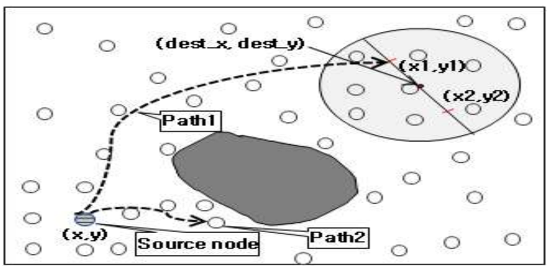

Figure 1: Dual path greedy forwarding

A. Dual Path Greedy Forwarding

Figure 1 shows an example of the dual path greedy forwarding. We assume that every node is equipped with a GPS (Global Positioning System) device. A source node transmits geocast messages to the geocast region by using two different paths. The source sends a message to the next hop node with a greedy forwarding for each path respectively. The next hop node is the one of the source's neighboring nodes, which is located in the closet geographical distance from the target region. Each node in the network sends a HELLO message at every interval. A HELLO message contains the geographical location of the node, therefore each node can know the locations of the neighboring nodes within a single hop. Note that in Figure 1, the message would be failed to be delivered, if a greedy forwarding was made with a single path only.

Upon receiving a geocast packet, a node first decides whether its location is included in the target region. The target region is shaped in circular, so the decision is made based on a central point of the circle ($dest_{-x}$, $dest_{-y}$) and the region radius. If the node locates within the geocast region, it starts a local flooding. Otherwise it forwards the received packet to the next node that has a shortest distance from (x_1, y_1) or (x_2, y_2) among neighbors. Those two points (x_1, y_1) and (x_2, y_2) are calculated at the source, based on the input parameter k and equations (2) and (3) below. For example in the figure, if the source wants to set the two points at the middle of the diameter across the central position of the region, the value of k is set to 0.5. The range of k parameter is 0 to 1. The equations (1), (2) and (3) show how to calculate the two target points (x_1, y_1) and (x_2, y_2) in Figure 1. r is the radius of geocast region and (x, y) stands for the location of the source node.

$$\Delta x = dest_{-x} - x, \;\; \Delta y = dest_{-y} - y \qquad (1)$$

$$(x_1, y_1) = \begin{Bmatrix} dest_{-x} + kr \times \frac{\Delta y}{\sqrt{\Delta x^2 + (\Delta y)^2}}, \\ dest_{-y} - kr \times \frac{\Delta x}{\sqrt{\Delta x^2 + (\Delta y)^2}} \end{Bmatrix} \qquad (2)$$

$$(x_2, y_2) = \begin{Bmatrix} dest_{-x} - kr \times \frac{\Delta y}{\sqrt{\Delta x^2 + (\Delta y)^2}}, \\ dest_{-y} + kr \times \frac{\Delta x}{\sqrt{\Delta x^2 + (\Delta y)^2}} \end{Bmatrix} \qquad (3)$$

Both (x_1, y_1) and (x_2, y_2) are identically distant from the source node. Then the source node embeds the location information separately into each packet towards different paths. With this different location information, path diversity is obtained and hence, the packet delivery ratio increases.

During the greedy forwarding, it is possible that the same intermediate node is selected in dual paths. Even if the path is different, the sequence numbers of two packets are same. This is because the destination nodes in the geocast region require duplication detection to prevent multiple packet reception from the different paths. However, during the greedy forwarding, the intermediate node needs to distinguish a packet towards the different path to prevent packet drop due to the unintended duplication detection. To do this, we added path type information in the packet header, and the packet towards different path has a different path type number.

B. Two Different ACK Schemes

We present two different ACK schemes to provide a reliable transmission. One is named as *Fast-ACK-before-Assurance (FAA)*, and the other is *Delayed-ACK-after-Assurance (DAA)*. These two schemes are applied when the source node wants to know that whether the nodes in the geocast region receive the packet well and to more improve the delivery ratio. We assume that every node in the geocast region is connected to at least one FS node even though the geocast region is partitioned.

1) Fast-ACK-before-Assurance (FAA)

In the geocast region, any node receiving a geocast packet from a node of the outer geocast region becomes a "flooding starter (FS)" node. In FAA, FS node is required to send an ACK to the source node when it starts a local flooding within the geocast region. If the source node successfully receives ACK, we can know that the packet reaches the geocast region without any loss. But, if the source does not receive ACK, it makes a retransmission of the packet towards the geocast region. This time, the source does a global flooding of the packet to make sure of its success delivery, with a penalty of the packet overhead increase.

After sending ACK, the FS node is responsible for locally flooding the packet in the geocast region. The FS node is replied by ACKs from the nodes in the geocast region. We define the ACK packet from the geocast member to the FS node as the Local-ACK. If any Local-ACK is missing by one of the members, the FS retransmits the packet to that particular node via unicast.

Every node in the geocast region makes the *neighbor state table* when the node receives a geocast packet. This table contains the information about whether neighbor nodes receive the packet or not. When a node overhears broadcasting from neighbor nodes, it updates its own neighbor state table. A node which receives a geocast packet transmits an ACK towards the FS node after waiting a *holding time (Ht)*. *Ht* is required to overhear packet transmissions from neighbors, and it is defined as the number of neighbors multiplied by the time taken to broadcast a geocast packet (T_1). T_1 is defined in the next subsection. A node in the geocast region sends its own *neighbor state table* embedded in the ACK message. The FS node makes an *aggregated ACK and neighbor state table* which is based on the received ACK messages. As a result, the FS node knows which node received the packet and which node did not.

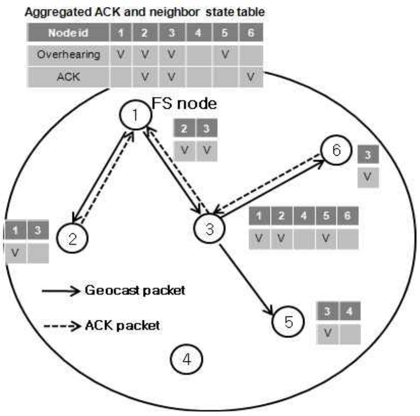

Figure 2: An example of Local-ACK transmissions

Figure 2 illustrates an example of Local-ACK transmissions. In the figure, the node 2 does not overhear the broadcasting from node 3, and node 3 does not overhear the broadcasting from node 6. The FS node only receives ACKs from node 2, 3 and 6. In this figure, node 5 receives a geocast message but it fails to send an ACK to the FS node because of a collision. However the FS node successfully guesses node 5 received a geocast message based on the neighbor state table from node 3. Finally, the FS node determines that only node 4 does not receive a geocast message through the aggregated ACK and neighbor state table,, so it retransmits a geocast message to node 4 by unicasting.

Sometimes, some nodes move out or in the geocast region while the FS node waits for Local-ACKs. To solve this problem, we add a margin to the geocast region. For example, if the average moving speed of the node is 20*m/s* and the Local-ACK aggregation time is 0.5 second, we set the 10*m* longer geocast region radius.

2) Delayed-ACK-after-Assurance (DAA)

In this method, the FS node sends an aggregated ACK to the source node after receiving ACKs from the other nodes within the geocast region. The FS needs to wait during a certain time to aggregate receiving ACK packets. We define this time as the *waiting time (Wt)* which is approximately calculated by the following equations (4), (5) and (6). This time is the sum of local flooding time in the geocast region and the aggregation time. In the equation (4), N is the number of neighboring nodes of the FS node. The FS node knows the number of one-hop neighbors by using HELLO messages. T_1 and T_2 are the time taken for broadcasting a geocast packet and unicasting an ACK packet back in a single hop, respectively. C is the maximum hop count from the FS node to any node in the geocast region. For example, if the diameter of a geocast region is 300*m* and the transmission range is 200*m*, C is set as 2. $\propto$ stands for the probability of collisions, ranging from 1 to 3. If FS node does not receive the ACKs in *Wt* time, $\propto$ will be increased by one. In the equations (5) and (6), the backoff time varies from 16 to 1024 slot times based on the IEEE 802.11 standard. In the simulation study, we set up the backoff time to 2N. Data sending time means a packet transmission time in a single hop. The DIFS, SIFS, RTS, CTS and ACK time are defined in the IEEE 802.11 MAC (CSMA/CA).

$$\mathrm{Wt} = \mathrm{N} \times (\mathrm{T}_1 + \mathrm{T}_2) \times \mathrm{C} \times \propto \tag{4}$$

$$\mathrm{T}_1 = \mathrm{DIFS} + \mathrm{Backoff} + \mathrm{SIFS} + \mathrm{Data\ sending\ time} \tag{5}$$

$$\mathrm{T}_2 = \mathrm{DIFS} + \mathrm{Backoff} + (3 \times \mathrm{SIFS}) + \mathrm{RTS} + \mathrm{CTS} + \mathrm{ACK} + \mathrm{Data\ sending\ time} \tag{6}$$

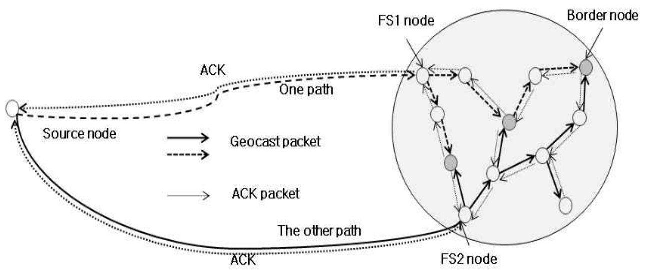

Figure 3: Dual path geocast concept with ACK

Figure 3 shows that both paths successfully reach the geocast region, and therefore two FS nodes exist. They start local flooding within the geocast region. When a node receives two geocast packets from both paths, it becomes a *border node*. The *border node* sets B (border) flag in the ACK packet, and sends the ACK packet including its neighbor state table to both FS1 node and FS2 node separately. As a result, the coverage area of FS1 node and FS2 node splits into two groups from border nodes. The same *Wt* time is utilized in FS1 node and FS2 node. This scheme is suitable when the source node wants to know how many nodes exist or which nodes exist in the geocast region. The source node doesn't know about that if the source uses the FAA.

IV. PERFORMANCE EVALUATION

A. Simulation Environments

Using *ns-2* simulator [19], we compare the performance of the proposed DPGP with the single path geocasting protocol (SPGP) and LBM [3]. We use three evaluation metrics: *packet delivery ratio*, *latency* and *packet delivery overhead*. The packet delivery ratio represents the percentage how many nodes received the packet in the geocast region. For example, if only two nodes among the four nodes in the geocast region receive the geocast packet, the packet delivery ratio is 50%. The latency represents how much time would be elapsed for delivering a geocast packet from the source to destination nodes. The packet delivery overhead is the total number of transmitted packets.

The network area is $2000\times2000m^2$. The number of nodes in the network is 100, 150, 200 and 250. The node mobility is 5*m/s* without pause time. The source node is fixed at the bottom left corner (200, 200). The transmission range is 250*m* and data rate of wireless link is 2Mbps. The IEEE 802.11 MAC protocol is applied. Every node sends a HELLO message at every second. The geocast region is circular shaped with 300*m* radius and the geocast region is randomly changed at every 2 seconds. The source node sends a geocast message with the payload size of 512 bytes at every 2 seconds. We simulate the DPGP with various values of parameter *k*. Table 1 shows the results of packet delivery ratio when 200 nodes are deployed in the network. The delivery ratio is the highest, when the *k* is 0.75. . This means that two paths exist apart from each other, therefore the effect of path diversity is maximized. However, too big *k* value (e.g. *k*=1) decreases the packet delivery radio because the geocast paths might be too far from the geocast region. Therefore, we set *k* to 0.75 for the next simulation environment. The total simulation time is 600 seconds. We repeat each scenario five times with different topologies.

The value of *k*	0.25	0.5	0.75	1
Packet delivery ratio(%)	96.9	97.7	98.6	98.1

Table 1: Packet delivery ratio with *k*

B. Simulation Results

First, we evaluate the DPGP without ACK. Figure 4 shows the packet delivery ratio. The parameter δ in the LBM is set as 100m. In the case of less than 200 nodes, the delivery ratio of the SPGP is 4~10% lower than the LBM and the DPGP. The results of all are almost same at 98~99%, at 250 nodes.

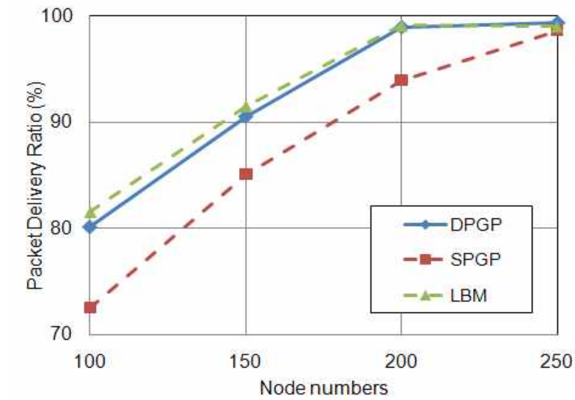

Figure 4: Packet delivery ratio *versus* Node numbers

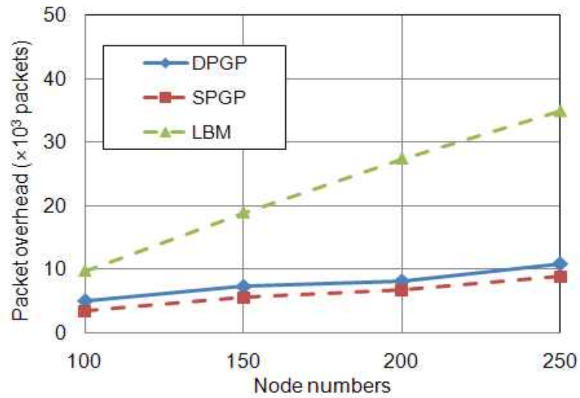

Figure 5: Packet overhead *versus* Node numbers

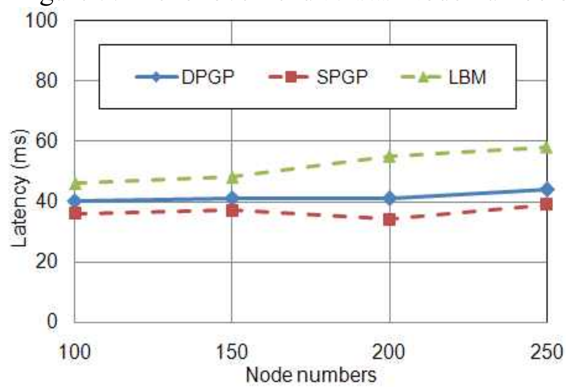

Figure 6: Latency *versus* Node numbers

Figure 5 shows the packet delivery overhead that has occurred from data transmission of the source node to the geocast region. As the number of nodes increases, the packet overhead also increases dramatically. The LBM uses a flooding scheme in forwarding zone, which generates a great number of overhead packets. On the other hand, the DPGP and the SPGP have relatively small packet overheads. When there are 200 nodes in the network, the SPGP generates 80% less packet overheads and the DPGP generates 70% less packet overheads when compared with the LBM.

Figure 6 compares the latency (end-to-end delay) of each scheme. The LBM has the longest latency, because there are a lot of contentions during the flooding. The latency of DPGP is higher than the SPGP because the DPGP has more hop counts to a geocast region than the SPGP and the interference between two paths in DPGP may cause additional delay.

Table 2 shows the simulation results of each scheme when an obstacle is dispatched on the network. We set two triangular obstacles with the approximate size of $3500m^2$ in the network, with 150 nodes deployed at random. The delivery ratio of the DPGP and the LBM are similar. The delivery ratio of SPGP is approximately 20% lower than the others. The latency of SPGP and DPGP are somewhat similar, which means that the DPGP has better performance than the SPGP when an obstacle exists in the network.

	Delivery ratio (%)	Latency (ms)	Packet overhead (10^3 packets)
SPGP	71.3	33.5	6.5
DPGP	90.9	35.2	9.6
LBM	91.8	50.1	17.4

Table 2: Simulation results with obstacles

Second, the geocast protocols were evaluated including ACK messages. We compare the proposed ACK schemes with SIP. All nodes in the geocast region using the SIP scheme transmit the ACK message to the source node when they receive the geocast packet.

Figure 7 shows the packet delivery ratio of each protocol with ACK transmissions. If the source node does not receive the ACK message for a period time (400ms), it transmits the same data packet again by flooding. When there are 100 nodes deployed in the network, the delivery ratio of the SPGP with ACK transmissions shows 12% enhancement compared to the SPGP without ACK. The DPGP and LBM with ACK show 8% improvement than their counterparts.

Figure 8 shows the packet delivery overheads with ACK transmissions. When DPGP scheme is applied with the FAA and DAA technique, the source node receives one or two ACKs from the geocast region. Therefore the overheads of the DPGP with FAA and DAA are smaller than the others. In the SPGP and the LBM with SIP, all nodes that receive a geocast packet transmit ACKs to the source node, causing high packet overhead. The LBM with SIP shows the worst performance of them all.

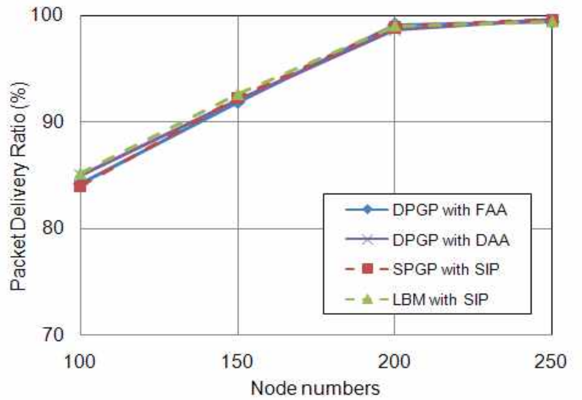

Figure 7: Packet delivery ratio with ACK

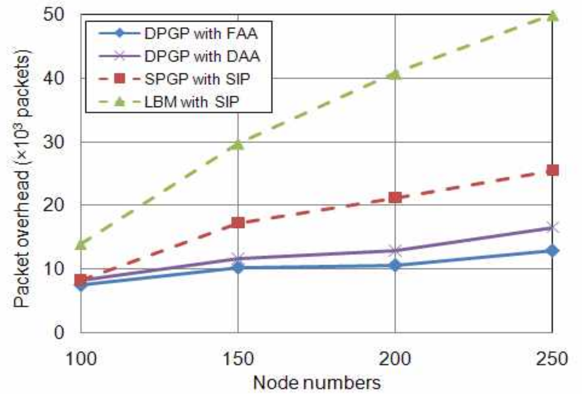

Figure 8: Packet overhead with ACK

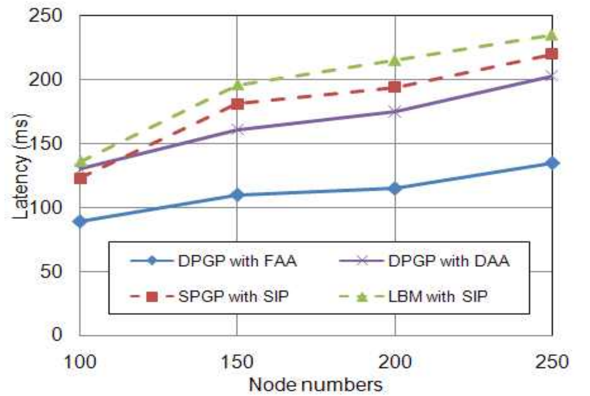

Figure 9: Latency with ACK

Figure 9 shows the latency of each scheme with ACK transmissions. The latency is calculated by the sum of the greedy forwarding time, the time taken for the transmission of ACK messages to the source node, and the additional time taken for retransmission of failed ACK receptions. The ACK aggregation time is additionally included in the DPGP with DAA. The DPGP with FAA has the shortest latency. The reason is that when the FS node receives a geocast packet, it transmits an ACK to the source node in a short time. As the number of nodes in the geocast region increases, the delay time of the SIP also increases. The latency of the LBM with SIP is longer than the SPGP with SIP.

V. CONCLUSION

Geocasting is an efficient method for delivering a message to a specific geographical area. In tactical environments, there are many applications that deliver messages to specific geographical areas such as guerilla appearance, unclear attack alarms, etc. To apply a geocast protocol in tactical networks, the reliability of geocast protocol should be improved. To enhance the performance and reliability of geocasting, we propose a reliable dual path geocasting protocol. Our proposed protocol introduces dual path greedy forwarding along with two ACK transmission techniques. The dual path greedy forwarding enhances packet delivery ratio to the delivery ratio of LBM. The proposed two ACK transmission techniques are FAA and DAA. FAA enables the FS node to send an ACK to the source node without waiting ACK aggregation time. Afterwards, this node assures that the packet delivery in the geocast region is guaranteed. DAA selects the FS node for aggregation of ACK messages generated by all nodes in the geocast region. Only an aggregated ACK will be transmitted to the source node. The performance evaluation of the proposed technique shows that the delivery ratio is better when ACK messages are used.

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