A Novel Geocasting Protocol for Multi-interface Tactical Ad Hoc Networks

Sun-Joong Yoon
Department of NCW
Ajou University
Republic of Korea
sun2015@ajou.ac.kr

Sung-hee Lee
Samsung Electronics
Suwon
Republic of Korea
sunghee.ish@gmail.com

Young-Bae Ko
Department of Computer Eng.
Ajou University
Republic of Korea
youngko@ajou.ac.kr

***Abstract*—Geocasting is an efficient protocol for disseminating tactical messages to nodes within a specific area. Most of the geocasting protocols consider a single interface and single channel-based network. In such networks, the performance of geocasting does not scale with the increase in network size and the traffic load. One of the development trends in tactical networks is that communication equipment has multiple interfaces and channels. Thus, we propose an efficient geocasting protocol using multiple interfaces and channels in tactical ad hoc networks. The proposed scheme consists of two phases: packet forwarding and local flooding. In the forwarding scheme, the orthogonal channels are guaranteed at minimum two hops when a packet is delivered from a source to a geocast region and latency is reduced by using multiple channels in multi-hop packet delivery. In the local flooding, the latency and packet delivery ratio are enhanced by using the main channel and sub-channels in a distributed manner. Our simulation study using ns-2 shows that the proposed protocol outperforms the performance compared with other existing protocols.**

Keywords ; Geocasting, multi-interface/multi-channel, tactical ad hoc networks

I. INTRODUCTION

Geocasting is an efficient protocol to disseminate messages to all nodes within specific geographical region [1]. For ensuring successful battlefield operation, many tactical messages should be delivered to the target regions within a short time period. For e.g., when the guerillas are detected in a specific area, information such as guerillas images, positions, etc, should be delivered rapidly to the soldiers fighting against them.

Several geocasting protocols [2], [3], [4], [5] have been proposed to enhance reliability and guarantee packet delivery. These protocols usually consider a single interface single channel (SISC) environment, which have several problems. The intra-flow interference occurs when the consecutive hops in a single path network attempts to transmit data using the same channel. Similarly, inter-flow interference occurs when multiple paths are used for reliable transmission of tactical data from a source to a destination. Moreover, broadcast storm problem causes poor performance in high traffic load condition as shown in [6].

In order to improve the required operational capacity (ROC) in tactical communication systems, multi-interface, multi-channel (MIMC) equipped terminals for vehicles and warfighters have been developed [7], [8]. Such devices can take advantage of orthogonal channels to overcome the limitations of the SISC environment. Soldier radio waveform (SRW) as a part of joint tactical radio systems (JTRS) supports multiple interface manpack radios carried for dismounted troops and platform-powered radios for ground and airborne vehicles [8]. Manpack terminals for soldiers have maximum of two interfaces while terminals for vehicles have four interfaces. Each interface can transmit and receive the signals independently. By exploiting such platforms of multiple interfaces and multiple channels, in this paper, we propose the MIMC-based geocasting protocol (MMGP) that enhances the performance by reducing intra and inter-flow interference and broadcast storm.

MMGP consists of two phases: *packet forwarding* from a source to a geocast region and *local flooding* within a geocast region. In the first phase, forwarding nodes attempt to use orthogonally different channel that is not used on the previous hop. intra-flow interference between consecutive hops can be minimized. By assigning orthogonal channels to the interfaces of the same node for more than one flow, inter-flow interference can be reduced. In the second phase, distributed use of the multiple channels for disseminating geocast packets is proposed to minimize the broadcast storm problem.

The rest of the paper is organized as follows. In Section II, we present the constraints of SISC-based geocasting using simulation study and channel assignment strategy introduced in Section III. We explain the detail of our proposed MMGP scheme in Section IV. Section V shows the results of the performance evaluation and finally in Section VI, we conclude the paper.

II. PROBLEMS OF THE SISC-BASED GEOCASTING

Most of the geocasting protocols have been designed for the SISC environment [9]. However, unique features of the tactical mobile ad hoc networks add more constraints to such protocols. To elaborate this issue, let us consider SRW radio having low data-rate of 2Mbps and long transmission range. Since many warfighters conduct an operation within the restricted area, the network density is usually high [10]. Thus, in such scenarios, the single channel networks become easily congested giving low performance.

To evaluate the limitations in SISC-based geocasting schemes, we measured the packet delivery ratio (PDR) of geocast protocols that have single/multiple paths using *ns-2* [18]. The PDR defines the percentage of nodes that received packets sent by a source in a geocast region. The packets are forwarded based on greedy forwarding and then locally flooded in a geocast region. Four hundreds nodes are randomly distributed in the rectangular area of 2000m x 2000m considering dense networks. For this evaluation, the transmission range of the nodes is set to 250m and nodes are mobile at the speed of 5m/s. The geocast packet (512bytes) is transmitted from a source to the designated circular geocast region of 300m radius. The geocast region is changed at every second. In case of using multiple paths, each path aims for the distinct destination points in a geocast region to take advantage of the multi-path diversity [2]. Fig. 1 shows that the PDR decreases as the number of transmitted packets by the source increases. For single path solution, the PDR decreases only after over ten packets are generated. This is due to the intra-flow interference over the forwarding path and the broadcast storm within a geocast region. In case of using multi-path, as the number of paths increases, the PDR decreases more severely because of the additional inter-flow interference between multiple paths.

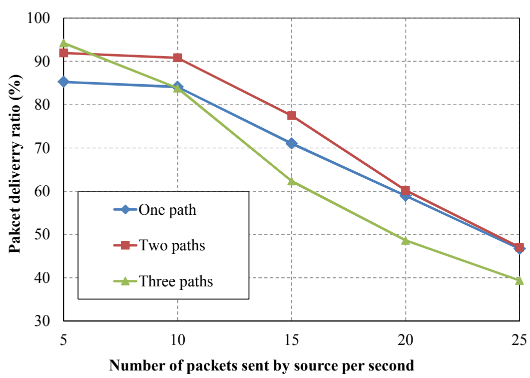

Fig. 1: PDR of SISC-based Geocasting by Varying Traffic Load

III. Interface Assignment for MIMC Tactical Nodes

Interface assignment considers a problem of assigning channels to the multiple interfaces equipped in the node. Here, we describe interface assignment strategies available in the literature and suggest our proposed scheme that considers the features of tactical mobile ad hoc networks.

Interface assignment strategies are classified into three categories [11]. The first category is a static assignment strategy. It assigns an interface to a channel for a long time. This method is further divided into two types: the common channel approach and the varying channel approach. In the common channel approach, all nodes have the same set of channels assigned to the interfaces, so it does not require channel switching. The varying channel approach might have different set of channels assigned to the interfaces of the neighboring nodes. For successful communication, a sender and receiver might require a coordination to ensure existence of a common channel. They may have longer routing paths in case the next hop node does not have the same channel as the sender. The second category is a dynamic assignment strategy. This method allows an interface to switch a channel frequently from one to another. There is no limit on how many channels can be utilized. However, it requires a coordination mechanism between neighbors. The third category is a hybrid interface-assignment strategy. It combines the static and dynamic assignment scheme. Some interfaces have fixed channels and the other interfaces can switch the channels. For example, one interface in each node is assigned a fixed common channel while others dynamically switch the channels. Similarly, a hybrid strategy can also have a fixed channel assigned to the receiving interface to which senders can tune and transmit data [11].

Previously, tactical networks operated with a single interface that had one main channel in common to all the nodes and the two or three sub-channels. If the main channel is attacked by jammers of the adversaries, one of the sub-channels was chosen. However, with multiple interfaces available in the current tactical nodes, we suggest modified hybrid assignment method. In [12], the common channel is only used for transmitting control packets. However, in this paper considering tactical networks, the main (common) channel is fixed at one interface and used for sending and receiving both the control and data packet. Sub-channels, allocated in other interfaces, are changeable and used only for transmitting data packets. The suggested assignment scheme has the compatibility of tactical legacy nodes that have a single interface.

IV. MIMC-based Geocasting Protocol

In this section, we describe our geocasting for MIMC-based tactical ad hoc networks. We first set up the network model and explain forwarding and local flooding scheme using the modified interface assignment scheme.

A. *Tactical Network Model*

In a MIMC-based tactical ad hoc network, C orthogonal channels can be used (e.g. C=3 in case of IEEE 802.11b). One of those is used as a main channel (Ch. M), which is fixed for one interface of each node. Some of the sub-channels (C-1) are allocated to the interfaces of the nodes. The number of channels is equal or larger than the number of interfaces. Each node is equipped with more than two, but less than C interfaces. Every node has a GPS (global position system) module, so each node can know its own location. The area of operation (AO) is predefined so each node can know the size of a network area. All nodes receive and transmit the packets with each other using the IEEE 802.11 MAC protocol. In case of Link-16, a node can switch the channel in maximum 33,000 per second, so we set the channel switching delay as 30us [13].

B. *MIMC-based forwarding to the geocast region*

All nodes send HELLO messages to one-hop neighbors at the predefined intervals using the main channel (Ch. M). The HELLO message contains the following fields: IP address, location information, channels assigned at each interface etc. A node receiving a HELLO message from a one-hop neighbor updates its *neighbor table* with the neighbor identifiers and their corresponding locations and sub-channels. In greedy forwarding, a node transmitting a geocast data packet selects the next hop node that is closest to the geocast region among the one-hop neighbors. If such neighbors are absent, perimeter routing such as GPSR [14] is applied to overcome a void situation.

In our proposed MIMC scheme, data packet transmission is done only after selecting an appropriate interface and a channel. In first case, if a sender node which has a packet for sending has two interfaces, it selects a channel that is not used in the previous hop for forwarding the packet to avoid the intra-flow interference. For e.g. if Ch. M was used in the previous hop, a sender selects one of the sub-channels of next hop node. If this sub-channel is the same channel that the sender has, the sender sends the packet without channel switching. Otherwise, the sender node changes its own sub-channel to the sub-channel of the next hop node and sends the packet. After that, it switches back to its own sub-channel.

If a sender node has more than three interfaces, first it checks the channels of the next hop node to see if it has a channel that is different from the ones that were used in previous two hops. Note that the channels used in previous hops are updated from the received *previous channel state table* (PCST) as shown in Fig. 2. Thus, a sender can select an orthogonal channel to forward the data packet to the next hop node. Otherwise, if a sender does not find a channel that was unused in two previous hops, it selects a channel that is different from the one previous hop channel and forwards data packet. If the sender node does not have the same channel of the next hop node, it changes one of sub channel to the selected channel and sends the packet.

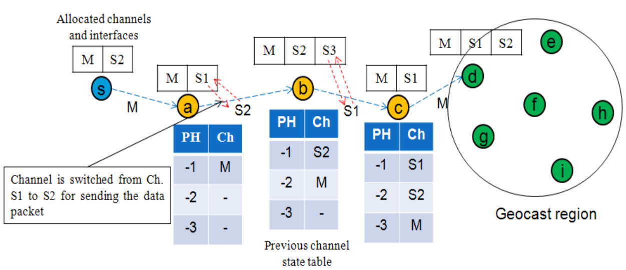

Fig. 2: MIMC-based Forwarding Scheme

Fig. 2 shows an example of the MIMC-based forwarding. *Node s, a* and *c* have two interfaces and are assigned the main channel and one of the sub-channels. Node *b* and *d* have three interfaces, respectively. Node *s* first sends the packet to node *a* using Ch. M. After receiving the packet, node *a* constructs the PCST. PCST has the information of three previous hops included in the data frame. Node *a* compares the sub channels with node *b*. Since it does not have any same sub-channel used by node *b,* one of sub-channels (Ch. S2) of node *b* is randomly selected. Node *a* then switches its sub channel (S1) to S2 temporarily for sending. This state remains until node *a* receives an acknowledgement from node *b*, after that it switches back to its sub-channel S1. Node *b* updates the PCST by adding the previous channel information. Node *c* has two interfaces and a sub-channel S1. When node *b* is forwarding the packet to node *c*, S1 is selected, since it is not used in the previous two hops. Thus, node *b* switches from Ch. S3 to S1 to send the packet. When node *c* forwards the packet to node *d*, it uses Ch. M without channel switching because it is different with the channels of two previous hops.

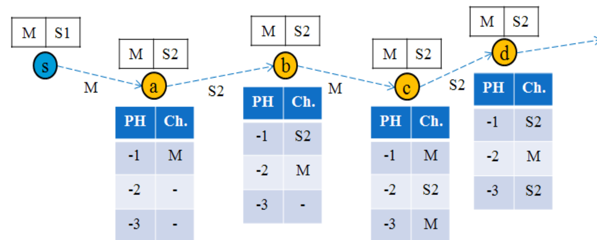

Fig. 3: The Worst Case of Packet Forwarding

Sometimes, orthogonal channels cannot be guaranteed over the minimum three hops. Fig. 3 depicts an example of the worst case for a single flow in multi-hop channel allocation. Most of the next hop nodes have two interfaces and has the same sub-channel. In this case, orthogonal channels can be assigned only for two hops. In order to prevent the worst case and enhance the orthogonal channel utilization in multi-hop packet delivery, we suggest cell-based sub-channel allocation scheme. AO is predefined, so we can know the network area. The network area is divided with small cells according to the location information. The length of vertical and horizontal lines of each cell is defined shorter than the transmission range of the nodes. Since a node can locate in which cell it belongs to, predefined sub-channels for that cell are allocated to its interfaces except the one that is assigned the main channel.

In case of dual-path geocasting (DPGP) [2], each path sets the different destination point in the geocast region to enhance the path diversity. Our forwarding scheme adds the channel diversity between the paths for multi-hop transmission. If a path sends the packet using Ch. M first, another path sends the packet using the sub-channel first. By doing so, the proposed scheme reduces inter-flow interference.

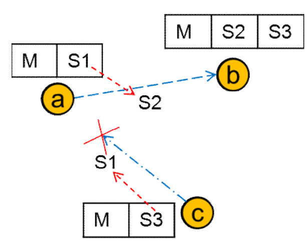

Fig. 4: Link Failure in Multi-flow Scenario

In some situations, multiple flows can cross each other's path. Fig. 4 shows an example of a link failure in a multi flow case. Node *c* tries to send the packet to node *a* using Ch. S1, but node *a* already switched Ch. S1 to Ch. S2 to send the packet to node *b*. Thus, node *c* fails to send the packet using Ch. S1. If such a failure occurs, node *c* tries to use another sub-channel of next hop node (node *a*) for sending the packet. Ch.

M is used as the last resort to send the data if the failure sustains in case of all sub-channels.

C. *MIMC-based local flooding*

As the traffic load increases in a geocast region, the performance decreases due to the broadcast storm problem in a SISC based network. Some schemes have been proposed to solve this problem in MIMC-based wireless networks [15] [16]. However, those schemes are proposed for static wireless mesh networks. They construct broadcasting trees using control packets and maintain those trees periodically. In case of mobile ad hoc networks, frequent changes of topologies make it hard to maintain such broadcast trees. Thus, those schemes are not appropriate for geocasting in tactical MANETs. So, we propose an efficient local flooding scheme using multiple interfaces and channels for tactical MANETs. When a node in a geocast region receives a geocast packet by unicast from a node existing outer region, it starts *local flooding* using Ch. M to one-hop neighbor nodes. The nodes that receive the packet by Ch. M, then count the number of its own neighbors. If the number of neighbors is above the threshold (here, we set the threshold as six [17]), the node received a packet using Ch. M, selects the most common sub-channel among the neighbors and floods the geocast packet. If the number of neighbors is below six, the flooding is done using Ch. M. In case that a node receives the geocast packet by a sub-channel, it floods the packet again using Ch. M. These processes are iterated in a geocast region, until all nodes receive the packet.

Fig. 5 shows an example of local flooding. Node *d* is the node that receives the packet from outer region. Node *d* floods the packet using Ch. M. Node *e, f* and *g* receive the packet from node *d*. In case of node *f*, it has seven neighbors. Since the number of the neighbor nodes is above six, it selects a common sub-channel to flood the packet. Five neighbor nodes has Ch. S2, three nodes has Ch. S1 and two nodes have Ch. S3 except the previous sender node. Node *f* floods the packet using Ch. S2. In case of node *j*, it does not receive the packet from node *f*, because it has Ch. S1. Since node *h* received the packet using a sub-channel (S2), it floods the packet to neighbor nodes using Ch. M. Thus, node *j* can receive the packet from node *h*. The proposed forwarding and local flooding algorithms are shown in Fig. 6.

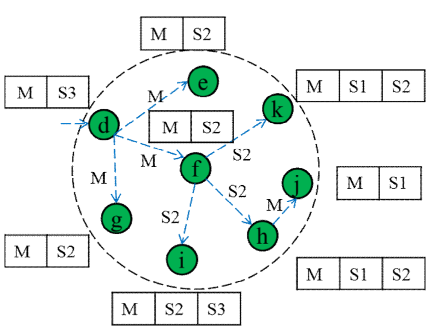

Fig. 5: An Example of Local Flooding

<u>MIMC-based forwarding ()</u>

If *this node is in the geocast region*
Go to MIMC-based local flooding;
Exit;
Else
Select the next hop node in the neighbor table;

Case 1: *the interfaces of sender node are two*
If *the previous channel is a sub-channel*
Send the packet using the main channel
Else
If *the number of sub-channel of next hop node is more than two*
Select the sub-channel that is different from the second previous channel;
If *the sub-channel is equal to the sub-channel of this node*
Send the packet;
Else
Switch the channel and send the packet;
Else
Select the sub-channel of next hop node;
Send the packet;

Case 2: *the interfaces of sender node are more than three*
If *the next hop node has a channel that is different from the ones used in two previous hops*
If *this channel is equal to one of the channels of this node*
Send the packet;
Else
Switch to sub-channel of next-hop node and send the packet;
Elseif *the next hop node has a channel that is different from the previous channel*
If *this channel is equal to one of the channels of this node*
Send the packet;
Else
Switch the channel and send the packet;

<u>MIMC-based local flooding ()</u>

Case 1: *This node receives the packet by unicasting*
Floods the packet using the main channel;

Case 2: *This node receives the packet by flooding*
If *the number of neighbors in the geocast region is below six*
Floods the packet using the main channel;
Else
Floods the packet using the sub-channel many neighbors have

Fig. 6: The Proposed Algorithms

V. Performance Evaluation

A. Simulation Environments

Using *ns-2*[18] simulation tool, we compare the performance of the proposed scheme (MMGP) with other protocols. The basic simulation parameters are same as we mentioned in section II. In addition, we set every node has two interfaces and three orthogonal channels are used considering the 802.11b standard to make MIMC network environment. One interface is used only for the main channel and another is used for one of the two sub-channels for manpack SRWs. Each node sends a HELLO message in one-second interval using the main channel to one hop neighbors. The total simulation time is 500 seconds. We repeat each scenario five times with different topologies.

B. Simulation Results

We conducted simulation studies with two scenarios. We first compared the performance between the SISC based SPGP (single path geocasting protocol) [2] and the MMGP in static and grid topology environment. Then we conducted the simulation comparing the proposed scheme with other protocols using two interfaces and three channels in mobile and random topology environments. The results of first scenario are illustrated in Fig. 7 and Fig. 8.

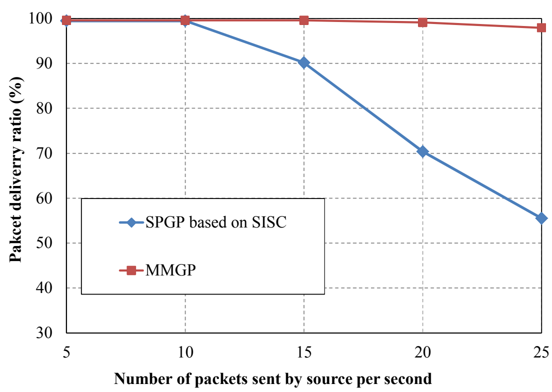

Fig. 7: PDR on Static and Grid Topology

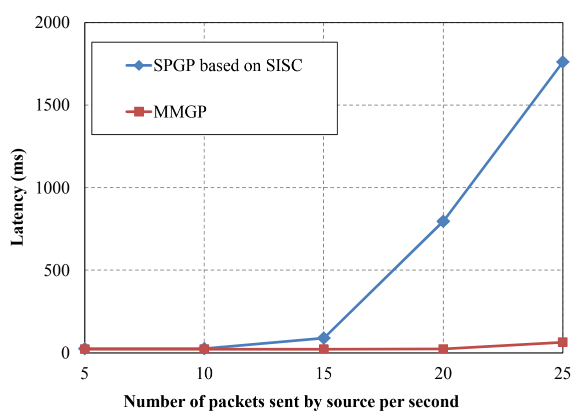

Fig. 8: Latency on Static and Grid Topology

Fig. 7 depicts the result of the PDR with single path. SISC-based SPGP only uses the main channel to send and receive data packets. The PDR of SPGP decreases sharply as the number of packets increases. However, there is only slight decrease in the PDR of MMGP. When the number of packets is thirty, the PDR of MMGP is still over 95%. It is almost 40% better than the SPGP. The reason is that MMGP reduced the intra-flow interference of multi-hop forwarding and minimized the broadcast storm problem in a geocast region.

Fig. 8 shows the average latency. When the traffic load is not high, there is no difference between MMGP and SPGP. As the number of packets is more than fifteen, the latency of SPGP increases sharply. It is mainly due to heavy contention and collision while sending packets in a geocast region

In the second scenario, we conduct the simulation that each scheme has single and two independent paths in mobile and random topology environment. Here, SPGP and DPGP also operate with two interfaces and three channels. In greedy forwarding, SPGP and DPGP forward a packet to next hop node using both the main and a sub-channel. Within a geocast region, all nodes of SPGP and DPGP flood packets using two interfaces of each node.

Fig. 9 depicts the results of PDR. When the traffic load is low (i.e. the number of packets is ten), there is no performance difference between the schemes using the same number of paths. However, as the number of packets increases the results of MMGP that uses one and two paths are substantially improved.

Fig. 10 shows the results of average latency from the source node to the nodes in the geocast region. When the traffic load is low, there is no difference of latency between the schemes. As the traffic load grows, the difference among the latency results become significant. In case of DPGP, latency increases substantially as the number of packets increases. The reason is that inter-flow interference increases between two independent paths and heavy contention in a geocast region. In case of SPGP, latency also increases sharply after the number of packets is over fifteen, due to increased contention among the packets in a geocast region.

Fig. 11 illustrates the overhead of delivering the data. Packet delivery overhead is counted as the number of data packets that are sent during greedy forwarding and local flooding. Packet delivery overhead also increases as the number of packets increases. The overhead of MMGP is lower than SPGP, because each node of MMGP forwards and floods packets only once. In case of SPGP, intermediate nodes and all nodes in the geocast region forward and flood the packets twice using the main channel and a sub-channel causing a lot of overhead.

VI. Conclusion

We present an efficient geocasting protocol called MMGP using multiple interfaces and channels for tactical ad hoc networks. MMGP reduces inter and intra-flow interference by forwarding packets from a source to a geocast region using channel switching considering a channel of receiver node. It also improves the performance by minimizing the broadcast storm by using the main channel and sub-channels alternately in a geocast region. The simulation results show that the proposed schemes enhance the PDR and latency substantially, as the traffic load is getting larger. We think the MMGP is useful for tactical applications that need to deliver many packets in a short time for satisfying QoS and ROC in MIMC-based tactical MANETs.

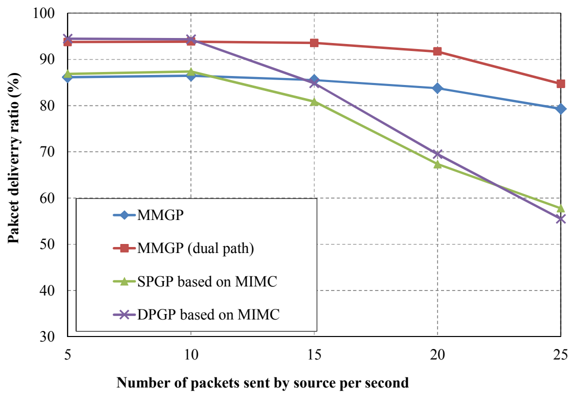

Fig. 9: PDR on Mobile and Random Topology

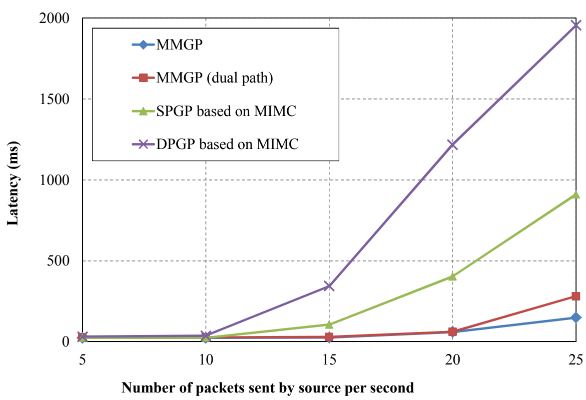

Fig. 10: Latency on Mobile and Random Topology

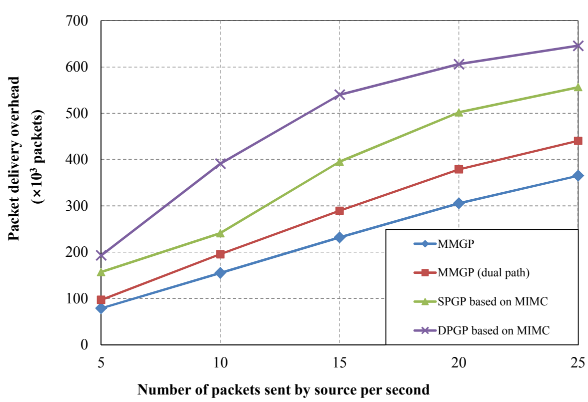

Fig. 11: Overhead on Mobile and Random Topology

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