Performance Evaluation of Load-Balancing Gateway Selection Method in Multi-hop Wireless Networks

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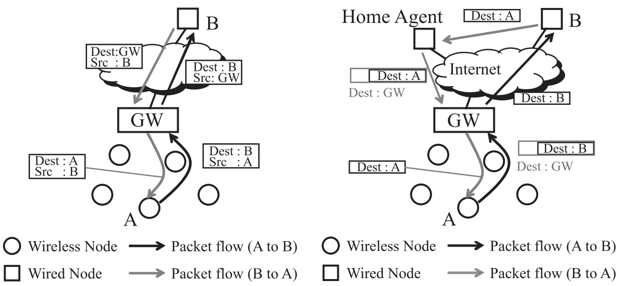
***Abstract*—In wireless multi-hop networks having multiple gateways to an external wired network, a host should select its connected gateway when it would like to communicate with an outside host. One possible and simple way is minimum hop gateway selection policy. In our previous study, we have already revealed that when the minimum hop gateway is selected, imbalance of traffic distribution in a network causes significant performance degradation. Wireless communication channel around the gateway is very important resource because all the external traffic goes through the gateway. So, in our previous work, we proposed load-balancing gateway selection, which takes account of not only traffic intensity at a gateway but also interference of wireless channel around a gateway. With a simple scenario, we showed that our proposed method improves gateway throughput performance. In this paper, we evaluate our proposed method with more sophisticated model and show that it improves throughput performance of load-concentrated gateway. We also show that it surprisingly improves throughput performance of not-load-concentrated gateway, i.e., this gateway obtains more throughput even though the number of its connected hosts is increased when our proposed method is applied. Our performance evaluation in this paper newly reveals that our proposed gateway selection method improves total network throughput by significantly reducing generated control packets for route error recovery.**

Keywords-*Wireless Multi-hop Network; Gateway Selection; Load Balancing.*

I. INTRODUCTION

Wireless multi-hop networks enable wireless hosts to communicate with each other by relaying packets at intermediate nodes, even when a destination host is located beyond single hop wireless channel area. When a wireless host in a wireless multi-hop network would like to communicate with a wired host located outside a wireless multi-hop network, packets should be transmitted through a wireless multi-hop network to a gateway node, which is connected to a wired network. For this gateway approach for expanding wireless multi-hop networks, several schemes have been proposed.

For communication between a wireless host and the gateway node, i.e., in a wireless multi-hop network part, two approaches, a proactive approach and a reactive approach, have been proposed. In a proactive approach [1]-[3], a gateway node periodically broadcast a control packet and a wireless host can identify its connected gateway. In a reactive approach [4][5], a wireless host transmits a control packet in a flooding fashion, e.g., a RREQ (Route Request) packet in AODV (Ad Hoc On Demand Distance Vector Routing) [6], and a gateway node responses it. When a wireless host receives this response packet, it can identify a gateway host and can transmit data packets.



(a) NAT approach (b) Mobile IP approach

Figure 1. Communication through gateway node

For communication between the gateway node and a wired host, i.e., in a wired network part, some mechanisms, which enable a corresponding gateway to receive response packets from a wired host, should be implemented. There have been proposed several approaches, which make use of existing networking technologies, Mobile IP [7] and NAT (Network Address Translation) [4]. In NAT approach (Figure 1 (a)), a gateway node behaves as a NAT router and exchanges source or destination address in arrived packets. In this approach, a node outside ad hoc network sends a packet to the designated gateway, which means even when an ad hoc host moves and the best gateway to be connected is changed, connection between this host should be through this designated gateway. In Mobile IP approach (Figure 1 (b)) [1]-[3], a gateway node behaves as a foreign agent. Mobile IP approach can be combined with the proactive approach in wireless network part. This is because a wireless host should identify its connected gateway in order to notify foreign agent change in case of change in a connected gateway and only the proactive approach enables a wireless host to identify its connected

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gateway. With this mechanism of notification of connected gateway, Mobile IP approach can be applied to the case of mobility of hosts and is preferable for ad hoc networks.

MIPMANET (Mobile IP for Mobile Ad Hoc Networks) [1] has been proposed as this Mobile IP approach. In MIPMANET, when there are multiple candidate gateways to be connected, a wireless host selects the shortest hop gateway. In the proactive approach, all the gateway nodes broadcast its advertized packet (control packet) and some useful information for gateway selection can be conveyed with this control packet.

We have already proposed load-balancing gateway selection [8], which takes account of not only traffic intensity at a gateway but also interference of wireless channel around a gateway. Simulation results in previous paper showed that our proposed method brings total throughput performance improvement when it was applied only to the wireless hosts, which have several candidate gateways of similar hop distance. In our previous work [8], we used simple simulation model of a square shape. In this model, there are two gateways located at each of two opposed corners. Hosts located close to the diagonal line have a tendency of having similar hop distances to these two gateways. These hosts with similar hop distance has great improvement of throughput with gateway selection because of no (or small) hop distance increase caused by a change of default gateway. This means that it is not surprising that our proposed method in this simple model improves gateway throughput performance. In this paper, we would like to use more general and sophisticated simulation model and show that our proposed method generally improves throughput of load-concentrated gateway. As our newly obtained performance evaluation results in Section 4 shows, our proposed method improves not only throughput of load-concentrated gateway but also of other gateways. Even though the number of hosts selecting these (other) gateways as their default gateway increases with our proposed method, throughput of these gateways are surprisingly improved. We newly reveal that our proposed method can reduces generated control flooding packets, which greatly improved total network performance.

The paper is structured as follows. First, in Section 2, we review the MIPMANET. In Section 3, we explain our proposed method in detail. We evaluate performance using our proposed method in Section 4. Finally, we conclude a paper in Section 5.

II. MIPMANET

MIPMANET is one of examples, which combine proactive approach in wireless part and Mobile IP approach in wired part. Figure 2 shows overview of MIPMANET behavior. In MIPMANET, a gateway node behaves as a foreign agent of Mobile IP. Each wireless host has global IP address, which is assigned at its home location. A gateway node periodically broadcast an advertizing packet, which

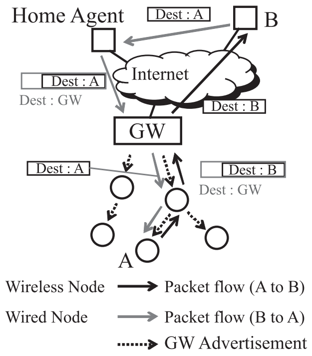


Figure 2. Packet flow in MIPMANET

includes its IP address and some information useful for gateway selection. When each wireless host receives this advertizing packet, it selects one adequate gateway, called default gateway. And a wireless host notifies to its home agent and registers this default gateway as a foreign agent.

Wireless multi-hop networks are generally constructed with hosts with global IP address without shared subnet part. So, when wireless host A would like to communicate with host B, it should first identify whether host A is inside its belonging wireless multi-hop network. Wireless host A can identify by sending RREQ packet of AODV in flooding fashion. When host B exists inside the same wireless multi-hop network, RREP (Route Reply) will be replied by host B. When host A cannot receive any RREP message even with sufficient latency, it can identify that host B is outside its wireless network. In this case, host A encapsulate data packet (to B) and transmits it to its default gateway. When default gateway receives this encapsulated packet, it decapsulates it and transmit this data packet (to B) simply to host B. Host B simply replies to host A of its global IP address, which means this replied packet is forwarded to home agent. Home agent forwards this replied packet to default gateway (foreign agent) of host A by encapsulation. When default gateway receives this forwarded reply, it decapsulates it and forwards it to host A (by using AODV RREQ flooding).

In MIPMANET, when there are multiple gateways in a wireless multi-hop network, all wireless hosts receive an advertizing packet from each gateway. Advertizing packets can convey hop count, which is incremented at each relay node, so a wireless host can identify its hop count to each gateway. MIPMANET [1] has proposed minimum-hop gateway selection policy. However, with minimum hop gateway selection policy, geographical imbalance of generated traffic may cause traffic load imbalance at gateway nodes. A gateway node has generally a tendency of traffic concentration because all external traffic goes through it, so traffic load imbalance will couse serious performance degradation.

III. LOAD BALANCING GATEWAY SELECTION

In this section, we explain about our previously proposed gateway selection method [8], cost function, which takes account of traffic load and wireless channel contention and our gateway selection method.

A. Cost Function

First, we define cost function of gateway node i affected by host k, C_{ki}, as follows.

$$C_{ki} = \sum_{h=1}^{h_{ki}} h^{-1} \tag{1}$$

where h_{ki} is the number of hops between host k and gateway node i.

When there exist n_i wireless hosts connected to gateway node i, we define total cost of gateway node i, C_i, as follows.

$$C_i = \sum_{k=1}^{n_i} C_{ki} \tag{2}$$

Each gateway node can obtain the number of hops, h_{ki}, by receiving RREQ packet from active hosts. It calculates total cost of gateway i, C_i, and distributes this calculated total cost to all hosts by broadcasting periodically an advertizing message. In equation (1), we considered wireless channel affection around the gateway node is approximately inversely proportional to distance to the gateway node. For details of our cost function, please refer to our previous paper [8].

B. Gateway Selection Method

When each host receives advertizing message from multiple gateways, it calculates new gateway costs. New gateway cost consists of gateway costs brought by currently connected hosts (gateway costs explained above), and costs brought by the corresponding host.

Figure 3 depicts one example of cost calculation and gateway selection. In Figure 3, two gateways, GW1 and GW2, have 4 and 2 connected hosts, respectively. When a focused host (gray colored one) would like to send data to an external host, it should select an adequate gateway.

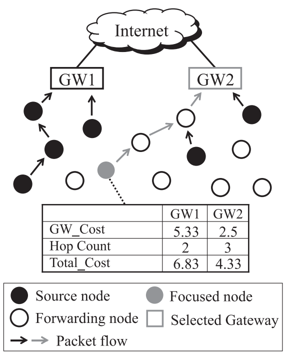


Figure 3. Load-balancing gateway selection

In this example, total gateway cost of GW1 and GW2 is 5.33 (=1/3+2*(1/2)+3*(1/1)+1/1) and 2.5 (=1/2+1/1+1/1), respectively. Focused host's hop count to GW1 and GW2 is 2 and 3, respectively. So, when this host is connected to GW1, total cost of GW1 is 6.83 (=5.33+1/2+1/1). When this host is connected to GW2, total cost of GW2 is 4.33 (=2.5+1/3+1/2+1/1). So, this focused host selects GW2 because GW2 gives smaller cost as its own default gateway.

As shown in this example, each host selects gateway node giving minimum total cost. This cost function takes account of not only traffic load but wireless channel contention around the gateway node. So, with this minimum cost gateway selection, throughput performance of communications through gateway node can be improved.

C. Threshold for Hop Count Difference

Li et al. [9] shows that throughput performance of wireless multi-hop session is seriously degraded with increase of the number of hops. When a gateway selection policy gives selection of a distant gateway, throughput performance might not be improved. In extreme case of selecting extremely distant gateway, throughput performance through gateway node may be degraded seriously, which means a gateway selection might bring worse throughput.

To prevent this situation, we restrictively apply our gateway selection policy to subset of gateways. We restrict candidate gateways as the following way. When there are multiple gateways (candidate gateways), hop count of the shortest gateway is set as baseline of gateway selection. Gateway nodes whose hop count is within threshold when compared with this baseline, are candidate of gateway selection. Other gateways are not candidate to be selected. For example, when hop count to GW1, GW2 and GW3 is 2, 3 and 4, respectively, and threshold is 1, only GW1 and GW2 are candidates. GW1 is the shortest gateway and its hop count is 2, so 2 is baseline. GW2 is within threshold when compared with this baseline (3=2+1), so GW2 is also a candidate. However, GW3 is outside of threshold from the baseline, so GW3 cannot be a candidate. When there is only one candidate, i.e. only the shortest gateway nodes in a candidate and other nodes are not inside the threshold, a host simply selects the shortest gateway node.

IV. PERFORMANCE EVALUATION

In this section, performance of our proposed method is comparatively evaluated with the minimum-hop gateway selection. We would like to use more general and sophisticated simulation model and show that our proposed method generally improves throughput of load-concentrated gateway.

A. Simulation Model

For simulation tool, we use Qualnet 4.5 [10]. In order to evaluate basic performance of our proposed method, we use a static model where no mobility of hosts are considered. Semiautomated node placement model (called in Qualnet) where square field is divided into cells and one host is located randomly in each cell, in used for node placement. When we use pure random model, there may be some heterogeneity of connectivity among wireless host. We would like to avoid evaluating our proposed method in this extremely heterogeneous situation, so semi-automated node placement, which avoids extremely heterogeneous host location is used.

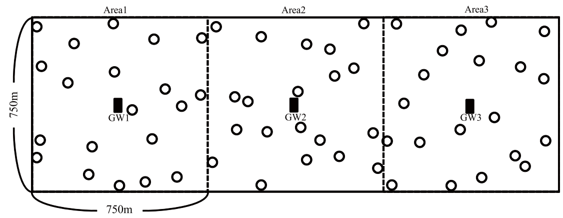


Figure 4. Simulation model (3 gateway)

Table I
SIMULATION PARAMETER

number of gateway	3	packet size	512 [byte]
number of node	60	packet interval	100 [msec]
wireless band	2 [Mbps]	advertisement interval	5 [sec]
radio range	250 [m]	simulation time	1000 [sec]

In this paper, we use a new network model as shown in Figure 4. One gateway node is located at the center of each square area, thus totally there are 3 gateway nodes. In each square area, 20 wireless hosts are located randomly with semi-automated node placement model. So, there are totally 60 wireless hosts in a whole network. GW advertisement is broadcast every 5 second. Each host is assumed to have exponentially distributed active time and holds communication to outside area through a gateway during this active time period. Inactive time period is also assumed to have exponential distribution and each host is alternately in each of active or inactive time.

We assume imbalanced traffic model where there are 4 active hosts in Area 1 and Area 3, and 16 active hosts in Area 2 on average. So, in Area 1 and Area 3, average active time and inactive time is 2.5[sec] and 10.0[sec], respectively. In Area 2, average active time and inactive time is 10.0[sec] and 2.5[sec], respectively. So, in this traffic model, Area 2 has more generated traffic than Area 1 and 3.

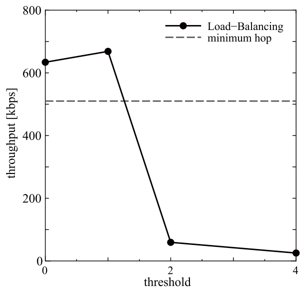
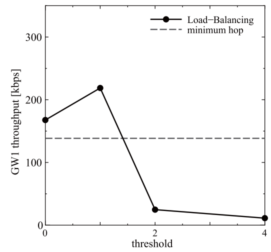
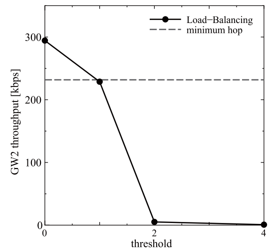


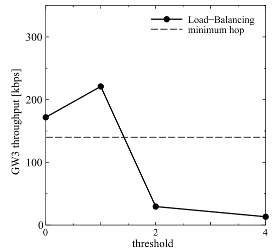
Figure 5. Gateway throughput characteristics



(a) GW1



(b) GW2



(c) GW3

Figure 6. Throughput characteristics of each GW

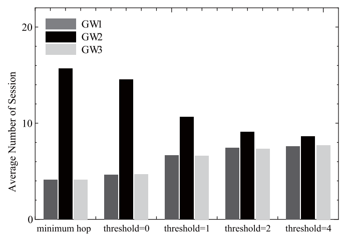


Figure 7. Average Number of Session

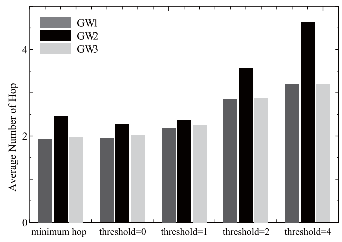


Figure 8. Average Number of Hop

MAC and routing protocol is IEEE 802.11DCF and AODV, respectively. Other simulation parameters are shown in Table 1.

B. Gateway Throughput

In this section, performance of our proposed method is comparatively evaluated with the minimum-hop gateway selection. Figure 5 shows total throughput performance of our proposed method. vertical axis shows total throughput of 3 gateway nodes. Horizontal axis shows threshold defined in Section III.C. The dotted line in this figure is total throughput of the minimum-hop gateway selection. As shown in this figure, total throughput of our method of threshold=1

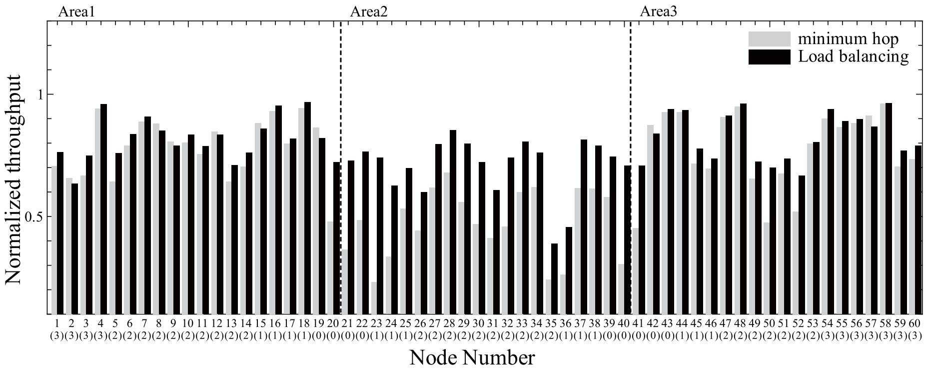


Figure 9. Normalized throughput of each node

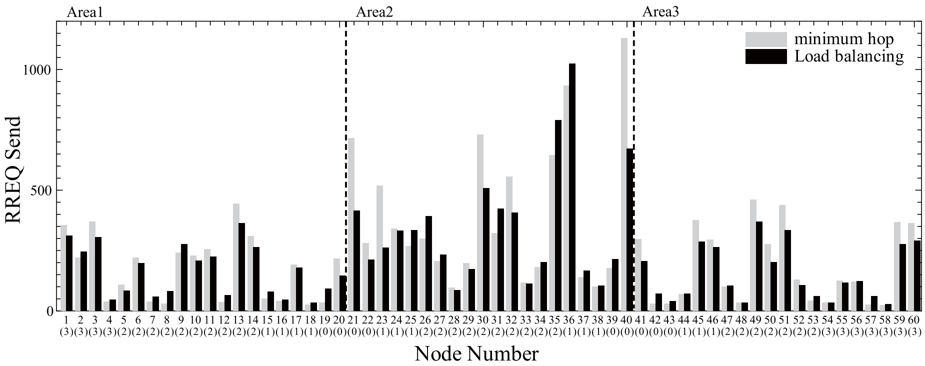


Figure 10. The number of RREQ sent by each node

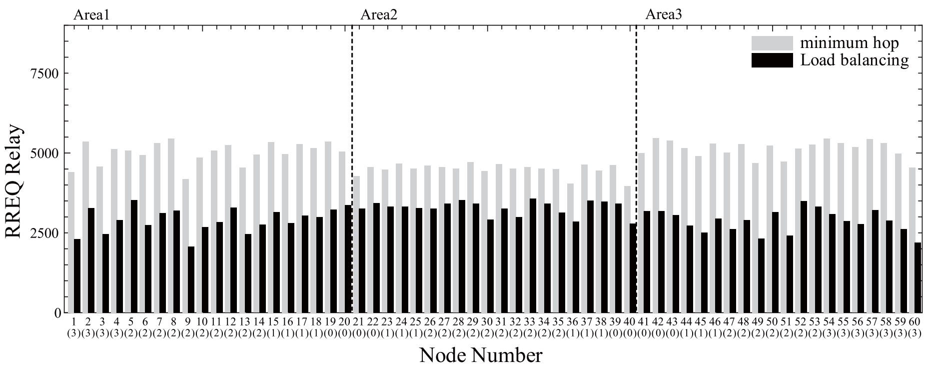


Figure 11. The number of RREQ relayed by each node

is improved approximately 31% when compared with the minimum-hop gateway selection.

In Figure 6 (a), (b) and (c), we show respective throughput of GW1, GW2 and GW3. Figures 7 and 8 show average number of session and hop in our proposed method, respectively. In a simulation model in this paper, more nodes generate traffic in Area 2 and more traffic is generated here. As threshold increases, the number of sessions arranged to each gateway is more balanced, as shown in Figure 7. This means from the viewpoint of load balancing, large threshold is preferable. However, as shown in Figure 8, the number of hops for each session increases with increase of the threshold. In ad hoc networks, increase of hops leads to significant throughput degradation. So, as shown in Figure 6, total throughput of GW1 and GW2 with larger threshold than 1 is degraded even though the number of its connected sessions is increased.

In the evaluation of our proposed method, hereafter, we use the best parameter value of threshold=1.

C. Detailed discussion for throughput performance

In this section, we evaluate throughput characteristics for each host. Figure 9 shows normalized throughput characteristics of each host. Vertical axis shows throughput

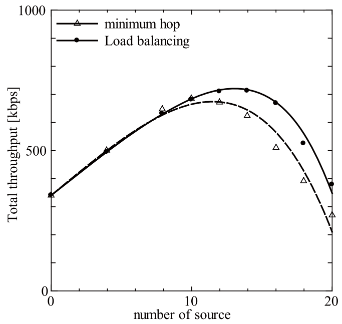


Figure 12. The number of souces v.s. gateway throughput characteristics

normalized with generated traffic volume. Horizontal axis shows node number. The number in parenthesis is hop count difference between the closest gateway and the second closest one. The node ID is allocated in the order of this number. In our simulation model, more active source hosts are located in Area 2 than other two areas, Area 1 and Area 3. In our proposed method, Area 2 traffic around the edge will be induced to other areas with load balancing effect. So, reduction of traffic intensity to GW2 is expected to improve throughput performance of all nodes in Area 2. Simulation results shown in Figure 9 confirm this load balancing effect in Area 2.

Figures 10 and 11 show RREQ generation characteristics and RREQ relay characteristics, respectively. As shown in Figure 10, the number of generated RREQ packets is generally decreased with our proposed method. This leads to great improvement of RREQ relay performance. With load balancing effect, some traffic concentrated to GW2 in minimum hop selection is shifted to other gateways. This leads increase of traffic intensity in Area 1 and Area 3. In ad hoc networks, increase of traffic generally causes decrease of normalized throughput even though absolute throughput increases. However, as shown in Figure 9, our proposed method can slightly increase normalized throughput in Area 1 and Area 3 even though traffic intensity to these two areas is increased. This surprising results are brought by decrease of control packets, i.e., generated and relay RREQ shown in Figures 10 and 11.

Figure 12 shows total throughput characteristics. In this evaluation, number of active sources in Area 2 is changed as simulation parameter and is horizontal axis of Figure 12. Vertical axis shows total throughput of the whole network, i.e., summation of GW1, GW2 and GW3 throughput. As shown in this figure, with our proposed method, concentrated traffic to Area 2 is adequately guided to other areas by load balancing effect, so the number of sources giving maximum throughput is shifted from 12 to 14. This means Area 2 can include more sources in our method.

Newly revealed features of our proposed method are as follows:

- Improvement in normalized throughput is obtained not only in heavy-loaded area but also in light-loaded area because of reduction of control overhead.
- This surprising win-win relationship for heavy-loaded and light-loaded area improves also total throughput of the whole network.

V. CONCLUSION

In this paper, our proposed method is comparatively evaluated with the minimum-hop gateway selection policy in a new topology. Our simulation results show that our proposed method takes into account gateway load balancing and improves total throughput with threshold 1. We revealed that our proposed method improves not only load-concentrated gateway throughput but also other gateway's throughput. We carefully investigated a reason for its throughput improvement and reveal that our proposed method can reduce the number of generated RREQ floodings and thus improves throughput performance of all hosts in a whole multi-hop wireless network.

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