Proposal and Evaluation of Multiple Gateways Distribution Method for Wireless Mesh Network

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ABSTRACT

Researches on the wireless mesh network in which access points (APs) of a wireless LAN are connected by an ad-hoc networks are recently drawing much attention. In the wireless mesh network, APs can be set up freely and its areas can be expanded easily. For the wireless mesh network, methods of utilizing multiple gateways (GWs) at the time of making a connection with an exterior network such as the Internet have been studied in order to resolve the congestion problem around GWs, which is the bottleneck in gaining a high throughput. Although a method of distributing packets to different GWs has been studied hitherto, the method tend to lower the communication throughput due to the function of TCP's congestion control. Thus, we propose a method of utilizing GWs effeciently by distributing packets to multiple GW "in units of session" (i.e. one of GWs is selected session by session). This method does not give any influence on the throughput of TCP communication. By conducting a simulation, we confirmed that our proposed method performed a higher TCP communication throughput than the existing method while the fairness is sufficiently maintained.

Categories and Subject Descriptors

C.2.2 [Computer-communication networks]: Network Protocols—Routing Protocols

General Terms

Design

Keywords

Wireless Mesh Networks

1. INTRODUCTION

As the wireless LAN does not require any cabling and its terminals can move freely, its wider use in future is expected. There are two methods for establishing a wireless LAN. One method is based on the infrastructure mode and the other is based on the ad-hoc mode. The infrastructure mode is a method generally used, in which terminals always make communications through wire-connected access points (APs). On the other hand, in the ad-hoc mode, terminals can communicate with each other directly. As an application of the ad-hoc mode, there is a mobile ad-hoc network (MANET). In MANET, terminals themselves can establish network infrastructure, but MANET is still in its research stage and the range of its use is limited, because there are still a number of problems. For instance, it consumes resources of relaying terminals (such as CPU and power) against user's intention. The communication route is not stable when terminals move, and there are also security problems such as attacks and eavesdropping by relaying terminals.

Accordingly, researches on the improvement in the MANET-based wireless mesh network are drawing much attention these days. In the wireless mesh network, APs have the function of creating MAENT and the connections among APs are made by wireless. Because the wireless mesh network does not use connecting cables, it has characteristics that APs can be placed freely and that the areas of the wireless network can be expanded easily. Furthermore, it does not have the problem of consuming resources at user terminals. Since APs which relay packets do not basically move, communication routes are relatively stable. In addition, because APs can be arranged by the same service provider, it is easy to provide secure communications. The wireless mesh network is expected to be used for public wireless networks, emergency netwroks at times of disasters, or for provision of local areas. The wireless mesh network is currently operated on a trial basis by various research organizations[1, 2, 3, 4, 5, 6, 7], and at IEEE, Task Group 802.11 "s" is setting forward the standardization of the wireless mesh network[7].

When the wireless mesh network is actually operated, it is expected that communications with exterior networks such as the Internet are frequently conducted and the areas around gateways (GWs) which are on the border with the wired section could get congested and thus, become a bottleneck. Also, it is known that the communication throughput is greatly lowered if the number of hops from an AP to a GW is large. In order to solve this problem, there have been studies on the methods of setting up multiple GWs between the wireless mesh network and the exterior network so as to use the GW having the smallest number of hops from the AP [8, 9, 10, 11]. In this method, however, if and when the

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terminals concentrates around a specific GW, that GW uses up, while other GWs are not effectively used. Therefore, a method of connecting one AP with multiple GWs so as to distribute the traffic has been studied [12]. In [13], AP calculates appropriate transmission ratio of packets among different GWs when it receives packets from terminals, and transmits them to different GWs based on the calculated ratio.

However, this method has a problem that the TCP communication throughput is greatly lowered due to the difference in transmission times of different routes as the result of the packets of the same session being distributed to multiple GWs.

In order to solve this problem, we propose in this paper a method of distributing the traffic to multiple GWs on a session by session basis. By adopting our proposed method, GWs are efficiently utilized, delays of packet transmissions are minimized, and the lowering of TCP transmission throughput is prevented. We demonstrate by conducting simulations that the throughput by our proposed method is not lowered while the fairness is throughly maintained.

The rest of the paper is organized as follows: We first explain existing technologies and their associated problems in Chapter 2 and our proposed method in Chapter 3. Then, we describe the evaluation of our proposed method based on simulations in Chapter 4, and finally give the conclusion of this paper in Chapter 5.

2. EXISTING TECHNOLOGIES AND THEIR PROBLEMS

In this Chapter, we introduce two existing GW selection methods for the wireless mesh network. One method is the "single GW selection method" and the other is the "multiple GW selection method". The former is a method of choosing one most appropriate GW from among multiple GWs and the latter is a method of using multiple GWs simultaneously so as to disperse the traffic. Meanwhile, as the GW selection methods for MANET are technically the same as those for the wireless mesh network, we introduce the methods for MANET as part of the existing technologies.

2.1 Single GW selection method

The single GW selection method is a simple technology. AP transmits a packet to a terminal of an exterior network through a GW which has the smallest number of hops. In the GW selection method for MANET, studies have been conducted on the basis of choosing a single GW [8, 9, 10]. In MANET, it is assumed that the terminals relaying packets are moving, and thus, the single GW selection method is suitable for securing the stability of the routes. However, if and when the distribution of terminals concentrates around a GW, the GW becomes congested and becomes a bottleneck, while other GWs remain unused.

In the meantime, in [11], for the wireless mesh network, improvement in the communication throughput is attempted by selecting an effective location of the GW, taking into account the state of distribution of terminals. However, in the actual environment, there may be cases where the location of GW is physically restrained, and sufficient efficiency may not be gained, depending on the environment.

2.2 Multiple GW selection method

In order to solve the above-mentioned problem of the single GW selection method, [12] is proposing a method where one AP utilizes multiple GWs at the same time in the wireless mesh network. AP calculates the most suitable transmission ratio of packets among multiple GWs based on parameters such as the number of hops to each GW and the available bandwidth of each transmission route. When AP receives packets from terminals, it forwards them by distributing them among multiple GWs in accordance with the above-said transmission ratio. Each GW then forwards the received packet to MGW (Master Gateway), which transmits the entire packets to the exterior networks altogether. However, in this method, differences in arrival times of packets of the same session occur because different GWs are used in the same session. In [12], it is not examined what influence these differences in arrival times would give to TCP communication. If the sequence of packets is not preserved due to the differences, packet retransmission would often initiated by the congestion control function of terminals, even if no packet loss occurs. Thus, in order to prevent the out of order packets, a method, that sequence control is executed in MGW before forwarding the packets to the exterior network, is being considered. In this method, however, because the packets transmitted through a route with shorter hops need to wait until the packets transmitted through a route with longer hops, the overall transmission time for the session becomes longer, and as a result, it has a problem that the throughput gets lower in the case of TCP communications.

3. OUR PROPOSED METHOD

In this paper, we adopt the multiple GW selection method in order to avoid traffic concentration to a specific GW, but propose a distribution method "in units of sessions" (the same packets of the same session are sent to the same GW) instead of the distribution method in units of packets (packets are sent to different GWs without regard to sessions). By distributing packets in units of sessions, we can avoid different arrival times of packets of the same session, and avoid the lowering of the throughput of TCP communications. Hereinafter, we call the method of distributing in units of packets as "packet-distributing method" and that in units of sessions as "session-distribution method".

In order to compare the session-distribution method with the packet-distribution method, we use WAPL (Wireless Access Point Link) [1] as the basic wireless mesh network system. The reason for our using WAPL is that the simulation environment of the fundamental wireless mesh network is already established and therefore, introduction and evaluation of our proposed method can be done easily. The basic function of WAPL is the same as that of other wireless mesh networks, and the results of this research can also be applied to other wireless mesh networks.

3.1 WAPL

The entire schematic picture of WAPL is shown in Fig.1. In WAPL, wireless AP is called WAP (Wireless Access Point). The WAP which connects with the wired section in order to

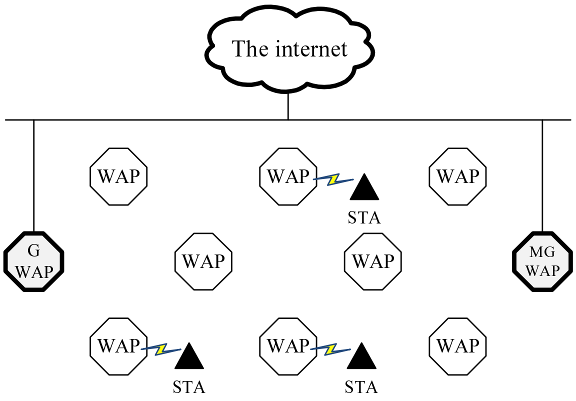

Figure 1: Entire Schematic Picture of WAPL.

have connections with the Internet is called GWAP (Gateway WAP), and the GWAP which aggregate packets from all other GWAPs and relay the packets to exterior networks is called MGWAP (Master GWAP). Communications with the exterior networks always go through MGWAP. Communications between GWAPs and MGWAP are connected by wire, and the communications between GWAPs and MGWAP do not become a bottleneck. MGWAP encompasses the function of GWAP.

GWAPs and MGWAP always check the volume of traffic around them, namely the traffic within their wireless ranges. GWAPs and MGWAP periodically flood messages including those of the traffic value and the number of hops to each WAP. The number of hops increases by one each time when passing through a WAP. From this message, each WAP obtains the knowledge of the traffic condition around GWAPs and MGWAP and also the number of hops to GWAPs and MGWAP.

3.2 Session-distribution method

We show the outline of the session-distribution method in Fig.2. When a WAP receives packets from terminals, it calculates the expected value of throughput based on the traffic and the number of hops to the nearby GWAPs at that moment, if the network portion of the packet-destination IP address indicates an exterior network, and selects one GWAP having the highest expected value of throughput as the most suitable GWAP. As regards the calculation method of the expected value of throughput, we will explain it in 4.2 later. WAP, at the same time, memorizes the relationship between the session and the most suitable GWAP, and transmits packets of the same session to the same GWAP thereafter. The same session means the traffic which has the same connection ID (i.e. same source IP address, destination IP address, protocol number, source port number and destination port number). GWAP sends the received packets to MGWAP, which memorizes the relationship between the session and the GWAP and sends the packets to a terminal of the exterior network. In the meantime, packets from a exterior network are once forwarded to MGWAP, which is the representative GW of WAPL. The packets are then forwarded to WAP to which destination terminals belong via an appropriate GWAP. In this way, the traffic of the same session can go through the same route. When another session is initiated, another most appropriate GWAP at that time is selected anew.

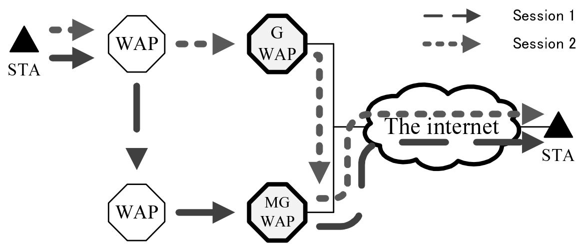

Figure 2: Session-distribution Method.

When a communication is initiated from an exterior network, MGWAP, upon receipt of a packet from the exterior network, floods a message looking for the most suitable GWAP at that time towards all WAPs within the system. WAP to which the destination terminal belongs responds the IP address of the most suitable GWAP. MGWAP which received the response memorizes the relationship between the session and GWAP, and in this way the route is determined.

3.3 Packet-distribution Method

In this Section, we show the case of applying the packet-distribution method to WAPL for the sake of comparison, in order to clarify the effect of the session-distribution method. The outline of the packet-distribution method applied to WAPL is shown in Fig.3. WAP calculates the expected value of throughput from the traffic and the number of hops to each GWAP and determines the transmission ratio to different GWAPs. We adopt the same calculation method for expected value of throughput as that for the session-distribution method. When WAP receives packets from terminals, it attaches sequence numbers to these packets and distributes them to different GWAPs in accordance with the transmission ratio. Each GWAP sends the received packets to MGWAP, which then forwards them to exterior networks. At this stage, MGWAP makes buffering of the packets received from GWAPs, and conducts a sequence control based on the sequence numbers and sends the packets to exterior networks. If all the sequence numbers are ready within a pre-determined time period, it is considered to be a time-out of the buffering, and sequence-controlled packets are sent to the exterior as they are. When the first packet comes back from the exterior against a communication initiated from the interior, and also when a communication is initiated from the exterior, MGWAP, upon receipt of a packet, floods to WAPs a message seeking for the transmission ratio to each GWAP. Then, the WAP to which the destination terminal belongs, sends back the transmission ratio to each GWAP. MGWAP, which obtained the response, attaches sequence numbers to the packets and distributes the packets to GWAPs in accordance with the transmission ratio. WAP makes buffering of the packets received from different GWAPs, and conducts a sequence control based on the sequence numbers and transmits the packets to terminals. In the case of the packet-distribution method, as the distribution ratio is required, WAP is inquired of the transmission ratio as regards the packets from the exterior, even if the communication was initiated from the interior.

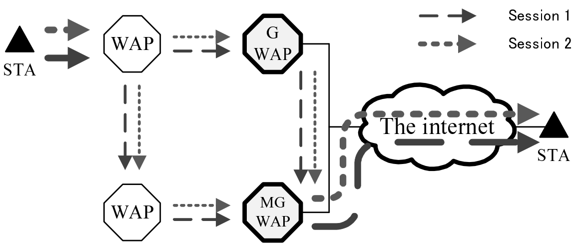

Figure 3: Packet-distribution Method.

4. EVALUATION BY SIMULATIONS

In order to demonstrate the effectiveness of the session-distribution method, we conducted simulations by using ns-2 (network simulator-2) [13]. We made a number of modifications to ns-2 so as to make effective simulations possible. Also, in order to select an appropriate GWAP, we looked for a calculation formula for the expected value of throughput by making a preliminary simulation. In addition, we obtained an appropriate time-out value of the buffering of the sequence control for the packet-distribution method, and made a comparison between the session-distribution method and the packet-distribution method. For the sake of comparison, the throughput and the fairness of the traffic were taken up as the items.

4.1 Modifications of the simulator

ns-2 is a free software generally used by research organizations. However, while the ad-hoc network function is sufficiently complete, it is presently not equipped with the infrastructure mode function for wireless LANs, and therefore, it cannot be used for simulations of the wireless mesh network. Accordingly, we created an effective simulation environment by making the following modifications to ns-2. We added such functions as beacon-dispatching, AP-selection based on the strength of wireless signals, and association and disassociation with APs to the IEEE802.11 function modules of ns-2. Meanwhile, although WAP needs to have two types of interfaces, namely the interface for the infrastructure mode and that for the ad-hoc mode, we filled this requirement by directly connecting the interfaces of interior modules of nodes having respective interfaces, without going through a network. GWAP likewise realized this by directly connecting the interfaces of the ad-hoc mode and the interior module of wire. We further gave ns-2 the function of both the session-distribution method and the packet-distribution method, which we explained in Chapter 3. In the simulation, for the sake of simplification, different channels are used in the side of infrastructure mode and the side of ad-hoc mode, and the same channel is used in the same mode.

4.2 Expected value of throughput

It is necessary to have a method of choosing the most suitable GWAP among GWAPs in the case of the session-distribution method, and a method of determining the transmission ratio to GWAPs in the case of the packet-distribution method. In this study, we adopted the way of determining in advance a formula for the relationships among the number of hops between WAP and GWAP, the traffic around GWAP, and TCP throughput, by doing a preliminary simulation, and then calculating the expected value of throughput of GWAP.

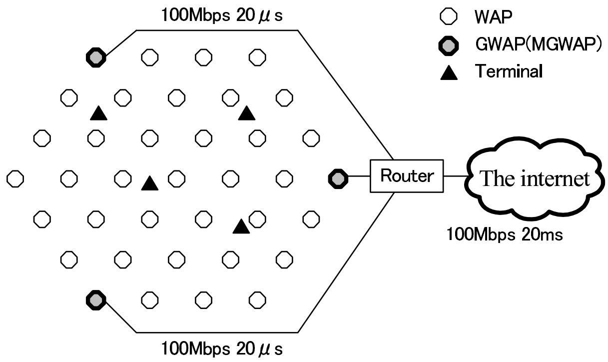

Figure 4: Simulation field.

In [14, 15], a method of utilizing values of RTT (Round Trip Time) or packet loss rate is proposed as the method of calculating TCP throughput, and it seems also possible to use this method for the calculation of the expected value of throughput. However, it is extremely difficult to obtain values of RTT or packet loss rates on a real-time basis in the wireless mesh network which receives a large influence from the traffic of control messages, etc. Thus, we thought it most appropriate to rely upon the method of calculating the expected value of throughput from the relationship between the volume of traffic near GWAP and the number of hops by doing a preliminary simulation. With the preliminary simulation, we can obtain an index of the expected value of throughput and can put the weight on the GWAPs. We perform the comparison hereafter by using the expected value of throughput obtained in this way.

In the preliminary simulation, we measured the throughput by giving the background traffic and establishing TCP sessions between the interior and the exterior terminals. We induced a simple equation from the relationship between the number of hops between WAP (to which the terminal belongs) and GWAP and the traffic around GWAP and the TCP throughput which the terminal obtained. Parameters used in inducing this formula are shown in Table.1. and the simulation field is described in Fig.4. We use 37 WAPs and made the distance between two WAPs at 80 m. We assumed that the network connecting GWAPs has the same network address and set the band at 100 $Mbps$ and the delay at $20\mu s$. We assumed the Internet as the exterior of the network connecting GWAPs and set the bandwidth at 100 $Mbps$ and the delay at $20\mu s$. We set some terminals within WAPL to generate the background traffic and changed the volume of traffic by adjusting the number of terminals. For the background traffic, we assumed FTP communications with the exterior terminal, streaming communications to receive from the exterior terminal, VoIP communications among interior terminals, and VoIP communications between exterior terminals and interior terminals. Although the ratio of these sessions is different depending on the system, we assumed the ratio of the traffic as 1:1:1:1 regardless of the number of terminals, assuming that various applications exist equally.

The Fig.5. shows the relationship (in the case of 3 hops between GWAP and WAP) between the traffic around GWAP and the TCP throughput obtained from the simulation.

Table 1: Simulation parameters (1).

Background-load generating terminals	
Number of terminals	1-60
Type of communication	FTP (exterior - interior) Streaming (exterior - interior) VoIP (exterior - interior, interior - interior)
TCP Window size	128
TCP version	Sack
Mesh network	
Number of WAP	37
Radio-wave reacheablee distance	100m
Distance of WAP	80m
Field	860x580 (m)
MAC protocol	IEEE802.11g

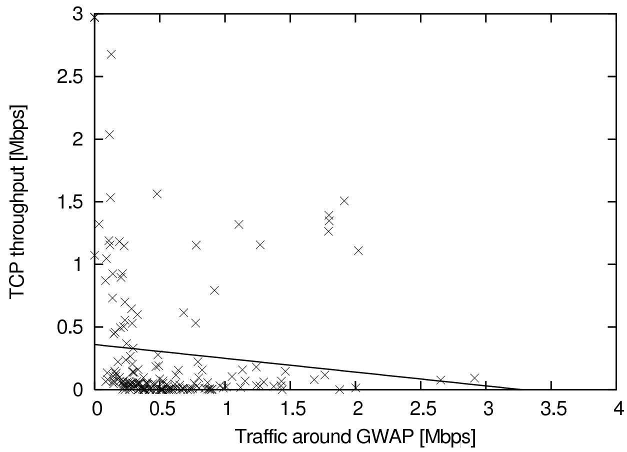

Figure 5: Relationship between the traffic around GWAP and the TCP throughput (3 hops).

The linear equation induced from the calculation of the approximate curve of linear function from these data by way of the least square method was "$y = 0.11x+0.36$". Here, "x" indicates the traffic around GWAP and "y" is the expected value of throughput. In the same manner, we looked for the calculation formula of the expected value for each number of hops as indicated in Table.2., by changing the number of hops and the volume of traffic around GWAP. For simulations hereafter, we decided to use the equation obtained here and to choose the most suitable GWAP in the case of the session-distribution method and the suitable transmission ratio among GWAPs in the case of the packet-distribution method.

4.3 Survey on the most suitable conditions for the packet-distribution method

In the case of the packet-distribution method, delays by the sequence control within WAPL might bring about the low throughput. Therefore, in order to avoid the decrease in the throughput in the packet-distribution method as much as possible, it is necessary to properly set up the time-out interval of the buffer used for sequence control. If the time-out interval of the buffer is short, inconsistency of sequence tends to often occur although delays get smaller. Thus, we

Table 2: Linear equations of each number of hops.

Number of hops	Simple equation
1	$-0.68x + 3.50$
2	$-0.26x + 1.11$
3	$-0.11x + 0.36$
4	$-0.19x + 0.26$
5	$-0.12x + 0.18$

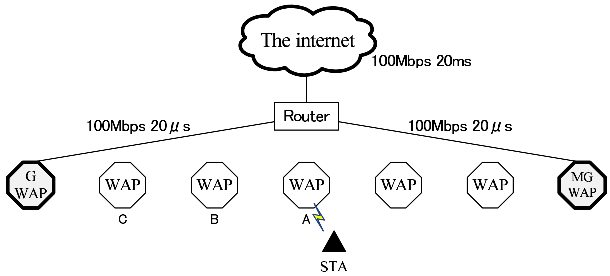

Figure 6: Simulation field.

surveyed the conditions in which TCP throughput gets the highest, by adjusting the time-out intervals of the buffer used for the sequence control within WAPL. In addition, for the sake of comparison, we also surveyed the case where no sequence control is applied within WAPL. Fig.6. shows the simulation field for throughput measurement, and Table.3. shows parameters for the simulation.

In order to keep the same route, we set up one GWAP, one MGWAP and five WAPs on a horizontal line in the field. The GWAP and the MGWAP are set at both ends of the line. As the network connecting GWAPs we set the bandwidth to $100Mbps$ and the delay to $20\mu s$. We assumed the Internet as the exterior network and set the bandwidth to $100Mbps$ and the delay to $20ms$. The window size of TCP is 128 and Sack is used for with the TCP version.

By setting up a terminal in the position A, we measured the TCP throughputs for $30s$ for the cases of the buffering time-outs of $15ms$, $10ms$, $5ms$, and $1ms$, and also for the case without any sequence control. The route from a WAP to a GWAP and that from a WAP to a MGWAP are both 3 hops and packets are communicated at the ratio of 1:1. Table.4. shows the results of the simulation. We can see that the throughput is the highest when the buffering time-out is $5ms$.

If we pay attention here to the frequency of Fast Transmit and that of TCP time-outs, we can see that there is no TCP time-out, and the frequency of Fast Transmit is small at the buffering time-out of $5ms$. If the timer is longer than $5ms$, no Fast Transmit is initiated, but TCP time-outs tend to occur frequently because the time period for a packet to stay in the buffer becomes longer. On the other hand, if the timer is shorter than $5ms$, TCP time-out does not occur because the packet is transmitted before the sequence control is completed, but Fast Transmit tends to occur easily as a result of sequence inconsistency. As regards the packet loss, we found that some loss was occurring in the ACK packets of TCP. We believe that this is because ACK packets

Table 4: Comparison of throughputs.

	Buffering Time-out (ms)	Throughput ($Mbps$)	First Transmit (times)	TCP Time-out (times)	Rate of Packet loss (%)	
					DATA	ACK
With sequence control	15	4.19	2	18	0	0.21
	10	4.49	8	11	0	0.29
	5	4.72	32	0	0	0.13
	1	3.71	41	0	0	0.01
Without sequence control	0	3.45	41	0	0	0.02

Table 3: Simulation parameters (2).

Terminals	
Type of communication	FTP
TCP Window size	128
TCP version	Sack
Mesh network	
Number of WAP	7
Radio-wave reacheablee distance	100m
Distance of WAP	80m
Field	1000x400 (m)
MAC protocol	IEEE802.11g

are being sent through an inward-directing route, namely a route from GWAP (MGWAP) to WAP in the middle, and thus, these packets have more opportunities of collisions than outward-going data packets. However, since the packets which are being lost are ACK packets, the packet loss does not give any influence on the frequency of TCP time-outs. From the above results, we perform simulations hereafter, assuming that the time-out interval of buffering in the packet-distribution method whereby a high throughput is expected, is $5ms$.

4.4 Overall throughput and traffic fairness when various kinds of traffic coexist

In order to study the influence of the situation when various kinds of traffic coexist in the actual mesh network, we constructed a network in the same conditions as stated in Section 4.2 and conducted a simulation of a situation where traffic was generated. We measured the transmission volume of packets running between the interior and the exterior of a wireless mesh network and evaluated the fairness of the distribution of the traffic running in the interior. The fairness referred to here means the indication as to how fair the traffic value running to each WAP is. The packets running between the interior and the exterior can be obtained by measuring the overall throughput of MGWAP.

Meanwhile, the reason for evaluating the fairness of the network traffic is that because in the case of the session-distribution method the unit of distribution is larger compared with the case of the packet-distribution method, it is possible that the fairness of the traffic of the entire network gets lower.

Simulation parameters and the traffic generation method are the same as Section 4.2, and in this state, we compared the case of applying the session-distribution method to WAP with the case of applying the packet-distribution method to WAP. We set up two GWAPs and one MGWAP. We conducted 3 times of simulations each for the number of terminals from 1 to 60.

We show the overall throughput of MGWAP of the session-distribution method in Fig.7. and that of the packet-distribution method in Fig.8. In each graph, we added a proximate curve based on the fourth equation for the sake of reference. Looking at the proximate curve, we can see that the overall throughput of around 10 - 12 $Mbps$ when the number of terminals is greater than 10 in the case of the session-distribution method. In the case of the packet-distribution method, the overall throughput reaches the highest value when the number of terminals is around 10, showing about 4 $Mbps$ and it gradually decreases down to about 1 $Mbps$ in proportion as the number of terminals increase. As the reason for better results of the session-distribution method in comparison with the packet-distribution method, we understand that the traffic of TCP is giving a large influence and that the fluctuation in the arrival time of packets gives a big negative effect in the case of the packet-distribution method. The reason that the throughput is restrained to the level of around 12 $Mbps$ in the session-distribution method is because the bandwidths around GWAP s and MGWAP are used up to their limits.

As the next step, we evaluated the fairness of the traffic running to each WAP. For the evaluation of the fairness, we used the following formula from [16].

$$FI = \frac{(\sum_{i=1}^{n} x_i)^2}{n \sum_{i=1}^{n} (x_i)^2} \quad (1)$$

The closer to 1 the value of FI (Fairness Index) is, the higher the fairness is. Here, "n" indicates the number of WAPs and "xi" indicates the transmission traffic of WAPi.

We show the graph of FI for the session-distribution method in Fig.9. and that for the packet-distribution method in Fig.10.

The horizontal axis indicates the number of terminals to generate the traffic and the verical axis indicates FI. In each graph, we added a proximate curve based on the fourth equation for the sake of reference. If we look at the proximate curve, when the number of terminals is around 30, FI

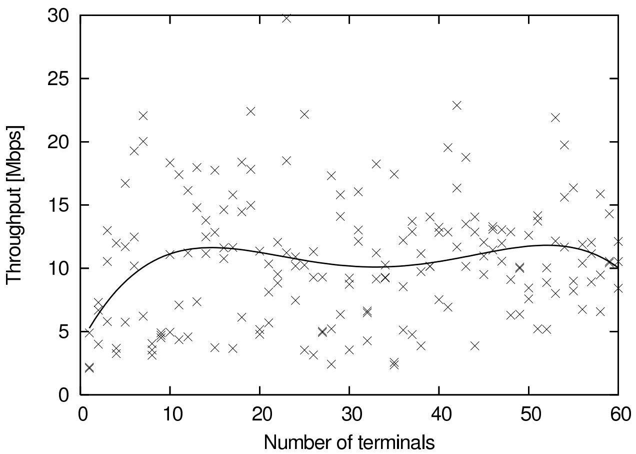

Figure 7: Throughput in MGWAP for the session-distribution method.

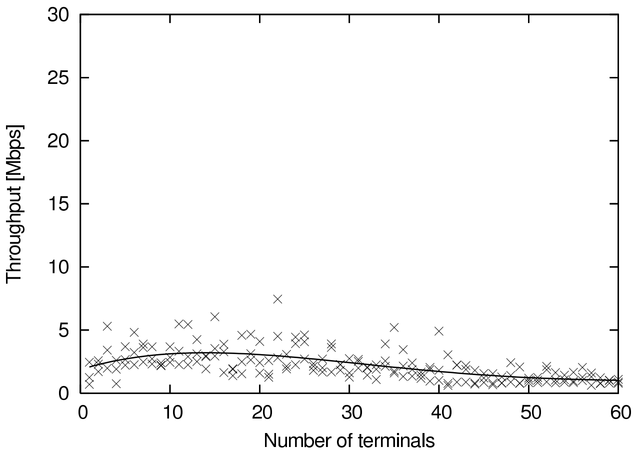

Figure 8: Throughput in MGWAP for the packet-distribution method.

for the packet-distribution method is about 0.24 and that for the session-distribution method about 0.17, and thus, the packet-distribution method has an advantage. However, when the number of terminals gets near 60, FI for the packet-distribution method converges to around 0.2 and that of the session-distribution method around 0.23, meaning that both methods have around the same value.

This is because even if the session-distribution method whose unit of distribution is rather large, it attains a sufficiently high fairness when the number of terminals gets large. When the number of sessions is small, the probability of a session being influenced by other sessions is low, and because it is more important to utilize network resources without loss when the number of sessions is large, we can say that the session-distribution method has a sufficient fairness.

From the results of the above-mentioned simulations, we can determine that the session-distribution method does not cause any fairness problem and that it has a higher overall throughput in MGWAP compared with the packet-distribution method.

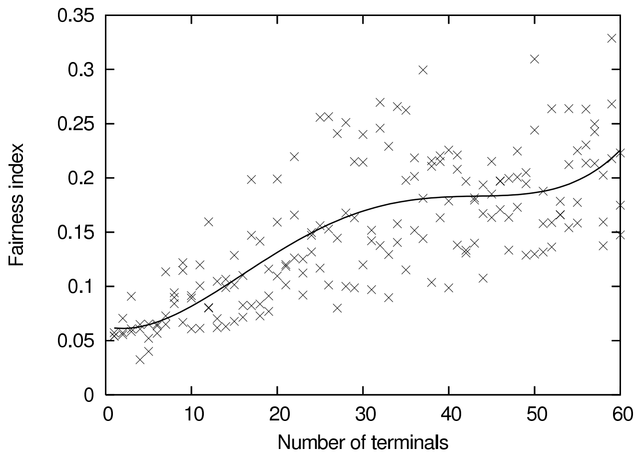

Figure 9: Fairness Index for the session-distribution method.

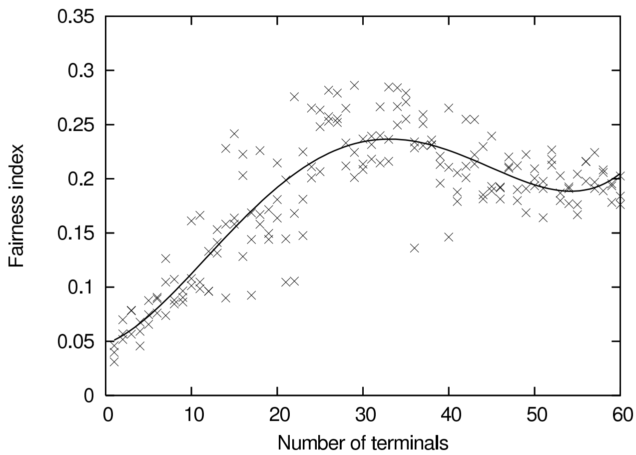

Figure 10: Fairness Index for the packet-distribution method.

5. CONCLUSION

In this paper, we proposed the session-distribution method with the objectives of attaining a higher TCP throughput in communications between the wireless mesh network and exterior networks and realizing an efficient use of GWs. We made a comparative evaluation of the session-distribution method and the packet-distribution method. As the result, we found out that we can get a higher TCP throughput by the session-distribution method compared with the packet-distribution method and also that the reasons can be clearly explained. In the characteristics of the overall throughput with the exterior network, we found out that the throughput is greatly improved in the case of the session-distribution method. Furthermore, in the fairness of the network traffic, it was demonstrated that the session-distribution method has a sufficient fairness compared with the packet-distribution method.

We adopted a method of performing a preliminary simulation to get the calculation formula of the expected value of throughput.

Although we used WAPL as the basic wireless mesh network, the concept of the session-distribution method is independent of the fundamental operation of the wireless mesh network, and therefore, the session-distribution method is applicable to other types of wireless mesh networks. Henceforth, we will implement the session-distribution method in real devices and perform evaluations.

6. REFERENCES

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Proposal and Evaluation of Multiple Gateway Decentralization Method for Wireless Mesh Networks

The 3rd International Conference on Ubiquitous Information Management and Communication, January 15-16, 2009, SKKU, Suwon, Korea

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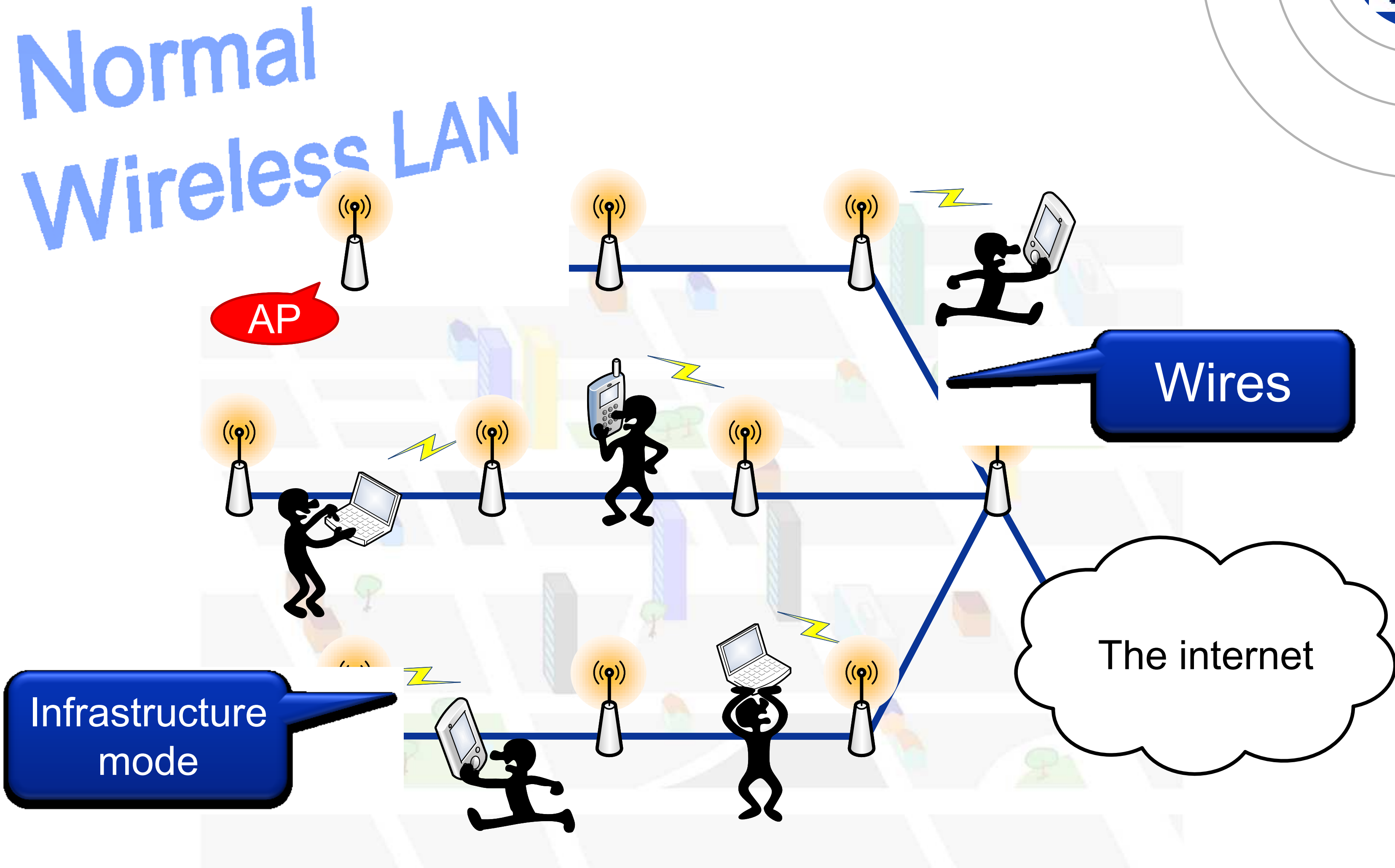
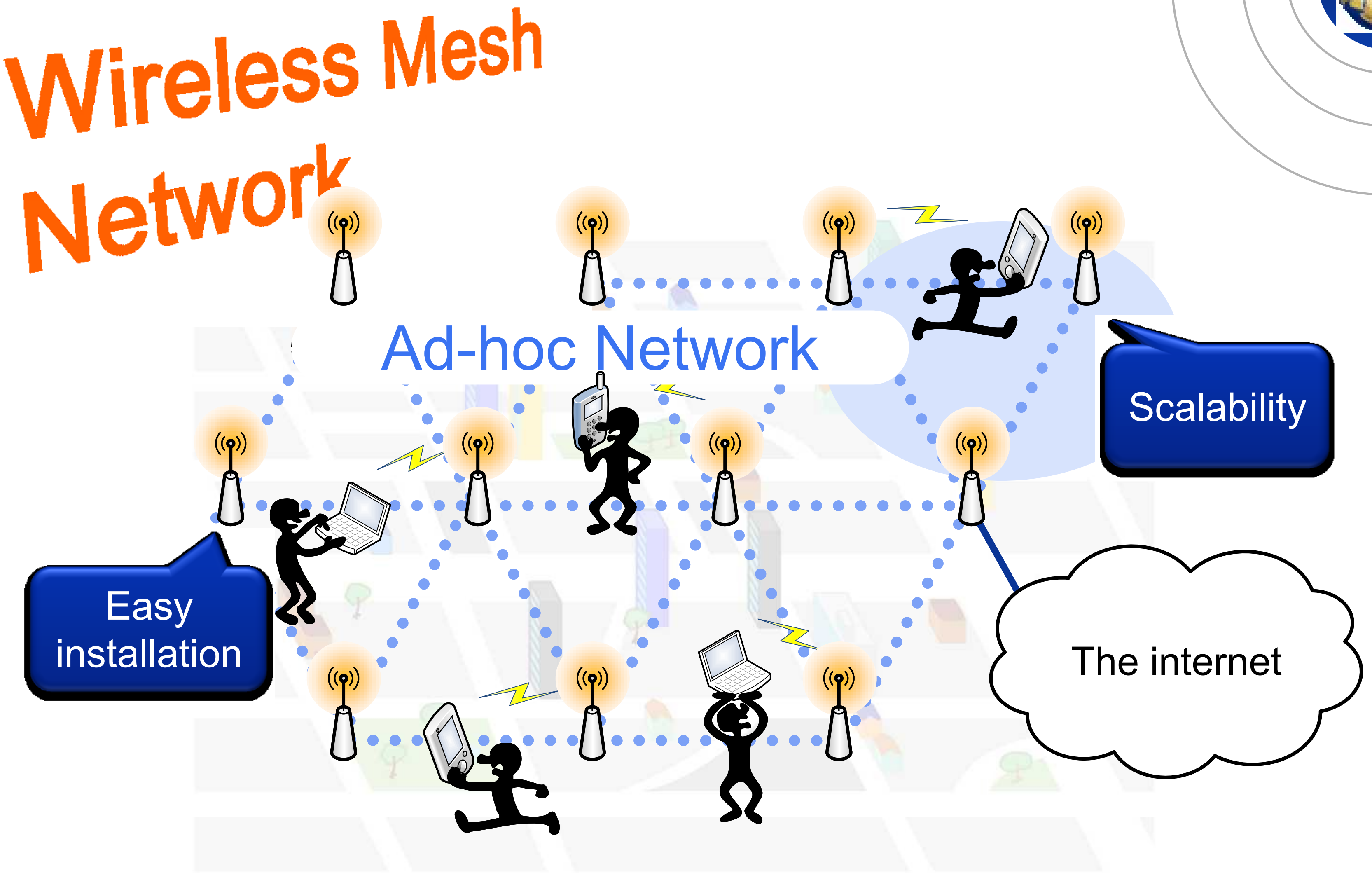
BACKGROUND –Wireless LAN-



Wireless LAN become popular due to location-free and Terminal mobility.

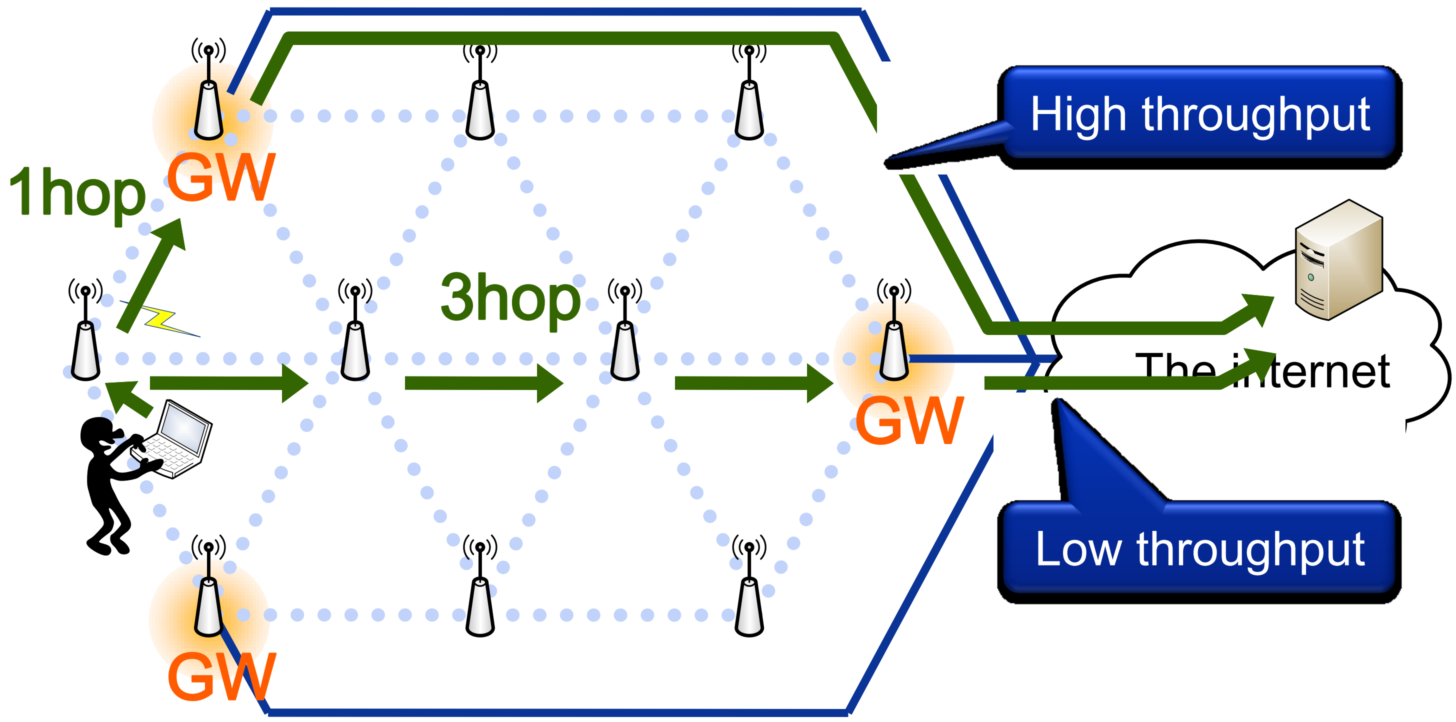


WMN is expected to grow due to easier installation and excellent scalability.

BACKGROUND –internet access-

Hop count should be minimized
to get high throughput

Utilization of multiple gateways

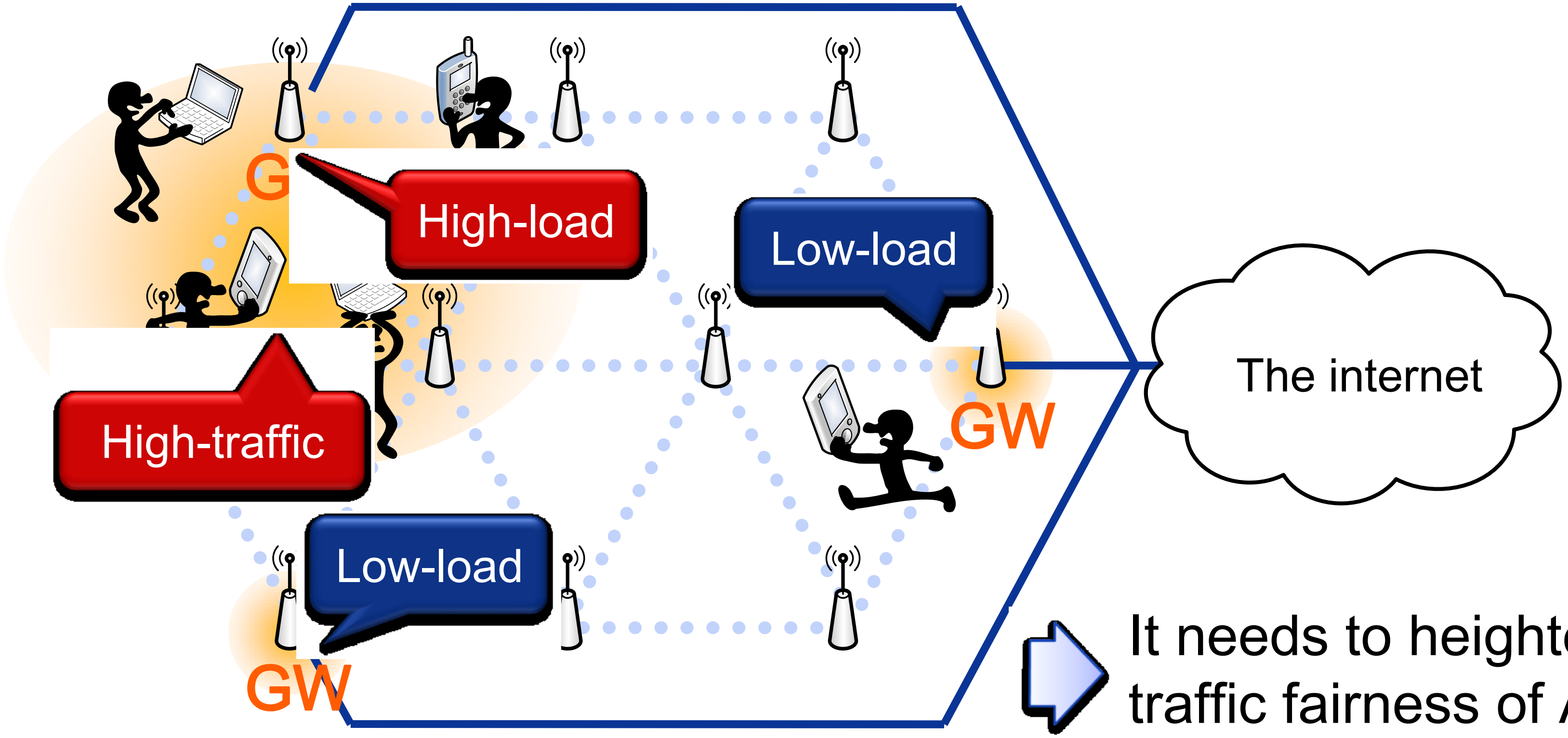


BACKGROUND –internet access-

When terminals concentrate around a specific GW

The Gateway uses up its bandwidth.

Other Gateways are not effectively used.



It needs to heighten traffic fairness of APs.

EXSITING TECHNOLOGY

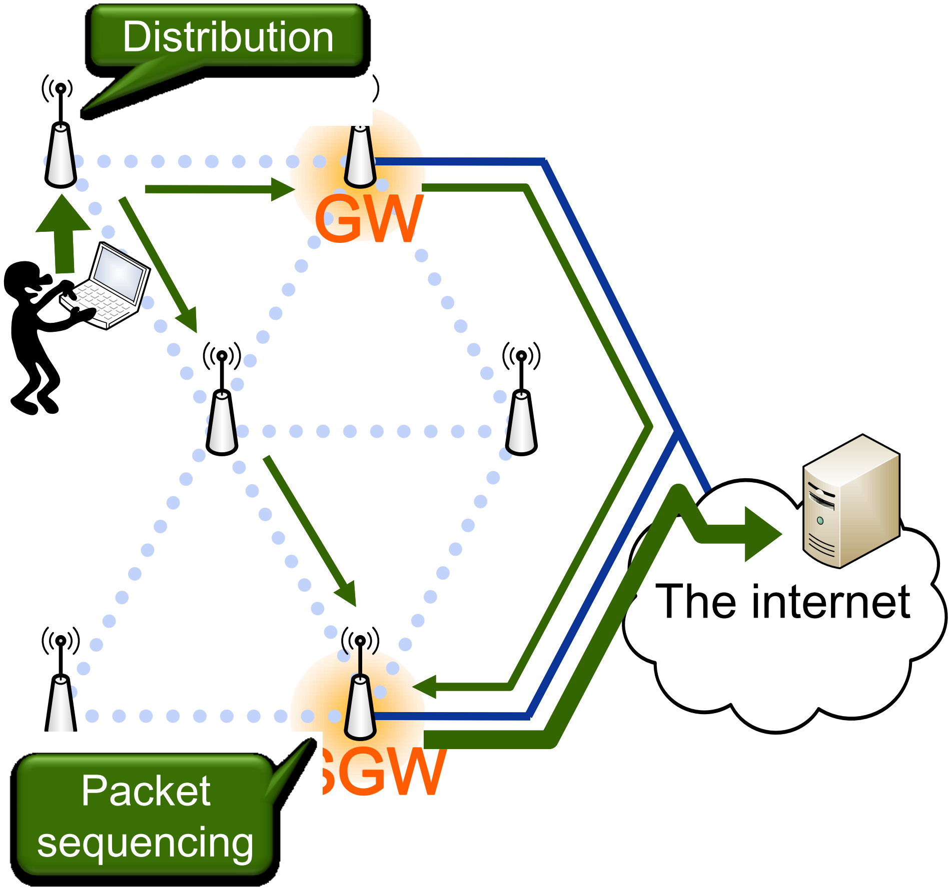
- **MGA：Multi Gateway Association**

  The method that transmits packets to multiple GWs.

  – All APs calculate transmission ratio based on parameters such as hop count and the bandwidth of each route.

  – AP transmits packets to GWs based on the ratio.

  – Super GW aggregates packets and conducts packet sequencing, and transmits them to the exterior network.

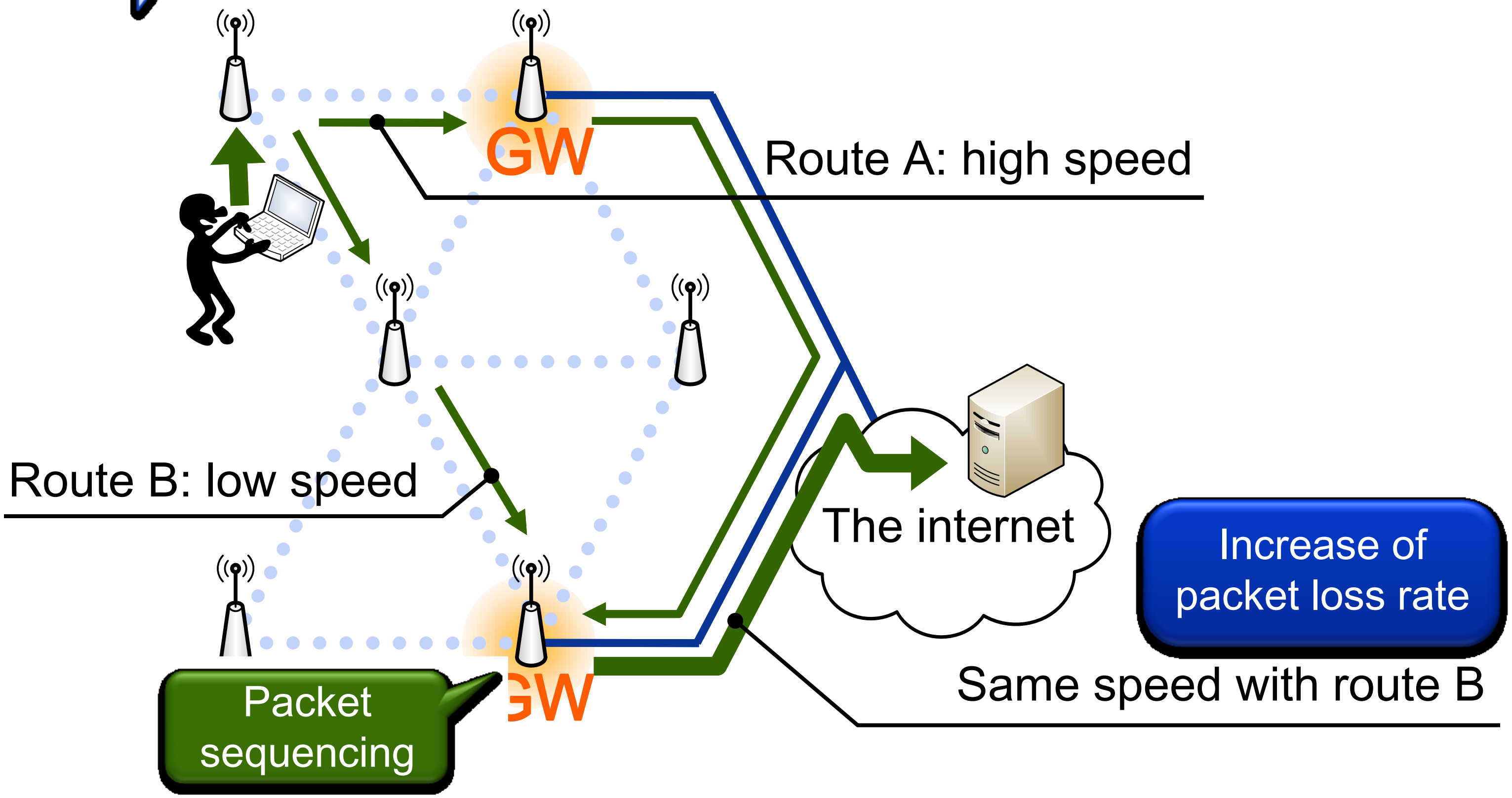


➡ **Fairness use of GWs**

PROBLEM OF MGA

One session is divided to two or more routes.

- Transfer speed depends on the route of the lowest speed due to packet sequencing.
    - TCP throughput gets lower.



PROPOSAL

- **Utilization of multiple Gateways.**
- **Consideration TCP characteristics.**

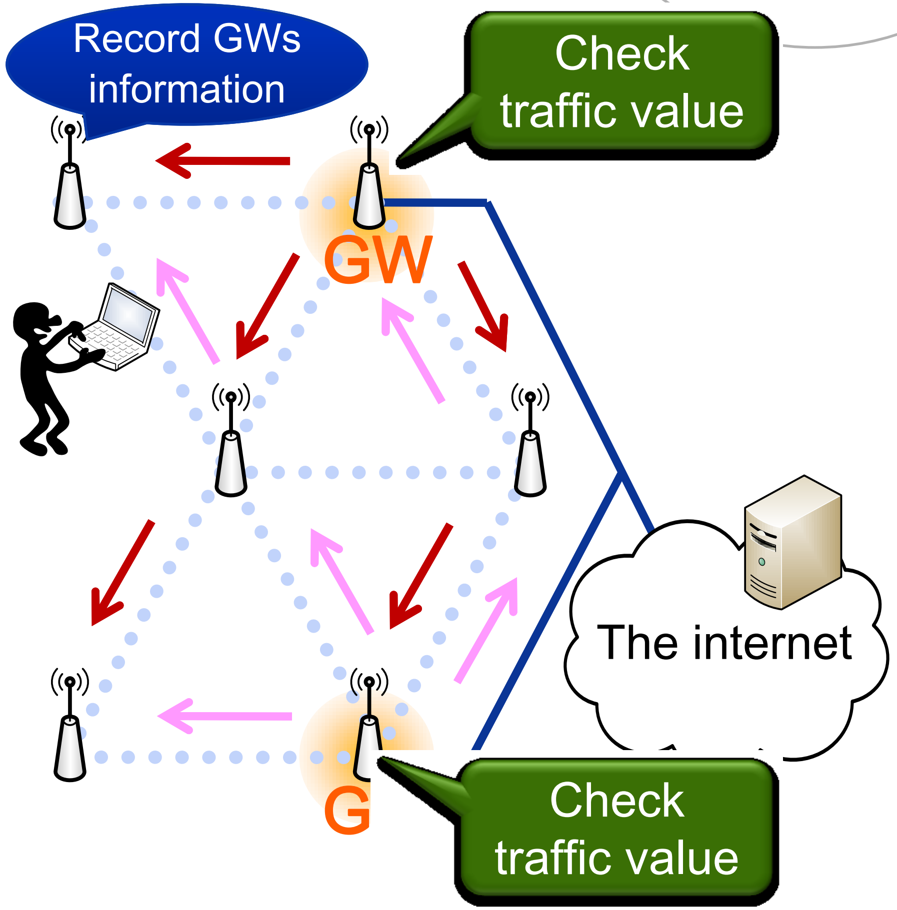
Session distribution method

Because the traffic is distributed on a session by session basis, delay of packet transfer is minimized, and the lowering of TCP transfer throughput is prevented.

PRINCIPLE OF PROPOSAL

Distribution of gateway information

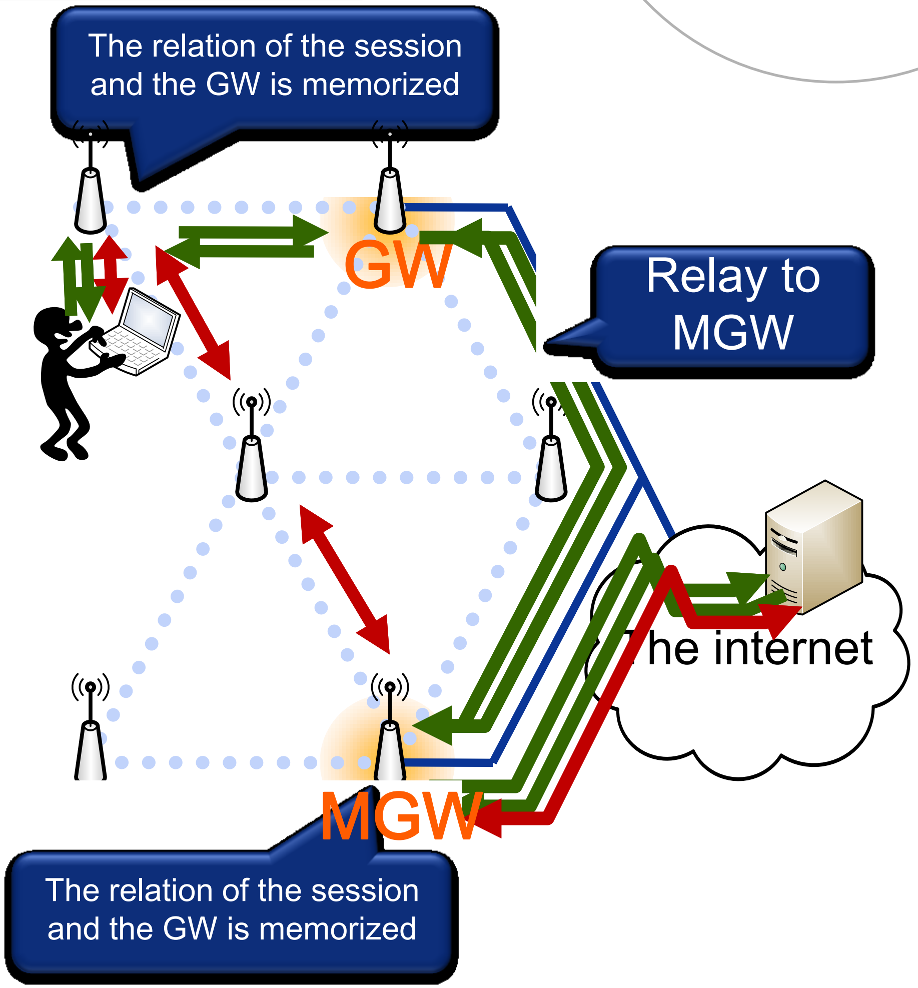
- GWs always check the volume of traffic around them.
- GWs flood messages that contains the traffic value and the number of hops to each AP.
- The number of hops is incremented each time when the message passes through an AP
- APs obtain the traffic condition of GWs and also the number of hops to GWs.



PRINCIPLE OF PROPOSAL

The method of session distribution

- The AP resolves a suitable GW according to the GW information.
- The AP memorizes the relation of session and the GW, and transmit packets.
- The GW relays packets to the master gateway.
- The master gateway memorizes the relation of the session and the GW, and transmits packets to exterior network.
- Subsequent packets of the same session trace the same route.



EVALUATION

- **Evaluation by simulations**
- **Modifications of ns-2**
  - Session distribution method (proposed method)
  - Packet distribution method
- **Traffic fairness and throughput**

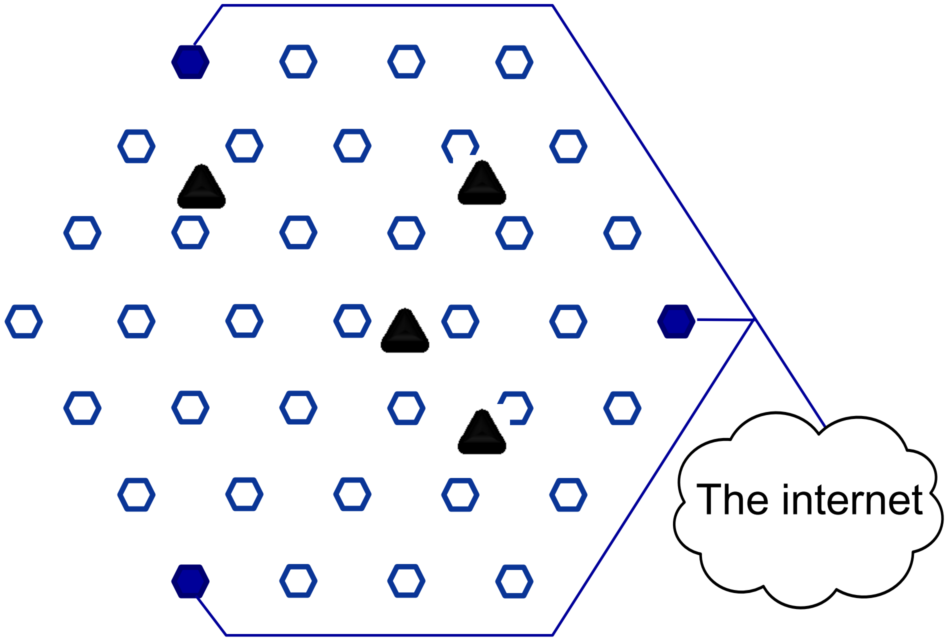
  Evaluation of degradation of traffic fairness of APs by distributing a session by session.

  And Evaluation of throughput at the Master GW.

EVALUATION - traffic fairness and throughput -

- We compared traffic fairness of APs of session distribution method with that of packet distribution method by giving the traffic.

Simulation parameters	
Radio-wave range of access	100m
Distance between APs	80m
Number of APs	37
Number of terminals	0-60
Type of communication	FTP(ext. - int.) Streaming(ext. - int.) VoIP(ext.-int. , int.-int.)
MAC protocol	IEEE802.11g
Field	860 x 580 m



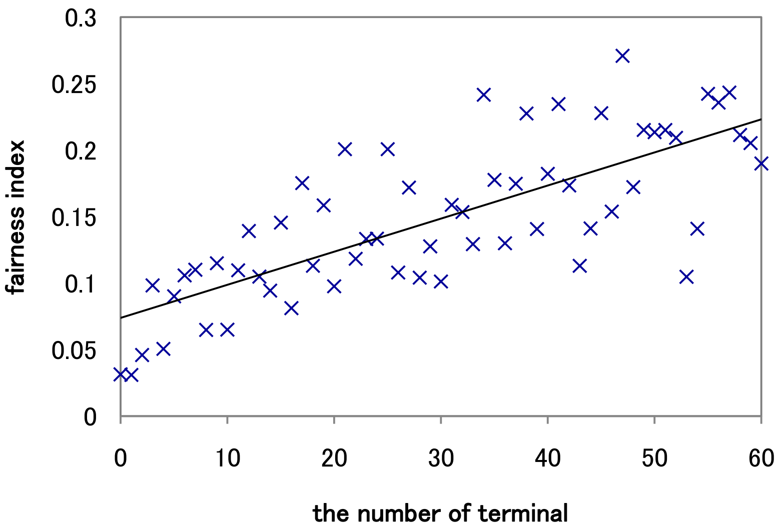
RESULT - traffic fairness -

Fairness Index

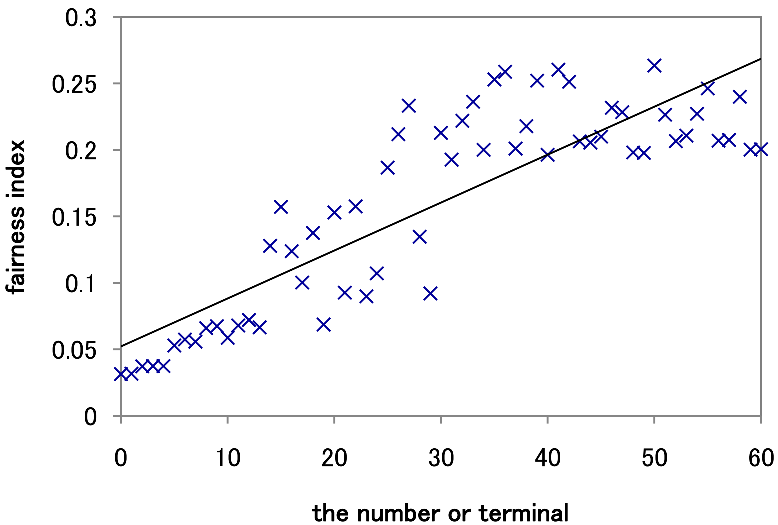
The closer to 1 the value of FI (Fairness Index) is, the higher the fairness is.
n indicates the number of APs and x_i indicates the transmission traffic of AP_i .

$$FI = \frac{(\sum_{i=1}^{n} x_i)^2}{n \sum_{i=1}^{n} (x_i)^2}$$

Session distribution method



Packet distribution method

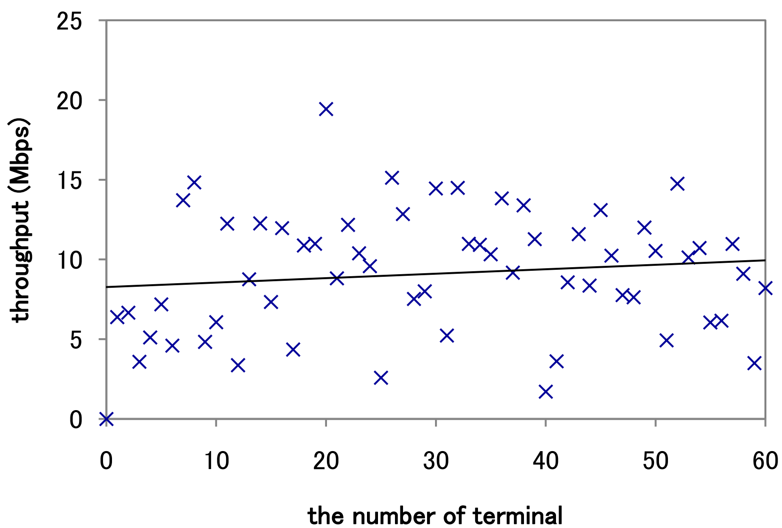


RESULT - traffic fairness -

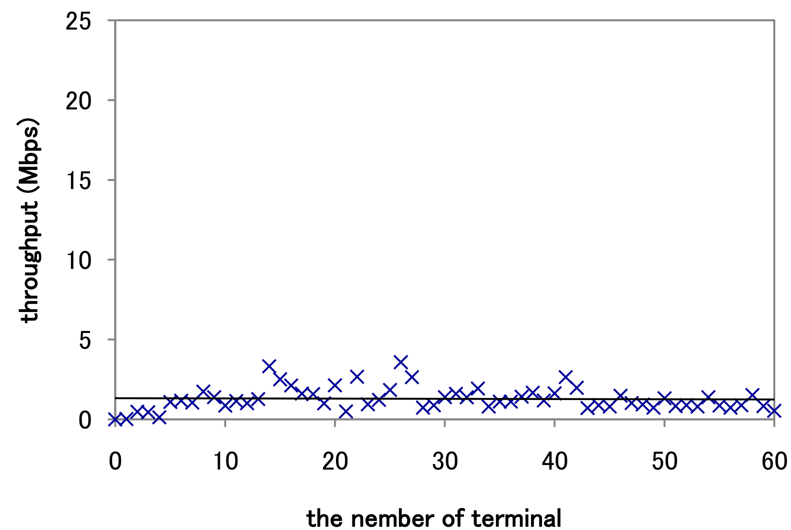
Throughput in Master GW

Measurement of the value of traffic through Master GW.

Session distribution method



Packet distribution method



- Session distribution method has higher throughput in Master GW compared to the packet distribution method.

CONCLUSION

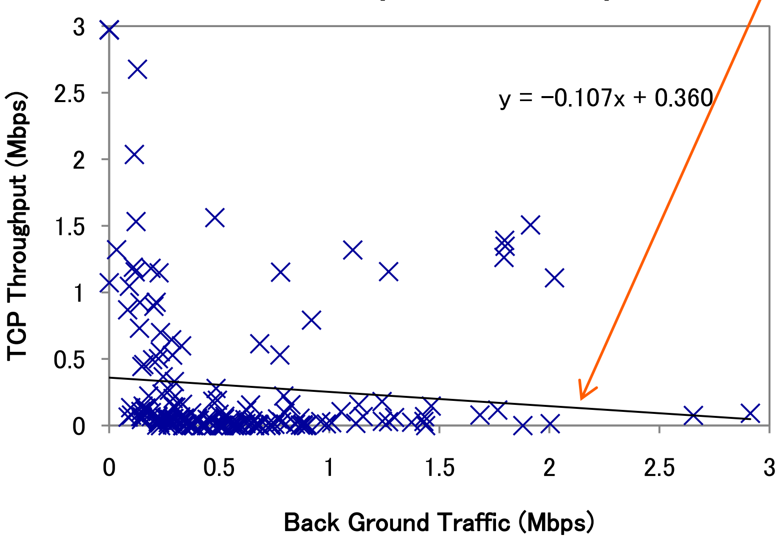
- **The proposal of session distribution method**
  - GWs flood the message of traffic of their and the number of hops to APs.
  - AP resolves a suitable GW according to GW information and distribute packets session by session.
- **Evaluation by simulation**
  - Session distribution method has higher efficiency in TCP communication.
  - Session distribution method does not cause any fairness problems
- **Future**
  - Proposed method has already been implemented.
  - Data collection using real devices.

Back up simulation of expected throughput

- We make up each traffic and hop count and throughput.
- We make first equation from relation of traffic and TCP throughput each hop count.

First equation approximate curve

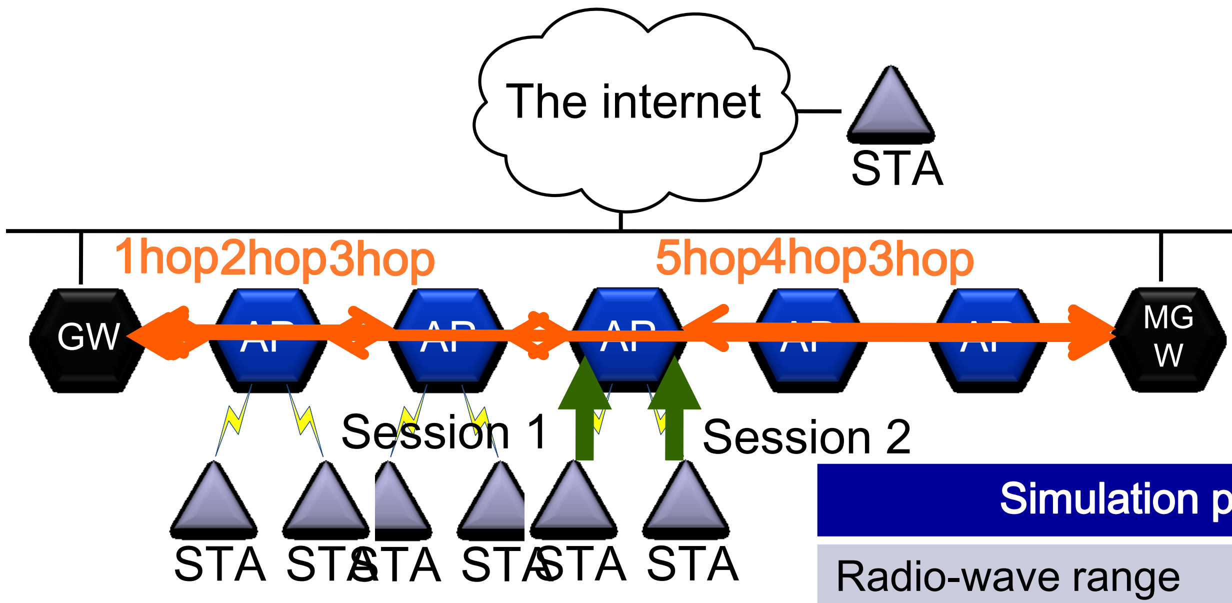
Example of 3 hops



hop	First equation
1	$y = -0.68x + 3.50$
2	$y = -0.26x + 1.11$
3	$y = -0.11x + 0.36$
4	$y = -0.19x + 0.26$
5	$y = -0.12x + 0.18$

EVALUATION – effect on TCP -

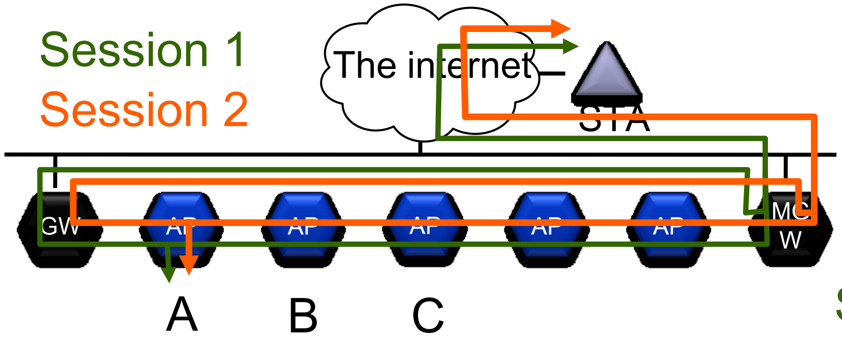
Evaluation of the remediation of TCP throughput

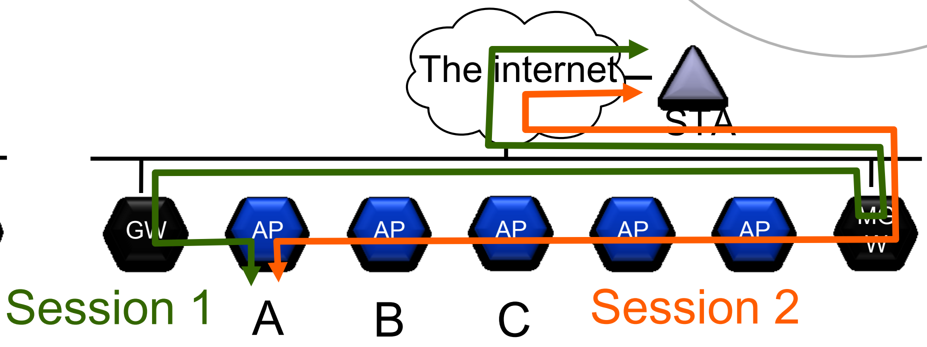


- Two TCP sessions are started from an AP to the exterior.
- Terminals changes its location and throughput is measured.

Simulation parameters	
Radio-wave range access	100m
Distance between APs	80m
Type of communication	FTP
MAC protocol	IEEE802.11g
Field	860 x 300 m

RESULT – effect on TCP -





Location		A	B	C
Packet distribution method	Session 1	1.5	2.1	2.6
	Session 2	1.2	1.6	1.8
	Total	2.7	3.7	4.4
Session distribution method	Session 1	10.6	5.9	3.4
	Session 2	1.7	1.6	2.7
	Total	12.3	7.5	6.1