Empirical Study on a Session Layer Resource Control over 802.11 DCF Wireless LAN

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Abstract: **Achievement of the QoS guarantee has come to be expected even in the wireless LAN communications. Because it is difficult to realize remodeling the MAC method of layer 2, we focus on the realization of per-flow QoS (throughput) using TCP control in layer 4. In the concrete, TCP-AV which has bandwidth reservation mechanism is used. A lot of paper has already been published about fairness of throughput in terms of the interaction between IEEE802.11 wireless LAN protocol and TCP, evaluated with simulation. However, many problems are remained caused by implementation. In particular, it is difficult only by simulation to evaluate influence that the implementation of the wireless LAN give to a fairness control matter and the influence due by non-equal control of TCP-AV. Thus it is important to evaluate it in the environment where the system is actually used.**

In this paper, we have investigated the degree of the fairness of per-flow throughput caused by the difference of implementation forms of wireless LAN interfaces, and evaluated per-flow throughput when TCP-AV is employed on wireless LAN on real machines. First, we have examined about the size of buffer of the wireless LAN access point, whether numerical value used by conventional simulation was proper. In addition, we have investigated the reason of the throughput unfairness caused by the difference of implementation forms of wireless LAN interfaces. Furthermore, as a result of evaluation using TCP-AV on a wireless environment, we have confirmed that TCP-AV can guarantee the bandwidth reservation up to 10% more of the fair-share value, which is represented as the maximum bandwidth divided by the number of flows.

Keywords: **TCP, wireless LAN, fairness, QoS**

I INTRODUCTION

In late years, the demand for multimedia communication including a video stream or the voice (VoIP) has been raised extensively. To guarantee the Quality of Service (QoS) is extremely important in such a communication. However, as far as QoS is concerned, the demand of quality is different from each other, depending on the media and applications. Therefore, we should define "QoS" for multimedia communication, and it is necessary to create a mechanism in which QoS is guaranteed. In addition, although the essence of the Internet (TCP/IP) is "best effort", QoS is required in many cases, thus implementing a mechanism for QoS guarantee into a protocol of the Internet has been examined.

One of examples of QoS guarantee on the Internet protocol is TCP-AV [1]. Instead of adding a QoS control mechanism to a router, TCP-AV replaces existing TCP protocol with itself. In TCP-AV, it changes a congestion window control parameter depending on a congestion state. As a result, it is possible to assure designated bandwidth, and therefore QoS can be realized such as improving the quality of streaming communications. QoS guarantee such as the bandwidth reservation is achieved in a wired environment by TCP-AV. On the other hand, QoS in a wireless environment is desired to be assured like a wired case, as wireless communications have been penetrating extensively. The typical example is VoIP.

Although users may demand the same quality to applications even in a wireless environment, it is more difficult for a wireless system to guarantee the same quality as a wired environment. Therefore in this study, we have evaluated whether TCP with bandwidth reservation function like TCP-AV can behave as expected even in a wireless environment. Particularly, by evaluating it with an implementation on real machines, we clarify influence caused by a difference of components of a system and/or size of buffers, which are difficult to be modeled for simulation. Also, we investigate a method of an effective QoS guarantee in a real wireless communications.

In this paper, we focus on two important problems about the QoS in a wireless environment; first, the problem of fairness of the wireless LAN, and second, the problem due to a difference of machines/implementation. When the number of terminals increases, the problem of the fairness of the wireless LAN becomes remarkable [2]. In addition, unfairness of the throughput among multiple TCP flows is already observed in simulation [3]. These fairness problems arise from both asymmetric characteristics of up and down flows in wireless LANs, and unequal opportunity to wireless terminals for transmission of MAC frames. Destruction of TCP-ACK in a buffer of wireless LAN Access Point (AP) leads to the cause of above unfair characteristics.

However, it is not clarified how often such unfairness happens actually, since the cause of uncertainty exists in a real environment such as noise and/or interference of a radio wave, structure of the OS and device driver, which cannot be considered in simulation. In addition, it is not clarified either, if the ACK destruction in the buffer of AP causes the unfairness on real machines also. The buffer size of AP in a real environment changes dynamically since it depends on the factors such as the cost reduction of memory and devices. Thus, it is important to review whether buffer can become a subject of discussion in this case.

Therefore we have investigated about the buffer size of AP. Furthermore, we have discussed about the unfairness problem peculiar on real machines, which arises from the configuration of wireless LAN interface. With a discussion of the problems on a real wireless environment based on such experiments, TCP-AV on a wireless network is examined whether it can guarantee the requested quality as in a wired environment.

The rest of paper is organized as follows. The fairness problem of the throughput of the TCP flow is discussed in section 2, the evaluation of TCP/TCP-AV in a wireless environment is shown in section 3, and the concluding remarks are stated in section 4.

II FAIRNESS PROBLEM OF TCP THROUGHPUT ON WIRELESS LAN

A problem of unfairness of TCP on a wireless LAN is that throughput becomes unfair among terminals. In other words, when many wireless terminals transmit data to a wired terminal through an AP at the same time, it occurs that some terminals have more than fair-share throughput while other terminals have almost 0Mbps throughput. Such a situation is illustrated in Fig. 1.

In this section, a characteristic of the control of the wireless LAN is explained and this unfairness problem is discussed.

A CSMA/CA RANDOM ACCESS MECHANISM

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is a standard access method applied in a wireless LAN. In this method, for avoiding a collision, if one wireless terminal emits a radio wave, other terminals wait certain period of time (IFS: Inter Frame Space). When the emission of the radio wave has terminated, other terminals can transmit their data after random-length period of time. A feature of this method is that all wireless terminals have an equal priority and decentralized control is realized.

A.1 RETRANSMISSION AND BACK-OFF

The first characteristic of the access method in a wireless LAN is equality of the transmission opportunity. The back off control is a method to avoid a collision as well as a carrier sense, which is determined by 802.11 standards. By the back off control, after DCF Inter Frame Space (DIFS) time in idol, a wireless terminal which is going to transmit a frame generates a random number within a range of prescribed Contention Window (CW), and the random time (back off time) is decided using this number. A fair transmission opportunity has been given to all wireless terminals by performing a carrier sense in random time. When frames have collided, the binary back off control within the range of CW, which increases to be doubled at each retransmission, reduces the probability to collide the frames again.

A.2 EQUAL ACCESS CHANCE FOR MAC LEVEL FAIR-SHAIR

The second characteristic of the access method is autonomic decentralized control. In Distributed Coordination Function (DCF) which is a basic access procedure for 802.11 wireless LAN, each wireless terminal inspects the usage of the channel and decides the transmission timing of the frame autonomously. CSMA/CA is used as an access control protocol.

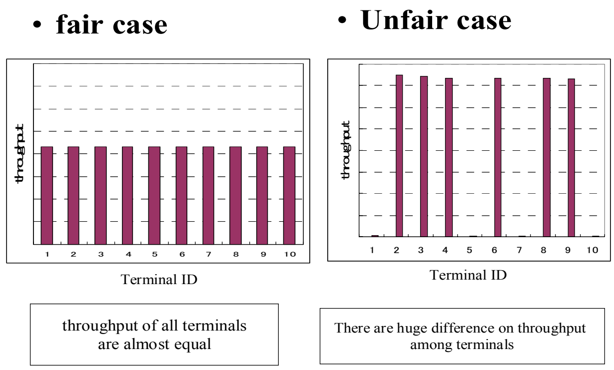


Figure1. Fairness of throughput over wireless LAN

In CSMA/CA, however, there is a possibility that transmitting a packet at the same time as a coincidence; namely, packets may collide on a wireless LAN. When a packet was not received normally by a collision, the packet is retransmitted. The probability of collision grows as the number of wireless terminals and the volume of communication traffic increase. This brings about a fall of the throughput. The implementation of Media Access Control (MAC) and TCP of each terminal are not taken into account in this case.

The unfairness happens in this way even though the fairness of the transmission right is tried to be achieved.

B TCP CHARACTERISTICS ON CSMA/CA

In TCP, if a terminal returns an ACK to every one segment, throughput deteriorates especially when Round Trip Time (RTT) becomes long. Therefore sender terminals can transmit multiple segments without waiting for an ACK so as to prevent from performance degradation. The size of the data which can be transmitted without waiting for ACK is called a window size.

B.1 TCP ACK LOSS IMPACT ON WINDOW CONTROL

In the case of window control, when an ACK has been lost, it is not necessary to retransmit because the data has been already arrived. Thus, when it has enough window size, even if several ACKs are lost, they are not necessarily to be retransmitted since they are confirmed with next ACK packets. When a terminal communicates with the window size of ten, it can keep communicating if more than one ACK out of ten is returned. In contrast, when the terminal communicates with the window size of one, it cannot readily raise the window size, because if one ACK dose not returns, the window size cannot be increased.

Therefore, the former can communicate with roughly ten times advantage in comparison with the latter. That is to say, even in the case of the same ACK loss, its influence is different by a window size. In this way, a terminal with a large window size transmits data steadily and can raise throughput. However, a terminal with a small window size has little chance to transmit data and cannot raise throughput.

B.2 PER FLOW THROUGHPUT FAIRNESS

The cause of unfairness shown by simulation is introduced in this subsection. According to the simulation, this is caused by an overflow of ACK in a buffer of AP. When the number of terminals increases, this problem becomes serious particularly. For example, as shown in Fig. 2, ten wireless terminals transmit data to one wired terminal via AP. In this case, ACKs are accumulated in a buffer of AP with the speed of 100Mbps, whereas the transmission of data is 54Mbps at most in a wireless LAN. Although AP is willing to send back the ACKs to wireless terminals, AP must get a transmission right also as one of the wireless terminals. However, with the synergistic effect that the AP can transmit ACKs for ten terminals only with 1/11 probability and that the speed of a wired link is high, ACKs are accumulated in the buffer steadily. If the buffer overflows, ACKs are discarded. The destruction of ACKs differently affects the behavior of terminals with different window size and leads to the unfairness of throughput, as explained in the previous subsection.

C TCP AND MAC PROTOCOL IMPLEMENTATION

In this subsection, the difference of MAC layer of the wireless client is explained, and TCP-AV as a suggestion technique and conventional TCP-RENO are compared. The difference of MAC layer of the wireless client, as shown in Fig. 3, cannot be expressed by simulation because this is a problem peculiar to a real machine.

C.1 MAC IMPLEMENTATION

There are two standards of the MAC layer in the data link layer; CSMA/CA of IEEE802.11 as a wireless standard and CSMA with Collision Detection (CSMA/CD) of IEEE802.3 as a wired standard. In CSMA/CD, when a terminal tries to transmit data it watches the communication situation of the cable (Carrier Sense), and when a cable becomes available the terminal starts the transmission. When multiple nodes start the transmission at the same time, since data collide in a cable and they are broken (Collision Detection), all terminals cancel the transmission, and retransmit after waiting in random time. When multiple nodes follow this method, all nodes share one cable and can communicate with each other (Multiple Access).

In this study, two kinds of wireless clients with different MAC layer are used; USB type and Ethernet converter type. The USB type wireless LAN client works in the framework of CSMA/CA of MAC layer. In the case of the Ethernet converter type wireless LAN, a terminal communicates as wireless at the end of Ethernet cable. Thus, from the viewpoint of the terminal, it works in the framework of CSMA/CD. In this paper, as USB type wireless LAN client, “BUFFLO AirStation 54Mbps 802.11 abg”[4] is used. As Ethernet converter type wireless LAN client, ”BUFFLO 2.4GHz 54Mbps wireless LAN Ethernet conversion media converter”[5] and “BUFFLO AirStation High Power wireless LAN Ethernet converter 54Mbps”[6] is used.

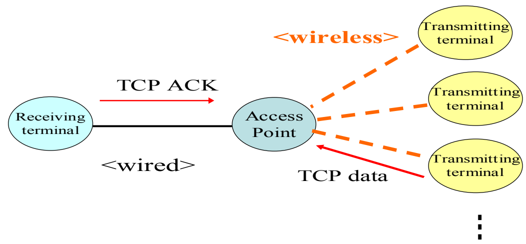


Figure2. Unfairness of TCP flows on simulation

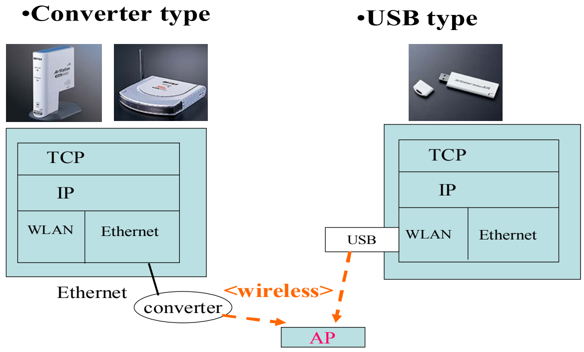


Figure3. Differences in connectivities between WIRELESS LAN clients and terminals in two cases

C.2 TCP IMPLEMENTATION

TCP-Reno, which is implemented widely, and TCP-AV for QOS realization are explained in this subsection.

II.C.2.1 TCP-RENO

TCP-Reno is a protocol widely implemented in transport layer. Here, TCP implementation [7] of Linux is explained in detail. Other TCP implementations, e.g., TCP in BSD-UNIX, are almost the same basically.

Usually, a kernel of a node works in a normal state (state *TCP_CA_OPEN*), and the congestion window size increases monotonously, based on normal TCP congestion window control algorithm (a slow start, congestion avoidance). When it continues to stay in this state, the size of data sent at a time grows. However, when an error happens, it changes to be in an abnormal state, and the congestion window suddenly decreases. As shown in Fig. 4, there are three states of *TCP_CA_RECOVERY*, *TCP_CA_CWR*, *TCP_CA_LOSS* in abnormal states, and it transits by causes such as “duplicate ACK/SACK”, “LOCAL DEVICE CONGESTION”, and “timeout”, respectively.

“LOCAL DEVICE CONGESTION” is an error that buffers in a device driver overflow, and occurs when quantity of data TCP sends off to the lower layer at a time exceeds the size of the buffer (NIC Descriptor value). Although the congestion window suddenly decreases in such a case, it returns to a normal state afterwards, and the congestion window begins monotonous increase again. In addition, when a network is congested, errors such as “duplicate ACK/SACK” and the “timeout” should occur frequently. In the case of these errors, it transits to an abnormal state, and the congestion window suddenly decreases and come back to the monotonous increase again afterwards.

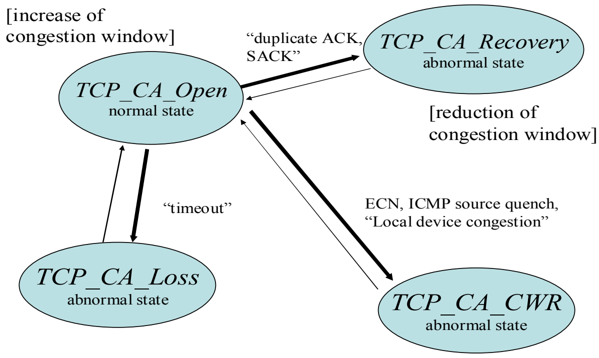


Figure4. State machine transition of congestion window

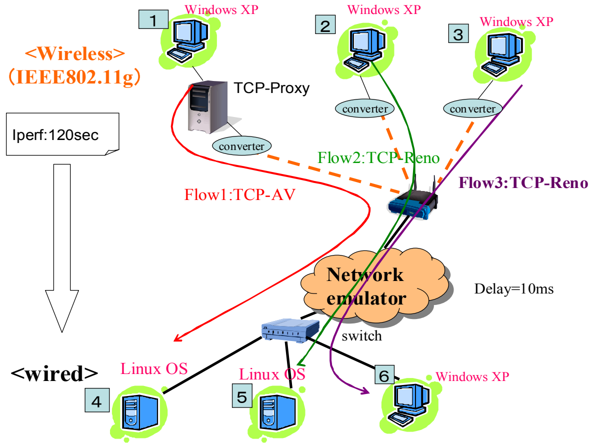


Figure6. Experimental network for evaluation of TCP-AV

II.C.2.2 TCP-AV

TCP-AV is developed for aiming at quality improvement of streaming communications. It is designed to control to assure a designated bandwidth. It expands the congestion control mechanism of existing TCP and adopts a retransmission control system to improve the burst loss tolerance of the packet. To be concrete, it includes a congestion window control mechanism that does not let the receive buffer of the retransmission client empty, and a retransmission mechanism to prevent transmission rate decrease at the time of temporary congestion outbreak.

III EVALUATION OF TCP/TCP-AV OVER WIRELESS LAN

In order to investigate the behavior of TCP-AV on a wireless LAN, the fairness of TCP is examined with experiments. Therefore buffer size of AP is measured and a difference of throughput of TCP is evaluated when the number of terminals increases. An index called Achievement Ratio (***AVR***) is defined based on throughput and target bandwidth for the evaluation of the performance of TCP-AV.

A EXPERIMENTAL NETWORK

Network configuration of the experiment about the fairness of TCP is shown in Fig. 5 and network for the experiment about ***AVR*** of TCP-AV is shown in Fig. 6. In the case of FLOW1 in Fig. 6, instead of changing the implementation of TCP of a transmission terminal, TCP is replaced to TCP-AV at installed TCP-Proxy. FLOW2 and FLOW3 are conventional TCP-RENO communications.

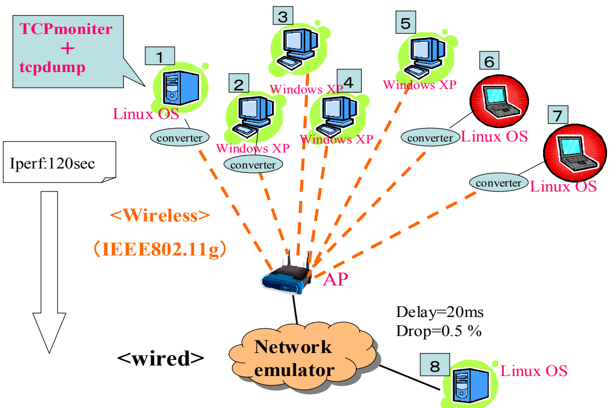


Figure5. Network configuration for experiments about fairness of TCP

In the case of Fig.5, all flows are TCP-Reno communications.

A.1 CONFIGURATION AND PARAMETERS

IEEE802.11g [8], which is extensively used currently, is employed as a wireless LAN. Throughput of three flows is measured, which is transmitted from wireless terminals to three wired terminals via AP, a network emulator, and a switch. *Iperf* [9] is used for the measurement of throughput. The measurement length is 120 seconds for the sake of stable measurement, in order to avoid the influence of transmission order and so on. Furthermore, as parameters of the network emulator in Fig. 5, 20 milliseconds delay and 0.5% packet loss are inserted as a normal environment. In the experiment shown in Fig. 6, 10 milliseconds delay is inserted. We have adopted this value so that the time to convert TCP into TCP-AV does not affect disadvantageously.

A.2 PERFORMANCE MEASUREMENT

The evaluation scheme of the experiment is as follows. In this paper, ***AVR*** is defined as an original index to evaluate TCP-AV. This examines what percentage in the total length of measured time the designated bandwidth can be achieved.

In this experiment, the measured 120 seconds is divided into every five seconds. First 5 seconds is removed since the difference depending on the injection order is observed in this section, so that the rest 23 sections are used. We have measured in how many sections out of 23 the designated bandwidth is achieved, and calculated the average of ten times trial. In addition, the Effective Bandwidth (***EB***) is measured which is the maximum bandwidth for data transmission. Although the theoretical value of maximum bandwidth in IEEE802.11g is 54Mbps, we have measured real bandwidth and called it as Normalized Required Throughput (***NRT***). This is about 25Mbps as a result of an experiment in which bandwidth of one flow in the same environment is measured.

A.3 WIRELESS LAN AP BUFFER SIZE

Next, the buffer size of wireless LAN AP is measured. As a wireless LAN AP, "BUFFLO wireless LAN BB router AirStation NFINITI GIGA 300Mbps 11n conformity" [10] is used. As shown in Fig. 7, a wired terminal sends User Datagram Protocol (UDP) packets, which are assigned sequential numbers, to a wireless terminal via AP [11]. The numbers of received packets are compared with assigned ones at the wireless terminal. If the number of received packet is equal to the total number of packet reception, communication is performed without a packet loss. However, if the numbers of received packets are not consecutive, the packets among the gap should be lost.

In the case of network configuration explained above, it is considered that the cause of the packet loss is buffer overflow of AP at the wired side. As a result of ten times measurement, the buffer size of AP is supposed to be about 300 packets. This value is almost the same with what is used in simulation.

B TCP OVER WIRELESS LAN WITH MIXTURE OF DIFFERENT IMPLEMENTATION

In order to evaluate in more realistic environment, different kind of wireless clients are mixed in the following experiment. Because the unfairness of the throughput does not happen with few numbers of terminals, seven transmission terminals are employed as shown in Fig. 5. As operating systems, Linux 2.4 is used for terminals ID1 and ID8, Linux 2.6 is used for terminals ID6 and ID7, and Windows XP is used for terminals ID2 – ID5. As wireless clients, Ethernet converter type is used for terminals ID1, ID2, ID6, and ID7, and USB type is used for terminals ID3 – ID5.

The difference of throughput in this experiment is shown in Fig. 8. In the case of the mixture environment using wireless clients of Ethernet converter type and USB type, large difference of throughput is caused by the difference of control at MAC layer. Actually, while throughput of USB type clients is always more than fair-share (***NRT***/7 = about 3Mbps), that of Ethernet converter type clients is around fair-share at most and less than 1 Mbps in the lower case. However, it is not clarified what kind of difference of control cause this difference of performance.

Therefore in order to guess the reason, we have used *tcpdump* which collects information of packets and a tool called the *TCP monitor* [12] which observes the behavior of the congestion window and the kind of errors. With these tools, the following two cases using converter type clients are compared; the higher throughput case

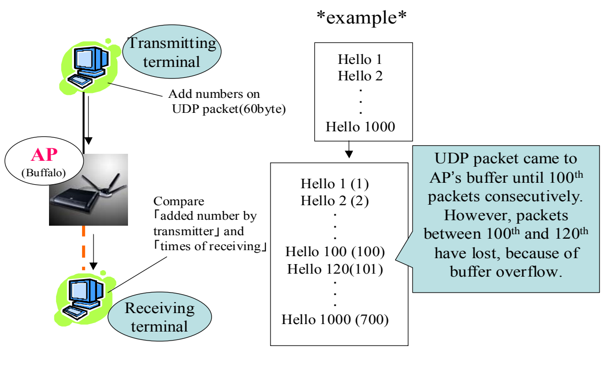


Figure7. Verification of AP's buffer size

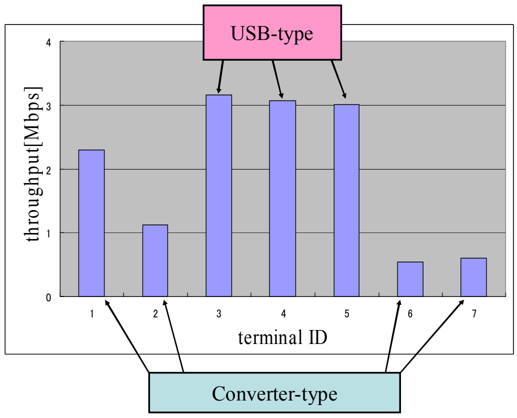


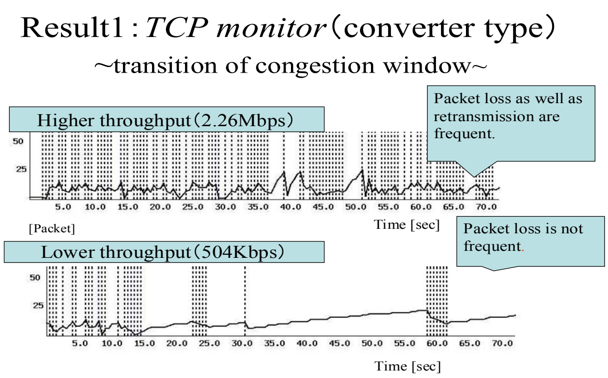
Figure8. Difference of throughput between USB-type and Converter-type

(2.26Mbps ≒ fair-share) like terminal ID1 in Fig. 8, and lower throughput case (504Kbps≒less than 1Mbps) like terminal ID6.

The monitored results are shown in Fig. 9. The solid line in the *TCP monitor* indicates the change of the congestion window, and the dashed line indicates that an error happens at the time. While three kinds of abnormal states can be distinguished with the TCP monitor, all errors happen in this experiment are receiving duplicate ACK or SACK. The result of *tcpdump* indicates the point of time for transmitting data and receiving ACK. This figure shows the timing and frequency of data transmission and ACK reception.

According to the results, when an Ethernet converter type client has achieved higher throughput, it transmits data frequently, and retransmits it aggressively even if a packet has lost. As a result, the congestion window increases and decreases repeatedly. However, when throughput is low, the window goes up slowly, and the frequency of transmitting data is low. This is considered to be caused by ACK loss explained in section 2.2.1.

When throughput is low, packet loss does not happen frequently because data is not transmitted frequently, thus the congestion window does not decrease. However, throughput is kept to be low. Therefore, it is supposed that the when the wireless side of the converter cannot send out a packet like ACK loss case, the converter might send a signal to OS in order to restrict the transmission. As a result, the quantity of transmission decreases, which leads to a fall of the throughput totally.



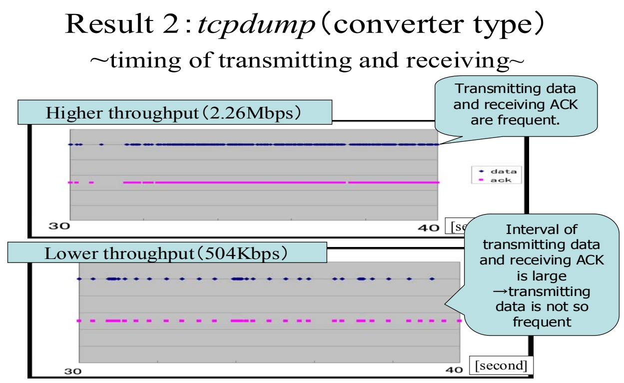


Figure9. Experimental results (*TCP monitor* and *tcpdump*)

C TCP-AV OVER WIRELESS LAN

Next, TCP-AV is evaluated with the value of ***AVR***, in the environment shown in Fig. 6. As operating systems, Linux 2.4 is used for terminals ID4 and ID5, and Windows XP is used for terminals ID1 – ID3 and ID6. As wireless clients, Ethernet converter type is used for terminals ID1 – ID3. In this case, bandwidth more than fair-share (***NRT*** /the number of flows) can be expected by positive retransmission control of TCP-AV. The result is shown as "3 flows" in Fig. 10. Here, "3 flows" means one TCP-AV flow and two TCP-Reno flows, as shown in Fig. 6. When the target is set to be around 40% of the ***NRT***, approximately 90% of ***AVR*** is achieved.

Furthermore, the number of flows from a terminal is increased to be five in total; one TCP-AV flow and 4 TCP-Reno flows. This result is shown as "5 flows" in Fig. 10. In this case, 90% of ***AVR*** is able to be achieved with the target of around 30% of ***NRT***. According to these results, up to 10% more than fair-share bandwidth can be achieved with this mechanism. This is due to equal characteristics of a data transmission right in CSMA/CA. Thus the effect of the number of terminal is larger than that of the number of flows.

In addition, a similar result has been obtained when TCP of one of seven flows from wireless terminals is converted to TCP-AV. When it has become an unfair terminal, higher throughput cannot be expected like terminal ID6 or ID7 in Fig. 8. Therefore we will analyze a difference between the case with higher throughput and that with lower throughput. A control method to eliminate an unfair terminal should also be discussed.

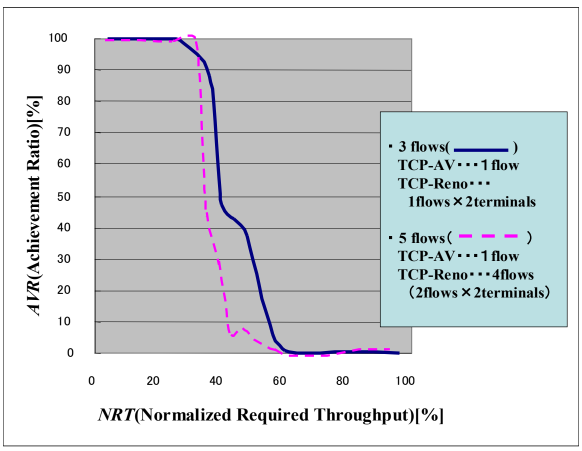


Figure10. ***AVR*** of TCP-AV

IV CONCLUSION

In this paper, we have examined the realization of QoS using real machines in a wireless environment. First, TCP-AV is evaluated on a wireless network. As a result, TCP-AV can assure the bandwidth reservation up to 10% more than the fair-share value. That is to say, QoS guarantee on unstable wireless environment can be achieved with it. Second, the unfairness problem of the throughput of the TCP flow is discussed. On this occasion, by examining the buffer size of AP, one of the causes of the unfairness on a real machine can be considered as the destruction of ACK by the buffer overflow, as shown in simulation. In addition, the difference of the control mechanism of MAC layer is raised as a cause of the unfairness of a real machine characteristic by examining it with *TCP monitor* and *tcpdump*.

In the future, we will try to improve the TCP-AV implementation based on these experiments.

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REFERENCES

[1] H.Shimonishi, et al., "Congestion Control Enhancements for Streaming Media", Vol.E89 B, No.9, pp.2280-2291 Sep. 2006.

[2] Anthony C.H. NG, David Malone, Douglas J.Leith, "Experimental Evaluation of TCP Performance and Fairness in an 802.11e Test-bed", ACM SIGCOMM 2005, pp.17-22 Aug.2005

[3] S.Pilosof,R.Ramjee,Y.Shavitt,P.Sinha,Understanding TCP fairness over Wireless LAN" INFOCOM 2003, 1-3 April 2003.

[4] BUFFLO AirStation 54Mbps 802.11 abg (WLI-UC-AG): http://buffalo.jp/products/catalog/network/wli-uc-ag/

[5] BUFFLO 2.4GH 54Mbps wireless LAN Ethernet conversion media converter (WLI3-TX1-G54) : http://buffalo.jp/products/catalog/item/w/wli3-tx1-g54/

[6] BUFFLO AirStation High Power wireless LAN Ethernet converter 54Mbps (WLI-TX4-G54HP) : http://buffalo.jp/products/catalog/item/w/wli-tx4-g54hp/

[7] Linux Kerner ver.2.4 implementation: http://www.linux.org/

[8] IEEE802.11 wireless LAN medium access control (MAC)and physical layer(PHY) specification,1999

[9] *Iperf*: http://dast.nlanr.net/Projects/Iperf/

[10] BUFFALO wireless LAN BB router AirStation NFINITI GIGA 300Mbps 11n conformity (WZR-AMPG300NH) : http://buffalo.jp/products/catalog/network/wzr-ampg30nh/

[11] Perl program of inspect the size of buffer: http://x68000.q-e-d.net/~68user/net/udp-2.html

[12] Saneyasu Yamaguchi, Masato Oguchi, and Masaru Kitsuregawa: "iSCSI Analysis System and Performance Improvement of sequential Access in Long-Latency Environment," IEICE Transaction on Information and Systems, Vol.J87-D-I, No.2, pp.216-231, February 2004.