TCP and UDP QoS Characteristics on Multiple Mobile Wireless LANs

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I. Introduction

Mobile wireless technologies are expected to enable mobile users to connect to the Internet anywhere. Mobile routers that are defined as movable Access Points (APs) of IEEE802.11 wireless LANs have become popular such as tethering of iPhone and accommodate several mobile devices, connecting them to the Internet. A system that is composed of both a mobile router and associated devices (terminals) is hereafter called a mobile WLAN (m-WLAN).With the increase in the number of m-WLANs, multiple high density m-WLANs have to use the same channel because the number of wireless LAN channels is limited and not very large. Because IEEE802.11 MAC uses the CSMA/CA protocol, multiple m-WLANs that use the same CSMA/CA domain are required to cooperate with each other.

This paper investigates flow level goodput characteristics in the case of multiple m-WLANs that share a single CSMA/CA domain. Goodput is hereafter defined as throughput of application of TCP/UDP, i.e. TCP/UDP payload throughput.Goodput characteristics is proven to be categorized into three by the difference of the distance between m-WLANs. In addition, another interesting characteristics, an unfairness problem, is revealed.

II. Related works

For many years, researchers have been devoted to solving interference problems among access points (APs) in multi-hop networks and in handovers. Solutions such as power control are effective in fixed APs. However, it is difficult to control the power for mobile APs because such mobile APs are likely to frequently move, and that the associated terminals also move together.

A mobile WLAN (m-WLAN) is a system that is composed of both a mobile AP (including tethering on iPhones or other smartphones) and associated mobile terminals, which is becoming popular. Investigation is needed for m-WLANs. [1]has already investigated the capacity characteristics of m-WLANs by theoretical analysis and simulation when multiple m-WLANs come close together. In addition to the capacity degradation, it is necessary to know the flow level quality degradation such as TCP/UDP goodputs and losses, to design controls for various applications. The flow level quality investigation can reveal a fairness problem between WLANs while the capacity characteristics investigation could not reveal.

This paper focuses on investigating QoS characteristics in the flow level, i.e., the TCP and UDP levels when multiple m-WLANs enter close proximity.

III. QoS characteristics at distances of multiple m-WLANs

To describe the QoS characteristics of m-WLAN, the characteristics are categorized into three states; State-1, State-2 and State-3 have different QoS characteristics and different implications of interferences. As shown in Fig.1, m-WLAN-1 and m-WLAN-2 are independent, and each m-WLAN system has a mobile router that is denoted as AP_i (i:the system number of m-WLANs), and N_i wireless terminals and a receiver terminal are connected to the AP_i. Mobile routers behave as APs and use the same channel. Each wireless terminal sends an uplink flow of TCP or UDP toward the receiver terminal through the AP. Fig.1illustrates three distance cases between two m-WLANs in the three states. An m-WLAN distance, d, is defined as a distance between APs. In the models, AP and associated terminals in the same m-WLAN are placed close enough with each other to use the whole capacity of bandwidth if the m-WLAN has no interferences. Dashed lines indicate virtual areas of carrier sense domains.

- State-1: An m-WLAN does not suffer from other m-WLANs because the m-WLAN distance d is large enough to receive interference from other m-WLANs. Although radio signals from other devices may reach the m-WLAN, they are too weak to cause a bit error. Therefore, the m-WLAN can use the full capacity of the channel.
- State-2: The m-WLANs interfere with other m-WLANs. Radio signals interfere with other signals in two ways. One way is by bit errors and the other is by carrier busy. Depending on the devices, in general, when the interference signals are strong, the signals are recognized as carriers. Thus, each terminal must wait to send data. On the other hand, when the signal is too weak to be recognized as a carrier, it may cause bit errors when sending the data. This result implies a MAC frame error, thus the error implies either retransmission or a packet loss due to retry-out. In this state, less than k times full

capacity is shared by k m-WLANs that interfere with each other.

Therefore, the goodput of the TCP and UDP decreases by carrier busy and by retransmission and back-off. As the m-WLAN distance become small, in other words, the interference signal becomes large, the probability of events such as a bit error and a carrier busy signal become large.

- State-3: An m-WLAN completely includes other m-WLANs in its CSMA/CA domain. In this state, multiple m-WLANs that use the same channel share a CSMA/CA domain. For this reason, all of the terminals and APs of all of the m-WLANs share a single CSMA/CA channel.

Three states are logical states. The size of the area of the state can be different in different places and in different system configurations. Moreover, not only the distance d determine the state, but also time and other factors that change the interference conditions contribute to device performance characteristics.

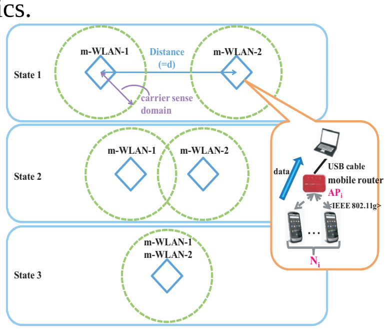

Figure 1. Three states Model

IV. TCP and UDP QoS measured in real machines

To know the flow level goodput values, experiments has been done with real machines, consisting of two m-WLANs, in other words, two APs and several terminals as in Fig.1. Goodput of each flow in the three states was investigated and determined according to the distance d between the m-WLANs. Two asymmetric models in terms of the number of terminals and a symmetric model were examined for TCP and UDP goodputs as follows. Considering a real situation, smartphones were used as portable wireless terminals.

- Model-A: symmetric model; $N_1 = N_2$ (TCP)
- Model-B: asymmetric case of TCP; $N_1 < N_2$ (TCP)
- Model-C: asymmetric case of UDP; $N_1 < N_2$ (UDP)

Fig.2 shows measured throughput per flow in Model-A, Model-B, and Model-C. Numbers of terminals are set to be;

- Model-A: $N_1 = N_2 = 5$
- Model-B: $N_1 = 2$, $N_2 = 8$
- Model-C: $N_1 = 2$, $N_2 = 8$

In Model-A and Model-B, two m-WLANs were in State-1 when the distance d was 24 m or more. At that distance, each m-WLAN had 20 Mbps in each total goodput. In Model-C, the total goodput was a little higher than that in Model-A and Model-B because UDP yields fewer overhead, since it has unidirectional flow and had no ACK/retransmit traffic.

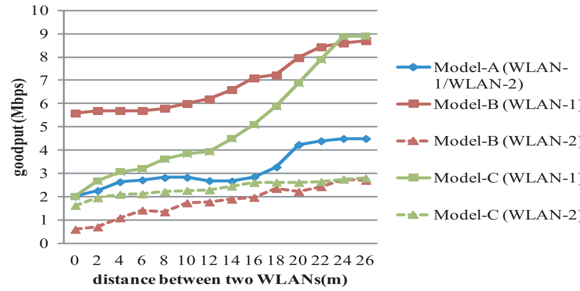

Figure 2. Goodput of TCP and UDP flows

In the middle of Fig.2, the m-WLANs were in State-2. The throughput was gradually lowered as the two m-WLANs were brought into proximity from d=24 m to 2 m. As explained before, the UDP and TCP show different characteristics. UDP flows evenly share the capacity, and the throughputs of all UDP flows are converged to the same value, approximately 2.0 Mbps at d=0m. However, the throughputs of all TCP flows in Model-B do not behave in the same way. The throughputs of the TCP flows in the m-WLAN-1 are larger than those of the UDP flows in m-WLAN-1. On the other hand, the throughputs of the TCP flows in the m-WLAN-2 are smaller than those of the UDP flows in m-WLAN-2. As a result, two TCP flows of m-WLAN-1 grabbed almost the same throughput as eight TCP flows of m-WLAN-2.

At $d < 2$ m, the two m-WLANs completely shared one CSMA/CA domain and showed 20 Mbps in total throughput of the two m-WLANs.

V. Unfairness in asymmetric traffic

For fair use of radio resources, multiple m-WLANs should fairly share the bandwidth of a WLAN channel. However, a m-WLANs does not always get a fair resource. In Model-B, the goodput of m-WLAN-1 per flow was 5.6Mbps, while that of m-WLAN-2 was 0.6Mbps. Therefore, total goodput of m-WLAN-1 and m-WLAN-2 were 11.2Mbps and 4.8Mbps, respectively. This means that total goodput is unfair between m-WLANs.

VI. Conclusions

Multiple mobile WLANs that use the same channel suffer from interference with each other. Three state models well explain flow level throughput as a function of the distance between the WLANs.The throughput characteristics of each state were measured through real machine experiments because the characteristics depend on the radio signal interferences and device implementations. In multiple mobile WLANs, TCP and UDP showed different characteristics because of congestion control and retransmission nature in TCP. The experiments also showed that an unfairness problem occurs between WLANs in the case of having different numbers of terminals when the WLANs share a single channel capacity with compliant with CSMA/CA.

References

[1] Micah Z.Brodsky, Robert T.Morris, ”In Defense of Wireless Carrier Sense”, ACM SIGCOMM 2009 conference on Data communication, pp.147-158, Aug. 2009.

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