# Context Aware Multi Rate Control
# in Densely Deployed IEEE802.11 WLAN
# for Avoiding Performance Anomaly

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*Abstract*— **In this paper, QoS characteristics such as TCP throughput is investigated for densely deployed mobile WLANs. Factors affecting throughput characteristics are discussed and evaluated by using real machines such as smartphones and portable APs. In IEEE 802.11 standards, Auto Rate Fallback (ARF) controls the transmission rate and one of the dominant factors for QoS. In order to understand the behavior of ARF, 1 to 18 sets mobile WLANs are examined under different parameters. Since ARF behavior is a vender specific one and it strongly depends on interference, signal strength and etc, the real terminals such as smartphones were used in the experiments. Performance anomaly drastically reduces the throughput not only in the WLAN which has a terminal with low transmission rate but also in the neighboring WLANs that share the same channel. In order to avoid unnecessary transmission rate degradation by ARF, Context Aware multi Rate Control (CARC) is proposed and evaluated. In CARC, Turning ARF on/off is controlled according to a context, for example, signal strength. The evaluation results show that the CARC can be cost-effectively implemented and improves the throughput performance of whole WLANs by 3.5 times than that without the application of CARC.**

*Keywords— WLAN; Wireless LAN; Mobile; Content aware; Throughput; QoS; Interference; Collision; Auto Rate Fallback; ARF; Performance anomaly; Capture effect.*

## I. INTRODUCTION

IEEE 802.11 based wireless local area networks (WLANs) have seen rapid deployment over the last decade, and are now a critical part of the wireless infrastructure in both residential and enterprise settings. Buoyed by the increasing base of Wi-Fi enabled consumer devices and the explosive growth in mobile data demand, there has been a recent emergence of a new form of WLAN in which the access point (AP) itself is a mobile device. Such mobile wireless LANs (WLANs), alternative termed as mobile hotspot networks, MiFi networks [1], or Wi-Fi tethered networks, are expected to grow over 400% in the next three years [2]. Mobile WLANs are composed of small form-factor mobile APs (either a stand-alone device or a smartphone or tablet with tethering capability), and a small number of connected client-devices such as laptops, other smartphones, and wearable Internet devices [3]. 3G, LTE, or WiMAX based cellular networks typically provide the backhaul connection from the mobile AP to the Internet.

Due to its small form factor and portability, wide-scale adoption of mobile WLANs could lead to extremely dense deployment of APs – a conference with several attendees using MiFi like devices being a typical example. In such settings, the throughput of the WLANs, and thus the quality of service (QoS) delivered to the users could be severely degraded due to interference and bandwidth sharing. The extent of degradation would evidently depend on both the physical distance and the situation of mixture of various bit rates. It is also necessary to consider throughput characteristics when many WLANs densely located use a certain channel combination. There could be several WLANs that use the same channel. This is because both the numbers of WLANs are more than the numbers of available channels and each AP selects a random channel regardless of other AP does.

In this paper, we study the effects of performance anomaly due to radio signal interferences and multi rate adaptation in physical transmission rate on QoS characteristics of mobile WLANs by using commercial mobile APs and clients. Our work is informed by the large pool of existing literature on fixed WLAN systems, and we contribute towards extending the findings in the mobile WLAN environment. Mobile WLANs differ from fixed WLANs in terms of two key characteristics: (i) WLANs typically consist of a small number of clients (between 1 and 5) which are located very close to the mobile AP; (ii)

WLANs exhibit a much more dynamic nature of interference due to the mobility of the AP. Moving APs might go in and out of range of multiple fixed APs or other moving APs. The numbers of fixed and moving APs that contributes the interferences usually dynamically varies. In contrast, enterprise/hotspot management techniques have to typically deal with a large number of spread out clients, and the dynamism is largely due to changes in load rather than movement of APs.

In terms of sharing the same channel, the QoS characteristics of mobile WLANs have been investigated in a few recent works [4-8]. These studies focus on analyzing throughput characteristics of two WLANs when distance between them is varied. The results indicate interference which reduces the throughput also affect on more than two WLANs densely located. In addition, when a number of terminals that participate to CSMA/CA increases, probability of contention or collision increases. This leads to further degradation in the performance. Especially, if a terminal uses auto rate fallback (ARF) or multi-rate adaptation [9-12], the situation becomes much worse because of nature of multi-rate and sending opportunity fairness in CSMA/CA or performance anomaly occurs so that throughputs of all WLANs are forced to decrease. Thus, this paper aims to investigate throughput characteristics of densely deployed mobile WLANs with and without consideration of the performance anomaly. A simple but effective ARF control, Context Aware multi Rate Control (CARC) is also proposed and evaluated. In order to capture from physical layer factors such as capture effect to MAC layer factors such as collision, real machines of APs and terminals were used in the evaluations in which from 1 to 18 sets of real WLANs are used.

This paper is organized as follows. Section 2 discusses related works and explanation of key technologies, performance anomaly  and ARF. In Section 3, factors affecting QoS characteristics of densely deployed mobile WLANs are discussed with experimental evaluations. Throughput degradation by low transmission rate caused by ARF is discussed in Section 4. In Section 5, CARC is proposed and evaluated to show improvement in throughput, followed by the conclusion in Section 6.

## II. Background

### A. Related Works

Considering interference, many researches have tried to effectively utilize bandwidth or to improve QoS of IEEE802.11 WLANs in a variety of different settings, for example, in multi-hop networks [11], and in the context of handovers [12][13]. They revealed interference between WLANs reduces SINR and then decreases capacity for whole WLANs in the same channel. They also proposed various solutions. For example, emission power adaptation methods, beam forming technologies, AP location designs,

and cooperative mechanisms. However, they do not consider the situation in which many densely deployed mobile WLANs exist. In the situation, much more interference is expected to affect characteristics of QoS such as throughput. Mobility also makes the solutions such as emission power adaptation to be limited. Mobile WLANs present a few unique characteristics that make the interference problem even more challenging than in fixed WLANs. Power control has also been shown to be an effective solution for interference mitigation in traditional fixed WLANs [14]. However, it is difficult for power control to be applied to mobile APs because it is assumed that such mobile APs move frequently and that the associated terminals also move with it. For example, if a person is carrying a mobile hotspot device in his pocket while walking/running, the AP and the connected client devices, such as body sensors, smart-shoes, etc. all move together.

When the number of WLANs more than numbers of non-overwrapping channels exists or some portable types of APs and tethering devices have a fixed channel number, for example channel 6 is often used in US [15], and often in especially smartphone tethering can not change the channel number, many numbers of WLANs have to share the channel or have to be operated in the same CSMA/CA domain. In terms of sharing the same channel, the QoS characteristics of mobile WLANs have been investigated in a few recent works [4-8]. They have disclosed throughput characteristics of two WLANs with different distance each other. The results indicate some factors which reduce the throughput also affect on more than two WLANs densely located. Moreover, when a number of terminals that are associated even to different WLANs and participate to the same CSMA/CA increases, probability of contention or collision increases. This would lead another performance reduction. Especially, if a terminal uses auto rate fallback (ARF) or multi-rate adaptation [9-12], the situation becomes much worse because of nature of multi-rate and sending opportunity fairness in CSMA/CA or performance anomaly occurs so that throughputs of all WLANs are forced to decrease.

That is why many WLANs densely deployed should be investigated. Thus, this paper is trying to understand QoS performance characteristics of densely deployed WLANs.

It is very difficult to simulate mobile WLANs for evaluating their QoS characteristics. For example, ARF functions are not standardized but are proprietary implemented and not disclosed by each MAC chip vendor. In addition, interference results in bit errors in received signals and affects from several important factors, such as device performance, multi-path characteristics, and equalizer performance. A pure computer simulation based approach to capture the complex nature of such interference is thus difficult. Also previous studies [13][14] have pointed out the inaccuracy of computer simulation models in reflecting the

true nature of interference in WLANs. Thus, empirical studies on real machines are required.

In this paper, throughput characteristics are investigated with numbers of WLANs, numbers of terminals in a WLAN by using real machines. Context Aware multi Rate Control (CARC) is also proposed and evaluated to improve the throughput.

### B. Performance Anomaly and Auto Rate Fallback

Even when only one terminal uses a low transmission rate, throughput of the all terminals and APs sharing the bandwidth, i.e. in the same CSMA/CA domain are decreased. This is called Performance Anomaly. Especially, combination of higher transmission rate and lower transmission rate cause severe throughput degradation for higher transmission rate terminal. For example, if a WLAN has a 54 Mbps and a 6 Mbps terminal, each throughput is roughly and logically calculated with a harmonic average, $1/(1/54+1/6)=5.4$ Mbps. This means that only 10% in throughput is obtained from 54Mbps of 802.11g capacity. This is because of even sending opportunity of CSMA/CA mechanism and multi-rate of transmission rate.

Originally, multi-rate is used for seeking better probability of success transmission by adapting any signal to interference noise ratio (SINR) environments and is implemented in auto rate fallback (ARF) mechanism. ARF generally lets transmission rate go down in case of successive retransmission and go up in case of successive success transmission. However, it is difficult for ARF to differentiate retransmission by poor SINR from retransmission by collision. This difficulty may cause unnecessary low transmission rate. Collisions are likely to happen when a WLAN has many terminals.

In the case of densely deployed WLAN, Performance Anomaly occurs over all WLAN which are sharing the same CSMA/CA domain. In other word, when one terminal lets its transmission rate go down, all the terminals that can sense its carrier have to wait to send their frames. This means that if one WLAN is likely to have significant retransmission rate, other WLANs could be suffered by Performance Anomaly. This seems like Performance Anomaly is propagated to over the WLANs.

## III. PERFORMANCE CHARACTERISTICS OF DENSELY DEPLOYED WLANs

### A. WLAN Performance Evaluation Model

For evaluations and discussions, mobile WLANs densely deployed are modeled as follows. A mobile WLAN consists of terminals and an AP. They are portable like MiFi or Tethering devices. Although through the authors' experience, many tethering-able smartphones including iphone 4S and Galaxy S could not change channel number, portable devices can change channel number to avoid using the same channel as other devices. Here, no matter the channel number can be changed or not, several WLANs assume to use the same channels and share the bandwidth with CSMA/CA because many WLANs are densely deployed. In the experiments, real machines which are sold in an IT shop are used. The experiment was done in a meeting room in a building of Tokyo Institute of Technology, Japan. Radio shield rooms were not used for the experiments in this paper because it is desired to know QoS characteristics of experiment devices and radio environment including characteristics of device performance, multi-path, and equalizer performance. Some characteristics of device performance used in this paper were already measured in a radio shield room and are disclosed in [16]. In order to share the same bandwidth with CSMA/CA, all WLANs in concerns should be kept within 4 m. Carrier signals spread 4 m with enough strength.

Throughput of uplink TCP traffic is employed as a performance measure. All the mobile terminals send TCP traffic toward a receiving terminal via AP.

Note that Physical layer capacity such as 54 Mbps consists of MAC throughput and MAC overhead and physical layer overhead. MAC overhead includes MAC ACK, back off, retransmission and so on. MAC throughput consists of TCP throughput and TCP ACK. Since TCP throughput depends on packet loss rate and round trip time (RTT), RTT is set to be ignorable small. Packet loss other than WLANs does not occur except AP buffers.

### B. Measured Throughput and Factors Affecting Throughput

Several main factors affecting throughput performance are here explained. TCP Packet loss can occur by retry out loss and buffer overflow in AP buffer. Since retry out results from more than a certain number of MAC retransmissions, for example, 7 times of retransmissions, it rarely occurs. On the other hand, buffer overflow easily happens when conditions are met. In the model, AP buffer for downlink is shared and used by the terminals.

As a numbers of the terminals increases, probability of buffer overflow increases. Competition to seize a buffer becomes severe as more numbers of terminals use the buffer. Many simulation results with small buffer and error free assumptions show unfairness of TCP throughput of uplink traffic. However, error does occur in practice and in the experiments, and buffer size is not so small even in portable APs. For long term, AP buffer are fairly used and throughput does not show unfairness. On the other hand, a number of active terminals affects TCP throughput characteristics. An active terminal is defined as a terminal which has backlog packet to send. A terminal which waits for TCP ACK and can not send any more TCP data packet is not an active terminal. When a terminal sends TCP data and exhausts its congestion window, it has to stop sending data and wait for TCP ACKs. Generally due to unfairness of uplink and

downlink in WLANs, APs are likely to have backlog and to be active terminals, especially with TCP traffic. Only active terminals contribute collisions. Thus, the number of active terminals affects MAC throughput and then TCP throughput.

Capture effect is an effect in which a MAC frame having stronger signal against noise wins and gets successful transmission in case of collisions. In mobile WLANs, parallel and successful transmission can be achieved if capture effect is effectively obtained. This happens on only collisions between WLANs. Especially, WLANs have large distance between them and AP and terminals in a WLAN have small distance, for example, 1 m and 0.1 m, respectively. This nature shows interesting characteristics. More numbers of collisions occur, higher throughput is obtained.

Auto rate fallback (ARF) can be a dominant factor of throughput characteristics. As ARF in a real device has a vender specific algorithm which is not disclosed, the implications of input and output of ARF is used. In other words, ARF can be error sensitive if transmission rate is decreased as error rate is increased. When ARF decreases transmission rate, it causes performance anomaly and throughput is drastically reduced.

### C. Measured Results

The experiment was done with turning ARF on of all the terminals and the AP. Smartphones, NEXUS S and Galaxy S were used as the terminals and a tiny AP, Planex MZK-MF300N was used as the AP. All APs used explicitly 802.11g. WMM (802.11e, EDCA) was not used. All the terminals sent uplink TCP traffic to a receiving terminal via the AP. Each WLAN was located with variable from 0.05 m to 1.0 m distance each other in lattice topology. A terminal and its AP are placed closely each other within 0.1 m.

Figure 1 shows throughput characteristics for numbers of WLANs. Numbers of terminals are fixed to 18. For example, in 2 and 6 sets of WLANs, each WLAN has 9 and 3 terminals, respectively. In the case of distance 0.05 m denoted "0 m" in the figure, the curve monotonically decreased as number of WLANs increased. As a number of active terminals including APs in whole WLANs increases, the throughput is likely to be decreased. Since very little capture effect was obtained because adjacent WLANs were too closely located to avoid interference from others, throughput is likely to be increased. In this case, capture effect was so little that could not win against effect of numbers of active terminals. Thus, throughput decreased.

On the other hand, in the case of distance 1.0 m denoted "1.0 m" in the figure, in contrast, the curve monotonically increased as the number of WLANs increased. This is because capture effect is enough to win against effect of the number of active terminals.

Note that throughput can be very small in large numbers of terminals in a WLAN or in no capture effect as in "0 m" case. Collision error frequently occurs when no or very little capture effect is obtained. The errors invoke ARF which reduces transmission rate and causes performance anomaly.
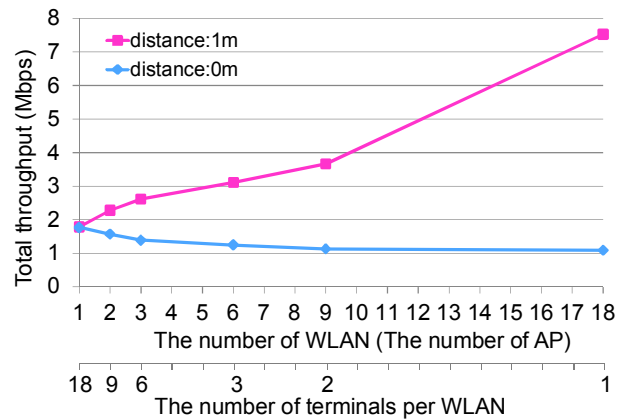


**Figure 1. Total throughput for number of WLANs**

## IV. PERFORMANCE ANOMALY

### A. Auto Rate Fallback and Performance Anomaly

Performance anomaly occurs regardless of ARF behavior, but is likely to occur with ARF. A sending terminal which is located far away from a receiving terminal has to use a low transmission rate. This causes performance anomaly. However, ARF is a significant reason why performance anomaly occurs in a mobile WLAN. This is because ARF often unnecessarily decrease a transmission rate. It is only suitable to decrease a transmission rate in a case of much noise or interference. If it is difficult to differentiate frame errors by collision from by noise, a transmission rate would be decreased by collision. The decreased transmission causes total throughput degradation or performance anomaly of the WLAN. In addition, in densely deployed WLANs it causes performance anomaly over the all WLANs that use the same channel. Thus, it is important to prevent a transmission rate from decreasing.

Let us look at experimental results in which one terminal drop its transmission rate down and performance anomaly occurs over all the WLANs. Figure 2 indicates a relation between transmission rates and throughputs of individual terminals. In the figure, total throughput was measured in two WLANs. Each had two terminals. One of the two terminals in one WLAN was set with ARF on, but both two terminals in the other WLAN were set with ARF off and set with fixed rate of 54Mbps. At around 70 sec, the terminal with ARF on was moved away from the original position. It

was moved back to the original position at 140 sec. Though the move caused transmission rate decreasing in the moved terminal, rest of the terminals remained unchanged in their transmission rate. This is because the other terminal need not to reduce their rate and were set with 54 Mbps fixed rate. However, throughputs of every terminal in both WLANs were reduced. Thus, for better use of radio resources and achieving good QoS, it is very important to prevent all the terminals in densely deployed WLANs from decreasing transmission rate.
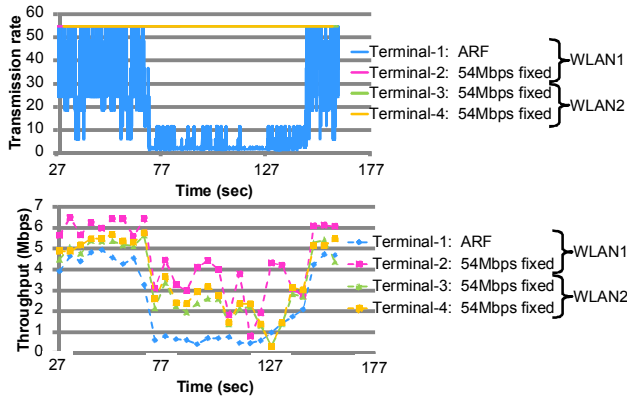


**Figure 2. Throughput and transmission rate with ARF**

### B. Throughput Degradation with Number of Terminals

In order to prevent unnecessary transmission rate decrease, factors affecting ARF should be known. A number of terminals in a WLAN is a key factor to cause transmission rate degradation. As the number increases, frame error rate by collision increases. In a mobile WLAN an AP and a terminal are usually very closely placed. Probability of frame errors by noise or interference is low although probability of frame errors by collision is mainly determined by the number of terminals in the WLAN.

Note that not only the number of terminals in the WLAN decides the collision rate, but also the number of terminals in other WLAN contributes to decide collision rate. Collisions between WLANs occur when Contention Windows are expired at the same time. It happens in nature as they hear their carrier each other. However, thanks to capture effect, stronger signals in a WLAN win against weaker noises from other WLANs and the collided frames are likely to be successful to be transmitted [17]. The successful rate depends on capture effect, in other words, SINR (signal to interference noise ratio). This indicates that capture effect is becoming small as the number of terminals of other WLANs is increasing. Summarizing the discussion above, probability of performance anomaly increases as the number of

terminals in a WLAN increases, and the number of WLANs increases.

Figure 3 shows total throughput for numbers of terminals per WLAN for number of WLANs. The experiment was done with turning ARF *on* of all the terminals and the AP. All the terminals sent uplink TCP traffic to a receiving terminal via the AP. Each WLAN was located with 1.0 m distance each other in lattice topology. Each terminal and its AP are placed closely each other within 0.1 m. The throughput curve shows that two or three terminals in one WLAN are enough to give ARF algorithm a specific error epoch which causes transmission rate degradation and results in poor throughput performance.
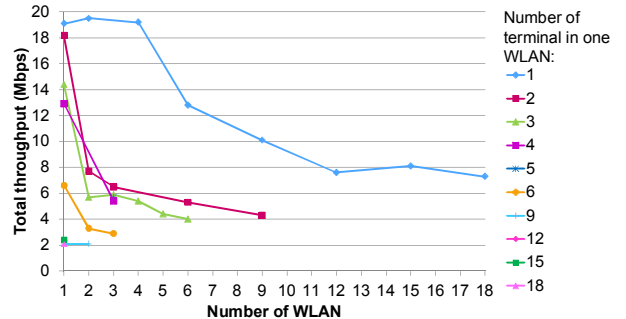


**Figure 3. Total throughput and retransmission rate or frame error rate for numbers of terminals in a WLAN**

Figure 4 shows total throughput for numbers of WLANs, each of which consists of from 1 to 18 terminals. The numbers of WLANs also much affected throughput characteristics.
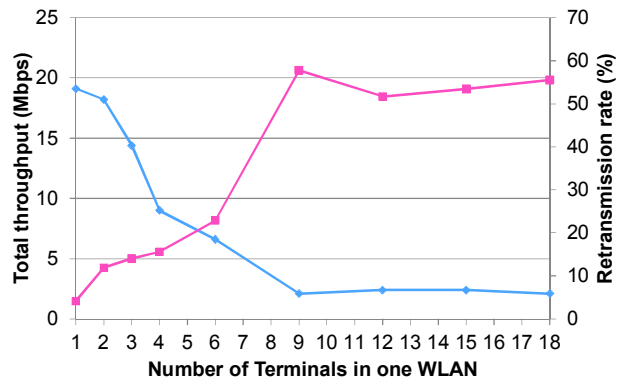


**Figure 4. Total throughput for number of WLAN**

Figure 5 shows total throughput for numbers of WLANs with keeping total numbers of terminals fixed. It is exactly the same results and is from a different point of view of Figure 3. On each curve, total numbers of terminals are not

changed but the numbers of WLAN and the numbers of terminals in each WLAN are changed. It indicates that when a fixed numbers of terminals should be accommodated in WLANs, it is better to form a few numbers of terminal and many numbers of WLANs.
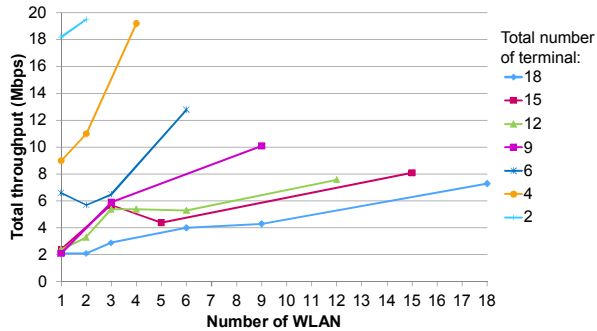


**Figure 5. Total throughput of WLANs of fixed numbers of terminals**

## V. CONTEXT AWARE MULTI RATE CONTROL

### A. ARF Control

Here, it is assumed that modification of ARF algorithm is not allowed but turning on/off of ARF function is allowed. Because ARF which is implemented in an LSI chip is supposed to be cost-efficiently made, modification of the algorithm would be difficult but API (application program interface) could provide turn on/off ARF functions.

When an AP and terminals are very closed placed in a WLAN such as mobile WLAN or tethering devices, ARF does not so effectively work. In addition, ARF causes unnecessary transmission rate degradation.

Based on these assumptions and discussions, an ARF control method will be introduced in the next subsection.

### B. CARC and Throughput Improvement

Context Aware multi Rate Control (CARC) is proposed for avoid unnecessary rate adaptations of ARF. In CARC, communication situations or context are categorized into two as shown in Table 1. One is called personal mode, and thither is local/public mode. In the personal mode, ARF or any rate adaptations are turned off and the transmission rate is fixed with the highest rate, for example, 54 Mbps in 802.11g. in the local/public mode, ARF is turned on. CARC is very simple and easy to be implemented as well as effective as described in the followings.

Context may be determined as follows. When tethering or mobile AP is used, personal mode is set. Otherwise local/public mode is set. In mobile WLANs, an AP and terminals are located so close each other, and there rarely have frame errors by noise bit errors. In this case, by turning

off ARF, unnecessary transmission rate adaptation can be prevented. Thus, personal mode is used. However, in the residence or public spaces, frame errors by bit errors are expected to occur because APs which is usually fixed and their associated mobile terminals are located with a certain distance. In addition, it is very difficult to estimate the optimal transmission rate because of terminal mobility. Thus, local/public mode is used.

**Table 1. Modes of CARC**

| Mode | ARF | Signal Strength | Context |
|------|-----|-----------------|---------|
| Personal | Off (Fixed rate) | Stronger signal | Mobile WLAN |
| Local/public | On | Weaker signal | Public hotspot and residential or office |

Note that turning ARF off means that the device has possibility to lose the connection in a case of lack of enough signal strength. Therefore, it is important to discuss how to switch the mode. Although optimal designs of changing mode according to the situation or context of communications are for further study, tentatively, the modes are set as follows. The mode in the terminal is switched by the received signal strength from the associated AP. If the terminal detects the signal over a specific threshold (called ARF threshold), it estimates the associated AP is closed and it uses personal mode. Otherwise, it uses local/public mode. On the other hand, a mobile AP in default uses personal mode. However, it may be desired to choose local/public mode in the case that the mobile AP is used in a resident instead of broadband routers for wired Internet access.

Through the discussion above, the advantages and disadvantages of turning ARF off should be quantitatively evaluated. First, total throughput is compared with and without CARC. In the experiments, the ARF threshold is set to be small enough so as for the terminals and the AP to use personal modes. Three mobile WLANs were employed, in which mobile terminals are connected to their associated portable AP and send uplink TCP traffic from the terminals to the receiving terminal via the AP. Numbers of terminal varied to show the effect of ARF in each experiment. The three APs were located with 1.0 m each. The terminals were located within 0.1 m to the associated APs. In this distance, personal mode should be obviously used. In the following experiments, CARC was not implemented in the terminals but ARF was manually turned on in local/public mode and off in personal mode in the terminals.

In order to investigate the performance of CARC, results of two experiments with personal mode and local/public

mode were compared. Figure 6 shows total throughput of the three WLANs. The three WLANs are called WLAN-1, WLAN-2 and WLAN-3 and each WLAN has one terminal at the initial settings. The figure has two curves of total throughput. One was measured in the experiment where all terminals were in personal mode and the other was where all terminals were in local/public mode. At time 30 sec. a new terminal was added to WLAN-1 and at 60 sec. the terminal was moved enough away where it could not be connected in the personal mode, i.e. at the fixed rate 54 Mbps, but could be connected in local/public mode.
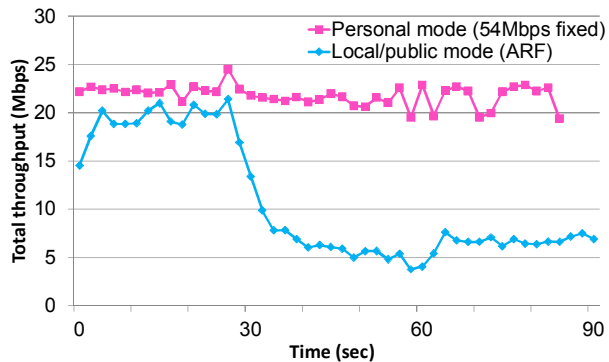


**Figure 6. Total throughput of personal mode and local/public mode**

At 30 sec in the Fig. 6, throughput of local/public mode was degraded because performance anomaly occurred. When a terminal changed its transmission rate from 54 Mbps to 5.5 Mbps due to frequent collisions, the total throughput of three WLANs drastically reduced from 22 Mbps to 5 Mbps. This was a really typical *performance anomaly*. On the other hand, that of personal mode was not degraded. The difference in the two curves at that time was approximately 3.5 times. This means that radio resources are efficiently used and QoS is much improved if all WLANs employ CARC.

After the moving, at 60 sec, in the case of personal mode, the terminal can not send any packets and its throughput becomes zero. Since the other terminal of WLAN-1 uses the bandwidth for the moving terminal, total throughput of WLANs just a little bit changes. On the other hand, in local/public mode, total throughput slightly goes up because capture effect gives a closer i.e. higher rate terminal higher priority.

## C. Discussions

Because ARF is a vender proprietary implementation as mentioned before, in order to justify the results, several kinds of smartphone and other devices were examined. Figure 7 shows total throughput of three WLANs and very similar results as Fig. 7. Each WLAN has one terminal at the initial settings as the same as the previous experiments. To see the difference of kinds of terminals, however, ARF was turned

on only in the one terminal and was turned off in the rest of the terminals and APs. The one terminal was replaced with either Nexus S, Galaxy S2 or Mac Book Pro. While individual ARF functions might be changed without notices from MAC chip venders, CARC is useful, independent of future ARF functions. it is estimated that CARC is useful. In addition, it is desired to implement CARC in MAC chips.

As stated in the related works, it is desired to develop cost effective algorithm in ARF to differentiate frame errors by collision from by noise. When this is difficult, CARC can be a good alternative which is very simple and easy to be implemented as well as effective to improve QoS.
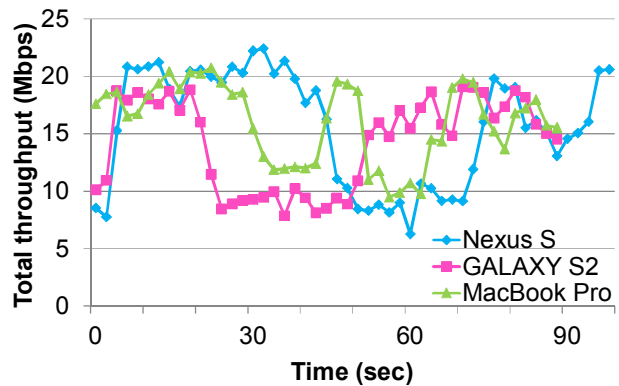


**Figure 7. ARF behavior of various wireless devices**

## VI. CONCLUSION

WLANs densely deployed are investigated in terms of throughput performance characteristics. In order to improve the throughput with avoiding performance anomaly, context aware multi rate control (CARC) is proposed. By interferences and collisions, performance anomaly resulting from ARF rate adaptation forces to decrease total throughput of whole WLANs as numbers of terminals in a WLAN increases and numbers of WLANs increases. When a terminal changed its transmission rate from 54 Mbps to 5.5 Mbps due to frequent collisions, the total throughput of three WLANs drastically reduced from 22 Mbps to 5 Mbps (performance anomaly). To avoid the unnecessary drop of the transmission rate, CARC turns-off ARF or any rate adaptation in personal mode such as in tethering or MiFi mode, but turns-on in local/public mode such as in fixed WiFi mode for resident or public WiFi. The experiments showed that employing the CARC achieves 3.5 times improvement in the total throughput. The authors hope that this investigation open up a new usage of control parameters for mobile WLANs in order to efficiently use radio resources and to obtain higher throughput.

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