Experimental Evaluation of Decision Criteria for WLAN handover: Signal Strength and Frame Retransmission

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Abstract. In ubiquitous networks, Mobile Nodes (MNs) may often suffer from performance degradation due to the following two reasons: (1) reduction of signal strength by an MN's movement and intervening objects, and (2) radio interference with other WLANs. Therefore, quick and reliable detection of the deterioration of a wireless link condition is essential for avoiding the degradation of the communication quality during handover. In our previous works, we focused on a handover decision criterion allowing MNs to maintain communication quality and stated the problems of existing decision criteria. Furthermore, we showed the effectiveness of the number of frame retransmissions through simulation experiments. However, a comparison between signal strength and the number of frame retransmissions could not be examined due to the unreliability of signal strength in simulations. Therefore, in this paper, by employing FTP and VoIP applications, we compare signal strength and the number of frame retransmissions as a handover decision criterion with experiments in terms of (1) and (2) in a real environment. Finally, we show the problems of signal strength in contrast to the effectiveness of the number of frame retransmissions as a handover decision criterion.

Key words: Wireless LAN Handover, Handover Decision Criterion, Signal Strength, Frame retransmission, FTP, VoIP

1 Introduction

WLANs based on IEEE 802.11 [1] have gained popularity due to their low cost, ease of installation, and broadband connectivity. WLANs are being set up not only in private spaces such as homes and workplaces, but also as hotspots in public spaces such as waiting areas and hotel lobbies. Furthermore, WLANs that are independently managed by different organizations are starting to complementarily cover not only one spot but a wide area, such as a city, by using

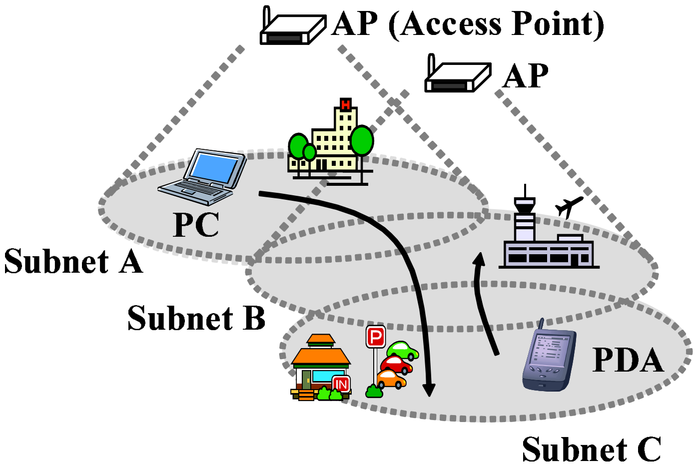

Fig. 1. Future ubiquitous mobile network based on WLANs.

multiple access points (APs). Many of these deployments [2][3][4] have already been progressing around the world. In the near future, WLANs will continue to spread until they overlap to provide continuous coverage over a wide area, and then they will serve as the underlying basis of ubiquitous networks.

In a ubiquitous network, mobile nodes (MNs) are very likely to traverse different WLANs (i.e., perform a handover) divided into different IP subnets during communication because of the relatively small coverage of individual WLANs, as shown in Fig. 1. When an MN moves between different WLANs, the signal strength received from the connected AP is reduced drastically due to the distance and/or any intervening objects between the MN and the AP. Thus, the communication quality may be degraded due to the reduction of signal strength. Furthermore, in such a network, radio interference with other WLANs frequently occurs due to the wide spread of WLAN services. In this case, the communication quality may also be degraded, even when the MN does not move.

To provide transparent mobility for MNs in a ubiquitous network, it is necessary for the MNs to seamlessly execute handovers between different WLANs, which are independently managed by different organizations. In other words, quick and reliable detection of the deterioration of WLAN link quality and the execution of the handover to a better WLAN are essential for achieving seamless and efficient communication. As a result, the handover decision criterion can play an important role in executing handovers by reducing the degradation of the communication quality due to (1) reduction of signal strength, and (2) radio interference with other WLANs.

In our previous works [5][6], we showed that communication quality is significantly degraded before handover in many of the existing mobility management schemes (e.g., Mobile IP (MIP) [8]), when upper layer (higher than Layer 3) information such as packet loss and round-trip-time (RTT) is employed as the handover decision criterion. Furthermore, we also showed through simulation experiments that the degradation of the communication quality before handover could be avoided by exploiting the number of frame retransmissions obtained from MAC layer (Layer 2): thus, the number of frame retransmissions has the potential to serve as a handover decision criterion. However, although some recent studies have employed signal strength as a handover decision criterion, a qualitative evaluation of signal strength was not performed in our previous works [5][6], because it is difficult in simulation experiments to consider the fluctuation of signal strength due to various effects such as multi-path fading, radio interference, intervening objects, and movement. That is, an investigation of the effectiveness of signal strength through simulation is exceedingly hard due to the unreliability and complexity of radio transmission.

In this paper, by employing FTP and VoIP applications in a real environment, we examine the effectiveness of these two criteria, i.e., signal strength and the number of frame retransmissions, in terms of performance degradation due to (1) the reduction of signal strength and (2) radio interference. Finally, we show that the performance degradation due to both (1) and (2) can be effectively avoided by utilizing the number of frame retransmissions, whereas it cannot be inherently avoided by utilizing the signal strength.

2 Handover decision criteria of existing studies

In a ubiquitous network, the most critical issue of handover arises from the change in IP address. When an MN moves between WLANs managed by different companies or organizations (i.e., different IP subnets), the IP address of the MN changes. As a result, the communication is terminated or interrupted by the handover. Many mobility management schemes such as MIP [8], mobile Stream Control Transmission Protocol (mSCTP) [9], and others [10][11][12] have been proposed to solve this problem, and the MN employing these existing schemes can maintain the communication during handover between different WLANs regardless of the various types of applications, such as FTP and VoIP communications.

However, these existing mobility management schemes, which make the handover decision based on upper layer (Layer 3 or 4) information such as packet loss [8] and RTT, could cause drastic performance degradation of the MN before handover. In our previous work [5], to investigate the effectiveness of upper layer information (packet loss and RTT) as a handover decision criterion, we used simulation experiments to evaluate the TCP goodput performance around handover. As illustrated in Fig. 2, an MN establishes a TCP connection for file transfer with a Corresponding Node (CN) via 802.11b WLAN, and moves away from an AP. Figure 3 shows that the TCP goodput performance significantly degrades before the packet loss ratio begins to increase. Furthermore, because the packet loss ratio changes dynamically due to various factors, such as congestion in a wired network and frequent and sudden transmission errors in a wireless

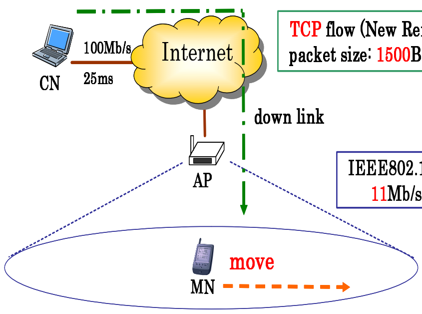

Fig. 2. Simulation model.

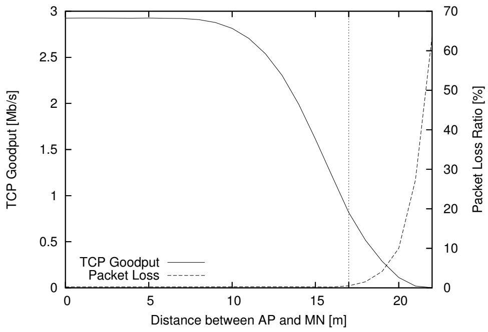

Fig. 3. TCP goodput and packet loss ratio.

Table 1. Received Signal Strength Indicator.

Vendor	RSSI Range
Atheros	0-60
Cisco	0-100

network, the setting of an optimal threshold for a handover decision is quite difficult. Therefore, the degradation of WLAN link quality cannot be promptly and reliably detected by exploiting this information; that is, upper layer information should not serve as a handover decision criterion.

To solve the above issue, some new enhanced methods have been developed which base the handover decision on information obtained from a lower layer. In particular, the majority of these methods employ the signal strength obtained from Layer 1 as the handover decision criterion [13]. Received Signal Strength Indicator (RSSI), shown as an integer value from 0 to 255, is a common index of signal strength. The maximum RSSI value obtained from each WLAN card depends on the vendor, as shown in Table 1 [14]. The RSSI is also used as a handover decision criterion for the intra-domain handover called roaming [15]. However, RSSI fluctuates abruptly due to various and complicated events such as multi-path fading, intervening objects, and movement. Because of this fluctuation, setting the optimal threshold for RSSI as a handover decision is very difficult; therefore, it also should not serve as a handover decision criterion.

Our previous studies [5][6][7] focused on the number of frame retransmissions obtained from Layer 2 as a new handover decision criterion. We evaluated the TCP goodput performance and the behavior of the number of frame retransmissions through a simulation experiment (Fig. 2). As shown in Fig. 4, the frame retransmissions begin to occur at a distance around 8 m between the AP and the MN, and the TCP goodput also begins to decrease soon after the occurrence of the frame retransmissions. This result shows that the degradation of TCP

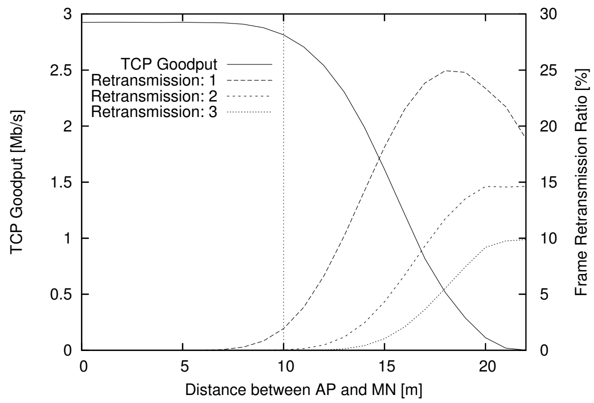

Fig. 4. TCP goodput and frame retransmission ratio.

goodput performance begins even when a frame retransmission occurs at least once. As a result, we showed that the number of frame retransmissions has the potential to serve as a handover decision criterion to effectively avoid TCP performance degradation. However, in [5][6], the comparison between the number of frame retransmissions and signal strength was not examined in detail because of the unreliability and complexity of signal strength, as described above; that is, the signal strength was not evaluated as a handover decision criterion.

Existing studies, including our previous works, focused only on the performance degradation due to the reduction of signal strength caused by movement and/or intervening objects. In a future ubiquitous network, many APs will be deployed to provide continuous coverage over a wide area. In such a network, performance degradation may also arise from radio interference with nearby APs. As a result, the handover decision criterion is required to detect the performance degradation due to (1) the reduction of signal strength and (2) radio interference with other APs. Therefore, in this paper we actually examine the effectiveness of signal strength and the number of frame retransmissions as a handover decision criterion in terms of (1) and (2) through extensive experiments in a real environment.

3 Wireless LAN

In this section, we briefly describe the mechanism of frame retransmission and the problems caused by radio interference, which may occur in a future ubiquitous mobile network.

3.1 Frame retransmission mechanism

Frame retransmission occurs for the following two reasons: (i) deterioration of signal strength and (ii) collision with other frames. In a WLAN, a sender can detect successful transmission by receiving an ACK frame in response to a transmitted data frame in the stop-and-wait manner. Therefore, when a data or an ACK frame is lost, the sender retransmits the same data frame until the number of frame retransmissions reaches a predetermined limit. Note that, with Request-to-Send (RTS)/Clear-To-Send (CTS), collisions between data frames, namely a hidden terminal problem, never occur due to the exchange of the RTS/CTS frames. If RTS/CTS is applied, the retransmission limit is set to 4 in the IEEE 802.11 specification [1]: A data frame can be retransmitted a maximum of four times (the initial transmission and three retransmissions), if necessary. Note that collisions may occur in an interference environment, which will be described in next section, even if RTS/CTS is applied.

If the sender does not receive an ACK frame within the retransmission limit, the data frame is treated as a lost packet. Considering the above discussion, we can see that data frames are inherently retransmitted before being treated as a lost packet. Therefore, the number of frame retransmissions can allow the MN to quickly perceive the deterioration of the condition of a wireless link, and may enable the MN to determine when the handover process should be started before packet loss actually occurs.

3.2 Radio interference

In the near future, many different organizations will begin to provide WLAN services. Each WLAN occupies a single channel to provide communication between an AP and the MNs connected to the AP. In such a network, an overlap of channels among nearby APs may frequently occur. Therefore, preventing the performance degradation due to radio interference will be a critical issue for effective communication in future ubiquitous networks.

In the IEEE 802.11b specification [16], 13 channels are offered between 2400 MHz to 2483 MHz at 5 MHz intervals. However, because 802.11b uses the DSSS (Direct Sequence Spread Spectrum) modulation technique at the 2.4 GHz band, the frequency band spreads to 20MHz. Therefore, a "clear" channel (without any interference) should be at least 20 MHz (for five channels) away from neighboring channels. Otherwise, the frequency band overlaps with other channels, thereby causing packet losses due to the radio interference. In Japan, channel 14 (from 2471 MHz to 2497 MHz) is also available and is independent from channel 11, and thus, we have four clear channels at the maximum.

WLAN, based on the IEEE 802.11 specification, employs CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). CSMA/CA is responsible for the access control of a wireless channel. When MNs try to transmit data over the wireless channel, they first search the channel state, and then determine if a data frame can be transmitted. If the channel state is *idle*, that is, other MNs are not transmitting any frames over the wireless channel during some fixed interval, these MNs can transmit the data frame in the Collision Avoidance (CA) manner. On the other hand, if the channel state is *busy*, i.e., one of the MNs occupies the channel for data transmission, other MNs have to wait until the channel state turns to *idle*.

If the search of the wireless channel fails, collisions with other frames transmitted from other MNs may occur and the number of packet losses may increase drastically. In the WLAN specification, because an MN can search only within the same channel, collisions with other frames will also occur in the situation where nearby APs use close channels (within five channels). Thus, the number of collision frames due to radio interference increases, with the increase of the number of transmitted frames over both in use channel and close channels. As a result, the radio interference can affect communication performance. Therefore, MNs are essentially required to detect the performance degradation due to radio interference.

4 Experimental evaluation

WLANs will begin to spread to outdoor environments, such as urban areas. Because a lot of intervening objects often exist in both indoor and outdoor environments, radio characteristics such as multi-path fading, noise, and radio interference are obviously more complex than that of an open space environment. Thus, reliable evaluation of the communication performance under an MN's movement, intervening objects, and radio interference is difficult through simulation experiments. Therefore, in this paper, we execute an experimental evaluation to take into account the multiple and complex radio characteristics in a real environment. More specifically, we focus on the communication performance in an indoor environment with a lot of intervening objects; in this environment, the radio characteristics are more notable than those of urban areas.

In experiments employing FTP and VoIP applications, we compare the following two criteria, i.e., signal strength and frame retransmission, in terms of (1) reduction of signal strength and (2) radio interference with other WLANs in a real environment. Through the experiments, we show the problems of signal strength as well as the effectiveness of the number of frame retransmissions as a handover decision criterion.

4.1 Effect of reduction of signal strength

In this section, we examine how the signal strength and the number of frame retransmissions can promptly and reliably detect the performance degradation due to the reduction of signal strength by an MN's movement and intervening objects in the indoor environment. In this experiment, we investigate the behavior of signal strength and the number of frame retransmissions.

As illustrated in Fig. 5, an MN communicates with a Corresponding Node (CN) via WLAN (802.11b). The transmission rate of the WLAN is fixed to 11 Mb/s, and the RTS/CTS mechanism is employed. An Analyzer Node (AN) captures the frames transmitted on the WLAN by using Ethereal 0.10.13 [17]. "ORiNOCO AP-4000" of Proxim Co. [18] is used for the Access point (AP) and "ORiNOCO 802.11a/b/g Combo Card Gold" of Proxim Co. [18] is used

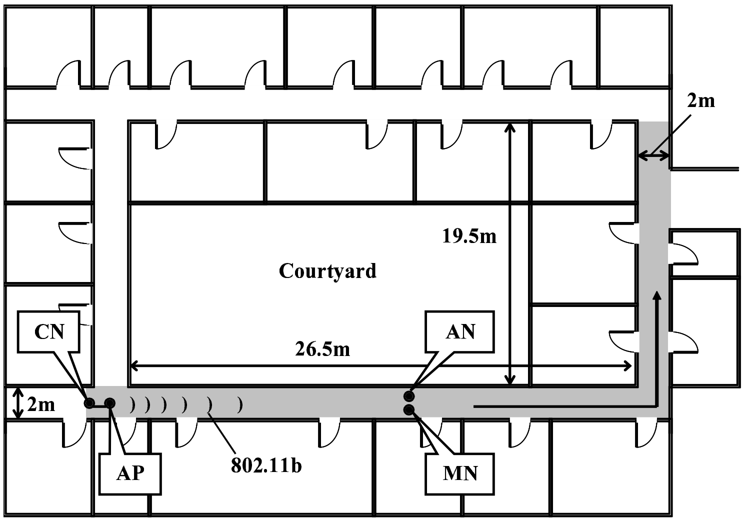

Fig. 5. Experimental environment (for reduction of signal strength).

for the WLAN card. Both the MN and the AN are equipped with this WLAN card for communication and frame capture. In this paper, by employing FTP (TCP) and VoIP (UDP) applications, we examine the characteristics of both signal strength and the number of frame retransmissions in detail by analyzing the captured frames. TCP goodput is used as the performance measure of the FTP application, and packet loss ratio is used as the performance measure of the VoIP application. In this experiment, because a WLAN card with an Atheros chipset is employed, the RSSI value, which is used as an index of the signal strength, varies from 0 to 60 [14], as shown in Table 1.

Case 1: Effect of distance from the AP

We examine how communication quality (TCP goodput performance for FTP and packet loss ratio for VoIP, the number of frame retransmissions, and the signal strength) changes with the increase of distance between the MN and the AP. Note that, in Case 1, we examine the stable and average communication performance at several distances; that is, the MN does not actually move through the environment. First, we focus on the FTP application and investigate the TCP communication performance when an MN downloads a 10 MByte file from the CN (an FTP server).

Figure 6 shows the change in the TCP goodput performance and the RSSI, and Fig. 7 shows how the TCP goodput performance and frame retransmission ratio change for 16 fixed points (2, 5, 10, 20, 27, 30, 35, 37, 39, 40, 41, 42, 43, 44, 45, 46 m). Note that "Retransmission: n" indicates the ratio of packets that experienced frame retransmissions "n" times to all the captured packets.

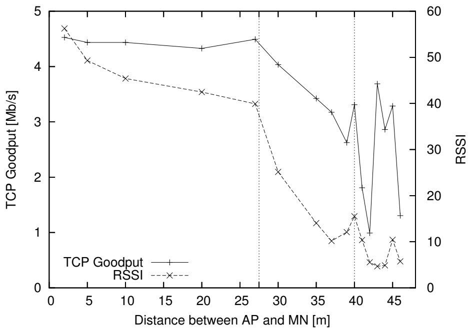

Fig. 6. TCP goodput and signal strength (FTP).

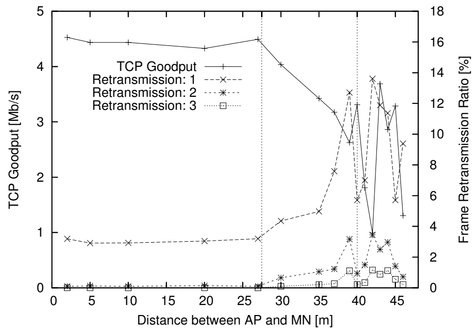

Fig. 7. TCP goodput and frame retransmission ratio (FTP).

In Fig. 6, the TCP goodput begins to decrease just after 27.5 m, where the MN turns a corner, i.e., the AP cannot view the MN directly. Beyond that, the TCP goodput performance drastically drops and then fluctuates abruptly beyond 40 m. On the other hand, the signal strength begins to decrease with the increase of the distance from the AP and also drastically drops beyond 27.5 m. However, it remains at a low value regardless of the drastic change of the TCP goodput beyond 40 m. From these results, we can see that quick detection of TCP goodput performance degradation is difficult when signal strength is used as the handover decision criterion.

In contrast, Fig. 7 shows that the frame retransmission ratio stays at a low level until 27.5 m. Beyond that, the frame retransmission ratio begins to increase with the decrease of the TCP goodput. In particular, "Retransmission: 2" and "Retransmission: 3" begin to increase in response to the decrease of TCP goodput performance, even though they stay nearly zero until 27.5 m. Then, after 40 m, the frame retransmission ratio just corresponds to the fluctuation of the TCP goodput. These results show that degradation of the TCP goodput performance begins when the frame retransmission ratio increases. That is, degradation of the TCP goodput performance due to the reduction of signal strength by an MN's movement and intervening objects can be detected by exploiting the number of frame retransmissions. Therefore, we suggest that the TCP goodput performance degradation before handover could effectively be avoided by utilizing the number of frame retransmissions.

Next, we focus on the VoIP application. The MN communicates with the CN using VoIP for 60 seconds. We employ Gphone 2.0 [19] as the VoIP application using G.711 codec, so that the consumed bandwidth for one direction is 80 kb/s.

Figure 8 shows the change in the packet loss ratio and RSSI, and Fig. 9 shows how the packet loss ratio and frame retransmission ratio change for 13 fixed points (2, 5, 10, 20, 27, 30, 32.5, 35, 37.5, 40, 42.5, 45, 46 m). From Fig. 8, we can see that the signal strength decreases continually, as indicated by the decrease of RSSI, even though packet loss rarely occurs until 40 m. Then,

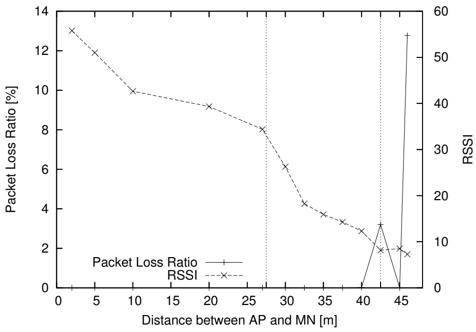

Fig. 8. Packet loss ratio and signal strength (VoIP).

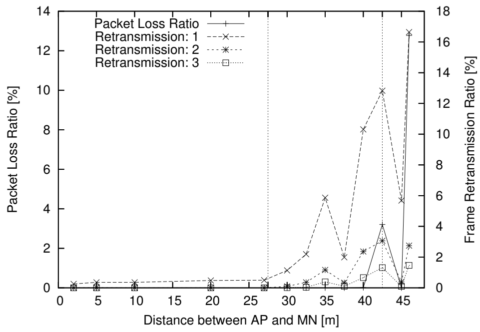

Fig. 9. Packet loss ratio and frame retransmission ratio (VoIP).

the packet loss ratio suddenly exceeds the upper bound loss rate of 3 % [6] that can maintain the VoIP communication quality at around 42.5 m and 46 m, thereby decreasing the VoIP communication quality. However, the signal strength still stays at a low value (8-10), even when the VoIP communication quality is degraded beyond 42.5 m. From this result, we can see that it is difficult to detect the occurrence of packet losses by exploiting signal strength.

In contrast, frame retransmission rarely occurs until 27.5 m. After that, the frame retransmission rate gradually increases in response to the degradation of the VoIP communication quality. In particular, “Retransmission: 2” and “Retransmission: 3” begin to increase around 38 m, soon before the VoIP communication performance actually degrades. That is, degradation of the VoIP communication performance due to the reduction of signal strength by an MN’s movement and intervening objects can be promptly and reliably detected by exploiting the number of frame retransmissions. Therefore, we suggest that the degradation of the VoIP communication quality before the handover could effectively be avoided by exploiting the number of frame retransmissions.

Comparing Fig. 6 and Fig. 8, we can explain the characteristics of signal strength and the number of frame retransmissions for FTP and VoIP applications. The value of RSSI when the communication quality begins to degrade depends on the applications, i.e., FTP is 40 and VoIP is 10. Therefore, signal strength cannot detect the difference of the communication quality between applications. On the other hand, as shown in Fig. 7 and Fig. 9, the number of frame retransmissions begins to increase just before the degradation of communication quality occurs, irrespective of the FTP application and VoIP application. From these results, we can state that the number of frame retransmissions can detect the degradation of communication quality due to the reduction of signal strength. Therefore, the number of frame retransmissions satisfies the first requirement for a handover decision criterion.

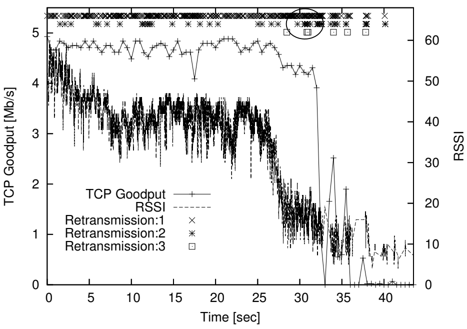

Fig. 10. FTP communication performance (actual movement).

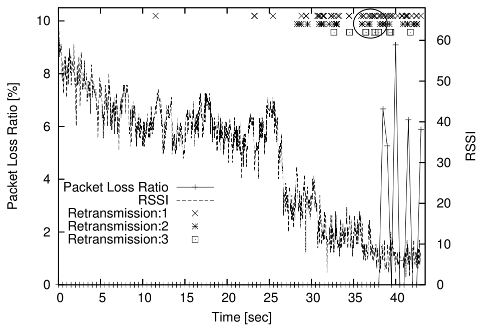

Fig. 11. VoIP communication performance (actual movement).

Case 2: Effect of actual movement

In Case 1, we evaluated how the stable and average communication performance of the MN changes for the number of fixed points. In Case 2, we investigate the communication performance as the MN actually moves away from the AP at a walking speed (approximately 4 km/h). Figure 10 shows the change in the TCP goodput, signal strength, and the number of frame retransmissions under FTP communication. Figure 11 shows the change in the packet loss ratio, signal strength, and the number of frame retransmissions under VoIP communication. Note that the horizontal axis quantity is travel time, and "Retransmission :n" indicates the occurrence time of a packet that experienced frame retransmissions "n" times.

From Fig. 10 and Fig. 11 and comparing these with the results of Case 1, we can see that RSSI fluctuates abruptly and drops drastically with the MN's movement. In Fig. 10, under FTP communication, the value of RSSI when the TCP goodput begins to decrease fluctuates approximately from 10 to 22. On the other hand, in Fig. 11, under VoIP communication, the value of RSSI ranges approximately from 4 to 8. That is, the value of RSSI when the communication quality begins to decrease differs depending on the application. As a result, setting a threshold is necessary for each application when signal strength is used as a handover decision criterion. In contrast, frame retransmissions frequently occur soon before the communication quality is degraded. Especially, "Retransmission: 3" occurs just before the communication quality actually decreases. From these results, the number of frame retransmissions can be used to detect the deterioration of the condition of communication quality, even if the MN actually moves. Through these experiments, we demonstrate that the number of frame retransmissions has the potential to serve as an optimal handover decision criterion for detecting the degradation of communication quality due to reduction of signal strength by an MN's movement and intervening objects, irrespective of the type of application.

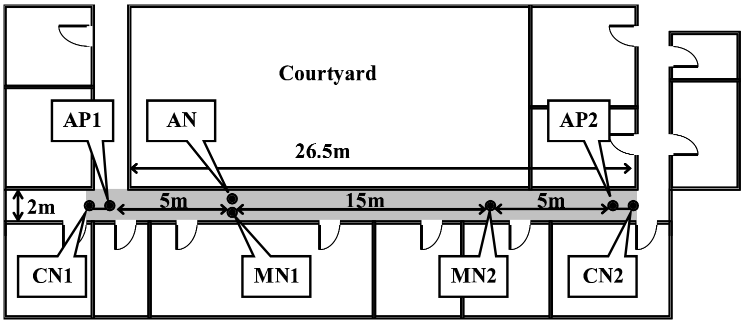

Fig. 12. Experimental environment (for radio interference).

4.2 Effect of radio interference

In this section, we examine how signal strength and the number of frame retransmissions can detect the performance degradation due to radio interference with other APs, as shown in Fig. 12. The distance between AP1 and AP2 is set to 25 m, and the distance between each AP and MN (AP1-MN1 and AP2-MN2) is set to 5 m in order to keep the communication quality and signal strength in good condition. Frame collisions due to radio interference frequently occur depending upon the number of frames transmitted over these wireless channels, as described in Sec. 3.2. Therefore, in this experiment, we focus on FTP communication, which commonly transmits a large number of frames. We investigate the communication performance when MN1 communicates with CN1 via AP1. In this case, the communication between MN2 and CN2 via AP2 causes the radio interference.

The transmission rate of both of WLANs is fixed to 11 Mb/s (the *fall-back* function is off), and RTS/CTS is employed. We investigate how the communication performance of MN1 varies due to the effect of radio interference with AP2. The channel of AP1 is fixed at 14. On the contrary, the channel of AP2 varies from 11 to 14 in each experiment. Note that the strength of radio interference increases according to the closeness of the channels between AP1 and AP2. We examine how the radio interference caused by AP2 affects the communication performance of MN1, when MN1 downloads a 10 MByte file from CN via AP1. In other words, we investigate the TCP goodput performance, signal strength, and the number of frame retransmissions in the following two cases: (a) without data transmission (only Beacon messages) and (b) with data transmission. That is, in (a), MN2 does not send/receive any data frames, and in (b), MN2 downloads the file.

Figures 13-15 show the change in the TCP goodput, signal strength, and "Retransmission: 1". In case (a) in all three figures, we can see that TCP goodput, signal strength, and the frame retransmission ratio still remain approximately constant, because a frame collision rarely occurs due to no data transmission be-

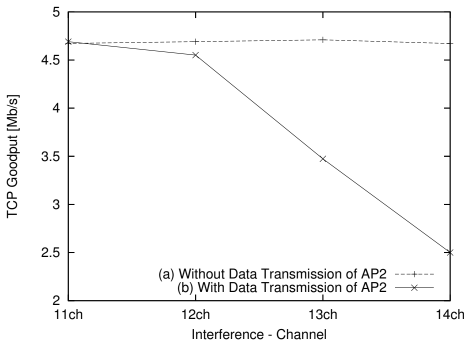

Fig. 13. TCP goodput performance.

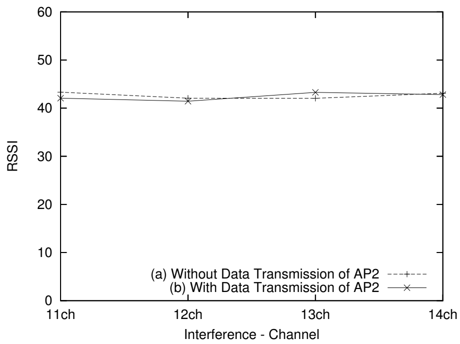

Fig. 14. Signal strength.

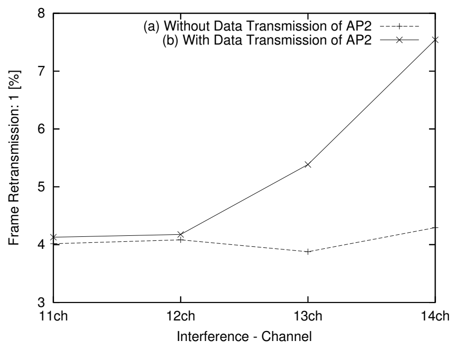

Fig. 15. Frame retransmission ratio.

tween MN2 and AP2; In such a case, collisions can still occur due to the beacon messages.

In Fig. 13, when the channel of AP2 is set to 11, the TCP goodput can be maintained even for case (b), which does have data transmission. This is because frame collisions due to radio interference do not occur between the channel of AP1 (14 ch) and the channel of AP2 (11 ch). On the other hand, the TCP goodput drastically drops as the channel of AP2 is set close to the channel of AP1 (14 ch). However, from Fig. 14, we can see that the signal strength does not decrease at all, even with the strong radio interference. As a result, we can state that signal strength cannot detect the degradation of TCP goodput due to radio interference, as mentioned in Sec. 3.2. In contrast, from Fig. 15, we can see that the number of frame retransmissions increases when the channel of AP2 approaches the channel of AP1. In particular, when the channel of AP1 and AP2 is the same (14 ch), the number of frame retransmissions drastically increases due to the failure of the CSMA/CA function.

From these results, we demonstrate that signal strength absolutely cannot detect the performance degradation due to radio interference. On the other hand, we also demonstrate that the number of frame retransmissions can promptly and reliably detect the degradation due to radio interference with other APs. An MN employing the number of frame retransmissions as the handover decision criterion can promptly and reliably detect the radio interference and can execute handover to the AP without radio interference. Through these experiments, we can state that the number of frame retransmissions can be an optimal handover decision criterion allowing MNs to detect the degradation of communication quality due to radio interference.

5 Conclusion

In a future ubiquitous network environment, MNs are very likely to traverse different WLANs during communication. Thus, to avoid the degradation of communication quality during handover, a handover decision criterion is necessary for detecting the degradation of communication quality due to (1) reduction of signal strength and (2) radio interference. In this study, we investigated the communication quality, signal strength, and the number of frame retransmissions through experiments in a real environment and clarified the problems of signal strength and the effectiveness of the number of frame retransmissions as a handover decision criterion. Furthermore, we investigated the difference of the characteristics of signal strength and the number of frame retransmissions between FTP and VoIP communications.

We showed that signal strength cannot promptly and reliably detect the degradation of communication quality in both FTP and VoIP communications when signal strength is reduced by an MN's movement and/or intervening objects. Moreover, the value of signal strength when the communication quality begins to be degraded is different between FTP and VoIP communications. Therefore, the experimental results demonstrated that it is difficult to set the optimal threshold for handover using signal strength. In contrast, we showed that the degradation of communication quality of a wireless link due to an MN's movement and intervening objects can be detected by exploiting the number of frame retransmissions. Next, we showed that signal strength absolutely cannot detect the degradation of the communication quality due to radio interference. In contrast, we showed that this degradation of communication quality can be detected by exploiting the number of frame retransmissions. Therefore, we conclude that the number of frame retransmissions, unlike the signal strength, can promptly and reliably detect the performance degradation due to (1) reduction of signal strength and (2) radio interference.

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