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A frequency cooperative ARQ scheme for multi-band WLAN

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Abstract: This letter proposes a frequency cooperative automatic repeat request (ARQ) scheme for multi-band WLAN where 60 GHz band is used for high-speed transmissions in combination with 2.4/5 GHz bands for maintaining connectivity in the presence of severe shadowing in 60 GHz band. The proposed scheme switches between 60 GHz and 2.4/5 GHz based on monitoring ACK reception and received SNR, where ACK frame is transmitted by 2.4/5 GHz for reliable retransmission. Simulation results show that the proposed ARQ scheme is less susceptible to severe shadowing caused by human activities than conventional non-cooperative ARQ schemes using only either 60 GHz or 2.4/5 GHz.

Keywords: 60 GHz, WLAN, shadowing, ARQ, multi-band system

Classification: Terrestrial Wireless Communication/Broadcasting Technologies

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1 Introduction

Rapid diffusion of mobile devices such as smartphones and tablets results in increasing demands for multi-Gbps wireless LAN (WLAN) systems for various applications such as kiosk file-downloading. Millimeter-wave (60 GHz) wireless communications are attracting attentions because of their great potentials to provide high-quality and high-speed data services by using 9 GHz wide unlicensed spectrum [1]. IEEE802.11ad standard for 60 GHz has been completed, and currently, researches and developments toward commercialization have been actively conducted [2].

Compared to conventional microwave (2.4/5 GHz) WLAN systems, coverage area of 60 GHz WLAN is much limited because of large free space propagation loss. In addition, link blockage due to shadowing is also a serious problem in 60 GHz WLAN, where 60 GHz link can be easily blocked by a human body moving around or standing on line-of-sight path between a transmitter and a receiver. To overcome these problems, researchers have suggested complementary use of 60 GHz and 2.4/5 GHz [3, 4, 5]. This approach is referred to as multi-band wireless system [5]. Multi-band wireless systems using 60 GHz and 2.4/5 GHz aim to achieve high-speed transmissions by 60 GHz as long as the 60 GHz link can be established and to maintain connectivity by 2.4/5 GHz when the 60 GHz link is lost.

To the best of our knowledge, how to switch operating frequency band between 60 GHz and 2.4/5 GHz has not been well addressed so far. This letter proposes a frequency cooperative automatic repeat request (ARQ) scheme using both 60 GHz and 2.4/5 GHz. In the proposed scheme, the operating frequency band is switched from/to 60 GHz to/from 2.4/5 GHz based on monitoring ACK reception status and received SNR. In order to lengthen the battery life of a mobile device, it is desirable not to use 60 GHz device and to avoid high power consumption in 60 GHz as far as it is out of 60 GHz coverage. In addition, ACK frame transmission should be as reliable as possible to avoid unnecessary re-transmission in ARQ. Thus, in the proposed scheme, ACK frames are transmitted by using 2.4/5 GHz at the expense of throughput degradation; however ACK frame reliability is enhanced. Computer simulation results show that the proposed scheme achieves shorter download time compared with non-frequency cooperative WLAN using only either 60 GHz or 2.4/5 GHz under severe shadowing in 60 GHz band.

2 Microwave/millimeter wave frequency cooperative ARQ scheme

Let us consider a multi-band WLAN where an access point (AP) has multi-band transceivers for 60 GHz and 2.4/5 GHz, and a station (STA) has a 2.4/5 GHz transceiver and a 60 GHz receiver. This means that STA can transmit and receive 2.4/5 GHz signals, and can only receive 60 GHz signals, and thus this configuration

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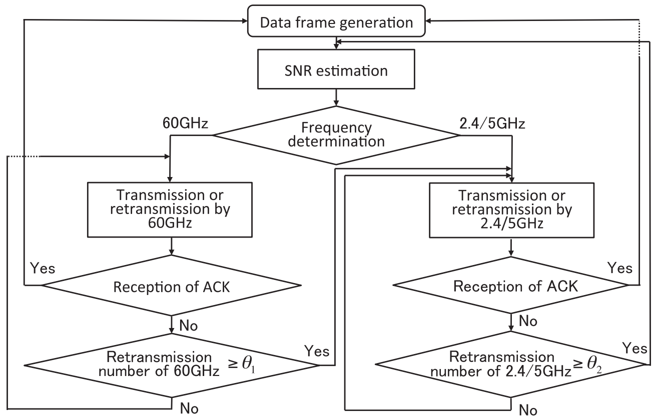

Fig. 1. Flowchart of the proposed frequency cooperative ARQ scheme.

will be effective to save battery power at STA because STA does not have a 60 GHz transmitter. However, AP/STA needs to know that it is within 60 GHz WLAN coverage before initiating 60 GHz transmission and reception. For this purpose, 60 GHz coverage detection using 2.4/5 GHz signals has been proposed [5]. In this letter, it is assumed that STA is within 60 GHz WLAN coverage and coverage detection is perfect.

Fig. 1 shows the flowchart of the proposed frequency cooperative ARQ scheme. The processing flow of the proposed ARQ scheme is described below:

(1) Data frame generation and determination of frequency band:

Once a data frame is generated at AP, STA estimates the received SNR of a 60 GHz signal transmitted from AP. If the required frame error rate (FER) can be achieved by the estimated SNR, AP starts data transmission using 60 GHz (go to (2)). Otherwise, AP uses 2.4/5 GHz for data transmission (go to (4)).

(2) Reception of ACK:

If STA receives a data frame by 60 GHz correctly, STA sends an ACK frame by 2.4/5 GHz. If AP receives the ACK frame, AP will generate the next data frame (go to (1)). Otherwise, go to (3).

(3) Retransmission by 60 GHz and switching to 2.4/5 GHz:

If the number of retransmissions by 60 GHz is less than a predetermined threshold θ_1, AP retransmits the data frame by 60 GHz (go to (2)). Otherwise, AP regards the 60 GHz band as unavailable and retransmits the data frame by 2.4/5 GHz (go to (4)).

(4) Reception of ACK:

If STA receives a data frame by 2.4/5 GHz correctly, STA sends an ACK frame. If AP receives the ACK frame, AP will generate the next data frame (go to (1)). Otherwise, go to (5).

(5) Retransmission by 2.4/5 GHz and determination of frequency band:

If the number of retransmissions by 2.4/5 GHz is less than a threshold θ_2, AP retransmits the data frame by 2.4/5 GHz (go to (4)). Otherwise, the received SNR is re-estimated. If the required FER can be achieved by the estimated SNR, AP uses 60 GHz for retransmission (go to (2)). Otherwise, AP uses 2.4/5 GHz for retransmission (go to (4)).

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3 Simulation

3.1 Simulation settings

Computer simulations were conducted to compare the performance of the proposed ARQ scheme with that of the conventional non-cooperative ARQ schemes using only either 60 GHz or 2.4/5 GHz, where both the data and ACK frames are transmitted by the same frequency band, 60 GHz or 2.4/5 GHz. It is assumed that shadowing occurs by human blocking during data transmission. For 60 GHz, a mathematical model in [6] was adopted to determine a time-varying propagation attenuation caused by one person. All parameters used in our simulations were the same as in [6] except $\bar{t}_D$, the average of shadowing duration t_D. Shadowing occurrence followed the Poisson distribution. If shadowing events by K (> 1) persons occur simultaneously, the propagation attenuation was determined by considering only the two largest attenuations as

$$A(t) = A_{u(1)}(t) + A_{u(2)}(t) \tag{1}$$

where $A_i(t)$, $i = 1, \cdots, K$, is the shadowing attenuation caused by the ith person and $u(j)$ is the user index of the jth largest attenuation. The attenuation model (1) was conceived from the experimental results presented in [7]. The average shadowing durations were set to $\bar{t}_D = 0.55$ or 10 sec. The former corresponds to the case where many people are walking with normal speed block the line-of-sight path from AP to STA. The latter is the case where a few persons stop between AP and STA for a moment.

The modulation scheme of 60 GHz was based on the low power SC of IEEE802.11ad where BPSK (626 Mbps) and QPSK (2502 Mbps) were used. The modulation scheme of 2.4/5 GHz was 64QAM (600 Mbps). The data frame size was 4,096 bytes. The ACK frame length was 14 bytes. For ACK transmission, 64QAM (600 Mbps) was applied for 2.4/5 GHz and BPSK (626 Mbps) for 60 GHz. The frame format of IEEE802.11n was adopted for 2.4/5 GHz transmissions and that of IEEE802.11ad for 60 GHz transmission. The two-level frame aggregation [2] was employed to reduce the overhead of control messages. The number of sub-frames of A-MPDU and A-MSDU was 21 and 2, respectively.

In simulations, the decision of received frames was carried out as follows: In advance, physical layer simulations were performed to obtain FER characteristic for each modulation scheme as a function of received SNR γ. For 60 GHz, propagation attenuation $A(t)$ at each time step was generated by (1), and the instantaneous SNR γ was computed as $\gamma = \bar{\gamma} - A(t)$ where $\bar{\gamma}$ is average received SNR in the absence of shadowing. Then, a modulation scheme was selected such that the required FER was satisfied, and FER was determined from the corresponding FER characteristic. Then, it was decided whether a frame was received successfully or not according to the FER. For 2.4/5 GHz, the propagation attenuation was assumed to be time-invariant, i.e., $A(t) = 0$. The average received SNR $\bar{\gamma}$ of 60 GHz and 2.4/5 GHz were set to 10.7 dB and 30.2 dB, respectively. It was assumed that the SNRs γ can be accurately estimated. The required FER was set to 10^{-3}. The thresholds were set to $\theta_1 = \theta_2 = 5$. In our preliminary simulation results, the thresholds did not affect the performance as long as $\theta_i \geq 2$.

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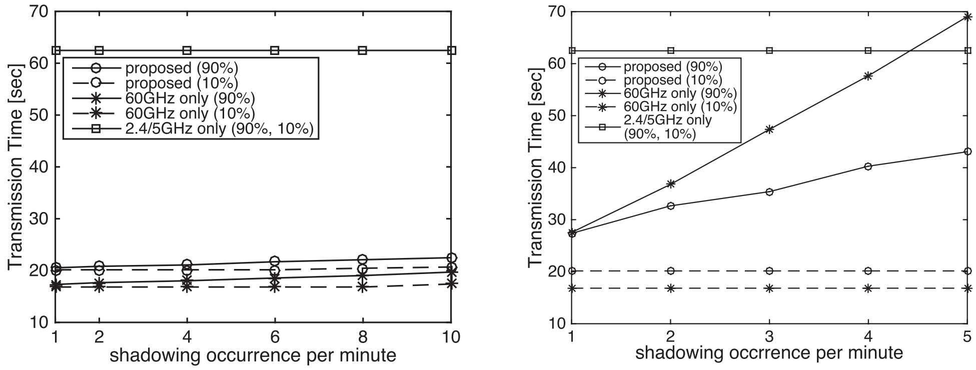
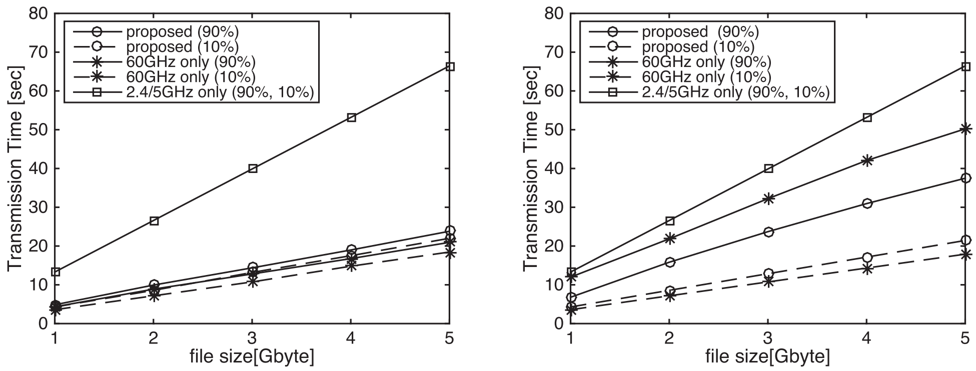


(a) $\bar{t}_D = 0.55$sec (b) $\bar{t}_D = 10$sec

Fig. 2. Transmission time versus the average number of shadowing occurrences per minute.



(a) $\bar{t}_D = 0.55$sec (b) $\bar{t}_D = 10$sec

Fig. 3. Transmission time versus file size.

3.2 Simulation results

The transmission time taken for downloading a file in the presence of shadowing was evaluated. The transmission time is defined as the time within which 90 (or 10)% of data frames for the file have been transmitted successfully. The effects of the shadowing duration, the shadowing frequency, and the file size on the transmission time were evaluated.

Fig. 2 shows the transmission time as a function of the average number of shadowing occurrences per minute where the file size was 4.7 Gbytes. It is clearly shown that the proposed ARQ scheme takes shorter transmission time than the scheme using only 2.4/5 GHz. In the case of short shadowing duration ($\bar{t}_D = 0.55$), the shadowing is not so severe that the performance of the proposed scheme is slightly worse than that of the scheme using only 60 GHz because of throughput degradation due to the use of ACK frame sent by using 2.4/5 GHz. On the other hand, when the shadowing is frequent and prolonged, the proposed scheme is superior to the scheme using only 60 GHz because the 60 GHz only scheme requires frequent retransmissions, while the proposed scheme can maintain transmission by using 2.4/5 GHz. Fig. 3 shows the transmission time for various file size where the average numbers of shadowing occurrences per minute for $\bar{t}_D = 0.55$ and 10 were set to 10 and 3, respectively. It can be seen that the proposed scheme

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can transmit a file faster than the scheme using only 60 GHz in the most cases, especially when the shadowing duration is long, and the file size is large.

4 Conclusion

In this letter, an ARQ scheme for the multi-band frequency cooperative wireless systems was proposed. The simulation results showed that the proposed scheme is effective when the shadowing is frequent and prolonged during large file transfers.

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