Proposal of Adaptive Downlink Modulation Using OFDM and MC-CDMA for Future Mobile Communications System

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***Abstract*:** **To meet the strong demand for broadband multimedia services by both nomadic and mobile users, it is important to increase the bit rate of future mobile communications systems. To enhance system capacity, novel technologies or new concepts for improving bandwidth efficiency are indispensable. In this paper, an adaptive downlink modulation using OFDM and MC-CDMA is presented for maximizing the system capacity and actualizing QoS (Quality of Service) control of future mobile communications. The basic concept of the proposal method is that a time frame is divided into two sub-frames, one is for OFDM and the other is for MC-CDMA, and the base station (BS) allocates a preferable modulation scheme to each user per each time slot in accordance with their service requirements and link conditions such as the received signal strength indication (RSSI) level and interference signal strength [1].The detailed concept of the proposed adaptive downlink modulation technique and slot allocation algorithm is discussed in this paper. Computer simulation was also conducted to evaluate the throughput performance of the proposed system. The simulation results show that the throughput performance of the proposed system is better than that of the system using OFDM or MC-CDMA only.**

1. Technology Concept

Many modulation schemes such as Single Carrier (SC), CDMA, OFDM, and Multi-Carrier (MC)-CDMA have been proposed for mobile systems, nomadic wireless access and fixed wireless access [2]-[5]. The selection of radio interface depends on the specifications of the system. OFDM is an attractive modulation scheme because of its high immunity to multi-path fading and its capability of offering a high transmission rate. However, the link quality of the OFDM system could be degraded when the co-channel interference signal strength from adjacent cells is increased.

OFDM and CDMA combined modulation schemes such as MC-CDMA and MC-DS/CDMA are attractive techniques that increase the process gains in the frequency domain and time domain, respectively [2]. In addition, the OFDM and CDMA combined scheme offers high transmission rate under multi-path fading environments and mitigates co-channel interference from adjacent cells. However, it is difficult to enhance its transmission rate per user by restricting the allocated bandwidth when the spreading factor (SF) is very large.

As explained above, each modulation scheme has distinct physical features. Namely, schemes have advantages and disadvantages in accordance with channel conditions such as the Carrier to Noise Ratio (CNR), Carrier to Interference Ratio (CIR), delay spread, and other parameters. The time and frequency spreading technique proposed in [3] is one method for adjusting the spreading factors in accordance with channel conditions. However, this method requires both a time and frequency spreading function for the user terminal and the base station has to be able to manage the complicated spreading codes to maintain the orthogonality between users.

The adaptive downlink modulation scheme using OFDM and MC-CDMA is a candidate for maximizing the system capacity of future mobile communications systems [1]. The basic concept of the method is that a time frame is divided into two sub-frames, one is for OFDM and the other is for MC-CDMA. In this scheme, the BS allocates a preferable modulation scheme and its parameters such as spreading factor, sub-carrier modulation and coding rate to each user per each time slot in accordance with the RSSI level and interference signal strength. As the hardware structures of OFDM and MC-CDMA are basically identical, the hardware complexity of the proposed method is much smaller than that of the time and frequency spreading techniques. In addition, the BS will be able to allocate the modulation scheme and its parameters depending on user request (QoS).

Using the adaptive downlink modulation scheme, the same channel frequency will be reused in every radio cell by allocating the OFDM scheme to users located in optimum RSSI and CIR conditions and the MC-CDMA scheme to users in harsh conditions, respectively. This feature also offers different service quality to different users in accordance with their requirements and channel conditions. By allocating the modulation scheme and its parameters (mapping pattern, coding rate, spreading factor, etc.) adaptively, users will be able to maintain their communications even in harsh wireless environments.

2. System Configuration

Figure 1 presents a frame structure of the adaptive downlink modulation scheme using OFDM and MC-CDMA. In this figure, a frame is divided into multiple slots. Some slots are allocated to OFDM and others to MC-CDMA. The transmission power for OFDM slots and MC-CDMA slots is set to be identical to maintain the continuity of the signal level between two modulation schemes.

Figure 2 presents a selection algorithm for the modulation scheme and its parameters. When the CNIR of the channel is high and the distance of the wireless link is short (RSSI level is high), the BS assigns an OFDM slot with high rate sub-carrier modulation such as 16QAM with a high coding rate. If the CINR is very low, the BS allocates an MC-CDMA slot with high spreading factor and low coding rate to maintain the communication link. The concept of this algorithm is based on the combination of adaptively allocating the radio interface and adaptive selection of its parameters. Moreover, the selection of the modulation scheme and its parameters will also be established with regard to the user's QoS. Consequently, the adaptive downlink modulation scheme will maximize the system capacity for wireless communications systems and respond to a user request by allocating a preferable modulation scheme to each time slot per user.

In this case, service areas of OFDM slots should be restricted around the BS and not overlap. Therefore, the same channel frequency can be allocated in every cell, which will enhance the efficiency of channel utilization. In contrast, the service area of MC-CDMA will be overlapped because co-channel interference between adjacent cells is mitigated using the spreading code in the frequency domain. The selection of the spreading code per user should consider the orthogonality between the other codes used in the same cell. As the same service areas of MC-CDMA signals are deployed as the current cellular systems, users will be able to establish their communication link in high mobility environments.

3. Computer Simulation

Computer simulation was conducted to evaluate the throughput performance of a wireless communications system using adaptive down link modulation technology. The parameters used in the simulation are summarized in Table 1. In each frame, OFDM or MC-CDMA slots are assigned to users independently in accordance with channel conditions under fast Rayleigh fading environments. Figure 3 shows the allocation diagram of the modulation scheme per each user. The users close to the BS (RSSI level is high) should be allocated OFDM to provide higher bit rate, and other users far from the BS (RSSI level is low) should be allocated MC-CDMA to enhance immunity to co-channel interference. If the number of OFDM slots is insufficient, MC-CDMA should be allocated to the users. At the same time, the modulation type for sub-carriers, coding rate and spreading factor (MC-CDMA), is selected at each slot by monitoring the

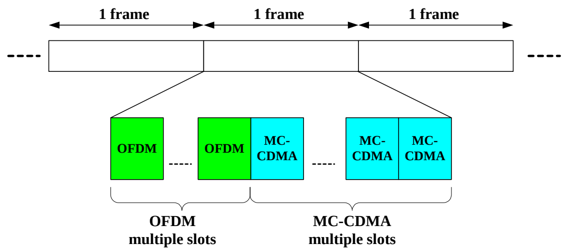

Figure 1: Frame structure

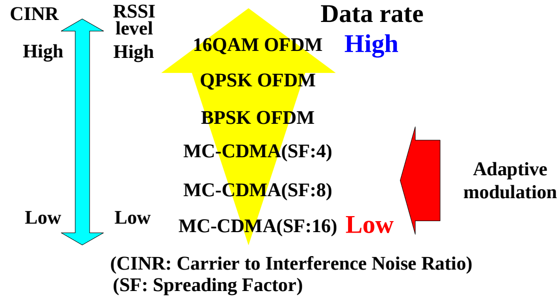

Figure 2: Selection algorithm of modulation scheme

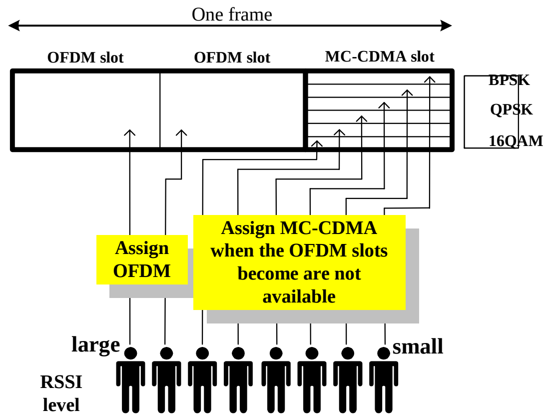

Figure 3: Allocation diagram of modulation scheme

RSSI and CIR level of the control channel transmitted from BS. These procedures actualize a QoS control that allocates high-speed data channels for the users located near the BS. Figure 4 shows a selection diagram of modulation type and coding rate in relation to the RSSI level and CIR. The RSSI threshold level that achieves the BER of 10^{-2} is derived by assuming the noise figure (NF) = 4 dB, absolute temperature = 290 K and bandwidth = 40 MHz. From Fig. 4, it is obvious that high throughput performance will be obtained when the RSSI level and CIR are high. Figures 5-7 show the selection diagrams of modulation type and coding rate in the same manner when the users are assigned the MC-CDMA system. For MC-CDMA, the spreading factor should be changed in accordance with the number of users, because the spreading factors should be greater than the number of users. Therefore, the modulation and coding type in relation to the RSSI level and CIR would be changed in accordance with the number of users assigned the MC-CDMA system. In these figures, the modulation schemes and coding rate

Bandwidth		40MHz
Number of sub-carriers		256
Symbol duration		Data:6.4μs , GI:1.6μs
Channel model		2-paths Rayleigh fading, б =300nsec
Maximum Doppler frequency		200Hz
Number of users		1〜19
OFDM slot length		16 Symbol
Shape of cell		hexagon
Radius of cell		400m
Transmission power		200mW (OFDM)
Propagation model		3.5th power attenuation
Shadowing deviation		7 dB
Chanel estimation		Ideal estimation
Channel frequency		5GHz
Modulation		BPSK , QPSK , 16QAM
Spreading factor (MC-CDMA)		4 , 8 , 16
Channel coding		Conbolutional coding (R=1/2 , 2/3 , 3/4 , K=7)
Transmission rate	OFDM	16Mbps(BPSK, R=1/2), 48Mbps(QPSK, R=3/4), 96Mbps(16QAM,R=3/4)
	MC-CDMA (SF=4)	4Mbps(BPSK, R=1/2), 10.7Mbps(QPSK, R=2/3), 24Mbps(16QAM,R=3/4)
	MC-CDMA (SF=8)	2Mbps(BPSK, R=1/2), 4Mbps(QPSK, R=1/2), 8Mbps(16QAM,R=1/2), 12Mbps(16QAM,
	MC-CDMA (SF=16)	1Mbps(BPSK, R=1/2), 2Mbps(QPSK, R=1/2), 5.3Mbps(16QAM,R=2/3),

Table 1: Simulation parameters

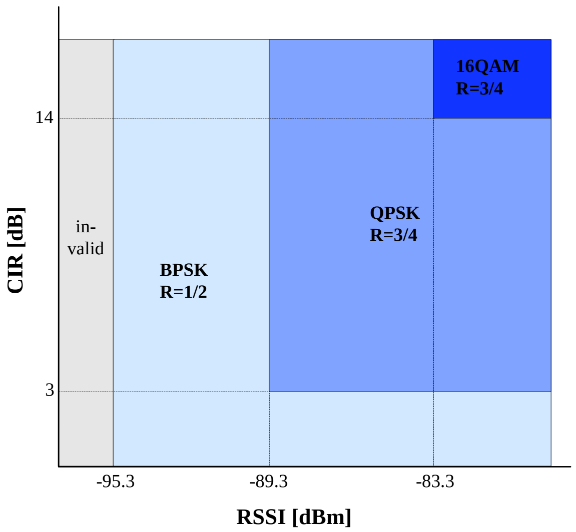

Figure 4: Modulation and coding types for the OFDM

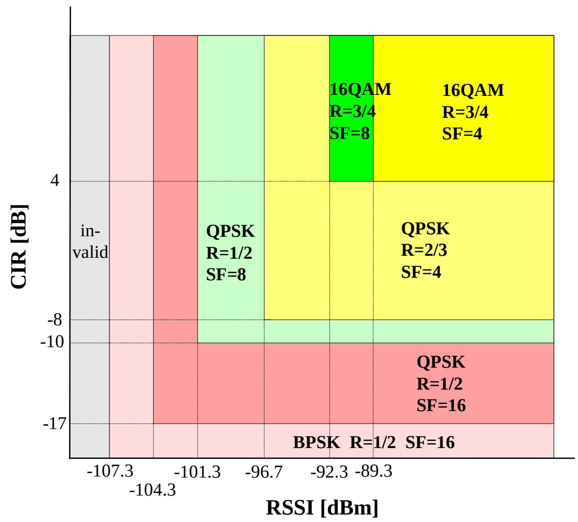

Figure 5: Modulation and coding type for the MC-CDMA users (The number of users is in the range of 1 and 4)

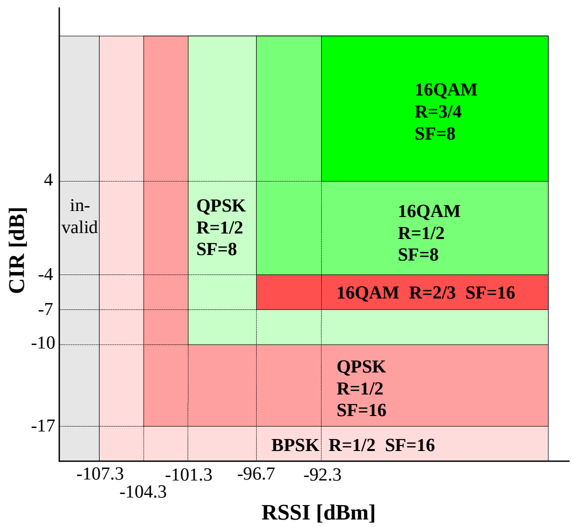

Figure 6: Modulation and coding type for the MC-CDMA users (The number of users is in the range of 5 and 8)

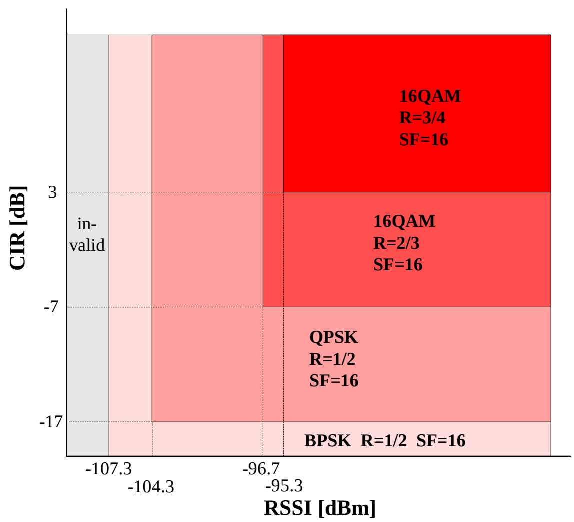

Figure 7: Modulation and coding type for the MC-CDMA users (The number of users is in the range of 9 and 16)

for the adaptive modulation technique are selected to achieve high throughput performance under different RSSI and CIR conditions. In the simulation, co-channel interference from two consecutive adjacent cells is considered. The target cell is set to one and users are arranged at random with equal probability condition in the cell. Throughput performance of the proposed system is evaluated by changing several parameters. More specifically, the parameters of number of users and frame structure of OFDM and MC-CDMA are changed to obtain the throughput performance under several conditions.

4. Simulation Results

Figure 8 shows the mean throughput performance per user versus the number of users. When the OFDM slot is set to 0, the MC-CDMA system is assigned to all users at any time. In the same way, when the MC-CDMA slot is set to 0, the OFDM system is assigned to all users at any time. In the OFDM system, the number of slots is set to be identical to the number of users. This means that a continuous OFDM signal is assigned to the user when the number of users is just one. In addition to this, each OFDM slot is assigned to one user. In other words, if the number of users is less than that of the OFDM slots, some slots will be vacant. This feature does not affect the simulation results of Fig. 8 because the vertical axis indicates the mean throughput performance of active slots.

From Fig. 8, the OFDM system shows the best performance when the number of users is less than two but goes to the bottom when the number of users is more than five because the frame length of the OFDM system extends when the number of slots is increased, and the throughput performance per user goes down. In addition, locations of users are spread in the cell coverage and some users should be located near the cell edge when the number of users is large. The users located in the cell edge area must be in worse CIR conditions and a low data late modulation scheme should be assigned for sub-carriers. This is the reason why mean throughput performance per user of the OFDM system worsens as a function of the number of users. On the other hand, the mean throughput performance per user of the MC-CDMA system shows stepwise characteristics depending on the number of users because the spreading factor of the MC-CDMA systems should be enlarged in accordance with the number of users. When the number of users is less than or equal to four, the size selected for the spreading factor is four. When the number of users is greater than four and less than or equal to eight, the spreading factor must be eight. In the same manner, the spreading factor must be sixteen if the number of users is in the range from nine to sixteen. From Fig. 8, the throughput performance of the MC-CDMA is almost flat even if the number of users is large. This characteristic means that MC-CDMA shows good performance under low CIR conditions. For the proposed downlink adaptive modulation scheme using OFDM and MC-CDMA, the highest mean throughput value is achieved when the number of OFDM slots and MC-CDMA slots are selected as one, respectively. The mean throughput performance per user of the proposed system is superior to that of the OFDM system when the number of users is above three, and superior to that of the MC-CDMA system at any case.

Figures 9 and 10 show the mean throughput performance per user of OFDM slots and MC-CDMA slots respectively when the number of users is changed from one to fifteen. In Fig. 9, the throughput performance of the OFDM system is identical to that of Fig. 8. When the number of OFDM slots is one, the mean throughput performance per user increases as a function of the number of users because the distance between BS and the nearest user is shortened and a high density modulation scheme such as 16QAM with high coding rate must be assigned for sub-carriers to the OFDM user. The more the number of users increases, the greater the probability that the user assigned OFDM slots is in good condition (RSSI level and CIR are high) for increase. This tendency is observed when the number of OFDM slots is two or three, but mean throughput performance per user does not increase when the number of users is less than or equal to the number of OFDM slots. In this figure, the best throughput performance is obtained when the number of OFDM slots and MC-CDMA slots is selected as one, respectively. In this case, the maximum value reaches around 45 Mbit/s. For MC-CDMA slots as shown in Fig. 10, the MC-CDMA system shows the best performance among the six cases. However, the highest throughput value of 6 Mbit/s is much smaller than that of the OFDM slot as shown in Fig. 9. From these simulation results, it is concluded that the adaptive downlink modulation assigning OFDM slots and MC-CDMA slots for each user in relation to channel conditions offers high-speed data communication services for OFDM users and some data rate for MC-CDMA users under harsh conditions at the same time. The proposed system offers types of QoS services depending on user locations and channel conditions.

Figures 11 and 12 show the mean throughput performance per user versus the number of OFDM slots when the number of users is selected to be sixteen and twenty, respectively, and the numbers of slots per frame is ten. In Fig. 11, the spreading factor of the MC-CDMA slots is set to be sixteen and the number of OFDM slots is changed from four to nine. As the number of users is sixteen, the number of OFDM slots is changeable from zero to nine in Fig. 12. In these figures, the mean throughput performance per user both of the OFDM slots and MC-CDMA slots decreases as a function of the number of OFDM slots. However, the total throughput performance is almost flat and slightly increasing depending on the number of OFDM slots. These simulation results indicate that the proportion of the high-speed users and lower rate users is adjustable without decreasing the total throughput performance of the system. Thus, the proposed adaptive downlink modulation scheme provides flexible and high performance broadband communications services for mobile and nomadic users.

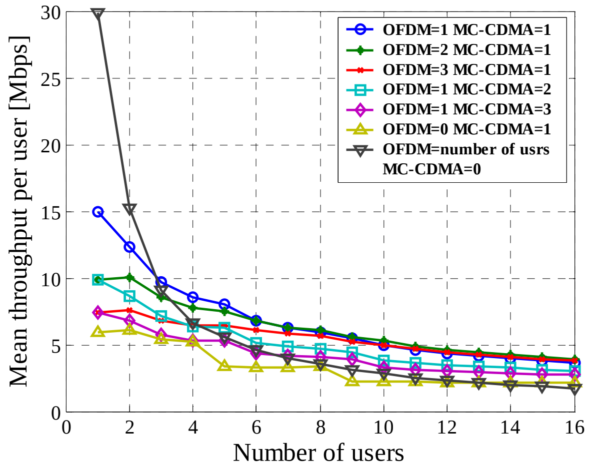

Figure 8: Mean throughput performance per user vs. number of users

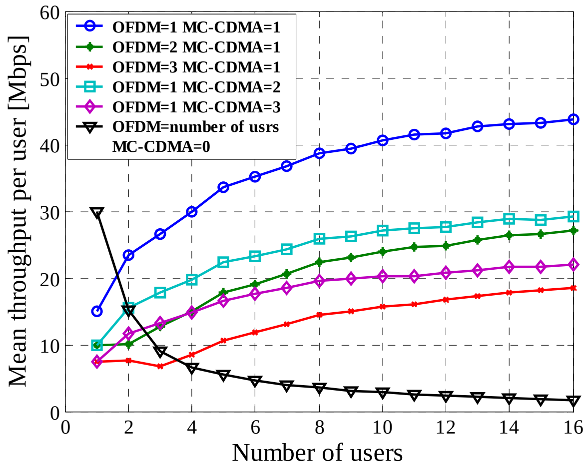

Figure 9: Mean throughput performance for OFDM slots per user of users vs. number of users

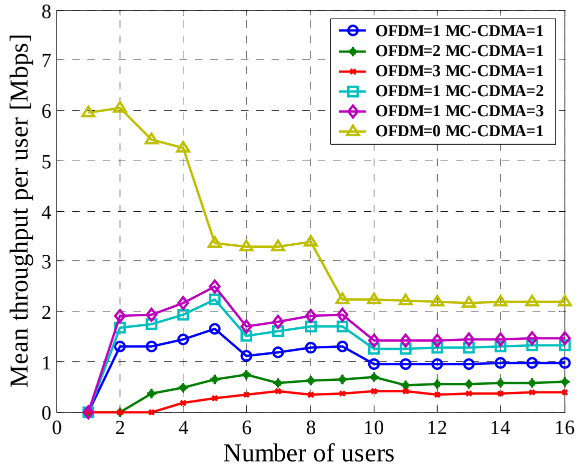

Figure 10: Man throughput performance per user for MC-CDMA slots vs. number of users

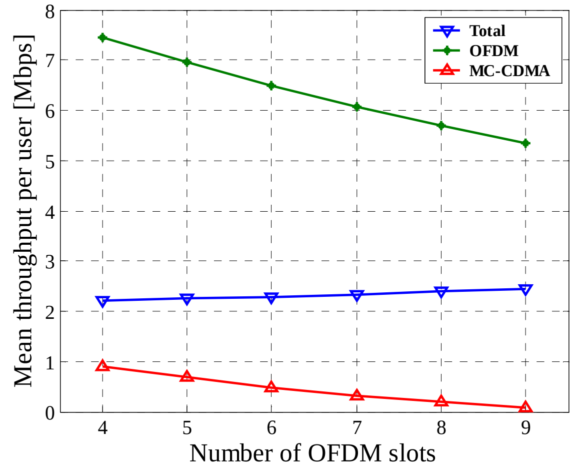

Figure 11: Mean throughput performance per user vs. number of OFDM slots when number of total slots and users are 10 and 20, respectively

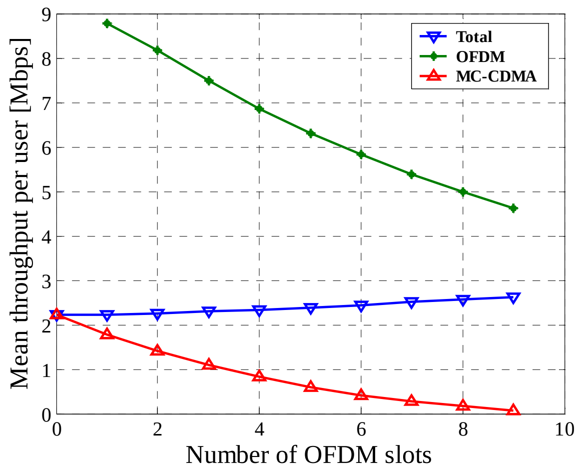

Figure 12 Mean throughput performance per user vs. number of OFDM slots when numbers of total slots and users are 10 and 20, respectively

5. Conclusion

This paper presented an adaptive downlink modulation scheme using OFDM and MC-CDMA for future mobile communications systems. The proposed scheme maximizes the system capacity by allocating a preferable modulation scheme to each time slot per user and offers types of QoS services depending on user locations and channel conditions. The detailed adaptive modulation technique and selection algorithm were explained in this paper. Computer simulation was conducted to evaluate the throughput performance of the proposed system by changing the number of users, OFDM slots and MC-CDMA slots. From the simulation results, according to the number of users, the proposed scheme using OFDM and MC-CDMA exceeds the throughput performance of the OFDM system or MC-CDMA system when the number of OFDM slots and MC-CDMA slots are selected as one respectively. The simulation results also indicate that the proportion of high-speed users and lower rate users is adjustable without decreasing the total throughput performance of the system. Thus, the proposed adaptive downlink modulation scheme provides flexible and high performance broadband communications services for mobile and nomadic users. Examination of other cases considering the QoS algorithm based on user requests and other communication environments are due to be advanced in the future. Furthermore, practical channel estimation schemes should be also considered in the future research.

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