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**Study on Efficient Random
Access Networks in OFDM-Based
Wireless Communications
(summary)**

Tomoya Tandai

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Chapter 1

General Introduction

Chapter 1 is devoted to a general introduction of the thesis. Efficiency of wireless communication networks in the time domain, the frequency domain, the spatial domain, and the areal domain are discussed and random access techniques are summarized in Chapter 2. In Chapter 3, a multipacket-per-slot reservation-based random access protocol with multiuser detection (MD) and automatic repeat request (ARQ) is proposed in order to enhance efficiency in the time domain. An uplink multiuser multiple-input multiple-output (MIMO) protocol in WLANs is proposed in order to enhance efficiency in the spatial domain in Chapter 4. In Chapter 5, a coexistence protocol for heterogeneous networks is proposed in order to enhance efficiency in the areal domain. In Chapter 6, an out-of-band emission suppression technique in orthogonal frequency division multiplexing (OFDM)-based wireless communications is proposed in order to enhance efficiency in the frequency domain. Total efficiency of a random access network based on OFDM wireless communications realized by combining the proposed four schemes is demonstrated in Chapter 7. Finally, Chapter 8 concludes this thesis.

Chapter 2

Efficient Wireless Communication Networks Based on Random Access and Other Techniques

This chapter has described the details of the efficiency enhancements in the time, frequency, spatial, and areal domains, respectively. Conventional techniques that enhance the efficiency in each domain have been reviewed.

In recent years, the throughput of the random access protocol has been enhanced by the application of signal processing techniques such as carrier sensing, successive interference cancellation, MD, and MIMO. Efficiency in the frequency domain is enhanced by OFDM, OFDMA, the channel bonding technique, the cognitive radio technique and so on. In order to enhance efficiency in the areal domain, HetNet has been proposed in LTE-Advanced. MIMO and MU-MIMO, effective techniques for enhancing efficiency in the spatial domain, are employed in IEEE 802.11n WLANs, WiMAX, and LTE.

Among the techniques that enhance the throughput, conventional random access protocols are reviewed. Random access protocols are categorized into a reservation-based group or a non-reservation-based group. They are also categorized into a group using signal processing or a group that does not use signal processing. The throughput of the random access protocol can be increased by employing the signal processing at the expense of the cost of the signal processing.

Chapter 3

Multipacket-Per-Slot Reservation-Based Random Access Protocol with MD and ARQ

This chapter has proposed a multipacket-per-slot reservation-based random access protocol with MD and ARQ (MPRMD). The proposed protocol enables a base station to maximally detect access request packets from terminals by giving a transmission opportunity efficiently and by receiving small packets with minimum necessary components using the multiuser detection. The proposed protocol can further enhance the efficiency by assigning one data slot to multiple terminals.

On the assumption that the QPSK-OFDM based packets are exchanged between the base station and the terminals with single antenna, the average throughput and the average delay were evaluated by the computer simulation. In the evaluation, all overheads of uplink access request packets and downlink slot-assignment packets except only for acknowledgment packets were included. It has been shown that the maximum throughputs of MPRMD with the average SNR of 30 dB reach 1.4 and 1.7 when a data packet is 10 times and 50 times as long as a control packet, respectively and outperform those of slotted ALOHA employing multiuser detection under the penalty of slight increase of delay.

In this chapter, MPRMD is on the basis of single-input single-output (SISO). On the other hand, in these years, MIMO has employed in several systems. MPRMD employing MIMO is the next step to further enhance the throughput.

This chapter also has theoretically analyzed the throughput and the transmission delay of a multipacket-per-slot reservation-based random access protocol with MD and ARQ in which the variable-length frame including the fixed-length AP transmission period is repeated.

It is proved by both the theoretical analysis and the computer simulations that in this type of the reservation-based protocol, when the packet generation follows the Poisson process, there appears two peaks in the throughput curve and the transmission delay does not exponentially increase according to the traffic load. Thus, this chapter provided the framework for deriving the throughput and the transmission delay of the general reservation-based random access protocol in which the variable-length frame including the fixed-length access request period is repeated.

Chapter 4

Uplink Multiuser MIMO Protocol for Throughput Maximization in Wireless Local Area Networks

This chapter proposes an efficient uplink MU-MIMO protocol in IEEE 802.11 WLANs. As a part of the proposed protocol, the OFDMA-based uplink access request transmission scheme is also proposed. By adopting the proposed protocol, the overheads to start the uplink MU-MIMO transmission can be reduced and the network throughput is enhanced. Computer simulations are performed and the results show that the network throughput is enhanced and that the transmission delay is reduced by the proposed protocol.

Chapter 5

Coexistence Protocol for Heterogeneous Networks Based on Carrier Sensing

In this chapter, local area small cell (SC) network coexisting with the large cell (LC) network is proposed. The proposed SC network uses uplink resources of the LC network with a transmission power that does not interfere with base stations in the LC network. In the proposed SC network, in order to avoid interference from mobile terminals in the LC network the SC terminal executes carrier sense at the beginning part of uplink slot and if the detected signal level is below a threshold then the SC terminal transmits a signal during the remained periods of the slot. Both single carrier communications and multicarrier communications are considered as the transmission schemes of the SC network.

The communication success probabilities and the averaged total throughputs in the proposed SC network are evaluated in the computer simulation. It is confirmed that in the case of single carrier communications if the radius of the SC network is about 50 m, almost the same averaged total throughputs as the data rate of the LC network can be achieved without interfering with the base stations of the LC network. It is also confirmed that the averaged total throughput in the SC network by the multicarrier communications is kept to about 3 Mbps even in the condition that about 90 % resources are consumed in the LC network.

As a future work, performance of the proposed SC network should be evaluated in other LC networks such as Personal Digital Cellular System (PDC) and Wide-band Code Division Multiple Access (W-CDMA).

Chapter 6

Out-of-Band Emission Suppression Technique by Regenerating Null Signals in OFDM-Based Wireless Communications

In this chapter, an out-of-band emission suppression technique referred to as null regeneration is proposed for OFDM-based cognitive radio. In the first step of the proposed method, after the null subcarriers are set in each OFDM symbol according to the result of the spectrum sensing, one packet consisting of multiple OFDM symbols with GIs is oversampled and buffered. In the second step, the buffered signal is converted to the frequency-domain signal at once by the larger FFT and null subcarriers are regenerated. Finally, the signal is inverse-fast-Fourier transformed and the time-domain signal is transmitted. Thus, the proposed null regeneration method can suppress the out-of-band emissions caused by the discontinuity between the consecutive OFDM symbols. Computer simulations are performed and it is confirmed that the proposed method can significantly suppress the out-of-band emission with no degradation in the packet error rate performance in the QPSK and the 16QAM modulation schemes and with slight degradation in the 64QAM modulation scheme.

Chapter 7

Efficient Random Access Network in OFDM-Based Wireless Communications

This chapter has proposed the efficient random access network based on OFDM wireless communications. This chapter has also shown the methods on how individually proposed four schemes are combined. The proposed MPRMD or the proposed uplink MU-MIMO protocol is used in the proposed SC communications of the heterogeneous network where both the LC and the SC communications employ the proposed OFDM out-of-band emission suppression technique. Thus, the proposed random access network based on OFDM wireless communications is realized.

Capacity of the proposed random access network based on OFDM wireless communications has been calculated. The maximum capacity of the proposed network is calculated as $5.04C$ bits/s/Hz/site that is about 5 times as large as that of the conventional network.

It is confirmed that the proposed random access network based on OFDM wireless communications is remarkably effective for the enhancement of total efficiency in wireless communications.

Chapter 8

Conclusion

In this study, four schemes have been proposed in order to realize an efficient random access networks in OFDM-based wireless communications.

In Chapter 3, a multipacket-per-slot reservation-based random access protocol with MD and ARQ has been proposed. The proposed protocol enables a base station to maximally detect access request packets from terminals by giving a transmission opportunity efficiently and by receiving small packets with minimum necessary components using the multiuser detection. The proposed protocol can further enhance the efficiency by assigning one data slot to multiple terminals.

On the assumption that the QPSK-OFDM based packets are exchanged between the base station and the terminals with single antenna, the average throughput and the average delay were evaluated by the computer simulation. In the evaluation, all overheads of uplink access request packets and downlink slot-assignment packets except only for acknowledgment packets were included. It has been shown that the maximum throughputs of MPRMD with the average SNR of 30 dB reach 1.4 and 1.7 when a data packet is 10 times and 50 times as long as a control packet, respectively and outperform those of slotted ALOHA employing multiuser detection under the penalty of slight increase of delay.

In Chapter 3, MPRMD is on the basis of SISO. On the other hand, in these years, MIMO has employed in several systems. MPRMD employing MIMO is the next step to further enhance the throughput.

Chapter 3 also has theoretically analyzed the throughput and the transmission delay of a multipacket-per-slot reservation-based random access protocol with MD and ARQ in which the variable-length frame including the fixed-length AP transmission period is repeated.

It is proved by both the theoretical analysis and the computer simulations that in this type of the reservation-based protocol, when the packet generation follows the Poisson process, there appear two peaks in the throughput curve and the transmission delay does not exponentially increase according to the traffic load. Thus, this paper provided the framework for deriving the throughput and the transmission delay of the general reservation-based random access protocol

in which the variable-length frame including the fixed-length access request period is repeated.

In Chapter 4, an efficient uplink MU-MIMO protocol in IEEE 802.11 WLANs has been proposed. As a part of the proposed protocol, the OFDMA-based uplink access request transmission scheme is also proposed. By adopting the proposed protocol, the overheads to start the uplink MU-MIMO transmission can be reduced and the network throughput is enhanced. Computer simulations are performed and the results show that the network throughput is enhanced and that the transmission delay is reduced by the proposed protocol.

Next step is the evaluation of the throughput and delay in the case that terminals are located in the randomly-selected positions and their SNR values at AP are different each other. Performance evaluation of the user grouping strategy that selects users with similar SNR values is also the next task.

In Chapter 5, local area small cell network coexisting with the LC network is proposed. The proposed SC network uses uplink resources of the LC network with a transmission power that does not interfere with base stations in the LC network. In the proposed SC network, in order to avoid interference from mobile terminals in the LC network the SC terminal executes carrier sense at the beginning part of uplink slot and if the detected signal level is below a threshold then the SC terminal transmits a signal during the remained periods of the slot. Both single carrier communications and multicarrier communications are considered as the transmission schemes of the SC network.

The communication success probabilities and the averaged total throughputs in the proposed SC network are evaluated in the computer simulation. It is confirmed that in the case of single carrier communications if the radius of the SC network is about 50 m, almost the same averaged total throughputs as the data rate of the LC network can be achieved without interfering with the base stations of the LC network. It is also confirmed that the averaged total throughput in the SC network by the multicarrier communications is kept to about 3 Mbps even in the condition that about 90 % resources are consumed in the LC network.

Next step is the evaluation of the total capacity in the case that many SC networks are located on the whole of the LC cells.

In Chapter 6, an out-of-band emission suppression technique referred to as null regeneration has been proposed for OFDM-based cognitive radio. In the first step of the proposed method, after the null subcarriers are set in each OFDM symbol according to the result of the spectrum sensing, one packet consisting of multiple OFDM symbols with GIs is oversampled and buffered. In the second step, the buffered signal is converted to the frequency-domain signal at once by the larger FFT and null subcarriers are regenerated. Finally, the signal is inverse-fast-Fourier transformed and the time-domain signal is transmitted. Thus, the proposed null regeneration method can suppress the out-of-band emissions caused by the discontinuity between the consecutive OFDM symbols. Computer simulations are performed and it is confirmed that the proposed method can significantly suppress the out-of-band emissions with no degradation in the packet error rate performance in the QPSK and the 16QAM

modulation schemes and with slight degradation in the 64QAM modulation scheme.

Next step is the evaluation of the total capacity in the multi-channel systems considering the adjacent channel interference.

In Chapter 7, an efficient random access network based on OFDM wireless communications has been proposed. Capacity of the proposed network is calculated and it is confirmed that the total capacity is enhanced to about five times as large as that of the conventional scheme when the proposed MPRMD is used in the proposed SC communications of the heterogeneous network in which both the LC and the SC networks employ the proposed OFDM out-of-band emission suppression technique.

Finally, it is concluded that the proposed random access network based on OFDM wireless communications is greatly effective for the enhancement of total efficiency in wireless communications.