Group-based Centralized Radio Resource Management Strategies in Wireless Local Area Networks

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Abstract

To improve the transmission performance of wireless local area networks (WLANs), this paper proposes a distributed coordination function-based (DCF-based) medium access control (MAC) protocol that enables centralized radio resource management (RRM). In the protocol, AP and associated stations form a cooperative group, and the central controller acts as a master to organize the access of associated stations. Once the cooperative group reserves the radio resource in a traditional DCF-manner, the central controller allocates the reserved radio resources to the stations by an orthogonal frequency division multiple access (OFDMA) scheme. Since the central controller dynamically allocates the fine-grained resource blocks (RBs) to the stations through the opportunistic two-dimensional scheduling based on the channel and traffic conditions of each station, the transmission opportunities can be granted to the appropriate stations. Numerical results confirm that the proposed protocol enhance the throughput while satisfying QoS requirements.

1. Introduction

With the proliferation of IEEE 802.11 devices, wireless local area networks (WLANs) will play an important role in next-generation wireless services. WLANs based on IEEE 802.11 standard [1] were originally developed and promoted as a wireless version of Ethernet. In addition, WLANs operate in unlicensed bands that should be shared by other wireless devices. For these reasons, carrier sense multiple access with collision avoidance (CSMA/CA) is adopted in a medium access control (MAC) protocol. The specific CSMA/CA mechanism defined in IEEE 802.11 standard is referred to as the distributed coordination function (DCF) [1]. Because of the same back-off rules imposed on every station, DCF provides equal access opportunity to all the contending stations, thus the fairness in terms of transmission opportunity is implicitly guaranteed. However, because of its fully distributed and contention-based channel access nature, the traditional DCF is insufficient from the viewpoint of the efficient use of radio resource.

One of the critical problems of DCF is the access grant mechanism. In traditional DCF, each station tries to acquire a transmission opportunity based on the presence of DATA frame to be transmitted. Such a random access mechanism increases the contention in the acquisition of the transmission opportunity. Additionally, in DCF, because the access of station is granted on fair transmission opportunity basis regardless of the transmission capacity of the station and the radio resource is exclusively occupied by the single station in a specific timing, DCF cannot fully utilize the radio resource. When there are multiple stations in a wireless network, to enhance the transmission performance, transmission opportunities should be granted to the stations based on their instantaneous channel and traffic states. Such a prioritized medium access works further effectively when orthogonal frequency division multiple access (OFDMA) is employed as a multiple access scheme in frequency selective fading channel. However, the traditional DCF neither prioritizes medium access by channel and traffic states nor employs OFDMA. Moreover, when numbers of stations are spatially distributed, a well-organized spatial reuse of radio resource is an effective scheme to utilize the radio resource efficiently, and it is well known that the transmission performance can be enhanced by reducing the frequency reuse distance [2]. However, DCF allows multiple stations to reuse the radio resource only when they do not cause mutual interference due to its interference avoidance mechanism.

These problems can be solved by introducing a centralized radio resource management (RRM) and a dynamic resource allocation using fine-grained small sized resource blocks (RBs). In a centralized RRM, a central controller gathers channel state information (CSI) and traffic state information (TSI) of the associated stations. In this paper, we

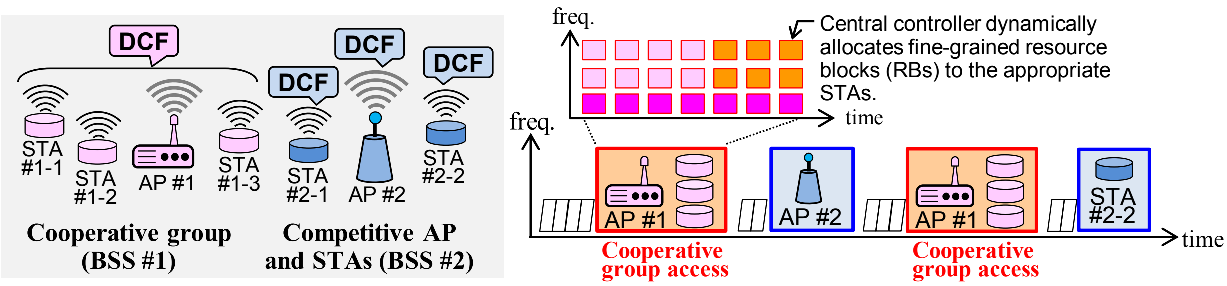

Fig. 1 Overview of group-based centralized RRM.

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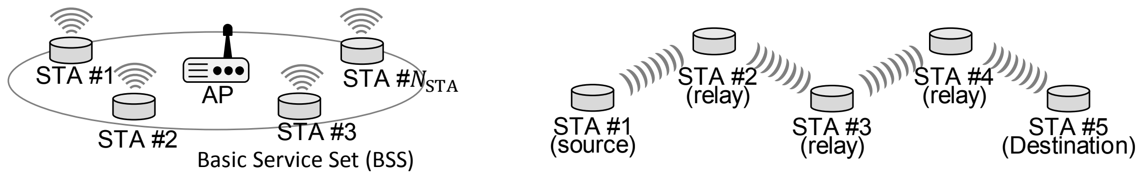
refer to the combination of CSI and TSI required for the centralized RRM as channel-and-traffic state information (CTSI). The central controller assigns fine-grained RBs to the stations based on their CTSI, the transmission opportunities can be granted to the appropriate stations. In addition, under frequency selective fading condition, multi-user diversity gain can be obtained by scheduling the transmissions in a manner that exploits the independence of channels conditions. For wireless systems operating in the unlicensed bands, however, such a centralized RRM cannot be directly introduced because CSMA/CA is already introduced for coexistence with the other wireless systems in a harmonized way.

Thus, this paper proposes a novel DCF-based MAC protocol that enables group-based centralized RRM while keeping spectrum coordination with the other wireless devices based on conventional DCF. Fig. 1 illustrates the overview of group-based centralized RRM. In the proposed protocol, the AP and associated stations form the cooperative group and attempt to reserve the radio resource in a traditional DCF-manner. Once the radio resource is successfully reserved, the central controller manages the access of each station by OFDMA scheme. Specifically, the central controller dynamically allocates the radio resource to the stations through the two-dimensional scheduling based on their CTSI, the transmission opportunities can be granted to the appropriate stations so as to enhance the throughput while satisfying QoS requirement with high probability.

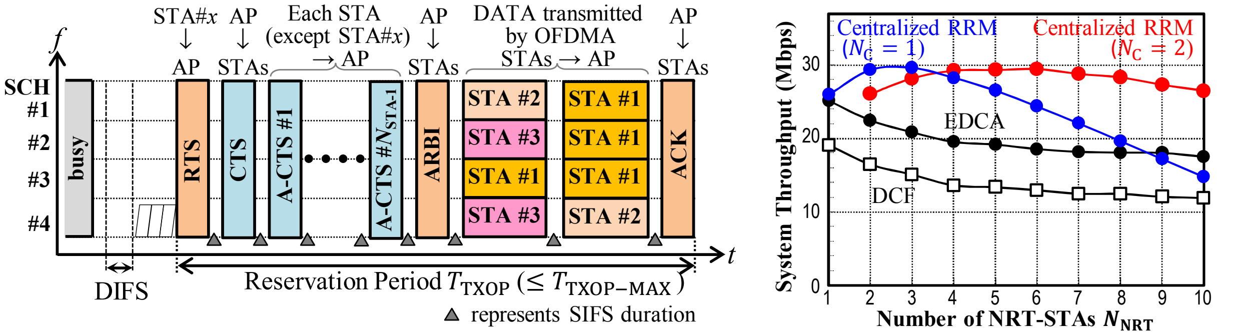


(a) Single-hop infrastructure network. (b) Multi-hop ad hoc network.

Fig. 2 Configurations of single-hop infrastructure network and multi-hop ad hoc networks.

2. Intra-BSS Group-based Centralized RRM for Single-hop Infrastructure Network

In a single-hop infrastructure network shown in Fig. 2(a), AP and associated stations located within the single-hop coverage area constitute a basic service set (BSS). In this section, we propose the DCF-based MAC protocol that enables the centralized RRM in a single-hop infrastructure network (*Intra-BSS group-based centralized RRM*). Throughout of this section, we focus on the BSS consisting of one AP and N_{STA} stations. In addition, we only consider the uplink transmission, since the sub-channel allocation is relatively easier in the downlink transmission.



(a) MAC Protocol for intra-BSS group-based centralized RRM. (b) Throughput vs. number of NRT-STAs.

Fig. 3 MAC protocol and throughput performance of intra-BSS group-based centralized RRM.

Fig. 3(a) illustrates a MAC protocol for intra-BSS group-based centralized RRM. In this example, the number of OFDMA sub-channels $N_{\mathrm{SCH}} = 4$. In this protocol, the AP acts as a master to organize all the stations in the BSS. When one of associated stations acquires the transmission opportunity using the traditional DCF protocol, it sends an RTS frame to reserve the radio resource. After receiving RTS frame successfully, AP broadcasts CTS frame to all the associated stations. After that, each station replies an additional CTS (A-CTS) frame to the AP according to the order specified in CTS frame. Each A-CTS frame contains the CTSI of the station. Thus, by exchanging RTS/CTS/A-CTS frames between AP and stations, the AP can obtain the CTSI of all the associated stations. Using the CTSI specified in A-CTS frames, the AP coordinates the allocation of RBs so as to maximize the multi-user diversity gain while keeping QoS requirement [3], then AP notifies the allocation of RBs by broadcasting an assigned resource block information (ARBI) frame. After the transmission of ARBI frame, each station transmits a DATA frame using the allocated RBs. Finally, the AP broadcasts ACK frame and releases the radio resource.

In the proposed protocol, to maximize a multiuser diversity gain, the AP collects CTSI of all the stations by exchanging the RTS/CTS/A-CTS frames. As shown in Fig. 3(a), the total number of RTS and A-CTS frames is equal to those of the stations (N_{STA}). This means that, when the number of stations increases, the signaling overhead would

Table 1 Simulation Parameters.

Sizes of Control frames	RTS : 20 Oct., others : 14 Oct.
Channel frequency	2.4 GHz-channel
Number of sub-channels	4
Total number of subcarriers	52 (based on 802.11g std.)
Number of subcarriers per sub-channel	13 (12 subcarriers for data and 1 subcarrier for pilot)
$T_{\mathrm{TXOP-MAX}}$	2.45 ms.
MCS for DATA frame transmission	64QAM (r = 3/4), 16QAM (r = 1/2) QPSK (r = 1/2), BPSK (r = 1/2), NULL

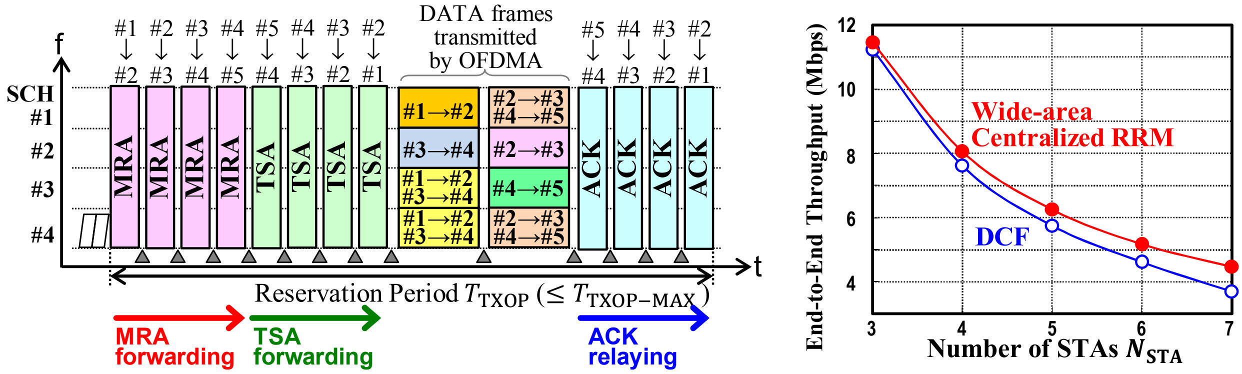
Table 2 Simulation Parameters.

Sizes of Control frames	MRA : (27 + L_{PL}) Oct. TSA : 14 Oct., ACK : 22 Oct. L_{PL} is the length of CTSI payload
Channel frequency	5.2 GHz-channel (20 MHz)
Number of sub-channels	4
Total number of subcarriers	52 (based on 802.11g std.)
Number of subcarriers	13 (12 subcarriers for data and 1 subcarrier for pilot)
$T_{\mathrm{TXOP-MAX}}$	determined by the number of hops
MCS for DATA frame ransmission	256QAM (r = 3/4, 5/6), 64QAM (r =1/2, 3/4, 5/6), 16QAM (r = 1/2, 3/4), QPSK (r = 1/2, 3/4), BPSK (r = 1/2), NULL
Path loss model	Indoor path loss model in ITU-R P.1238
Delay profile	TGn Channel Model E

become overwhelming and it degrades the throughput performance. In order to reduce the signaling overhead caused by centralized RRM, we further introduce a station-grouping scheme which groups all stations within the BSS into clusters. In the station-grouping scheme, AP and associated stations in the BSS are simply grouped into clusters.

To discuss the effectiveness of centralized RRM, we evaluate system throughput of WLANs using proposed protocol. In the performance evaluation, we consider the BSS consisting of a single AP, single RT-STA (station with real-time traffic) and N_{NRT} NRT-STAs (stations with non-real-time traffic). All stations have the same distance from the AP (30 m), and the associated stations in the BSS are equally grouped into N_{C} clusters. The RT-STA generates one packet in every 20 ms., and each NRT-STA generates a packet according to the Poisson process with the arrival rate λ. The sizes of packets generated by RT-STA and NRT-STA are 200 byte and 1500 byte, respectively. As a QoS requirement, we assume that each packet generated by RT-STA is transmitted successfully within allowable transmission delay (12 ms.). Physical layer specifications are mainly based on IEEE 802.11g standard except that OFDMA is additionally introduced for the intra-cluster multiple access. Other major parameters including modulation and coding scheme (MCS) parameter sets are summarized in Table 1. We introduce a 16-path exponentially decayed Rayleigh fading model. we further introduce a station-grouping scheme which groups all stations within the BSS into clusters.

Fig. 3(b) shows the system throughput versus the number of NRT-STAs when the number of clusters $N_{\mathrm{C}} = 1$ and $N_{\mathrm{C}} = 2$. Here the system throughput is defined as the sum of individual station's throughput in the BSS. Please note that, when the number of clusters $N_{\mathrm{C}} = 1$, all associated stations belong to the same cluster, that is, clustering scheme is not adopted. For comparison, we also evaluate the throughput of WLAN with traditional DCF protocol and that with enhanced distributed channel access (EDCA) protocol defined in IEEE 802.11e. In Fig. 3(b), there is an optimum number of NRT-STAs that maximizes the throughput of WLAN using proposed protocol. For example, when the number of clusters $N_{\mathrm{C}} = 1$, throughput of proposed DCF is maximized when $N_{\mathrm{NRT}} = 2$ and it is much higher than that of DCF and EDCA. This result shows the trade-off between the multi-user diversity gain and the MAC efficiency, that is, as the number of NRT-STAs N_{NRT} increases, the transmission rate of DATA frames is improved by multi-user diversity gain, while the excessive signaling overhead degrades the MAC efficiency. Therefore, with the the increase of the number of stations N_{NRT}, the throughput of WLAN using proposed protocol is severely degraded. However, by adjusting the number of clusters N_{C} , the proposed DCF still achieves a higher throughput than the DCF and EDCA regardless of the number of stations N_{NRT}.



(a) MAC Protocol for group-based wide-area centralized RRM in multi-hop ad hoc network.

(b) End-to-End throughput vs. number of STAs.

Fig. 4 MAC protocol and throughput performance of group-based wide-area centralized RRM.

3. Group-based Wide-area Centralized RRM for Multi-hop Ad hoc Network

Centralized RRM cannot be directly introduced into a multi-hop ad hoc network because there are some requirements to be satisfied. Firstly, stations are required to reserve the radio resource for their exclusive use throughout multi-hop wide area. Secondly, it is necessary to determine which station plays a role of central controller that manages the access of associated stations. Thirdly, to properly allocate the radio resource to the stations, the CTSI of all stations must be gathered at the central controller. The objective of this section is the proposal of MAC protocol that satisfies the above requirements and enables a *group-based wide-area centralized RRM* in a multi-hop ad hoc network.

Fig. 4(a) illustrates a MAC protocol for wide-area group-based centralized RRM. In the proposed protocol, at first, each station that wishes to transmit DATA frame tries to acquire the transmission opportunity by the traditional DCF protocol. After the acquisition of transmission opportunity, to reserve the radio resource at as many hops as possible, a *medium reservation advertisement* (MRA) frame is forwarded from the station until the MRA frame is delivered to the destination station or the forwarding of MRA frame is interrupted by the intermediate relay station. In this paper, we refer to the process of hop-by-hop relaying of MRA frame as *MRA forwarding*. MRA forwarding enables the stations constituting the multi-hop network to reserve the radio resource for their exclusive use throughout multi-hop wide area. MRA forwarding is also utilized to determine the station that acts as the central controller and to gather the CTSI of associated stations at the central controller. After the MRA forwarding, the central controller dynamically controls the access of associated stations. Specifically, based on the CTSI of each station, the central controller assigns RBs to the appropriate stations so as to enhance the end-to-end throughput. Assigned resource block information (ARBI) is notified to stations by relaying *transmission schedule advertisement* (TSA) frame, and the stations transmit their DATA frames on the assigned RBs. In the proposed protocol, since the opportunistic two-dimensional scheduling provides multi-user diversity gain and reduces the frequency reuse distance, the transmission rate of DATA frame can be increased.

We evaluate the transmission performance of multi-hop network employing the proposed protocol and discuss the effectiveness of centralized RRM. For comparison, we also evaluate the performance of multi-hop networks using the traditional DCF protocol. We assume that N_{STA} ($3 \leq N_{\mathrm{STA}} \leq 7$) stations constitute the multi-hop network. Fig. 2(b) corresponds the network topology when $N_{\mathrm{STA}} = 5$. STA #1 generates traffic destined to STA #N_{STA} according to the Poisson process with the arrival rate λ, and the stations except STA #1 and STA #N_{STA} work only as relay. Since the objective of our proposal is to enhance the end-to-end throughput, we focus on the saturated condition, that is, the arrival rate λ is high enough to saturate the throughput while satisfying a required transmission delay ($\leq$ 12 ms.). The physical layer is mainly compliant with IEEE 802.11 OFDM specifications. Other major parameters including MCS parameter sets are summarized in Table 2. In DCF protocol, each STA adaptively selects MCS used for the transmission of DATA frame according to the instantaneous received SNR.

Fig. 4(b) shows the end-to-end throughput versus the number of existing stations N_{STA}. In this figure, for the smaller N_{STA}, the end-to-end throughput of multi-hop network with centralized RRM is almost same as that with conventional DCF. This is because, when the number of existing stations is too small, the gain achieved by an opportunistic medium access and concurrent transmission (i.e., reduction of frequency reuse distance) cannot be obtained. On the contrary, for the larger N_{STA}, the end-to-end throughput of multi-hop network with centralized RRM is much higher than that with conventional DCF. From the result, we can conclude that the proposed protocol is effective to enhance the end-to-end throughput of multi-hop ad hoc network.

4. Conclusion

To improve the transmission performance of WLAN operating in unlicensed band, this paper introduced the group-based centralized RRM strategies and proposed the DCF-based MAC protocol that enables the group-based centralized RRM. In the proposed protocol, the central controller acts as a master to organize the associated stations and attempts to reserve the radio resource in a traditional DCF-manner. After the reservation of radio resource, the central controller dynamically allocates the radio resources to the stations according to their CTSI, and the transmission opportunities can be granted to the appropriate stations. Numerical results confirmed that the centralized RRM strategies are effective way to enhance the throughput while satisfying QoS requirements.

5. References

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