A New Multichannel Access Protocol for IEEE 802.11 Ad Hoc Wireless LANs

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***Abstract*— The IEEE 802.11 wireless local area networks (WLANs) standard supports several equal-capacity communication channels which can be simultaneously shared and accessed by mobile stations. In such multichannel communication system, a mobile station basically can transmit on any of these channels based on a suitable access control protocol. However, with the feature of one transceiver per mobile station, the standard restricts mobile stations to operate in one selected channel and the other channel capacities are wasted inevitably. In this paper, we propose a new carrier sense multiple access (CSMA) based protocol, called multichannel access protocol (MAP), to support parallel transmissions in IEEE 802.11 ad hoc WLANs. To realize the proposed MAP protocol over contemporary ad hoc WLANs, the MAP protocol is not only compliant with the IEEE 802.11 standard but also taking one transceiver constrain into consideration. All mobile stations with MAP will contend for channel access right in a dedicated channel during a periodical contention reservation interval (CRI) and then transmit data frames over different channels by a channel scheduling algorithm (CSA). Given a number of requests, the problem of finding a proper schedule for these requests to be served on a multichannel system so that the longest channel busy period is minimal is known to be NP-hard [3]. The time complexity of proposed heuristic CSA is $O(|X|\log|X| + |X|M^2)$ where $|X|$ and M denote the number of successful requests in the CRI and the number of available channels respectively. Simulation results show that the proposed MAP protocol with CSA achieves an obviously higher throughput than conventional IEEE 802.11 WLAN with single channel.**

***Index Terms*— ad hoc, CSMA/CA, local area network, MAC, NP-hard, wireless**

I. Introduction

Next-generation wireless networks are envisaged to support high data rates, packet-oriented transport, and multimedia traffic. Providing high-capacity transmission is one of the most important issues in wireless communication systems. With a selected modulation scheme, high-capacity wireless networks may be realized either by assigning a single wide-band channel or by using multiple narrow-band channels that may partially overlap to each other. The latter approach, which we consider in this paper, has been adopted by the IEEE 802.11 wireless local area networks (WLANs) [4]. The unlicensed nature of ISM (Industrial, Science and Medical) bands make IEEE 802.11 standard extremely attractive for customers. The most popular bandwidth is probably the 2.4 GHz (2.4 GHz–2.4835 GHz) band as it is available for use throughout most of the world. In recent years nearly all of the commercial developments and the basis for the IEEE 802.11 standard have been in the 2.4 GHz band. In the direct sequence spread spectrum (DSSS) specification, the 83.5 MHz radio spectrum are divided into 14 channels and some of them can be used simultaneously and independently. Using all frequencies to transmit data at a same location may cause electromagnetic wave interference that will decrease the transmission quality; therefore, standard suggests that at least 25 MHz or 30 MHz guard band should be maintained for any two adjacent cells. As a result, there are totally 3 available channels can be utilized concurrently for data transfer in current IEEE 802.11 WLANs. In other words, if the channel data rate is 2 Mb/s (or 11 Mb/s in IEEE 802.11b [5]), the aggregated network bandwidth in WLANs will be 6 Mb/s (33 Mb/s). Unfortunately, with one transceiver constrain, the standard only defines the medium access control (MAC) operations for single channel mode. Intuitively, the simplest way to achieve multichannel access is to upgrade mobile stations to equip several transceivers [6], [9], [10]. From the view point of cost effectiveness, it is worth to enhancing the standard MAC protocol for single transceiver to support multichannel access.

The performance of multichannel slotted ALOHA systems, where multiple equal-capacity channels are shared by many users, has been analyzed in [2], [11], [12]. The design of efficient wireless media access protocols and the evaluation of their performance in the presence of multichannel transmission (especially in the IEEE 802.11 WLANs) are still open issues [1], [7]. The common idea of recent proposed schemes is somewhat similar to frequency-division multiple access (FDMA) schemes used in cellular systems. The major difference is that there is no central controller and thus the channel assignment is done in a distributed fashion via carrier sensing such as in a traditional carrier sense multiple access (CSMA) scheme. Use of carrier sensing to perform channel assignment also distinguishes it from the traditional *broadcast scheduling* problem in a spatially disperse packet radio network, where channel assignment is performed via a central control or via additional message communication and synchronization [8].

The IEEE 802.11 WLANs standard [4] defines two possible network configurations: the Infrastructure and ad hoc configurations. An infrastructure WLAN connects mobile stations to a wired network via access point (AP). Basically, the AP is a fixed station that provides mobile stations the access to the distribution system (e.g., Internet). On the other hand, an ad hoc WLAN is composed solely of stations within mutual communication range of each other and they are able to communicate to each other directly. In both configurations, all adjacent mobile stations access to a same channel will form a basic service set (BSS). In the BSS, the basic distributed coordination function (DCF) using carrier sense multiple access with collision avoidance (CSMA/CA) mechanism is used as the basic channel access protocol to transmit asynchronous data in the contention period.

Our goal in this paper is to investigate a new multichannel CSMA protocol, which is still compatible with IEEE 802.11 standard, for supporting multichannel transmission by single transceiver in the ad hoc WLANs where all mobile stations can hear each other as defined in standard [4]. We note that papers [6], [9], [10] had proposed some possible solutions for this scenario by adopting dual transceivers to achieve this goal. In paper [10], Wu *et al.* proposed a so-called dynamic channel allocation (DCA) scheme which needs one transceiver to be fixed in a dedicated control channel for contention and another transceiver to be tunable among the other channels for data transmission. When a station receives a RTS control frame from sender in control channel, it will scan all channels except the control channel and choose the first detected idle channel to inform sender to transmit data. Nevertheless, dual-transceivers requirement increases both the implementation complexity and implementation cost, and becomes impractical for present WLAN adapters. In this paper, a contention and reservation based multichannel access protocol (MAP) is proposed to support multichannel transmission over ordinary IEEE 802.11 ad hoc WLANs in which each mobile station only equips with single transceiver.

The remainder of this paper is organized as follows. In Section II, we describe the proposed multichannel access protocol (MAP) in detail. In Section III, we present the channel scheduling algorithm (CSA) for efficiently schedule requests into multiple channels. In Section IV, we analyze the performance of the proposed MAP and then present a set of simulation scenarios that are designed for evaluating the performance of proposed protocols. Finally, the conclusions and discussions are given in Section V.

II. MULTICHANNEL ACCESS PROTOCOL (MAP)

In this section, we will introduce our proposed multichannel access protocol (MAP) in detail. The reason we consider multichannel transmission is that the maximum throughput of using single channel MAC protocol is bounded by the bandwidth of one channel. Thus, using multiple channels will experience less normalized propagation delay per channel than its single-channel counterpart. However, there are several challenges needed to be solved before obtaining the network throughput gain. These problems are presented as follows:

- How to allocate channel(s) for mobile stations to content the channel access right in single transceiver case?
- How to ensure every mobile stations to have contention results for performing the distributed channel scheduling algorithm once the contentions are resolved?
- How to allocate the successful requests (source-destination pairs) to proper channels in a collision-free manner such that the channel efficiency is maximal? This problem is especially difficult in a distributed system.
- How to transmit broadcast and multicast frames in multi-channel systems?

In general, if all mobile stations are equally allocated to channels, the collision probability of each request attempt will be minimized accordingly. However, based on the constrain that the sender and receiver of a request must stay in the same channel to complete the request-to-send/clear-to-send (RTS/CTS)

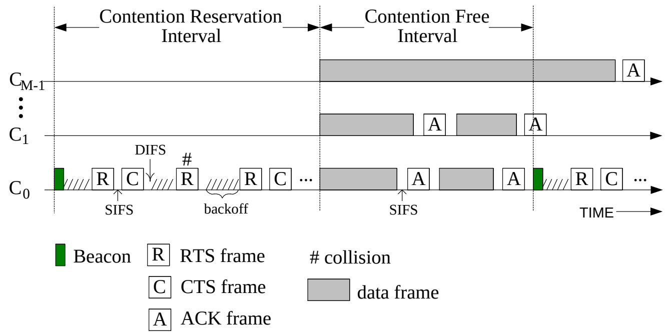


Fig. 1. An illustration of the contention and allocation procedure of proposed MAP.

handshaking, a mobile station with single transceiver can only exchange data with other mobile stations which listen to the same channel. As a result, few data frames will be transmitted successfully and some stations will never communicate with each other. If we assign mobile stations to access channels dynamically, a complicated channel scheduler has to be provided for the distributed ad hoc WLANs. In stead of employing such complicated scheme, our MAP protocol allocates a dedicated *contention* channel for all mobile stations to content and all the other channels are serving as *data* channels permanently. To further enhance channel utilization, the assigned contention channel can be also used to transport data frames after the contention period. Fig. 1 illustrates the channels' usage in MAP protocol in which channels $C_1 \sim C_{M-1}$ are the dedicated data channels and channel C_0 alternatively plays the role of the contention channel and data channel.

Mobile stations will first send the RTS in channel C_0 and then wait the CTS to make sure the contention is success, if they have data frames to transmit. After then, the successful sender and receiver will tune to one of available channels $C_0 \sim C_{M-1}$ according to channel scheduling algorithm (CSA) to execute data transfer. The details of channel assignment for successful requests will be described in Section III. Recall the usage of one contention channel ensures every receiver to successfully receive and to reply the corresponding CTS in the IEEE 802.11 ad hoc WLANs. The successful pair of sender and receiver should not leave the contention channel right away unless all requests have been received. Based on this concept, the channel access is naturally partitioned as two alternative and non-overlapping time intervals: *contention-reservation interval* (CRI) and *contention-free interval* (CFI). In MAP protocol, the CRI is fixed and the interval of CFI is depending on the schedule of contention results of CRI. For the sake of compatibility, all contentions in the CRI are still following the IEEE 802.11 standard contention police. The difference is that a successful RTS/CTS handshaking in MAP protocol doesn't mean that data frame has to be sent immediately. In stead of, data frame transmission is delayed until the CFI.

For the last broadcasting/multicasting problem, there are several approaches can be employed. Recall to the recipients of broadcast/multicast frame will not reply the ACK, the sender dose not aware of the transmitted frame is success or not. Furthermore, the MAP does not enforce all stations stay in the contention channel during CRI. Therefore, the broadcast or multicast senders must transmit their frames several times and should be spread over different contention intervals.

A. The Beacon Operation

In standard, one of members in ad hoc WLAN is in charge of performing time synchronization function via periodically generating the beacon frames. In MAP protocol, the beacon frames are also used to announce the starting of the CRI and the CRI time interval. This can be done by appending an additional information element, which carries the CRI information, into the beacon frame. Therefore, when a mobile station wants to access the medium, it must receive the beacon frame before contending the medium access right. If the generated beacon frame doesn't appear correctly (for example, destroyed by noise or the coordinator moves out the WLAN, etc.), the other mobile stations will follow the standard to content to be the beacon generator. This procedure will continue until a correct beacon frame appears. Since then, all mobile stations start sending RTS frame for reservation as usual.

III. Channel Scheduling Algorithm (CSA)

Without loss of generality, a data frame transmitted in MAP can be any length and a mobile station can send or receive multiple data frames in the CFI window as well. Notice that broadcast and multicast frame should be transmitted in the dedicated contention channel during CRI. Therefore, in this section, the proposed channel scheduling algorithm (CSA) only deals with the unicast data frames.

In this section, we will describe the channel assignment scheme for scheduling all successful unicast requests in every CRI. Recall that successful requests can be detected by every station and data frame transmissions are deferred to be served in the CFI. As soon as the CRI finishes, mobile stations will individually perform channel scheduling algorithm to determine the channel and time instance for each request. Let $X = \{x_1, x_2, \cdots, x_n\}$ denote a set of new arrival requests, in which $x_i = (s_i, d_i, l_i)$ stands for a request with transmission period l_i (includes the time periods of transmitting the complete data frame and the following acknowledgement (ACK) control frame, and the necessary idle SIFS) from mobile station s_i to mobile station d_i. Given a set of traffic requests, the channel/time scheduling problem is to assign a channel and a time interval for each of the requests such that the channel utilization is maximized and the longest busy time of channels is minimized. Let $A(X) = \{(c_1, t_1), (c_2, t_2), \cdots, (c_n, t_n)\}$ is the *channel/time assignment* of X; where c_i is the assigned channel and t_i is the scheduled starting time for request x_i. In the case of single transceiver, a mobile station will not transmit or receive data frames in two or more channels at the same time. Thus, we say that a request x_i is *intersected* with another request x_j if ($t_j \le t_i < t_j + l_j$ or $t_j < t_i + l_i \le t_j + l_j$ or $t_i \le t_j < t_j + l_j \le t_i + l_i$) and ($s_i = s_j$ or $s_i = d_j$ or $d_i = s_j$ or $d_i = d_j$). It is desirable that the designed CSA should efficiently prevent from incurring request intersections.

At first, the CSA sorts the set X by their transmission periods and then assigns them into data channels one by one. Assume a WLAN supports a number of M parallel channels. Let $F = \{f_0, f_1, \cdots, f_{M-1}\}$ denote a set of the free times of data channels, in which f_i stands for the channel free time of the i-th channel. The initial channel free time is zero. That is, $f_i = 0,\ 0 \le i \le M-1$.

Each time the CSA schedules a request to a data channel, the request with the shortest transmission period and the channel with the smallest f_i are first considered. If the assignment will result in request intersection, channel with the second earliest free time is considered. This process will be repeated until conflict is not incurred. Once the channel, say k, is assigned for request, say x_i, we have $c_i = k$ and $t_i = f_k$. Moreover, the free time of the k-th channel will become $f_k + l_i$. Above scheduling process is repeated until all requests have been scheduled. Apparently, at most M channels are investigated for a request and the worst case is that the request is assigned to the channel with the latest free time. Since the time complexity of intersection check is $O(M)$, the time complexity of the CSA will be $O(|X| \log |X| + |X| M^2)$ where $|X|$ is the number of successful requests during CRI.

Since the number of transceiver per mobile station is limited to one, all stations must listen to the contention channel during whole CRI. As a result, an amount of $(M-1) \times \text{CRI}_{\text{interval}}$ is inevitably wasted for every CRI. Besides, channel capacity could be further wasted by the external fragments caused by the channel scheduling algorithm. Therefore, in our opinions, the channel utilization should be further enhanced. The straight way to enhance channel utilization is to allow the CRI and CFI to overlap to each other. However, it incurs three new interesting problems.

- The on-serving stations, which do not listen to the contention channel, will lost the channel status information of the next cycle.
- The original beacon generator may be one of on-serving stations and the next CRI should be started by the other station.
- The broadcast and multicast frames transmitted in CRI may fail to reach all mobile stations.

To overcome the first problem of synchronization, the beacon frame should contain the channel status information. This can be done by appending an additional information element that carries the exact free times of channels since the last cycle. Based on this information, even though a station has past several contention intervals, it will immediately synchronize with the others as soon as it detects the beacon frame. The second problem can be treated as the situation of missing beacon frame as mentioned in section II-A. The other mobile stations, who had received the precedent beacon, will follow the standard to content to be the beacon generator. About the last problem, several approaches can be applied. For example, one may enforce the broadcast or multicast senders to transmit these data frames several times and spread in different contention intervals.

There is another challenge needed to be conquered: how to further minimize the channel wastage in the CFI? If the longest fragment among channels can be scheduled in the contention channel, the next CRI can start at the earliest time and the bandwidth wastage can be certainly minimized. This goal can be easily achieved by *swapping* the scheduled requests in the channel with the longest fragment and in the contention chan-

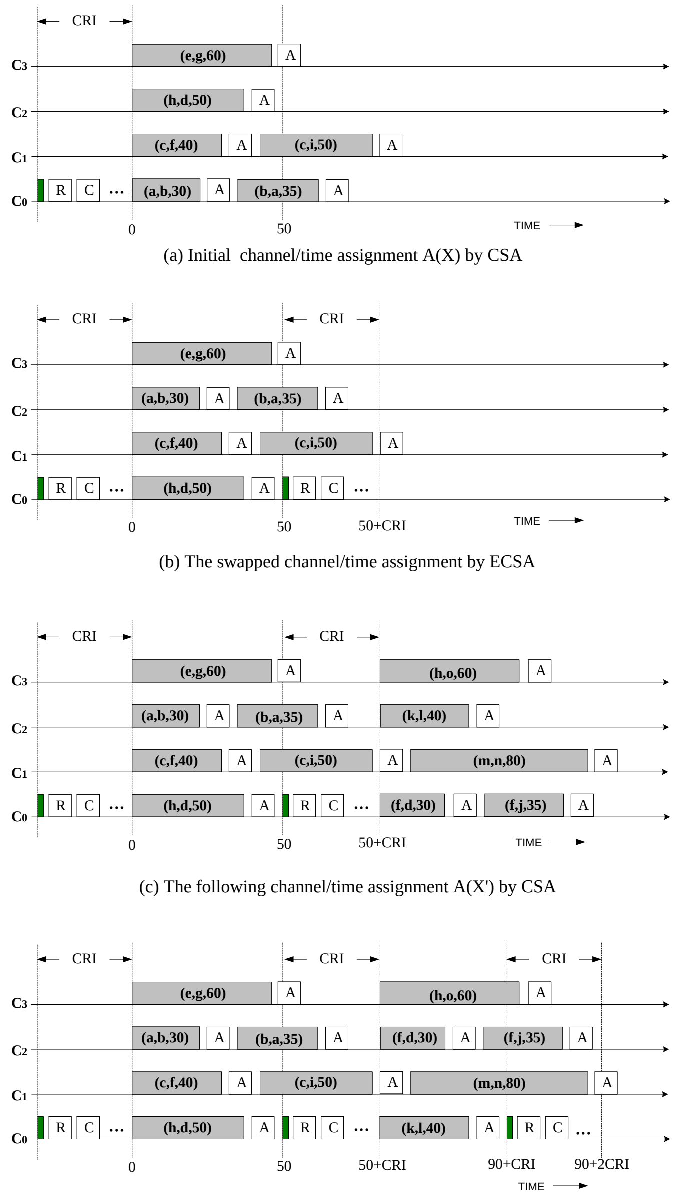
Procedure CHANNEL_SCHEDULING
Input: a set X of successful requests and a set F of the channel free time of M channels in WLANs;
Output: a feasible channel/time assignment $A(X)$;
Begin
  Sort request set X by transmission periods;
  For i = 1 to $|X|$
  Begin
    Unmark all channels;
    For count = 0 to $M - 1$
    Begin
      Select the unmark channel, say k, that has the earliest free time;
      If no intersection occurs after assigning channel k for request x_i **Then**
        c_i = k;
        t_i = f_k;
        f_k = f_k + l_i;
        BREAK LOOP
      Else
        Mark channel k;
      End-if
    End-for
  End-for
  If the earliest free channel is not the contention channel **Then**
    Swap the scheduled requests in the earliest free channel and in the contention channel;
  End-if
End

Fig. 2. The channel schedule algorithm (CSA).

nel after the channel scheduling. The detailed CSA is listed in Fig. 2.

A. Example of MAP

For illustration, an example is designed and shown in Fig. 3. We assume four independent channels, noted as $C_0 \sim C_3$, are supported in the IEEE 802.11 WLANs. Nine mobile stations, labelled from a through i, are desiring to access the medium in the WLAN. In this scenario, each mobile station can transmit/receive data to/from another directly. These requests of Fig. 3(a) are represented as X = {(a,b,30), (b,a,35), (c,f,40), (c,i,50), (h,d,50), (e,g,60)}. According to CSA, the first request (a,b,30) with the shortest transmission period will be allocated to C_0 and the free time of channel C_0 will become $f_0 = 30$. (Remind that we assume the transmission period includes the necessary SIFS and the time period of transmitting a data frame and an ACK frame.) As scheduling the second request (b,a,35), since it will *intersect* with request (a,b,30) in channels $C_1 \sim C_3$, it must be scheduled into channel C_0 just after request (a,b,30). Thus, $f_0 = 30 + 35 = 65$. On the other hand, request (c,f,40) can be successfully allocated to channel C_1 without any conflict. The fourth request (c,i,50) cannot be allocated to channel C_2 because it will *intersect* with (a,b,30) and (c,f,40) simultaneously. Thus, request (c,i,50) will be allocated to channel C_1. The remainders of (h,d,50) and (e,g,60) are allocated to channels C_2 and C_3 respectively. Therefore, we have a feasible channel assignment A(X) = {(0,0), (0,30), (1,0), (1,40), (2,0), (3,0)}. The earliest free channel of the channel/time assignment $A(X)$ is channel C_2 (as shown in Fig. 3(a)). From above descriptions, requests scheduled in channels C_2 and C_0 will be swapped by the swapping procedure and the next CRI will start at time 50 as shown in Fig. 3(b).



(a) Initial channel/time assignment A(X) by CSA

(b) The swapped channel/time assignment by ECSA

(c) The following channel/time assignment A(X') by CSA

(d) The swapped channel/time assignment A(X') by ECSA

Fig. 3. An example of channel assignment by CSA for four channels.

In order to illustrate the consecutive schedules in the MAP protocol, we assume new requests in the next CRI are X'={(f,d,30), (f,j,35), (k,l,40), (h,o,60), (m,n,80)}. For request set X', the following channel/time assignment $A(X')$ by CSA will become $A(X') = \{(0, 50 + \text{CRI}), (0, 80 + \text{CRI}), (2, 50 + \text{CRI}), (3, 50 + \text{CRI}), (1, 90)\}$. Similarly, the earliest free channel is channel C_2 (with channel free time $90 + \text{CRI}$ as shown in Fig. 3(c)) and requests in it will be migrated to the contention channel. The swapped channel/time assignment is shown in Fig. 3(d).

IV. SIMULATION MODEL

In order to evaluate the performance of MAP, we use a detailed simulation model which is based on the distributed coordination function (DCF) of IEEE 802.11 WLANs [4]. In simulations, we considered the realistic system parameters (e.g., the

TABLE I

SYSTEM PARAMETERS IN SIMULATIONS

Parameter	Normal Value
Channel bit rate	2 Mb/s
Transmission Range	100 meters
RTS frame length	160 bits (80 μs)
CTS frame length	112 bits (56 μs)
ACK frame length	112 bits (56 μs)
Preamble and PLCP header	192 bits (192 μs)
MAC header length	272 bits (136 μs)
A slot time	40 bits (20 μs)
SIFS	10 μs
aCWmin	31 slots
aCWmax	1023 slots
Air propagation delay (δ)	1 μs

direct sequence spread spectrum (DSSS) physical specification) in IEEE 802.11 MAC protocol, which are listed in Table I. The RTS/CTS exchange precedes data frame transmission and data frame is followed by an ACK. For simplicity, only unicast data frames are considered in simulations. The DCA [10] approach and the IEEE 802.11 protocol are also simulated for comparisons.

Assume there are three independent channels in wireless network. Each mobile station in MAP, and IEEE 802.11 protocol has one transceiver and its radio transmission range is 100 meters. On the other hand, each mobile station with DCA scheme equips two transceivers. The frame arrival rate of each mobile station follows the Poisson distribution with a mean λ, and the frame length is an exponential distribution with a mean of m octets, which including PHY and MAC header. Each simulation run lasts 600 seconds ($\approx 3 \times 10^7$ slots) and each simulation result is obtained by averaging the results from ten independent simulation runs.

A. Simulation Results

The simulation results are shown in Fig. 4 through Fig. 7, which depict the total throughput (excluding the control overheads) derived by protocols DCA, MAP, and IEEE 802.11 CSMA/CA under different numbers of mobile stations N, different frame arrival rates λ (frames/sec/station), different mean frame lengths m, different numbers of channels M, and different contention reservation intervals CRI.

Fig. 4 compares the throughput (in Mb/s) of three protocols in WLAN with multiple channels under different network loads when N = 16 and m = 500 octets. The IEEE 802.11 protocol first saturates when $\lambda \approx 20$ (and the network load is about 71.424% = $(N \times \lambda \times m)$/(2 Mb/s) = $(16 \times 20 \times 500)$/(2 Mb/s)) and the maximal network throughput is about 1 Mb/s regardless of parameter M. On the contrary, MAP can easily achieve up to 1.7 Mb/s even when $\lambda \approx 20$ and M = 3. Furthermore, in the case M = 3, the maximum throughput of MAP will reach about 2.5 Mb/s. Undoubtedly, the significant network throughput gain is obtained from parallel transmissions on multiple channels. Moreover, MAP and DCA will obtain a higher aggregate network throughput when more parallel channels are used; however, the throughput enhancement is getting smaller and smaller. This phenomena is mainly caused by the number of active mobile stations as mentioned before. We also note that we

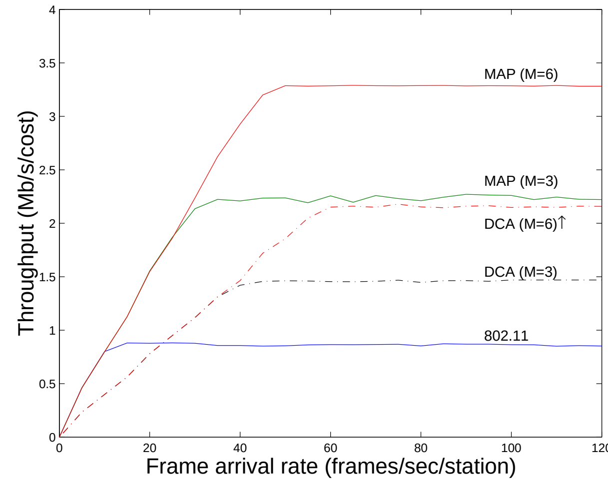


Fig. 4. Comparisons of cost-benefit derived by MAP, DCA, and IEEE 802.11 protocols under different numbers of channels and different frame arrival rates when N = 16, m = 500, and CRI = 300.

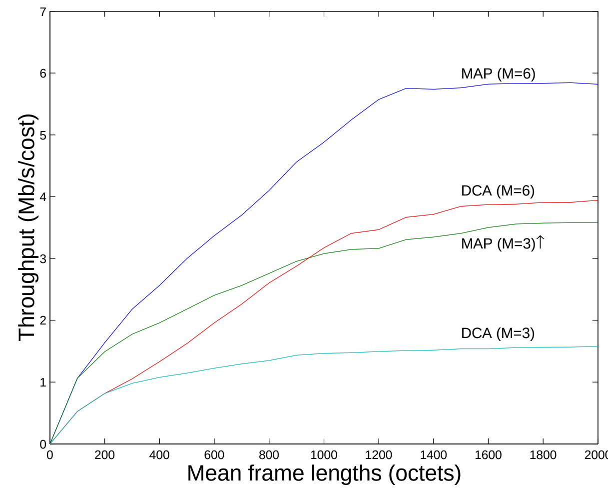


Fig. 5. Comparisons of throughput derived by MAP and DCA protocols under different number of channels and different mean frame lengthes when λ = 50, CRI = 300, and N = 16.

seriously take the hardware cost into considerations, the MAP will apparently outperform DCA in which the derived throughput is the normalized throughput per transceiver. According to this result, we conclude that, under the single transceiver constrain, the MAP can provide higher throughput than both IEEE 802.11 protocol and DCA scheme.

Fig. 5 illustrates how the network throughput affected by the frame length and the number of available channels. In this simulation, the CRI window size is set as 300 slots, the frame arrival rate per each mobile station is 50 frames (heavy load) and the number of mobile stations is 16. In order to investigate the effect of frame length, different mean frame lengthes from 200 octets to 2000 octets are simulated. From this figure, we can find that given a longer mean frame length, a higher network throughput will be derived in MAP and DCA protocols. Moreover, the maximal network throughput is proportional with the number of available channels. For example, the maximal network throughput of MAP in cases M = 3 and M = 6 are about 4.1 Mb/s and 6.6 Mb/s respectively. And, in DCA scheme, the

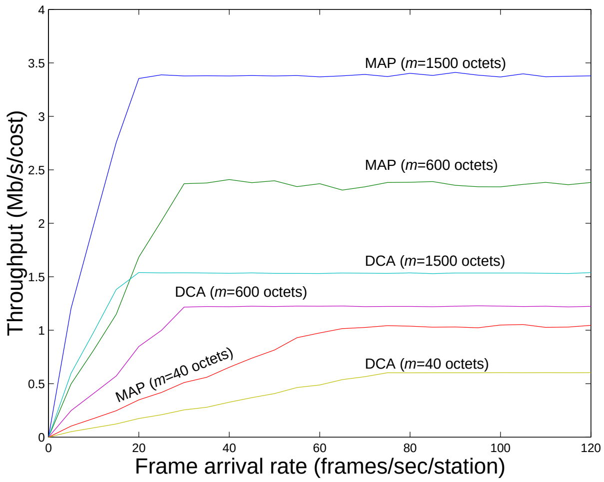


Fig. 6. Comparisons of throughput derived by MAP and DCA protocols under different mean frame lengthes and different frame arrival rates when M = 3, CRI = 300, and N = 16.

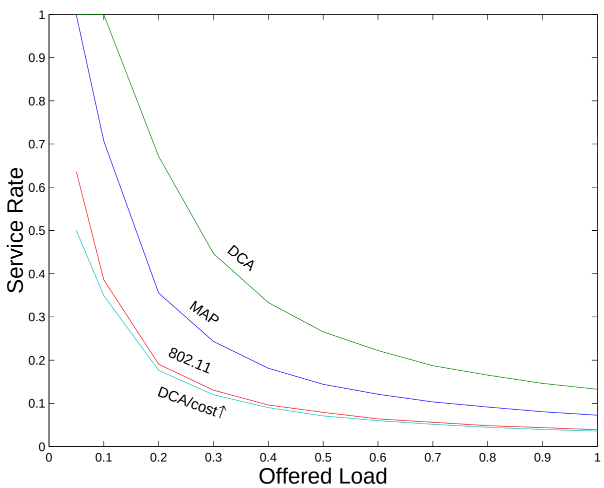


Fig. 7. Comparisons of service rate derived by MAP, DCA, and IEEE 802.11 protocols under different offered loads when M = 3, m = 40, CRI = 300, and N = 16.

maximal normalized network throughput in cases M = 3 and M = 6 are about 1.8 Mb/s and 4.5 Mb/s respectively. The throughput improvement by increasing channel in both MAP and DCA is similar. However, in our opinions, the DCA using two transceivers should obtain a higher throughput gain. We conclude that the drawback of DCA is it does not have an efficient data scheduling method (likes CSA)which would likely waste the network bandwidth.

Fig. 6 illustrates how the network throughput per transceiver affected by the frame length and the frame arrival rate. In this simulation, the CRI window size is also set as 300 slots, M = 3, and N = 16. In order to investigate the effect of frame length, different mean frame lengthes: 40 octets, 600 octets, and 1500 octets are considered. From this figure, we can find that given a longer mean frame length, a higher network throughput will be derived in MAP. The reason is that, when the CFI is relatively longer than CRI, long frames potentially reduce channel wastage. Again, we emphasize that the MAP apparently outperforms DCA in terms of normalized throughput per transceiver.

Fig. 7 shows the service rate derived by MAP, DCA, IEEE 802.11 and DCA/cost under different offered loads when the CRI window size is 300 slots, M = 3, m = 40, and N = 16. The service rate degrades when network load is heavy. Note that the DCA scheme gets a higher service rate than MAP and IEEE 802.11 protocols, since DCA uses two transceivers to transmit packets. But if we consider the cost-benefit, MAP can use channels more efficiently than DCA. According to above simulation results, we conclude that, under the single transceiver constrain, the MAP can provide higher throughput than both IEEE 802.11 CSMA/CA protocol and DCA in IEEE 802.11 ad hoc multichannel WLAN.

V. Summary and Conclusions

In this paper, we proposed a new CSMA protocol called *multichannel access protocol* (MAP) to support multichannel transmission over IEEE 802.11 ad hoc WLANs in which every mobile station only equips one transceiver. The channel scheduling algorithm (CSA) was also proposed to efficiently utilize channel capacities. The MAP protocol is compliant with the IEEE 802.11 standard. All mobile stations with MAP protocol will content for channel access in a dedicated channel during a periodical contention reservation interval and then transmit data frames over different channels. Moreover, CSA had also introduced to further minimize the bandwidth wastage. Simulation results showed that the proposed MAP protocol with CSA achieves an obviously higher normalized throughput than conventional IEEE 802.11 CSMA/CA protocol and DCA scheme.

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