INTERFERENCE AWARE ADAPTIVE MAC PROTOCOL FOR MC-CDMA ADHOC WIRELESS LANS

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***Abstract*— Multi-Carrier Code Division Multiple Access (MC-CDMA) is recently considered as a key technology for future wireless systems. Its high capacity and collision avoidance capability can fulfill the increasing demand for high throughput and Quality of Service (QoS). The application of MC-CDMA divides the frequency channel in many parallel channels, separated from each other in code domain. We refer to these parallel channels as codechannels (cchs). In order to exploit the advantages of this spread spectrum technique, the Medium Access Control (MAC) protocol has to be aware of the multichannel structure of the MC-CDMA network. Mobile Stations (MSs) should be equally distributed among the cchs for better utilization of the resources and collision avoidance. Additionally, the assignment of a link to a cch should be done under consideration of the interference situation in the network. This is very important for the prompt operation of the link as the different cchs loose their orthogonality in asynchronous systems. In this paper we present an adaptive, interference aware MAC protocol for MC-CDMA adhoc Wireless Local Area Networks (WLANs), which adapts the allocation of resources to both interference and utilization degree of the different cchs, in order to achieve high capacity.**

***Index Terms*—**Adaptive MAC, IEEE 802.11a,e, interference awareness, MC-CDMA, multiple channels, W-LAN.

I. INTRODUCTION

Adaptability of the Medium Access Control (MAC) protocol is an essential issue for modern networks, which is aiming in the achievement of high throughput. The protocol should adapt its operation to the current interference situation in order to achieve the needed Signal to Interference and Noise Ratio (SINR) for the demanded Quality of Service (QoS) of the application.

In an asynchronous Code Division Multiple Access (CDMA) network, although power control [9] is applied, receivers sense interference from all other transmitting stations in this scenario. Interference comes from both other transmissions which take place on the same codechannel (cch) as the considered data transfer and from transmissions in other cchs. Latter is denoted as Multiple Access Interference (MAI) and is caused from the orthogonality loss of Walsh-Hadamard spreading codes in asynchronous systems.

The use of Minimum Mean Square Error (MMSE) MultiUser Detector (MUD) at the receivers can reduce the effect of MAI. The SINR at the detector is thus increased and the information frame can be correctly received. In high interference environments though, the MAI can be very high for the MUD to achieve the needed Bit Error Rate (BER). Such a situation occurs when a receiving station is very close to an interferer and is referred to as the “near-far-problem”.

Previous work has been carried out to solve this problem. In [11], [12] a partial sampling MMSE and an adaptive minimum BER detector were presented. With Binary Phase Shift Keying (BPSK) modulation and less than the maximum number of cchs active, the above solutions show a good performance. Furthermore in [13] and [14] complex receiver constellations are analysed and their performance with BPSK is proven to approach the ideal maximum SINR receiver with perfect channel knowledge.

In order to overcome the “near-far-problem” with higher Physical layer modes (PHY modes) and in fully loaded systems, though, the application of an adaptive interference aware MAC protocol is inevitable. The key idea of the proposed method is to lead stations which block each other due to high MAI to share the same cchs in a Time Division Multiple Access (TDMA) manner. The MAI is then substantially reduced. Additionally, the proposed protocol provides manners for the distribution of active links among all cchs, for higher utilization of the frequency channel.

The rest of the paper is organized as follows: a description of the Multi-Carrier Code Division Multiple Access (MC-CDMA) technique and the MC-CDMA based Wireless Local Area Network (WLAN) protocol is given in section II. In section III, a detailed presentation of the adaptation algorithm is given. Section IV contains an extended presentation and discussion on simulation results. Section V summarizes this work with concluding remarks.

II. MC-CDMA BASED W-LAN

A. MC-CDMA

MC-CDMA has gained recently significant attention and has become a promising candidate for future wireless high capacity communication networks. Multicarrier techniques are generally robust against multipath fading, provide high spectral efficiency and interference rejection capabilities. MC-CDMA has several other advantages, such as frequency diversity and immunity against frequency selective fading and impulse noise [11].

In MC-CDMA systems, each symbol of the data stream of one user is multiplied by each element of the same spreading code and is placed in several narrow band subcarriers. Multiple chips are not sequential, but transmitted in parallel on different subcarriers [5]. The major characteristic of MC-CDMA is that one single data symbol is spread in the frequency domain [3].

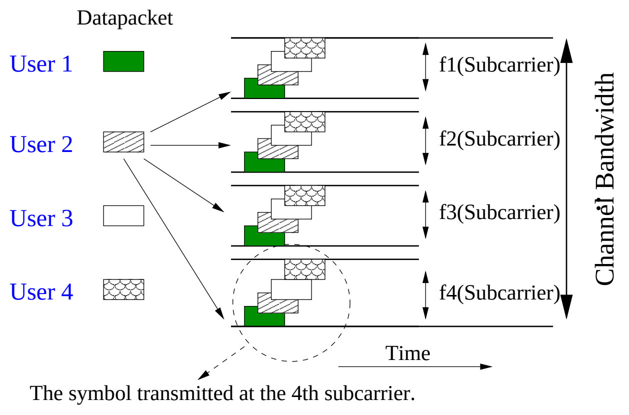

Figure 1. MC-CDMA. The symbol transmitted at the 4th subcarrier carries a fraction (chip) of 4 datapackets, which belong to 4 different users.

B. *The MAC Protocol for MC-CDMA*

The protocol of the proposed system is based on the MAC protocol of the IEEE 802.11a WLAN, with some modifications needed to support the MC-CDMA Physical layer (PHY layer).

A Mobile Station (MS) ready to transmit has to select a cch. For this selection two methods are possible:

- The first is to select a cch before every packet transmission. Initially this selection is done randomly. For later transmissions, the station does not select cchs, which have already been reserved by other stations (according to the standard the considered station has set a Network Allocation Vector (NAV) for an occupied channel).
- The second method consists of selecting the cch with the least traffic and keeping this cch for the entire duration of the connection.

Before accessing the medium a station should detect the medium as idle for a duration called Distributed Coordination Function Inter-Frame Space (DIFS), and signals the intended data transfer by transmitting a Ready To Send (RTS) packet (Fig. 2).

All stations that receive this control packet, and are not the intended receivers, set their NAV timer, interrupt their backoff down counts, and defer from the medium in order not to interfere with the transmission. If the receiver of the RTS is idle i.e. able to receive data, it responds with a Clear To Send (CTS) packet, after a time called Short Inter-Frame Space (SIFS). In case the receiver is busy the RTS transmission is repeated after a new backoff. Mobile stations which receive this CTS set their NAV timer as well. The sender can now transmit its data packet after SIFS. The receiver acknowledges a successful reception by an Acknowledgement (ACK) also a SIFS time after the end of the data frame. The above standard DCF procedure is followed in every cch for each data transmission. The RTS-CTS handshake is used for power control too, as suggested in [9].

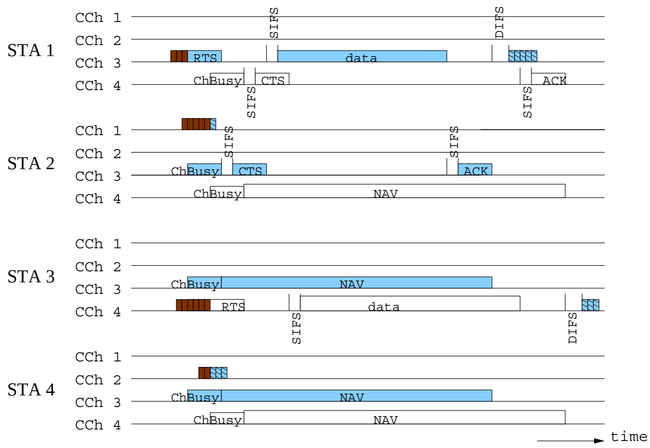

Figure 2. DCF applied on 4 cchs

In case two or more stations access the same cch on the same frequency band at the same time, a collision occurs. Although the backoff mechanism provides a manner to resolve collisions, in scenarios with lots of participant MSs, collisions are a limiting factor for the QoS requirements of the wireless network, such as throughput and delivery delays. The proposed modification of the protocol has an advantage in this respect, since each frequency channel is divided into Spreading Factor (SF) parallel cchs, only n/SF stations compete against each other in accessing one cch. The collision probability is therefore reduced.

III. The Interference Aware MAC Protocol

The proposed algorithm distributes stations among all cchs, while links blocking each other by the "near-far-problem", are placed on the same cch in order to reduce MAI:

```
if(last2_or_3of5_transm_failed()){
    //Good Channel = Channel was in use and
    //working fine for more than 3 transmissions
    if(Good Channel){
     //List channels idle time descending
     Initialize_LessUsedCChList(CChList);
     Index = 0;
     Good Channel = false;
     if(PropabilisticDecision(backoff/Contention Window){
       UseNextCCh(CChList[Index]);
       Index = (Index+1) mod 4;
```

```
    }else{
      IncreaseBackoff();
    };
  }else{
    UseNextCCh(CChList[Index]);
    Index = (Index+1) mod 4;
  };
}else{
  IncreaseBackoff();
};
```

Every time a control packet is received or missed, the station updates its transmission history, which holds the results of the last five transmission attempts. If two initiated transmissions in a row, or three of the last five transmissions fail, the station comes to the conclusion, that the actual cch is not useable. This decision control is necessary to make the algorithm more robust against random transmission errors.

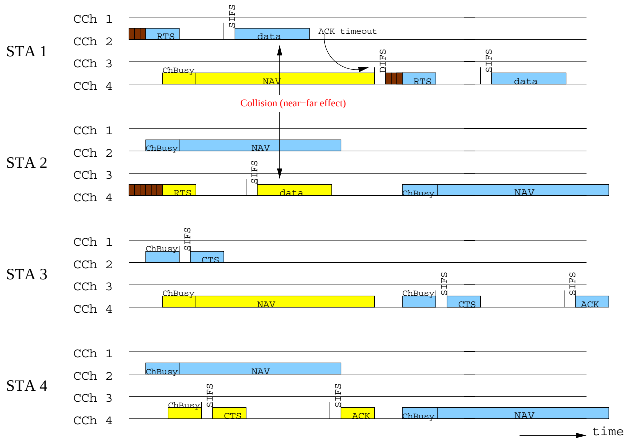

Figure 3. The cch-change procedure

Depending on a list of cch idle times, the station will do its first change (Fig.3) to the cch with the highest idle time. This first change is made with a certain probability in order to avoid a cch change of all interfering stations at the same time. This probability is given as the quotient of the last backoff timer length to the length of the station's contention window. The information about the idle times are collected while the station is idle itself by monitoring the cchs. In order to test the new channel correctly, the transmission history is cleared after every cch change.

The station keeps switching cch now until a new useable cch is found. A cch is useable if the 'last two or three out of five' criterion is not met. A single failed transmission only leads to an increase of the Contention Window (CW) as described in the Distributed Coordination Function (DCF)[6].

IV. Simulation Results

For the performance evaluation of the proposed system, we use event-driven simulations to measure the throughput that is practically achievable. The parameters of the simulation setup are given in Table I.

Fig. 4 shows the simulated scenario consisting of 16 terminals establishing 8 links in a 10mx10m area, addressing Small Office-Home Office (SOHO) scenarios. Simulations are performed using the QPSK ½ PHY mode for control packets and the 64QAM ¾ PHY mode for data packets.

Connection 1 (con. 1) from MS1 to MS2 starts on cch 0 and stabilizes on cch2, where its major interferer, con. 2 (MS3 to MS4), is placed. Accordingly, con. 3 (MS5 to MS6) changes from cch2 to cch0 in order to reduce the interference received from con. 4 (MS7 to MS 8), and con .8 (MS15 to MS16) changes from cch0 to cch3, where con. 7 (MS13 to MS14) is placed. Con. 5 (MS9 to MS10) and con. 6 (MS11 to MS12) are fixed on cch1.

TABLE I. Simulation Parameters

Parameter	Value
Max. TxPower	17dBm
Spreading Factor	4
Cwmin	7 slots
Cwmax	1023 slots
Number of Subcarriers	48 Data + 4 Pilot
Subcarrier Spacing	0.3125 MHz
Channel Bandwidth	20 MHz
Carrier Frequency	5.25 GHz
Noise Level	-93dBm
Path loss Factor	3.5
TxRate Data	54Mbps
TxRate Control	12 Mbps
RTS/CTS	enabled
Symbol Interval	4 µs = 3.2 µ + 0.8 µs
Guard Interval	0.8 µs
Preamble	16 µs
Max. Propagation Delay	0,15 µs
PDU Length	1024 Byte

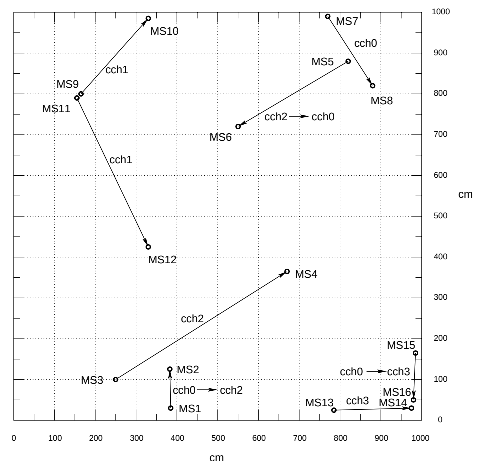

Figure 4. Simulated Scenario

Figure 5 presents the system throughput with the offered load. When the adaptation algorithm is disabled, the system throughput reaches a maximum of about 27Mbit/sec in overload, which corresponds to 85.7% of the theoretical maximum [1]. This is due to near-far-problems, as can be seen from Fig. 6 presenting the carried load per link. Due to high interference, con. 2 and con. 4 achieve low throughputs, while con.8 is blocked for higher loads.

The application of the proposed method for an interference aware MAC protocol, changes the situation drastically. The graph in Fig. 5 shows a linear rise of the

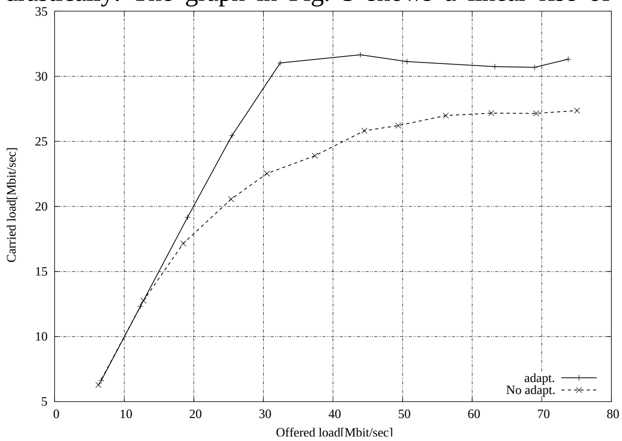

Figure 5. System throughput with and without the adaptation method vs. offered system load.

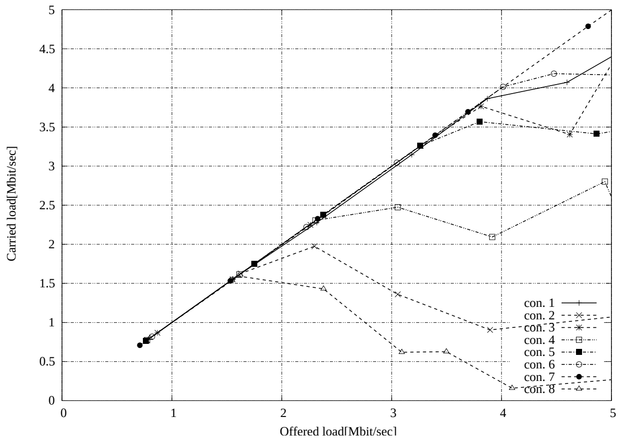

Figure 6. Throughput per link without adaptation vs. offered load per link.

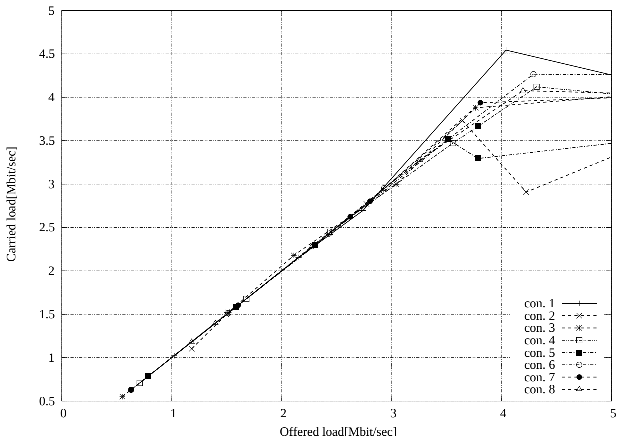

Figure 7. Throughput per link with adaptation vs. offered load per link.

network throughput with the offered load, up to the maximum of 31,5Mbit/sec [1]. Fig. 7 presents the carried load of each link, which also rises linearly to a maximum of 3.9Mbit/sec: 31.5Mbit/sec for a frequency channel correspond to 31.5/4 = 7.87Mbit/sec for a cch. Since the algorithm distributes equally the MS among the cchs, each MS can achieve 3.9 Mbit/sec.

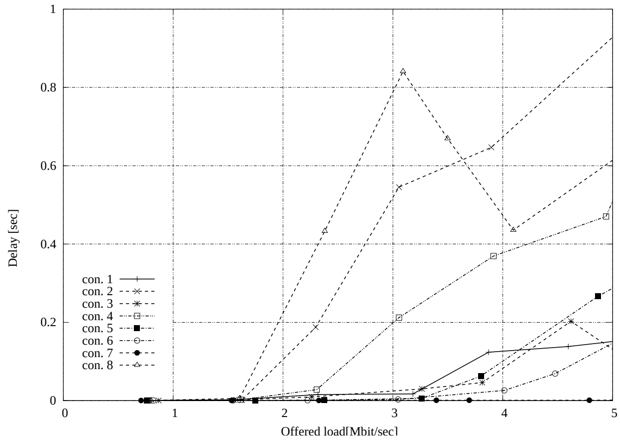

Figure 8. Mean queueing delay of successfully transmitted packets per link vs. offered load per link, without adaptation.

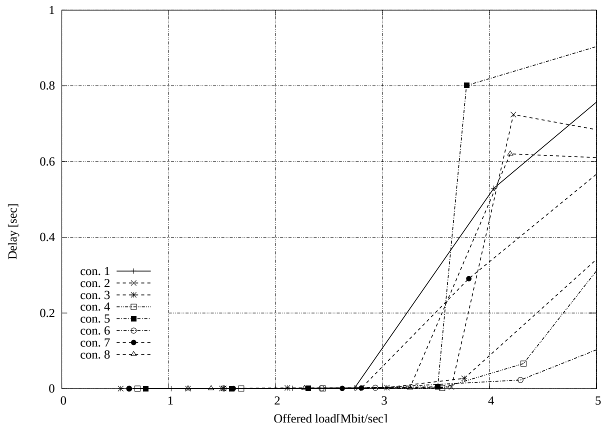

Figure 9. Mean queueing delay of successfully transmitted packets per link vs. offered load per link, with enabled adaptation.

Figure 8 depicts the mean delay for all successfully transmitted data packets, without adaptation. For small offered load the delay is low, but rises rapidly with the offered load for the three links experiencing near-far-problems. In Fig. 9 the corresponding results for enabled adaptation are presented. The delay is very low, for offered load less than the theoretical maximum system throughput, thus high QoS can be achieved.

Figures 10 and 11 present the service time of the network vs. the offered load. For the case without adaptation, Fig. 10, the service time for con. 3, con. 4 and con. 5 is low, but slightly increased compared to the analytically calculated one of 1037.5 µsec [1], due to collisions. On the other hand, for con. 2 and con. 7, the service time reaches high value s, since these links are blocked from high interference, and manage to transmit successfully a data packet only after several retransmissions. This condition is improved rapidly when applying the adaptation method, as depicted in Fig. 11.

The service time for all links approaches the theoretical minimum.

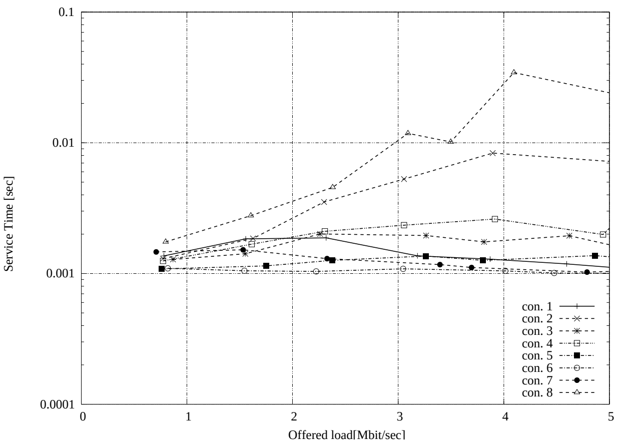

Figure 10. Mean service time of successfully transmitted packets per link vs. offered load per link without adaptation.

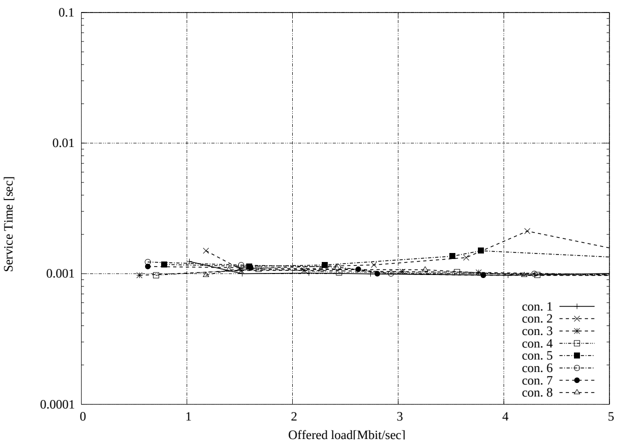

Figure 11. Mean service time of successfully transmitted packets per link vs. offered load per link with enabled adaptation.

V. CONCLUSION

In this work we introduced an adaptive, interference aware MAC protocol for MC-CDMA adhoc WLANs, which adapts the allocation of network's resources to the interference status of different cchs and their degree of utilization. The simulation results show the ability of the proposed protocol to overcome the MAI in an asynchronous MC-CDMA network and thus deploy its high capacity and collision avoidance characteristics.

Our future work focuses on further development of the MC-CDMA system and expansion to multihop, which is very important in indoor wireless communication, where the topology is limiting the transmission range.

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LIST OF ABREVIATIONS

ACK	Acknowledgement
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
cch	Codechannel
CDMA	Code Division Multiple Access
CTS	ClearToSend
CW	Contention Window
DCF	Distributed Coordination Function
DIFS	DCF InterFrame Space
MAC	Medium Access Control
MAI	Multiple Access Interference
MC –CDMA	Multi-Carrier Code Division Multiple Access
MMSE	Minimum Mean Square Error
MS	Mobile Station
MUD	MultiUser Detector
NAV	Network Allocation Vector
PHY layer	Physical layer
PHY mode	Physical Layer mode
QoS	Quality of Service
RTS	RequestToSend
SIFS	Short InterFrame Space
SINR	Signal to Interference and Noise Ratio
SF	Spreading Factor
SOHO	Small Office Home Office
TDMA	Time Division Multiple Access
WLAN	Wireless Local Area Network