A new Distributed Coordination Function

Adapted to MC-CDMA based W-LANs

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***Abstract* - IEEE 802.11a/e has become a worldwide wireless local area network (W-LAN) standard, with a rapid development. Many proposals have been made for its further expansion, and some of them focus on multicarrier code division multiple access (MC-CDMA), a novel, high capacity, multicarrier modulation scheme. The use of MC-CDMA in the physical layer, divides the frequency channel from the point of view of medium access control (MAC) layer to many channels separated by different spreading sequences, which we refer to as codechannels (cchs). Previous work [1] has proven the collision avoidance ability of this approach, while achieving higher throughput and low delays. In this paper we present and evaluate a new distributed coordination function (DCF) for the MAC protocol, optimized for the multichannel structure of MC-CDMA networks. Scope of the new DCF is to reduce the backoff times and prioritize some mobile stations (MS) by allowing them to iterate through cchs during backoff. This method leads to a more symmetric distribution of load among the codechannels, which enhances the network performance, as can be seen from the simulation results.**

Keywords; MC-CDMA; W-LAN; Smart Backoff; multiple channels; IEEE 802.11a,e.

1. Introduction

The IEEE standard 802.11a/e Wireless Local Area Network (WLAN) has become a worldwide standard with constant improvement. Its wide employment both for office and home applications has increased the demand for Quality of Service (QoS) and higher throughput especially in scenarios where delay sensitive traffic has to be supported. One suggestion for the further development of the 802.11 protocol is the use of Multi Carrier-Code Division Multiple Access (MC-CDMA), a novel, high capacity, multicarrier modulation scheme [5]. A MC-CDMA based system was proposed in [1] where the main functionality of the Medium Access Control (MAC) protocol is the same as in the standard 802.11a. Both the analytical and simulation results show its high throughput performance which is up to 51,68% higher than the one of the Orthogonal Frequency Division Multiplexing (OFDM) based System.

In this work we propose a further extension for the MC-CDMA system, with a new Distributed Coordination Function (DCF), adapted to the multichannel structure of Code Division Multiple Access (CDMA). The main characteristic of the new function is Smart Backoff, a procedure which allows a MS to iterate between codechannels (cchs) during backoff. This method leads to a more symmetric distribution of load among the cchs. Additionally, active connections can take advantage of the whole channel bandwidth and are not limited to the capacity of a single cch.

The rest of the paper is organized as follows: at first an introduction is provided on the MC-CDMA technique and the MC-CDMA based W-LAN protocol. In section III a detailed presentation of the Smart Backoff algorithm is given. Section IV contains an extended presentation and discussion on simulation results. Section V summarizes this work with some concluding remarks.

2. Modified System Description

2.1. MC-CDMA

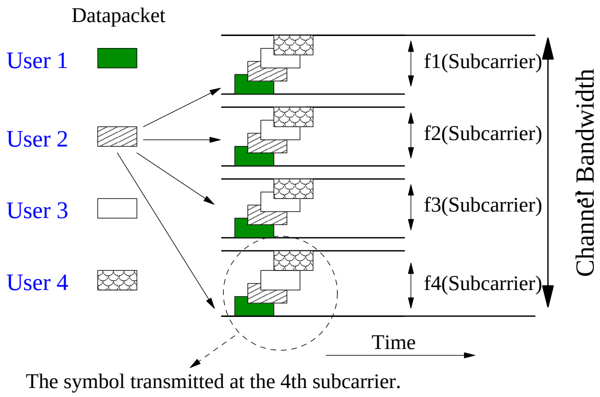

Figure 1: MC-CDMA. The symbol transmitted at the 4th subcarrier carries a fraction (chip) of 4 data packets, which belong to 4 different users.

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 sequentional, 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].

2.2. The MAC Protocol for MC-CDMA

The protocol of the proposed system is based on the Medium Access Control (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).

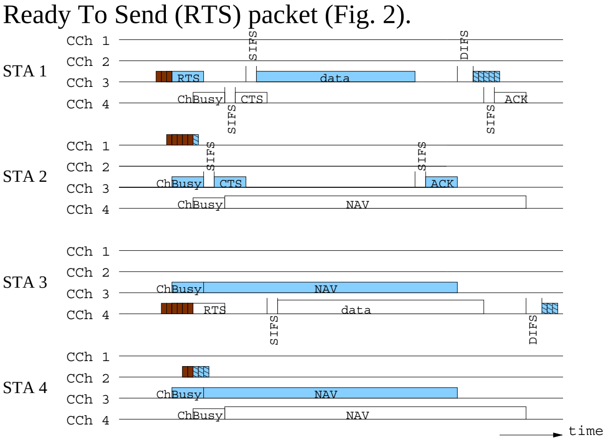

Figure 2: DCF applied on 4 cchs

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].

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.

3. Smart Backoff

We define Smart-Backoff as a backoff procedure spanning over many cchs. This procedure allows a station to change the cch, in case latter is blocked, to another one in idle. It is assumed that MSs in idle state can monitor all cchs.. Monitoring of the cchs is carried out both in PHY-layer (by sensing the channel) and logically by setting the NAV timer. During backoff, a station marks the time when a cch becomes idle Compared with the standard IEEE 802.11 W-LAN [6], in the MC-CDMA system each MS utilizes separate NAV states for each cch.

According to the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) procedure, after detecting the medium idle for time DIFS, a MS defers for a certain time, called backoff, before transmitting its packet in order to avoid collisions. The duration of the backoff time is defined in [6]:

$$\text{Backoff Time} = \text{Random} \cdot \text{aSlotTime}$$

with:

Random, a uniformly distributed random natural number in interval [0, CW], and aSlotTime 9µs. The Contention Window (CW) has a starting value of 7 and is doubled after a collision, respectively reduced after a collision resolution.

If the down count, carried out in steps of 9µs, of the backoff timer is not interrupted by another transmission the MS can start its packet transfer, as described in the introduction. In this case there is no difference with the known DCF [6], [1].

The Smart-Backoff procedure, shown in Fig. 3, allows a MS to iterate between cchs during backoff thus reducing the delay of a data transfer. For this purpose, MSs applying Smart Backoff monitor all cchs during backoff and mark the moment a cch got idle. If the backoff down count is interrupted one of the three cases shown in Fig. 3 occurs:

1. Another cch seems idle. The MS has to monitor the cch for at least a DIFS interval to determine whether it is idle and then it can continue the down count of backoff timer in this cch.

2. Another cch is determined idle and the MS can directly continue its backoff timer down count in this cch.
3. No cch is idle. The MS must wait.

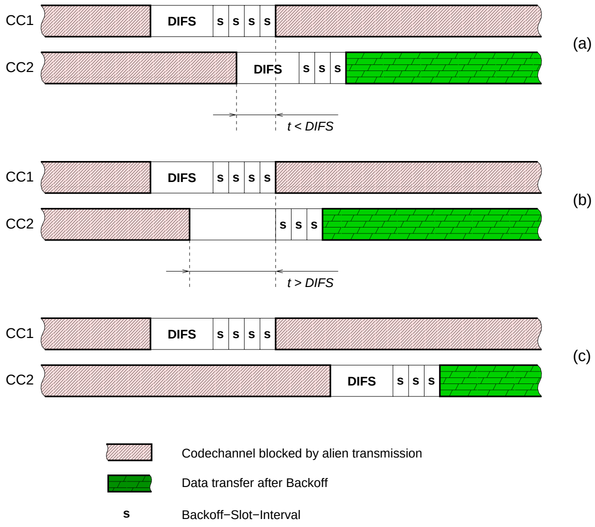

Figure 3: Smart Backoff

Should two or more cchs be idle, when the backoff down count is finished, the MS will choose one of them, preferably the one that is idle for the longer period. One other functionality of Smart Backoff, though, is to prioritise MSs with heavy load or delay sensitive applications towards others. To achieve this Smart Backoff is combined with parallel transmissions. As shown in Fig. 4, prioritised Stations can transmit two or more packets in parallel if after Smart Backoff the correspondent amount of cchs is idle.

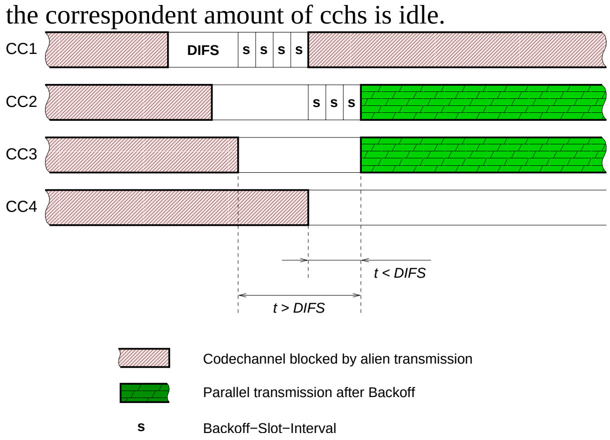

Figure 4: Parallel transmission

The Smart Backoff procedure allows MSs a better utilisation of the multichannel structure of MC-CDMA systems. It must be further mentioned, that Smart Backoff can be applied as well, in other systems than CDMA, which use multiple channels, to exploit their extra degree of freedom.

4. Simulation Results

4.1. Using Smart Backoff to achieve load balance among cchs

For the performance evaluation of the proposed system, we use event-driven simulations to measure the throughput that is practically achievable. For the evaluation of delay measurements, the Least Relative Error (LRE) algorithm [7] is used with maximum relative error 2%. Further parameters of the simulation setup are given in Table I.

Table I: Simulation Parameters

Parameter	Value
Max. TxPower	17dBm
Spreading Factor	4
Cwmin	7 slots
Cwmax	255 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

Fig. 5 shows the simulated scenario consisting of 10 terminals establishing 5 links in a 10mx10m area, addressing Small Office-Home Office (SOHO) scenarios. Simulations are performed using the QPSK ½ PHY layer mode (PHY mode) for control packets and the 64QAM ¾ PHY mode for data packets. Parallel transmissions are not allowed, all MSs are capable of Smart Backoff and the load generators deliver load with Poisson distribution.

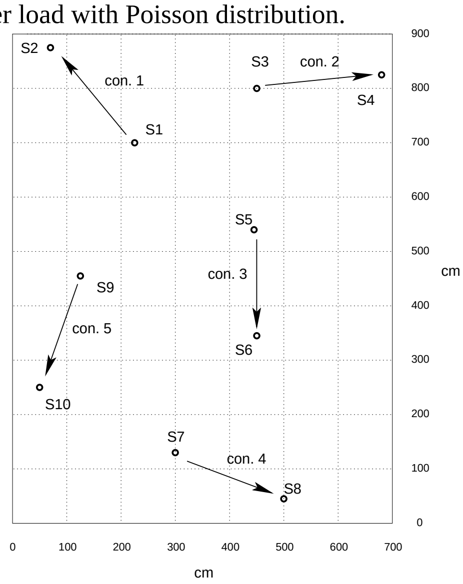

Figure 5: Simulated scenario

Although power control [9] is applied receivers sense interference from all other transmitting stations in this scenario. Interference comes both from other transmissions which take place on the same 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. To reduce this effect a Minimum Mean Square Error (MMSE) MultiUser Detector (MUD) is used at the detectors [11], [12].

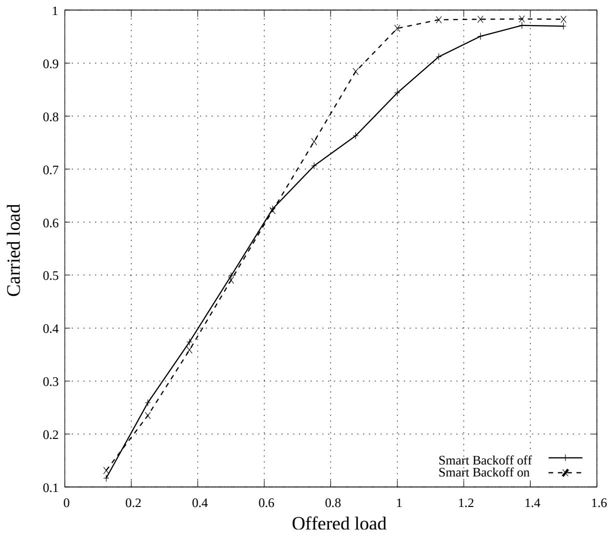

Figure 6: Comparison of system throughputs with and without Smart Backoff

In Fig. 6 the carried system load vs. the offered load is given for the cases of both activated and deactivated Smart Backoff. The generated load is a percentage of maximum theoretical net throughput measured at the MAC level, which i s for 64QAM ¾ 31,58 Mbit/s [1] for the MC-CDMA based W-LAN.

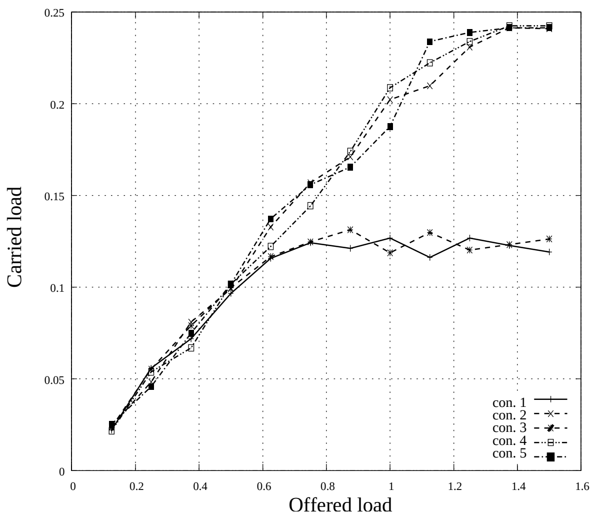

Figure 7: Throughput per connection without Smart Backoff

The system's performance with Smart Backoff is better for higher offered load. The maximum achieved throughput is 30.94 Mbit/s, which corresponds to 98% of the theoretical maximum [1].

The benefit of Smart Backoff appears for offered load more than 0.6. A system with Smart Backoff has an almost linear behavior for load up to 0.9. This effect can be explained from the observation of Fig. 7 and Fig. 8, showing the throughput per link with deactivated and activated Smart Backoff respectively. In the first case, without Smart Backoff, connections 1 and 2 which share the same cch, manage half of the throughput of other connections, which stand alone in one cch, pointing out the fact that assigning a fixed cch to a link degrades the system. Connections 1 and 2 reach their saturation throughput with offered load 0.75, although the system's resources are not completely utilised.

Fig. 8 depicts the benefits of Smart Backoff for the throughput of active links. Connections 1 and 2 are no longer blocked when the offered load excesses 0.75, since they can take advantage of the unused resources in the other 3 cchs. The system's resources are now equally distributed among the active connections.

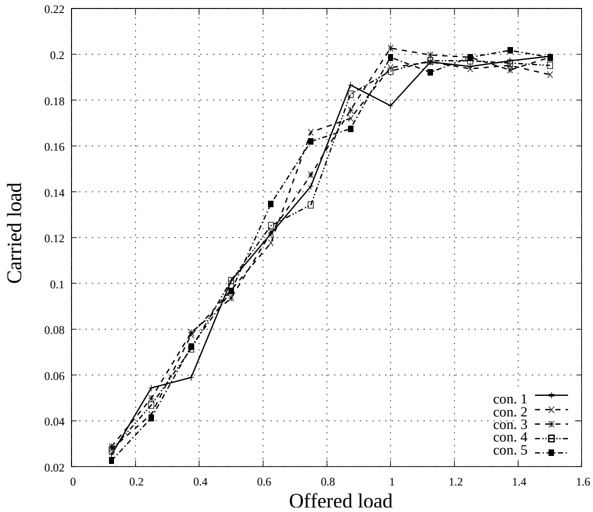

Figure 8: Throughput per connection with Smart Backoff

In Fig. 9 the mean (over all successfully received packets) queue delays for the two operation modes are shown. Smart Backoff has a clear advantage over standard DCF for offered load up to 0.9. Afterwards its performance degrades since it becomes difficult to detect a free cch when the offered load reaches and exceeds the maximum channel capacity (load = 1.0). It must be pointed out that by applying Smart Backoff the queue delay is limited to less than 10 msec, even if the offered load reaches 80% of the channel capacity.

The transmission time is 1msec for both Smart Backoff and standard DCF which allies with the theoretical analysis given in [1], and remains constant with the offered load since no collisions occur [1].

[1].

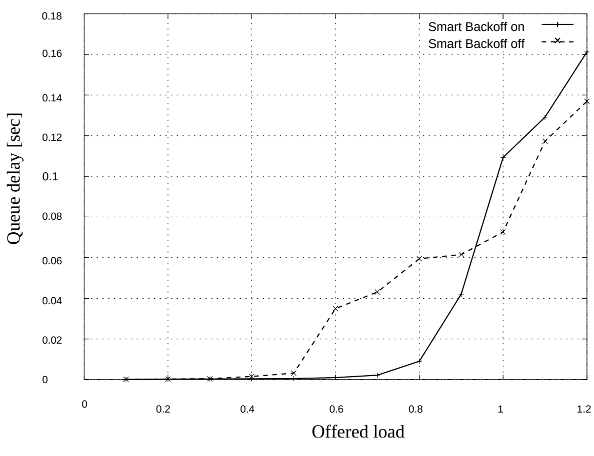

Figure 9: Comparison of queue delays with and without Smart Backoff

4.2. Using Smart Backoff to prioritise a MS

In order to investigate the potential of the new method to prioritize a MS in a network, we further simulate the scenario given in Fig. 10. It is a typical SOHO scenario in a 10x10m area with 6 active links. The PHY mode used for simulations is QPSK ½ both for control and data packets.

Each transmitting MS is offered different amount of traffic as given in Table II. The connections are using a fixed cch according to Fig. 10, which was randomly chosen during association. Station 9 generates 4,5 Mbps of Poisson load in total for connections 5 and 6, and uses optionally Smart Backoff with the ability to transmit in three cchs in parallel.

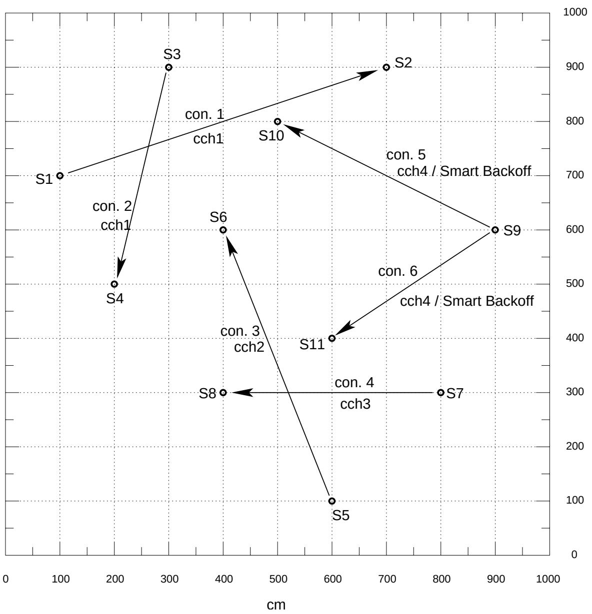

Figure 10: imulated scenario with prioritized station (S9)

In Table II the simulation results are presented. Connections 1 to 4 can carry the entire offered load since the capacity of the cchs is not exceeded. Links 5 and 6 can only achieve the transmission of all generated packets by using Smart Backoff. With the standard DCF and fixed on one cch the carried load is limited to 2.490 Mbps, corresponding to the maximum capacity of a cch with the applied PHY mode [1].

Table II: Throughput per Link

Connection number	Offered load (Mbps)	Carried load DCF (Mbps)	Carried load Smart Backoff (Mbps)
1	0.500	0.500	0.500
2	0.870	0.870	0.870
3	1.320	1.320	1.320
4	1.540	1.540	1.540
5+6	4.500	2.490	4.500

Table III provides an overview on the simulated queue delays per connection. For connections 5 and 6, with the prioritized MS 9 as transmitter, the application of Smart Backoff reduces the queue delay almost by a factor of 45. This has an effect on the other links which now face more traffic in their cchs thus their queue delay is slightly increased.

Table III: Queue Delay per Link

Connection number	Mean queue delay DCF (sec)	Mean queue delay Smart Backoff (sec)
1	0.0022	0.0043
2	0.0026	0.0058
3	0.0021	0.0060
4	0.0022	0.0054
5+6	0.3990	0.0082

Conclusion

In this work we presented and evaluated a new DCF for the MAC protocol, optimized for the multichannel structure of MC-CDMA networks. The new function adapts the MAC protocol to the multichannel structure of CDMA and leads to a traffic balance among the cchs and connections by applying Smart Backoff, a procedure which allows a MS to iterate between cchs during backoff. In this way, connections can take advantage of the whole channel bandwidth and are not limited to the capacity of a single cch.

As mentioned in section III the tradeoff for applying Smart Backoff is the use of four correlators at the receiver, in order to make it possible for a MS to monitor all four cch in idle.

Our future work focuses on further development of the MC-CDMA system, expansion to multihop communication, and design of an adaptive protocol to mitigate the problem of the near-far-effect with higher PHY modes, two parameters which are very important for the QoS support in modern multimedia home environments.

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List of Abbreviations

ACK	Acknowledgement
cch	Codechannel
CDMA	Code Division Multiple Access
CSMA/CA	Carrier Sense Multiple Access/ Collision Avoidance
CTS	ClearToSend
CW	Contention Window
DCF	Distributed Coordination Function
DIFS	DCF InterFrame Space
IEEE	Institute of Electrical and Electronics Engineers
LRE	Limited Relative Error
MAC	Medium Access Control
MAI	Multiple Access Interference
Mbps	Megabits per second.
MC–CDMA	Multi-Carrier Code Division Multiple Access
MMSE	Minimum Mean Square Error
MS	Mobile Station
MUD	MultiUser Detector
NAV	Network Allocation Vector
OFDM	Orthogonal Frequency Division Multiplexing
PHY layer	Physical layer
PHY mode	Physical Layer mode
QoS	Quality of Service
RTS	RequestToSend
SDL	Specification and Description Language
SIFS	Short InterFrame Space
SF	Spreading Factor
SOHO	Small Office Home Office
WLAN	Wireless Local Area Network