# A new Distributed Coordination Function for W-LANs with multiple channel structure

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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. From the point of view of medium access control (MAC) layer, by the use of MC-CDMA, the frequency channel is divided in many channels separated by different spreading sequences, which we refer to as codechannels (cchs). Previous work [1] has proven the achievements of this approach. The network reaches higher net throughput while the queue and transmission delays are kept low since almost no collisions occur. In this paper we present and evaluate a new distributed coordination function (DCF) for the MAC protocol, best suited for W-LANs with multiple channel structure. Although in this work the new DCF is analysed for the MC-CDMA approach, its functionality is not limited to spread spectrum systems. Scope of the new DCF is to reduce the queue delay and prioritize some mobile stations (MS) by allowing them to start parallel Backoff timers in more than one cch. The outcome is a more symmetric distribution of load among the codechannels, which enhances the network performance, which can be seen from the simulation results.**

***Keywords-component; MC-CDMA; W-LAN; Parallel Backoff; multiple channels; IEEE 802.11a,e***

## I. 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 Parallel Backoff, a procedure which allows a MS to start parallel Backoff timers in more than one codechannel (cch) 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 Parallel Backoff algorithm is given. Section IV contains an extended presentation and discussion on simulation results. Section V summarizes this work with some concluding remarks.

## II. MODIFIED SYSTEM DESCRIPTION

### 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].

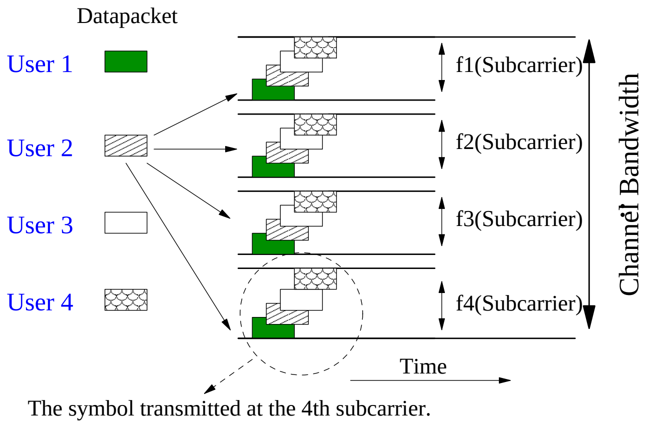

Figure 1. MC-CDMA. The symbol transmitted at the $4^{th}$ subcarrier carries a fraction (chip) of 4 datapackets, which belong to 4 different users.

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].

### *B. 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).

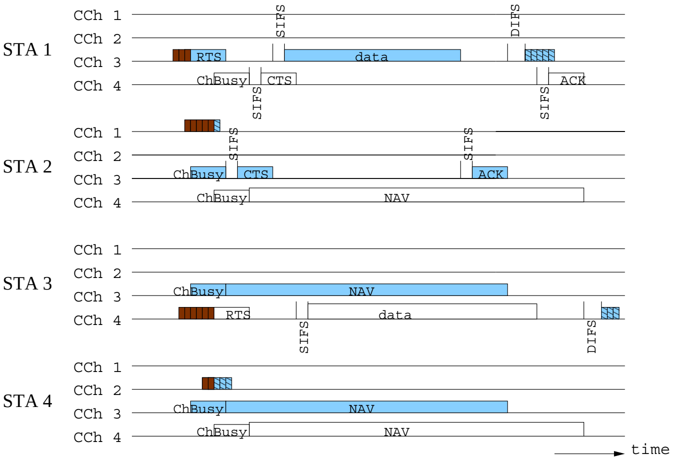

Figure 2. DCF applied on 4 cchs

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.

## III. PARALLEL BACKOFF

When applying Parallel Backoff a MS can start more than one backoff procedures in different channels, which in the case of a MC-CDMA system are the cchs. It is assumed that MSs in idle state can monitor all cchs. Monitoring of the cchs is carried out in PHY-layer, by sensing the channel.

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 Parallel Backoff procedure, shown in Fig. 3, allows a MS to start parallel backoff procedures in different cchs thus reducing the delay of a data transfer. For this purpose, MSs applying Parallel Backoff monitor all cchs for a time DIFS, and start a backoff timer in every cch determined as idle. The down count of the backoff timers is carried out in parallel. Should a transmission start in a cch then the corresponding backoff timer is stopped. If more then one down counts reach zero the MS may transmit more than one packet in parallel according to its prioritisation. This procedure has 3 main advantages:

1. MSs are not transmitting permanently on the same cch, thus leading to a load balance on the network as can be seen from the simulation results in the next section.
2. By transmitting in parallel, prioritized MSs can achieve their QoS demands even in high loaded networks.
3. The queue delay of a packet transfer can be minimized as the Parallel Backoff increases the possibility that at least

one backoff timer down count will reach zero without being interrupted.

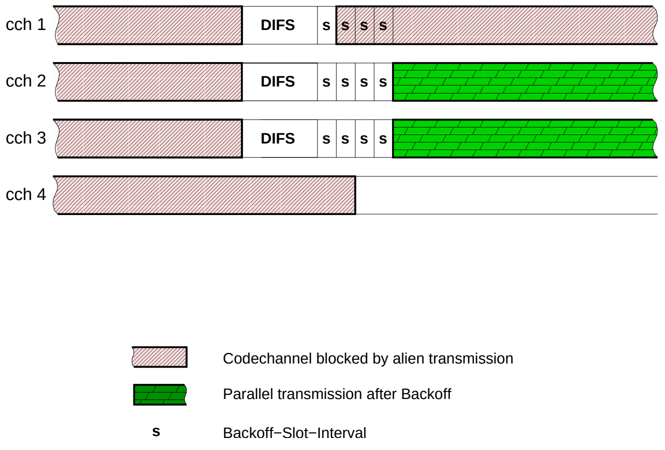

Figure 3. Parallel Backoff procedure with parallel transmission in two cchs

## IV. SIMULATION RESULTS

### A. *Using Parallel 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. The 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. 4 shows the simulated scenario consisting of 10 terminals establishing 5 links in a 8mx10m 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 Parallel Backoff and the load generators deliver load with Poisson distribution.

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].

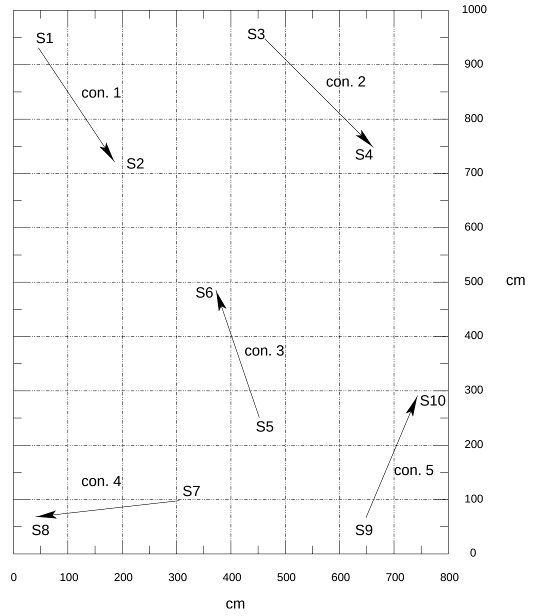

Figure 4. Simulated Scenario

In Fig. 5 the carried system load vs. the offered load is given for the cases of both activated and deactivated Parallel Backoff. The generated load is a percentage of maximum theoretical net throughput measured at the MAC level, which is for 64QAM ¾ 31,58 Mbit/s [1] for the MC-CDMA based W-LAN.

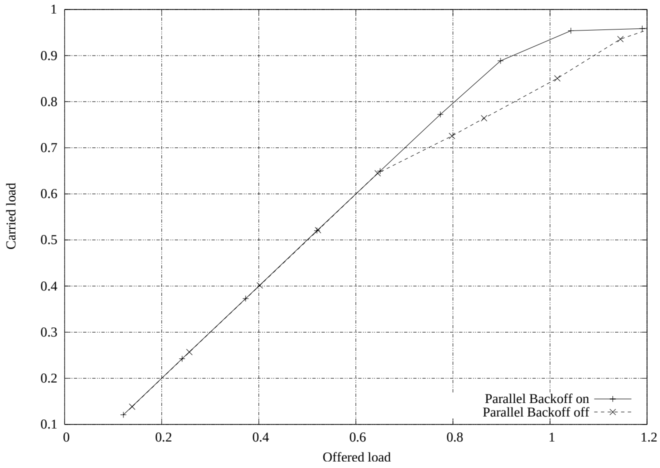

Figure 5. Comparison of system throughputs with and without Parallel Backoff

The system's performance with Parallel 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].

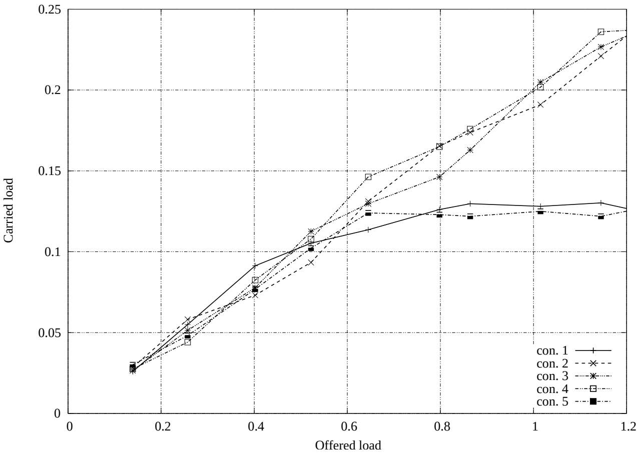

Figure 6. Throughput per connection without Parallel Backoff

The benefit of Parallel Backoff appears for offered load more than 0.6. A system with Parallel Backoff has an almost linear behaviour for load up to 0.9. This effect can be explained from the observation of Fig. 6 and Fig. 7, showing the throughput per link with deactivated and activated Parallel Backoff respectively. In the first case, without Parallel 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 0.65, although the system's resources are not completely utilised.

Fig. 7 depicts the benefits of Parallel Backoff for the throughput of active links. Connections 1 and 2 are no longer blocked when the offered load excesses 0.65, 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. When load exceeds 1.0, the distribution of the system's resources is not equal among the MSs any more. As soon as two MSs collide the other transmitters take advantage of their shorter backoff times and manage more packet transmissions.

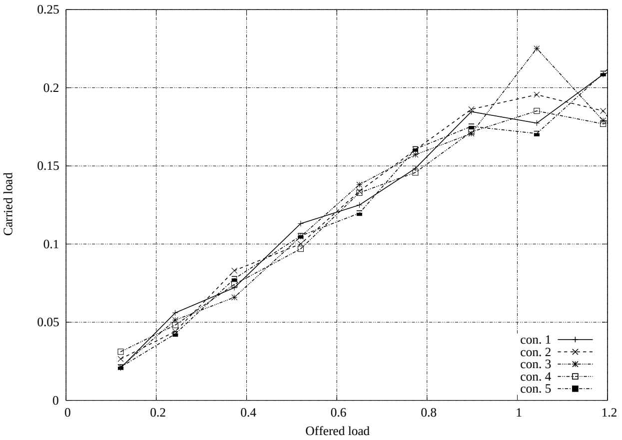

Figure 7. Throughput per connection with Parallel Backoff

In Fig. 8 the mean (over all received packets) queue delays for the two operation modes are shown. Parallel 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). Additionally, when the offered load exceeds the maximum channel capacity by 20% collisions become more probable due to the nature of Parallel Backoff, leading to higher queue delays. It must be pointed out that by applying Parallel Backoff the queue delay is limited to less than 5 msec, even if the offered load reaches 90% of the channel capacity.

The transmission time is 1msec for both Parallel 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].

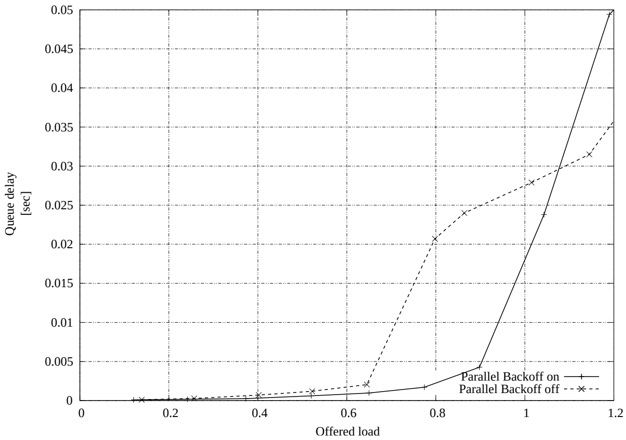

Figure 8. Comparison of queue delays with and without Parallel Backoff

### B. Using Parallel 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. 9. It is a typical SOHO scenario in a 10x8m area with 6 active links. The PHY mode used for simulations is QPSK ½ both for control and data packets.

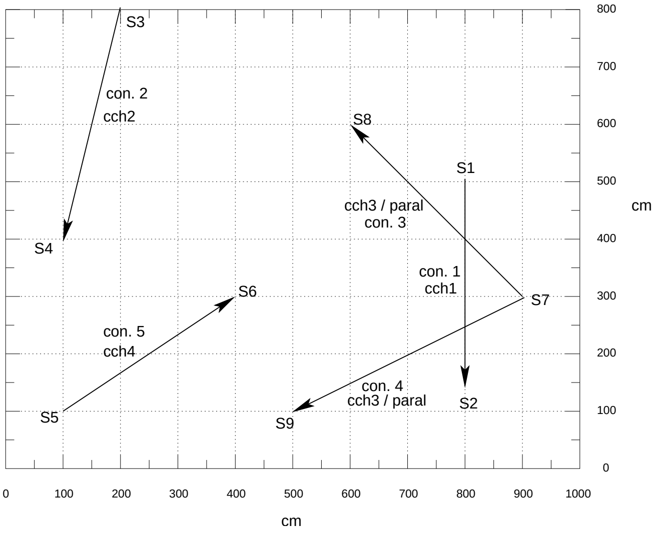

Figure 9. Simulated scenario with prioritized station (S7)

Each transmitting MS is offered different amount of traffic as given in Table II. The connections are using a fixed cch according to Fig. 9, which was randomly chosen during association. Station 9 generates 4,2 Mbps of Poisson load in total for connections 5 and 6, and uses optionally Parallel Backoff with the ability to transmit in three cchs in parallel.

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 Parallel 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 | DCF load (Mbps) | | Parallel Backoff load (Mbps) | |
|---|---|---|---|---|
| | **Offered** | **Carried** | **Offered** | **Carried** |
| 1 | 1.163 | 1.163 | 1.180 | 1.180 |
| 2 | 1.130 | 1.130 | 1.147 | 1.147 |
| 3 | 1.622 | 1.622 | 1.737 | 1.737 |
| 4+5 | 4.293 | 2.507 | 4.162 | 4.145 |

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 Parallel 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 Parallel Backoff (sec) |
|---|---|---|
| 1 | 0.0011 | 0.0050 |
| 2 | 0.0012 | 0.0033 |
| 3 | 0.0033 | 0.0046 |
| 4+5 | 0.1182 | 0.0070 |

## V. 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 Parallel 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.

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

## ACKNOWLEDGEMENT

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## LIST OF ABREVIATIONS

| | |
|---|---|
| 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 |
| 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 |
| SIFS | Short InterFrame Space |
| SF | Spreading Factor |
| SOHO | Small Office Home Office |
| WLAN | Wireless Local Area Network |