Multiband OFDM Alliance – The next generation of Wireless Personal Area Networks

Guido R. Hiertz, Yunpeng Zang, Jörg Habetha and Hamza Sirin

Abstract—**Next generation *Wireless Personal Area Networks (WPANs)* are intended for a variety of applications. The *Multi Band OFDM Alliance (MBOA)* is currently developing a new Physical Layer (PHY) and Medium Access Control (MAC) protocol, which fit the needs of this mass market. The MBOA standards provide wireless technology offering data rates of up to 480Mb/s. Besides support for *Quality of Service (QoS)*, ease of use and reliability are major features of the upcoming standard. Furthermore, the MBOA protocol provides seamless isochronous and packet oriented services. In this paper we provide technical insight into the new MBOA MAC and PHY layer, and we present detailed simulation results of the *Distributed Reservation Protocol (DRP)* and the *Prioritized Channel Access (PCA)* using the WARP2 simulation environment.**

Index Terms—**Multi Band OFDM Alliance (MBOA), Wireless Personal Area Networks (WPAN), MAC, Distributed Reservation Protocol (DRP), Ultra Wide Band (UWB)**

I. Introduction

THE market for *Wireless Personal Area Networks (WPANs)* is dominated by the Bluetooth technology. Its ease of use and the energy conserving procedures as well as the wide scope of applications led to a worldwide market success. The WPAN *Working Group (WG)* 802.15 began to standardize Bluetooth as an IEEE standard [20] in 1999.

Similar to the Bluetooth market the *Universal Serial Bus (USB)* is a tremendous success for wired short-range devices. With the introduction of version 2.0 of USB [21] the maximum throughput is increased from 12Mb/s to 480Mb/s. Its easy and cheap deployment leads to a wide field of applications. Besides the use of USB for *Human Interface Devices (HIDs)* for *Personal Computers (PCs)* a variety of *Quality of Service (QoS)* sensitive applications like video, audio and high speed device access similar to IEEE 1394 (Firewire, [17]) are available.

As an evolutional process towards the replacement of wired connections and as a successor to Bluetooth the IEEE WG 802.15 develops a high speed WPAN standard. 802.15.3 defines a new Medium Access Control (MAC) layer [4] and 802.15.3a standardizes a new *Physical (PHY)* layer [18], [19]. However, 802.15.3a has not yet been able to agree on a baseline proposal. Furthermore, the centralized MAC protocol of 802.15.3 has shortcomings for infrastructure-less ad hoc networks. This is why major industrial companies have established the *Multiband OFDM Alliance (MBOA)* [1], in order to develop new PHY and MAC specifications based on *Ultra Wide Band (UWB)* OFDM technology, which fits the needs of a high volume mass market. MBOA comprises most of the world's biggest Semiconductors, *Consumer Electronics (CE)*, PC and mobile phone manufacturers. Because of its huge market support, it can be expected that MBOA will set the de facto standard for the next generation of WPAN. Applications of the new standard include (but are not limited to) Wireless USB, Wireless IP (quick file transfer, use in handheld devices owing to the low power consumption, voice or video streaming, etc.), and Wireless 1394. Hence, the WiMidia Alliance (http://www.wimedia.org) has adopted the MBOA standard.

The authors have contributed key features to the MBOA MAC specification, which will be presented in this paper. The paper is organized as follows. In the following section (II.A) we will give an overview of the MBOA PHY technology. Then we will present the new MBOA MAC [5] in more detail in section III.A. Chapter IV contains simulation results for the MBOA MAC, and some conclusions are drawn in section V. Throughout this paper all units and abbreviations are defined according to [7].

II. High Speed WPAN PHY

In this section we will introduce the MBOA physical layer (PHY). It is based on the well known Orthogonal Frequency Division Multiplexing (OFDM) technology.

A. Multiband OFDM (MB-OFDM)

To support a wireless version of USB 2.0 [22] the MBOA PHY is designed to achieve data rates of up to 480Mb/s. In between 3168MHz and 10560MHz five band groups are defined. Support of band group 1 is mandatory. Support for all others is optional. Except for the highest band group, all groups consist of three frequency bands. One frequency band in MBOA is 528MHz wide and is divided into 128 OFDM subcarriers. 122 out of them are used for data pilot and guard subcarriers as shown in Table 1.

Up to seven *Time Frequency Codes (TFC)* in conjunction with 5 frequency band groups provide totally 30 logical channels over the UWB frequency band. Each TFC provides a

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hopping sequence applied to a band group. According to the TFC pattern, devices either hop through the frequency bands in their band group, referred to as *Time-Frequency Interleaving (TFI)*, or keep transmitting in a single band, namely *Fixed Frequency Interleaving (FFI)*. Hopping is done per OFDM symbol. Each symbol lasts 312.5ns, as shown in Table 1.

TABLE 1
PHY PARAMETERS

Parameter	Value
Number of data subcarriers	100
Number of pilot carriers	12
Number of guard carriers	10
Number of total subcarriers	122
Subcarrier frequency spacing	4.125MHz
Symbol interval (TSYM)	312.5ns

Convolution coding with a basic rate of 1/3 and the constrain length of 7 is used for *forward error correction (FEC)*.Further coding rates of 1/2, 5/8 and 3/4 are achieved through bit puncturing. Robustness is increased due to bit interleaving. In the MBOA PHY, each symbol interleaving block corresponds to six consecutive OFDM symbols. Table 2 gives the information on the data rate, modulation and coding rate of each MBOA PHY mode.

TABLE 2
MODULATION, CODING & DATA RATES

Data Rate (Mb/s)	Modulation	Coding rate (R)	Coded bits per 6 OFDM symbols (NCBP6S)	Info bits per 6 OFDM Symbols (NIBP6S)
53.3	QPSK	1/3	300	100
80	QPSK	1/2	300	150
106.7	QPSK	1/3	600	200
160	QPSK	1/2	600	300
200	QPSK	5/8	600	375
320	DCM	1/2	1200	600
400	DCM	5/8	1200	750
480	DCM	3/4	1200	900

Owing to the high operation frequency the MBOA PHY also provides the ranging and location awareness ability with an accuracy of 7.1cm at the 4224MHz clock.

TABLE 3
INTERFRAME SPACES DEFINDED FOR MBOA

PHY Parameter	Value
pMIFSTime	6 * TSYM = 1.875µs
pSIFSTime	32 * TSYM = 10µs
pCCADetectTime	15 * TSYM = 5.625µs
pSlotTime	8µs

III. NEXT GENERATION WPAN MAC

In this section, we are describing version 0.93 [5] of the new MBOA MAC layer. It is designed for high-speed, short-range communication infrastructure-less networks.

A. MBOA

Support for QoS is a crucial feature for WPANs. Thus four *Access Categories (ACs)* are defined to support prioritization. The mapping between these four ACs to 802.1D user priorities and their QoS parameter values can be found in Table 4, where TXOPLimit with value of zero indicates that only one packet can be transmitted in a TXOP. Furthermore, MBOA supports asynchronous and isochronous traffic based on packets of arbitrary length of up to 4095B.

TABLE 4
PCA QOS SETTINGS USED IN THE SIMULATION

Priority	AC	CWmin	CWmax	TXOP-Limit	AIFSN
1	AC_BK	15	1023	1 frame	7
2	AC_BK	15	1023	1 frame	7
0	AC_BE	15	1023	1 frame	4
3	AC_BE	15	1023	1 frame	4
4	AC_VI	7	511	1024µs	2
5	AC_VI	7	511	1024µs	2
6	AC_VO	3	255	256µs	1
7	AC_VO	3	255	256µs	1

1) Medium Access

To combine the efficiency of TDMA based systems with packet based technology MBOA introduces the *Prioritized Channel Access (PCA)* and the *Distributed Reservation Protocol (DRP)* [2], [3]. While the first one is well known from the *Enhanced Distributed Channel Access (EDCA)* defined in [8], the latter one is based on an advanced reservation scheme providing collision free access to the channel.

a) Prioritized Channel Access

The PCA is very similar to the *Enhanced Distributed Channel Access (EDCA)* [8] as surveyed by the authors in [9], [10], [11], [12]. It is a contention-based *Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA)* scheme relying on a prioritized backoff procedure.

Virtual stations of different priority inside every device compete for the channel access. Prior to every transmission attempt a device has to sense the channel as idle for a static period called *Arbitration Interframe Space (AIFS)*. Afterwards, it has to keep on sensing the channel for multiples of a SlotTime. For the current MBOA PHY [6] a SlotTime is equal to 8 µs. The amount of SlotTimes is a random number drawn from a uniformly distributed interval of (0, CW). The initial value of CW is CWmin. The duration of AIFS and CWmin depend on the priority of the backoff. Whenever the device senses the channel as idle it decreases its slot counter by one. If the slot counter reaches zero the device may transmit a data packet. If the device senses the channel as busy, it freezes its slot counter. After the channel is sensed as idle for an AIFS period again, the backoff procedure starts counting down the remaining slots. With every failed transmission a device doubles it CW to reduce the probability of a collision with other devices. As an example, a PCA based channel access sequence is depicted in Fig. 1.

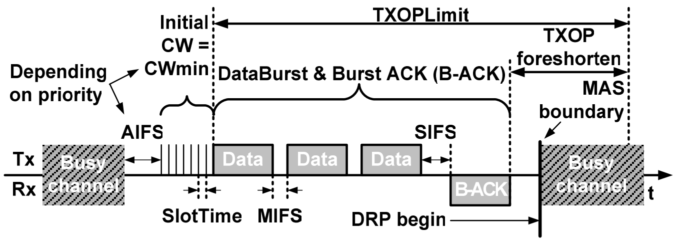

Fig. 1. The PCA is based on CSMA/CA. Devices start transmitting after a random period.

b) Distributed Reservation Protocol

The *Distributed Reservation Protocol (DRP)* provides a collision free channel access. It announces future transmissions and thus allows devices to coordinate their channel access [2], [3]. Time is divided into superframes, which comprise 256 *Medium Access Slots (MASs)* of length 256µs each. At the beginning of a superframe a *Beacon Period (BP)* consisting of n MAS, with 1≤n≤ mMaxBPLength, allows for the transmission of n*3 beacons. Each device sends a single beacon per BP. At the end of the BP the *Data Transfer Period (DTP)* starts, which lasts (256-n)*MASs.

Devices have to transmit beacons for synchronization, device discovery, sleep-mode operation and other purposes but especially to announce reservations. All active devices have to listen to all beacons in the BP and thereby learn from their neighbors about blocked MASs. Hence, a reserving device provides information about the starting MASs and the number of MASs to be reserved. These slots may be used for either hard or soft reservations. A hard reservation enables the device owning the slot to start its transmission immediately at the beginning of the reserved MASs, since all other devices must complete their transmissions a SIFS plus a guard interval before the reserved MAS. The reserved MAS itself should be used solely by the reserving device and its communication partners. No other transmission is permitted during that period. Hence, MBOA supports isochronous *real-time (rt)* traffic via DRP [2], [3].

For less strict demands on QoS support, DRP provides soft reservations. During a soft reservation the PCA is used. Only the owner of a reservation can access the medium with the highest priority AIFS and without any perform backoff. All other devices have to wait for an additional random time after AIFS according to PCA. The purpose of soft DRP is that, if the owner of the reservation does not fully use the reserved MASs, other devices can still use the unused MASs in the PCA mode.

A reservation can be negotiated explicitly or implicitly between sender and receiver(s) of a data stream. The sender initiates an explicit DRP negotiation with a DRP Request frame, which carries the so called *DRP Information Elements (DRPIEs)*, and sends it to the intended receivers. In the DRPIE the information of the proposed reservation information is conveyed. A unicast DRP Request is acknowledged immediately by the receiver, a multicast frame is not acknowledged. Afterwards, the intended receivers respond with a DRP Response frame, which establishes the reservation.

An implicit DRP negotiation is performed using the beacon frame. The device which starts a DRP reservation includes the proposed DRPIEs in its beacon frame. The intended receiver responds in its next own beacon with a corresponding Information Element.

In both cases of implicit or explicit DRP negotiation the receiver indicates to the sender whether the reservation must be shifted, is acceptable or not. Once a reservation has been established both the sender and the receiver of a DRP reservation inform their neighbors about the reservation by including the reservation in DRPIEs in their own beacon frames.

If there is any remaining time during a hard reservation, a frame exchange of *Unused DRP Announcement (UDA)* and *Unused DRP Response (UDR)* allows other devices to reuse the residual reservation time.

c) Device ID

To reduce the overhead, the well known 802 standard MAC addresses of 6B length are transformed to a shorter *Device ID (DEVID)* of 2B length.

TABLE 5
DEVIDS USED BY MBOA

DEVID Type	Begin	End
Private	0x0000	0x00FF
Generated	0x0100	0xFEFF
Multicast	0xFF00	0xFFFE
Broadcast	0xFFFF	0xFFFF

A "Generated DEVID" is a randomly chosen address. However, a device may not use a DEVID, which is already in use. Any device that detects a DEVID conflict should regenerate its DEVID.

d) Transmission Opportunities

Regardless if a device accesses the channel via PCA or DRP, the duration of every frame exchange is bounded by a TXOPLimit. For *Transmission Opportunities (TXOPs)* gained via DRP the TXOPLimit equals the duration of the reserved MASs. For PCA channel access the TXOPLimit is given per priority. However, the duration of a TXOP gained under PCA is further restricted by the closest DRP reservation, since no PCA transmission may delay or foreshorten any reserved MAS. When accessing the medium with PCA or making a new DRP reservation, a device has to respect all existing reservations. Besides these limitations, all decisions regarding the data exchange are solely up to the transmitting device.

e) Acknowledgment policies

MBOA defines three *Acknowledgment (ACK)* policies:

- No-ACK
- Immediate ACK
- Burst ACK.

To allow the receiver to distinguish between the desired ACK policies, each directed frame carries an "ACK policy" field in the frame control field inside the MAC header.

Immediate ACK policy works similar to standard 802.11.

Each successfully received *Mac Protocol Data Unit (MPDU)* is acknowledged after a *Short Interframe Space (SIFS)* period by the receiver. The SIFS period is needed for *transceiver (TRX)* turnaround and frame checking. It is used in between every frame exchange. With No-ACK policy no ACK is generated at all. Burst ACK policy increases the efficiency, since a group of MPDUs is acknowledged with a single frame by the receiver [16].

f) Minimum interframe space & frame aggregation

In between every consecutive frame a transmitting device may enhance the efficiency by using the *Minimum Interframe Space (MIFS)* instead of SIFS. Further, every device may benefit from frame aggregation, i.e. the concatenation of subsequent frames into a single data stream. However, the aggregated stream is subject to the same maximum size as any data frame payload.

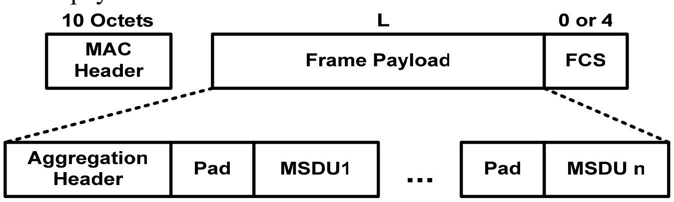

Fig. 2. An aggregated frame consists of multiple independent PDUs. The aggregation header indicates the length of each MSDU.

g) Fragmentation & RTS/CTS handshake

To reduce the *Packet Error Ratio (PER)* under bad channel conditions a device may choose to split any MSDU into a maximum of eight fragments.

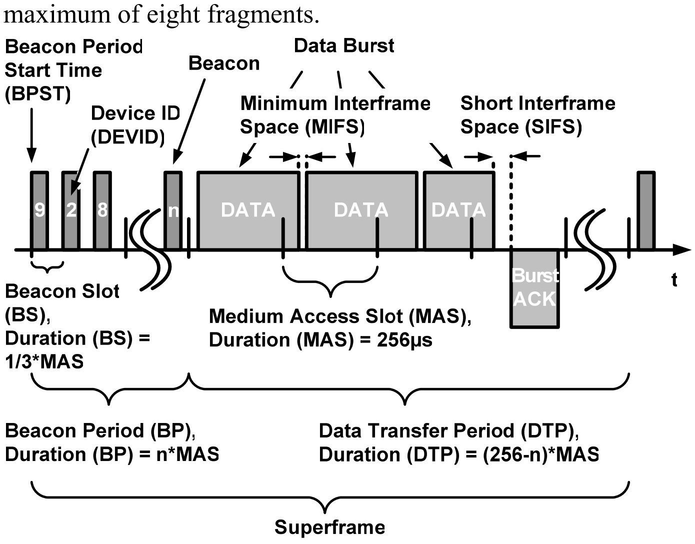

Fig. 3. Each Superframe consists of 256 MASs. n MASs are used for the BP. The rest is used for the DTP.

To cope with the hidden station problem inherent in every wireless network, the *Request To Send (RTS)/Clear To Send (CTS)* handshake known from 802.11 may be used. However, the overhead of an RTS/CTS handshake is needless when DRP is used.

h) Beacon period & Beacon frames

Each superframe starts with a *Beacon Period (BP)*. The maximum length of the BP is defined as mMaxBPLength which is a multiple of MASs. Each MAS in the BP consists of three Beacon slots. During the BP devices sequentially broadcast Beacons at the base rate (currently 53.3Mb/s). Each Beacon shall not exceed a length of mMaxBeaconLength which is equal to mBeaconSlotLength - SIFS - mGuardTime. And mBeaconSlotLength is one third of a MAS, i.e. 85µs. The mGuardTime is 12µs. Hence, a Beacon lasts at most 63µs, see Fig. 3.

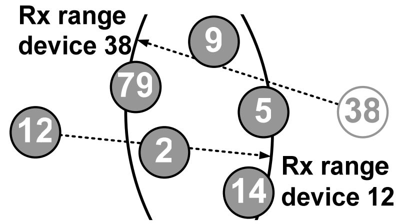

Fig. 4. Device 38 enters an existing WPAN. However, device 12 and 38 are mutually out of reception range. Hence, device 38 cannot receive beacon information from 12.

With every received beacon a device learns about its direct neighborhood. In a beacon a device broadcasts which beacon slots are occupied by which DEVID. Thus, each device learns about its neighbor's neighborhood, too. Therefore, if during the last three superframes a device does not receive a Beacon in a Beacon slot and it does not learn via neighbor beacons that the slot is occupied it treats the slot as empty. Once a device is powered up it scans for an empty beacon slot during three superframes. Then it announces its presence in a randomly chosen Beacon slot in between the highest-numbered Beacon slot and the end of the BP. If all Beacon slots are occupied, a device proceeds to send during the Signal Beacon Period and prolongs the BP by adding its Beacon to the succeeding MAS of the BP of the next superframe. A typical scenario of joining device is depicted in Fig. 4 and Fig. 5.

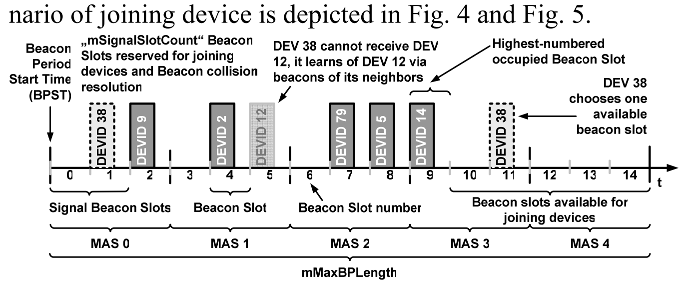

Fig. 5. Having sensed the channel and waited for at least a full superframe, device 38 learned about its neighborhood and its neighbors' neighborhood. Hence, it is aware of all occupied beacon slots and is able to join the WPAN.

A device will aperiodically skip a beacon transmission to be able to detect beacon collisions. Additionally, a device may detect a beacon collision if neighboring devices report an empty Beacon Slot or a different DEVID than its own in the corresponding Beacon Slot.

Establishing a single, joint BP with overlapping WPANs is important for energy conservation, since the BP is the only period a device must stay awake and be able to receive. Thus, battery powered devices may stay in sleep mode mainly and only need to power up during the BP and DRP periods they are involved in. A BP may be contracted to reduce the BP length. Therefore, the highest-numbered device which does not experience any collisions shifts its beacon slot to the earliest empty beacon slot in the next superframe.

In a situation of overlapping networks a coordination procedure is needed, since both WPANs are very likely to have different BPs. Hence, devices which detect alien BPs have to refrain from interference to alien BPs and DRP reservations. However, an additional BP provokes extra overhead and reduces energy conservation for sleeping devices. Therefore, MBOA defines a procedure to merge coexisting BPs. After announcing a protection DRP period for the alien WPAN, devices start shifting their beacons, thereby merging the BPs into a single BP.

i) Transmit power control (TPC) and rate adaptation

The receiver of a transmission may use the Link Feedback Information Element to inform the transmitter about the suggested ideal PHY mode or transmission power for a particular link. However, the transmitter may not follow the suggestion. The method to determine the optimum PHY mode and transmission power must regard the tolerable *Packet Error Rate (PER)*, which is application dependent. The implementation of TPC and rate adaptation is out of scope of the standard.

j) Distance measurements

The MBOA MAC incorporates means of distance measurements between two devices. It uses the roundtrip time which is measured by a special *Range Measurement* (RM) request frame, which has the Imm-ACK flag set. The distance "d" is calculated as

$$d = \frac{(t_{R1} + t_{R2} - t_{T1} - t_{T2}) * c}{2 * 4224\text{MHz}}$$

With t_{T1} being the send time of the RM request, t_{T2} being the send time of the corresponding ACK frame and c equal to the speed of light. t_{R1} holds the time when the RM request has been received, while t_{R2} presents the time when the ACK frame has been received. After having received all RM frames, the recipient sends a RM Report frame to the initiator. According to the accuracy of the hardware calibration constants included in each timing values "t", the most accurate results are given in units of c/4224MHz, which equal 71mm. However, with slower clock timing like c/528MHz, the lowest boundary of the precision equals 568mm. The precision of the measurement can be further reduced by timer clock differences between the transmitter and the receiver side, noise, imprecise calibration and motion. Furthermore, it is important to notice, that the PHY layer must not present non line of sight signal peaks to the higher layer. Those are likely to be introduced by multipath transmissions and diminish the precision.

IV. Simulative Analysis

We use event-driven stochastic simulations to analyze the efficiency of the MBOA MAC layer. Simulation campaigns have been performed based on the MBOA *Orthogonal Frequency Division Multiplexing (OFDM) Physical Layer (PHY)*. For delay results, we give the empirical *Complementary Cumulative Distribution Function (CDF)* of the resulting stochastic data, using the discrete *Limited Relative Error (LRE)* algorithm that also measures the local correlations of the stochastic data [13]. By measuring local correlations, the accuracy of empirical simulation results can be estimated. All delay results presented in this paper are within a maximum limited relative error of 5%.

The simulations were performed using the *Wireless Access Radio Protocol 2 (WARP2)* simulation environment developed at the Chair of Communication Networks, RWTH Aachen University [14]. It is programmed in the *Specification and Description Language (SDL)* using Telelogic's TAU SDL Suite (previously named *SDL Design Tool (SDT)*). The error model used in WARP2 to accurately simulate the Wireless Medium (WM) is presented in [15].

In the following all devices are within reception range of each other. Thus no hidden stations appear in our simulations. In scenario 1 we survey the maximum achievable throughput of the MBOA MAC layer. Using a simple scenario of one transmitting and one receiving device we provide simulation results on the upper boundary of the throughput in the absence of transmission errors. In this simulation both DRP and PCA are evaluated with the three kinds of acknowledgement policies and frame aggregation. The simulated superframe consists of an 8-MAS beacon period and a data transmission period of 248 MASs, which is used as the TxOP length in the DRP mode. In the PCA mode, the traffic takes the QoS values of AC_VI which can be found in Table 4. The burst size for Burst-ACK policy is set to 16 frames and the package aggregation timeout value is 100µs. Besides, the MIFS and the Burst Mode preamble specified in [6] are used in the burst transmission mode as well.

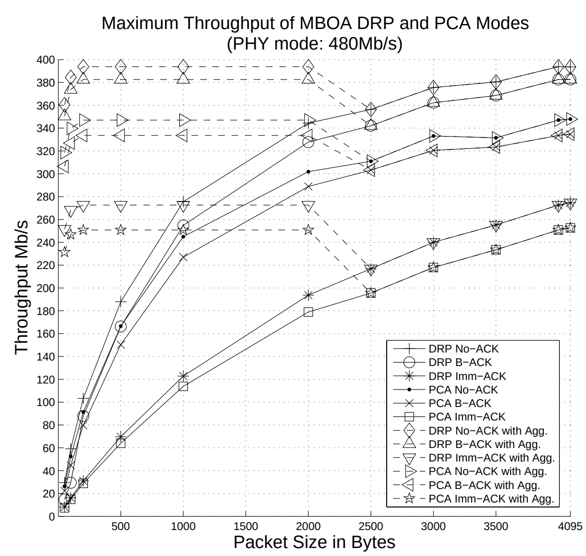

Fig. 6. Scenario 1: the efficiency of MBOA MAC with access methods of DRP and PCA combined with three ACK policies and frame aggregation as a function of the packet size.

The simulated maximum MAC layer throughput for MBOA system with a PHY mode of 480Mb/s is given in Fig. 6. The simulation results show that the throughput of DRP always outperforms the one of PCA with the same ACK policy by several Mb/s. That is because in the PCA mode even with the highest UP, the sender has to wait for an AIFS duration and perform a backoff before transmitting, which decreases the throughput. As expected, in both DRP and PCA modes the No-ACK policy achieves the highest throughput, followed by the Burst-ACK with a slightly lower value due to the overhead

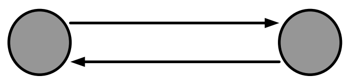

Fig. 7. Scenario 2: The duplex route connection.

of transmitting Burst-ACK frames. As shown here, frame aggregation is very important for an efficient packet oriented MAC. The throughput for small-size packets achieved with frame aggregation is comparable to the throughput of packets of big size.

In scenario 2, a duplex route connection is evaluated. Two devices share the channel capacity, as shown in Fig. 7. The throughput and delay performance of the duplex route are evaluated in three cases. In the first case, the DRP mode is used for both devices while the PCA with AC_VO and AC_BK are used in the other two cases, respectively. In all three cases, the packet length is fixed to 1800B, the ACK policy is set to Imm-ACK and no aggregation is performed.

The throughput results are presented, in Fig. 8, as a function of the traffic load offered by the upper layer. Since the two unidirectional routes of the duplex connection have their own reservation in the first case, the same throughput can be achieved by each route without suffering from collision. However, in PCA cases the two unidirectional routes have to content with each other for the channel resources. Therefore a throughput difference of these two routes can be observed, even if all the settings are the same. PCA routes with AC_VO can offer higher throughput than those with AC_BK due to the shorter AIFS time, the smaller backoff window size and the larger TxOP.

The delay evaluation results presented in Fig. 9 indicate that the PCA routes give a good delay performance for the light

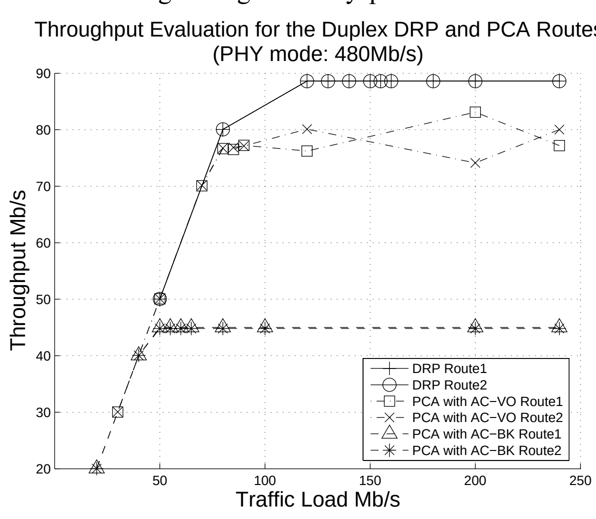

Fig. 8. Scenario 2: Throughput evaluation of the duplex route between two stations, when DRP, PCA with AC_VO and PCA with AC_BK are used as the channel access methods. ACK policy: Imm-ACK. Packet length=1800B.

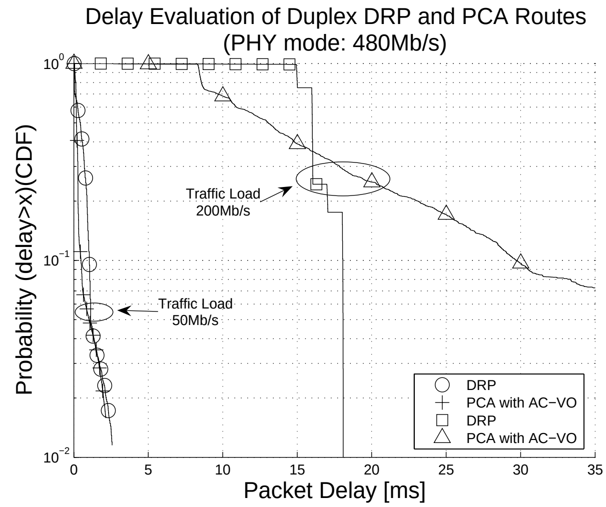

Fig. 9. Scenario 2: Delay evaluation under light traffic load (50Mb/s) and heavy traffic load (200Mb/s) of the duplex route between two stations when DRP, PCA with AC_VO are used as the channel access methods.

traffic load, but suffer from quite high delays in a heavily loaded situation. However, the DRP routes can provide, even with a heavy load, a bounded maximum delay which depends on the reservation pattern used for the transmission.

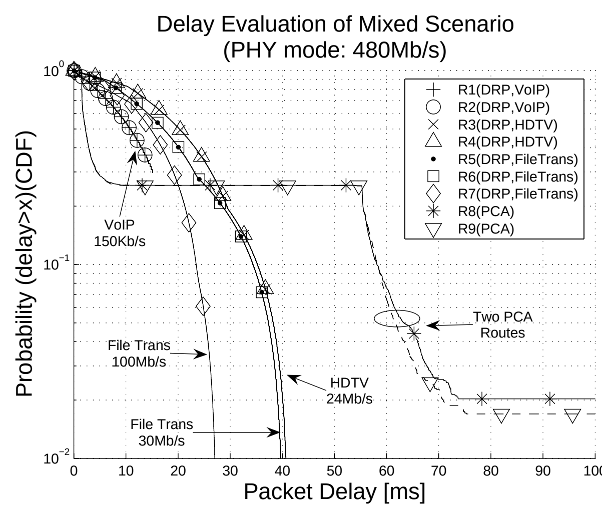

Fig. 10. Scenario 3: Delay evaluation of the mixed scenario with 7 DRP routes and 2 PCA routes sharing a single 480Mb/s channel.

Scenario 3 describes a mixed scenario on a single 480Mb/s channel. One pair of devices communicate via *Voice over IP (VoIP)* (150kb/s for each direction, 120B packet size, R1-2). A wireless streaming server provides HDTV to two different clients (24Mb/s of each, 1500B packet size, R3-4). Other two routes for file transfers at 30Mb/s (R5-6) and one route for a file transfer at 100Mb/s (R7), each using 1500B packets, are also simulated. The above mentioned routes are all using DRP. Additionally, two PCA connections participate in this scenario with AC_VO and 1500B packet size (R8-9). As presented in Table 6, DRP provide constant QoS support for the highly prioritized transmissions, while PCA fits for the low prioritized traffics. Fig. 10 shows that the delays for in DRP routes are bounded to some reasonable values. However, part of packets in the PCA routes experience unbounded large delay, even other PCA packets perform good in delay evaluation. This shape of the PCA delay distribution is mainly due to the MASs reserved by DRP routes, which can get access to the medium without any delay. PCA packets can only try to get access to the channel when a MAS is not reserved, otherwise they have to wait till the end of the DRP reservation and contend for the access again.

TABLE 6
THROUGHPUT RESULTS FOR SCENARIO 3

Route	Traffic Load (Mb/s)	Packet Size (B)	Access Method	Ack Policy	Throughput (Mb/s)
R1	0.15	120	DRP	No	0.15
R2	0.15	120	DRP	No	0.15
R3	24	1500	DRP	No	23.98
R4	24	1500	DRP	No	23.98
R5	30	1500	DRP	Burst	30.00
R6	30	1500	DRP	Burst	30.02
R7	100	1500	DRP	Burst	99.89
R8	200	1500	PCA	Imm.	13.00
R9	200	1500	PCA	Imm.	12.82

V. CONCLUSIONS

In this paper we have presented the new MBOA MAC protocol, in the development of which we have been heavily involved. We have implemented the MAC protocol in an event driven simulator and provide a performance evaluation of both the DRP and the PCA access methods. Simulation results indicate that the protocol is very efficient and that real-time services can be supported very well with DRP. PCA should only be used for all non-delay critical types of access, because larger delays can be expected.

Based on the complete PHY and MAC specifications of MBOA a very powerful WPAN with data rates of several hundred Mb/s can be set up and several companies have announced chipsets for the year 2005. In conclusion, MBOA seems to be well positioned for the race of the competing WPAN standards.

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