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Re:	**Call for Contributions for Modifications of 802.16 MAC and 802.11a/HIPERLAN/2 PHY for the WirelessHUMAN™ Standard - documents** IEEE 802.16.4-00/01
Abstract	This document analyses major issues in the operation of a WirelessHUMAN system and proposes a TDD/TDM system based on 802.16 MAC and 802.11a PHY. Advantages and disadvantages of TDD are thoroughly analyzed. The document proposes solutions to mitigate TDD drawbacks, to ensure proper operation in the presence of interference, to accommodate increased propagation delay. Issues like adaptive power control, rate control and co-channel interference are discussed both for a standalone system and in a cellular environment with sectorization and frequency reuse.
Purpose	To show that a TDD/TDM system for the WirelessHUMAN standard is feasible and has clear advantages. To outline the required modifications of 802.16 MAC and 802.11a PHY.
Notice	
Release	
Patent Policy and Procedures	

Proposed modifications of 802.16 MAC and 802.11a PHY for a WirelessHUMAN Standard employing TDD/TDM

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Introduction

The changes proposed in this document are based on IEEE 802.11a PHY [1] and 802.16 MAC [2] standards. They are designed to integrate these two into a wireless MAN system that employs time-division-duplexing (TDD) and time-division-multiplexing (TDM). The system will operate in the medium and high license exempt bands at 5-6GHz (U-NII) as defined by the Federal Communications Commission (FCC) in [3]. For a point-to-multipoint system, FFC allows an EIRP of up to 17 dBm/MHz in the medium band (5.25…5.35 GHz) and 23 dBm/MHz in the higher band (5.725…5.825 GHz).

IEEE 802.11a physical layer (PHY)

The 802.11a standard was developed to provide a wireless LAN with speeds up to 54 Mb/s in the 5.7-5.8GHz U-NII bands. 802.11a employs TDD and TDM with collision detection and collision avoidance at the MAC level. It occupies a single channel of 16.6MHz. Modulation is OFDM with 52 carriers out of which 48 are data carriers and 4 are pilots; each OFDM symbols takes 4 µs out of which the guard interval (cyclic prefix) uses 0.8 µs. The communication takes place in bursts (or packets) that are called frames in 802.11a. We will use PHY frame when referring to such a burst to distinguish between MAC and PHY frames.

A PHY frame consists in a preamble of 16 µs, a SIGNAL field of 4 µs and a DATA field with a variable number of OFDM symbols. The PHY frame is self-contained carrying enough information for the receiver to synchronize,

P	P	P	P	S	DATA

Fig. 1: 802.11a PHY frame: P = Preamble, S = SIGNAL

equalize and decode it. The first 8 µs in the preamble are used to acquire the automatic gain control (AGC), coarse frequency offset recovery and coarse symbol synchronization. The next 8 µs are used for fine offset recovery and symbol synchronization. The last 4 µs in the preamble are also used for channel equalization. During SIGNAL and DATA fields, frequency and symbol synchronization can be tracked using the 4 pilots whose combined signal-to-noise (SNR) has a 12 dB improvement over data carriers. The OFDM channel equalizer (one-tap FIR on each carrier) is easy to implement, it can be initialized in one OFDM symbol and it can track quick channel changes. The SIGNAL field transports the length of the packet (in bytes) and the transmission rate (6, 9, 12, 18, 24, 36, 48 or 54 Mb/s). Thus, each data packet can be fully decoded by the receiver PHY without any previous information or any contribution at the MAC level. The DATA field contains 16 bits for the SERVICE field, the true payload data, 6 bits for TAIL and the padding bits used to fill up to an integer number of OFDM symbols. The first 7 bits in SERVICE are used to initialize the (de)scrambler and the 6 bits in TAIL are used to return the convolutional encoder/decoder to state zero.

Overall, the 802.11a PHY provides great robustness, packet independence, narrow band interference rejection, and multi-path immunity (up to 0.8 µs or 240m). Note that, for long-distance communication, the large path loss requires use of directional antennas, which in turn shorten the multi-path effects. Thus, we think a guard interval of 0.8 µs should be appropriate for MAN applications at 5.7 GHz. These properties make 802.11a PHY a strong candidate for MAN operation in the unlicensed bands.

IEEE 802.16 media access control layer (MAC)

The 802.16 MAC is designated for long distance point-to-multipoint wireless links. It supports QoS for real-time traffic and it is connection oriented, thus providing increased efficiency through header compression. The entire traffic (uplink and downlink) is controlled by and goes through the base station (BS). It supports already several different PHY layers and access schemes with both TDD and FDD. In the following we detail the operation of the 802.16 MAC with TDD/TDM, which we believe is a strong candidate for operation in the unlicensed band in conjunction with 802.11a PHY.

In 802.16 MAC (with TDD/TDM) the basic data exchange is grouped in frames, called hereby MAC frames to distinguish between MAC and PHY frames. One MAC frame consists in one downlink subframe and one uplink subframe separated by pauses called Tx/Rx Transition Gap. The uplink subframe is further divided into three portions: Registration Contention, Bandwidth (BW) Request Contention and scheduled uplink data. The downlink subframe basically contains the DL (downlink) Map, the UL (uplink) Map and payload data for various subscriber stations (SS). The entire downlink is multiplexed in time (TDM) in a contiguous RF burst. Registration Contention is reserved for SS's that do not have a known round-trip delay and want to enter the network.

DOWNLINK	G	REG. CONT.	BW REQ. CONT.	G	SUL1		G	SULn	G

Fig. 2: 802.16 MAC frame: G = Transition Gap (Tx/Rx or CPE)
REG. CONT. = Registration Contention
BW REQ. CONT. = BW Request Contention
SUL = Scheduled Uplink

Therefore, Registration Contention includes the maximum allowed round-trip delay in addition to the required time-slots. BW Request Contention is reserved for registered stations (with known round-trip delay) that want additional uplink BW. The scheduled part of the uplink consists in SS's bursts according to the schedule established by the BS in the UL Map. Upon transition between one SS to another on the uplink, a break called CPE Transition Gap is inserted.

In the following sections we analyze the feasibility of a TDD/TDM system based on the 802.11a PHY and 802.16 MAC. Then, we detail the changes needed to adapt 802.11a PHY to the scope of 802.16. We also outline changes required to 802.16 MAC for efficient operation in the unlicensed bands with an 802.11a PHY.

Reasoning and outline of the proposed system

The main advantage of TDD in the U-NII band is that both the uplink and the downlink can operate in the high-power band. We believe that using frequency-division-duplexing (FDD) with a separation of less than 100MHz at 5.7GHz is technically extremely difficult due to poor transmit-receive separation. Therefore, a feasible FDD system should operate at least one of the links in the lower-power bands. TDD has also the advantage of occupying a single channel for both uplink and downlink, and thus it is less sensitive to interference caused by other wireless systems in an unlicensed environment. TDD can also divide the available bandwidth between the uplink and downlink more efficiently than FDD systems. TDD permits more effective power control (due to the channel symmetry) and requires less expensive RF hardware. However, there are several limitations of a TDD/TDM system as opposed to a FDD/FDM one.

Round-trip delay

First, the round-trip delay has to be accounted in the link budget. In 802.16 MAC, this is embedded in the Registration Contention period, but it should still be considered as wasted bandwidth. Propagation measurements in [4] at 5.8GHz report a path loss coefficient between 2 and 2.6 for line-of-sight (LOS) and around 3.5 for non-line-of-sight (NLOS). Assuming the maximum EIRP allowed for the higher band, an antenna of 26 dB on the receiver side and the receiver sensitivities defined in 802.11a PHY (see [1] page 40) we obtain, for different rates, LOS coverage between 5 and 50 km and NLOS coverage between 3 and 10 km. These results are summarized in table below. Note that receiver sensitivities used in this estimation are based on a 10 dB noise factor and that better

P	P	P	P	S	DATA	P	S	DATA	P	S	DATA

figures can be obtained in practice.

Path loss coefficient	Distance [km]	
	54 Mb/s	6 Mb/s
2.0 (LOS)	8.3	59.2
2.6 (LOS)	5.1	23.1
3.5 (NLOS)	3.3	10.3

Such a long distance capability could be important for distributing wireless internet to remote communities, farms, cottages, etc. However, in a TDD system, the round-trip delay for 50 km will be 333 μs, which will account for 16.6% overhead in the largest MAC frame (2 ms) as presently defined in 802.16 MAC. Therefore we suggest increasing the allowed MAC frame length to reduce the overhead of the system when operating over a large distance.

PHY Preamble overhead

Second drawback in a TDD/TDM system is that both the uplink and the downlink operate in a burst mode as opposed to a FDD/TDM system where downlink operates in continuous mode or a FDD/FDM system where both links operate in continuous mode. The burst (or packet) mode requires re-synchronization, re-equalization, etc. for each packet. Therefore the preamble shall be transmitted with each data packet causing an additional overhead. Here, the advantage of OFDM is that it requires only one symbol for equalization as opposed to rather long training sequences used with other modulations. In 802.11a PHY, the preamble required for automatic gain control (AGC), synchronization, carrier-offset recovery and equalization takes the space of only 4 OFDM symbols (16 μs).

However, the preamble overhead can be further reduced. On the downlink, since channel may differ from SS to SS, different destinations may require different rates. This means that downlink may contain several 802.11a PHY frames with different rates. For efficiency, it is preferable to group all messages with the same rate in a single PHY frame and to concatenate the PHY frames in a single RF burst. Since AGC, synchronization and carrier-offset recovery are only required for the first PHY frame (once set, they can be tracked using the pilots), we propose to shorten the PHY preamble for the other PHY frames in the downlink such that it consists of only the last 4 μs of the 802.11a preamble. This will provide enough information to refresh the equalization, so the PHY frames remain statistically independent. In terms of implementation this requires a minor change from 802.11a. To support this feature, we suggest to use a reserved bit (see below) in the SIGNAL field to specify if the current PHY frame is the last in the sequence or is followed by another PHY frame with shortened preamble. Note that, if we were to concatenate complete 802.11a PHY frames, the implementation would be more difficult due to longer processing delay. For example, a new packet can enter the synchronization block before having decoded the SIGNAL field from the previous packet.

Recall that each packet in 802.11a PHY has a 16-bit SERVICE field, out of which only 7 bits are used to initialize the scrambler. We propose to use the other 9 bits to transport useful data, e.g. MAC headers. This is particularly important when using the lowest data rate (6 Mb/s), where the overhead caused by SERVICE and TAIL fields amounts to a full OFDM symbol (4 μs).

Operation in a multi-sector environment

The third limitation of a TDD system takes place when used in a multi-sector, cellular environment. Here the area to be covered is divided in several sectors, with the SS's in each sector being assigned to different BS. All BS's are usually grouped in the same physical location that will call hereby a HUB. If number of sectors is greater than the number of channels available, then same frequency is used by several BS's in the same HUB. The co-channel interference caused by one BS in transmission will prevent all BS's operating on the same frequency from receiving anything from their SS's. Due to the big difference in power, adjacent channel interference may cause the same problem in an FDD system as long as the downl for this problem is to synchronize the BS's operating in the same HUB so that all transmit and receive at the same time. This forces all BS's to use the same ratio between uplink and downlink, reducing somehow the TDD flexibility in this area. However, as opposed to FDD, this ratio can still be adjusted, e.g. by a HUB controller that collects traffic and buffer statistics from all BS's.

Fig. 3: Concatenated PHY frames: P = Preamble, S = SIGNAL

Power control in sectorized and non-sectorized environments

In a non-sectorized environment the BS may choose to transmit with different power levels for different SS's. However, in a sectorized environment (with or without frequency reuse), all BS's shall use the same power level to minimize the adjacent-channel and eventually the co-channel interference. For the uplink, it is better to equalize the received power at the BS level. Therefore, power shall be finely controlled at SS's to allow approximately equal received levels at the BS. Here, the channel symmetry can be employed, so the SS's can use the received signal strength indicator (RSSI) to calculate the optimum power for the uplink. We propose to increase the resolution of the transmit-power control (TXPWR_LEVEL) for the 802.11a PHY (now only 8 levels). We also propose to have a known relationship between scales and resolutions of TXPWR_LEVEL and RSSI to allow simple power control.

Interference and rate control in unlicensed bands

Note that 802.16 MAC does not require the Clear Channel Assessment (CCA) function in the 802.11a PHY. However, the hardware associated with this function can be used to assess the channel interference during the short breaks like Tx/Rx Transition Gap and CPE Transition Gaps. This may prove extremely useful to assess the available data rate for a certain connection in an unlicensed environment. For each received PHY frame, the modified 802.11a PHY shall report to the MAC the interference level measured during the gap before the current frame. If the same known scale is used by PHY to report the interference level and the received signal strength indicator (RSSI), the MAC can collect statistics of these and decide the optimum rate for each link. The MAC can also decide to raise the transmitted and/or received power levels at the BS side to "hide" the interfering signal.

Other changes

Since duration of an OFDM symbol in 802.11a PHY is 4 μs, the basic time allocation unit in 802.16.HUMAN shall be also 4 μs. Note that the PHY preamble duration is also multiple of 4 μs. We propose to have the transition gaps (Tx/Rx and CPE) also 4 μs. This will also affect also the structure of the DL Map and UL Map, where BW allocation shall be redefined in terms of the PHY rate and number of OFDM symbols. However, having higher granularity will significantly reduce the overhead caused by the MAC management messages and some MAC headers.

Detailed changes to 802.11a PHY

Clear Channel Assessment (CCA) function

The Clear Channel Assessment (CCA) function is not needed and shall be removed. It shall be replaced by the Received Interference Level Indicator (RILI) defined below.

Received Interference Level Indicator (RILI)

A new parameter called Received Interference Level Indicator (RILI) shall be added to the parameters reported by the PHY layer in RXVECTOR. The receiver shall detect and memorize the signal level during the transition gap (4 μs) prior to the first symbol in the preamble of the current PHY frame. It shall report this level as RXVECTOR.RILI. The scale and resolution of RILI and RSSI shall be the same. The PHY layer shall report to the MAC layer, the scale and resolution of these parameters (in dB), upon initialization.

TXPWR_LEVEL parameter

The range of TXPWR_LEVEL parameter in TXVECTOR shall be enlarged to allow better resolution. The PHY layer shall report to the MAC layer the ratio between the scale and resolution of TXPWR_LEVEL and RSSI/RILI, upon initialization.

PLCP Header – SIGNAL field

The reserved bit R (bit 4) in the SIGNAL field shall be renamed TX_CONCAT and it shall used to specify if the current PHY frame is or is not followed by a frame with shortened preamble. The meaning of this bit is described below.

SIGNAL.TX_CONCAT = 1 – a PHY frame with a shortened preamble follows the current frame.
SIGNAL.TX_CONCAT = 0 – this is the last PHY frame in the sequence.

PLCP Header – SERVICE field

In 802.11a, the first 7 bits in the SERVICE field (16 bits) are used for (de)scrambler initialization and the other 9 bits are reserved. The last 9 bits in the SERVICE field shall be allocated for the MAC header to reduce the protocol overhead. At MAC level the CRC shall be extended over the SERVICE field.

Transmitting concatenated PHY frames

A new parameter called TX_CONCAT shall be added to parameters of the PLCP transmit procedure in TXVECTOR. This parameter has to possible values:

TXVECTOR.TX_CONCAT = 1 – a PHY frame with a shortened preamble follows the current frame.
TXVECTOR.TX_CONCAT = 0 – this is the last transmitted PHY frame in the sequence.

The PLCP transmit procedure shall copy this parameter into the SIGNAL.TX_CONCAT bit. When TX_CONCAT = 0, the transmit procedure shall end as described in 802.11a standard. When TX_CONCAT = 1, the transmit procedure, upon finishing the OFDM symbols in the current frame shall start transmitting the last 4 μs of the preamble, waiting for the MAC to initiate the transmit procedure of the next PHY. Upon, receiving the TXVECTOR parameters of the next PHY frame, the PHY layer shall produce the SIGNAL field, followed by the DATA field.

Receiving concatenated PHY frames

Upon receiving the last OFDM symbol in a frame, the PHY layer shall look at the TX_CONCAT bit in the SIGNAL field. If SIGNAL.TX_CONCAT = 0, the PHY layer shall proceed as described in 802.11a standard. If SIGNAL.TX_CONCAT = 1, it shall not reinitialize the synchronization machines after receiving the last symbol in the current frame. Instead, it shall use the first 4 μs after the end of the current frame to reinitialize the channel equalizer and then it shall initiate a new PLCP receive procedure starting with the SIGNAL symbol.

Summary of changes to 802.16 MAC

PHY Slot

The PHY slot, which is the basic time allocation unit, shall be changed to 4 μs. The Rx/Rx Transition Gap and CPE Transition Gap shall be fixed to 4 μs.

Frame length

The duration of the 802.16 frame shall be allowed larger values, e.g. 4 ms, 8 ms and 16 ms in addition to 0.5 ms, 1 ms and 2 ms.

Downlink with multiple rates

If the downlink subframe of a MAC frame contains payload with different rates, then the payload shall be sorted and grouped in ascending order of the rates. Payload with same rate shall be grouped in the same PHY frame. When requesting transmission of a PHY frame, the MAC shall set/reset the TXVECTOR.TX_CONCAT parameter to specify whether this is or is not the last PHY frame in the sequence.

BS synchronization – HUB management convergence sublayer

A HUB Management Convergence Sublayer shall be added to the 802.16 MAC. This will provide a mechanism to synchronize all BS's in the same HUB, such that they all transmit and receive simultaneously under supervision of a HUB controller. This sublayer will also maintain and be able to report statistics of the uplink and downlink traffic in terms of available and requested BW. Such information can be used by a HUB controller to change the way it allocates the available BW between uplink and downlink across the entire HUB.

Conclusions

We have analyzed the advantages and disadvantages of TDD/TDM and the feasibility of a wireless point-to-multipoint system based on 802.16 MAC and 802.11a PHY under the scope of the WirelessHUMAN/802.4 PAR. We have considered potential 802.4 applications ranging for sparse populated area where the range of the system is highly important to dense populated areas where cellular deployment with sectorization and frequency reuse is required.

We have proposed the following solutions to overcome the TDD/TDM drawbacks and to improve the overall system behavior in unlicensed bands:

- To reduce the preamble overhead via PHY frame concatenation.
- To reduce co-channel and adjacent-channel interference in a cellular environment via BS synchronization.
- To accommodate increased propagation delay via larger MAC frames.
- To equalize received power level at the BS using adaptive power control at the SS's. This is facilitated by extending the 802.11a PHY power control resolution and by using known scales for both power control and received-signal-strength detection.
- To improve the bit-rate/error-rate control by adding an interference level detector to the 802.11a PHY and comparing received signal strength with the interference level when deciding the optimum rate.

The changes required to implement the above features and integrate the two standards have been outlined for the 802.16 MAC and detailed for 802.11a PHY. We think that we have kept these changes to a minimum, especially for the 802.11a PHY. This way it is very likely that 802.4 and 802.11a systems could share the PHY ASIC's, reducing costs for both of them. We believe that a WirelessHUMAN system as outlined in this document can be both technically and economically feasible.

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