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Source(s)	Mika Kasslin Nokia Research Center Itamerenkatu 11-13 FIN-00180 Helsinki, Finland Voice: +358-9-4376 6294 Fax: +358-9-4376 6856 mailto:mika.kasslin@nokia.com Nico van Waes Nokia Networks 313 Fairchild Dr. Mountain View, CA, USA Voice: +1-650-625-2201 Fax: +1-650-625-2058 mailto:nico.vanwaes@nokia.com
Re:	Call for Contributions for Proposed Modification of Specified MAC/PHY standards for WirelessHUMAN™ (TG4); issued 2000-11-17.
Abstract	We propose some modifications to the system concept the TG1 MAC is based on to make it more feasible for TG4. Some specific modifications to the MAC and messages defined are proposed.
Purpose	The system concept with related messaging modifications should be incorporated into the TG1 MAC to make it usable for TG4.
Notice	
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A WirelessHUMAN^{TM} System

Mika Kasslin, Nico van Waes

1 Foreword

This document first describes a system concept that is proposed to be used in WirelessHUMAN^{TM}. The basic idea is to have more flexibility on the system level to make it more feasible to deploy in various enviroments and usage scenarios in the 5GHz U-NII bands. In addition to the PMP mode specified in [1] by TG1, we propose a mesh mode that can be easily incorporated into the IEEE 802.16 standard.

In the latter part of the document we propose a list of modifications and additions to the 802.16 MAC described in [1]. Part of the modifications are to realise a mesh mode while some do apply also to the PMP mode and are more general requirements due to the operation in unlicensed bands. Thus this proposal concentrates on system concept and MAC, while for a PHY there is a separate proposal [2].

2 System concept

For lack of a functional requirements document, this section gives a brief overview of the system envisioned.

Contrary to the other 802.16 projects, networks in the unlicensed bands can be more adhoc installed and relocated. Further, propagation conditions and interference situations may vary greatly not only between different networks but also within a single network or cell. Hence a more flexible deployment architecture, with inherent redundancy, creates significant added value.

The system as envisioned hence does not only support the rigid PMP architecture based on 802.16.1, but also mesh deployments. The mesh specific definitions in PHY and MAC in itself could also support PMP, but for legacy reasons the non-mesh capable 802.16.1 definitions need to be supported.

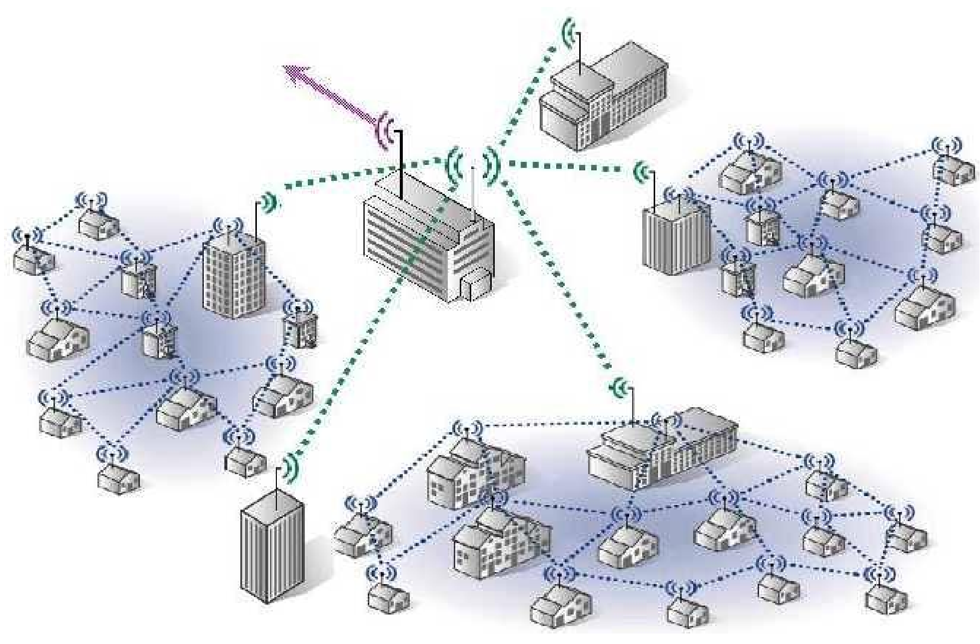

Figure 1. A two-layer network deployment example.

Figure 1 depicts a network deployment example, using both PMP and mesh mode configurations, with a wireless PtP backhaul link. Naturally, both PMP and mesh mode deployments can also be deployed seperately.

The system is envisioned to be IP-centric, with “Internet access” being its dominant feature. The intention is to have a general 802.16 IP-convergence layer, which is transparent to the layers underneath.

2.1 Mesh mode

The mesh mode is proposed to provide for easy, fast and cost-effective network set-up, installation, deployment and extension that are not always feasible with PMP, especially in unlicensed bands. In a mesh mode we would have a solution for extending broadband services to a mass market. Each radio in the network becomes part of the infrastructure and can route data through the wireless mesh network to its destination. The system is oriented more towards residential and SOHO markets which results in needs to operate in densely populated diverse geographical locations. Propagation conditions are diverse, interference situations relatively local and PMP deployment would require careful network planning in order to provide for connections to all the subscriber units.

With a mesh mode the WirelessHUMAN™ system would add robustness and reliability of the networks in addition to the features already mentioned. Each subscriber unit, i.e. a node, does have typically connections to a number of other nodes in the network instead of a single radio link to the base station. A node may select any of the links it does have to its neighbors to forward traffic originated in the node itself or in some other node in the network. Probability of the connection outage is much lower than it is in PMP mode. And in unlicensed bands with non line-of-sight links the ever changing link qualities are the problem. In the mesh mode the more nodes that are added to the network, the more robust and far-reaching the network can become. Further, use of a mesh mode would solve the problem of repeaters that would be needed in any case and there would be no need to have separate repeater functionality in the system.

On contrary to the traditional mesh systems our proposal does not use contention based access scheme. We propose a relatively traditional TDD/TDMA scheme with a fixed frame size and scheduled traffic accesses. Nodes exchange schedule control packets on a common channel to avoid collisions within each two-hop extended neighborhood (Figure 2). Nodes are mandated to listen all the control packets from their neighboring nodes.

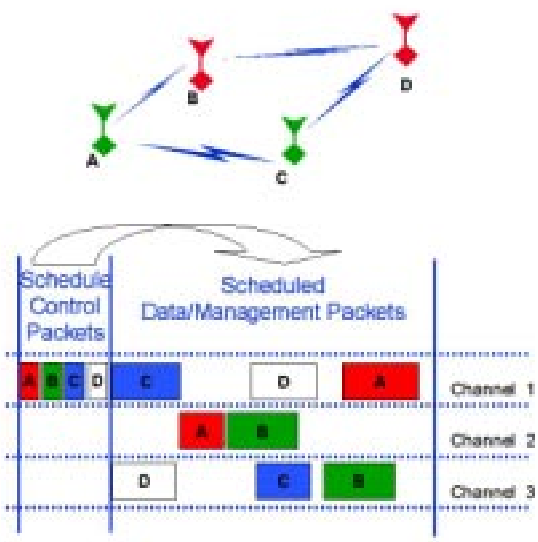

Figure 2 Basics of the channel scheduling in the mesh mode.

Control packet schedule can be determined on a minimized contention basis. A device, knowing its neighboring devices up to two hops away, can compute which neighbor receives priority in each Ctrl slot (a possibility to transmit a control packet). When the device computes the highest priority for itself, it will use that slot and transmits a control packet. Hence, without any over the air messaging, contention in Ctrl slots is minimal. It should be noticed that a table of neighbors needs to be maintained anyway for routing purposes.

Basics of the MAC and required MAC management messages are introduced in the following section in details.

3 Definitions and abbreviations

3.1 Definitions

Base Station	The central node in a PMP architecture
Airhead	A node in a mesh network, which has a local connection to the core-network.
Node	A (radio)device within a network, typically used to indicate a device which is not an Airhead
Subscriber Station	A node in a PMP architecture, which is not a Base Station

3.2 Abbreviations

ACK	Acknowledgement
ARQ	Automatic Retransmission reQuest
BER	Bit Error Rate
CI	CRC Indicator
CRC	Cyclic Redundancy Check
CSI	Convergence Subprocess Indicator
DFS	Dynamic Frequency Selection
DL	Downlink
EC	Encryption Control
EKS	Encryption Key Sequence
FC	Fragment Control
FSN	Fragment Sequence Number
GM	Grant Management
HCS	Header Check Sequency
HT	Header Type
IP	Internet Protocol
MAC	Medium Access Layer
NACK	Negative Acknowledgement
NMS	Network Management System
OFDM	Orthogonal Frequency Division Modulation
PA	Power Amplifier
PER	Packet Error Rate
PHY	Physical Layer
PLCP	Physical Layer Convergence Procedure
PMP	Point-to-Multipoint
PS	Physical Slot
PtP	Point-to-Point
QoS	Quality of Service
RSSI	Received Signal Strength Indication

RTG	RX Transmission Gap
SS	Subscriber Station
TDD	Time Division Duplex
TTG	TX Transmission Gap
VCXO	Voltage Controlled Crystal Oscillator
UL	Uplink

4 MAC

4.1 Frame structure

4.1.1 PMP mode

Only support of the 802.16.1 TDD option is envisioned in PMP mode. Further, no need to support different and flexible frame size can be seen. Thus we propose a frame of 8.192 ms to be used in PMP mode which would result in similar timing requirements as in the mesh mode presented in below. Otherwise the basics of the framing defined in 802.16.1 could be used such in the PMP mode. Slightly different schedule signaling method should, however, be considered. In TG1 the focus is in licensed bands with much more stable conditions than TG4 and thus there is no specific need to adapt PHY parameters rapidly. For WirelessHUMAN™ system we should consider signaling all the parameters used in DL and UL parts of the frame in the beginning of the frame in a kind of control channel. That would require some changes to the DL-MAP and UL-MAP messages defined in TG1 MAC.

4.1.2 Mesh mode

In mesh mode, several data subframe frequencies may simultaneously be used by different nodes in the network. A TDD frame has a fixed duration and contains one downstream and one upstream subframe. The frame is divided into an integer number of physical slots (PS), which help to partition the bandwidth easily. The TDD framing is adaptive in that the bandwidth allocated to the downstream versus the upstream can vary. The split between upstream and downstream is a system parameter and is controlled at higher layers within the system.

The frame structure is provided in Figure 3.

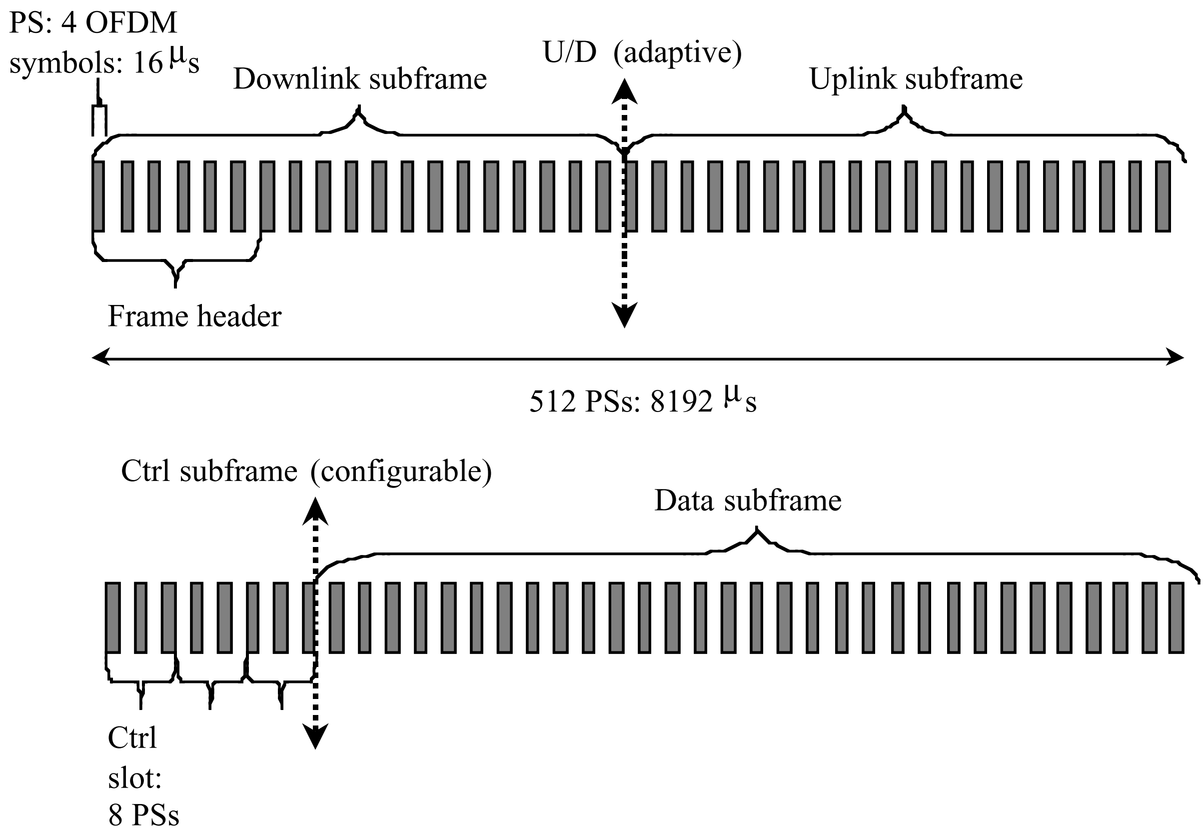

Figure 3 PMP and Mesh mode frame structure

As compared to 802.16.1, the frame length is fixed and significantly longer, to increase efficiency (in terms of statistical multiplexing etc..). The PMP mode frame structure is otherwise the same as 802.16.1. In the mesh mode, the Frame header (now called Ctrl subframe) is split in several slots, as they will come from different devices, which each contain a similar UL/DL allocation map. Whereas the Frame header is of variable size, the number of Ctrl slots is envisioned a configurable value, assumed 6 through the remainder of this document.

It should be noticed however, that in mesh mode, there is no such thing as an Uplink/Downlink boundary. Devices may arbitrarily reserve transmit and receive PS's in a frame. An allocation rule in a device may not receive and transmit in adjacent PS's is sufficient to allow TTG/RTG switching without loss of capacity to the network. Both TTG and RTG have a fixed maximum duration of 1 PS.

As described in section 2.1, the Ctrl slots are used on a minimized contention basis. A device, knowing its neighboring devices up to two hops away, can compute which neighbor receives priority in each Ctrl slot. When the device computes the highest priority for itself, it will use that slot.

4.2 Adaptive Modulation

Adaptive modulation is provisioned on a link-by-link basis. Transmissions to different devices, be it SS's in PMP mode or devices in mesh mode, must each start on a PS boundary. During a single PS, the modulation is hence fixed.

The bandwidth allocated for Frame headers and Ctrl slots is always used with the most robust modulation.

The remaining transmission slots are grouped by SS. During its scheduled bandwidth, a SS transmits with the modulation specified by the base station, as determined by the effects of distance and environmental factors on transmission to and from that SS. In the mesh mode, the modulation is indicated by the transmitting node and confirmed (as requested or reduced) by the receiving node. The receiving node hence acts similar to the BS in the PMP mode.

SS Transition Gaps separate the transmissions of the various SSs during the uplink subframe. They contain a gap to allow for ramping down of the previous burst, followed by a preamble allowing the BS to synchronize to the new SS. In the mesh mode, these gaps serve as guard interval for the ramping down of the currently transmitting node and the ramping up of the next transmitting node.

4.3 MAC management messages

This section gives a short introduction to new MAC management messages that are proposed for either to support more feasible PMP mode or to realise the mesh mode described earlier. All the messages have been designed using the generic MAC PDU format and maximising the reuse of the MAC Header formats defined in the TG1 MAC specification.

4.3.1 Mesh Schedule message

For the schedule information delivery a new Mesh Schedule message is needed. The contents of the new message is depicted in Table 1. Each of the sections are specified in Figure 4 through Figure 8. Various fields are respectively described in Table 2 through Table 6.

The Mesh Schedule message consists of a header, followed by a variable number of requests and responses and is ended by a CRC-field. An Extended message field is specified for messaging other than requests and responses. The total size is however no longer than 64 octets.

The extension field can for example be used to distribute neighborhood information, channel measurement results and information requests.

The mesh Ctrl slot architecture can support multiple connection over the same connection ID using multiple reservations. This feature is suitable to accommodate different QoS requirements, since the PHY mode is indicated in the request.

Packet section	**Length**
Header	6 bytes
List of requests	Nr req * 4 byte
List of responses	Nr resp * 4 byte
Extension	Variable
Pkt end	4 bytes

Table 1. Contents of the Mesh Schedule message.

	8	7	6	5	4	3	2	1
Octet 1	EC=1	EKS=11		Rsvd		Nr requests		
Octet 2	Nr responses			Ext	Rsvd			
Octet 3	Node ID (mapped from MAC address)							
Octet 4								
Octet 5	Ctrl slot-nr			Rsvd		Nr. Hops		
Octet 6	Frame nr							

Figure 4. Transfer syntax of the Header section of the Ctrl slot

	8	7	6	5	4	3	2	1
Octet 1	Start frame offset			Posi…				
Octet 2	…tion		Node ID					
Octet 3	Duration				Channel			
Octet 4	Pers/Pri				PHY mode			

Figure 5. Transfer syntax of the request element.

	8	7	6	5	4	3	2	1
Octet 1	Start frame offset			Posi…				
Octet 2	…tion		Node ID					
Octet 3	Duration				Channel			
Octet 4	Pers/Pri				Mode	Rsvd		

Figure 6. Transfer syntax of the response element.

	8	7	6	5	4	3	2	1
Octet 1	Extension Identifier							
Octet 2	Length							
Octet ..								
Octet M								

Figure 7. Transfer syntax of the extension element.

	8	7	6	5	4	3	2	1
Octet 1	CRC-32							
Octet 2								
Octet 3								
Octet 4								

Figure 8. Transfer syntax of the Mesh Schedule message end.

Name	**Length**	**Purpose**
Frame nr	8 bit	Identifies the MAC frame and shall be used in scrambler initialization.
Ctrl-slot nr	3 bit	Identifies the control slot number
Ext	1 bit	0=No extension field, 1=Extension field after request/response lists
Nr. Hops	3 bit	Indicates the number of hops to the air-head
Node ID	16 bit	Mapping from the MAC address
Nr requests	4 bit	Number of requests in the packet
Nr responses	4 bit	Number of responses in the packet
Rsvd	8 bit	For future use

Table 2. Contents of the Header of the Mesh Schedule message

Name	**Length**	**Purpose**
Start frame offset	3 bit	Start frame identifier as frame offset: 0=current, 1=next, etc.
Position	7 bit	The start position of the reservation in 4-tick blocks
Node ID	6 bit	Identifies the destination node
Duration	4 bit	The number of PSs reserved
Channel	4 bit	Logical frequency channel number
Pers/Pri	4 bit	Persistency/Priority field

PHY mode	4 bit	Indicates the PHY mode used in the requested channel

Table 3. Contents of the request element.

Name	**Length**	**Purpose**
Start frame offset	3 bit	Start frame identifier as frame offset: 0=current, 1=next, etc.
Position	8 bit	The start position of the reservation
Connection ID	6 bit	Identifies the connection
Duration	6 bit	The number of PSs reserved
Channel	4 bit	Logical frequency channel number
Pers/Pri	4 bit	Persistency/Priority field
PHY mode	1 bit	0= as requested, 1= reduce mode
Rsvd	3 bit	For future use

Table 4. Contents of the response element.

Name	**Length**	**Purpose**
Identifier	8 bit	Identifies the extension field (defines also the length of the field)
Extension data field	8*(M-1) bit	The actual content of the extension element

Table 5. Contents of extension element.

Name	**Length**	**Purpose**
CRC-32	32 bit	CRC-32

Table 6. Contents of the Pkt end.

4.3.2 Common new messages

For both PMP and mesh mode some new MAC management messages are needed. These are mainly to support link quality estimation, channel assessment and other functionalities specific for unlicensed band operation. No specific messages are proposed in this document but new messages related to the functions defined later in this proposal will be needed.

4.4 Data PDUs

In the mesh mode, the header is followed by data and only by the CRC field if the CI flag is set. The transfer syntax is given in Figure 9.

	8	7	6	5	4	3	2	1
Octet 1	EC	EKS		Rsvd		Length…		
Octet 2	Length							
Octet 3	CSI	FC		FSN				CI
Octet 4	TX Power			Pkt type			Rsvd	
Octet 5	Rsvd							
Octet 6	HCS							

Figure 9. Transfer syntax of the mesh data packet header.

For comparison, the PMP header, derived from the 802.16.1 MAC, is specified in Figure 10.

	8	7	6	5	4	3	2	1
Octet 1	EC	EKS		Rsvd		Length		
Octet 2	…Length							
Octet 3	Connection ID							
Octet 4								
Octet 5	HT=0	CSI	FC		FSN			
Octet 6	CL	TX power			Rsvd			
Octet 7	GM (uplink only)							
Octet 8	HCS							

Figure 10. Transfer syntax of the Header section of a PMP PDU

4.5 MAC primitives

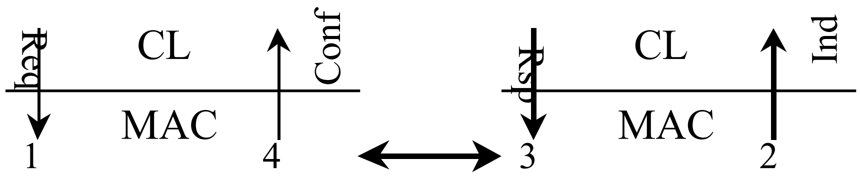

Figure 11. Use of MAC primitives

4.5.1 MAC-CREATE-CONNECTION primitives

In mesh mode, a Request is send to the MAC to facilitate initial network entry of a node. The MAC first listens to the designated channel and acquires node ID's from all devices it can hear. Based on this, it finds an appropriate Ctrl slot and sends out its own MAC address using the Extention data field.

Nodes overhearing this transmission send up an Indication to notify the CL of this new node.

The CL then instructs the MAC in a Response to notify the new node of its own neighbors (which immediately notifies its neighbors of the new node).

The MAC of the new node then passes this information up in one or more Confirmations to the CL.

4.5.2 MAC-TERMINATE–CONNECTION primitives

In mesh mode, a Request is send to the MAC to terminate connection. This is only done when a node permanently leaves the network, and hence rare. The MAC sends out a Ctrl slot to announce its termination.

Nodes overhearing this transmission send up an Indication to notify the CL of this departing node. The CL then instructs the MAC in a Response to notify the departure of its neighbor to all its neighbors. The MAC of the departing node may confirm its departure to the CL after sending the notification.

However, the MAC may also send a departure Response after a timer, tracking the time since the last message from a neighbor, has expired. In this sense, a node may leave the network without announcing its departure (something which may happen if power to the device is lost).

4.6 Quality of Service

QoS classes are defined above the Convergence Layer (for example in 802.1p). The CL will map these classes to priority classes in the MAC. The MAC hence does not need to have its own definitions of QoS classes.

4.7 ARQ mechanism

ARQ is provided on a link-by-link basis. Packets are send over a link with one-by-one incrementing sequence numbers. An ARQ bit could be used in the packet header to toggle ARQ within one connection (as opposed to establishing multiple ARQ-connections per link). In contradiction to 802.16.1, which returns all sequence numbers, a bit map is returned. This significantly reduces the ARQ overhead.

	8	7	6	5	4	3	2	1
Octet 1	first NACKed Seq. Nr…							
Octet 2	…first NACKed Seq. Nr				Last received Seq. Nr…			
Octet 3	…Last received Seq. Nr							
Octet 4	Length…							
Octet 5	…Length		Bit map					
Octet ..								

Figure 12. ARQ element

5 Radio Subsystem

5.1 Synchronization

802.16.1 requires synchronization. Also to maintain a mesh network, synchronization is needed. Synchronization in a mesh architecture, where there is normally no direct link to a reference system (as the BS is in the PMP architecture) is performed by synchronizing to the node nearest to a reference node.

Each network has a single node (normally a “BS”) to which all the others synchronize. The procedure is divided into clock and time synchronization. The clock synchronization ensures that the clocks in the nodes are running at the same speed (within ± 0.6 ppm, the value to be verified). The time synchronization takes care of the network time.

5.1.1 Clock synchronization

The synchronization sequence (a.k.a. preamble) is used to both define the symbol timing as well as the burst timing. In OFDM, the phase drift between consecutive time domain symbols does define the possible payload clocking error. From this value the frequency error correction factor can be derived. Thus the system clock (e.g. VCXO) in the receiver can be corrected to be equal the clock in the transmitter.

5.1.1.2 Time synchronization

Once the clocking is set, the next step is to synchronize the network time. The network time synchronization is originated from a master clock node. This node will provide the frame structure, that is, defining the beginning and the end of the frame in time. When a time-stamp is received, the network time is based on the reception time. The offset, caused by propagation delay can relatively easy be measured and compensated for. Since new nodes connect to nodes closer to the master clock node, this synchronization will implicitly spread through the network.

5.2 Dynamic Frequency Selection

As WirelessHUMAN is geared towards unlicensed bands, an effective DFS scheme is required. DFS is to be used entirely for channel selection even though the same measurements may be used for link adaption.

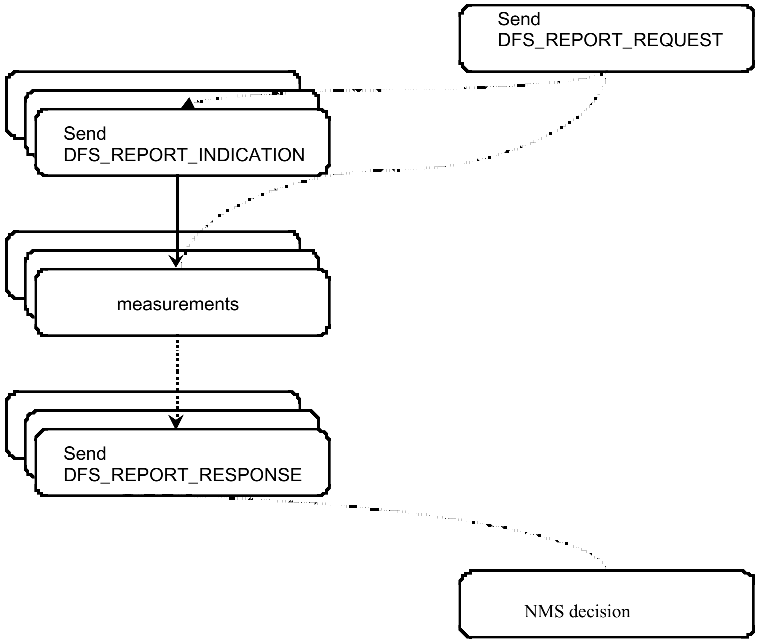

Figure 13. DFS procedure

The DFS in a FWA network differs from that of a WLAN in that a BS cannot make autonomous decisions, since this will create frequency re-use problems. Hence, DFS is principally an NMS feature.

The DFS procedure is similar in PMP and mesh architectures. Both the base-station and the airhead will broadcast a DFS_REPORT_REQUEST. In the mesh architecture this report is routed to nodes with a higher hop-count. The requests are send in the extention field of the Ctrl slot (see Figure 7).

In the PMP case, the BS can indicate a period in the DL subframe where all nodes perform their measurements on all available channels. Each of the SS's then sends DFS_REPORT_RESPONSE back, which should be delivered to the NMS system for processing.

5.3 Link Adaptation

A link adaptation scheme needs to be facilitated to select an appropriate link mode in order to maximize capacity. For link adaptation purposes RSSI measurements and BER parameters can be considered. As the information to be distributed is small (channel, RSSI value, BER/PER and perhaps a few others), it can be send periodically in the empty parts of the Mesh Schedule messages in a mesh mode.

	8	7	6	5	4	3	2	1
Octet 1	Extention Identifier							
Octet 2	Length							
Octet 3	Connection ID						Rsvd	
Octet 4	BER/PER				Channel			
Octet 5	RSSI							
Octet 6	Optional spare							
Octet …	Optional spare							

Figure 14. Link Adaptation Extention

5.4 Power Control

The TX power is transmitted in the data packet header in both PMP and Mesh mode. From this information, the destination node can estimate the pathloss and modify its own power level. The transmission power levels will be defined in the PHY. The addition of the TX power field compared to the original 802.16.1 header allows scrapping the ranging messaging.

References

[1] "Draft Standard for Air Interface for Fixed Broadband Wireless Access Systems", Document Number IEEE 802.16.1/D1-2000, December 2000

[2] "PHY for WirelessHUMAN™", M.Kasslin, N.van Waes, Contribution to TG4