IEEE 802.11
Wireless Access Method and Physical Specification

MAC/PHY Functional Partitioning

Wim Diepstraten
NCR WCND-Utrecht
NCR/AT&T Network Product Group
Nieuwegein The Netherlands
Tel: (31)-3402-76482
Fax: (31)-3402-39125
Email: Wim.Diepstraten@utrecht.ncr.com

Greg Ennis
Symbol Technologies
1101 S. Winchester Blvd., Suite B-110
San Jose, CA USA 95128
Tel: (408) 249-9890
Fax: (408) 446-4630
Email: gennis@aol.com

Phil Belanger
Xircom
2105 Landings Drive
Mountain View, CA USA 94043
Tel: (415) 691-2500
Fax: (415) 691-1064
Email: pbelange@xircom.com

Abstract

This document is a contribution regarding the MAC/PHY interface, and the corresponding issues regarding the allocation of functions to the MAC and the PHY. We explore here the implications of the basic 802.11 goal for a "single" MAC above multiple PHYs. It is increasingly clear that to accomplish this goal the MAC definition must in some sense be "parametrized" to accomodate the various PHYs.

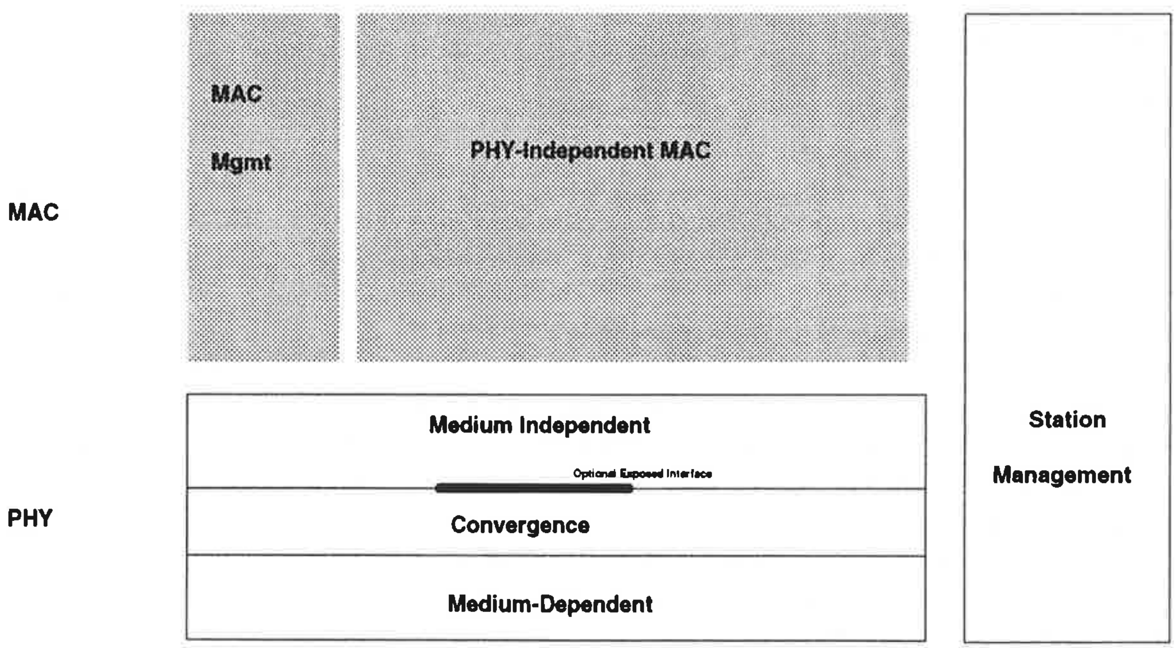
The authors believe that there are certain common functions implemented within all PHYs which can be supported across the MAC/PHY interface in a PHY-independent manner (the ***core*** of the MAC/PHY interface). However, certain aspects of specific PHYs have no analog in other PHYs and will require special PHY-specific extensions to the core interface functions. Similarly, a basic MAC frame structure can be defined which accomodates PHY-specific extensions (to handle hopper timers or transmit power control fields, for example), and the MAC state machine could also include PHY-specific algorithm extensions (e.g. for retransmission control). However, a universal interface between MAC and PHY can be defined which accomodates all PHYs.

1. Introduction

It is a basic requirement of the 802.11 standard that it accomodate multiple PHYs. Early in the project it was also deemed important that a single MAC support all PHYs. As work has progressed on the standard, it has become apparent that in general it should be possible for the basic MAC functions to be universal, although a universal MAC on top of all PHYs may not be an optimal MAC for any given PHY. In the analysis of MAC/PHY combinations involving a specific PHY it often is found to be most natural, and even necessary, for the MAC to be "PHY-aware". Consequently we propose that the MAC be structured in such a fashion that any PHY-specific functions which might be appropriate are clearly distinguished from the core functions of the MAC.

This document is a contribution to the development of an architectural model and interface definition for the 802.11 MAC and PHY. We present arguments supporting the need for PHY-awareness on the part of the MAC, and we also propose some modifications to the current 802.11 model. The resulting model allows most of the MAC functions to be handled in a PHY-independent fashion, with a structured approach to the incorporation of a limited set of PHY-dependencies.

The current 802.11 model is depicted in the following figure:



In the current model, the MAC includes a *MAC Management* component, the exact functions of which have not yet been specified. In the following sections we propose that the MAC Management component can be made responsible for PHY-dependent actions which the MAC may need to take, acting as a submachine of the general MAC state machine. Such PHY dependencies may affect the contents of MAC frames and the commands given to the PHY. A complete MAC would thus consist of the PHY-independent core component together with one or more PHY-specific MAC Management components.

We also propose that the key interface which needs to be specified - and the one which can be exposed - is that between the MAC and the PHY. This interface can be defined in a way which is PHY-independent, allowing separate MAC and PHY modules to be easily integrated. However, since not all PHYs will support exactly the same command set, the interface must include a generic command/indication mechanism which all PHYs can use with various PHY-specific commands or parameters.

This paper is organized as follows: Section 2 categorizes the ways in which PHY dependencies can affect the MAC. Section 3 then presents an extension to the existing 802.11 model which solves the issues raised in Section 2. Section 4 describes the resultant MAC/PHY interface within the extended model. Section 5 then presents an example of a relatively complex system operation (scanning) and describes how the model can accomodate the required functions in the context of two different PHYs. Finally, Section 6 discusses the issues from the 802.11 issue list which have been addressed in this paper.

The authors of this paper admit that they are more familiar with the RF PHYs than with the infrared PHY. Although we believe that the model is general enough to handle the infrared case, we would welcome further contributions along these lines from the 802.11 "infrared community".

2. MAC-Level PHY Dependencies

PHY-specific dependencies may affect the MAC in various ways. We categorize them here as pertaining to *PHY Control* issues, the MAC *State Machine*, and *Information Exchange*.

2.1 PHY Control

All PHYs will support certain core functions, such as those connected most closely with the actual transmission and reception of bits. Consequently the MAC/PHY interface can include provisions for these functions in a PHY-independent manner, such as "Send Bit" and "Bit Received". Other functions within the PHY level may be specific to a given PHY, and yet can be controlled via an interface function which is PHY-independent - an example here may be a "Send Preamble" interface command which yields the generation of a different preamble for each specific PHY.

However, there are certain features which are truly unique to a given PHY. For example, there is no obvious analog to a chipping sequence within the non-DSSS PHYs. For the upper layers to control the setting of a chipping sequence will require an interface function into the DSSS PHY which does not exist within the other PHY interfaces. It is likely that there will be similar PHY-specific interface requirements for FHSS and infrared PHYs also. (Note: the current proposals for a DSSS PHY do not specifically require that multiple chipping sequences be used, but such an interface function should probably be present in any event).

We can summarize the situation in the following fashion: the most natural approach to the PHY interface will involve a set of core interface functions which all PHYs support, together with extensions to this core set which are PHY-specific.

2.2 State Machine

The MAC may need to operate differently in the presence of different PHYs. This involves the actual MAC state machine, which can perhaps best be viewed as a "conditional" state machine, conditional upon the specific PHY.

We have the following examples:

- In an FHSS context, it may be beneficial for the MAC to schedule retransmissions subsequent to the next hop (for diversity). Similarly, the transmission of a long frame may be delayed until the next hop if the time remaining is insufficient. These are both examples of FHSS-specific queue management actions within the MAC.

- In a PHY that uses multiple antennas for diversity, the MAC may want to influence which antenna is to be used for transmission of a given frame (e.g. retransmit using a different antenna).

The examples illustrate the *dynamic* nature of certain MAC actions in the presence of different PHYs, where here we distinguish between the PHY-dependent actions which are performed regularly and frequently during the course of normal operation (even on a per-frame basis), and the *static* PHY-dependent actions which need only rarely, such as at initialization.

How are such dynamic PHY-specific MAC actions to be implemented within the MAC entity? We suggest the following solution, based upon the existing 802.11 MAC model: make the "MAC Management" entity responsible for such dynamic PHY-specific actions.

The exact manner in which this could be accomplished requires further analysis, but the basic idea would be for the MAC state machine to incorporate the MAC Management entity as a submachine which implements all dynamic PHY-dependent actions.

Static PHY-dependent actions (such as those which occur at initialization) would be the responsibility of the Station Management entity.

2.3 Information Exchange

Certain PHY-specific information may need to be exchanged among the stations in order for the PHY to operate properly. The following examples come to mind:

- bitrate
- time remaining in current hop
- chipping sequence
- transmit power level
- frequency channel identifiers

The example of a multi-bitrate PHY is an interesting one. Consider a PHY which is capable of operating at different bitrates, where the PHY receiver can determine from the incoming signal what bitrate was used during transmission (e.g. via distinguishable formats for the PHY header or other PHY signalling means). In this case the PHY entities would be exchanging this information among themselves. Nonetheless, it is likely important that the MAC be aware of, or perhaps even control, the bitrate. This requires MAC/PHY interface functions which are specific to those PHYs which support multiple bitrates, and in fact probably must involve the actual rate values. This could be perhaps accomplished via a parametrized function at the MAC/PHY interface, and there need be no direct MAC-to-MAC exchange of information.

However, the other examples demonstrate that we should not require that all PHY-specific information exchanges happen in a PHY-to-PHY manner. The information in the other examples may be relatively complex and will certainly need to be error protected. If we were to demand of each PHY that it be capable of exchanging such control information reliably between peer PHY-entities, it would mostly likely require complex PHY headers, and a duplication of the existing MAC-level data processing and error-detection functions within the PHY. Instead, a natural approach is to use the MAC to support the exchange of such PHY control information when appropriate.

This could be accomplished through a PHY-dependent MAC sublayer (perhaps with a corresponding header) or by accomodating optional PHY-dependent frames or fields within the MAC. The sublayer approach would be most appropriate if the information needs to be included on each frame, whereas separate frames or optional fields may be better if the information is only transmitted occasionally.

3. Extending the Current IEEE Model

Given the above considerations, we suggest that the MAC layer be divided into the following components (based upon the existing IEEE 802.11 model):

MAC

- PHY-Independent MAC component, responsible for basic data transmission and reception, medium access and other PHY-independent functions. This would include such functions as medium allocation, deferral/backoff strategies, MAC-level acknowledgments, association control, CRCs, duplicate detection, power management, and addressing.

- MAC Management component, which includes dynamic PHY-dependent functions required for control of a given PHY. Thus there would be definitions required for the FHSS, DSSS, and Infrared MAC Management entities. This component would be responsible for such functions as frequency control for hopping, scanning, setting transmit power level and receiver defer threshholds, and power management of the PHY.

- PHY-Dependent MAC Sublayer, which would be present if certain PHY-specific data needs to be exchanged on every frame in an error-protected fashion. This might include such information as hop timings, channel identifiers, or power control fields. As the lowest sublayer of the MAC, this sublayer would also be responsible for controlling the (possibly exposed) interface with the PHY.

Note that even though the MAC entity may incorporate a PHY-dependent MAC sublayer, this does not mean that the core interface functions down to the PHY are PHY-dependent. These core interface functions can be completely generic (e.g. "Send Bit") - it is the meaning of the bits within the MAC which may involve some PHY-dependencies. Consequently the topmost portion of the PHY can be viewed as a "medium independent" layer (responsible for handling this generic upper interface) and a "convergence" layer, which converts the generic interface functions into those specific to this medium.

In fact, all of the PHY-specific functions which need to be handled across the MAC/PHY interface could be represented in a universal fashion (PHY-independent), with certain parameters or signals ignored by certain PHYs. Consequently, the entire MAC/PHY interface can be implemented with the PHY-dependencies limited to the interpretation (rather than the presence) of certain signals. This would allow for a universal interface between the MAC and any of the PHYs, which could be exposed (with the MAC as DTE and the PHY as DCE).

Thus we have the following partitioning of the PHY:

PHY

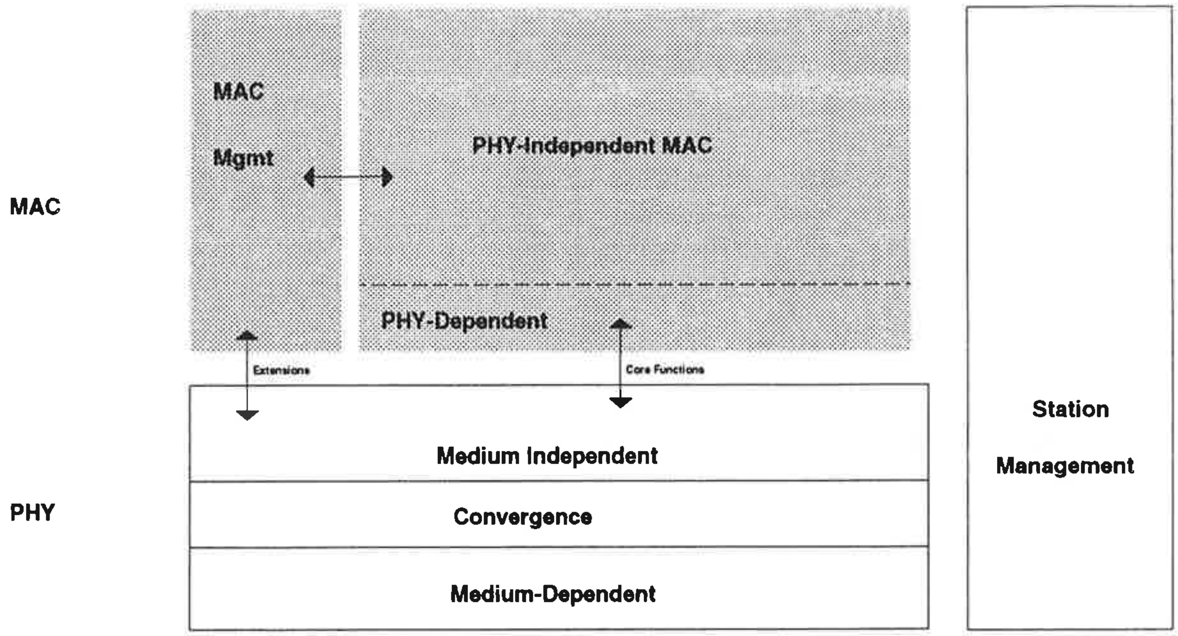
- Medium Independent component, which provides the interface to the MAC (i.e supports the core functions and handles the universal representation of the MAC/PHY interface). For example, a "generic" command may come across the MAC/PHY interface requesting that transmission begin. The PHY's Medium Independent component would receive that command, but the specific action to be taken (e.g. preamble or PHY-header generation) would be the responsibilities of the lower PHY levels (which are medium dependent).

- Convergence sublayer, which converts the MAC interface functions to those appropriate for the specific PHY

- Medium dependent component, which is actually responsible for the PHY functions as appropriate for the given PHY (such as modulation, preamble generation and related PHY-header interpretation).

There is also, of course, a Station Management entity which exists "off to the side" of the stack and which is responsible for certain management functions within the node. Note that these functions would be relatively static, as opposed to the more dynamic (and even per-packet) functions provided by the MAC Management entity within the MAC.

This is depicted in the following figure.



The interface between the MAC and PHY is depicted above as a set of core functions with PHY-specific extensions. This of course can be implemented in a variety of different ways. It is probably best to define the extensions for the various PHYs in a uniform fashion, allowing a common interface to be used for all PHYs (though each PHY would only implement its specific extension functions). The MAC/PHY interface could then easily be optionally exposed.

4. MAC/PHY Interface

As discussed above, we can distinguish between those functions which need to be supported across the MAC/PHY interface on a per frame basis, those which happen frequently though not necessarily on each frame, and those that happen only upon initialization. The first two (the dynamic functions) are those which should be the responsibility of the MAC (with the MAC Management component involved in the case of certain PHY dependencies), while the static functions would be the responsibility of the Station Management entity.

The following are the control/indication functions needed on a per frame basis:

1. Support variable PHY preamble length
2. Tx and Rx control (basic bitlevel data transfer interface)
3. Indication of status information on each frame received, such as:
   - Receive signal level
   - Signal Quality
   - Silence/Interference Level
   - Bitrate received
   - Antenna diversity information
4. Support for short training (e.g. for Acks)
5. Dynamic bitrate selection
6. Dynamic Tx power control, with associated Defer Threshhold control
7. Diversity option control

Items 1, 2 and 3 are self-explanatory. Item 4 pertains to the possibility of using short training at the PHY for an Ack frame, in which case the PHY needs to be signalled that an Ack is being generated. Item 5 pertains to a mixed-bitrate environment in which the MAC may send to different stations at different bit rates (perhaps depending upon state information maintained in the MAC). Item 6 has been discussed in reference [1]. Item 7 pertains to a function in which the MAC may signal information to the PHY upon frame transmission requests allowing transmitter diversity to be managed in the case of a retransmitted frame.

The following are functions that need to be controlled within the MAC, but are not directly related to a specific frame:

8. Support for power management/sleep mode
9. Frequency/Band selection (hopper control and multichannel reassociation).

The following static control functions would be the responsibility of Station Management:

10. PHY identification
11. PHY initialization
12. PHY service specification
13. PHY specific statistics collection and reporting

With these functions in mind, we can present a more specific description of the MAC/PHY interface. The interface would include:

- Bit level data signals in the transmit and receive directions, synchronous with a clock generated by the PHY.
- Command signals in the MAC-to-PHY direction.
- Status indication signals in the PHY-to-MAC direction.

The passing of commands and status indications across the interface would likely be a combination of distinct signals for certain simple critical functions (e.g. Carrier Sense) and an encoding for functions which involve more complicated information and which are invoked less frequently (e.g. frequency tuning). Commands and status indications can include parameters. We identify parameters in the following description through the use of square brackets [].

Transmit related

- Set Threshhold Command [Defer Threshhold]
  This command sets the defer threshhold for carrier sense.
- Transmit Enable Command [Transmit Level, Bitrate, Short/Long Preamble, Retransmit]
  In response the PHY begins transmission, e.g. generates a PHY header/preamble.
- Clear-to-Send Indication
  Generated by the PHY when it is time for the MAC to pass down the data bits of the frame.
- MAC delivers frame bits synchronous with PHY supplied clock.
- Transmit Disable Command [Defer Threshhold]

Receive related

- Carrier Sense Indication
- Start and End MAC Frame Indications
- Receive data bits synchronous with supplied receive clock
- Received Frame QoS Status Indication [bitrate, signal level, signal quality, SNR/Interference level, ...]

Additional commands and status indications would be necessary which are not specifically associated with the transmission or reception of a given frame, including:

- Frequency/Band Selection
- Chipping Sequence control
- Power Management control
- Get-PHY-Parameters command, with corresponding response from PHY including such information as Tx/Rx and Rx/Tx Turnaround Time, CS delay, CS sensitivity, speed/symbol rate, antenna information, and preamble length
- PHY initialization commands

As described earlier, the PHY dependent commands and parameters should be coded in a fashion which allows a universal (PHY-independent) interface to be used between MAC and PHY.

5. An Example: Scanning

In this section we look at a specific example to illustrate how the above model can handle a variety of situations. The example concerns the process of a station scanning for a new access point. We look at both the case of an FHSS system, and a multi-frequency DSSS system. In both cases it is clear that the MAC needs to be actively involved, and we believe that our proposed model accomodates this in a natural fashion.

5.1 FHSS Scanning

In a hopper environment, the different BSS's (incorporating different access points) will be operating on different hopping sequences. As a station roams, it will need to reassociate from one access point to another, hence must move from one hopping sequence to another. The station can determine which access point is the proper one for the reassociation by scanning the frequencies in some fashion, thereby removing itself (perhaps temporarily) from its current hopping sequence. While scanning, the station is not following a set hopping sequence, and in fact may be traversing the channels in a manner different from any of the hopping sequences in use in the network. During the intialization process for example, a new station must find other stations to establish or join a network. The best way to quickly find other stations is to scan the frequencies looking for traffic with the desired Network Id. This scanning follows no preset pattern. During the scanning process, a station will not dwell on a particular frequency for the normal dwell time, so the timing would be different from normal hopping as well.

During this period, ordinary data transfers cannot occur, but (depending upon the actual scanning algorithm) special frames may be transmitted or received which need to be handled by the MAC. Consequently the MAC needs to be intimately involved in the scanning process. (Note that the initialization of a station will involve the same scanning process). Until a successful transition takes place, the moving station must maintain sychronization with its old BSS so that it can immediately resume operation after a scan.

Another reason to allow the MAC to control hop timing is hop synchronization. For example, the MPDU header could contain a field that describes the time left in the current hop. This is an example of PHY-specific information which is best exchanged between stations within error-protected MAC fields.

MAC control of frequency tuning and hop timing can also be used to improve system robustness. One of the properties of a good hopping sequence is that the frequency on slot n is not adjacent to the frequncy for slot n+1. This means that it is likely that a FH system will hop "away" from narrow band interference. If the interference is present on one hop it is likely to be absent on the very next hop. The MAC can take advantage of this property by enhancing the retransmission algorithm. This also improves performance in the presence of fades on a given channel.

The above considerations can be accomodated easily within the model that we have proposed for the MAC/PHY functional allocation and interface. The MAC's control over frequency tuning would be the responsibility of the (PHY-dependent) MAC Management entity, using the tune frequency command across the interface. The hop timing or other information which needs to be exchanged would be naturally placed within the PHY-dependent sublayer of the MAC.

5.2 DSSS Scanning

Scanning in a DSSS context will similarly involve a station periodically attempting to hear other access points than the one with which it is currently associated. In this case, there may be multiple access points on the same frequency channel, and consequently the station will not have to tune to a different channel to hear them. However, in a multi-channel DSSS environment, it will be necessary to tune to the other channels in use within this network to find all access points within range.

Thus the basic scanning is similar to the FHSS case. However, the channels which must be examined are different (and fewer in number). The exact scanning algorithm will thus be different, and after a selection has been made of a new access point for reassociation it is not necessary to first establish synchronization. Similar to the FHSS case, it may be necessary to take special action to ensure proper behavior during periods when the station is away from its normal channel.

The specific scanning for the DSSS case can be included in the DSSS version of MAC Management. The "Tune Frequency" command (used also in the FHSS) is important in the DSSS context to allow the MAC to control the scanning operation.

6. Issues Addressed

1.5 Should the protocol model generated during the July 1992 meeting be adopted by the 802.11?

No. There should be a PHY dependent layer added to the MAC and the exposed interface should be called out as between MAC and PHY..

9.3 Must the same MAC work in a minimum system and a maximum system?

Yes. The same MAC must support minimum and maximum system configurations.

12.1 What is the MAC/ PHY interface?

The bulk of this paper describes this interface.

12.3 What is the intelligence level at the MAC/PHY interface?

The MAC/PHY interface should assume a "dumb" PHY. A single MAC can be designed to work effectively with different "dumb" PHY implementations.

12.4 Is the layer that provides PHY independence the same as the MAC/PHY interface?

No. PHY independence is achieved in a PHY dependent sub-layer within the MAC. This must be a sub-layer because it adds and removes fields in the MSDU header. This must be a MAC function because it involves transfer of the PHY specific information to a peer sublayer and the information is best sent in the protected portion of an MPDU. It also requires formatting and interpretting the MSDU header, which should only be done by the MAC.

12.8 Does a PHY independence layer need to be specified in the MAC?

Yes.

12.9 Should data and control information be passed simultaneously across the MAC/PHY logical interface?

Yes.

13.7 Is MAC support required for Power Control?

Yes.

13.8 Is MAC support required for antenna diversity?

Yes.

18.2 Will the standard support one MAC driving multiple PHYs of different rates?

Yes. A single MAC should support multiple PHYs with different rates. Preamble length and other parameters reported by PHY.

18.3 Will the standard support PHYs with variable data rates?

Yes.

18.4 Will the standard allow the PHY data rate to vary as a function of signal quality?

Yes. The MAC must tell the PHY to change the data rate based on information presented to the MAC by the PHY. The PHY must not make this decision independently. The MAC needs to understand the timing of MPDU transmissions and can not know that if the PHY is independently making these decisions.

18.5 Is data rate agility only a PHY matter?

No. The MAC must decide when to switch data rates. (Support argument 1.2.) However, the data rate indication must occur in the PHY preamble to allow proper clocking, bit alignment , and other PHY functions.

24.3 How will multiple PHY support for the MAC be specified?

A PHY dependent MAC sublayer will be defined that generates and processes PHY specific information in the MPDU header. There will also be a MAC management entity that implements certain PHY specific functions. The PHY layer will also include PHY specific and PHY independent sublayers.

24.6 Does the PHY layer provide the PHY type to the MAC layer?

Yes. The MAC must be able to identify the type of PHY being used.

24.7 Will the MAC standard specify the support of multiple PHYs...?

Yes. A single MAC must support multiple PHYs.

24.8 What functions are required in the Medium Independent PHY layer?

Provides the interface to the MAC that implements the core functions described in section 4 of this paper.

24.9 Given a Frequency Hopping (FH) PHY, which protocol entity is responsible for the real time aspect of the PHY?

(Ambiguous wording of the issue...) The MAC must tell the PHY when to tune to a new frequency and therefore controls the timing of the frequency hopping. The PHY controls all other real time aspects.

25.2A Must the MAC work on a single channel PHY?

Yes.

25.2B Will the standard support multiple channel PHYs?

Yes.

References

[1] Wim Diepstraten, NCR: "The Potential of Dynamic Power Control", Doc P802.11-92/76

[2] IEEE P802.11 Issues Document, Doc 802.11-92/64