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Title	**TG3 MAC Support for Advanced Antenna Technologies**
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Re:	IEEE 802.16.3-01/12 (TG3 MAC Draft TOC) IEEE P802.16/D3d2-2001 (Draft Standard Airlink Interface for Fixed Broadband Wireless Access Systems)
Abstract	This contribution discusses some issues associated with MAC support of advanced antenna technologies, in particular adaptive array systems.
Purpose	To discuss and propose certain options for the MAC layer in order to support advanced antenna technologies.
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TG3 MAC Support for Advanced Antenna Technologies

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Introduction

The draft air interface standard (IEEE P802.16/D3d2-2001) that came out of TG1 is based solely on systems with fixed sector antennas. In TG3, we are required to support advanced antenna technologies, due to the more challenging propagation conditions and higher bandwidth efficiency requirements. The purpose of this contribution is to discuss some options that are necessary for the MAC protocol to support advanced antenna technologies, specifically when such antennas are employed at base stations (BS).

Common types of "advanced antenna" systems, as opposed to fixed sector antenna systems, include diversity switching, diversity combining, space-time coding, and adaptive arrays. The simplest are the diversity switching systems, in which the BS uses multiple sector antennas, and the subscriber station (SS) dynamically chooses the best sector based on the propagation condition, sector loading, interference, and so on. Typically, the sector antennas are fixed and frequency planning is required for interference mitigation. Here we have assumed that a single MAC domain covers multiple sector antennas. Otherwise, the system is no different than the TG1 baseline if each sector has its own MAC domain.

Rather than simply switching between antennas, diversity combining systems take signals arriving at multiple antennas and combine them to produce the maximum signal-to-noise ratio (SNR). The antennas are typically spaced at least several wavelengths apart so the received signals have independent fading characteristics. The primary motivation for using diversity combining is to combat severe multipath environment, rather than to increase the capacity. It is not possible for two SS to use the same frequency at the same time. However, in as much as it improves the SNR, capacity improvement is possible. Moreover, if both BS and SS employ multiple antennas, which in a sense provide parallel physical channels, significantly capacity increase can be obtained. Space-time coding systems go a step further, using not only spatial, but also time diversity by transmitting the same symbol from different antennas at different times.

Adaptive array systems differ from diversity combining systems primary in their use of trained weights to process signals from multiple SS. Typically, such arrays have elements that are spaced less than one wavelength apart to allow coherent combining, as well as elements that are spaced multiple wavelength apart to provide the diversity gain. The array processing using trained weights provides not only the array gain, but also interference suppression, which can be on the order of 15-20 dB and 20-25 dB, respectively, for reasonably sized arrays. Consequently, multiple SS that are spatially separated can use the same frequency at the same time, resulting in a frequency reuse many times larger than conventional systems. The number of simultaneous, co-frequency SS is limited by the degrees of freedom of the array. In contrast to diversity combining, this capacity increase does not require multiple antennas at the SS, thus keeping down the economically sensitive factor of SS cost.

In this contribution, we will focus on the adaptive array systems.

Spatial-division Multiple Access (SDMA)

Adaptive array systems obtain their capacity increase from their ability to distinguish SS that are spatially separated, thus allowing them to reuse the same frequencies. At any given time, multiple point-to-point links are established for different SS, rather than a single point-to-multipoint link in which all SS can hear the same messages in the downlink. This introduces a number of issues for multiple-access that are very different from the baseline mechanism as described in the draft TG1 MAC, which we will elaborate in the following paragraphs.

1. Multiple access control is required for both uplink and downlink, as both are point-to-point links. When time-division duplex (TDD) is used, the uplink and downlink are typically tied together to take advantage of channel reciprocity. When frequency-division (FDD) is used, such a constraint is not necessary, but the performance of array processing may be reduced if the channel is varying in time.
2. Multiple co-frequency SS are allowed to transmit at the same time, up to the limit set by the degrees of freedom of the array. This suggests a natural contention-based multiple-access scheme in the uplink, where a SS can transmit whenever it needs to, unless the BS tells it otherwise. Only when the array

loading approaches the limit does the BS need to send channel usage maps to SS to control their transmission. The contention mechanism is simple, has a low overhead, and incurs the lowest delay.

3. An alternative is to separate random access from on-going traffic by providing a dedicated random access channel. The size of random access channel can be much smaller due to SDMA capability.
4. A more substantial change is required regarding the use of uplink and downlink channel descriptors (UCD and DCD). Since downlink signals are isolated between SS, a simple broadcast of UCD cannot reach all SS. One way to emulate broadcast is to send the same message many times using randomly pointed beams. A SS may have to wait an extraordinarily long time in order to get a chance to receive the UCD message. To reduce the waiting time, we could increase the frequency of UCD messages. But this is costly in terms of overhead. Some UCD parameters, such as ranging slot time and random access slot time, are highly likely to be common between systems, and highly unlikely to change over time. Therefore, it is better to fix these slots and make them standard, so SS can be provisioned with such parameters and do not have to wait for a very long time to get over the air.
5. A further argument for making UCD and DCD optional for adaptive array systems is that they are not necessary. The main purpose of UCD and DCD is describes the channel burst profile for the purpose of supporting adaptive modulation in the TG1 PHY. Adaptive array systems use multiple point-to-point links, so there is no need to change modulation for the duration of the link, and no need for UCD and DCD.
6. For the same reason as UCD and DCD, it is necessary to opt to unicast (or multicast) uplink and downlink maps (UL-MAP and DL-MAP) rather than broadcasting them. The BS can use UL-MAP and DL-MAP to tell SS about the duration of the point-to-point link. It does not need to send the maps in every frame, unless it wants to change the session, make it longer or shorter as the dynamic resource allocator requires. Therefore, we propose that for adaptive array systems, alternative UL-MAP and DL-MAP be used, as described in the next section.

Uplink and Downlink Maps

Based on the discussions of the preceding section, we propose the following options for the UL-MAP and DL-MAP, applicable only to systems that use adaptive antenna arrays:

UL-MAP Message Format

Syntax	Size	Notes
UL-MAP_Message_Format() {		
Generic_MAC_Header()		
Management Message Type = 3		
Uplink Channel ID	TBD	
Random Access	TBD	If this flag is on, the SS is allowed to transmit freely on this uplink channel.
Allocation Start Time	TBD	
Allocation Duration	TBD	

DL-MAP Message Format

Syntax	Size	Notes
DL-MAP_Message_Format() {		
Generic_MAC_Header()		
Management Message Type = 3		

Downlink Channel ID	TBD	
Allocation Start Time	TBD	
Allocation Duration	TBD	

Note: TBDs are pending on the PHY specification.

Frame Structure

In adaptive array systems, typically each SS is provisioned a unique word (UW) that is used for array training. UW are not required if the system uses blind training, but blind training requires significantly more processing power and longer training times because more samples are needed. It is not really necessary for this kind of communications system. The air link frame should provide training slots in which the SS will transmit their UW and the BS will update array weights. The size of the training slots is determined by the time-bandwidth product required by the training algorithm, which is being studied in the TG3 PHY subgroup. It should be noted that similar slots might be necessary for adaptive equalization, even in systems that do not employ adaptive arrays.

Training slots also provide entry opportunities for SS to gain access to the network. If random access is allowed, as discussed previously, then the SS can send data right after the UW. Otherwise, it will send only the UW, which is a signal to the BS that the SS wants a resource allocation. Therefore, the training slots can double as the randomly access slots used in the baseline TDMA system.

Synchronization and Ranging

Synchronization is basically the same as the baseline, whereby the BS periodically transmit a known sync sequence, using either an omni-directional antenna pattern, or randomly pointed beams. A SS listens and attempts to lock on to the frequency.

Once synchronization is achieved, and the SS learns about the training slots, it can send its UW to start ranging. It adjusts its ranging parameters until the BS detects the UW and sends a reply. Thus, the training slots can also double as the ranging slot. Once the UW is detected and a link is established, residual ranging errors can be measured by the BS and reported to the SS using the appropriate MAC messages.

Conclusions

In summary, we discussed some characteristics of the adaptive array systems, and found that the UCD and DCD mechanisms in the draft TG1 MAC are not necessary for this kind of system, and would be very hard to emulate, causing either very long delays or high overhead. Therefore, we propose to include another option in the standard, to will allow such systems to use its training slots for ranging and random access. We also propose an optional UL-MAP and DL-MAP that are more suitable for such systems.