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Re:	Physical Layer Task Group Call for Contributions -- Session #4, September 22, 1999
Abstract	Proposal for 802.16 to use 4/16 QAM physical layer based on Netro's CellMAC air interface.
Purpose	
Notice	
Release	
IEEE Patent Policy	

Proposal to Use 4/16 QAM Physical Layer based on Netro's CellMAC™ Air Interface for BWA

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Introduction

Netro's ATM/TDMA/FDD air interface, CellMAC which has been under development since 1995, was purpose-built to enable wireless operators to provide voice and broadband data and multimedia services to the small and medium enterprise. Netro's AirStar broadband wireless access system, with the CellMAC™ air interface fully developed, has been commercially shipping for over a year. AirStar, which is also available as Lucent's OnDemand Broadband Wireless Access system and as Siemens' SRAMP, with CellMAC™ is installed in over 30 customer sites worldwide at multiple frequencies many of which are in commercial operation delivering voice and broadband data services to the small and medium enterprise.

Netro believes that CellMAC is the only air interface that is commercially available today at multiple frequencies that satisfies all of the System Requirements set forth by the 802.16. With the IEEE 802.16 moving at a rapid pace, Netro is pleased to open CellMAC to this standards activity and requests that it be given full consideration.

Overview

A wireless ATM point to multipoint network imposes unique requirements to the medium Access Control (MAC) layer. The MAC layer must provide a regulating mechanism for sharing the common bandwidth among the multiple users, and in addition comply with additional requirements that are arising because of the commercial success of wireless ATM access networks, such as:

- Service Transparency - Any service, T1/E1 (structured and unstructured), POTS, Internet Protocol, Bridged Services, Frame Relay, or Cell Relay can easily be mapped onto ATM adaptation layer and service class with commercially available chipsets.
- Future proof architecture - Any current or future service can be easily mapped onto ATM.
- Dynamic Bandwidth Allocation - The ability to achieve statistical multiplexing for bursty data services, which allows bandwidth and equipment reuse by a substantial factor.
- Core network independence - Base station can easily adapt traffic for transport on any core network, TDM, ATM, or IP.
- Grade of Service - Bandwidth allocation is in accordance with the PCR, SCR, CDV, and MBS traffic contract for each service.
- Scalability - All real-time processing can be purely hardware based enabling scalability up to 155 Mbps and beyond through scaling clock frequency of ASIC silicon.
- PMD Layer independence - Operates at arbitrary bit rates to enable use on any channelization plan worldwide. Can support either FDD or TDD operation.
- High spectral efficiency and low overhead - Spectral efficiency equivalent to point to point systems. Mini-slot and piggy-back mechanism in upstream enable low MAC overhead and symmetry of spectral efficiency.

The CellMAC reference model is shown in Figure 1. The physical medium dependent (PMD) sublayer employs 4 and 16QAM modulation in a frequency duplex mode. The transmission convergence sublayer abstracts the media access control layer from the PMD layer and maps the link management, bandwidth management, and user data transfer mechanism onto the PMD layer.

The Media Access control layer has three main components: link management, bandwidth management, and user data transfer. The link management function provides for automatic subscriber transmit power control and ranging calibration, and for the admission of new users onto the network. The bandwidth management function processes bandwidth reservation requests from subscribers and schedules constant-bit-rate and bursty data traffic according to quality of service criteria. The user data transfer provides the data link control for mapping higher layer user data onto TC-PDUs and for user data encryption over the air interface. The media access control protocol is the subject of a separate contribution.

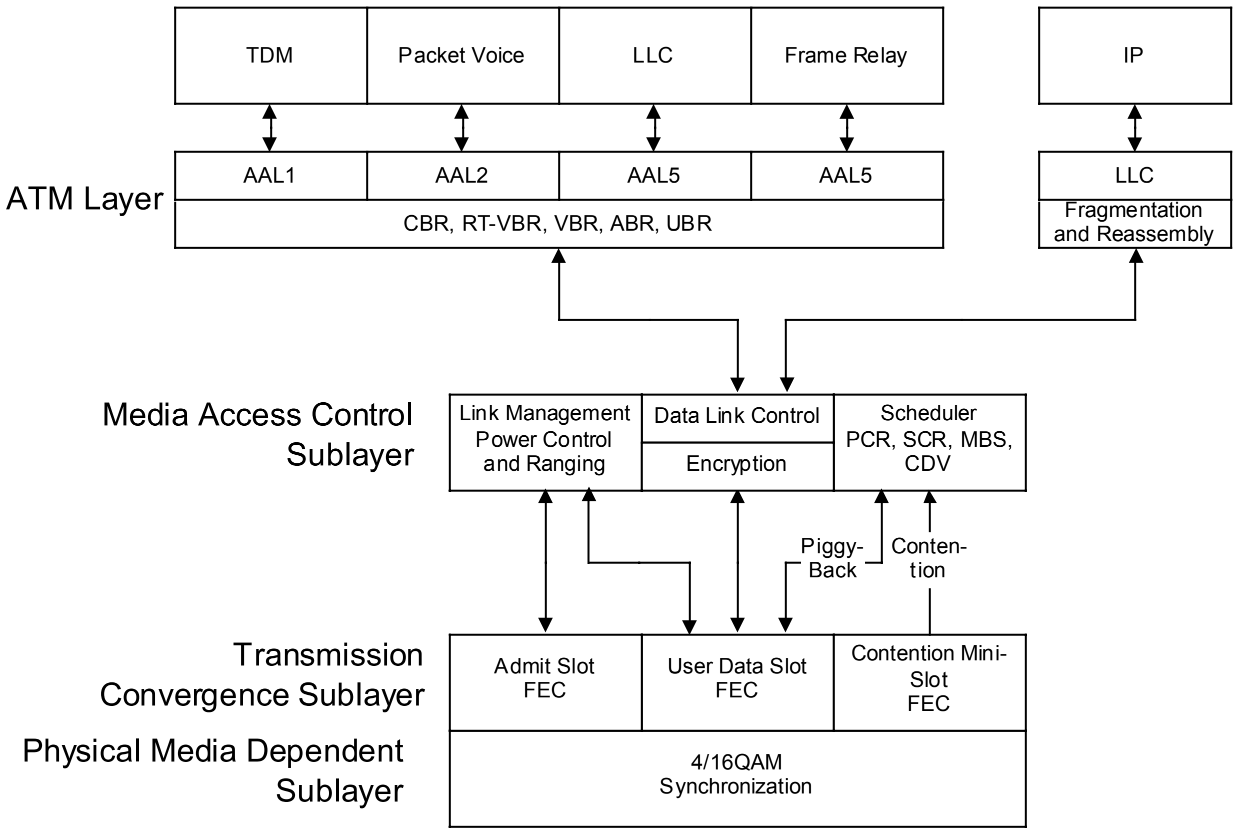

Figure 1: CellMAC™ Reference Model

Transmission Convergence Layer

The transmission convergence layer abstracts the Media Access Control Layer from the Physical Medium Dependent Sublayer. The transmission convergence sublayer maps the Media Access Control mechanisms for link management, bandwidth reservation and granting, and user data transfer onto the physical medium dependent sublayer. The TC layer described herein is specified for operation with physical medium dependent sublayer which employs frequency division duplexing and 4/16QAM modulation[1]. This TC layer can be extended to support time division duplexed PMD layers and different modulation schemes such as 8PSK, 32/64QAM, or OFDM.

The transmission convergence layer achieves symmetric spectral efficiency between the upstream and downstream transmissions. Both employ 67 octet protocol data units. Each protocol data unit carries a net user payload of 47 bytes. This achieves a spectral efficiency which is in accordance with ETSI TM4 recommendations of four E1s per 7 MHz channel, or 8xE1 per 14 MHz channel.

The downstream direction is time division multiplexed and operates in a broadcast mode with a distinct MAC address for each subscriber terminal. Although time division multiplexed, there is no concept of a frame structure where time slots are mapped to subscriber terminals. Rather, traffic is passed downstream as it is received from the network interface in an on-demand fashion.

The transmission is divided to timeslots, each timeslot carries a 67-byte TC-PDU including one ATM cell.

The upstream direction consists of bursts from any of the terminals, each burst contains a TC-PDU that includes an ATM cell and/or MAC-level signaling, as discussed below.

The upstream mode is time division multiple access (TDMA), but no TDM frame exists in this direction either.

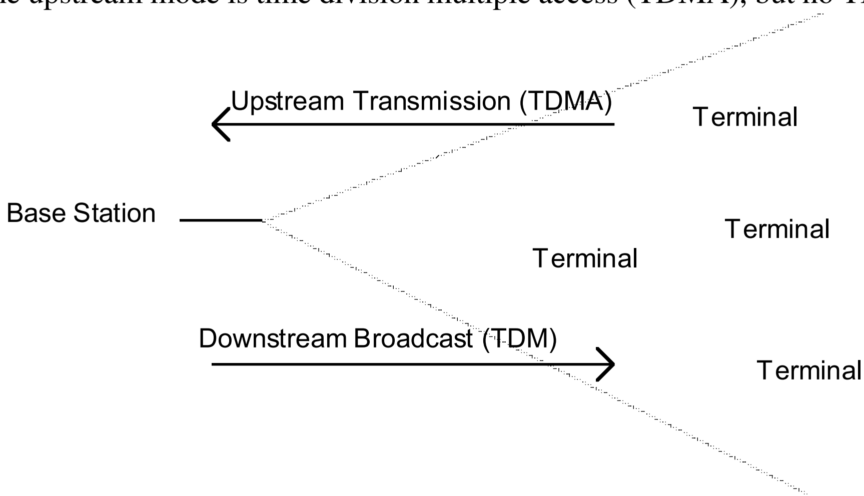

Figure 2: Downstream Broadcast/ Upstream Bursts

Downstream

The 67 octet downstream TC-PDU consists of 48 octets of user payload, 9 octets of FEC, and 9 octets of CellMAC overhead.

67 Octet Downstream PDU		
CellMAC Header (9)	Payload (48)	FEC (9)

Scrambling is applied to the CellMAC Header and 48 octet payload to maintain spectral mask properties. The PDU ends with a 9-octet FEC field, of which 70 bits contain BCH code with t=7. The FEC is calculated across the CellMAC Header and 48 octet payload. Further details of the FEC and Scrambling can be provided in a subsequent contribution.

Upstream

The upstream flow includes bursts of single user data traffic, contention slots and admission bursts.

Upstream User Data TC-PDU

67 Octet PDU				
PMD Overhead (3)		CellMAC Header (9)	Payload (48)	FEC (8)
Gap (1)	Sync (2)			

Figure 3: Upstream User Data TC-PDU

This is the PDU that carries user data and management traffic in the form of ATM cells. This PDU has the same size as the downstream PDU: 67 octets. However, since it is a burst, 3 bytes of the structure are spent on burst support: one octet gap, allowing for timing imperfection and signal rise and fall times between successive bursts from different terminals, and a preamble for base station modem synchronization.

The CellMAC Header includes the following information:

- Subscriber Terminal Identifier (STI) - Source terminal CellMAC address of this User Data TC-PDU.

- Connection Identifier (CID) of this TC-PDU. For ATM transport systems, the CID would map directly to the VCI of the ATM cell. For IP transport systems, the CID can be mapped to a VLAN ID per IEEE 802.11Q, to a logical IP interface, or not used for connection-less transport.
- A bandwidth reservation request including CID and Cell Count of any connection within this terminal, requesting COUNT=0 to 7 TC-PDUs).
- A second CID and Cell Count, same as above, for another (or same) connection.
- Payload Type Indicator. For ATM transport systems this is mapped to the ATM payload type indicator field.
- Cell Loss Priority, For ATM transport system this is mapped to the ATM cell loss priority field.
- Header Error Check for integrity checking of the CellMAC Header.

Note that with this header, each terminal can send two independent bandwidth reservations, including up to 7 TC-PDUs each, thus every user data transmission is an opportunity to request up to 14 more TC-PDUs without resorting to a contention slot, to be described next.

The CellMAC Header, except for the HEC byte, and 48 octet payload are scrambled to maintain spectral mask properties. The eight octets for FEC consists of a 54-bit BCH code with a correction factor of t=6, and two bits reserved. Additional details of the scrambling and FEC parameters can be provided in a subsequent contribution.

Upstream Contention Slot

A terminal that did not transmit for a long time, probably because it had no traffic, has no opportunity to piggyback a request as discussed above. Such terminal may use a contention slot to send a grant request.

<table>
<tr><td colspan="4">11 Octet Contention Minislot TC-PDU</td></tr>
<tr><td colspan="2">PMD Header (2)</td><td>Request (5.5)</td><td>FEC (3.5)</td></tr>
<tr><td>Gap (1)</td><td>Sync (1)</td><td colspan="2"></td></tr>
</table>

Figure 4: A contention Minislot (one of 6)

A contention slot is a 67-octet slot divided into six 11-octet minislots and one extra 1-octet gap. Each minislot includes:

- Subscriber Terminal Identifier (STI) - Source terminal CellMAC address of the request.
- Reservation Request consisting of the CID and Count of any connection within this terminal, requesting Count=0 to 7 TC-PDUs).
- A second reservation request consisting of CID and Count, for another (or the same) connection within the subscriber terminal.

Note that a minislot request carries the same two requests as an upstream User Data TC-PDU. Any of the six minislots may come from a different terminal.

A ternary valued feedback for each contention minislot is provided in the Response Field of the downstream CellMAC header. The two-bit response field for each contention minislot is encoded to give an indication of successful transmission, collision, or nothing received. The use of ternary valued feedback from the base station to the subscriber enables the most advanced of random back-off algorithms to maximize throughput on the contention minislots.

Upstream Admit Slot

A new terminal must register itself by transmitting a special packet called “Admit request”. An Admit slot is a granted slot period in which new terminals can transmit a 32-octet structure, that is preceded by guard slots in which no grants are given, because a new terminal does not have a precise delay information to compensate for the distance to the base station. The key information in an Admit Request is the terminal’s IEEE 48-bit MAC address that identifies the device uniquely. In response, the terminals receive a downstream packet with an assigned CellMAC address (STI) and delay/power setting.

32 Octet Admit PDU				
PMD Header (8)	IEEE MAC (6)	STI (1.5)	Reserved (9.5)	FEC (8)

Figure 5: Upstream Admit TC-PDU

The upstream Admit TC-PDU has the following structure:

- 8 octet sync preamble
- 6 octet IEEE MAC Address
- 1.5 octets STI
- 9.5 octets reserved
- 54 bits FEC (BCH t=6)
- 2 bit reserved

During user data slots and contention slots, the timing window of the preamble detector is very small, within a symbol. However, because new users do not yet have their ranging delay resolved, they will require the timing window to be held open during the entire slot.

The details of the FEC and scrambling can be provided in a subsequent contribution.

Forward Error Correction

Availability of microwave links depends on the line-of-sight microwave link system gain budget to maintain a cell loss ratio of 10^{-6} or better. The CellMAC contribution to this performance is efficient forward error correction. In order to natively support an ATM link layer, the atomic unit of bandwidth allocation is required to be an ATM cell. For PDUs of this size, the use of BCH code provides BER performance exceeding Reed Solomon with the same overhead.

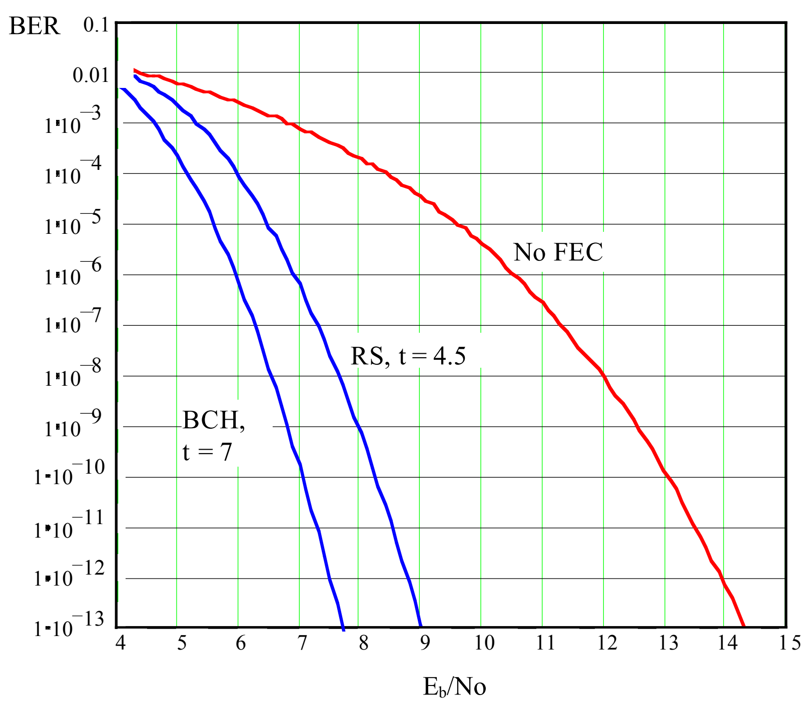

Figure 6: BCH code performs better than Reed-Solomon with the same overhead

Physical Medium Dependent Sublayer

The specifications for the physical layer of the air interface are given in Table 1.

Table 1: Physical Medium Dependent Sublayer

Parameter	Value
Spectral Shape	$\alpha = 0.3$ Root Raised Cosine
Channelization	Arbitrary
Modulation	4/16 QAM
Symbol Rates	Arbitrary depending upon Channelization and spectral mask
Spectral Efficiency	1.17 bps/Hz (4QAM, ETSI channels) 2.34 bps/Hz (16QAM, ETSI channels)
C/N for 10^{-6} BER	9.5 dB, Theoretical (4QAM) 19.2 dB, Theoretical (16QAM)

Duplexing

The system employs frequency division duplexing.

Compliance to PHY Call for Contributions

Meet System Requirements

CellMAC™ air interface was purpose-built to meet the requirements of wireless operators delivering voice and broadband data services to the SME and MTUs. The physical layer herein provides for symmetric spectral efficiency between the downstream and upstream paths enabling symmetric services to be delivered. The transmission convergence layer utilizes an PDU size which enables single ATM cell to be transmitted, which is a key criteria for meeting QoS objectives for ATM transport based system. A strong FEC is proposed herein which provides coding gain which is symmetric between the downstream and upstream, enable system gain and link budget planning to be engineered identically in each direction for cell loss ratios of 10^{-6} or better.

Spectrum Efficiency

The CellMAC air interface meets the ETSI TM4 recommendations for spectral efficiency of 4xE1 of net user payload in a 7 MHz channel, or 8xE1 in a 14 MHz channel.

Simplicity of Implementation

Netro's AirStar system which employs the CellMAC air interface, currently utilizes off the shelf PMD ASICs from the cable and terrestrial video broadcast industries.

The burst receiver implementation is no more complex than is currently employed by DOCSIS systems.

CPE Cost

The TC and PMD layers described herein lend themselves to the same low cost ASIC implementation as that for cable modems.

Spectrum Resource

The TC and PMD layers described herein have already been implemented for a variety of channelization schemes to meet the needs of spectrum allocations worldwide.

System Diversity Flexibility

The PMD described herein has been field proven in systems from 39 GHz down to 10.5 GHz. It can operate at frequencies down to 2.5 GHz. It has been tested with a variety of base station sector antenna patterns and subscriber antenna beamwidths supporting cell sizes from 1 to 15 km. It can theoretically support not only terrestrial, but stratospheric applications.

Protocol Interfacing Complexity

The CellMAC™ air interface specifies MAC as well as TC and PMD layers. Hence, the physical layer described herein has been interfacing with a MAC layer in over 30 deployments worldwide at multiple frequencies. Both 4 and 16QAM have been tested with the MAC layer. The PMD provides the necessary fault management and performance monitoring statistics for operation of commercial networks.

Reference System Gain

	4QAM	16QAM	
Transmit P_{1dB}	30	30	dBm
Transmitter Back-Off	1	3	dB
Transmit Power	29	27	dBm
Thermal Noise Power	-106.3	-106.3	dBm
Receiver Noise Figure	0	0	dB
Noise Power	-106.3	-106.3	dBm
Carrier to Noise	9.5	16.5	dB
Receive Sensitivity	-96.8	-89.8	dBm
Reference System Gain	125.8	116.8	dB

Robustness to Interference

The CellMAC air interface was purpose built for broadband wireless access systems which will be deployed in a cellular topology. The CellMAC air interface enables the use of a frequency reuse pattern with four sector cells and only four degrees of freedom which achieves a frequency reuse distance factor of 5. This results in adjacent cell co-channel interference isolation of 14 dB. The physical layer described herein operates with less than a 3 dB degradation in BER performance for a carrier to interference ratio of 14 dB which is less than the link margin for typical link availabilities at 10 GHz and above.

Robustness to Channel Impairments

Because of the use of highly directional antennas at the subscriber premises, extensive field testing has demonstrated that multipath is not an issue for 4QAM modulation at 10.5 GHz and above. Multipath for 16QAM interference can be mitigated through the use of adaptive equalization techniques employed by cable modem or terrestrial video broadcast chipsets in the downstream direction, and through burst equalization in the upstream direction. The PHY can also be used at frequencies down to 2.5 GHz.