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Media Access Control Layer Proposal for the 802.16 Air Interface Specification

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Purpose:

This presentation is intended to provide an overview of the submission IEEE 802.16.1mc-00/09, “Media Access Control Layer Proposal for the 802.16 Air Interface Specification”.

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IEEE 802.16.1 MAC Proposal

March 6-10, 2000
Albuquerque, NM

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Presentation Overview

Very Quick Overview

Changes since last Proposal

MAC Evaluation Criteria

Conclusions

Very Quick Overview

Quick Overview

- Point to multi-point MAC protocol
  - Upstream
    - Time divided into continuous stream of mini-slots
    - Contention-based access for latency tolerant applications
    - Reservation-based access for low-latency applications
    - Polling-based access for variable-rate applications
    - Message formats allow efficient scheduling of different message types
  - Supports fragmentation, concatenation, and payload header suppression
  - MAC User Data Formats
    - Variable-length MAC PDU
    - ATM cell (with header suppression) MAC PDU
    - Generic User Data PDU (*new*)
- Full set of MAC management messages
  - Network access, entry, and ranging
  - Upstream bandwidth allocation
  - Dynamic connection creation/modification/deletion

Quick Overview (cont.)

- Service Flows
  - Provides mechanism to manage upstream and downstream QoS
  - Integral to bandwidth allocation process (using mini-slots)
  - Multiple service flows per SS
    - each can have a different set of QoS parameters
- Upstream controlled by variety of scheduling services
  - Best Effort
  - Polling
  - Unsolicited Grant
- QoS Parameters used in conjunction with scheduling services
  - Provides ability to bound delay and jitter
  - Specifies bandwidth
- Scheduling algorithms not defined by the MAC

Changes to the Proposal Since Working Group Session #5

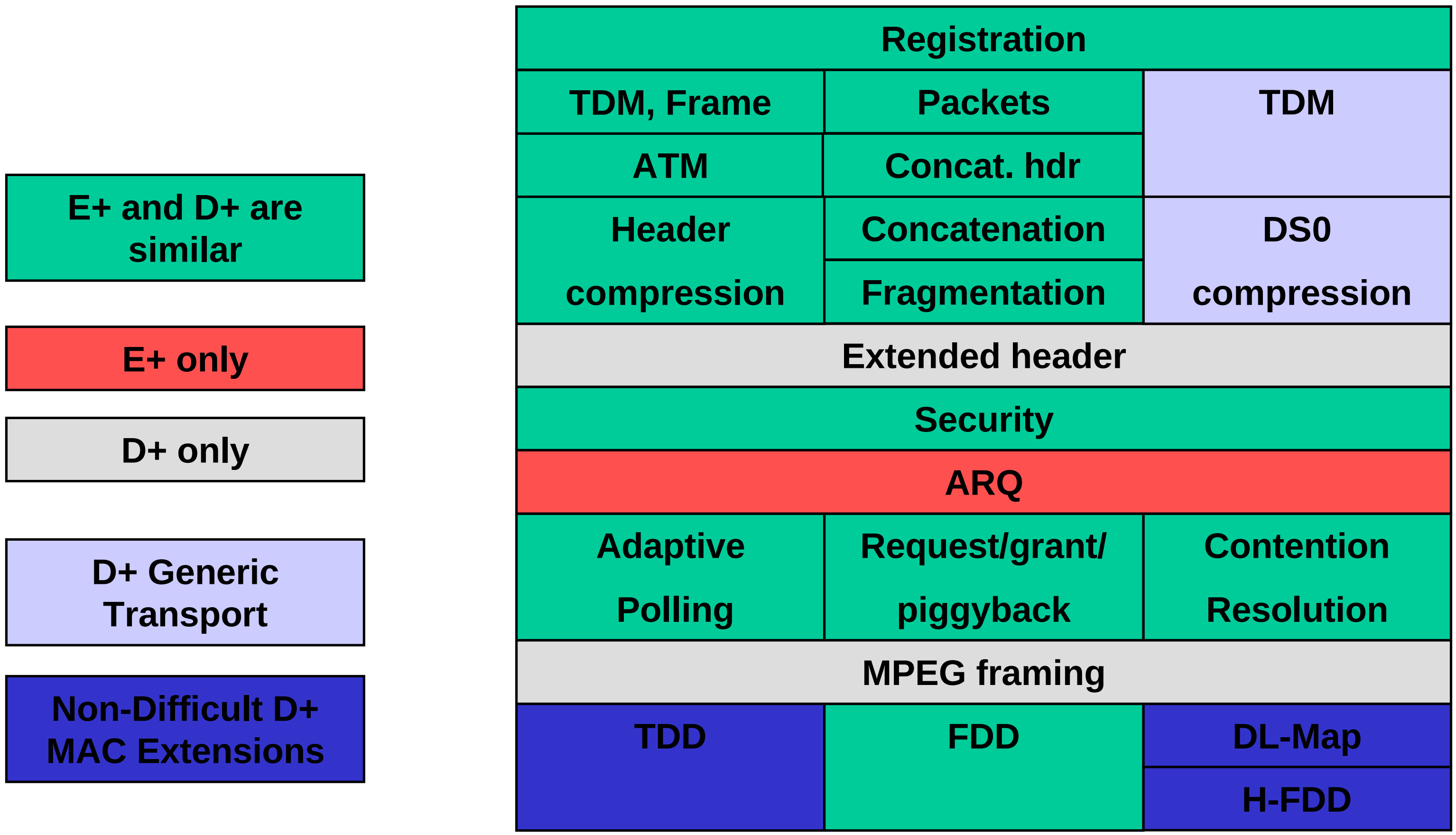
Differences Since Session #5

- Added a generic payload mode
  - Allows vendor-specific payload types and convergence processes
  - Alternative method to ATM adaptation
- Simplified the ATM cell PDU format
  - Less implementation complexity
- Added ATM classifiers ala the Ethernet/802.3 classifiers
  - Completes the MAC Service Definition
- Expanded upstream burst profiles to 3 pairs
  - Burst profiles can be targeted to CPE or service type
  - Can support three levels of adaptive FEC coding in the PHY
- Make the concatenation header optional
  - Tradeoff of robustness versus header efficiency

Differences Since Session #5 (cont.)

- Add power control bits to the User PDU message formats
  - Provides additional BS control of CPE Tx Power
  - Works in conjunction with standard maintenance ranging process
  - Caveat: can only be used for active, symmetric traffic
- Added a new Extended Header that only supports UGS synchronization (w/o the PHS index)
  - Minimize bandwidth utilization for ATM CBR traffic
- Added the Dynamic Channel Change message
  - Allows CPE to be moved among different channels
  - Ensures services are maintained during channel change
    - e.g., UGS begins on the new channel before moving the CPE to that channel

A Quick Comparison

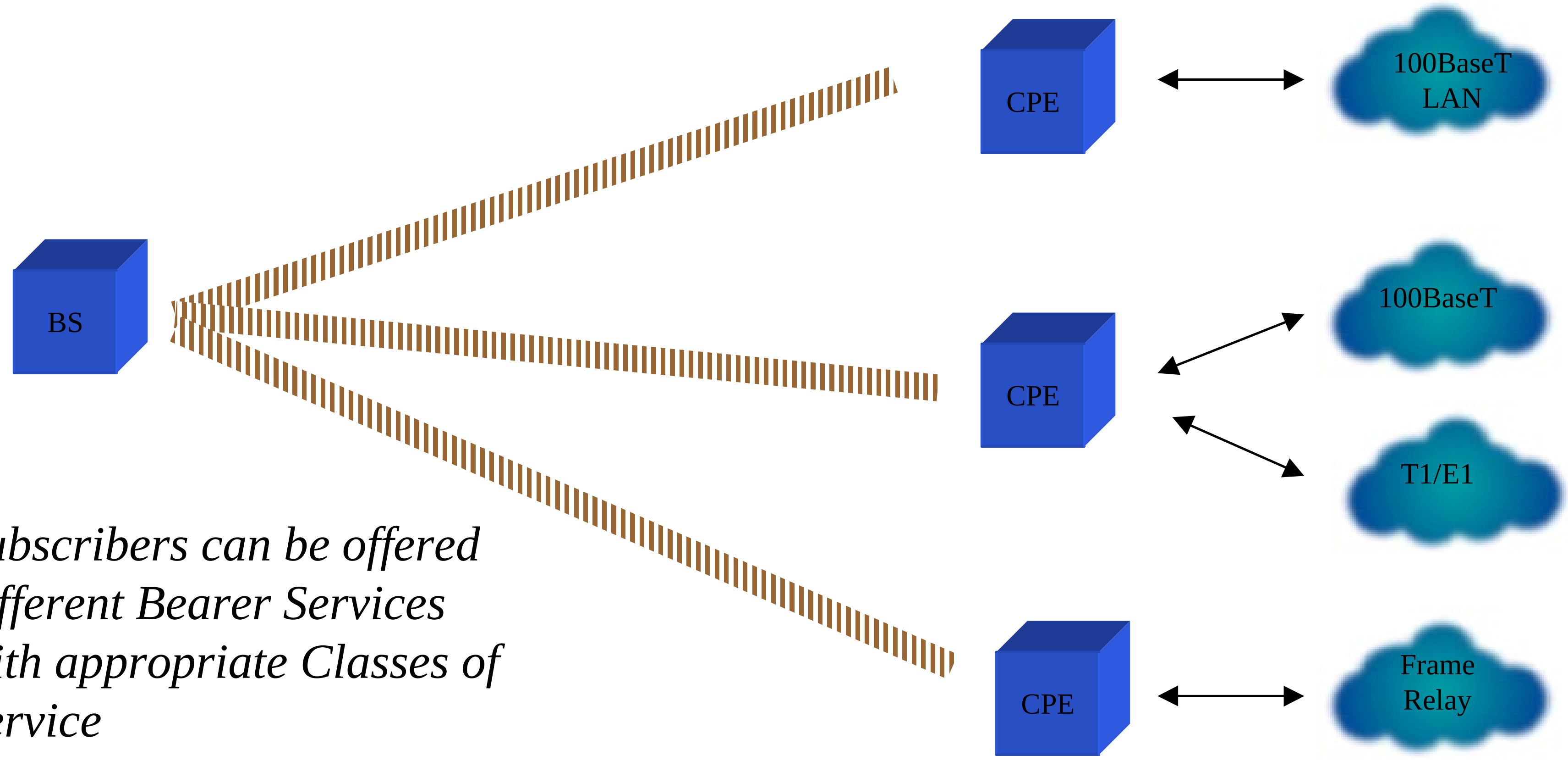


MAC Evaluation Criteria

- Meets System Requirements
- Mean Access Delay and Variance
- Payload and Bandwidth Efficiencies
- Simplicity of Implementation/Low Complexity
- Scalability
- Service Support Flexibility
- Robustness
- Security
- Maturity
- Sign On Process
- Adequacy of Management Functions
- Ability to Work with PHY Variations
- Extensibility

Bearer Services - A Simple Example

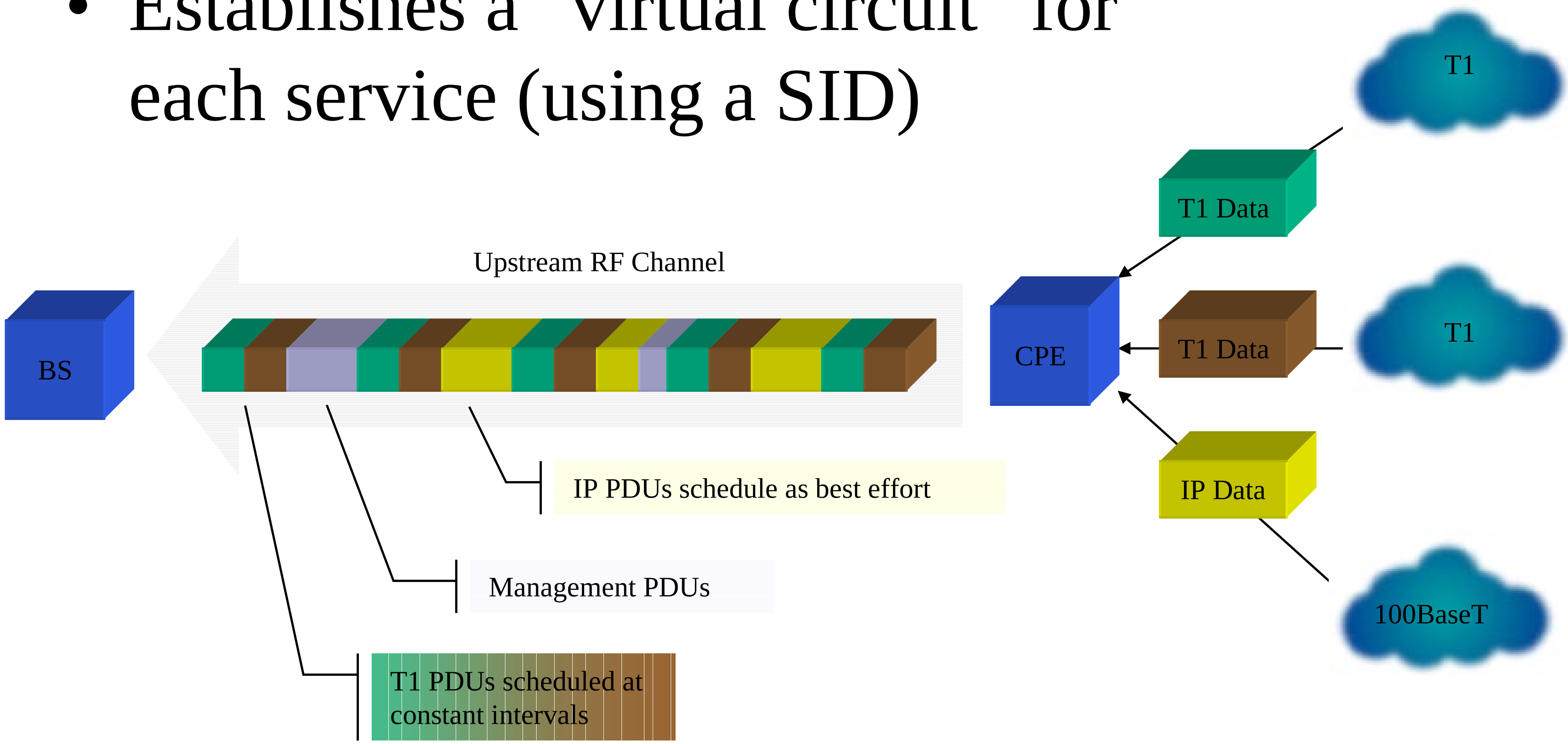
- Each RF Channel supports multiple CPEs
- Each CPE supports multiple subscribers



Subscribers can be offered different Bearer Services with appropriate Classes of Service

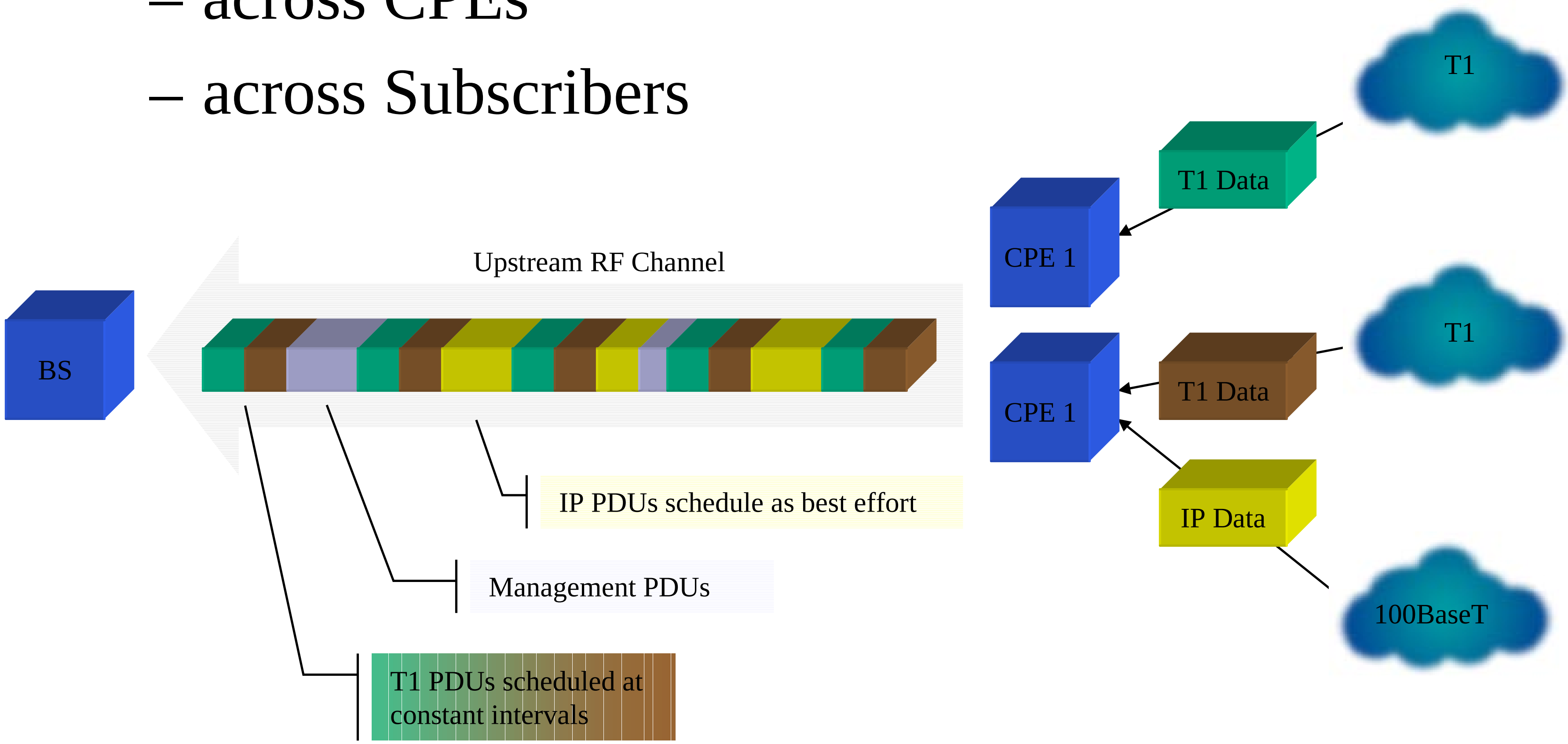
Bearer Services - Service Flows

- Key to providing different services
- Establishes a “virtual circuit” for each service (using a SID)



Bearer Services - Service Flows

- Service Flows are unique
  - across CPEs
  - across Subscribers



Bearer Services - PDU Formats

- 802.3/Ethernet
  - Direct, native support for IP-based protocols
  - Fast, efficient
  - No convergence process required
- ATM with Adaptation Layers
  - Chosen to support leased-line services
  - Existing standards by the ITU and ATM Forum
    - DS1, E1, Frame Relay, …
    - No need to develop new convergence process
    - Uses proven technologies

Bearer Services - Scheduling and QoS

Supports different types of services using the scheduling and QoS parameters

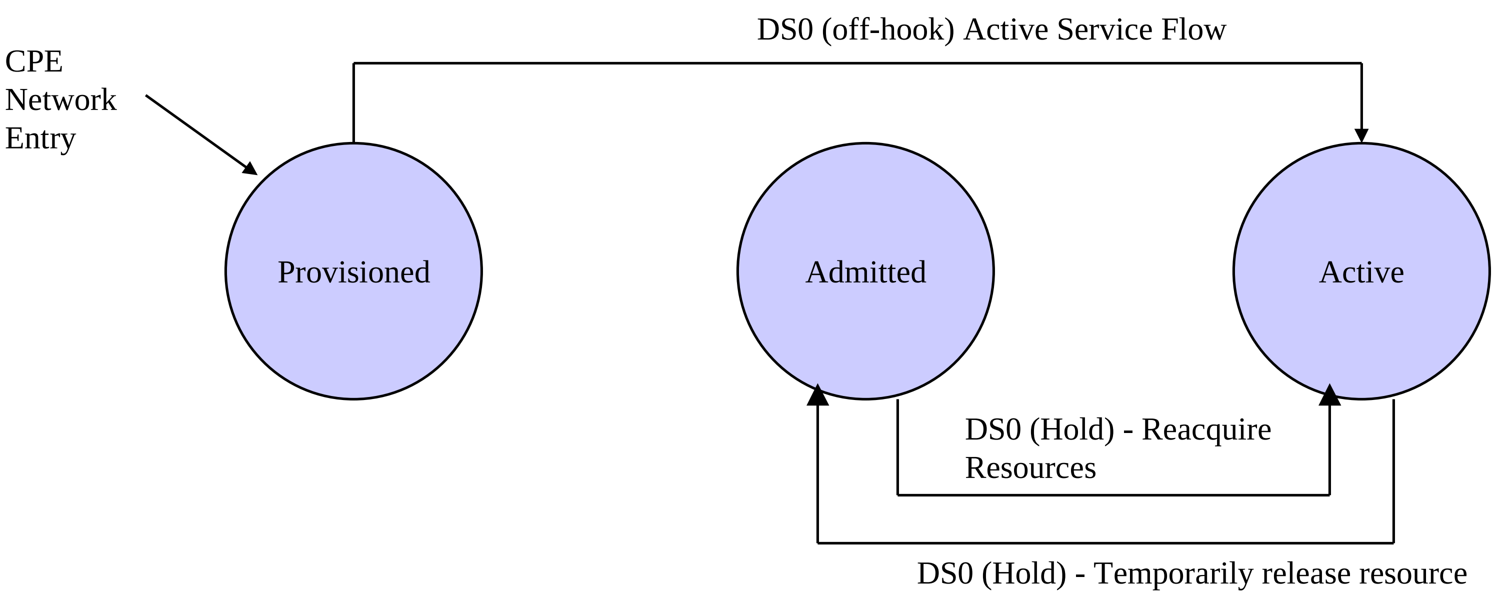
Application	Service Class	MAC PDU Type	MAC Scheduling
Circuit Emulation	CBR	ATM/AAL1	Unsolicited Grant Service
Web Browsing	UBR	802.3/Ethernet	Best Effort
VoIP	CBR	802.3/Ethernet	UGS with Activity Detection
Frame Relay	CBR	ATM/AAL5	Unsolicited Grant Service
	VBR	ATM/AAL5	Real Time Polling
Streaming Video	VBR	802.3/Ethernet	Real Time Polling

Bearer Services - Service Flows

- Three-tiered Service Flow approach
  - Provisioned - known to both BS and CPE
  - Admitted - Resources reserved but not used
  - Active - Resources committed
- Why provision without use?
  - To allow quick establishment of service flows
- Why have an admitted state?
  - To allow resources to be temporarily allocated to other services (but can be resumed at any time).

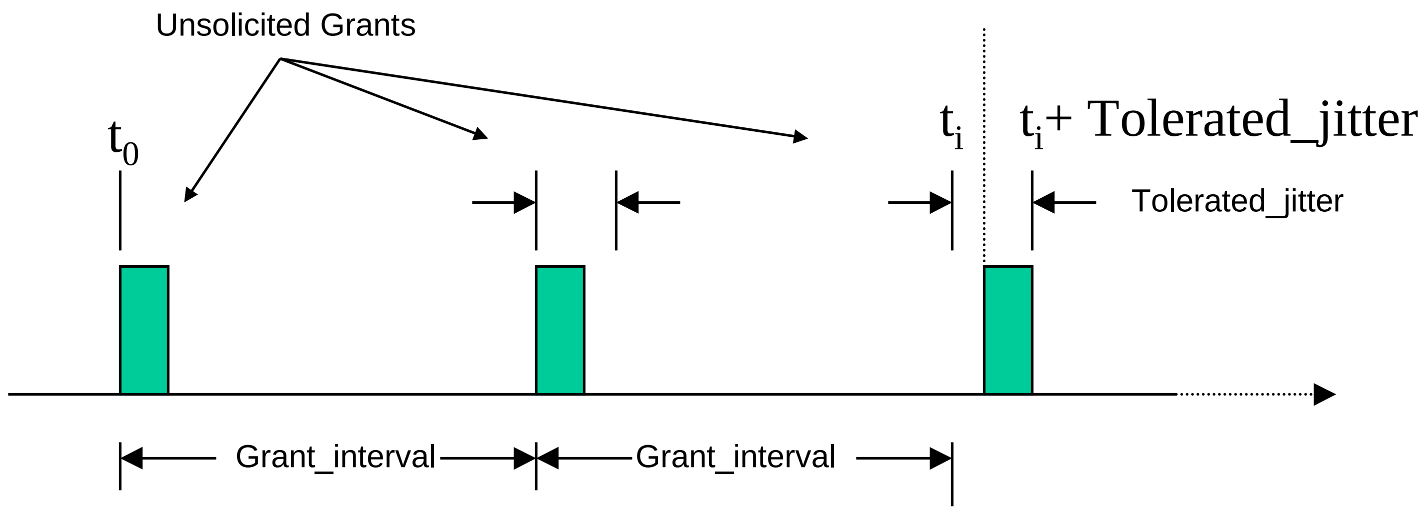
Bearer Services - Service Flows (cont.)

- Two-Phase Activation Model
  - Conserve network resources until end-to-end connection has been established
  - Fast policy checks and admission control



Mean Access Delay and Variance - Jitter

- Access delay is tightly controlled:
  - For UGS, each grant must start within the tolerated jitter parameter
  - Ideal interval start given by: $t_i = t_0 + i * Grant\_Interval$
  - Actual interval start, t' must meet: $t_i <= t' <= t_i + Tolerated\_jitter$
  - Timing resolution in uS; accuracy to BS master clock
- With FDD PHY, no latency introduced by sharing of RF Channel
  - TDD introduces latency when controlling jitter



Mean Access Delay and Variance - Slip

- Grant allocation will not be perfect
  - Small phase errors occur over time causing slip
- MAC must take this into account
  - method for detecting and requesting additional bandwidth required
  - UGS Queue Indicator (2 byte extended header)
  - BS allocates up to 1% additional bandwidth to Service Flow

Payload and Bandwidth Efficiencies

- Direct support for Ethernet/802.3 Frames
  - No adaptation process required
  - Payload Header Suppression
    - eliminates repetitive information
    - defined in a generic manner for widest possible use
- Direct support for ATM
  - CES and other services do require adaptation
  - Simpler to use existing technologies and standards than redefining specialized adaptation layers processes

Payload and Bandwidth Efficiencies

- Extended Headers
  - Only carries additional functionality when needed
  - No need for separate messages
    - example: piggy-back requests can be integrated with fragmentation, where there are most needed
    - example: encryption key sequence carried in the security header, where it is absolutely required
  - Designed for robust operation while minimizing bandwidth usage
    - can be directly implemented with hardware

Payload and Bandwidth Efficiencies

Static comparisons can be misleading...

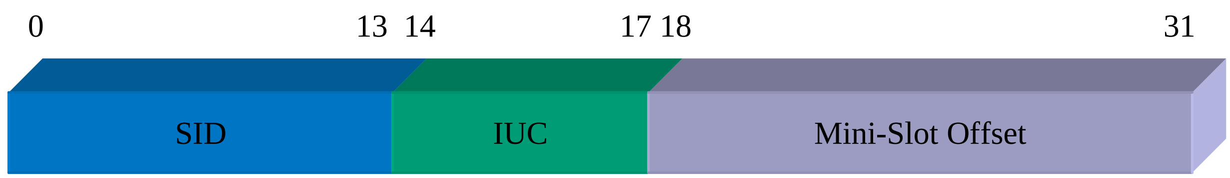
MAC Comparison	Non Fragmented Packet	Fragmented Packet	Fragmented Packet w/Security
Ensemble Proposal - Header - Piggy-Back Request - Key Exchange Msg	 6 bytes	 6 bytes 6 bytes	 6 bytes 6 bytes 11+ 9 bytes at some periodic rate
Total	6 bytes	12 bytes	12 bytes + 20 bytes at some periodic rate
This Proposal - Header - Piggy-Back Req - Key Exchange	 6 bytes	 6 bytes (frag. Header) 6 bytes (frag. EH)	 6 bytes (frag. Header) 6 bytes (frag. EH) 0 bytes (included in EH)
Total	6 bytes	12 bytes	12 bytes

…dynamic protocol operation must also be taken into account.

Payload and Bandwidth Efficiencies

- Management messages designed for efficiency
  - originally developed for bandwidth-limited environment
  - carried directly over MAC w/o convergence process
  - TLVs used for low-rate management functions...

  …high-rate functions designed for hardware implementation; e.g., MAP message entries:



Simplicity of Implementation/Low Complexity

- Implementations of very similar MACs exist today
  - Key functions of MAC are designed to be implemented in hardware
    - yields best possible performance
    - requires a single CPE ASIC
  - Other functions implemented in software for flexibility
    - Comprehensive used of TLVs

Simplicity of Implementation/Low Complexity

- Proposal is large but not complex
  - it is a *complete* MAC definition
    - No convergence processes need to be defined
    - Includes provisioning and other definitions
      - required by Service Providers and Operators to deploy complete solutions
  - the details are there, for example:
    - State transition diagrams are defined for all transactions between the BS and CPEs
- Could start developing solutions today

Simplicity of Implementation/Low Complexity

- MAC allows centralized scheduling
  - Vendor implements appropriate algorithms
  - CPEs not involved in scheduling process
- Simpler than distributed schemes
  - CPEs must perform scheduling when upstream grants are aggregated in a single burst
    - Weighted queuing algorithms are difficult to implement
  - Fewer inter-operability issues
    - Less chance that CPE schedulers will conflict

Scalability (Operational Bandwidths)

- Similar MAC implementations currently scale from
  - 3 Mbps upstream and 30 Mbps downstream

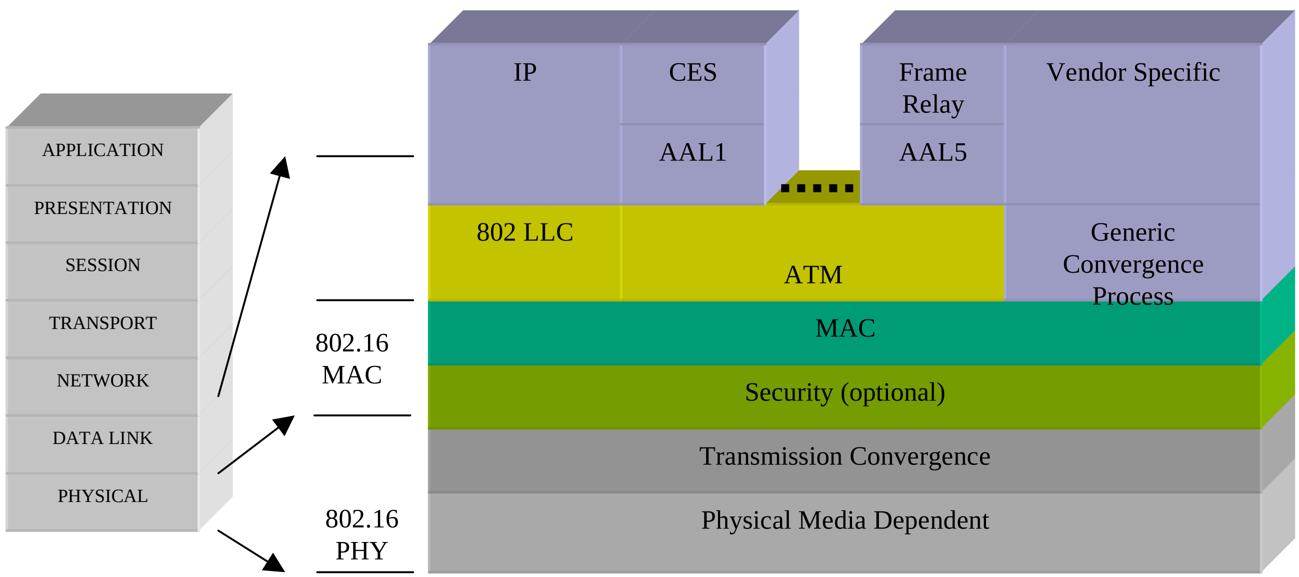
    to
  - 41 Mbps upstream and 40 Mbps downstream
- Ensuring scalability...
  - decouple mini-slot granularity from symbol rate
  - flexible MAP message generation
  - centralized scheduling
  - simple CPE MAC access modes

Scalability (Connections and Services)

- 8192 unique Service Flows per domain
  - No restrictions on Service Flows per CPE or Subscriber
- Similar MAC implementations support 1500 CPEs per domain
- Ensuring scalability...
  - No address space limitations
  - Generic scheduling mechanisms
    - can support ATM service classes or specialized service classes using the generic PDU format

Service Support Flexibility

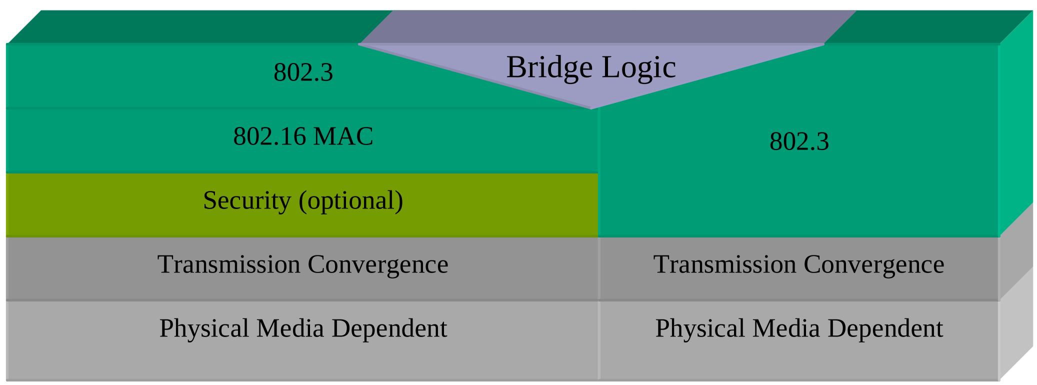
- Flexible Protocol Stack
  - Directly supports IP
  - Supports ATM and Service over ATM
  - Generic Convergence Process for special cases



Service Support Flexibility

- Interworking functions
  - MAC does *not* require a bridge, router, or switch
  - …but does support their use.

<u>Example:</u>
802.16 MAC can carry the 802.3 PDUs but it does not require the use of a bridge at either the router or CPE



Robustness and Ranging

- Tightly controlled initial ranging process
  - Allows unsynchronized CPEs to enter network w/o interfering with existing CPEs
- Well-defined maintenance ranging process
  - Slow loop ranging occurs < every 2 seconds
    - Power, time, and frequency offset
  - MAC headers contain CPE Tx power ranging bits
    - Allows quick power control loop for active traffic
    - Used to handle quick fade conditions (rain, dust, …)

Robustness and MAC Formats

- MAC Headers protected by 16-bit HCS
- Ethernet frames protected by 48-bit CRC
- Fragments carry...
  - First/Middle/Last indication
  - Sequence count
  - 16-bit HCS and 48-bit CRC
- Key sequence count for encryption carried with payload
  - prevents encryption from getting out of sync

Robustness and CRC Usage

- Why carry the CRC on MAC Header?
  - Only erred MAC message is deleted
  - Hardware need only store MAC message it is currently receiving
- But E+ has CRC in PHY TDU
  - TDU (with no ARQ) may contain parts of multiple MAC messages
  - Part and/or whole MAC messages in erred TDU are dropped
  - Additional coupling between MAC and PHY

Robustness and Burst Profiles

- Different Services require different FEC
  - Examples:
    - UDP packets get lower FEC
    - ATM carrying CES get higher FEC
  - Implemented with 3 pairs of data grants
    - Scheduler can apply as needed
- Feature can not be leveraged if different services are carried in the same burst

Robustness and Link Failure

- Loss of single CPE does not affect network
  - CPE re-enters network using initial ranging
- Selectable Ranging Backoff Start and End
  - Allows for optimal contention intervals based upon number of CPE
  - Minimizes network entry time when large number of CPE attempting to re-enter network

Robustness and Link Failure

- Handling PHY Errors at the right Layer
  - Errors in MAC header or extended header
    - Header Check Sum (HCS) detects error
    - MAC message and payload dropped
  - Errors in MAC payload carrying Ethernet/IP
    - Ethernet CRC detects error
    - MAC payload dropped (extended header kept)
  - Errors in MAC payload carrying ATM or generic payload
    - MAC payload passed to higher layer

Robustness and Spectrum Management

- Dynamic Channel Change Message
  - Used to move a CPE among different channels
  - Upstream, Downstream, or both at same time
  - Ensures QoS needs met
    - e.g., grants are generated on new channel before CPE switches
  - Applications
    - Load balancing - e.g., different modulations on different channels
    - CPE movement within a sector
      - when additional channels are added
      - when sector is divided into small partitions (90° to 30°, etc.)

Security

- Authentication
  - Uses Public/Private Keys and X.509 certificates to authenticate BS and CPE
- Payload Encryption Process
  - 56-bit DES in CBC Mode[1]
    - Cyphertext errors don't propagate in plaintext
    - Not coupled to the PHY layer
    - Strongest conventional block cipher mode
    - Equivalent speed to all block cipher modes

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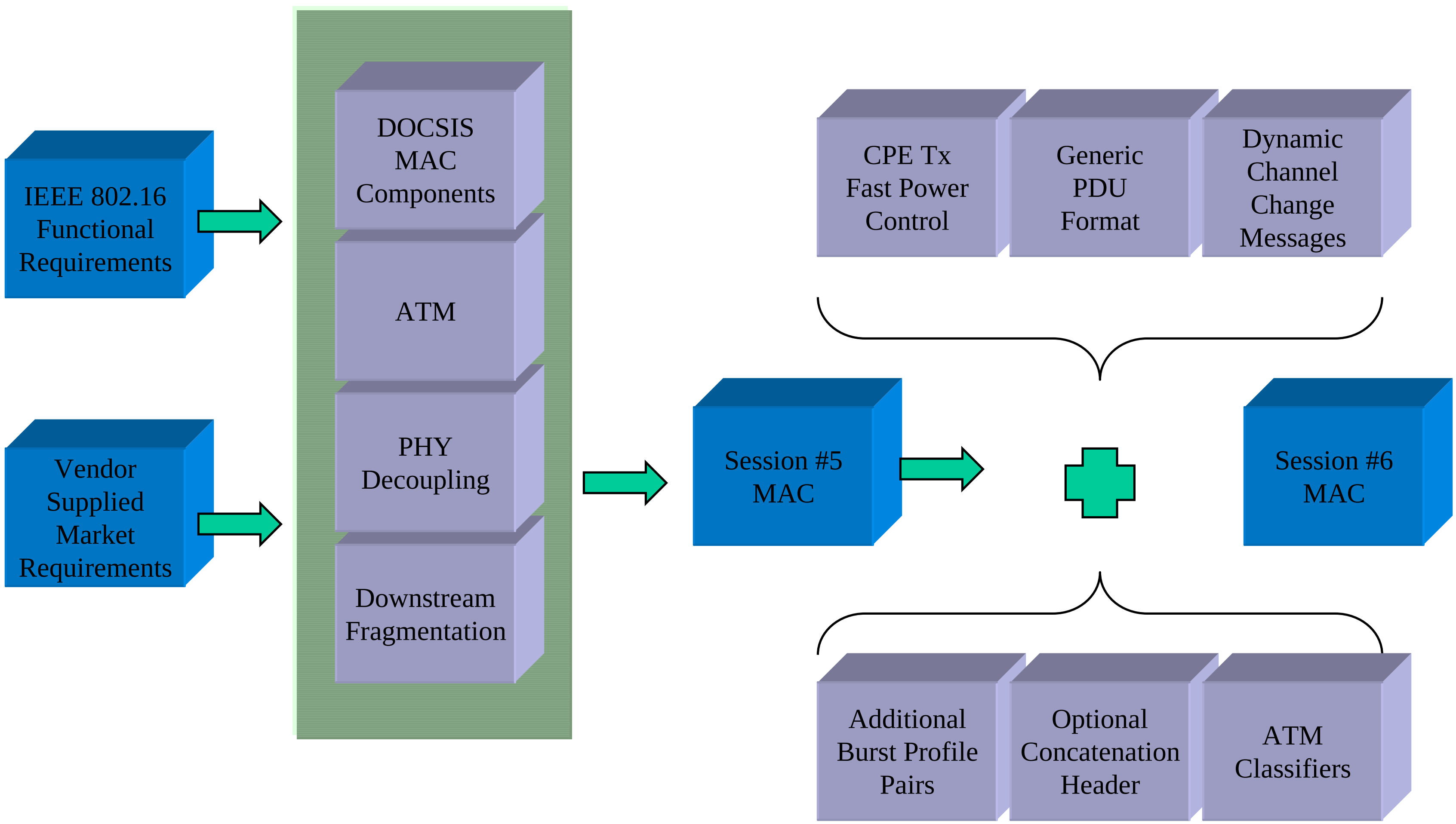
[1] B. Schneier, *Applied Cryptography*, Wiley & Sons, 1996

Maturity - The Proposal Evolution



Maturity - Benefits of This Approach

- Based heavily on the DOCSIS 1.1 MAC
  - Leverages cable modem MAC technology

  ...but is ***not*** a cable modem solution
- What makes it mature?
  - built upon existing technology
    - that has undergone extensive testing
    - multiple, independent low-cost implementations
    - fielded in large systems
    - continual improvement: on-going Change process
  - Academic/technical research (modeling, etc.)

Sign-On Process

- Initial Ranging
  - Special contention intervals are used
    - prevents collisions with CPEs already on the network
    - ranging process achieves CPE timing and power synchronization
    - CPE burst characteristics are adjusted before allowed to register
- All timing is derived from the BS
  - No timing source required at the CPE
  - SAP definitions to allow timing derivation to upper protocol layers
- Fully automated sign-on process - reduces operator burden
  - Definition of the CPE/network provisioning process
  - CPE authentication
  - Service and QoS authentication and authorization
  - Centralized access control

Adequacy of Management Functions

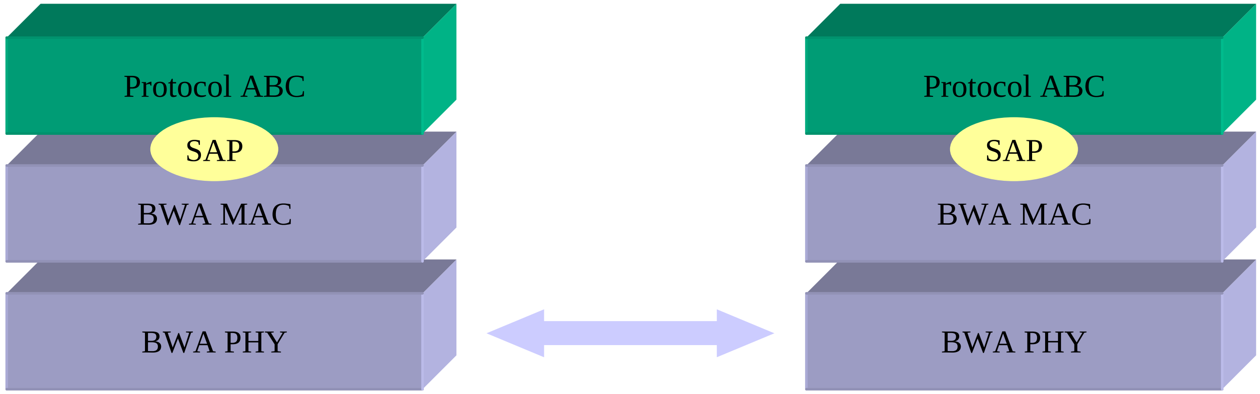
- Complete set of Management Functions
  - Ranging (initial and maintenance)
  - Bandwidth Allocation Management
  - Connection and QoS Management
    - Dynamic service flows
  - Spectrum Management
    - Burst profiles for upstream transmissions
    - Dynamic Channel Changes
  - Security Management
    - Complete Encryption Key Management Protocol

Ability to Work with PHY Variations

- MAC/PHY Independence
  - Does ***not*** require a cable modem PHY
  - MAC is not tightly coupled to the PHY
  - Most PHY parameters are encoded as TLVs
    - allows easy addition and modification of parameters
  - MAC can handle scaling of PHY symbol rates
    - Mini-slot sizing is decoupled from the symbol rate
- Upstream transmission characterized by Burst Profiles
  - Allows each burst to use different parameters
    - Modulation Type (QPSK, 16-QAM, …), Symbol Rate (5 - 40 Msps), FEC coding (t and k values)

Extensibility - Generic PDU Format

- Uses same MAC header formats, scheduling, etc.
- Delivers PDU between equivalent peers
- Allows vendor-specific algorithms, e.g. TDM
- Only recommended in special cases
  - If it can't be supported with ATM or 802.3/Ethernet
  - Requires new convergence processes to be defined and implemented
  - Requires specialized interoperability testing between vendors



Extensibility - E+ MAC

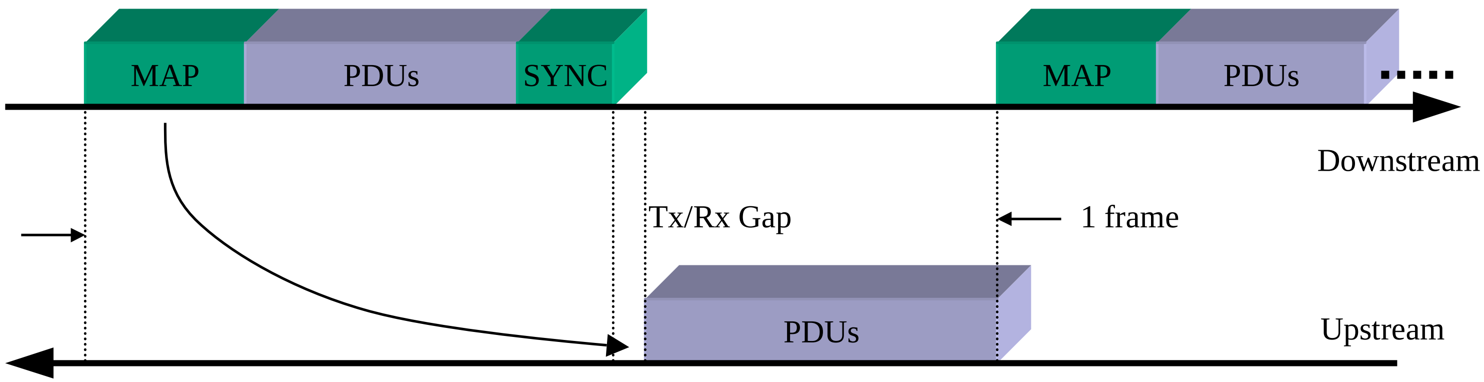
- MAC is minimal; convergence layers complex
  - Convergence layers still to be defined
  - Convergence layer for CES over ATM is complex
  - Convergence layer definitions will significantly increase 802.16 completion time
  - Prediction: manufacturers will use ATM to carry CES to speed introduction
- Better to limit to ATM and IP
  - Generic mode added, but will likely used for specialized or “niche” applications

Extensibility - Encryption Algorithms

- 56-bit DES acknowledged to have limited lifetime, will need new algorithms
  - Changing data encryption algorithm
    - has no impact on overall structure
    - has no impact on operation of the protocol
  - Consistent use of TLVs for key management protocol
  - Flexibility in setting key lifetimes
  - Flexibility in setting key lengths
  - Not coupled to the PHY

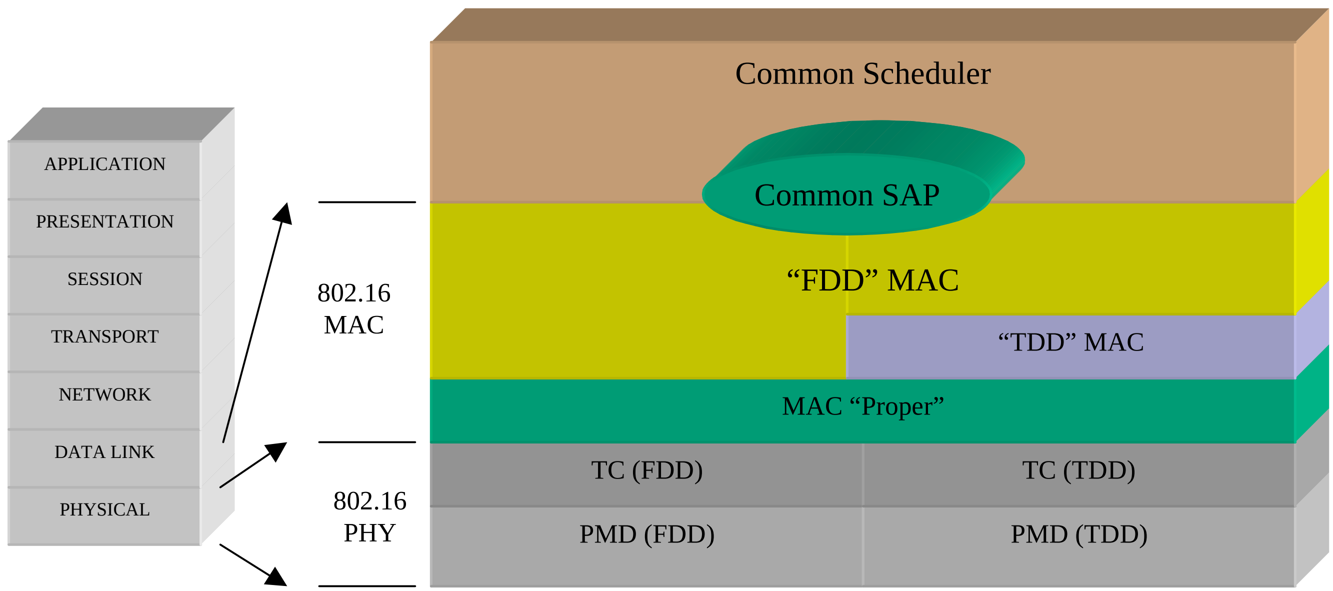
Extensibility - Additional PHY Layers

- TDD Support
  - No modification to MAC messaging form or function
  - Requires modification of Scheduler
    - MAP messages still define appropriate upstream burst times
    - Non-transmission upstream interval has no mini-slot definitions
    - MAP transmitted at start of every frame to define upstream sub-frame



Extensibility - TDD Support and Scheduling

- TDD introduces additional jitter into the traffic flows
  - Requires larger jitter buffers to handle non-continuous channels
  - Buffer size must scale with split point and data rate
- Scheduler can no longer view channels as continuous set of transmission opportunities: Complicates scheduling algorithms



Conclusions and Summary

Conclusions

- Supports the functional requirements
  - Multiple classes of services
  - Multiple services per subscriber
  - Multiplexing allows statistical gains
- Uses proven technologies
  - Extensive implementation experience
  - Extensive research
    - academic/commercial
  - History of on-going change process to strengthen the MAC technologies

Conclusions (cont.)

- Robust *and* efficient solution
- Well defined
  - A complete solution
  - No undefined convergence layers/processes
- Tailored for hardware implementation
  - Faster operation
- Extensible
  - Can be extended to support different PHYs components and features