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Media Access Control Protocol Based on DOCSIS 1.1

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Purpose:

This presentation is intended to provide an overview of the submission IEEE 802.16.1mc-00/01, “Media Access Control Protocol Based on DOCSIS 1.1”

Media Access Control Protocol Based on DOCSIS 1.1

IEEE 802.16.1mp-00/01

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MAC Overview

Introduction

Key Features

Reference Protocol Stack

Relationship to Other Layers

Introduction

- Protocol based on DOCSIS 1.1
  - Annex L of submission describes changes made based on BWA requirements

- Modifications to support BWA system requirements
  - Addition of MAC Message format for ATM cells
  - Support for ATM cell header suppression
  - De-coupling of mini-slot size from symbol rate
  - Support for higher symbol rates
  - Addition of downstream fragmentation

Key Features

- Point to multi-point MAC protocol
  - Continuous downstream broadcast
  - Burst TDMA upstream (with multiple upstreams possible)
    - Time divided into continuous stream of mini-slots
    - Contention-based access for latency tolerant applications
    - Reservation-based access for low-latency 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
- Full set of MAC management messages
  - Network access, entry, and ranging
  - Upstream bandwidth allocation
  - Dynamic connection creation/modification/deletion

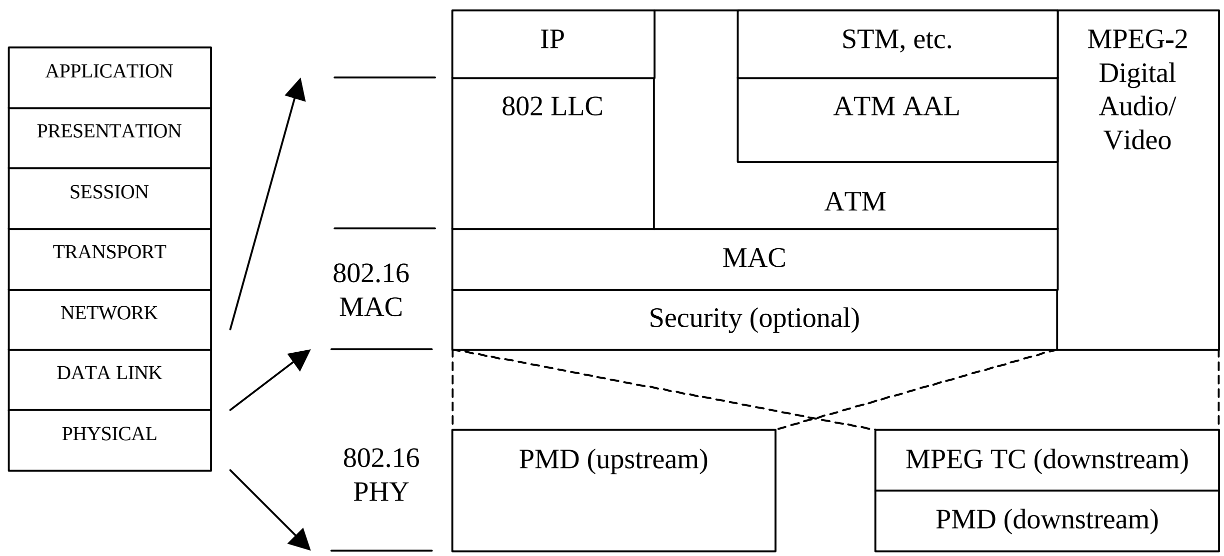
Key Features

(continued)

- 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

Reference Protocol Stack

- Support for Ethernet/802.3
- Support for ATM and adaptation layers
- Optional Security Layer



Relationship to Other Layers

- Upper Layer Relationships (MAC Service Definitions)
  - Data Service Interface
    - request transmission and indicate reception
    - synchronize upper layers with grants
    - synchronize upper layers with master clock
  - Control Service Interface
    - service flow construction complete (indication)
    - creation/deletion/modification of service flows (request/response/indicate)
- Lower Layer Relationships (PHY Interfaces)
  - Upstream Burst Characteristics and Control
  - Downstream transmission Characteristics and Control
  - Feedback for calibration and ranging algorithms

Message Formats

Mac Header Formats

MAC PDU Formats

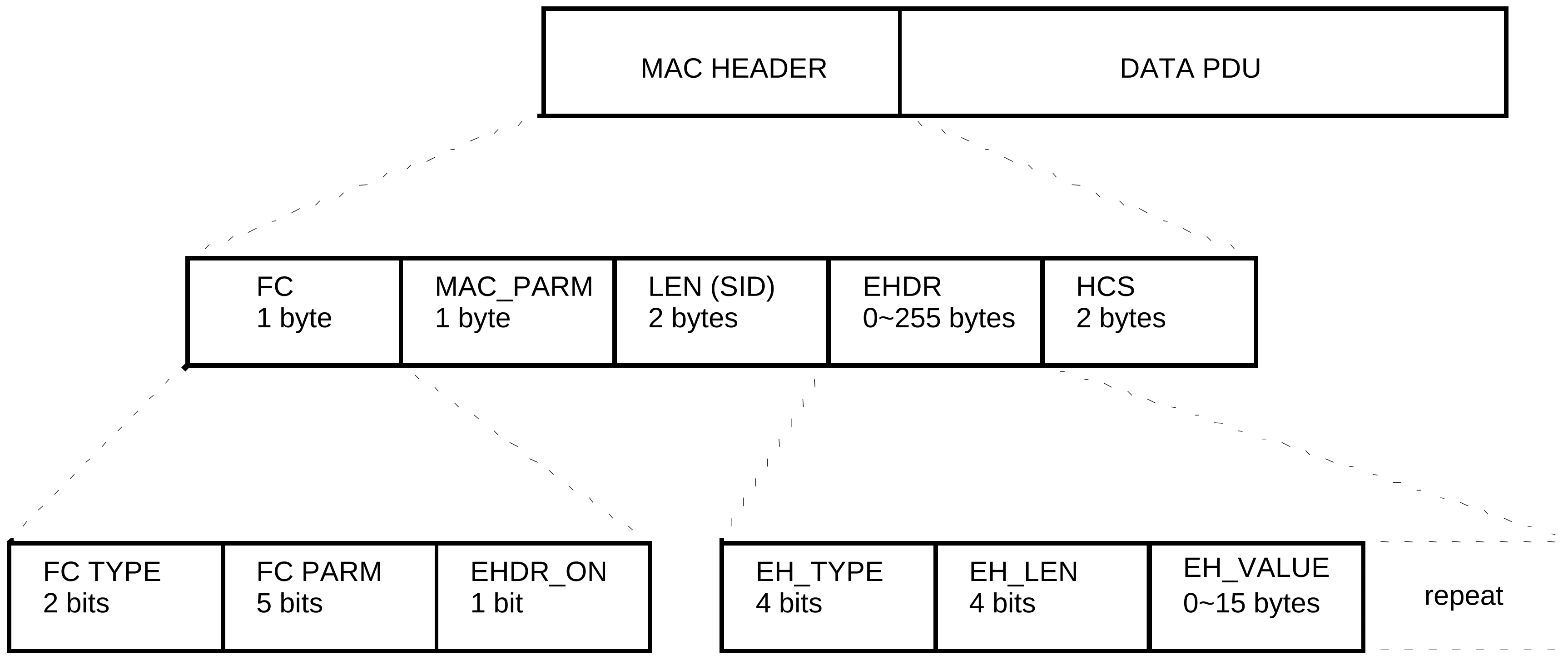
MAC Management Messages

Dynamic Service Messages

Concatenation and Fragmentation

Payload Header Suppression

MAC Header Formats

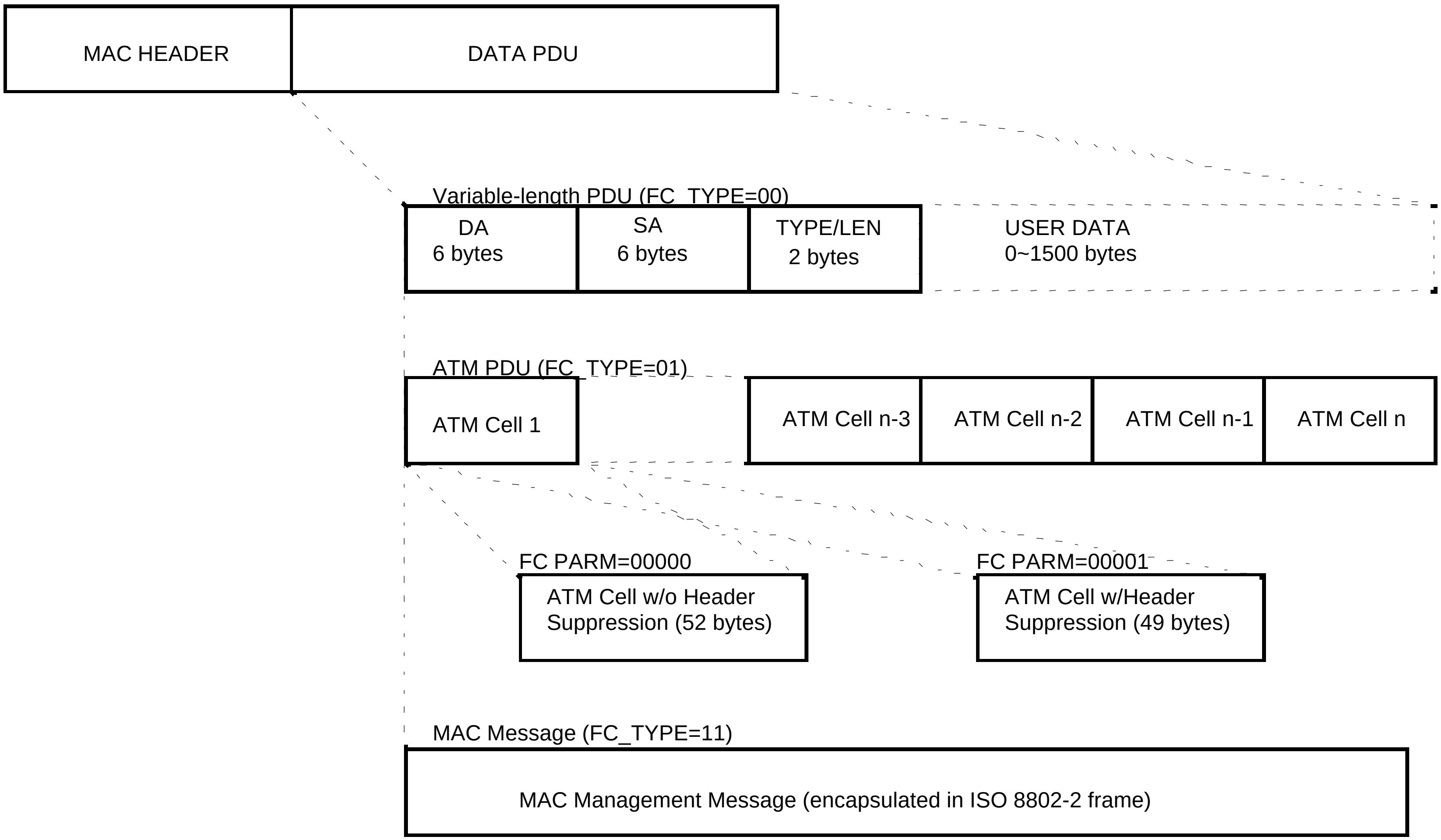


FC_TYPE determines type of PDU:
00 Variable-length PDU (802.3)
01 ATM cells
10 Reserved
11 MAC-specific (Management)

FC_PARM further modifies FC_TYPE

IF EHDR present (EHDR_ON=1), MAC_PARM = Length of EHDR
and LEN = Length of EHDR plus PDU
IF EHDR not present (EHDR_ON=0),
LEN = Length of PDU

MAC PDU Formats



MAC Mgmt Messages (downstream)

- Time Synchronization (SYNC)
  - conveys system time for MAC domain
- Upstream Channel Descriptor (UCD)
  - defines burst characteristics of upstream channel
- Upstream Bandwidth Allocation Map (MAP)
  - allocates upstream bursts in units of mini-slots
  - defines acknowledgement time for requests
  - informs SS of still-pending requests
- Range Response (RNG-RSP)
  - conveys frequency, time, and power calibration to SS
- Registration Response (REG-RSP)
  - conveys network entry and QoS information/acceptance

MAC Mgmt Messages (upstream)

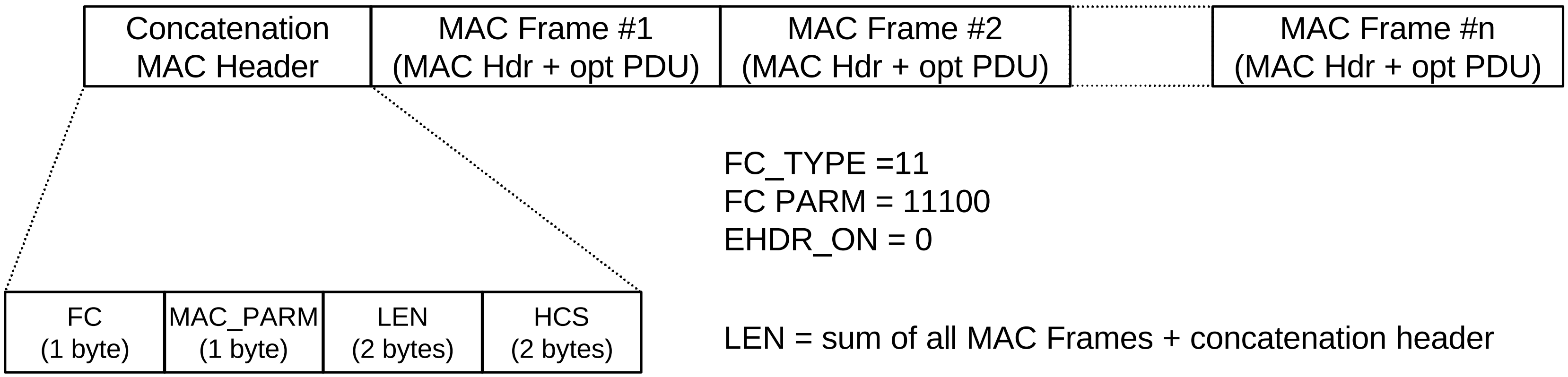
- Range Request (RNG-REQ)
  - used by SS during initial and station maintenance intervals
  - arrival provides closed-loop timing information
- Registration Request (REG-REQ)
  - contains one or more QoS configurations
  - contains network access parameters
  - contains authenticating information relative to configuration information
- Registration Acknowledge (REG-ACK)
  - Acknowledgement of SS for REG-RSP contents
- Grant Request (REQ)
  - used to request a data grant
  - transmitted by SS during a request interval
    - during broadcast intervals: supports Best Effort services
    - during unicast intervals: supports Polling services

Dynamic Service Messages

- Dynamic Service Addition (DSA-REQ, DSA-RSP, DSA-ACK)
  - Used to add a new service flow to an existing SS
- Dynamic Service Modification (DSC-REQ, DSC-RSP, DSC-ACK)
  - Used to modify an existing service flow of a SS
- Dynamic Service Deletion (DSD-REQ, DSD-RSP, DSC-ACK)
  - Used to delete an existing service flow from a SS

- Can be initiated by either the BS or SS
- Three step negotiation
  - Request - initiates the process
  - Response - respond with confirmation or negotiated parameters
  - Acknowledge - respond with confirmation (not used for deletion)
  - Used to support IP telephony and other dynamic applications

Concatenation (upstream)

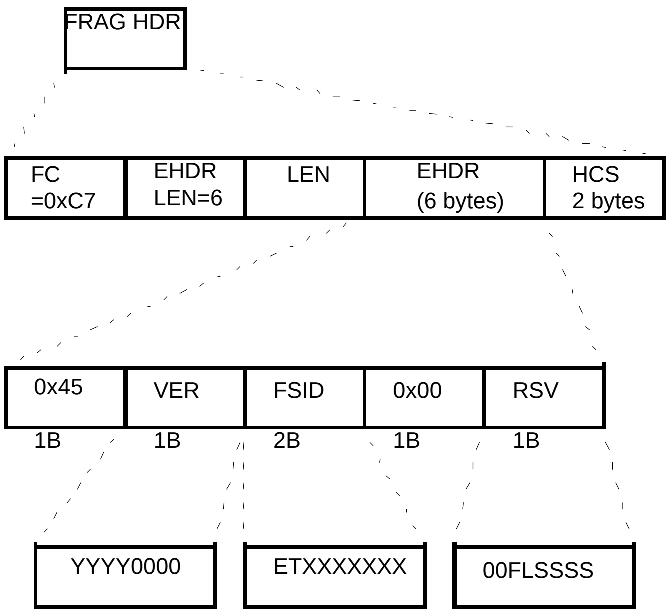


- One or more MAC messages can be concatenated
  - any type of message (user or management) can be concatenated
  - all must use the same service flow
- Example use:
  - concatenation of short Data PDUs to improve upstream efficiency

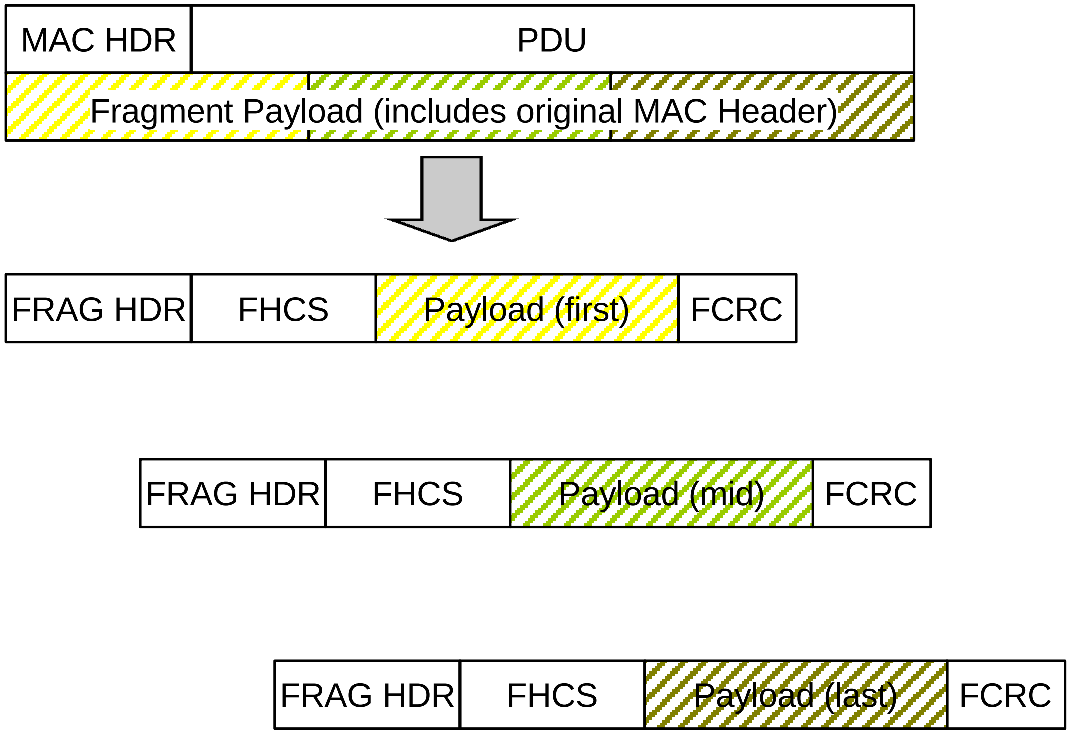
Fragmentation

- Applicable in both directions
  - 4-bit sequence counter to check for lost fragments
  - each fragment carries a separate fragment CRC (FCRC)
  - each fragment carries a separate fragment HCS (FHCS)
  - carries keying information to support encryption
- Upstream
  - initiated whenever a grant is less than request length
  - built-in mechanism to piggy-back additional requests
  - carries SID to allow identification of fragment
- Downstream
  - initiated by scheduling mechanism to support QoS requirements
  - same format as upstream message
  - carries FSID to allow identification of fragment

Fragmentation



YYYY = Key Sequence Number
E = Enable BPI; 1 = enable, 0 = disable
T = Toggle; 0 = even; 1 = odd
F = Set on First fragment; cleared otherwise
L = Set on Last fragment; cleared otherwise
SSSS = 4-bit sequence number



FHCS = Fragment HCS
FCRC = Fragment CRC

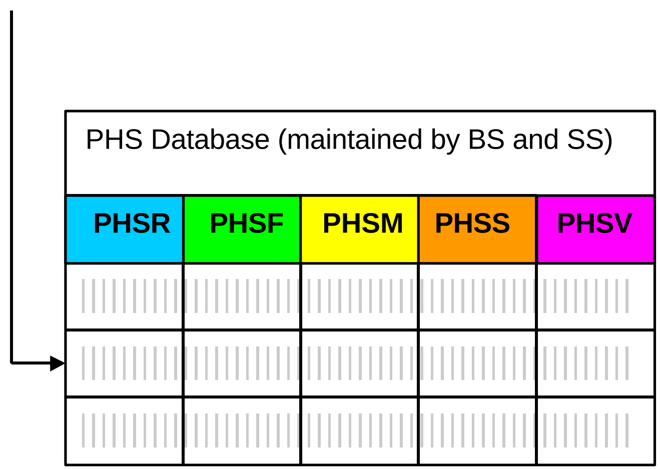
Payload Header Suppression

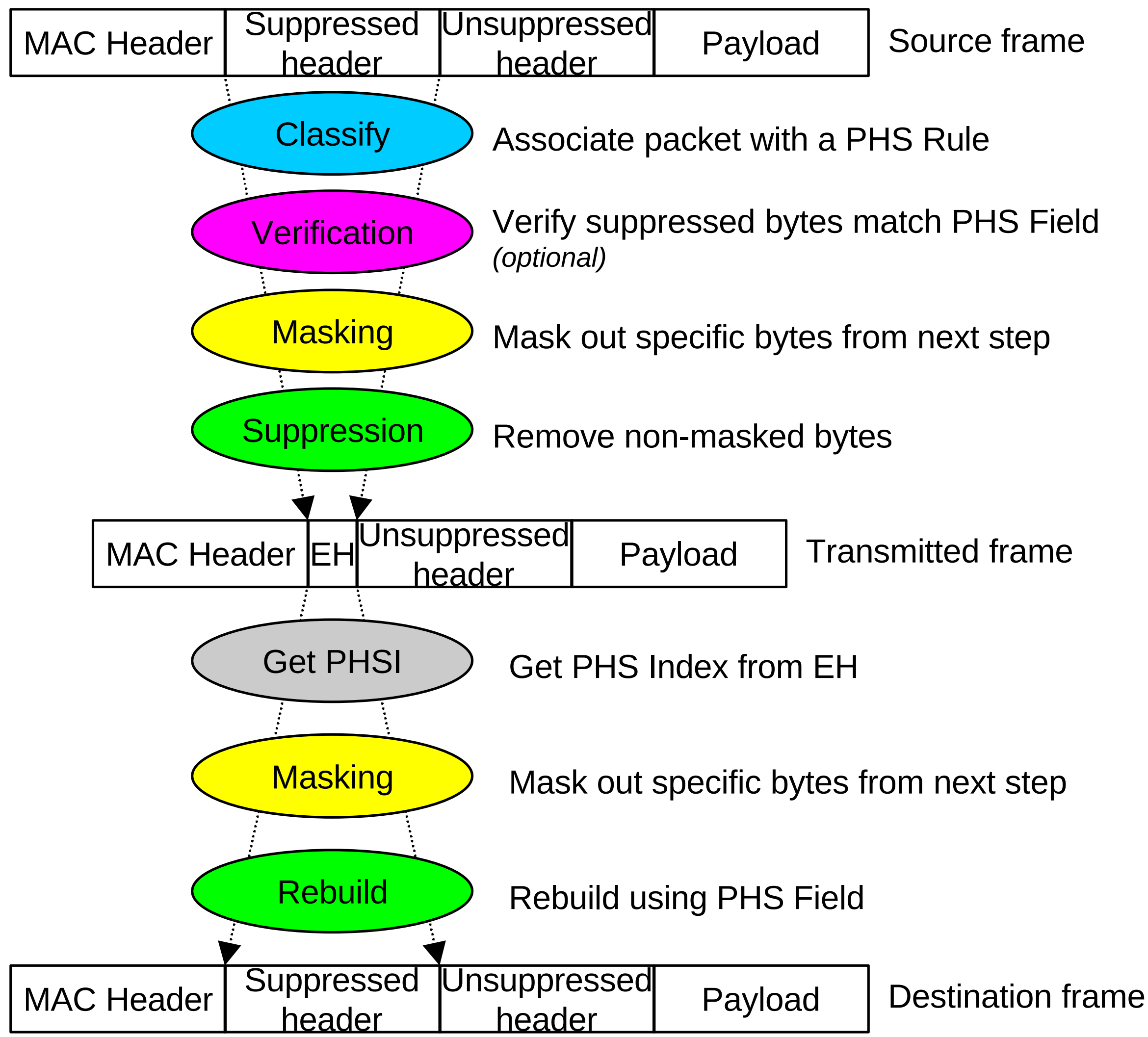
(variable-length PDUs)

DEFINITIONS

PHSI - Index
PHSR - Rule(s)
PHSF - Replacement Field
PHSM - Mask for PHSF
PHSS - Size (length)
PHSV - Verify

Extended Header carries PHSI

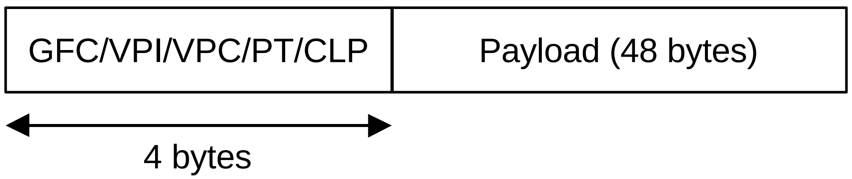




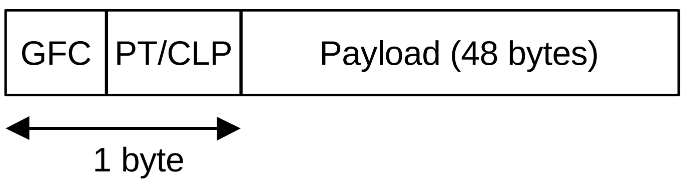
Payload Header Suppression

(ATM)

FC_PARM=00000
Unsuppressed Header (cell length = 52 bytes)



FC_PARM=00001
Suppressed Header (cell length = 49 bytes)



- HEC always suppressed
  - PHY-layer FEC assumed
  - No ATM cell synchronization needed
  - rebuilt at receiving station
- Header Suppression
  - Applies to all cells in a burst
  - Support for single ATM cell bursts
  - VPI/VPC suppressed
  - GFC/PT/CLP fields packed
    - supports Adaptation Layers
  - VPI/VPC rebuilt at receiving station
    - last non-suppressed VPI/VPC used

MAC Operation

Downstream Access

Upstream Access

Allocation Maps and Scheduling Services

Upstream Scheduling Examples

Piggy-back Requests

Fragmentation of Concatenated Frames

Downstream Access

- All traffic broadcast to all SS in a MAC Domain
- SS must examine downstream for its address
  - Ethernet/802.3 MAC address used to identify destination SS
  - ATM VPI/VPC fields used when transporting ATM Cells
  - FSID used to support addressing of fragmented MAC payloads
- QoS is controlled by scheduling algorithms in the BS
  - BS directly controls the downstream
  - BS meets all QoS requirements via scheduling

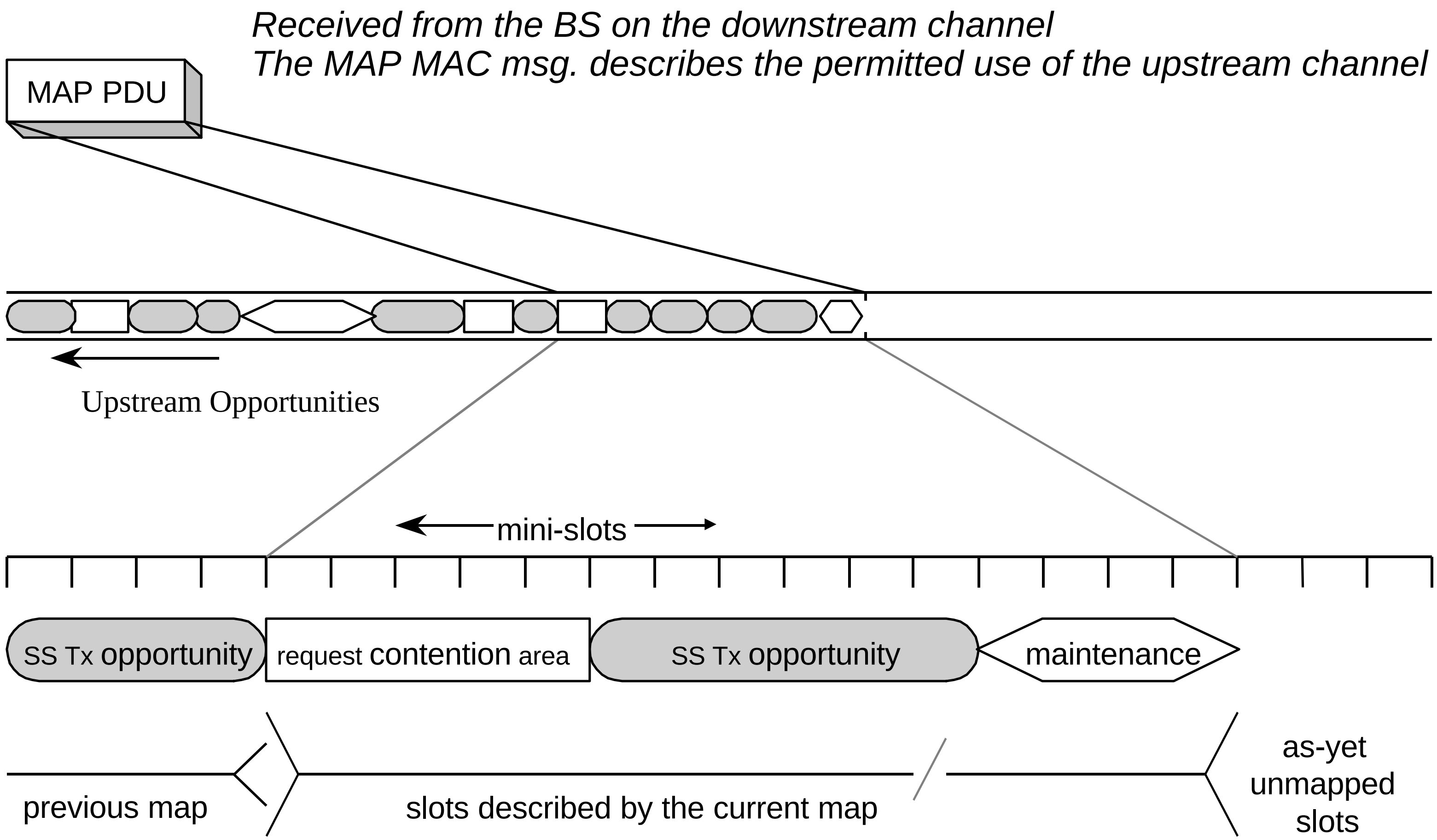
Upstream Access

- Timing based on mini-slots
  - Length independent of modulation symbol rate
  - Timing relative to downstream SYNC MAC message
- Burst size in units of mini-slots
  - Typical mini-slot size: 8, 16, or 32 bytes
  - Multiple mini-slots assigned to a station for a burst
    - Burst includes PHY layer overhead
- MAP messages allocate mini-slots to SS
- Available mini-slot usages:
  - Contention (collision or polled)
  - Unsolicited (reservation-based or polled)
  - Transmission with contention
  - Maintenance (initial and ranging)
- Reservation request in upstream MAC burst

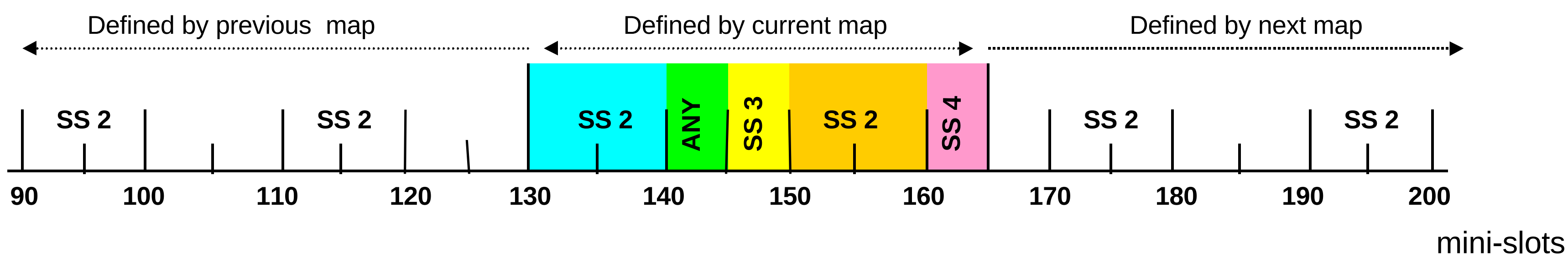
Scheduling Services

- Best Effort (BE)
  - contention request/grant mechanism
  - traditional IP traffic
- Unsolicited Grant (UGS)
  - constant grants allocated to SS without contention
  - CBR traffic
- Unsolicited Grant with Activity Detection
  - switch between UGS and rtPS based on activity
  - VoIP with activity detection
- Real-Time Polling (rtPS)
  - periodic unicast request opportunities
  - VBR traffic
- Non-Real-Time Polling (nrtPS)
  - non-periodic unicast request opportunities

Allocation MAP Example



Unsolicited Grant Service (UGS) Example



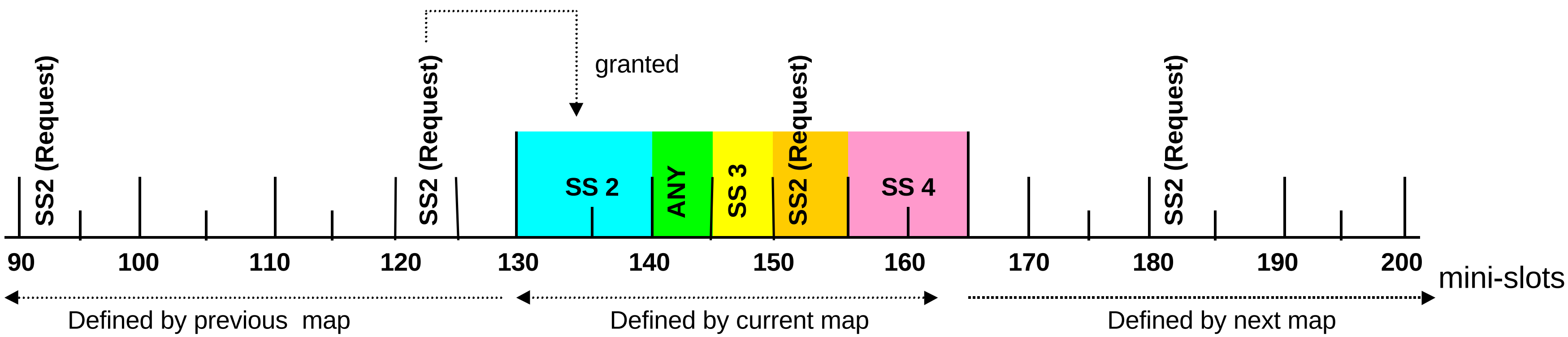
Current Map Message

Mini-slot Start Time = 130		
SID	**IUC**	**Offset**
SS 2	**Data Grant**	**0**
Any	**Request**	**10**
SS 3	**Data Grant**	**15**
SS 2	**Data Grant**	**20**
SS 4	**Data Grant**	**30**
0	**Null**	**35**

Using SS #2 as an example:

- Grant Interval every 20th mini-slot
- Grant Size is 10 mini-slots
- Interval Usage Code (IUC) is unicast for SS #2 only
- IUC is for a data grant
  - Upstream data transmission
  - Independent of user PDU content
  - Piggy-back and contention requests not allowed

Real-Time Polling (rtPS) Example



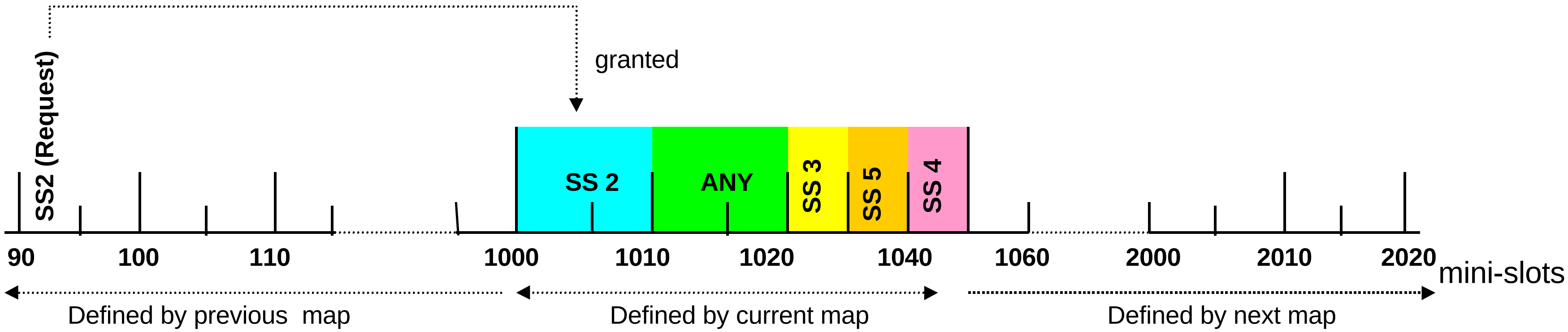
Current Map Message

Mini-slot Start Time = 130		
SID	**IUC**	**Offset**
SS 2	**Data Grant**	**0**
ANY	**Request**	**10**
SS 3	**Data Grant**	**15**
SS 2	**Request**	**20**
SS 4	**Data Grant**	**25**
0	**Null**	**35**

Using SS #2 as an example:

- Polling Interval every 30th mini-slots
  - Fixed duration
  - Short interval since unicast (5 mini-slots)
- IUC is unicast for SS #2 only
- Polled IUC specifies a *request message only*
  - upstream transmission granted separately
    - Data Grant based upon Polled Request
    - Grant size varies based upon Request
  - independent of user content

Non-Real-Time Polling (nrtPS) Example



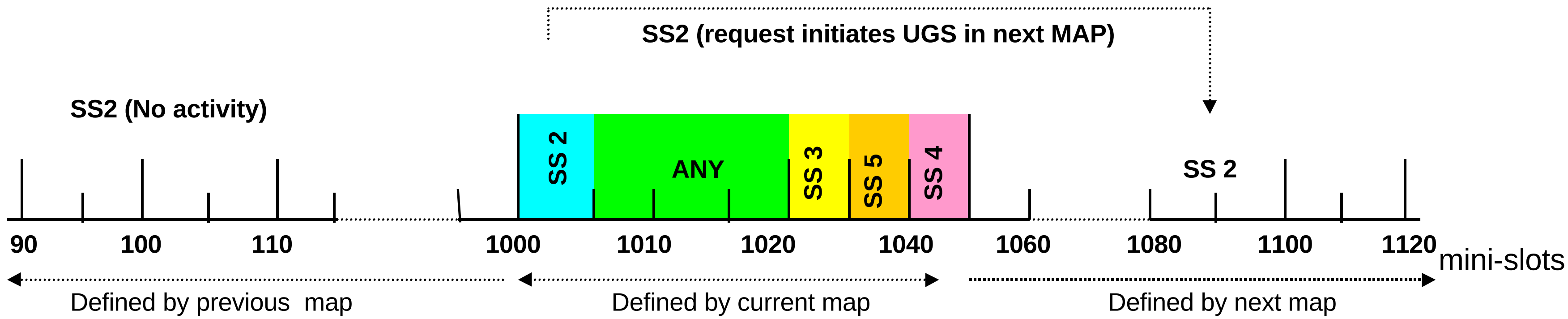
Current Map Message

Mini-slot Start Time = 1000		
SID	**IUC**	**Offset**
SS 2	**Data Grant**	**0**
ANY	**Request**	**10**
SS 3	**Data Grant**	**20**
SS 5	**Data Grant**	**25**
SS 4	**Data Grant**	**30**
0	**Null**	**35**

<u>Using SS #2 as an example:</u>

- Very similar to real-time Polling service
- Minimum instead of nominal polling interval
  - typically less than one second
  - Short interval since unicast (5 mini-slots)
- SS can also use contention intervals to gain upstream access

UGS with Activity Detection Example



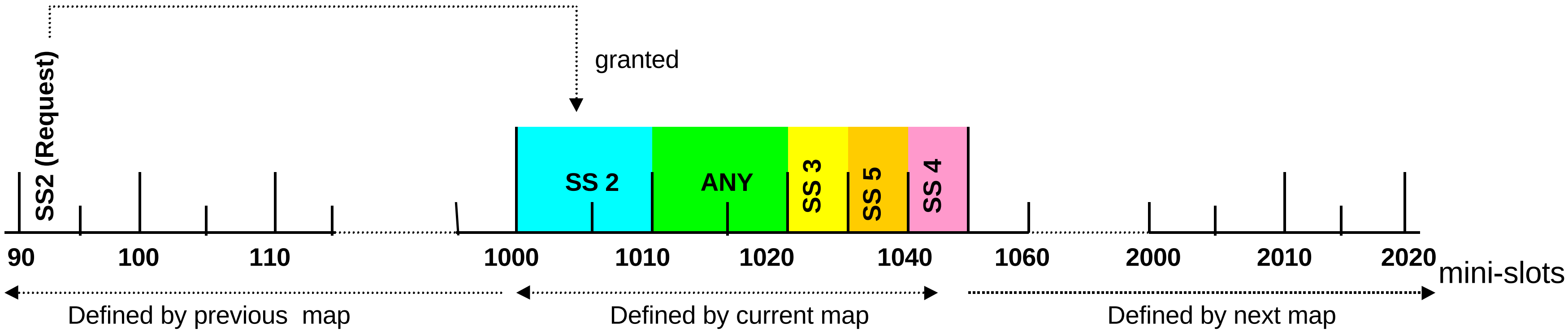
Current Map Message

Mini-slot Start Time = 1000		
SID	**IUC**	**Offset**
SS 2	**Request**	**0**
ANY	**Request**	**5**
SS 3	**Data Grant**	**20**
SS 5	**Data Grant**	**25**
SS 4	**Data Grant**	**30**
0	**Null**	**35**

<u>Using SS #2 as an example:</u>

- SS2 inactivity detected by BS
  - no use of unsolicited grants
- BS provides unicast request opportunities toSS2
  - Unsolicited grants are stopped
- SS2 becomes active by requesting an upstream grant
- BS reverts to UGS upon seeing the request

Best Effort (BE) Service Example

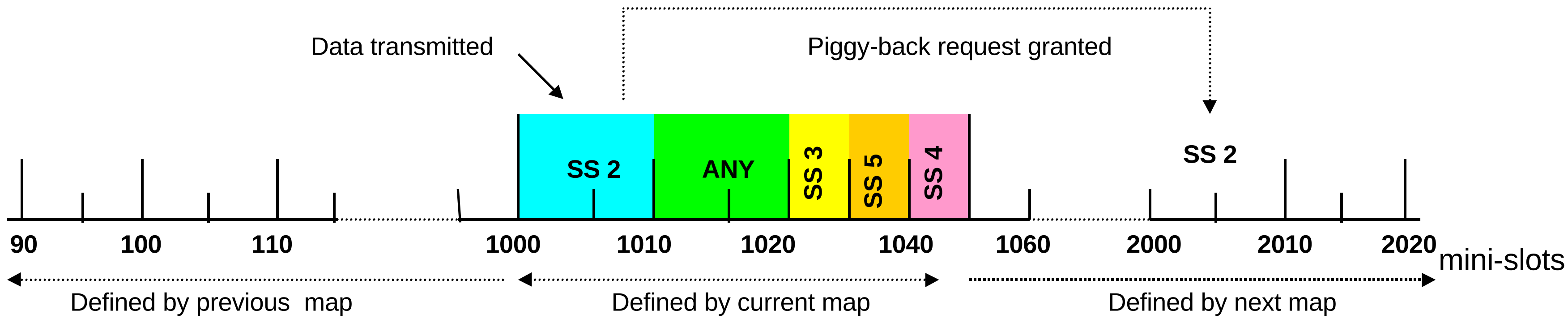


Current Map Message

Mini-slot Start Time = 1000		
SID	**IUC**	**Offset**
SS 2	**Data Grant**	**0**
ANY	**Request**	**10**
SS 3	**Data Grant**	**20**
SS 5	**Data Grant**	**25**
SS 4	**Data Grant**	**30**
0	**Null**	**35**

- Multiple SS use contention interval to request grant
  - random starting offset into interval
  - acknowledgement via following map(s)
    - data grant
    - data grant pending
  - contention resolved using truncated binary exponential back-off to pick next request slot
- 2 maps required per upstream data transmission

Piggy-back Requests

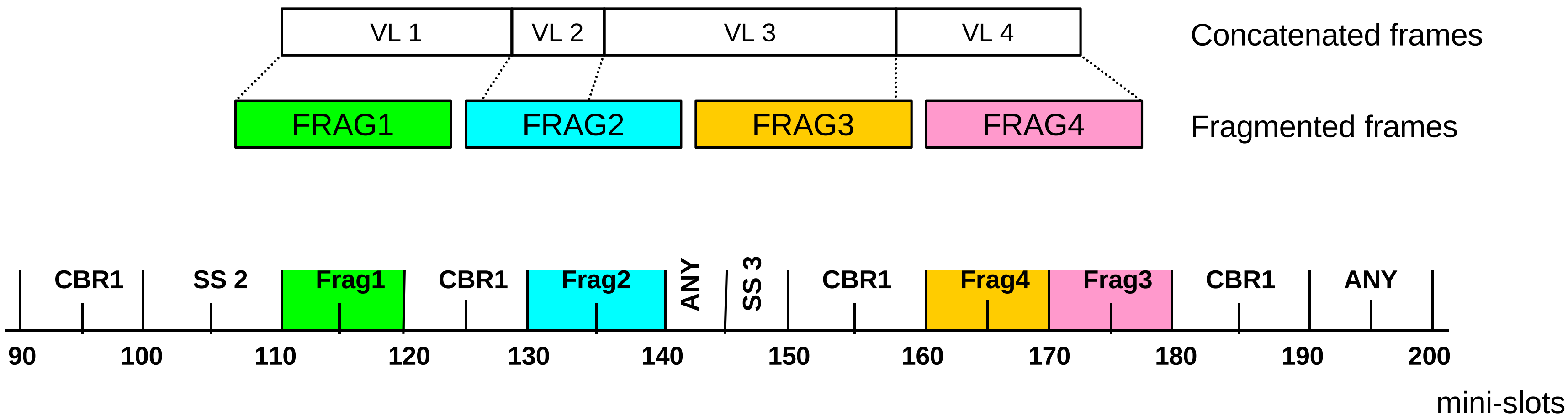


Current Map Message

Mini-slot Start Time = 1000		
SID	**IUC**	**Offset**
SS 2	**Data Grant**	**0**
ANY	**Request**	**10**
SS 3	**Data Grant**	**20**
SS 5	**Data Grant**	**25**
SS 4	**Data Grant**	**30**
0	**Null**	**35**

- Used to request additional bandwidth
  - request occurs in extended header of MAC PDU
  - Not subject to contention
- Can be used to eliminate the “2 Map” handshake if data is ready to be transmitted by the SS

Fragmenting Concatenated Messages



- Divides a stream of variable-length messages into a set of fixed-sized packets to simplify the scheduling based on QoS requirements
  - concatenate variable-length frames
  - fragment them into packet lengths that are easier to schedule
  - interleave the fragments with the USG and rtPS services
    - does not introduce latency or jitter into the USG or rtPS services
    - excellent technique for scheduling Best Effort services

Quality of Service (QoS)

Basic Features

Service Flow Object Model

Classifiers

QoS Parameters

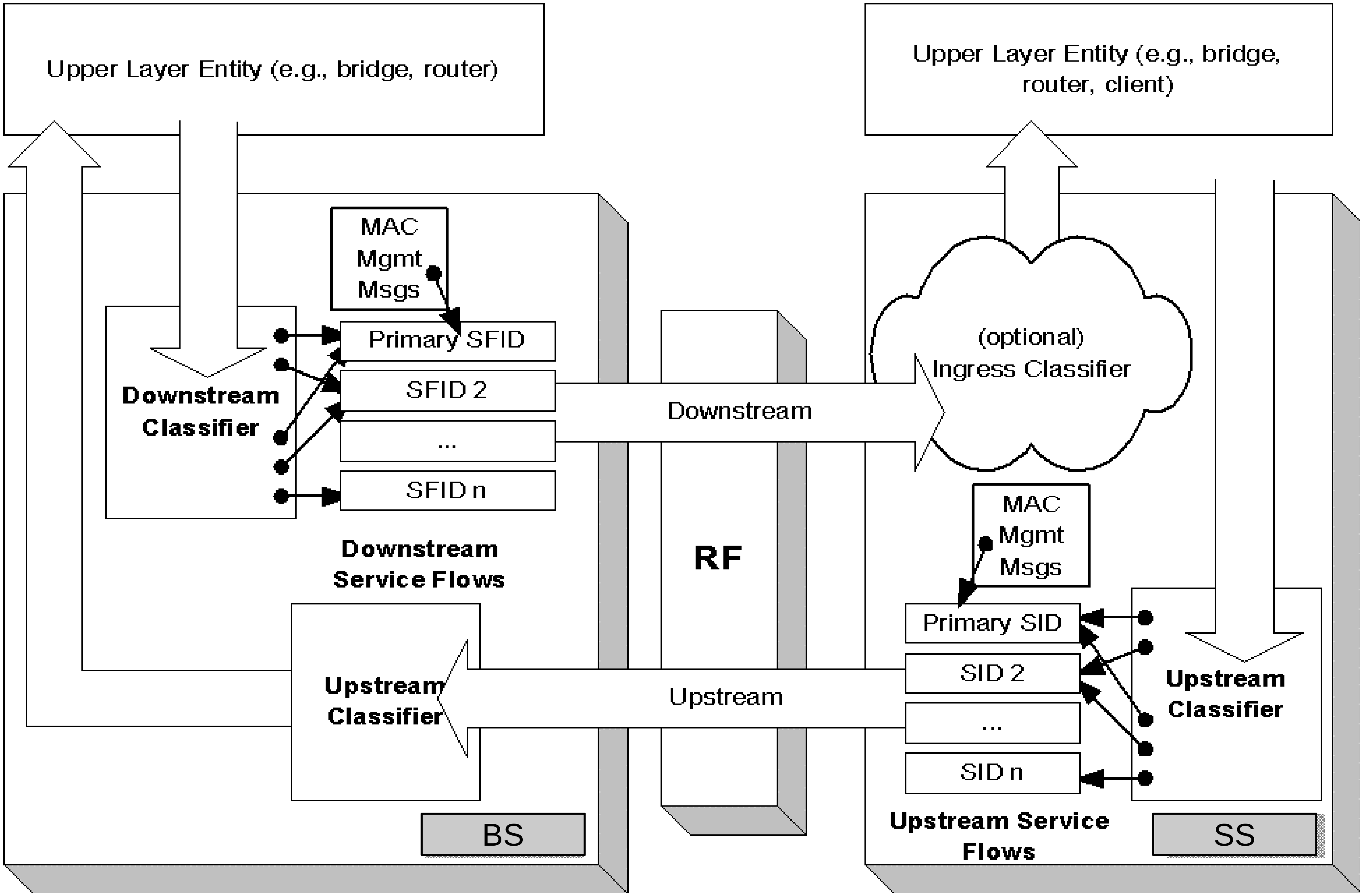
ATM QoS Mappings

Latency and Jitter

Basic QoS Features

- Every connection is defined as a Service Flow
  - Can be statically provisioned
  - Can also be created, modified, and deleted dynamically
- Service Flow
  - Unidirectional - upstream and downstream defined separately
  - Shapes, polices, and prioritizes traffic based upon QoS parameters
  - Assigned QoS characteristics
    - Upstream Scheduling Service
    - QoS Parameters: max bandwidth, priority, nominal grant interval, etc.
    - Supporting capability use:
      - fragmentation
      - payload header suppression
      - concatenation
      - piggy-back requests
- Scheduling algorithms not defined by MAC protocol

Service Flow Object Model



Classifiers

- Classifiers are used to assign data to the appropriate Service Flow
  - Applied at both the upstream and downstream ingress points
  - Allows multiple Subscriber flows through a SS to use different QoS levels
  - No requirement that the classification process be implemented in a specific manner
- Classifications can be based upon content from different protocol layers
  - Layer 2
    - Protocol types
    - ATM VPI/VPC, 802.3 addresses
  - Layer 3
    - IP classifiers
  - Layer 4
    - TCP/UDP classifiers

QoS Parameters

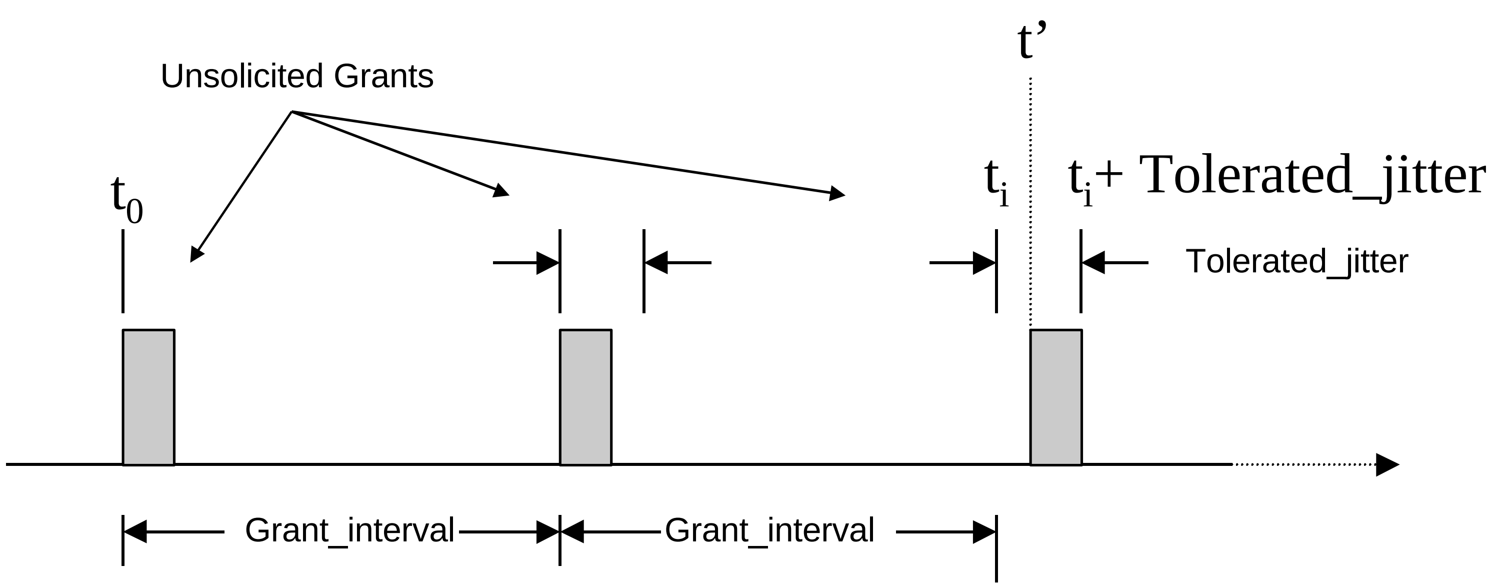
Service Flow Parameter	Unsolicited Grant	Real-Time Polling	Unsolicited Grant w/Activity Detection	Non-Real-Time Polling	Best Effort
Traffic Priority	N/A	N/A	N/A	Optional	Optional
Maximum Sustained Traffic Rate	Optional	Optional	Optional	Optional	Optional
Maximum Traffic Burst Size	N/A	Optional	Optional	Optional	Optional
Minimum Reserved Traffic Rate	N/A	Optional	Optional	Optional	Optional
Unsolicited Grant Size	Mandatory	Optional	Mandatory	N/A	N/A
Assumed Min Reserved Rate Packet Size	Optional	Optional	Optional	Optional	Optional
Maximum Concatenated Burst	N/A	Optional	Optional	Optional	Optional
Nominal Polling Interval	N/A	Mandatory	Optional	Optional	N/A
Tolerated Poll Jitter	N/A	Optional	Optional	N/A	N/A
Nominal Grant Interval	Mandatory	Optional	Mandatory	N/A	N/A
Tolerated Grant Interval	Optional	N/A	Optional	N/A	N/A
Grants per Interval	Mandatory	Optional	Mandatory	N/A	N/A

ATM QoS Mapping

ATM Service	BWA MAC Service	BWA MAC QoS Parameters
CBR	Unsolicited Grant	Grant Size Grants per Interval Nominal Grant Interval Tolerated Grant Jitter
rtVBR	real-time Polling	Minimum Reserved Traffic Rate Maximum Sustained Traffic Rate Maximum Traffic Burst Nominal Polling Interval Tolerated Polling Jitter
nrtVBR	Non real-time Polling	Minimum Reserved Traffic Rate Maximum Sustained Traffic Rate Maximum Traffic Burst Nominal Polling Interval
GFR	Best Effort	Minimum Reserved Traffic Rate
ABR	Best Effort	Minimum Reserved Traffic Rate Maximum Sustained Traffic Rate Maximum Traffic Burst
UBR	Best Effort	

Jitter

- For USG, each grant must start within the tolerated jitter parameter
  - Measured from start of the grant interval
- Ideal interval start given by: $t_i = t_0 + i * \text{Grant\_Interval}$
- Actual interval start, t' must meet: $t_i <= t' <= t_i + \text{Tolerated\_jitter}$
- Timing resolution in uS; accuracy to BS master clock



Latency

- Unsolicited Grant Service
  - latency is bounded by continuous allocation of upstream grants
  - inefficient if grants not used
  - when combined with Activity Detection, gives best of UGS and polling
- Polling Service(s)
  - introduces latency but is more efficient for bursty traffic
  - requests are short relative to unsolicited data grants
    - real-time requests provided at a nominal interval in rt-PS
  - only allocates grants when necessary
- Best Effort
  - variable latency
  - no guarantee on delay
    - caused by contention for requests

Network Access

Network Entry Sequence Diagram

Initial Ranging & Synchronization

Network Access and Authentication

Periodic Ranging

Security

Network Entry Sequence Diagram

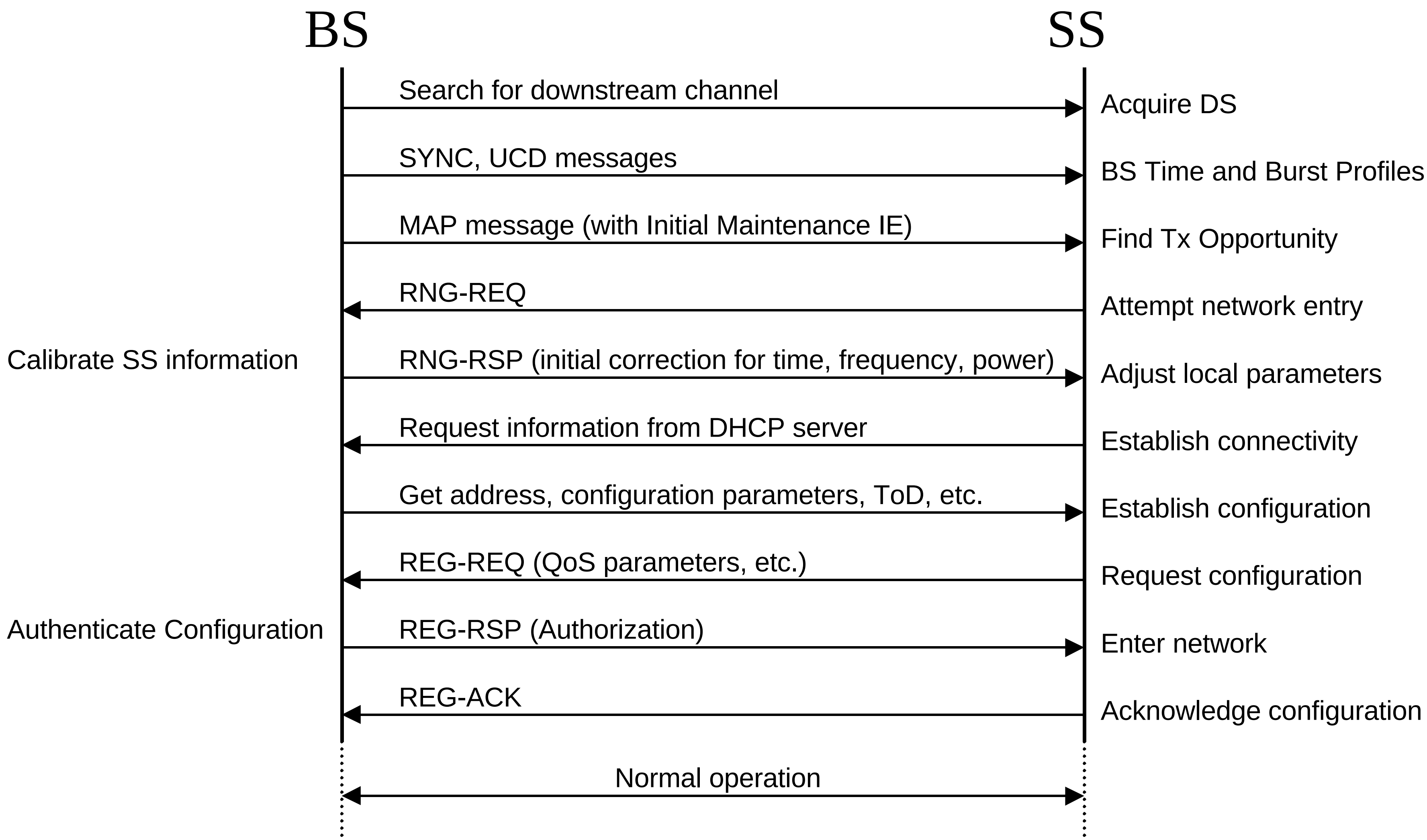


Diagram does not show exception conditions

Initial Ranging & Synchronization

- Acquire MAC domain information
  - Search for valid downstream channel
  - Search for SYNC message(s)
    - aligns SS time directly to BS time
  - Search for UCD message(s)
    - determines upstream channel characteristics
  - Search for MAP message(s)
    - defines Initial Maintenance intervals
- SS transmits RNG-REQ message to BS
- BS determines initial corrections for time, frequency, & power
- BS transmits RNG-RSP message for SS

Network Access and Authentication

- Occurs once SS has performed Initial Ranging
- SS obtains requests information from DHCP server
  - SS IP Address
  - Configuration Profile (from TFTP server)
    - contains network access and QoS profile(s)
  - Time Of Day
    - used for time stamping logs and key refresh
    - not related to system time synchronization
- SS downloads new firmware version (optional)
- SS retrieves configuration profile(s)
  - SS generates REG-REQ using these profile(s)
  - BS authenticates the profiles and responds with REG-RSP
  - SS responds with REQ-ACK to acknowledge negotiated configuration
- SS enters network and begins forwarding traffic

Ranging

- Ranging Parameters for Upstream Transmission
  - RF Power
  - Timing
  - Frequency
  - Equalizer coefficients (optional)
- Ranging Types
  - Initial
    - When SS enters the network
  - Maintenance
    - Scheduled at regular intervals
  - Both types have identical functionality
    - Initial ranging must allow for SS transmission without time synchronization
- BS can generate RNG-RSP without a request from a SS
  - used to quickly calibrate a SS

Security

- DOCSIS Baseline Privacy Plus Interface (BPI+)
  - Optional (implementation and use)
  - Optional by Service Flow
- Authentication
  - RSA Private/Public Key
  - Digital X.509 Certificates
- Privacy
  - DES Encryption using Cipher Block Chaining mode
  - Only user payload is encrypted

Conclusions

Benefits

Benefits

- Supports BWA system requirements
- Derived from existing standards
- Scales to support high transmission rates
- Available OPNET modeling and field data
- Good independence from PHY layer
- Optional security protocol
- Support for multiple bearer services to each SS
- Efficient usage of bandwidth
- Ability to bound delay and jitter
- Statistical multiplexing gain
- System timing derived solely from BS

Additional Information

Modifications from DOCSIS

Security Message Formats

Modifications From DOCSIS

- Added MAC PDU definitions for ATM
  - Supports single and multiple ATM cell transfer
  - Suppresses header components to achieve more efficiency
- De-coupled mini-slot size from symbol rate
  - Mini-slot size fixed to small number of bytes regardless of symbol rate
  - SYNC message carries Upstream ID to identify clock
  - Allows use of higher symbol rates
- Added downstream fragmentation
  - Same format as upstream fragmentation
  - Uses LEN field of EH Header to distinguish from encryption only
  - New Fragmentation SID (FSID) defined to support re-assembly
- Added additional data grant Interval Usage Codes
  - Now have 4 IUCs; each can have different burst characteristics
  - Supports FEC specifically for ATM cells

Security Message Formats

- Example of format for unfragmented, variable-length PDU