IEEE 802.16e MAC

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Mar. 22, 2006

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Introduction

IEEE 802.16 Overview

- IEEE 802.16 (BWA)
  - A standard that defines a Wireless network on a Metropolitan Area (WirelessMAN)
  - Specifies the PHY and MAC of the air interface
  - Providing wireless broadband connectivity to fixed and nomadic users
  - Licensed/Unlicensed bands (10-66 GHz, 2-11 GHz)
  - QoS support
  - MAC supports multiple PHY specification
    → SC, SCa, OFDM, OFDMA
- IEEE 802.16e
  - Extension to IEEE 802.16-2004 MAC & PHY
    → Backward compatibility
  - Adding mobility and increasing data speeds
  - Licensed bands (2-6 GHz)
  - MAC supports multiple PHY specification
    → SCa, OFDM, OFDMA
  - Adding mobility related functionalities
    → Handover, Power saving

WiBro Overview

- Standardization
  - TTA Project Group 302 (TTA TG302)
  - 16e was adopted as the baseline document for WiBro (Wireless Broadband) standard in Jan. 2004
- Harmonization with IEEE 802.16e (mobile broadband MAN) was made
  - Support all mandatory features of IEEE 802.16e
- 2.3 GHz licensed bands
- OFDMA/TDD PHY

WiBro System Parameters

Parameter	Value
System Bandwidth	10 MHz
Number of used tones	864 out of 1,024
Number of data tones	768
Number of pilot tones	96
Tone spacing	9.765625 kHz
Ratio of cyclic prefix time to the basic OFDM symbol time	1/8
Basic OFDMA symbol time	102.4 μs
Cyclic prefix time	12.8 μs
OFDMA symbol time	115.2 μs
TDD frame length	5 ms
Number of symbols in a frame	42
TTG+RTG	161.6 μs

MAC Features

MAC Features

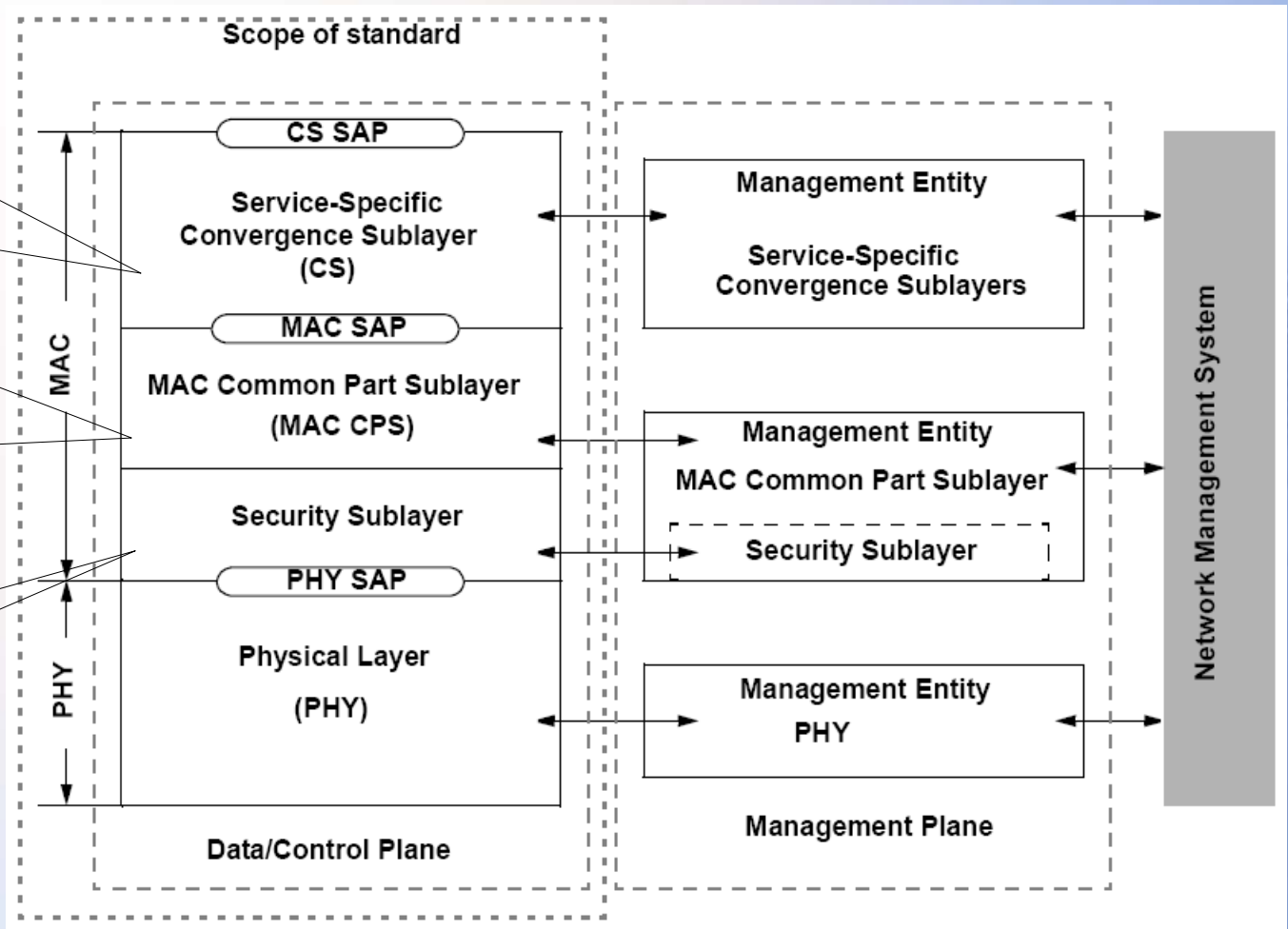
- Flexible BW Allocation by MAP
- Message Based MAC Signaling
- Dedicated Feedback Channel
- Various BW Request Mechanism
- Payload Header Suppression Support
- Security Support
- Sleep Mode Support
- HARQ/ARQ Support
- Handoff Support
- QoS Support
- AMC/Power Control Support

MAC Protocol Stack

- Transformation of external network data into MAC SDUs
- Payload header suppression

- System Access
- Bandwidth Allocation
- Connection set -up
- Connection maintenance
- QoS

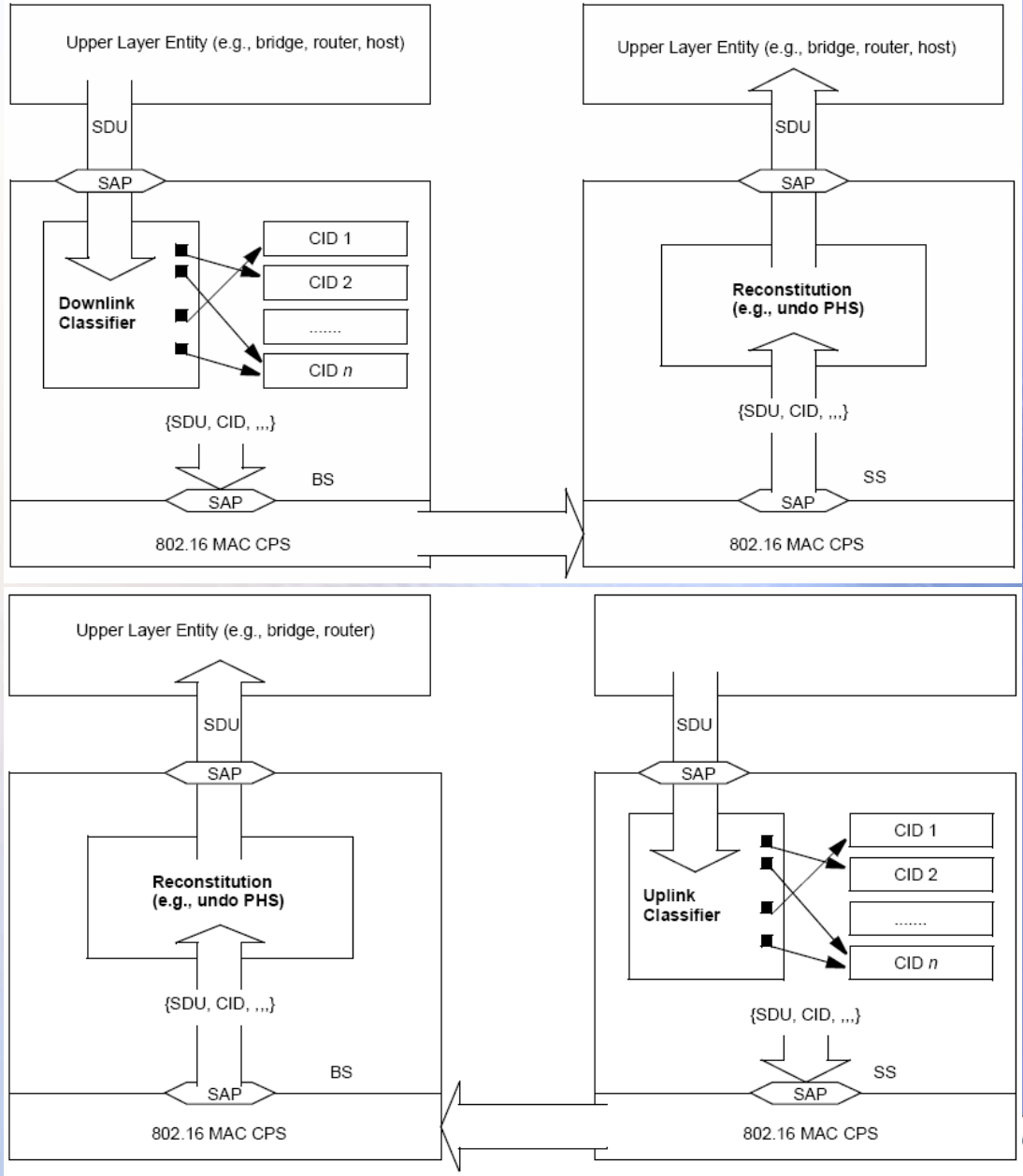
- Authentication
- Secure key exchange
- Encryption



Convergence Sub-layer (CS)

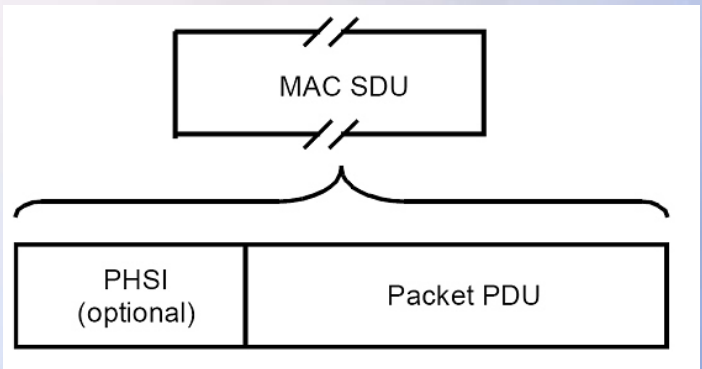
Convergence Sub-layer

- Tx
  - IP Packet from Network
  - Packet Classification
    - IP Address
    - Port No.
    - Protocol
    - Service Type
  - Header Suppression
  - CS PDU to MAC CPS
- Rx
  - CS PDU from MAC CPS
  - Header Reconstruction
  - IP Packet to Network

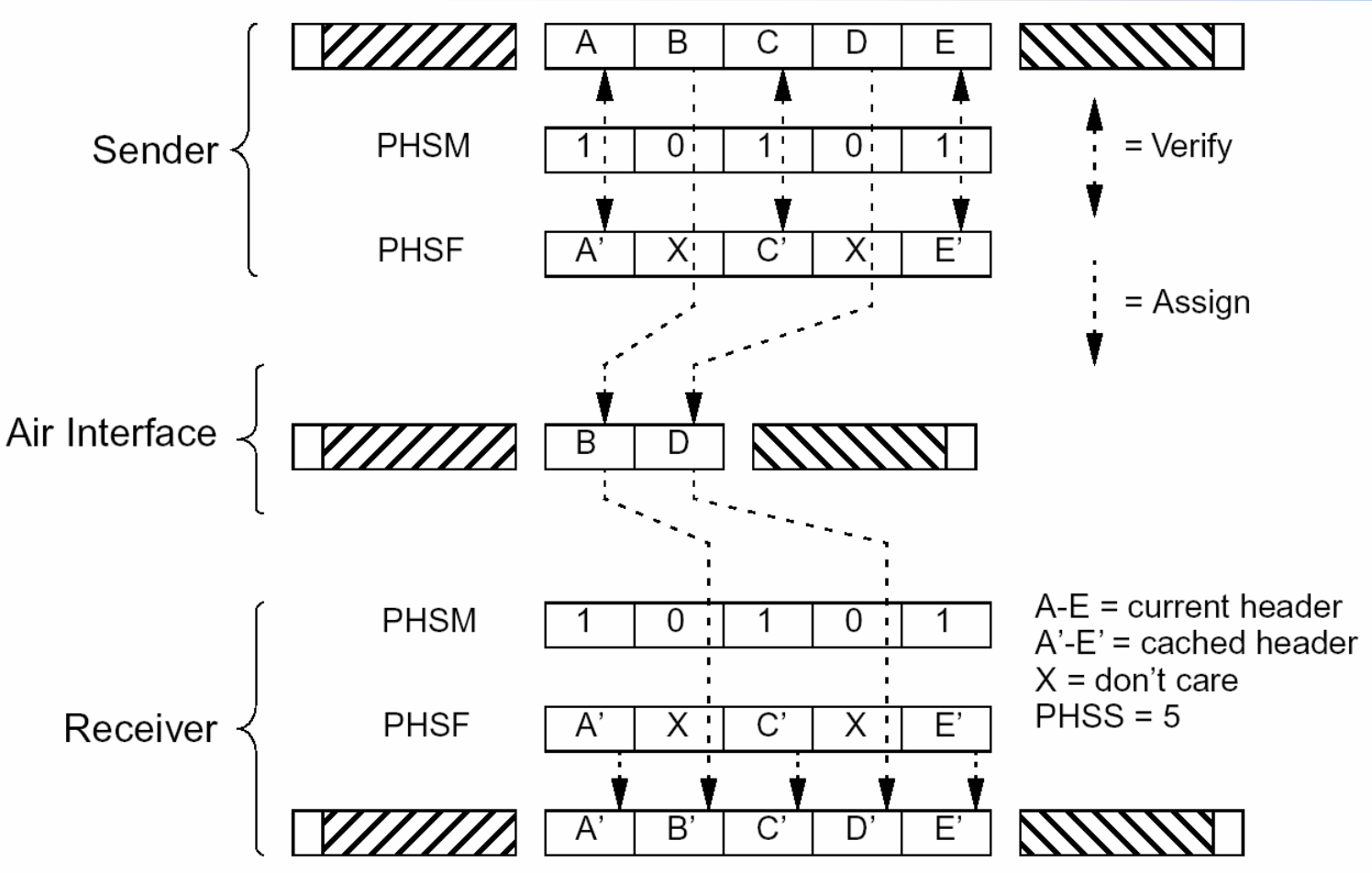


Packet Header Suppression

- Packet Header Suppression (PHS)
  - A repetitive portion of the payload headers of the higher layer is suppressed
  - PHSF (field): The header content which is suppressed
  - PHSI: After PHS, MSDU is prefixed with PHSI
  - PHSM: Select bytes not to be suppressed
    - The bytes in the higher-layer headers are suppressed except the bytes marked by PHSM
  - PHSV can be set (verification)
  - Receiver recover suppressed header (PHSF) using CID and PHSI



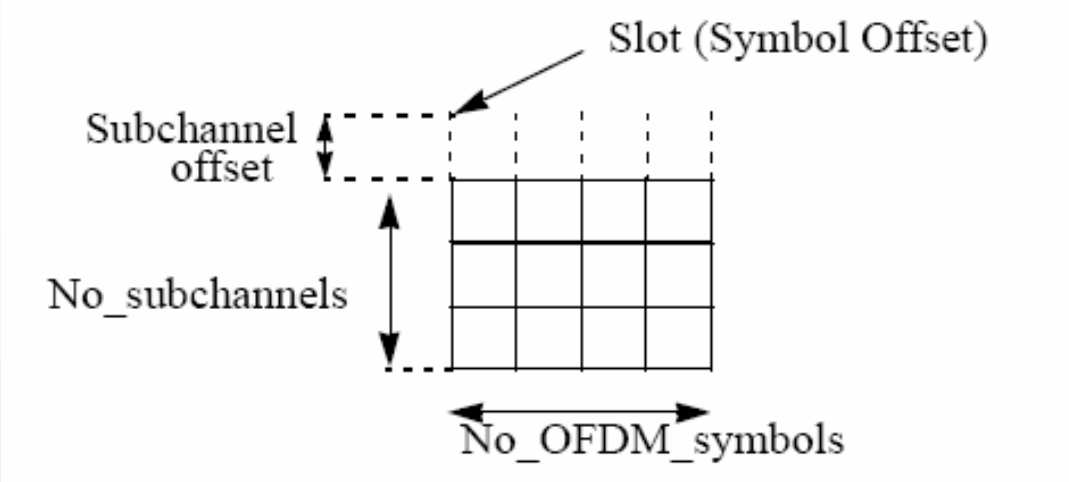
PHS with masking



Frame Structure

OFDMA basic terms definition

- Slot
  - A time (symbol) and subchannel dimension
  - The minimum possible data allocation unit
- Data Region
  - A two-dimensional allocation of a group of (logically) contiguous subchannels, in a group of contiguous OFDMA symbols.

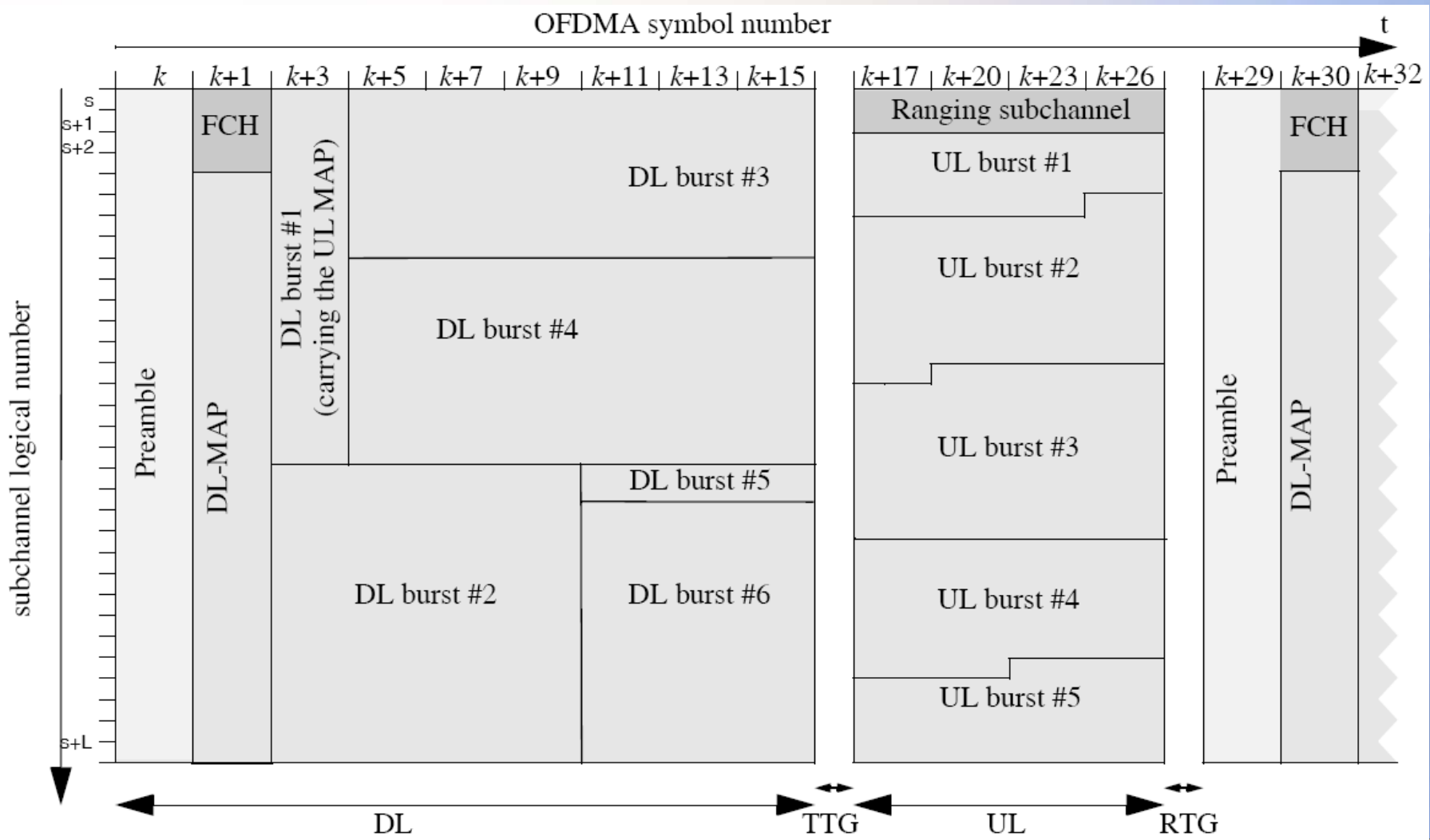


Frame Structure

- Preamble
  - First symbol of the downlink transmission
  - Specify cell ID (0 – 31)
  - Specify segment number (0 – 2)
  - Frame synchronization
  - Frequency offset estimation
- Frame Control Header (FCH)
  - First two transmitted subchannels
  - QPSK rate ½ with four repetitions
  - Contains DL_Frame_Prefix
    - Subchannel bitmap
    - DL-Map coding, repetition and length
- DL/UL-MAP
  - Information on burst allocation
  - PHY control message IEs (IE: Information Element)
- DL/UL burst
  - Data and control message

Frame Structure

- OFDMA-TDD (with only mandatory zone)



Identifier

Identifier

- 48 bit MAC Address
  - Universal MAC address
  - Used during initial ranging and as a part of authentication process
- 16 bit Connection Identifier (CID)
  - Unique only in one BS
    - That is, there can be 2^16 connections in a cell
    - One SS maintains up to three management CIDs and multiple transport CIDs
  - Three pairs (DL & UL) of management CID
    - Shall be assigned in the RNG-REQ/RSP messages
    - Same CID value is assigned to both DL and UL Established at SS initialization
    - To exchange MAC management messages
    - Inherently three different level QoS for management connection
  - Transport Connection Identifier
    - To exchange MAC data PDU

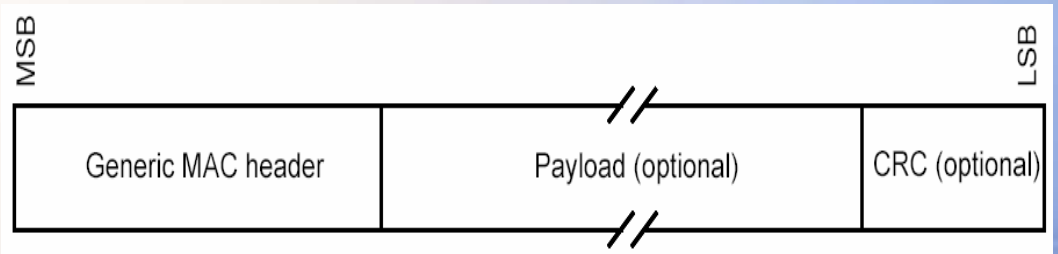
Identifier

- Management Connection
  - Basic CID
    - Short and time-urgent MAC management messages (ARQ, DBPC-REQ/RSP, FPC, MOB_SCN-REQ/RSP, etc.)
  - Primary Management CID
    - Longer, more delay tolerant MAC management messages (DSA-REQ/RSP, DSC-REQ/RSP, etc.)
    - Can be packed and/or fragmented
  - Secondary Management CID
    - Delay tolerant, standard-based management messages (DHCP, TFTP, SNMP, etc.)
    - Carried in the IP datagram
    - Can be packed and/or fragmented
- Transport Connection
  - A multiple number of transport connections
  - At the connection setup, assigned from the serving BS
  - For MAC data PDU transmission

MAC PDU construction

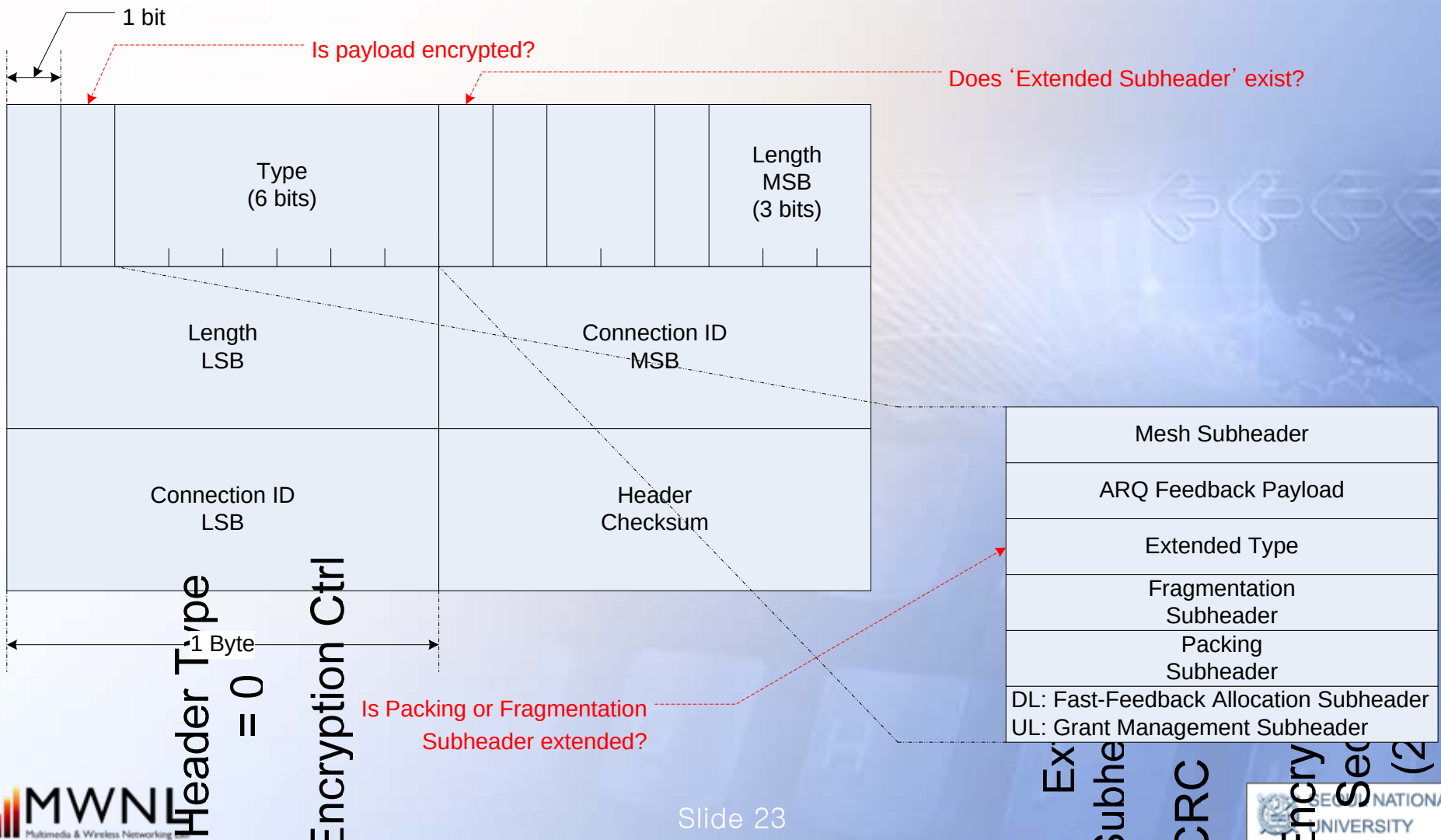
MAC PDU Format

- Generic MAC header
  - 6 bytes long
  - MAC PDU length
  - CID
  - Subheader indicator
  - EKS
  - Encryption indicator
  - CRC Indicator
- Payload (optional)
  - Variable Size
  - Encrypted Portion of MAC PDU
  - MAC message or data
- CRC (optional)
  - 4 bytes long
  - Generic MAC header & ciphered payload



MAC Header

- Generic MAC header

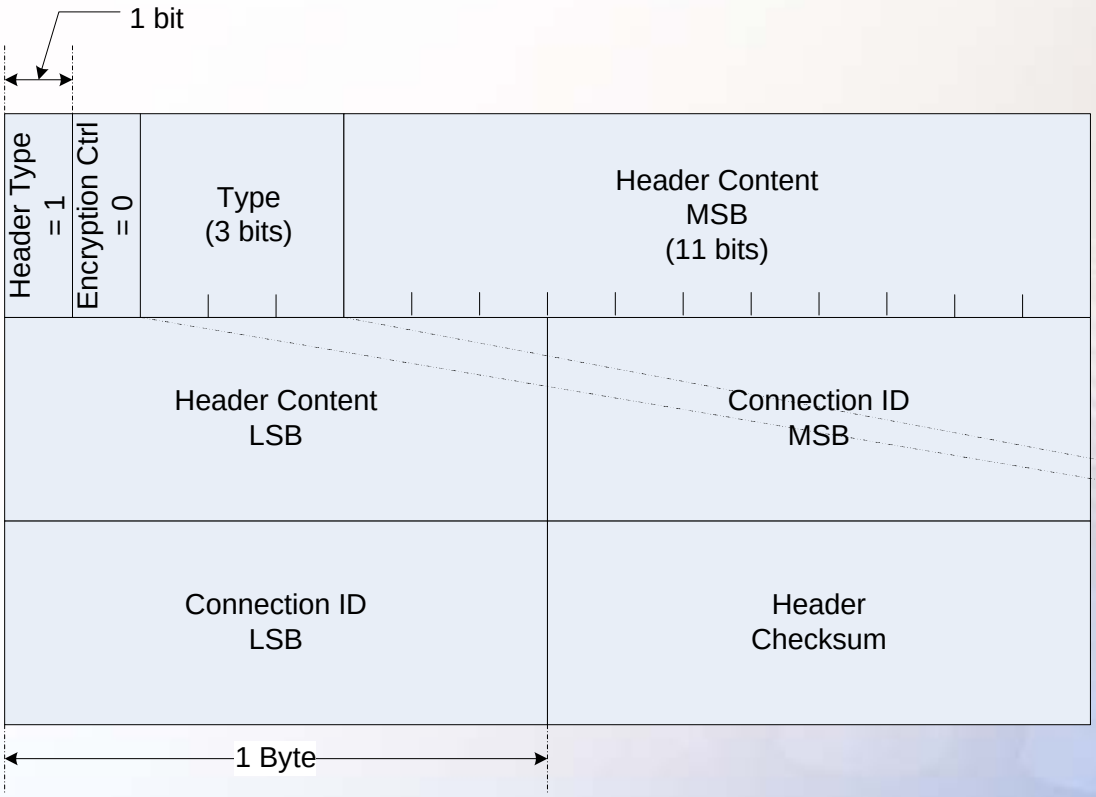


MAC Header

- MAC header without payload
  - Applied to UL only
  - No encryption, no CRC
  - Two types of MAC signaling header
    - Type I & II

MAC Header

- MAC signaling header Type I

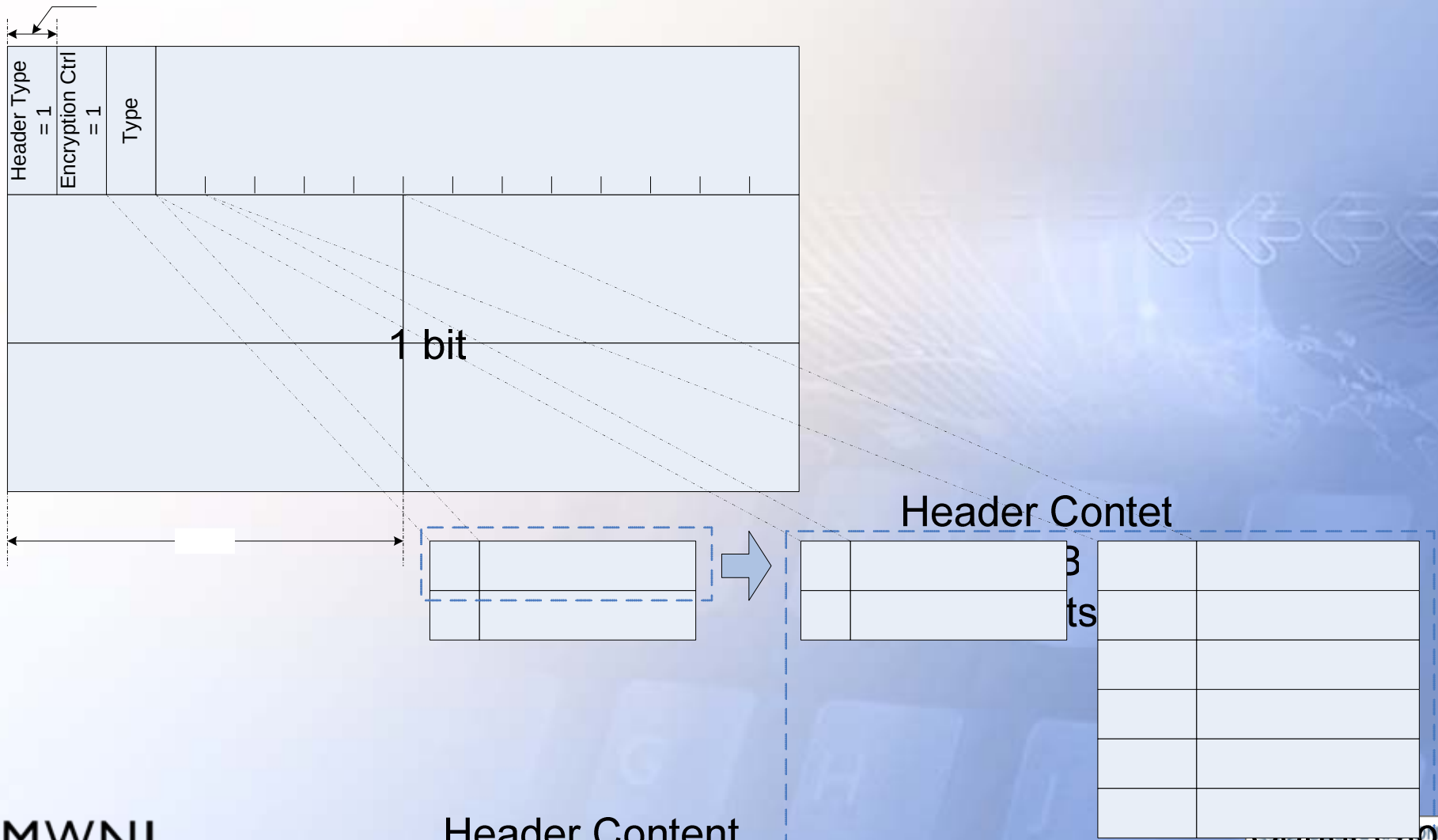


Payload does NOT exist

000	Bandwidth Request Incremental
001	Bandwidth Request Aggregate
010	PHY Channel Report
011	Bandwidth Request with UL Tx Power Report
100	Bandwidth Request and CINR Report
101	Bandwidth Request with UL Sleep Control
110	SN Report
111	CQICH Allocation Request

MAC Header

- MAC signaling header Type II

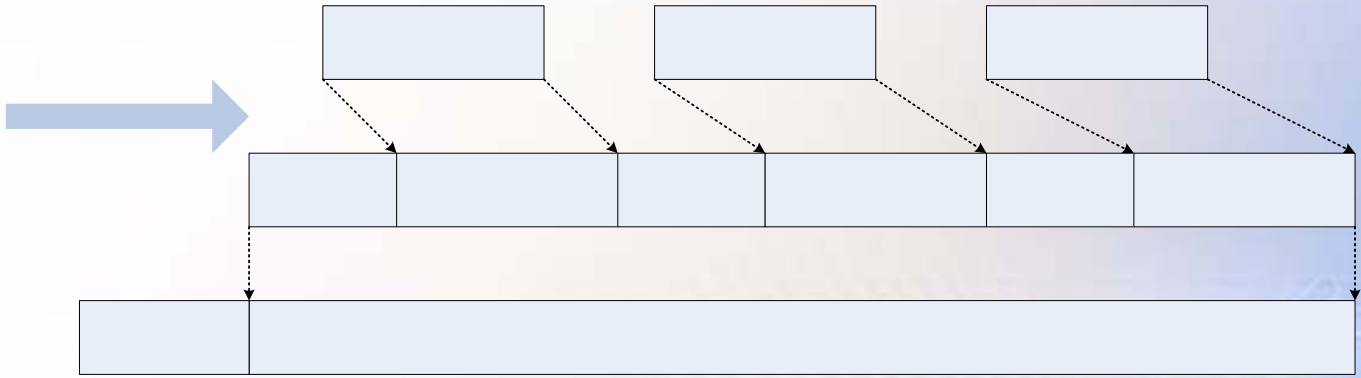


MAC Header

- MAC Subheader
  - Fragmentation subheader
  - Grant Management subheader
  - Packing subheader
  - ARQ Feedback
  - Mesh subheader
  - FAST-FEEDBACK allocation subheader

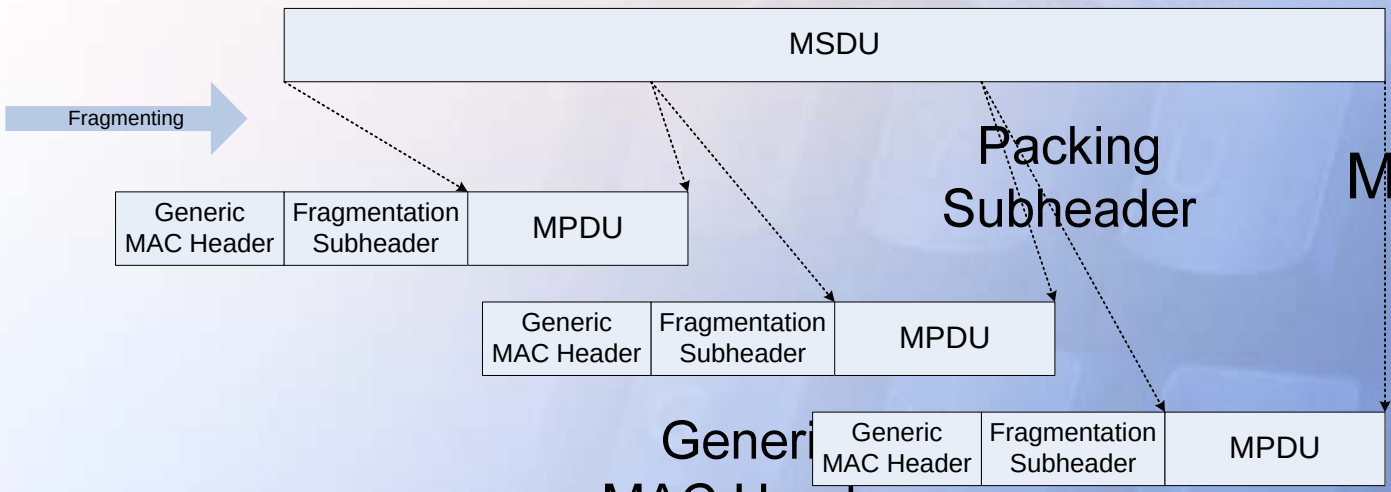
MAC PDU Construction

- Packing



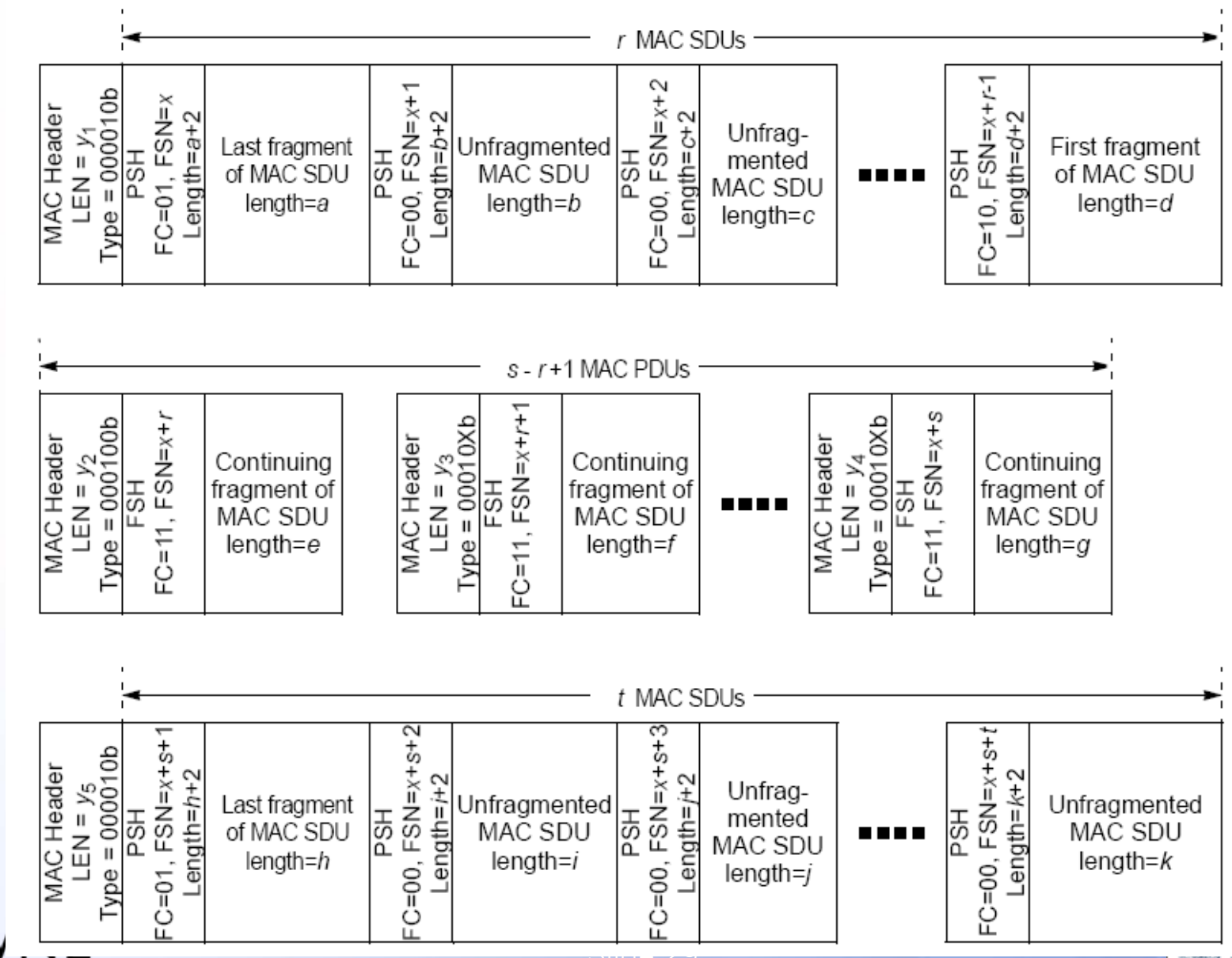
MSDU

- Fragmenting



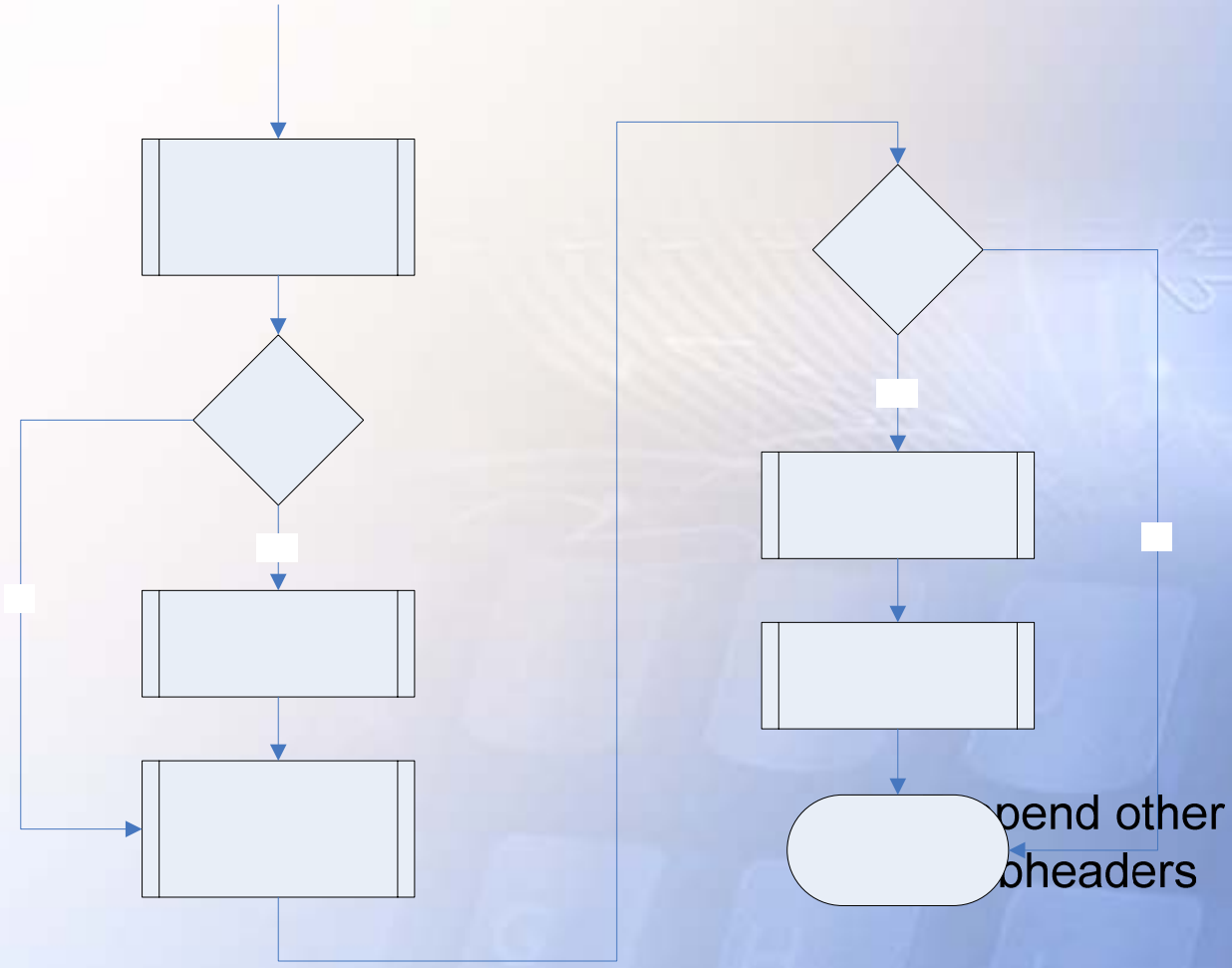
<Fragmenting Description>

Packing with Fragmentation



MAC PDU Construction

- SDL for MPDU construction

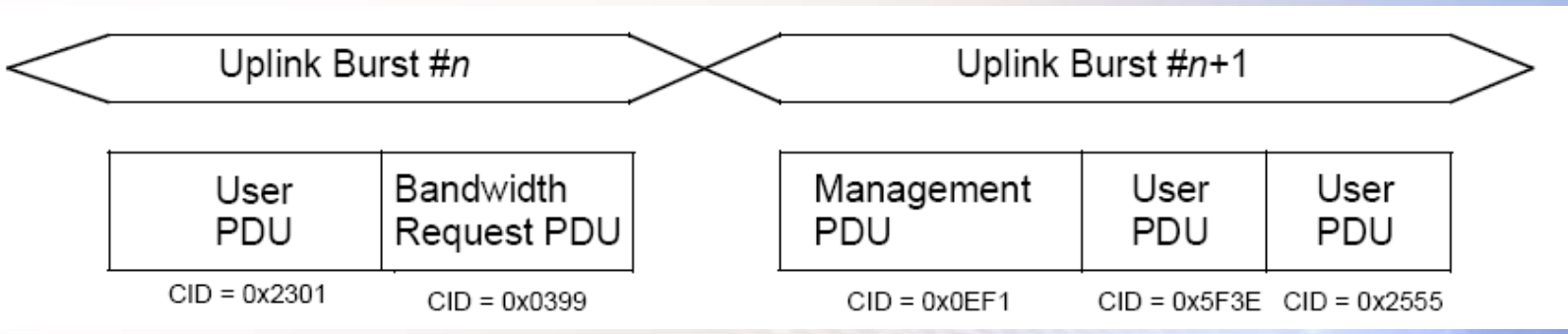


MAC PDU Construction

- CRC
  - Header Type = 0
  - Coverage: Generic MAC header , ‘encrypted’ payload
- Encryption
  - Generic MAC header shall not be encrypted
  - EC, EKS, and CID in Generic MAC header
- Padding
  - Unused data bursts ➔ 0xFF

Concatenation

- Multiple PDUs into a single transmission burst



ARQ support

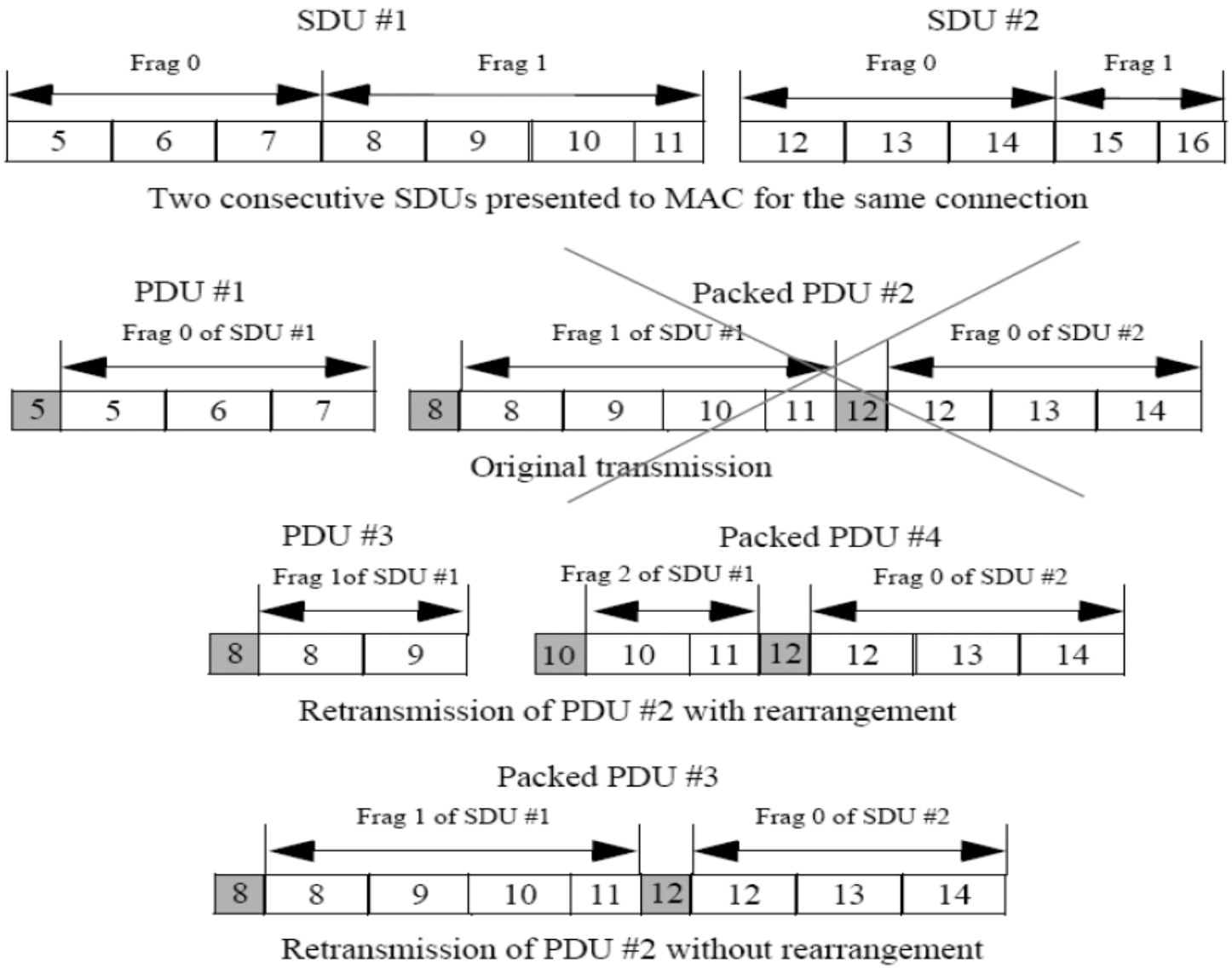
ARQ mechanism

- Optional and unidirectional
- Per-connection basis
- The basic unit of ARQ: Block
  - Each SDU is logically partitioned into blocks
  - Block size : ARQ_BLOCK_SIZE
- Unit of transmission: Fragment
  - Block is the basic unit to make the fragment
  - If fragmentation is not enabled, each fragment shall contain all blocks of parent SDU
- Sequence number for ARQ: BSN (Block Seq. No.)
  - Fragmentation/Packing sub headers contain a BSN
- Fragment can be rearranged when the blocks are retransmitted (flexible)

Type of ARQ

- 4 types of ARQ feedback (ACK)
  - Selective ACK
    - Using 16-bit Selective ACK map
  - Cumulative ACK
  - Cumulative ACK + Selective ACK
    - Cumulative ACK to BSN
    - From the BSN + 1, selective ACK is applied.
  - Cumulative ACK + Block sequence ACK
    - Cumulative ACK to BSN
    - Using 2 or 3-bit Sequence ACK Map
    - From the BSN + 1, block sequence ACK is applied.
    - Similar to the run length coding.
- Flexible Acknowledgement
  - According to the error pattern, any one of these four ACKs can be sent at every ACK time.

Example of ARQ Block Usage



Scheduling Services and Bandwidth Allocation

Scheduling Services

- Uplink Scheduling Services
  - Demand Assigned Multiple Access (DAMA) services based on request and grant
  - Each scheduling service is associated with a set of rules for allocating uplink capacity for the request-grant protocol

- Unsolicited Grant Service (UGS)
  - Periodic, fixed-sized, real-time data stream
  - BS schedules grants of the negotiated size in a preemptive manner
  - This eliminates the overhead and latency of bandwidth request
  - Ex) T1/E1, VoIP without silent suppression
- Real-time Polling Service (rtPS)
  - Periodic, variable-sized, real-time data stream
  - Dynamic in nature, but offers periodic dedicated requests
  - Ex) MPEG video

Scheduling Services

- Non-Real-time Polling Service (nrtPS)
  - Delay-tolerant, variable-sized data stream with minimum data rate requirement
  - These connections may utilize random access transmit opportunities
- Best Effort (BE)
  - Data stream with no minimum service level
  - SS sends requests for bandwidth in either random access slots or dedicated transmission opportunities
- Extended rtPS
  - Taking efficiency of both UGS and rtPS
  - Unicast grants in an unsolicited manner like in UGS
  - UGS allocations are fixed in size, ertPS allocations are dynamic
  - Ex) VoIP WITH silent suppression
  - Newly introduced by 16e

Data Delivery Service

- For mobile network
- 5 delivery services:
  - UGS, RT-VR (Variable Rate), NRT-VR, BE, and ERT-VR
- Using scheduling services:
  - Being supported by UGS, rtPS, nrtPS, BE, and ertPS, respectively

Bandwidth Requests and Grants

- Request
  - Mechanism that informs the SSs' needed uplink bandwidth allocation
  - Bandwidth request is incremental or aggregate
  - SSs shall periodically use aggregate type
  - Method
    - Bandwidth Stealing
      - Using BW request header
    - PiggyBacking
      - Using grant management subheader
      - Piggybacked case can use only incremental type and most requests are incremental for efficiency
    - Polling
      - BS allocates to the SSs the bandwidth for the purpose of making bandwidth requests
      - Polling is done on SS basis, not CID basis

Bandwidth Requests and Grants

- Method (cont'd)
  - Polling
    - Unicast
    - Multicast and Broadcast
  - Using PM (Poll Me) bit (polling)
    - SSs with active UGS connections to be polled to request bandwidth for non-UGS connections
    - The SSs which have UGS connection shall not be polled unless PM bit is set in the packet header
  - Contention-based CDMA Bandwidth request
    - Select code with equal probability among a Ranging codes from the code subset allocated to Bandwidth Request
    - Transmitted during the ranging subchannel
- Grants
  - Bandwidth is always requested on a CID basis and bandwidth is allocated (i.e., granted) on an SS basis.
  - To the SS's Basic CID ~~or multicast or broadcast CID~~.

Bandwidth Requests and Grants

- Usage Rule

Scheduling type	PiggyBack Request	Bandwidth stealing	Polling
UGS	Not allowed	Not allowed	PM bit is used to request a unicast poll for bandwidth needs of non-UGS connections.
rtPS	Allowed	Allowed	Scheduling only allows unicast polling.
nrtPS	Allowed	Allowed	Scheduling may restrict a service flow to unicast polling via the transmission/request policy; otherwise all forms of polling are allowed.
BE	Allowed	Allowed	All forms of polling allowed.

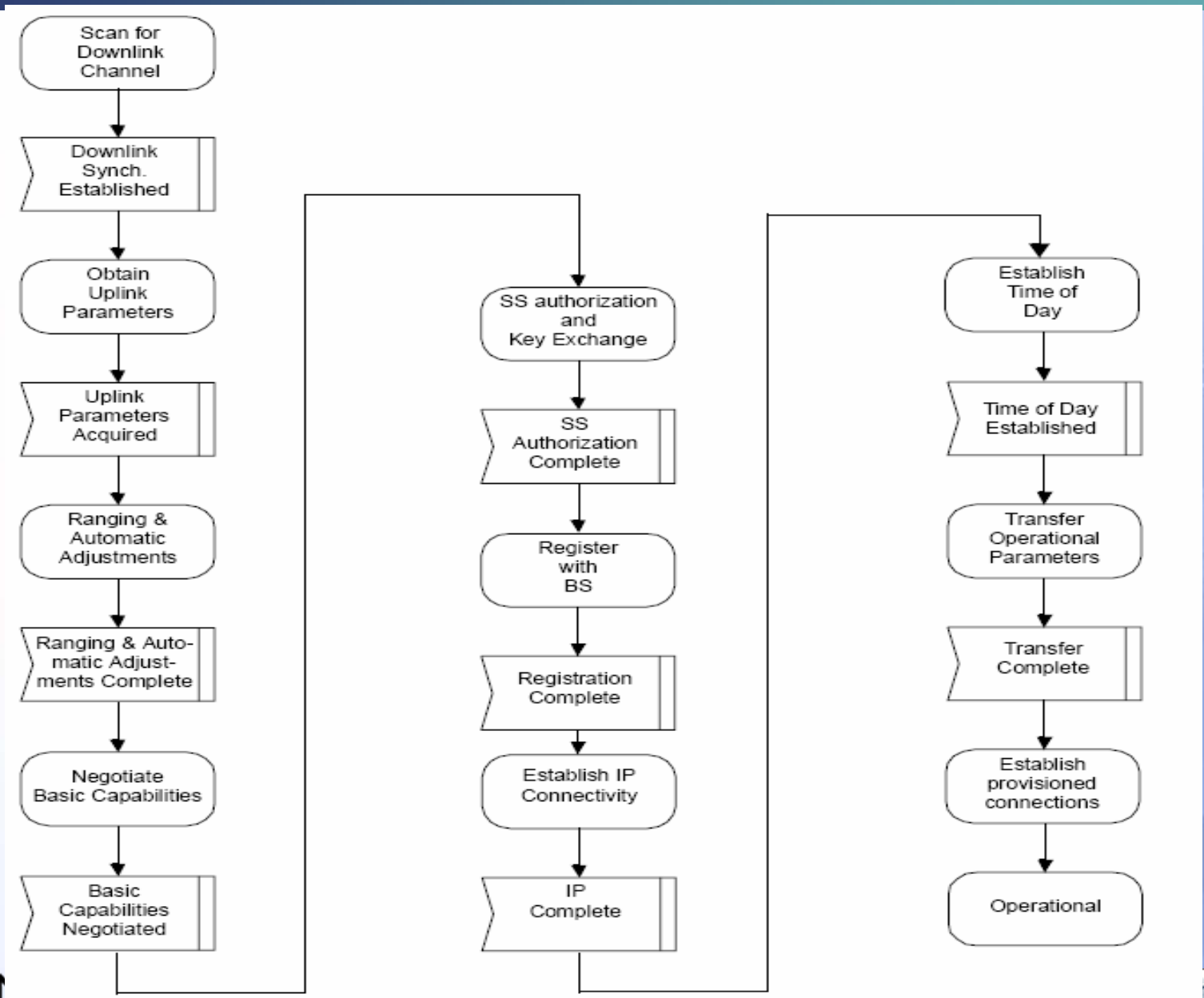
Network Entry and Initialization

SS Initialization

- Initialization process
  1. Scan for DL channel and establish synchronization with the BS
  2. Obtain transmission parameters (from the UCD message)
  3. Perform ranging
  4. Negotiate basic capabilities
  5. Authorize SS and perform key exchange
  6. Perform registration
  7. Establish IP connectivity
  8. Establish time of day
  9. Transfer operation parameters
  10. Set up connections

  Note: Implementation of phases 7, 8, 9 at the SS is optional.

SS Initialization



Ranging

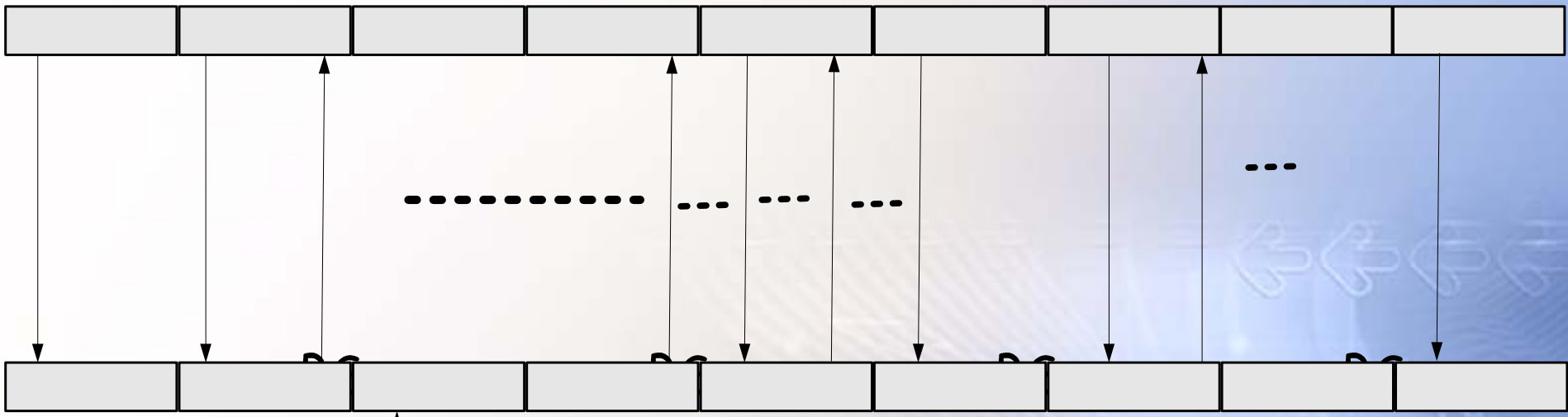
Ranging

- Ranging
  - A collection of processes by which the SS and BS maintain the quality of the RF communication link between them.
  - Distinct processes are used for managing uplink and downlink.
- Downlink burst profile management
  - Burst profile: a set of parameters that describe the transmission properties associated with an interval usage code.
  - The downlink burst profile is determined by the BS based on the feedback from SS.
  - The SS monitors the CINR and compares the average value against the allowed range of operation.
  - The SS has full responsibility to determine its optimal burst profile.

Ranging

- Contention-based initial ranging
  - During SS initialization, allows an SS jointing the network to acquire correct transmission parameters, such as time offset and Tx power level, so that the SS can communicate with the BS.
  - Shall begin by sending initial-ranging CDMA codes (in case of OFDMA PHY)
  - Such that the SS's transmissions are aligned with the BS receive frame for OFDMA PHY, and received within the appropriate reception thresholds.
- Uplink periodic ranging
  - Following initial ranging, periodic ranging allows the SS to adjust transmission parameters so that the SS can maintain uplink communications with the BS
  - Also contention-based in case of OFDMA
  - There could be unsolicited RNG-RSP so that CDMA code tx can be delayed accordingly

Initial Ranging Procedures



DCD/UCD/
DL-MAP

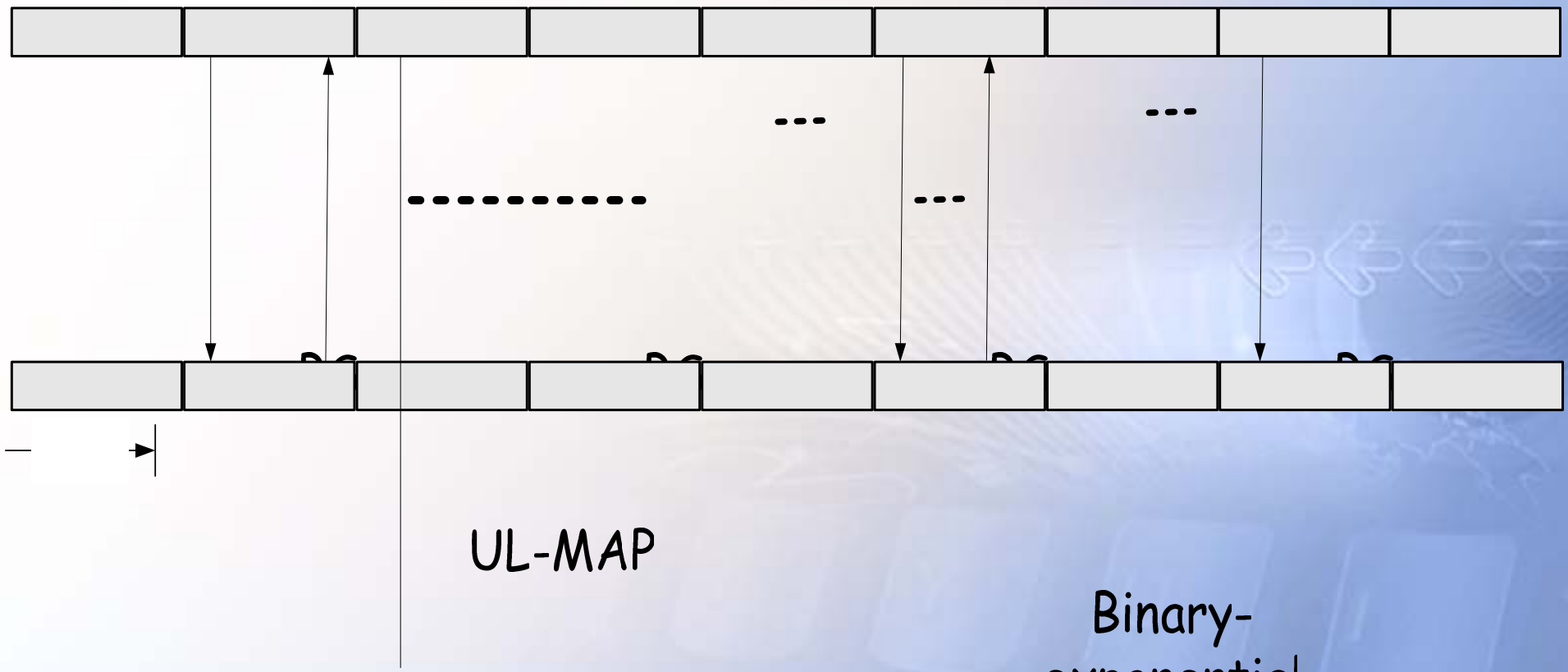
UL-MAP

Binary-
exponential
Random
Backoff

RNG-REQ
(Code)

RNG-REQ

Periodic Ranging Procedures



UL-MAP

Binary-exponential Random Backoff

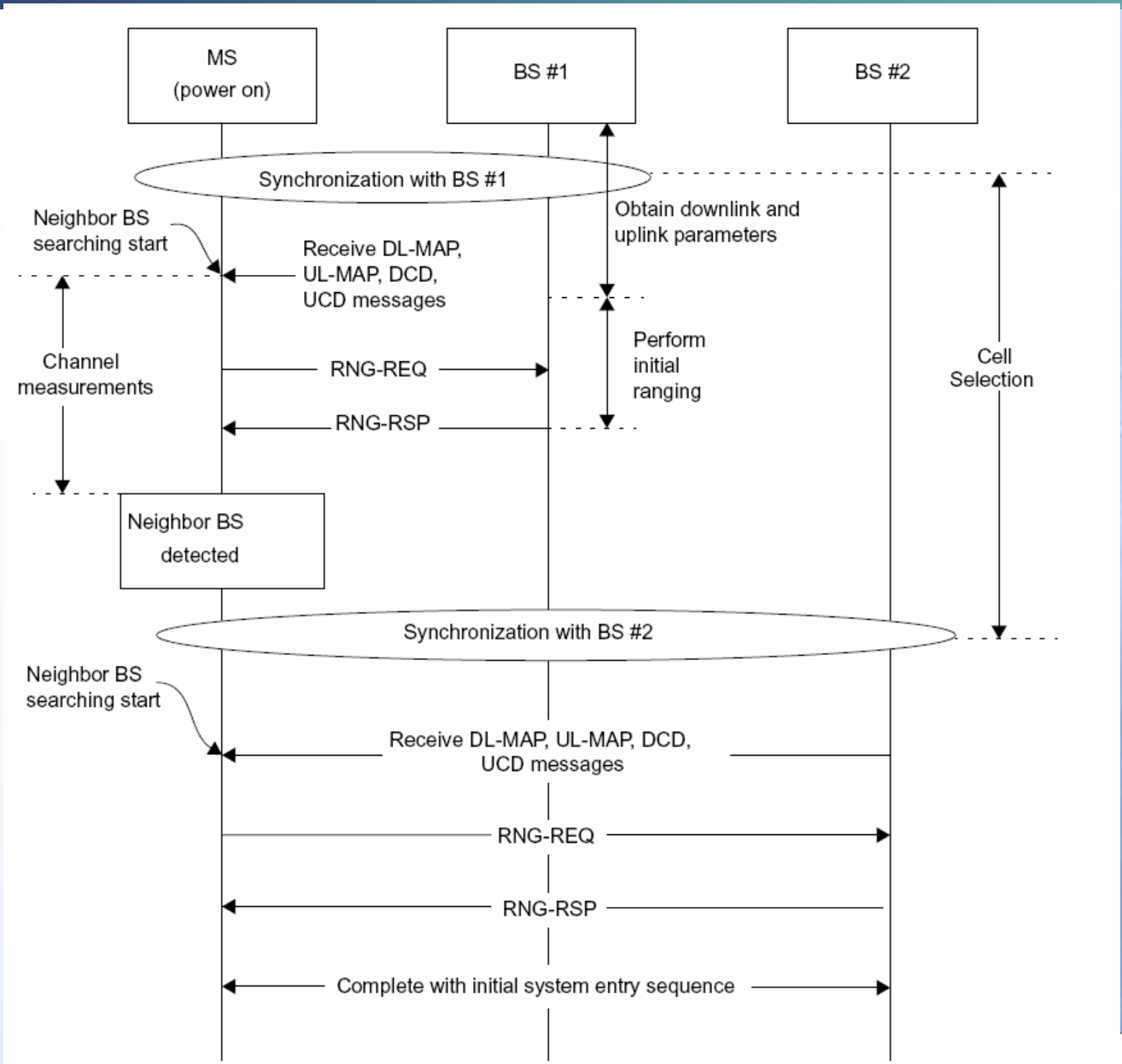
RNG-REQ (Code)

Handover

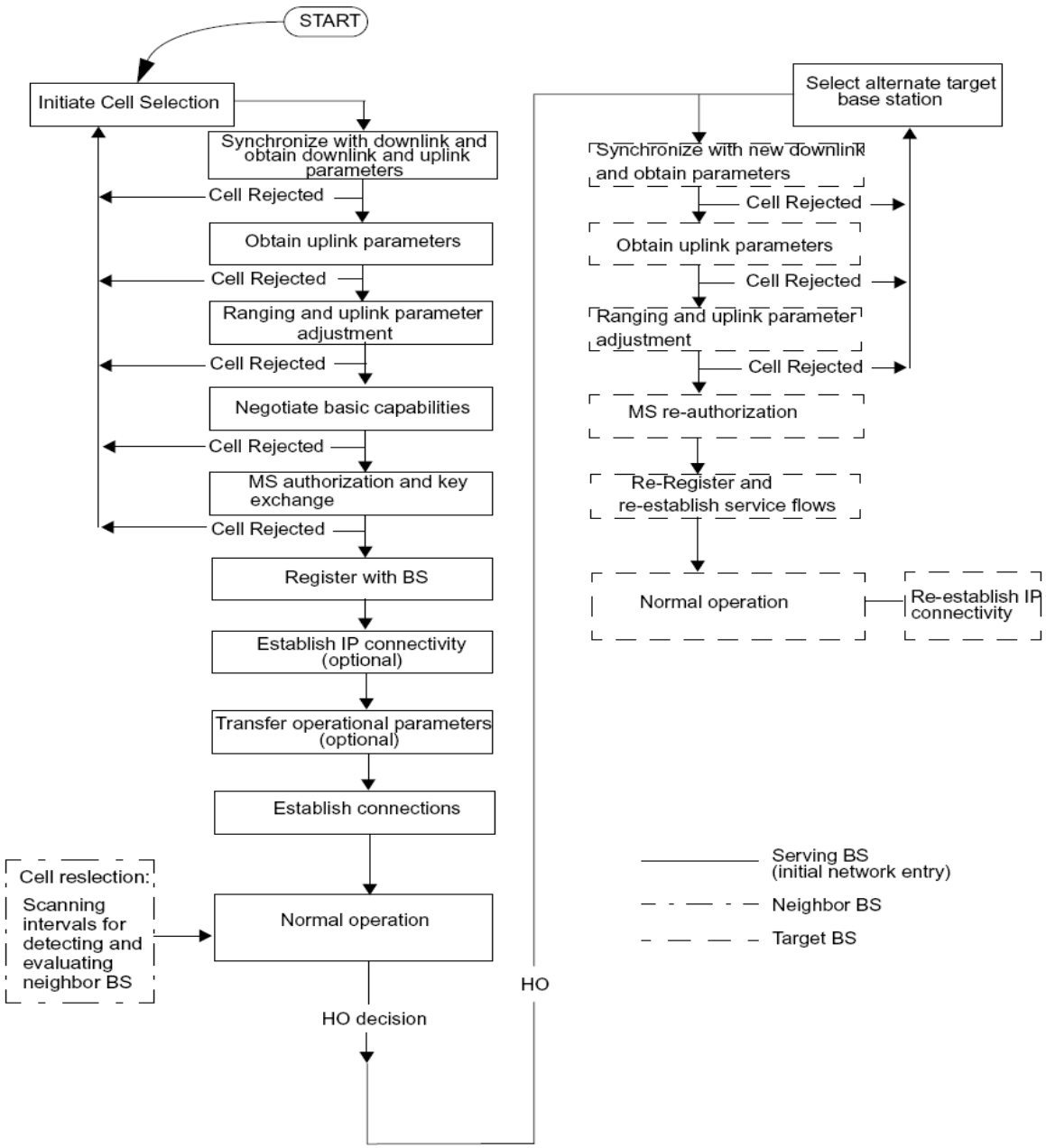
Handover Procedures

- Network topology acquisition
  - Network topology advertisement
  - Scanning of available BS
  - Association Procedure
- Handover process
  - Cell reselection
  - Handover decision & initiation
  - Target BS scanning
  - Network re-entry
  - Termination of service
  - (Handover cancellation)

Cell Selection



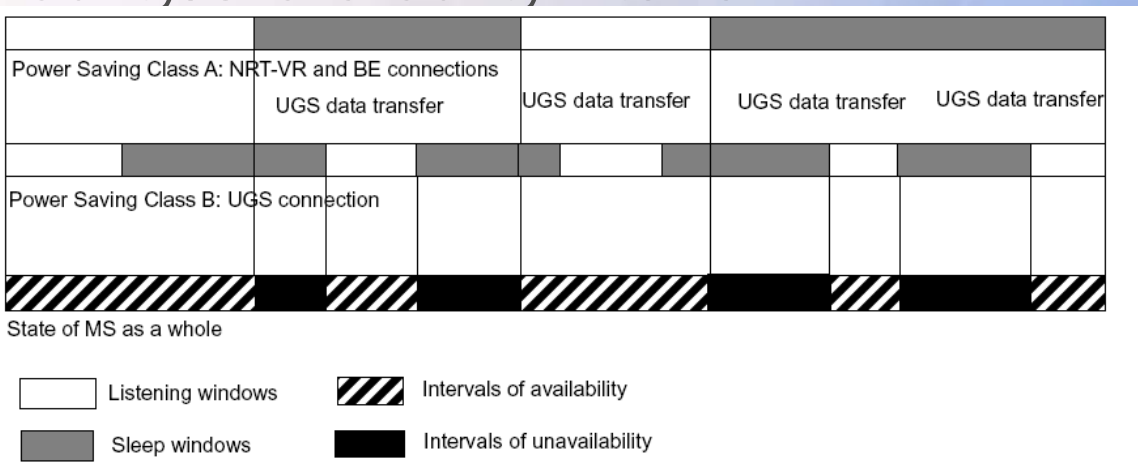
Handover and Initial Network Entry



Power Saving Scheme & Idle Mode

Sleep Mode for Mobility

- Sleep Mode
  - a state in which an MS conducts pre-negotiated periods of absence from the serving BS
  - Optional for MS and mandatory for BS
  - MOB_SLP-REQ/MOB_SLP-RSP messages
- Power Saving Class
  - A group of connections, which have common demand properties
  - Activation/Deactivation
    - Activation means starting sleep/listening windows sequence associated with this class
  - Availability/Unavailability interval



Power Saving Classes

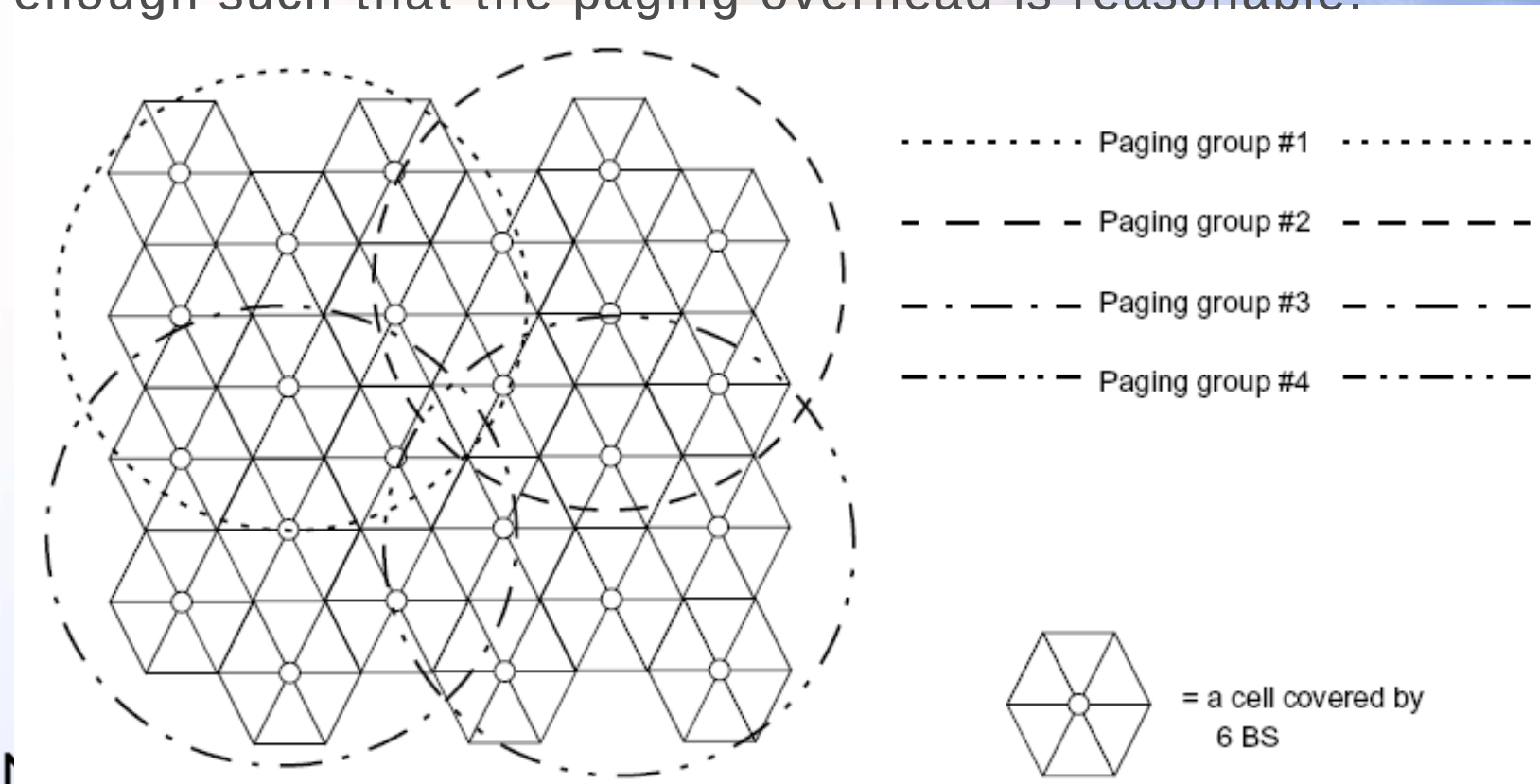
- Type I
  - Recommended for connections of BE, NRT-VR
  - Principal relevant parameters
    - Initial-sleep window
    - Final-sleep window base
    - Listening window
    - Final-sleep window exponent
  - Sleep window = min(2*(Previous sleep window), Final-sleep window base*2^(Final sleep window exponent))
  - BS terminates active state of Power Saving Class by sending MOB_TRF-IND message.
- Type II
  - UGS, RT-VR
  - Principal relevant parameters
    - Initial sleep window
    - Listening window
  - All sleep windows are same size of the initial sleep window
- Type III
  - Multicast, management (e.g., periodic ranging, MOB_NBR-ADV)
  - Principal relevant parameters
    - Final-sleep window base
    - Final-sleep window exponent
    - Start frame number for sleep window

MS Idle Mode

- Introduction
  - An optional function
  - Mechanism that allows MS to become periodically available for DL broadcast traffic message without registration at specific BS as the MS traverses an air link environment populated by multiple BSs
  - Benefits the network and BS by providing a simple and timely method for alerting the MS to pending DL traffic directed toward the MS, and by eliminating air interface and network HO traffic from essentially inactive MS

Paging Groups

- To offer a contiguous coverage region in which the MS does not need to transmit in the UL, yet can be paged in the DL if there is traffic targeted at it.
- Should be large enough so that most MS will remain most of the time within the same paging group, and small enough such that the paging overhead is reasonable.



MS Idle Mode

- MS Idle Mode Initiation
  - Begins after MS De-Registration
  - DREG-REQ/DREG-CMD messages are relevant
  - MS-initiated Idle mode
  - BS-initiated Idle mode
- MS Paging Listening Interval
  - The MS shall scan, decode the DCD and DL-MAP, and synchronize on the DL for the preferred BS in time for the MS to begin decoding any BS
- BS Broadcast Paging message
  - An MS notification message indicating either the presence of DL traffic pending, through the BS or some network entity, for the specified MS or to poll the MS and request a location update without requiring a full network entry
  - A paging message shall be transmitted during the MS paging Listening Interval if there is any MS that need paging

MS Idle Mode

- Paging Availability Mode Termination
  - MS re-entry to the network
  - Paging Controller detection of MS unavailability through repeated, unanswered paging message
  - Expiration of the Idle Mode System Timer
- Location Update
  - Locate update conditions
    - Paging group update
    - Timer update
    - Power down update
    - Mac hash skip threshold update
- Network Re-Entry from Idle Mode
  - The MS shall initiate network re-entry with the target BS by sending a RNG-REQ including Ranging Purpose Indication TLV with bit #0 set to 1 and Paging Controller ID TLVs

References

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