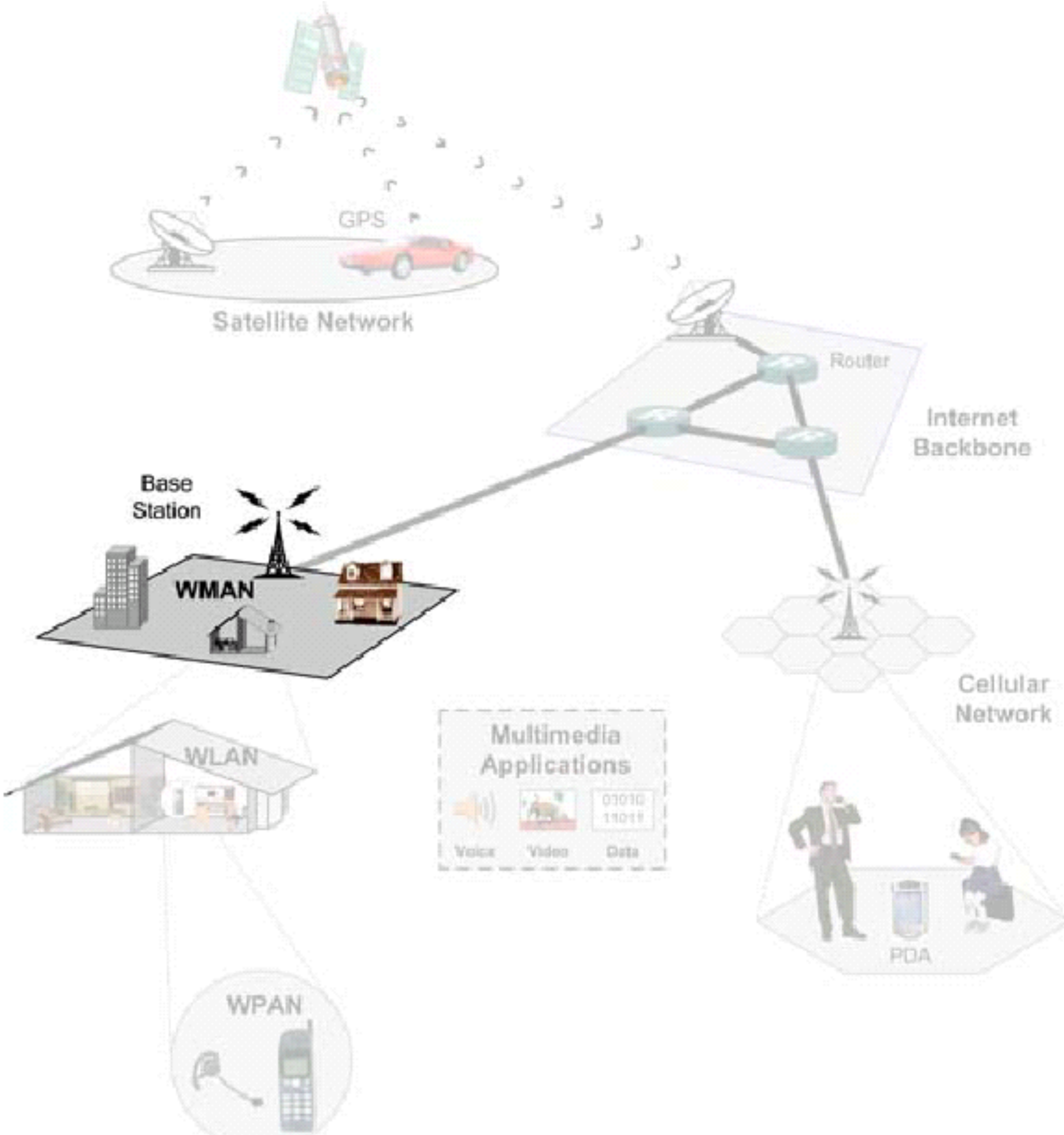
Part-III:
Wireless Metropolitan Area Networks

鄭瑞光

台灣科技大學電子系


GPS
Satellite Network
Router
Internet
Backbone
Base
Station
WMAN
Cellular
Network
Multimedia
Applications
Voice
Video
Data
WLAN
PDA
WPAN

Outlines

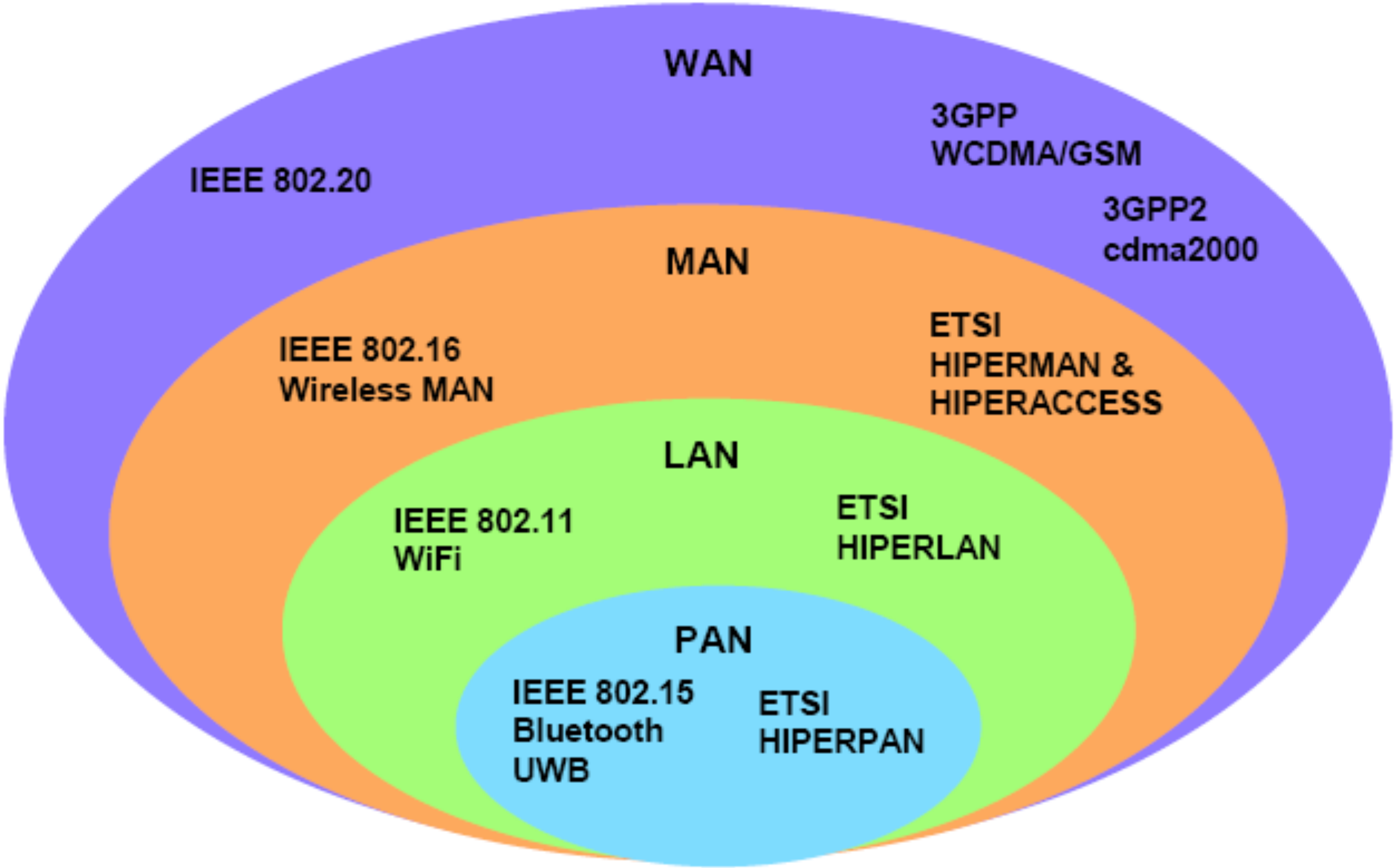
- Chapter 7. IEEE 802.16
  - Introduction
  - IEEE 802.16.1
  - Physical Layer
  - Media Access Control (MAC)
  - QoS Support
  - IEEE 802.16a

Introduction

- IEEE 802.16
  - Started in July, 1999.
  - An IEEE Standard for Wireless Metropolitan Area Networks
- WiMAX: Worldwide Interoperability for Microwave Access
- WiMAX Forum:
  - Formed in June 2001
  - Facilitates the deployment of broadband wireless networks based on the IEEE 802.16 standard (802.16-2004 and 802.16-2005) by ensuring compatibility and inter-operability of broadband wireless access equipments

Introduction

Global Wireless Standards



Introduction

- IEEE 802.16 Standard Family:
  - Air Interface
    - IEEE Std 802.16-2001 (Air Interface for 10-66 GHz)
    - IEEE Std 802.16a-2003 (Amendment including 2-11 GHz)
    - IEEE Std 802.16c-2002 (Amendment including 10-66 GHz Profiles)
    - IEEE Std 802.16-2004: Revision, incorporating and obsolescing IEEE Standard 802.16-2001 and its two amendments
    - IEEE Std 802.16f-2005: Management Information Base for Fixed Systems
    - IEEE Std 802.16-2004/Cor1-2005: Corrigendum to IEEE Std 802.16-2004
    - IEEE Std 802.16e-2005: Amendment on enhancements to support mobility

Introduction

- IEEE 802.16 Standard Family:
  - Conformance Task Group
    - IEEE Standard 802.16/Conformance01-2003 (10-66 GHz PICS)
    - IEEE Standard 802.16/Conformance02-2003 (10-66 GHz TSS&TP)
    - IEEE Standard 802.16/Conformance03-2004 (10-66 GHz Radio Conformance Tests)
    - IEEE Standard 802.16/Conformance04-2006 (<11 GHz PICS)
  - Coexistence
    - IEEE Standard 802.16.2-2001 (Coexistence for 10-66 GHz)
    - IEEE Standard 802.16.2-2004 (Revision, including expansion to 2-66 GHz)

Introduction

- Wireless metropolitan area networks (WMANs or WirelessMAN™).
  - Goal: to provide highspeed wireless Internet access similar to wired access technologies such as cable modem, digital subscriber line (DSL), Ethernet, and fiber optic.

Introduction

- IEEE 802.16
  - is designed for MAN with hundreds or thousands of high-speed subscribers
  - MAC is built to accommodate a point to multipoint (PMP) topology
  - BS has full control on the bandwidth allocation on
    - uplink (subscriber station (SS) to BS) channel and
    - downlink (BS to SS) channel
  - BS provides access allocation via a request-grant mechanism
  - supports multiple radio options

Introduction

- IEEE 802.16.1
  - First WMAN standard in 2002
  - 10~66 GHz frequency bands
- IEEE 802.16.2
  - recommended practice for the coexistence of WMAN and WLAN
- IEEE 802.16a
  - MAC and physical layer specifications for the 2~11 GHz bands
  - capability of serving mesh networks
- P802.16c
  - system profiles (for interoperability) for 10~66 GHz

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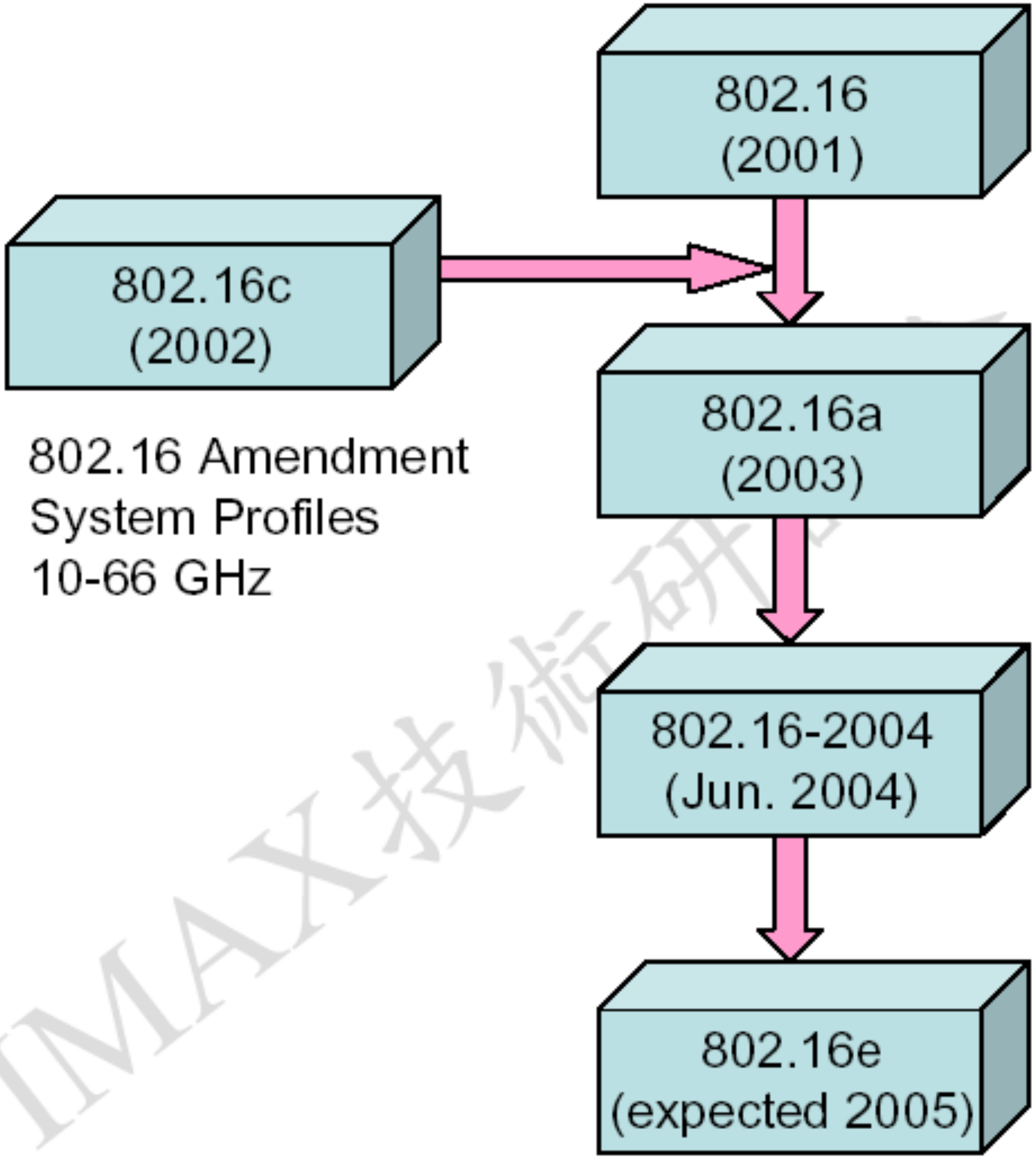
802.16 Standard Evolution



Fixed Wireless Broadband
10-66 GHz

802.16 Amendment
System Profiles
10-66 GHz

802.16 Amendment
Fixed Wireless Broadband
2-11 GHz

802.16-2004 Revision
Combination of 802.16,
802.16c, and 802.16a

802.16 Amendment for
Combined Fixed and Mobile
Wireless Broadband From
2-6 GHz

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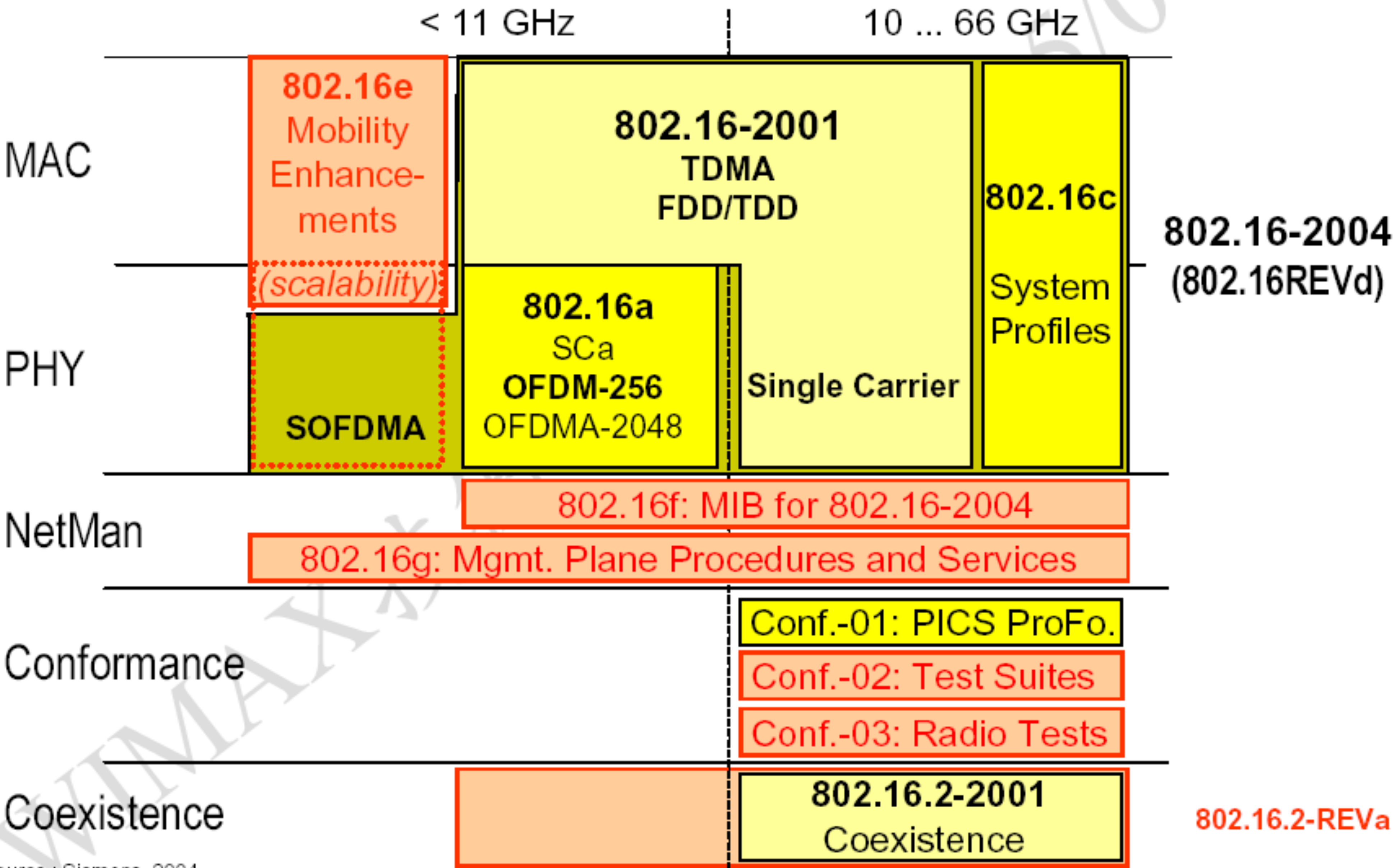
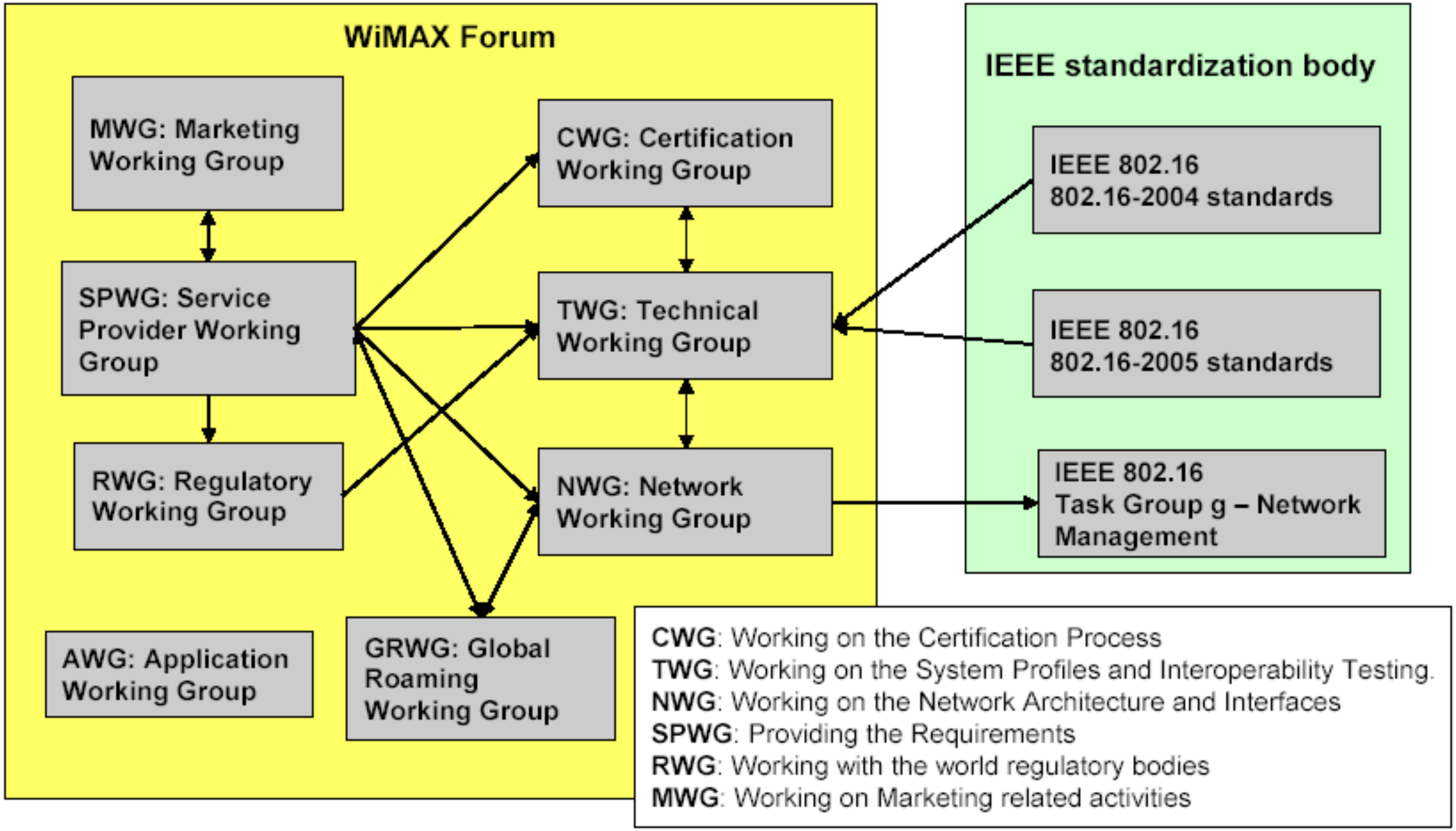
802.16 Family

PICS : Protocol Implementation Conformance Statement



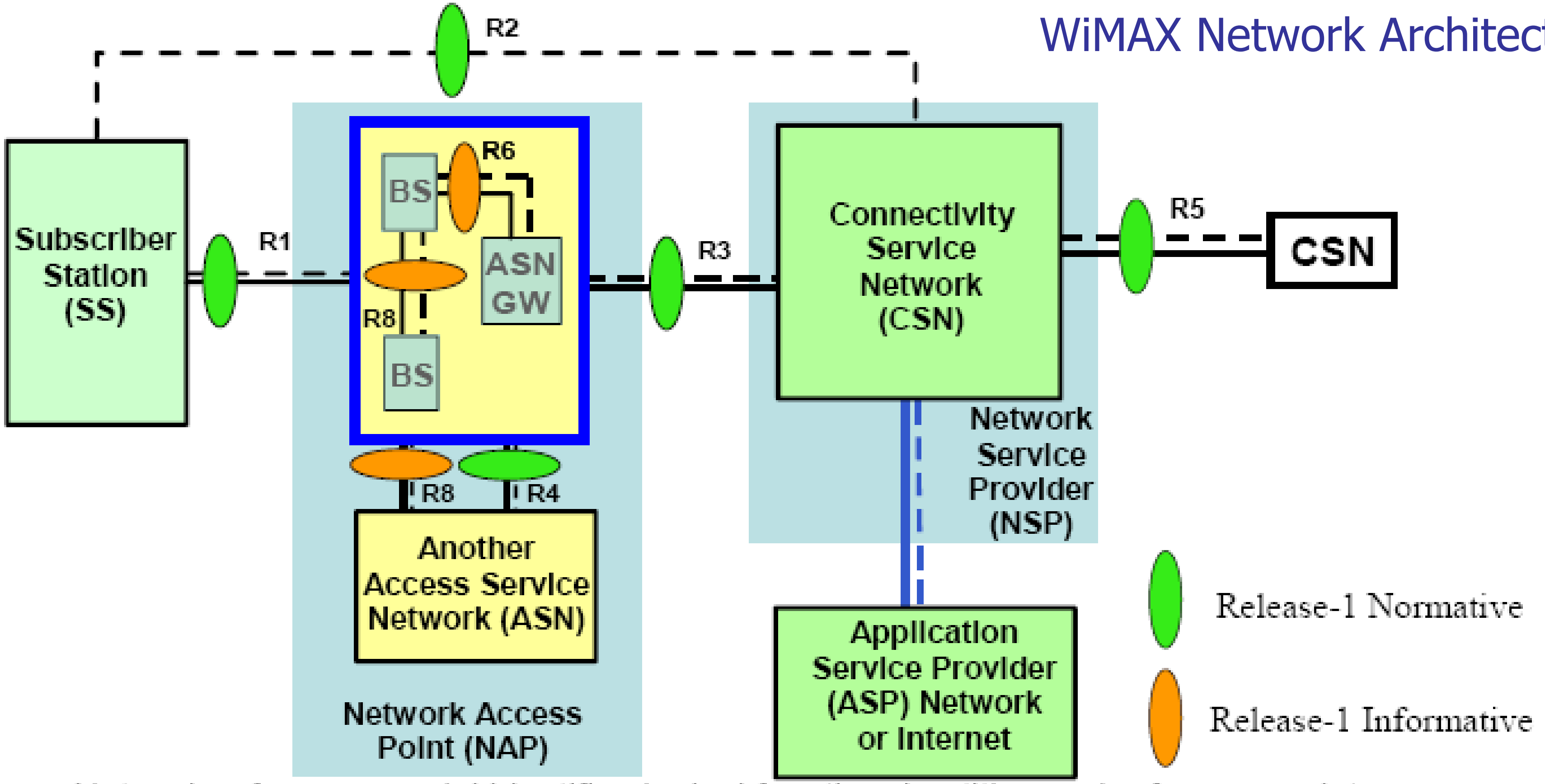
Source : Siemens, 2004

WiMAX Forum and IEEE 802.16 Relationship



Introduction

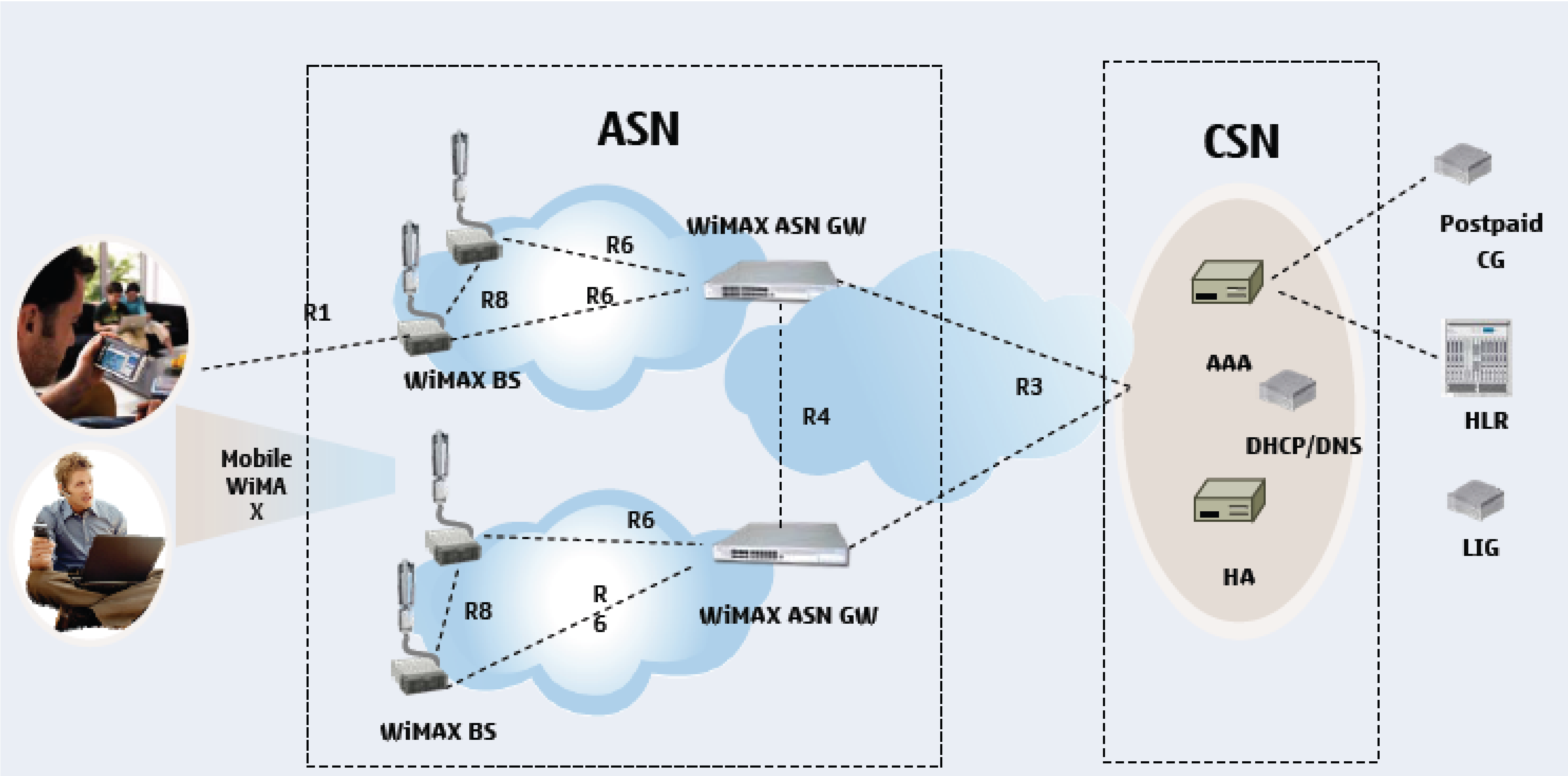
WiMAX Network Architecture



- Network reference model identifies logical functional entities and reference points over which inter-op is achieved between functional entities.
- In Release 1 intra-ASN inter-op not supported.

Source: Ericsson

Introduction

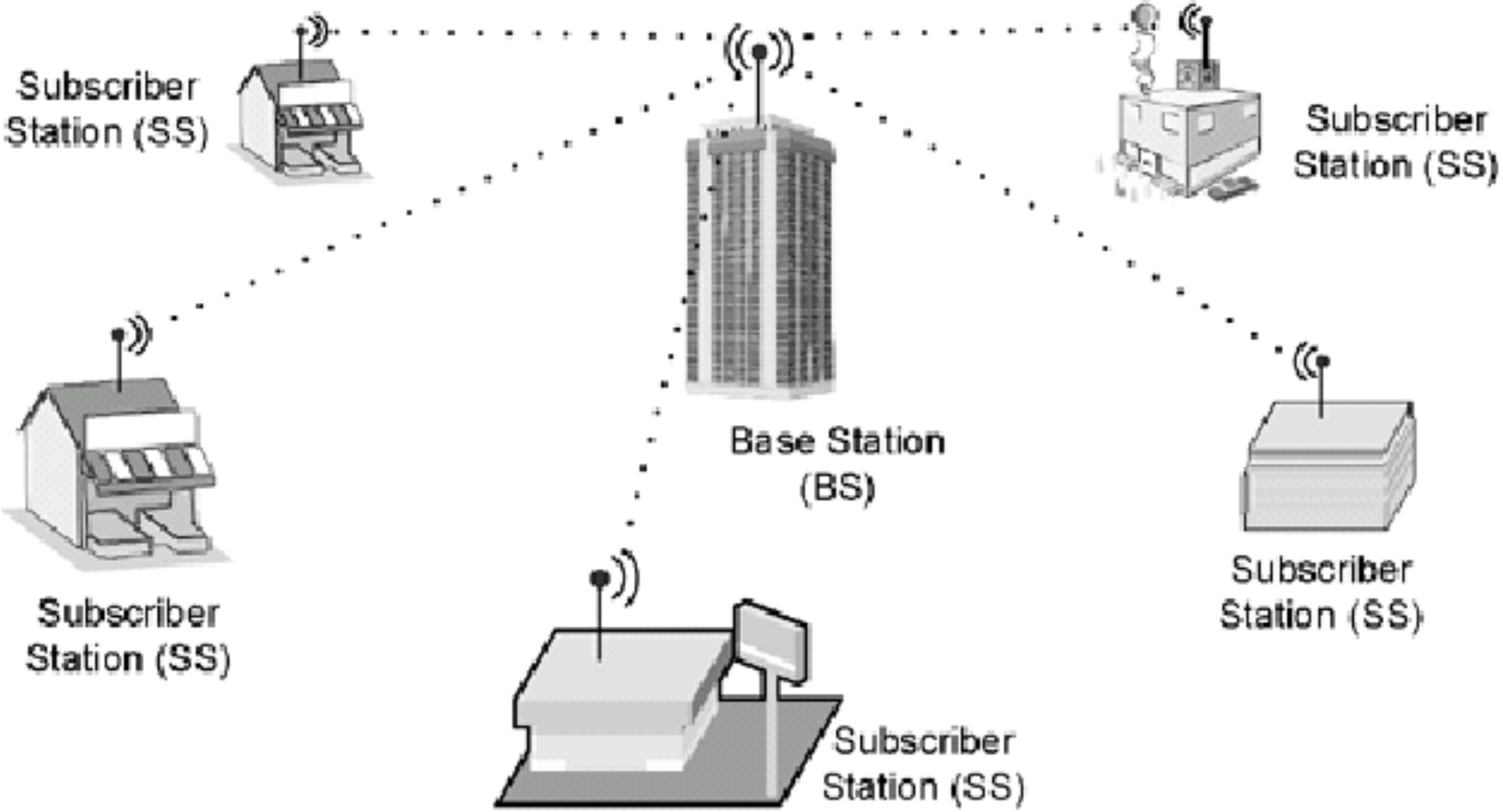


Source: Nokia

WiMAX Network Architecture

IEEE 802.16.1

- Architecture
  - Network Topology:
    - PMP
    - no direct communication between the SSs
  - Frequency band
    - 10 to 66 GHz (line of sight)
    - channels spacing 25 or 28 MHz
    - data rates >120 Mbps
  - Protocol Stacks
    - MAC
      - Service Specific Convergence Sublayer (CS)
      - MAC Common Part Sublayer (CPS)
      - Security Sublayer


Subscriber
Station (SS)
Subscriber
Station (SS)
Base Station
(BS)
Subscriber
Station (SS)
Subscriber
Station (SS)
Subscriber
Station (SS)

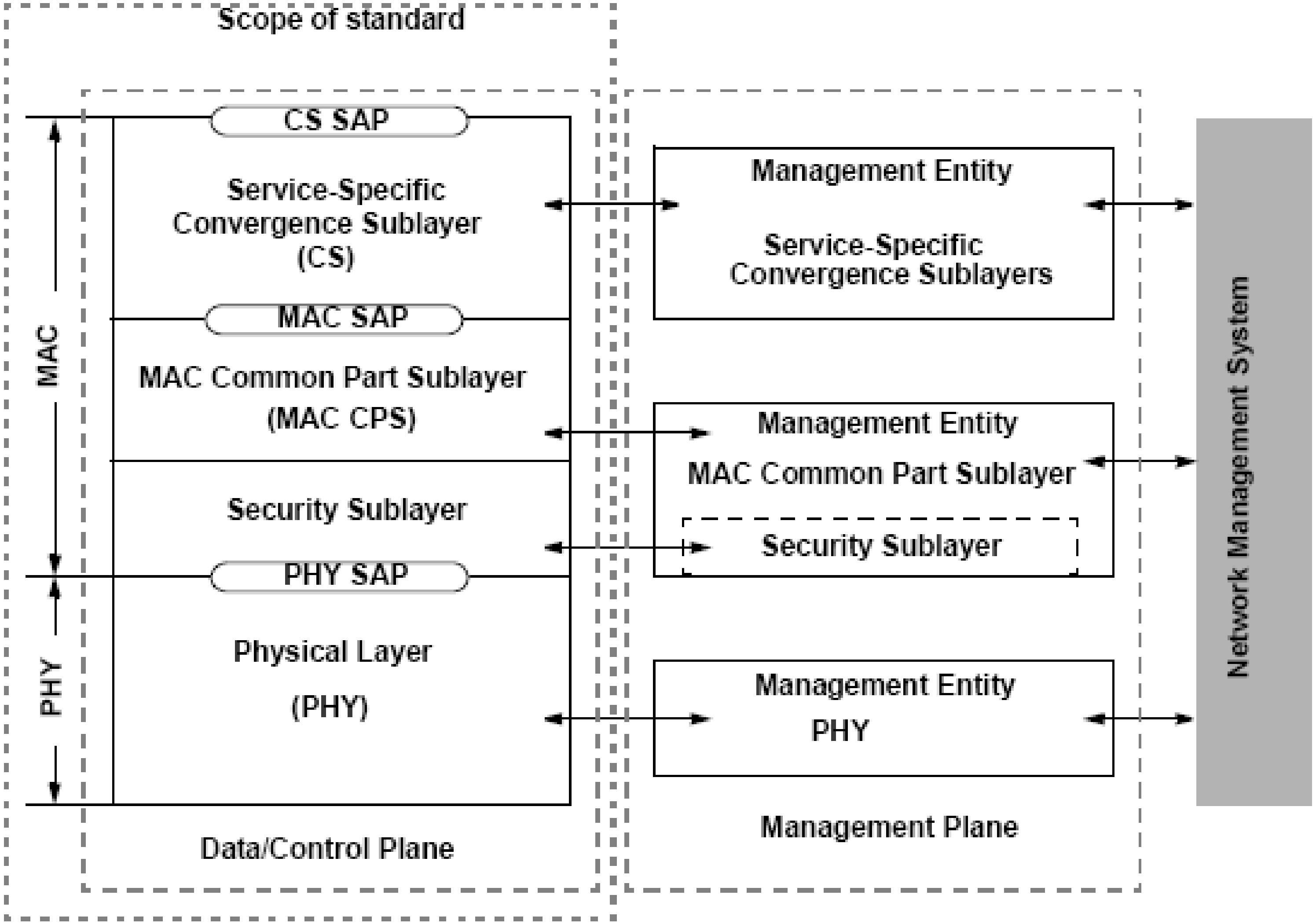


Figure 1—IEEE Std 802.16 protocol layering, showing SAPs

IEEE 802.16.1

- MAC
  - Service Specific Convergence Sublayer (CS)
    - Functions:
      - transforms incoming network data into MAC data packets
      - preserving or enabling QoS
      - allowing bandwidth allocation
    - Two CS specifications are defined
      - ATM CS
      - Packet CS
        - IPv4, IPv6, Ethernet, virtual local area network (VLAN)

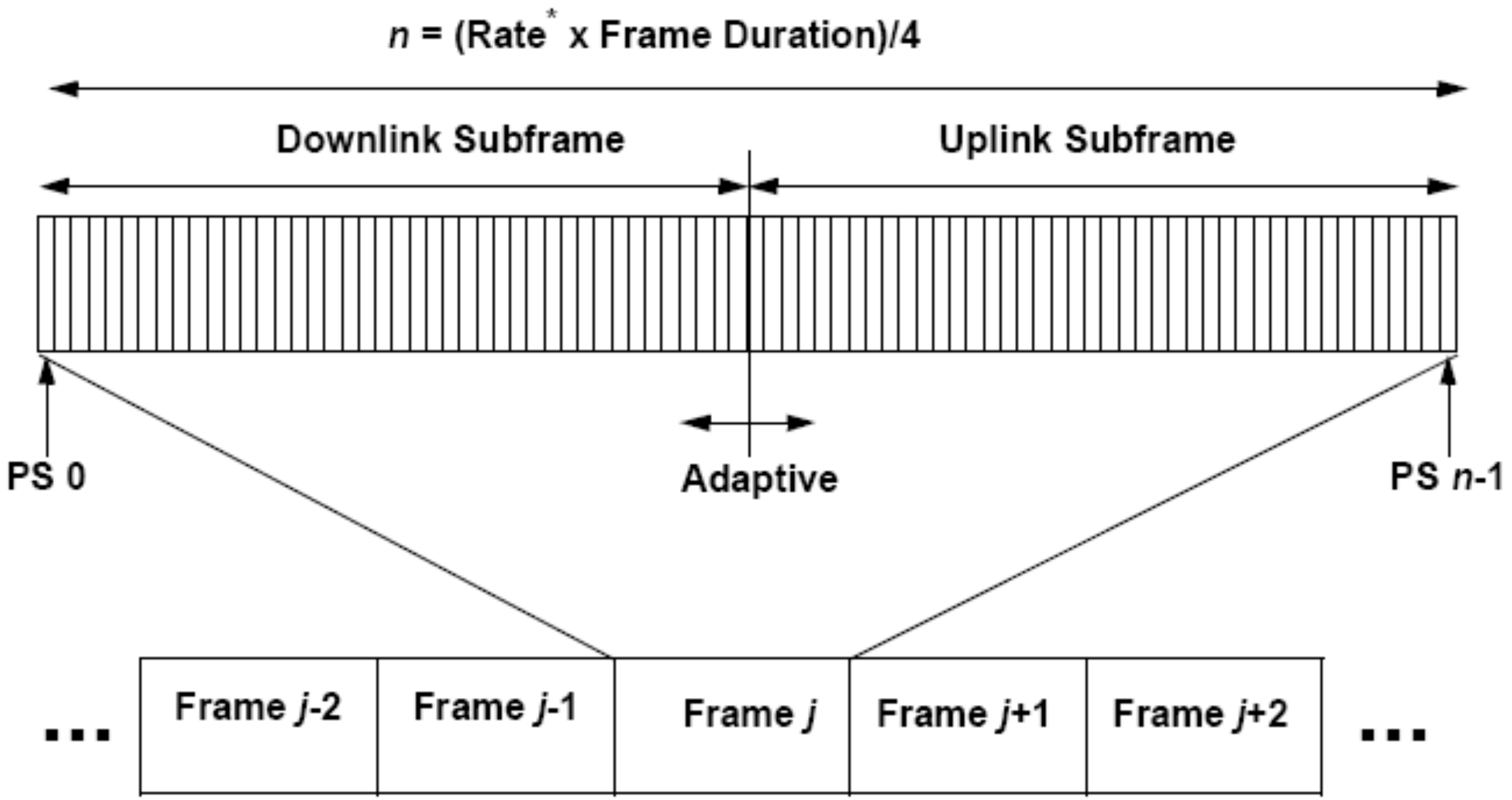
IEEE 802.16.1

- MAC Common Part Sublayer (CPS)
  - Functions:
    - access control
    - bandwidth allocation
    - connection establishment
    - connection maintenance
- Security Sublayer
  - Functions:
    - authentication
    - key exchange
    - encryption

IEEE 802.16.1

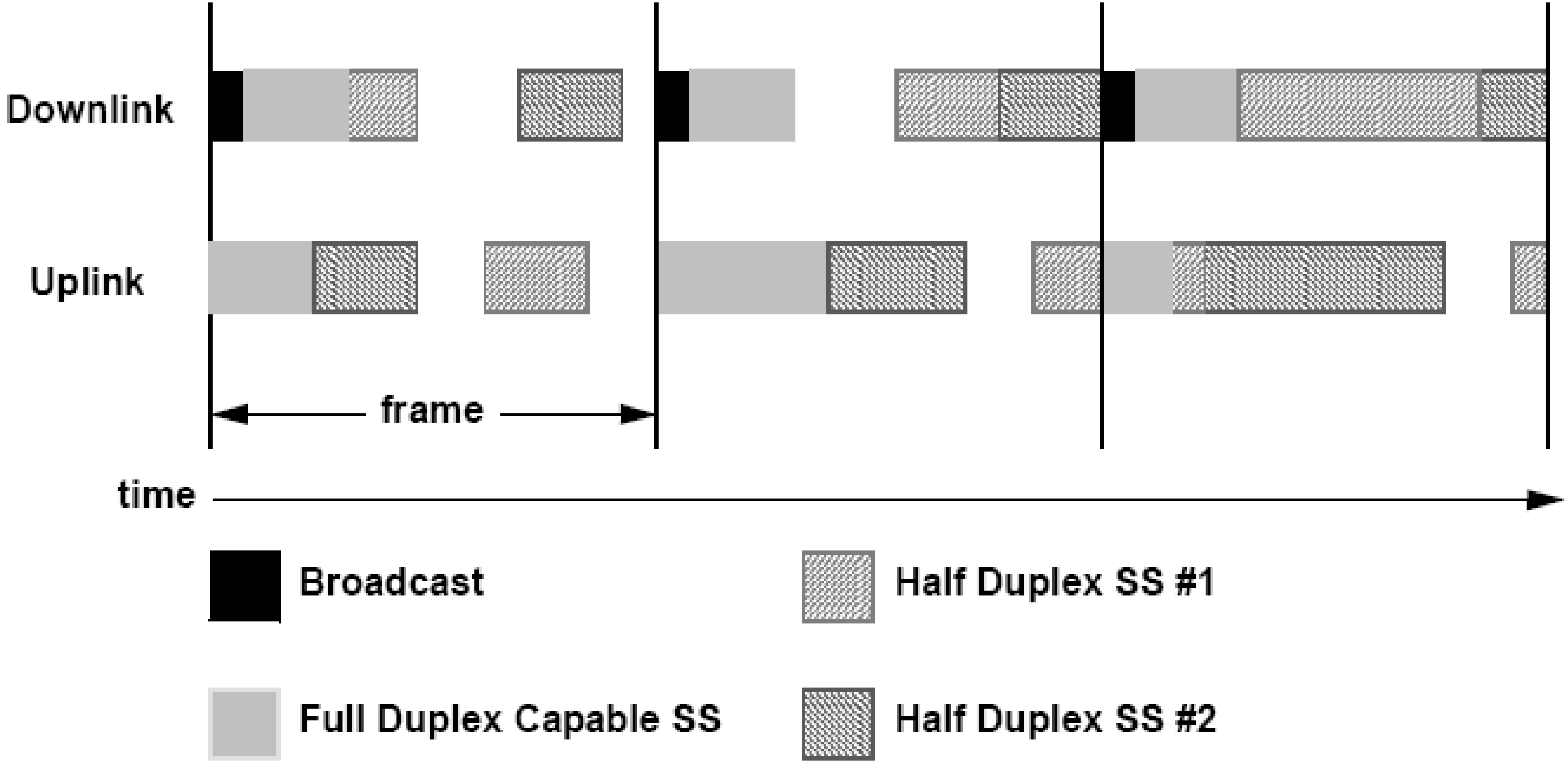
- PHY
  - 10 to 66 GHz frequency bands
    - channel bandwidth
      - U.S.: 20 or 25 MHz, data rate up to 96 or 120 Mbps
      - Europe: 28 MHz, data rate up to 134 Mbps)
  - Single-carrier modulation
    - all data are sequentially transmitted in a single frequency
    - directional antennas can be used
  - Duplexing
    - Frequency Division Duplexing (FDD)
    - Time Division Duplexing (TDD)
  - uplink and downlink channels are structured into frames
  - all SSs and the BS are synchronized
  - full duplex SS or half duplex SS

TDD Frame Structure



[*] for SC, SCa, the Rate is the Symbol Rate; for OFDM, OFDMA, the Rate is the nominal sampling frequency (Fs).

FDD Frame Structure



IEEE 802.16.1

- Adaptive data burst profiling:
  - transmission parameters of each SS is modified on a frame-by-frame basis in both uplink and downlink transmissions
- Data burst profiles
  - include radio modulation type and FEC
    - three types of modulation schemes: QPSK, 16QAM, 64QAM
  - are identified by an Interval Usage Code (IUC)
    - Downlink Interval Usage Code (DIUC)
      - DIUC is included in Downlink Channel Descriptor (DCD) message
    - Uplink Interval Usage Code (UIUC)
      - UIUC is included in Uplink Channel Descriptor (UCD) message
  - DCD and UCD messages are transmitted periodically by the base station

IEEE 802.16.1

- Media Access Control (MAC)
  - Connection oriented
  - Connections are identified by Connection Identifiers (CIDs)
    - CIDs: management, announcements, broadcasting, and transportation.
  - Each connection is associated with a unidirectional service flow (SF)
    - An SF is a unidirectional flow of packets that provides a particular QoS

IEEE 802.16.1

- Channel Access
  - UL:
    - several SSs share the channel in a TDMA fashion
    - Uplink Map Message (UL-MAP) is used to define
      - UL channel assignment
      - uplink data burst profiles (i.e., UIUC)
  - DL:
    - BS sends packets to SSs
    - Downlink Map Message (DL-MAP) is used to define
      - DL channel assignment
      - downlink data burst profiles (i.e., DIUC)

Time Relevance

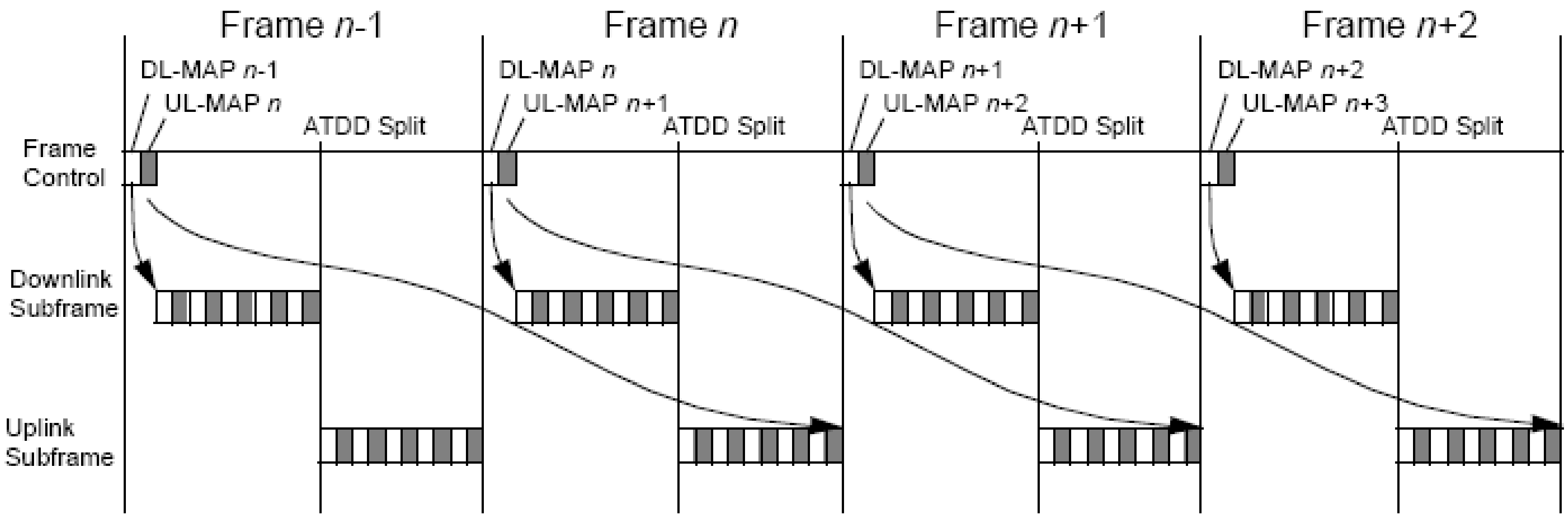


Figure 46—Maximum time relevance of DL-MAP and UL-MAP(TDD)

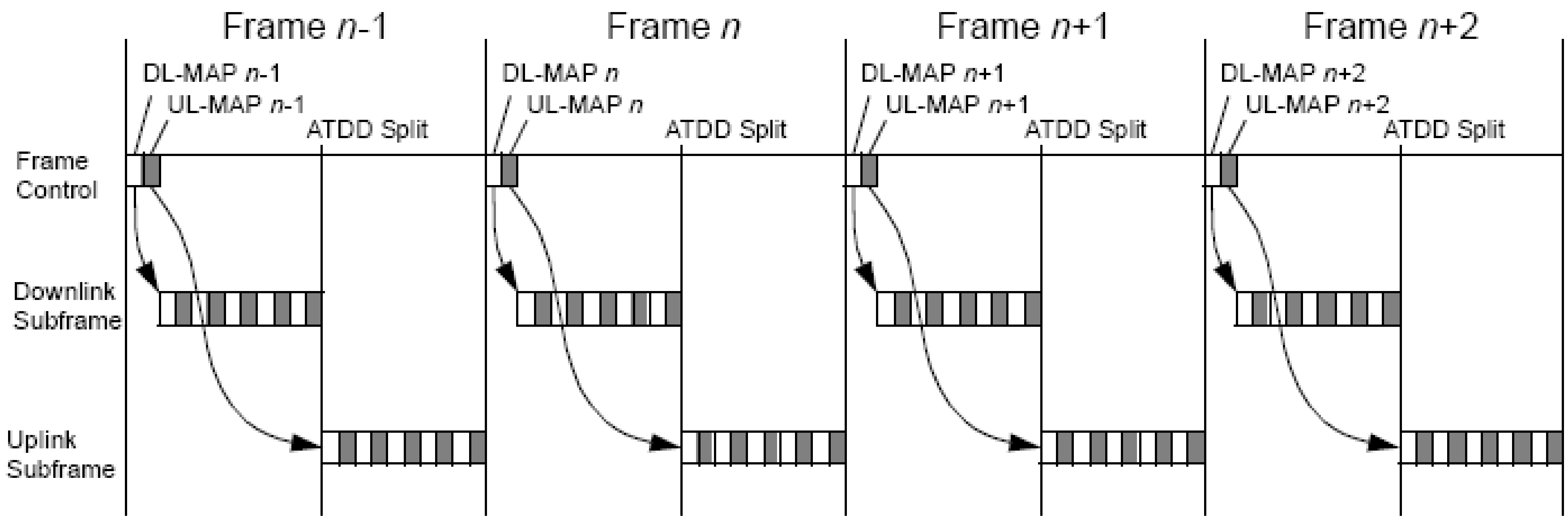


Figure 47—Minimum time relevance of DL-MAP and UL-MAP (TDD)

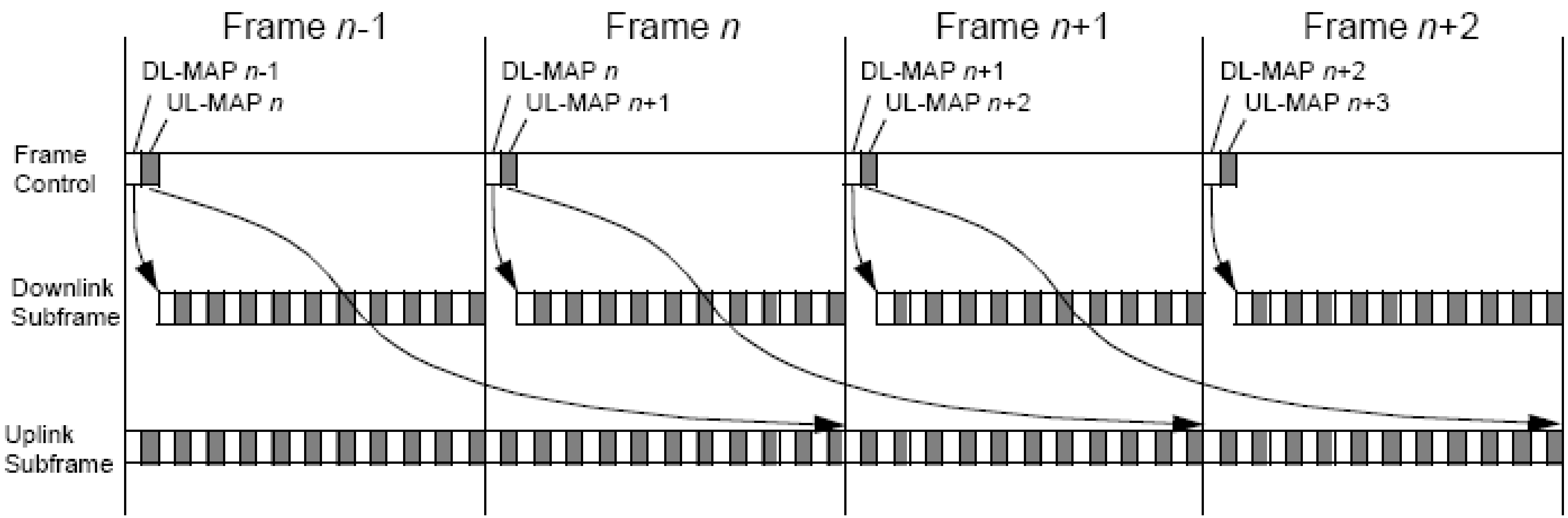


Figure 48—Maximum time relevance of DL-MAP and UL-MAP (FDD)

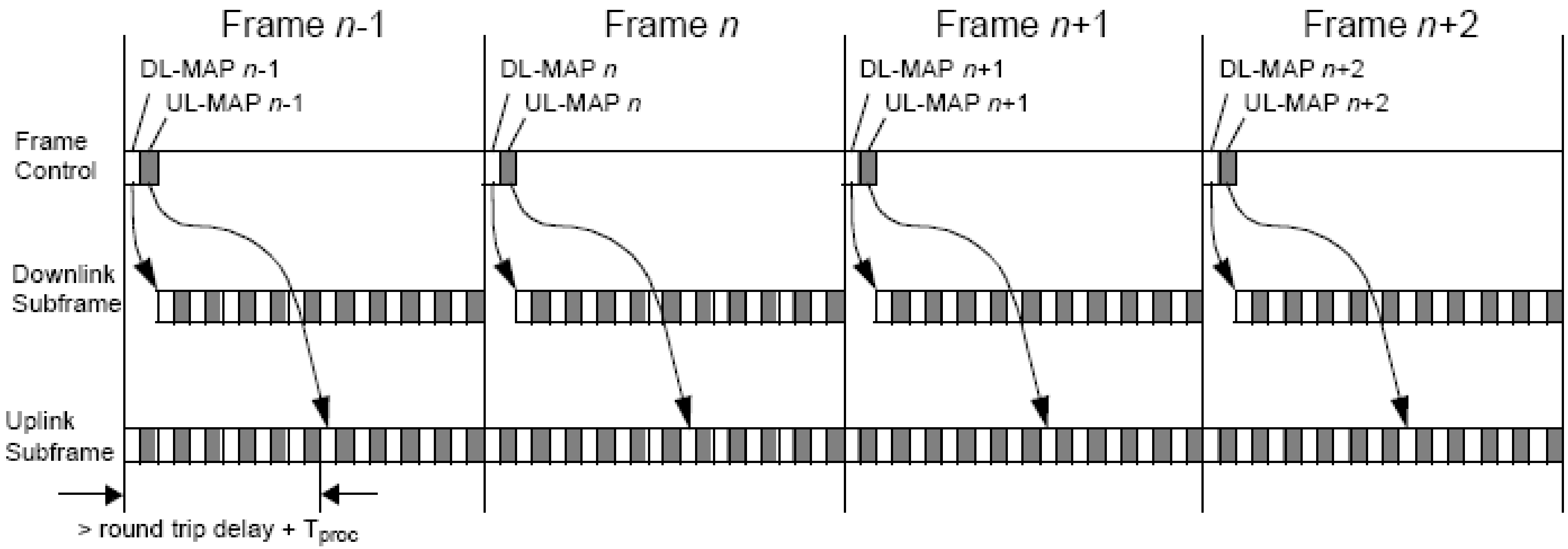
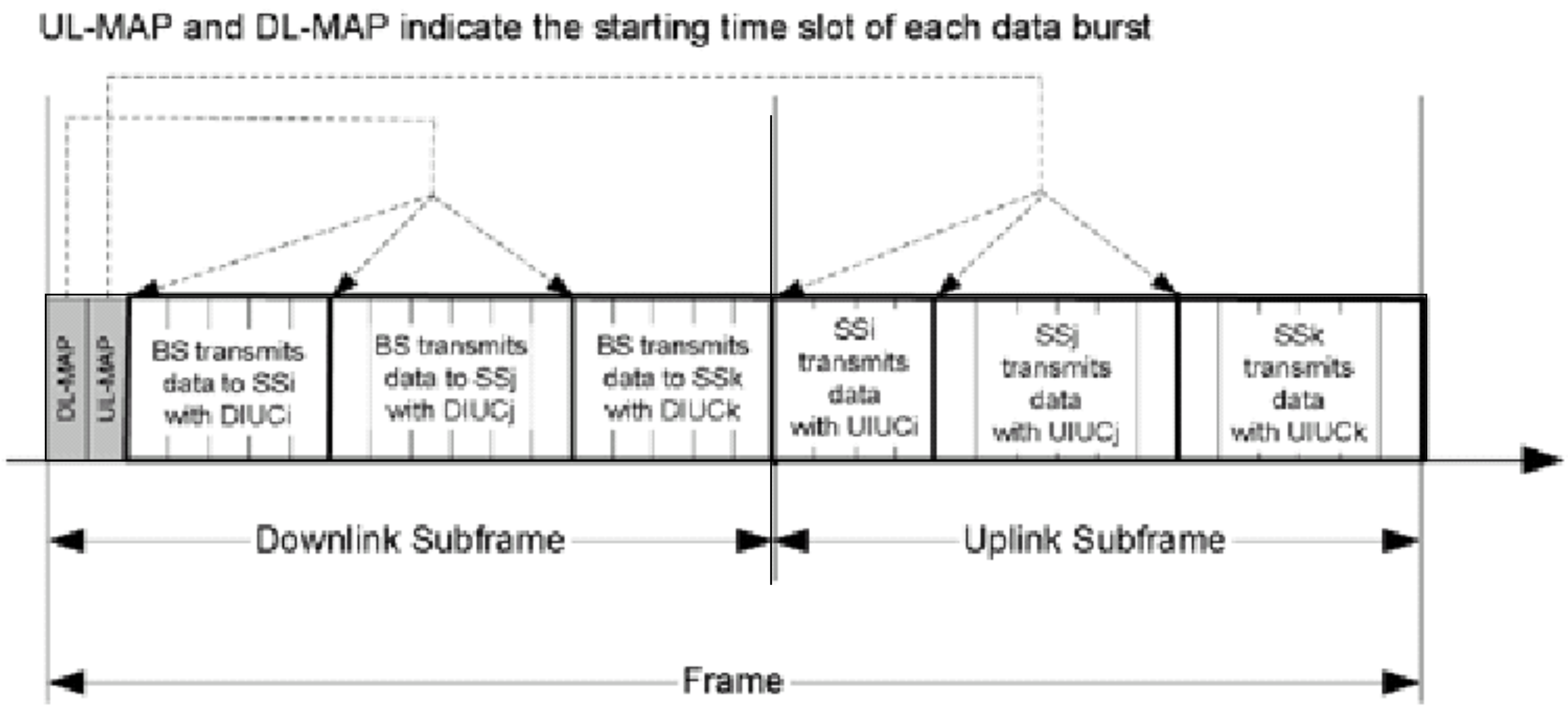


Figure 49—Minimum time relevance of DL-MAP and UL-MAP (FDD)

DL-MAP and UL-MAP



FDD DL Subframe

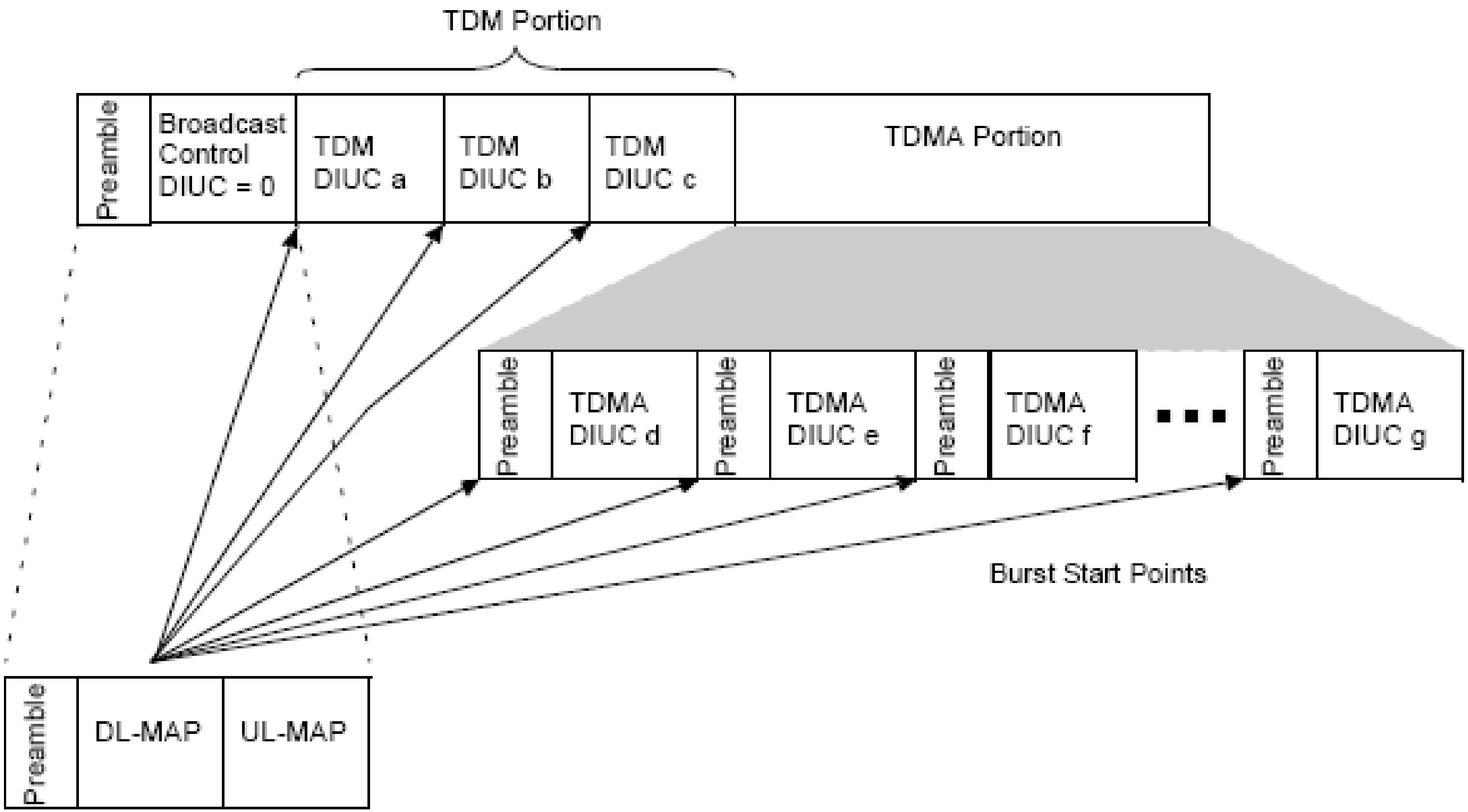


Figure 141—FDD downlink subframe structure

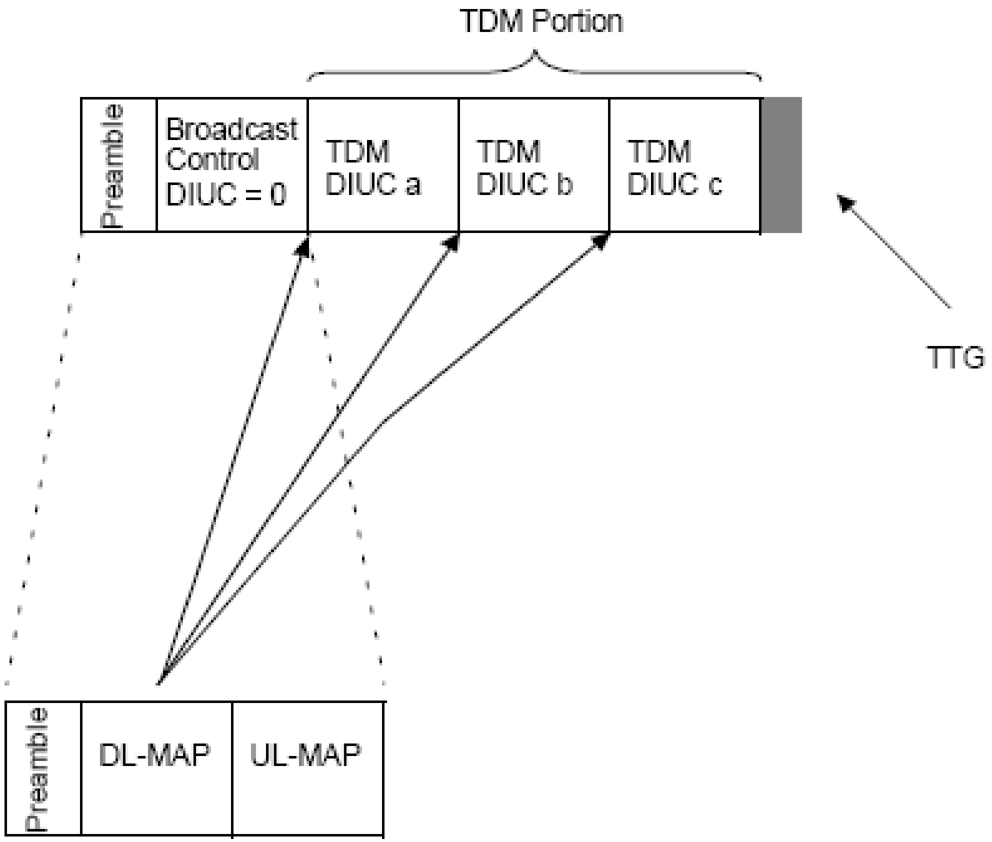
FDD Downlink Subframe

- FDD downlink subframe starts with
  - Preamble: physical layer transition and synchronization
  - DL-MAP: starting time slots for TDM and TDMA methods
    - TDM portions
      - not separated by gaps or preambles
      - contain data transmitted to
        - full duplex SSs
        - half duplex SSs scheduled to transmit IN this frame
        - half duplex SSs NOT scheduled to transmit in this frame
    - TDMA portions
      - separated by preambles and gaps
      - contain data transmitted to
        - half duplex SSs
      - allows an individual SS to decode a specific portion of the downlink without the need to decode the entire downlink subframe
  - UL-MAP

TDD Downlink Subframe

- TDD downlink subframe starts with
  - Preamble:
    - physical layer transition and synchronization
  - DL-MAP: only TDM portion
    - TDM portion
      - Ends with a Transmit/Receive (Tx/Rx) Time Gap (TTG)
  - UL-MAP

TDD Downlink Subframe Structure



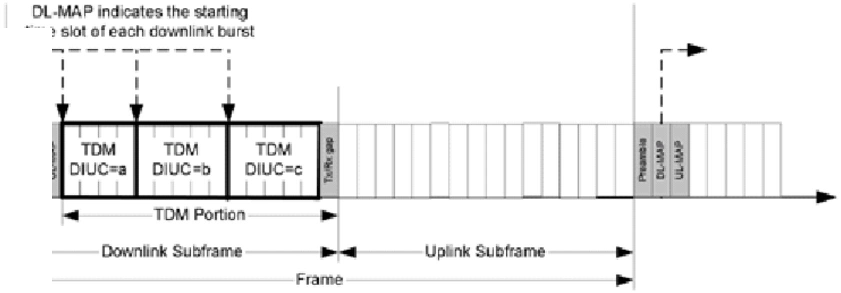
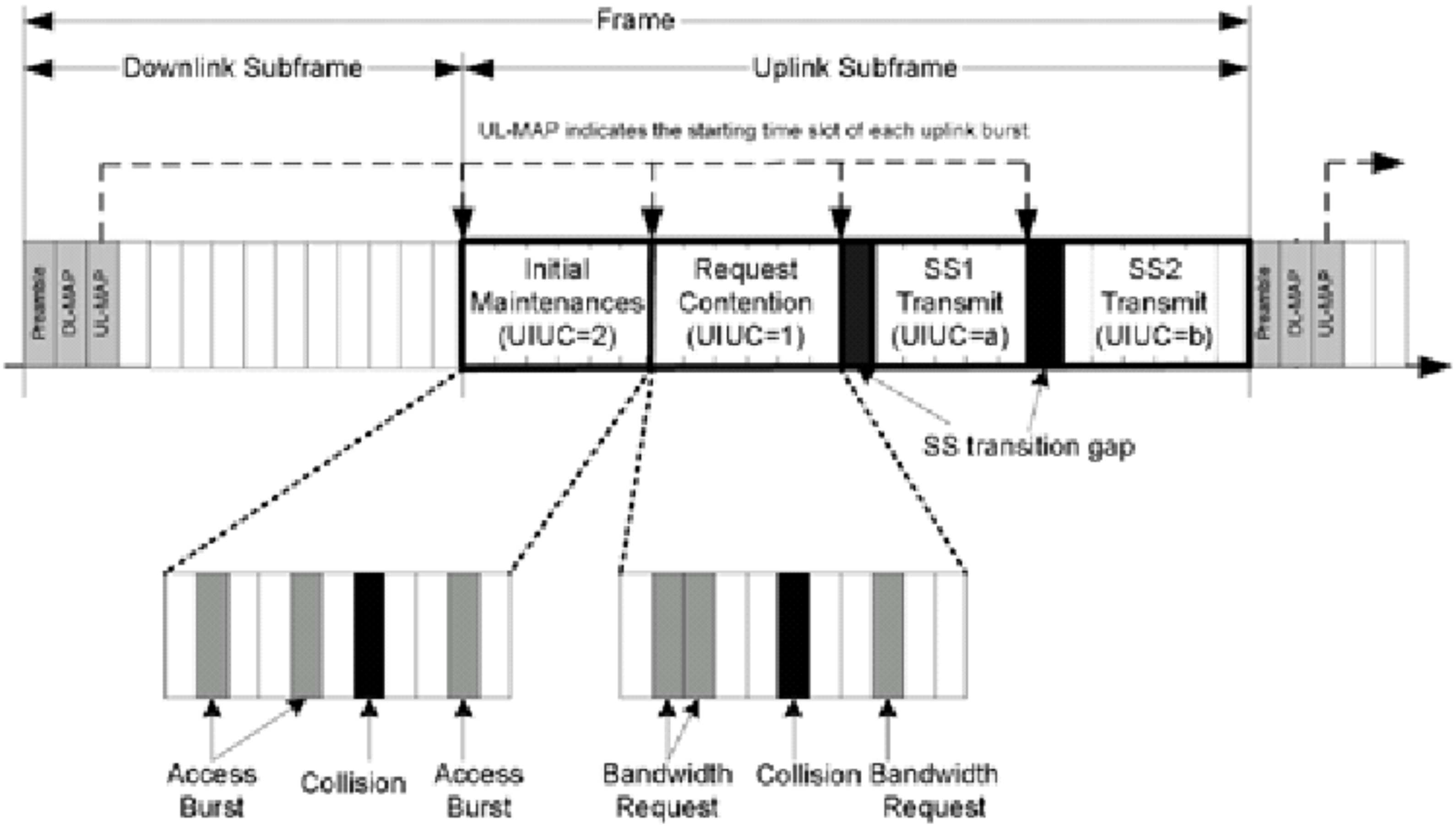


Figure 140—TDD downlink subframe structure

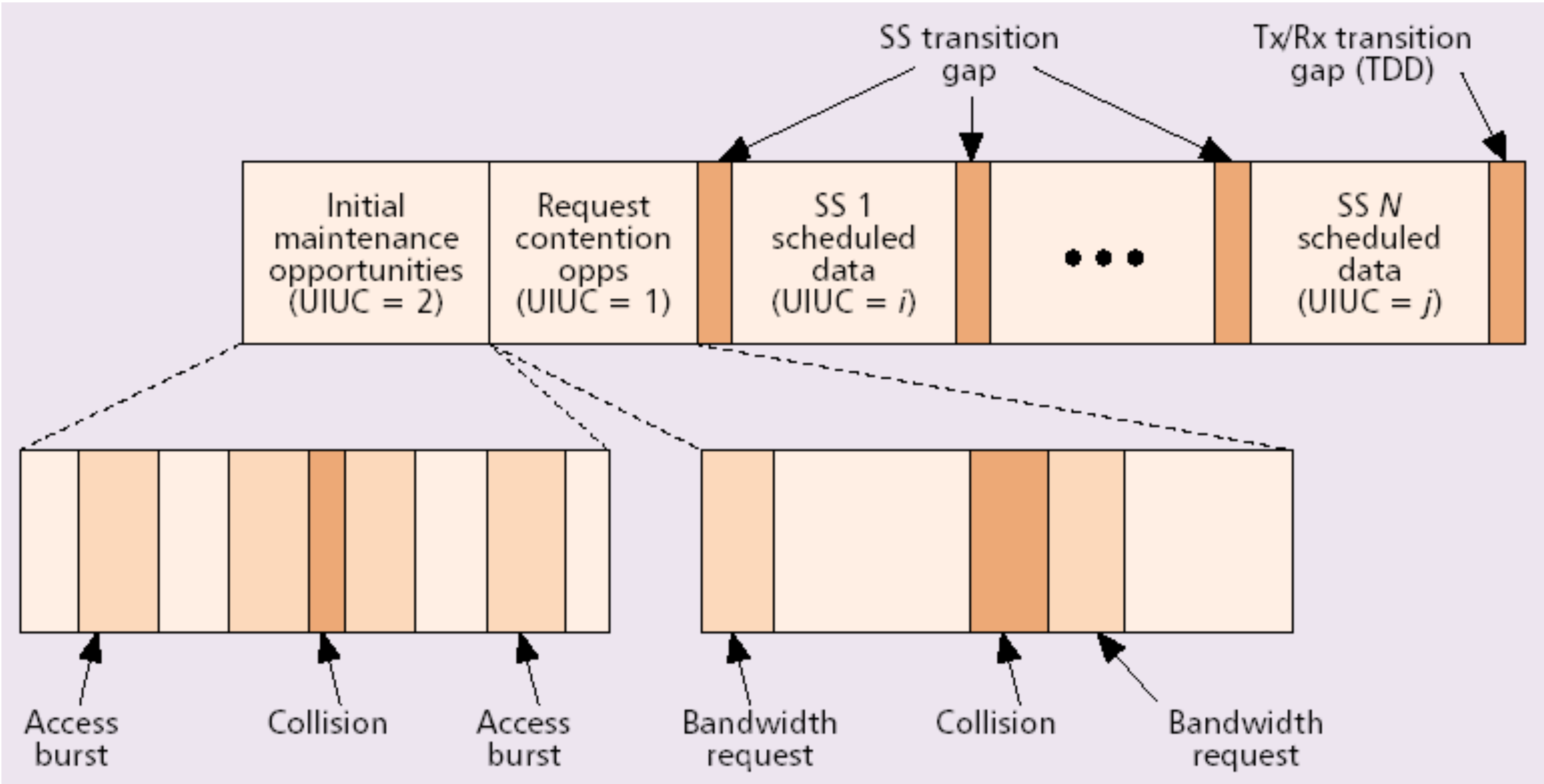
Uplink Subframe

- Uplink subframe
  - used by SSs to transmit data to the BS
  - Contains three periods:
    - Initial Maintenance period: UIUC = 2
    - Request Contention Opportunities period: UIUC = 1
    - Scheduled Data Grants period: UIUC != 1 or 2
  - BS announces the periods and associated burst classes in the preceding downlink subframe's UL-MAP

Uplink Subframe Structure



Uplink Subframe Structure



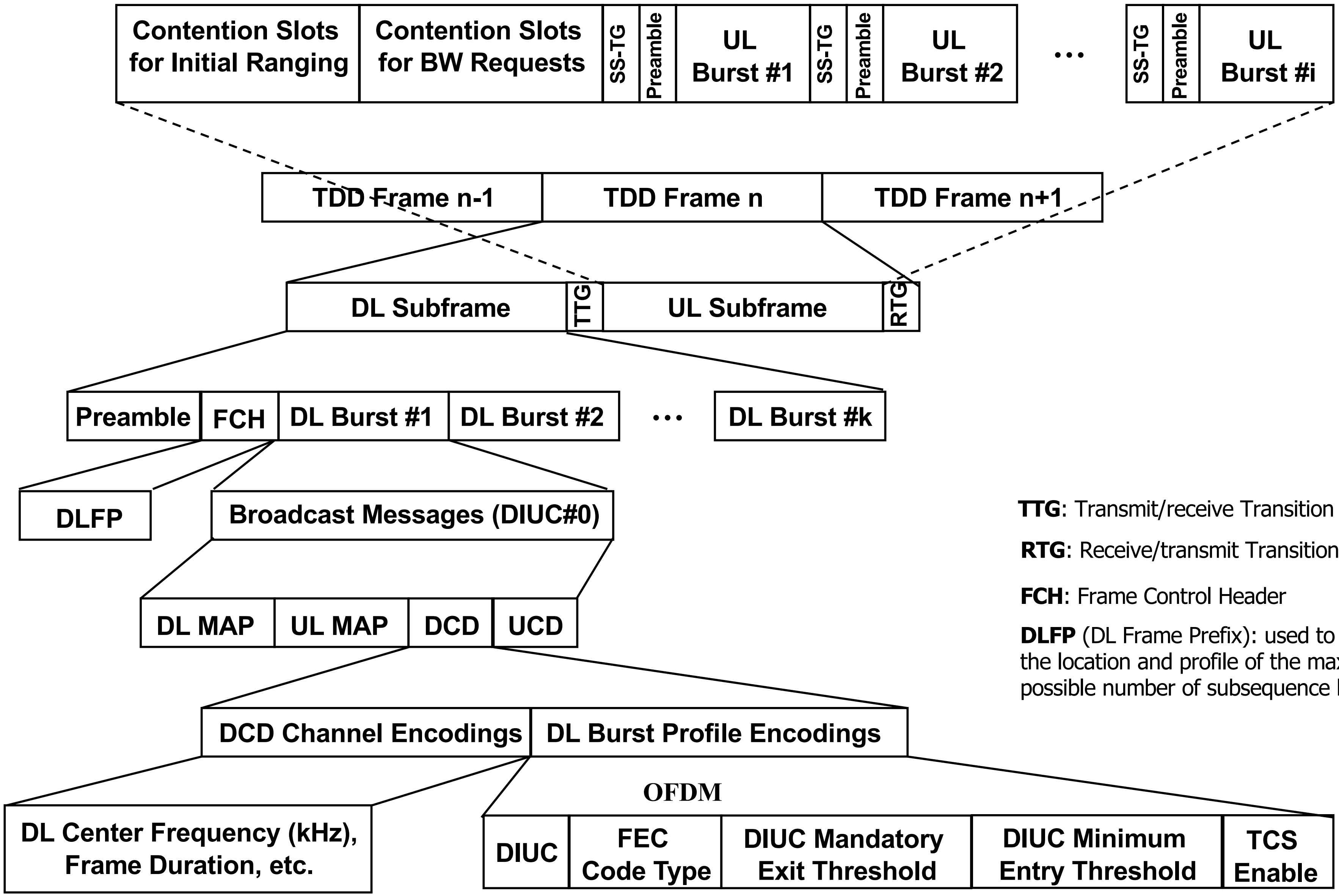
Uplink Subframe Structure

- Initial Maintenance Period
  - SSs send ranging requests
  - BS uses such requests to
    - determine network delay
    - request power changes
    - request downlink burst profile changes
  - Collisions can occur

Uplink Subframe Structure

- Request Contention Opportunities
  - SSs request bandwidth based on BS's multicast/broadcast polls
  - Collisions due to simultaneously SSs access
- Scheduled Data grants period
  - SS transmits data based on grants allocated by the BS
  - Scheduled Data period
    - separated by SS transition gap
    - (starts with a preamble to allow the new SS to synchronize)
  - No collision

Frame Format (TDD)



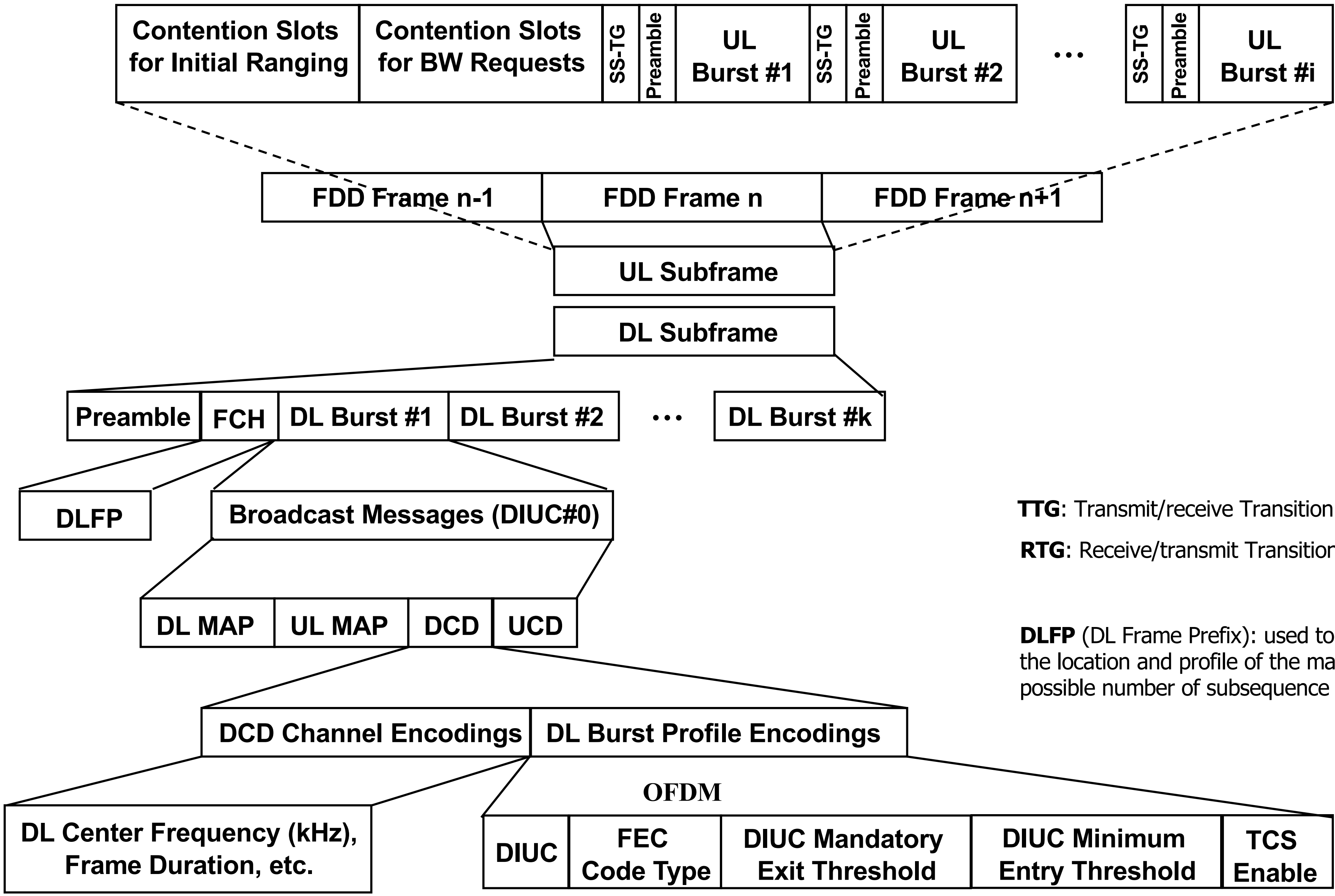
TTG: Transmit/receive Transition Gap

RTG: Receive/transmit Transition Gap

FCH: Frame Control Header

DLFP (DL Frame Prefix): used to specify the location and profile of the maximum possible number of subsequence bursts

Frame Format (FDD)



TTG: Transmit/receive Transition Gap

RTG: Receive/transmit Transition Gap

DLFP (DL Frame Prefix): used to specify the location and profile of the maximum possible number of subsequence bursts

Contention Resolution

- Contention resolution process:
  - based on a truncated binary exponential backoff, with
    - an initial backoff window
    - a maximum backoff window
  - algorithm is defined in the standard

Request-grant process

- Bandwidth request mechanism
  - Bandwidth is always requested on a connection (i.e., CID) basis.
  - Stand-alone BW Request
    - Incremental bandwidth Request
    - Aggregate bandwidth Request
  - Piggyback BW Request
    - Incremental bandwidth Request
  - BW Request can be transmitted in
    - Contention request opportunities: in Request Contention period
    - Contention-Free Request Opportunities: in predefined time slot

Request-grant process

- Bandwidth allocation
  - Grant Per Subscriber Station (GPSS)
    - BS allocates bandwidth for individual SSs
    - SS distributes bandwidth to each connection within the SS
  - Grant Per Connection (GPC) → removed in 802.16-2004
    - BS allocates bandwidth to individual connections (CID)
  - In 10 to 66 GHz bands, only GPSS is allowed
  - BS announces the allocated bandwidth in UL-MAP
  - bandwidth allocation is mainly based on
    - requested bandwidth
    - QoS parameters
    - available network resources

Service Flow Scheduling Service

- A service flow
  - a unidirectional flow of packets that provides a particular QoS
- Four types of service flows:
  - Unsolicited Grant Service (UGS)
    - real-time applications with constant bit rate (CBR)
  - Real-Time Polling Service (rtPS)
    - real-time applications with variable bit rate (VBR)
  - Non-Real-Time Polling Service (nrtPS)
    - non-real-time applications
  - Best Effort (BE) Service
    - applications that don't have any QoS requirements

Service Flow Scheduling Service

- Unsolicited Grant Service (UGS)
  - real-time service flows with periodic data packets of fixed size
  - SS
    - cannot use any contention request opportunities
    - cannot “steal bandwidth” to send another bandwidth request
    - cannot piggyback a request in the transmitted data
    - can requests a poll for non-UGS service by setting Poll-Me bit
    - can use Slip Indicator (SI) flag to update the state of UGS service flows
  - UGS service flow IE
    - UGS size
    - nominal grant interval
    - the tolerated grant jitter
    - request/transmission policy

Service Flow Scheduling Service

- Real-Time Polling Service (rtPS)
  - real-time service flows with periodic data packets of various sizes
  - SS
    - cannot use any contention request opportunities
    - can "steal" bandwidth if it is in the GPSS mode
    - can piggyback a BW Request on a data packet
    - can dynamically specify the size of the requested grant
  - Compared to UGS,
    - rtPS has additional overhead due to polling
      - BS should poll the SS frequently enough to meet the delay and bandwidth requirements of real-time applications
    - rtPS can handle variable grant sizes

Service Flow Scheduling Service

- Non-Real-Time Polling Service (nrtPS)
  - non-real-time service flows with data packets of various sizes
  - BS
    - needs to poll the SS on a regular basis (periodically or nonperiodically)
    - can send unicast request opportunities
  - SS
    - can use contention request opportunities
    - can "steal" bandwidth if it is in GPSS mode
    - can piggyback a BW Request on a data packet

Service Flow Scheduling Service

- Best Effort (BE) Service
  - service flows without QoS support
  - SS
    - issues its requests in a contention period
    - can "steal" bandwidth if it is in GPSS mode
    - can piggyback a BW Request on a data packet

Service Flow Scheduling Service

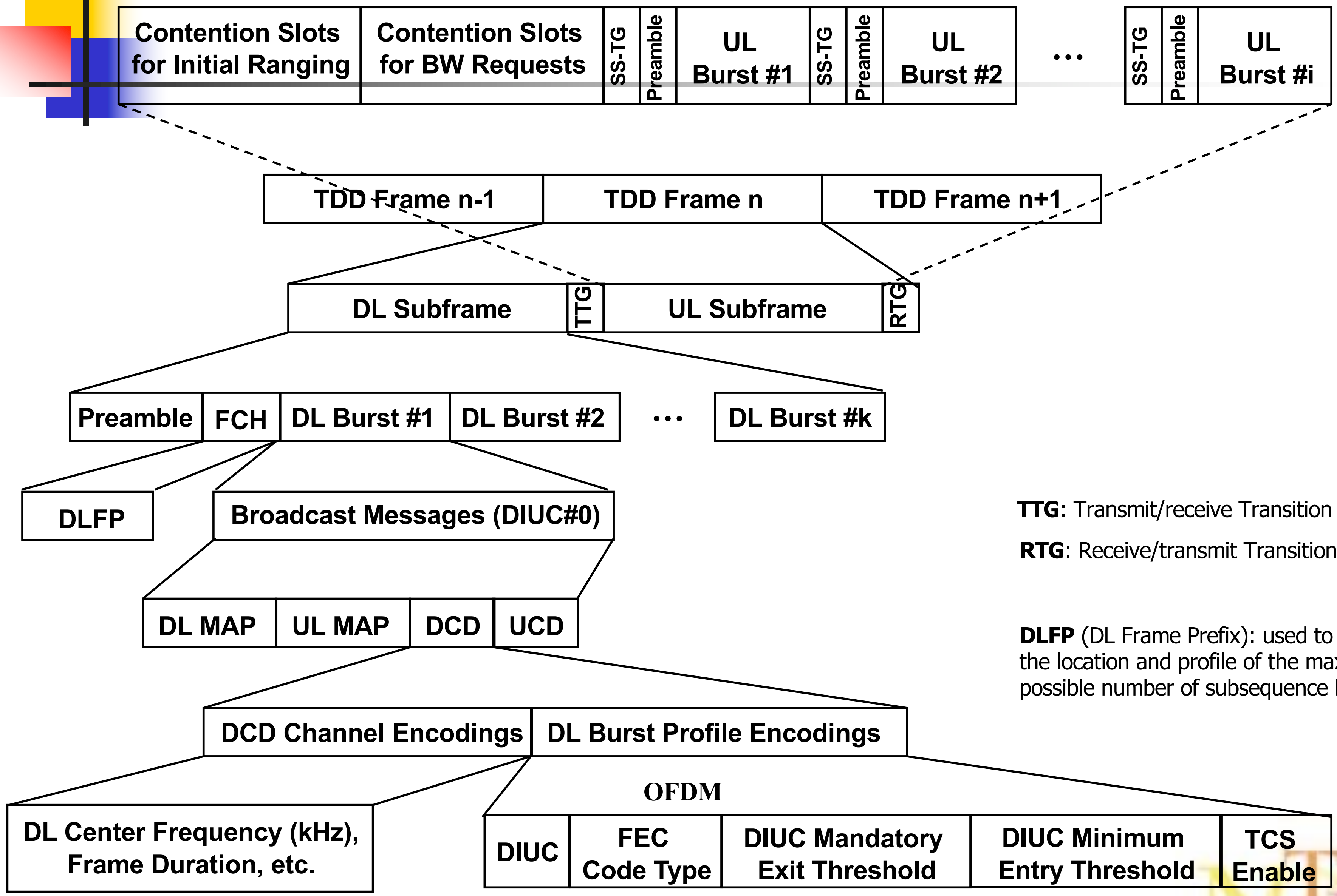
- Details of bandwidth allocation, scheduling, and reservation management intelligence are out of the standard's scope and are left to be vendor specific.

- The ability to employ different combinations of these access mechanisms allows vendors to
  - differentiate their products,
  - tailor solutions to unique needs and users,
  - optimize system performance, and
  - use different bandwidth allocation algorithms while maintaining consistent interoperability.

Network Entry and Initialization

- Steps required by an SS to enter the network
  - scan for a downlink channel and synchronize with the BS
    - acquire the channel control parameters from DL-MAP
  - searches for an uplink Channel Descriptor to obtain transmit parameters
  - adjust local parameters (e.g., transmit power)
  - negotiate basic capabilities
  - authorize SS and perform key exchange
  - perform registration
  - establish IP connectivity
  - get timing information from BS
  - get operational parameters from BS

Frame Format (TDD)

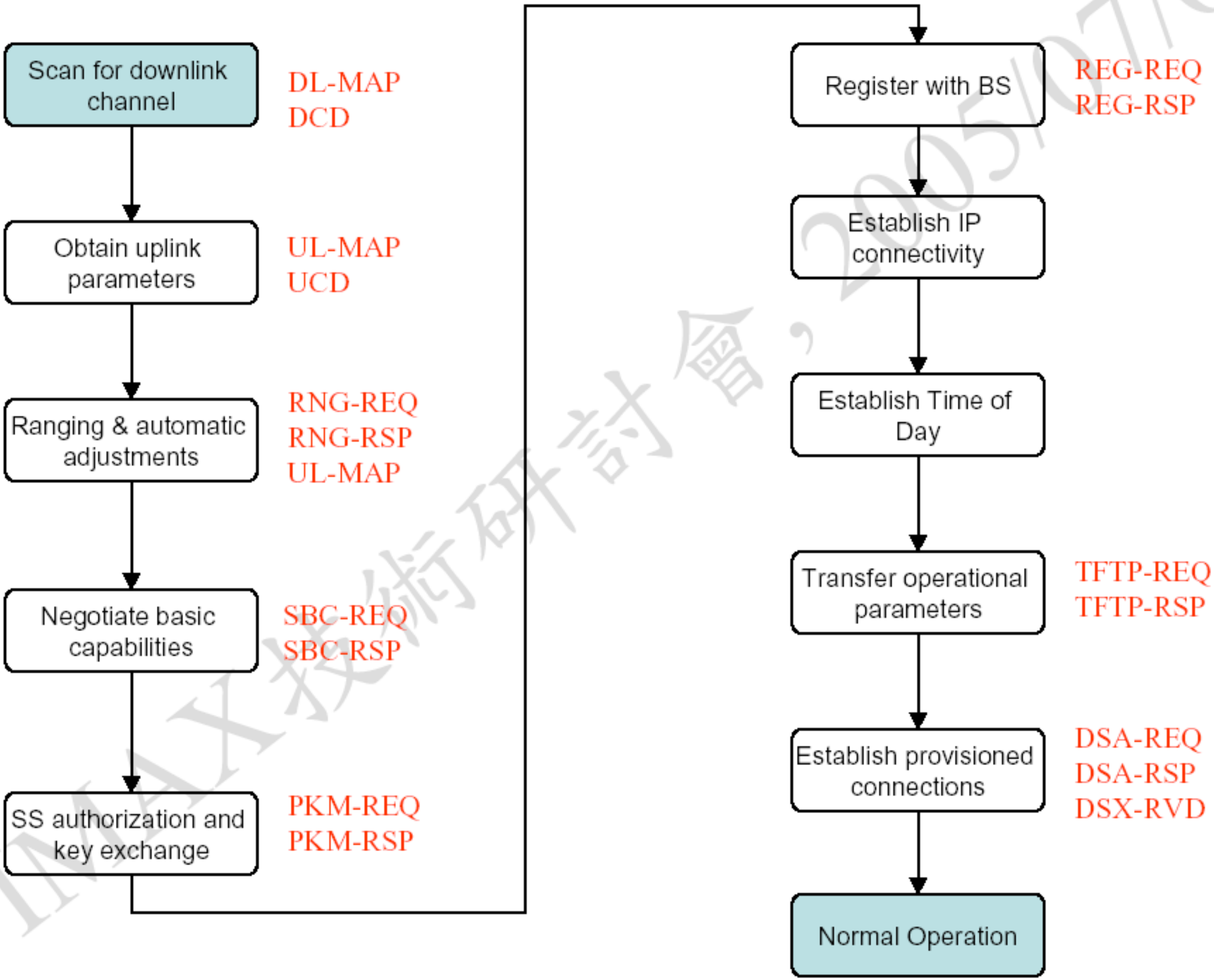


TTG: Transmit/receive Transition Gap

RTG: Receive/transmit Transition Gap

DLFP (DL Frame Prefix): used to specify the location and profile of the maximum possible number of subsequence bursts

Network Entry and Initialization



QoS Support

- Each network application, first, has to register with the network.
- The network will associate the application with a service flow by assigning an unique Service Flow ID (SFID).
- All packets must be tagged with this assigned SFID in order for the network to provide the appropriate QoS.
- When the application wants to send data packets, it is required to establish a connection with the network and receives a unique CID assigned by the network.
- Therefore, the IEEE 802.16 data packets include both CID and SFID.

QoS Provision

- Service model
  - SS:
    - Subscribe with the ISP to receive network service
    - Establish connection with the network when they want to transmit data
    - Two ways to define a QoS parameter set:
      - explicitly specifying all traffic parameters, indirectly referring to a set of traffic parameters via specifying a Service Class Name
      - specifying a Service Class Name along with modifying the parameters
  - Network:
    - Makes decision based on given QoS parameter set and the available network resources

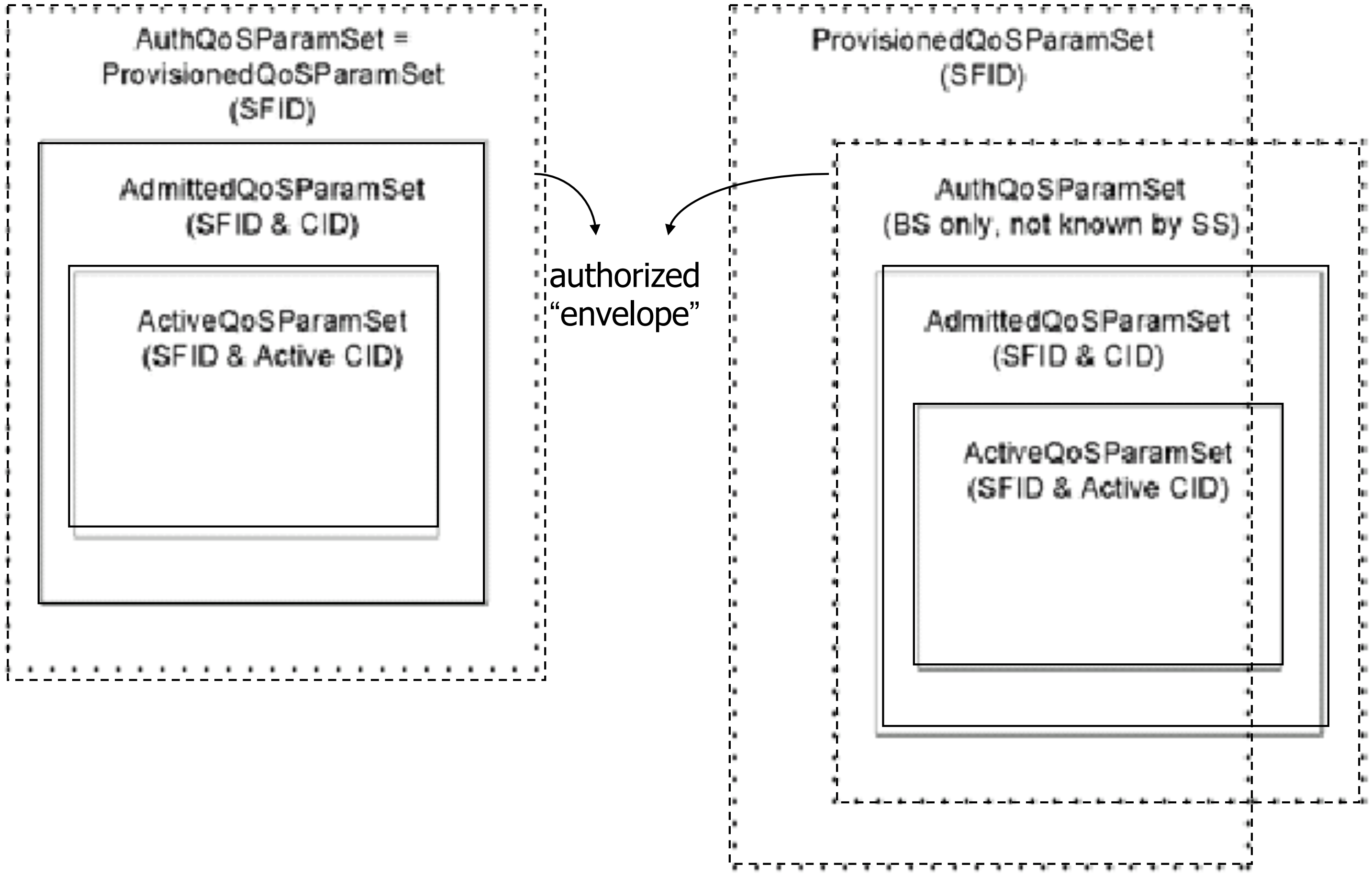
QoS Provision

- Set of tools that support UL and DL QoSs:
  - configuration and registration functions for service flows
  - a signaling function for dynamically establishing QoS based service flows and traffic parameters
  - scheduling and QoS traffic parameters for uplink and downlink service flows
  - grouping of service flow properties into service classes to allow grouping of requests

QoS Provision Model

- Sets of QoS parameters:
  - *ProvisionedQoSParamSet:*
    - A set of external QoS parameters provided to the MAC
  - *AdmittedQoSParamSet:*
    - A set of QoS parameters for which the BS/SS are reserving resources.
  - *ActiveQoSParamSet:*
    - A set of QoS parameters that reflect the actual service being provided to the associated active service flows.

QoS Provision Model



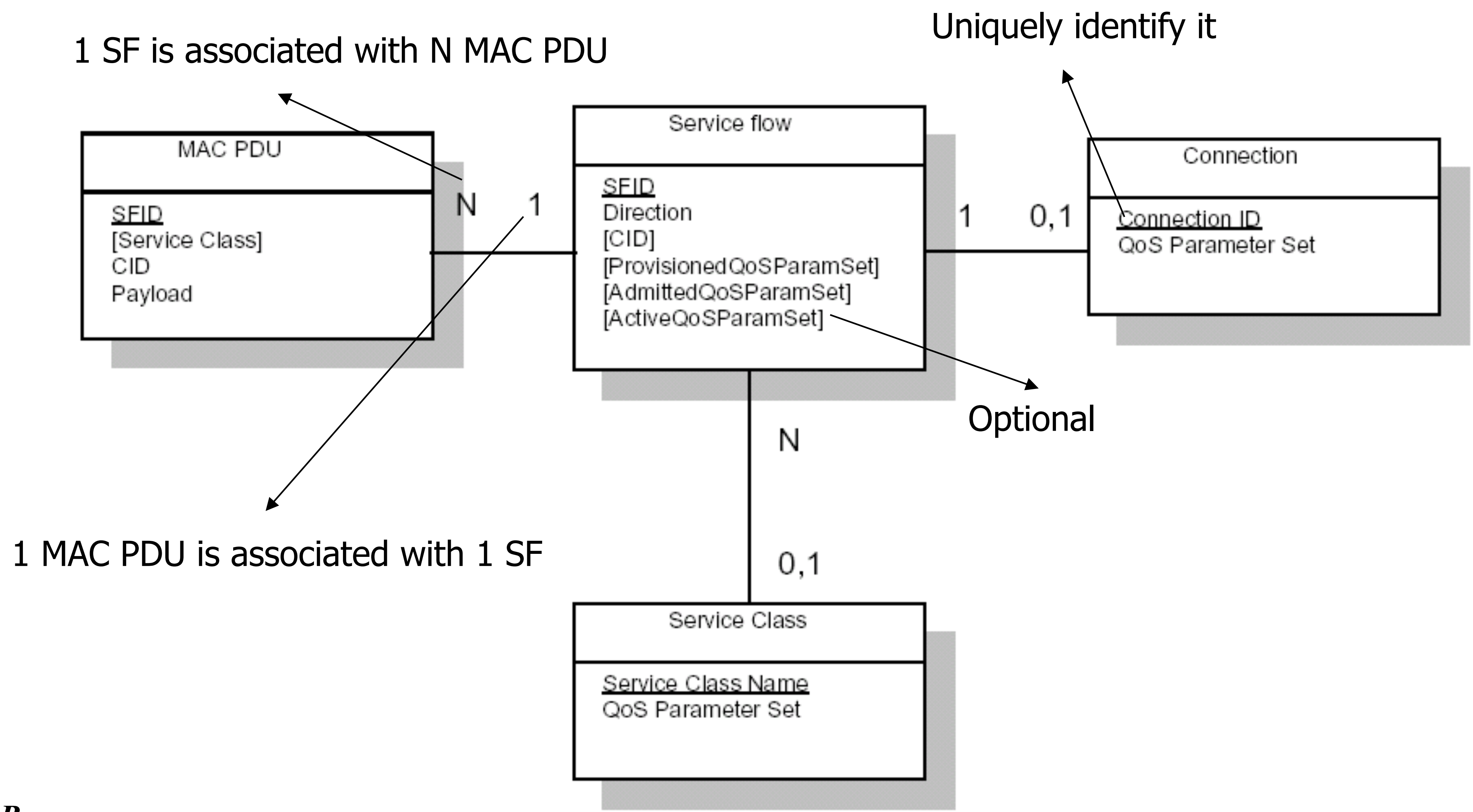
(A) Provisioned Authorization Model “Envelopes”

(B) Dynamic Authorization Model “Envelopes”

QoS Provision Model

- The standard assumes an Authorization Module in the BS that approves or denies every change of QoS parameters associated with a service flow.
- "envelope" model
  - used to limit the possible values of the AdmittedQoSParamSet and ActiveQoSParamSet
- Two models:
  - Provisioned Authorization Model
    - ProvisionedQoSParamSet determines the authorized “envelope”
  - Dynamic Authorization Model
    - authorization module determines the authorized “envelope”

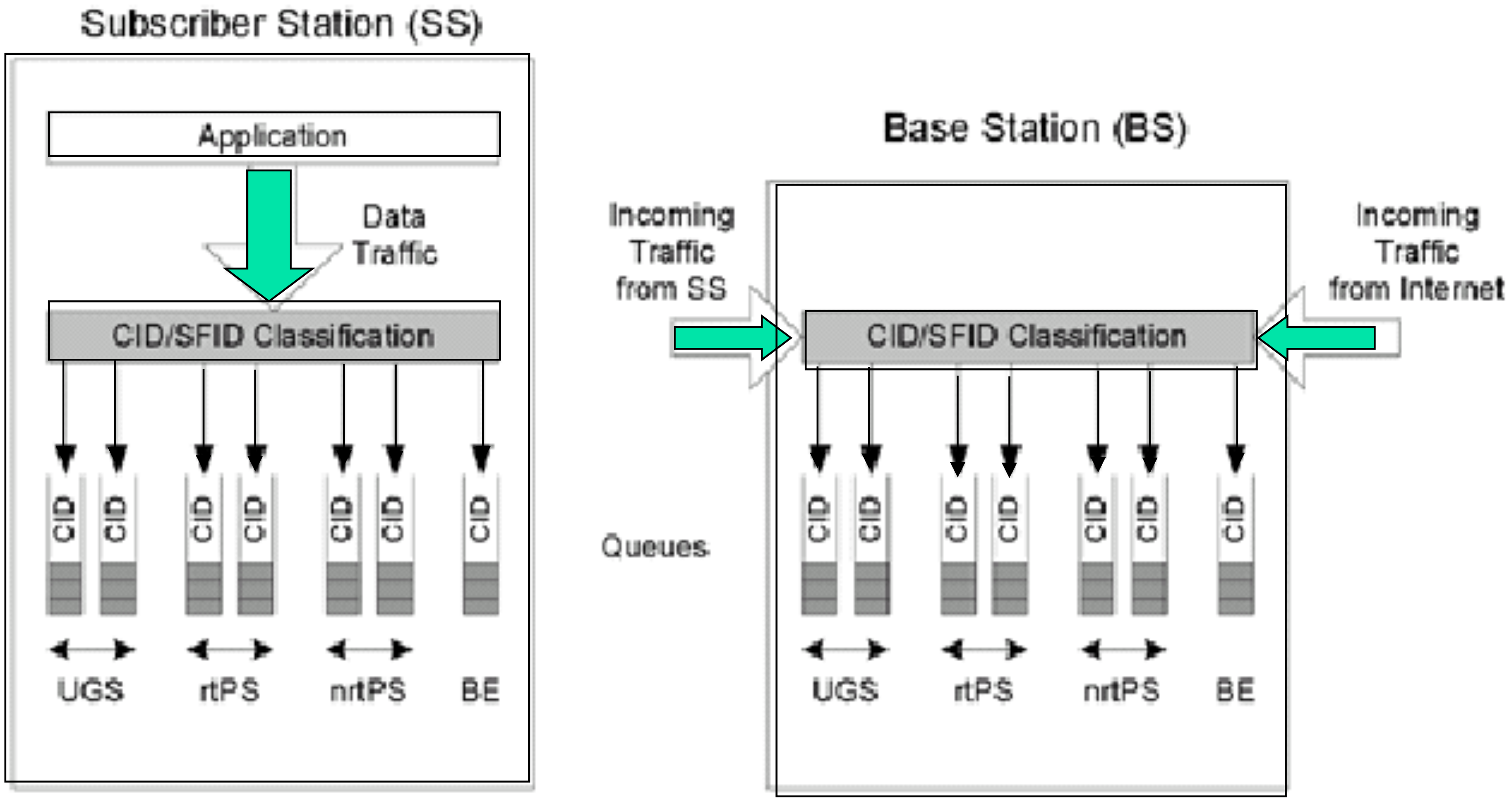
Object Model



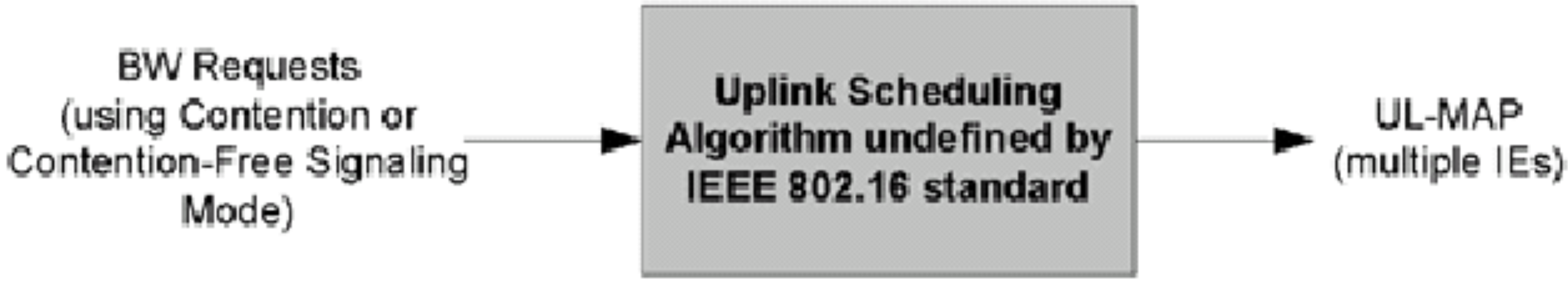
QoS Mechanisms

- Classification
  - identifies packets based on CID and SFID, and forwards packets to corresponding queues
- Channel Access
  - uses TDM for the downlink and TDMA for the uplink
  - both TDM and TDMA are collision-free channel access schemes which support strict QoS requirements
- Packet Scheduling
  - allocates bandwidth for connections in terms of the number of time slots allocated per connection on the TDM channel
  - determines when a connection is allowed to transmit the data
  - the packet scheduling algorithm is not defined in the spec.

Classification Module



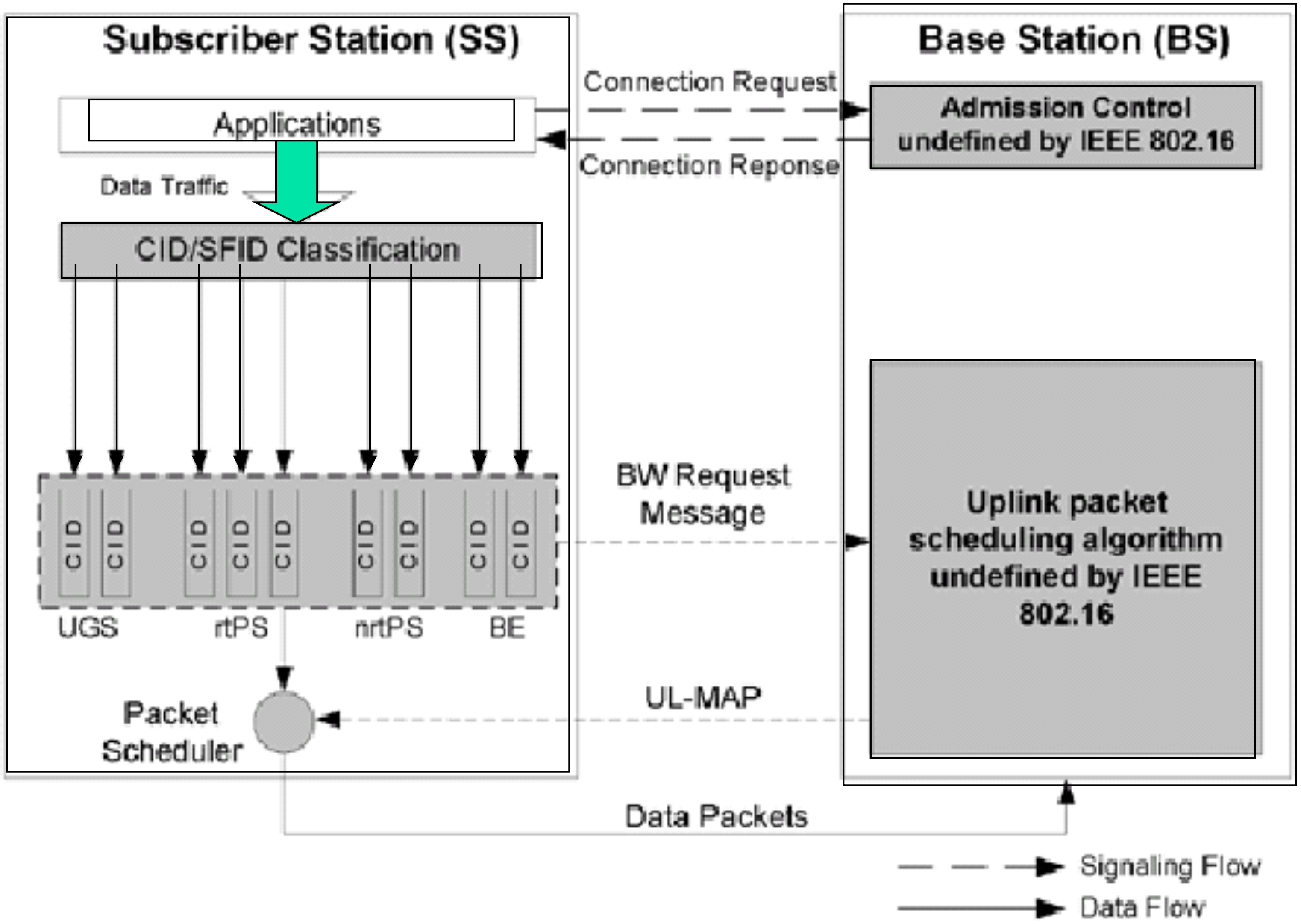
Uplink Scheduling Process



QoS Mechanisms

- Two modes of allocating bandwidth:
  - GPC:
    - uplink scheduling algorithm distributes the bandwidth on a per-connection basis
    - packet scheduling module at each SS is simple because it just follows the UL-MAP
  - GPSS:
    - uplink packet scheduling distributes bandwidth on a per-station basis.
    - packet scheduling algorithm at each SS needs to allocate bandwidth to connections

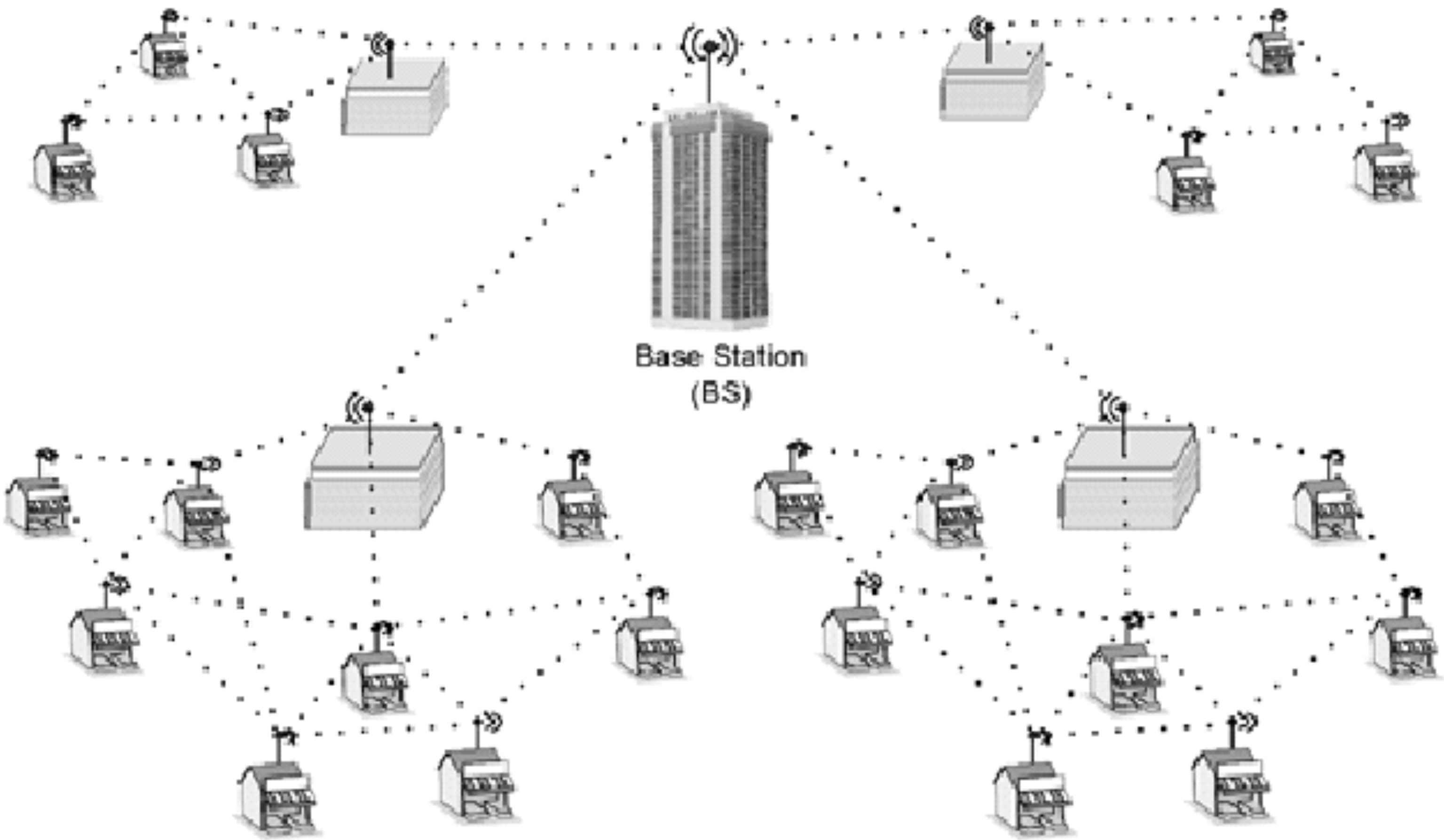
802.16 QoS Architecture



802.16a

- Mesh network topology
  - direct line of sight between BS and SS is not required
  - SSs can communicate with each other
  - support of a mesh topology is more complex since we need to consider
    - routing,
    - collision avoidance and resolution between adjacent SSs,
    - synchronization,
    - etc.

IEEE 802.16a Mesh Network Topology



802.16a MAC Discussions

- Scheduling mechanisms
  - distributed
  - centralized
- Both mechanisms can employ with
  - directional antennas,
  - adaptive antenna systems, or
  - regular omni-directional antennas

802.16a MAC Discussions

- Distributed Scheduling mechanisms
  - SSs need to coordinate their transmissions with their neighbors that are up to two hops away
  - broadcast available resources/requests/grants to neighbors
  - SSs need to ensure that their resulting transmissions do not collide with already scheduled data and control traffic
  - can be executed in
    - coordinated manner
      - employs scheduling packets that are transmitted in collision-free, regular periods within scheduling control subframes
    - uncoordinated manner
      - allows contention-based access while avoiding conflicts with the schedules established using the coordinated scheme
      - the SS backs off and tries to retransmit in case of collisions

802.16a MAC Discussions

- Centralized Scheduling mechanisms
  - BS allocates all resources based on resource requests from all the SSs that are up to a predetermined hop count from this BS.
  - BS announces its allocation to all SSs within its hop range, the SSs forward the allocation to other neighbor SSs
  - the mechanism assumes that SSs know their hop count from the BS in order to avoid multiple redundant transmissions of the same data
  - It is suggested that the grant messages contain parameters required for SS to compute its allocated resources, instead of the actual granted schedule