Chapter 3.

Cellular Systems

Outline

- Cellular Concept
- Handoff Management
- Power control
- Channel Allocation

- Cellular Systems

Cellular vs. Wireless LAN

The cellular industry

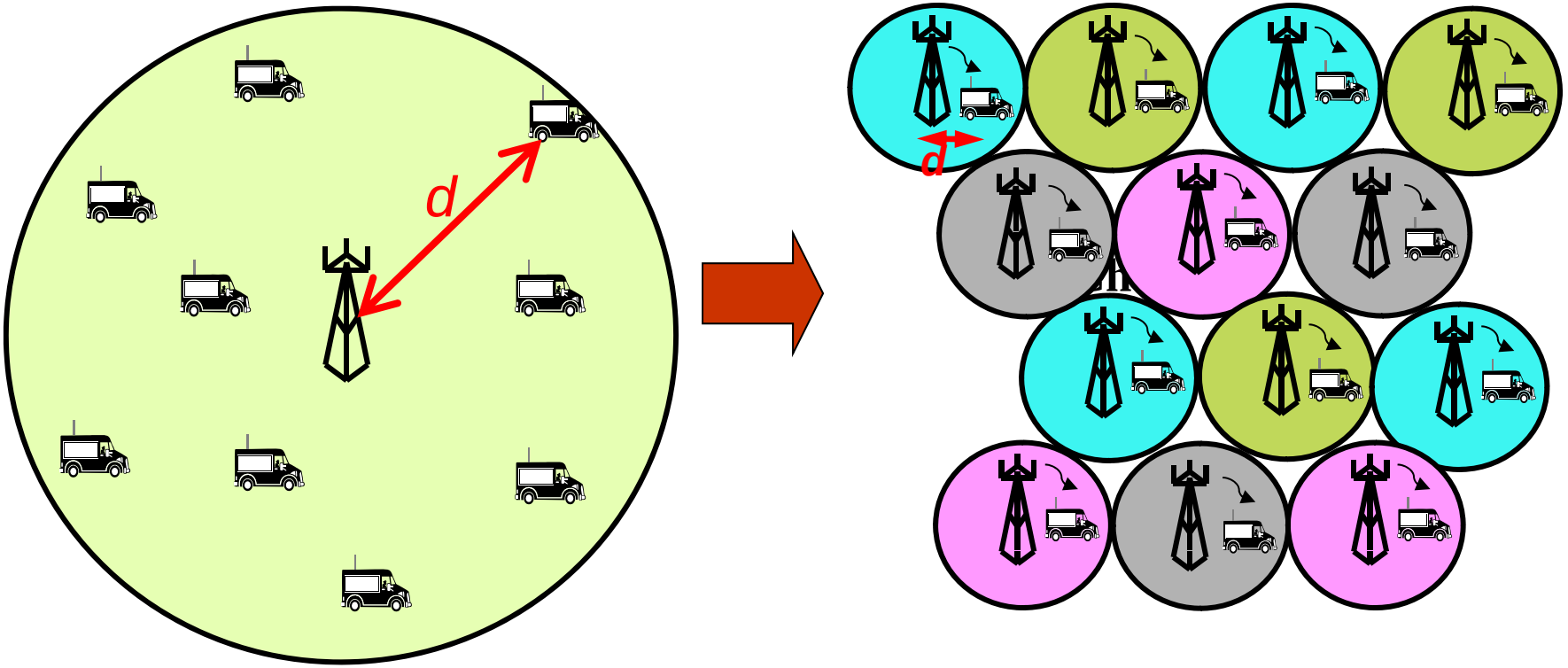
- Wide area coverage.
- Global roaming.
- Mobile users at vehicular speeds.
- Subscription-based.
- Licensed bands.

The wireless LAN industry

- Local coverage.
- No handoff or roaming.
- Users in hot-spot area
- Revenue through equipment sales.
- Unlicensed bands.

Cell Structure (1/2)

- Replace single high power transmitter covering a large service area with lots of low power transmitters (base stations) each covering a fraction of the service area (cell)
- BS relays information to and from a transmitting/receiving unit (mobile station)



Cell Structure (2/2)

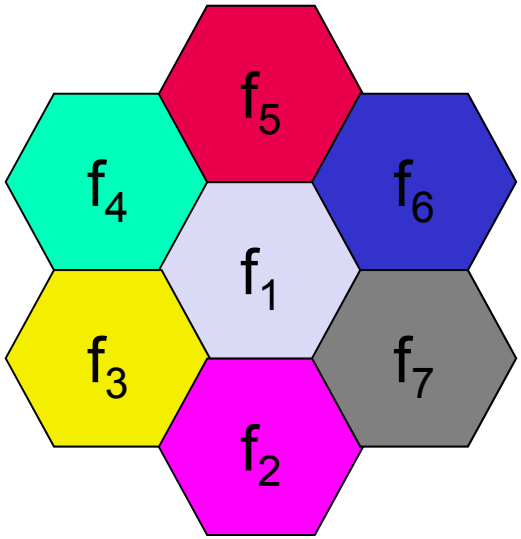
- Advantages of cell structures:
  - Higher capacity, higher number of users
  - Less transmission power needed
  - More robust, decentralized (one BS vs. many BSs)

- Problems:
  - Fixed network is needed for BSs
  - Handoff necessary
  - Interference with neighboring cells

- Cell sizes from 100s m in cities to10s km on the country area

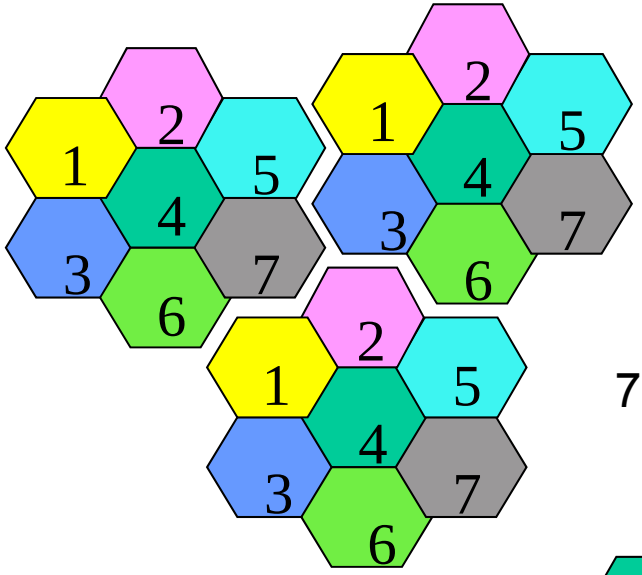
Frequency Planning (1/2)

- Transmit power drops off with distance.
- Cell structure allows reuse of the same frequency in sufficiently distant cells
- Each base station (BS) is allocated a subset of carrier frequencies
- Nearby BSs are allocated a different subset to avoid interference

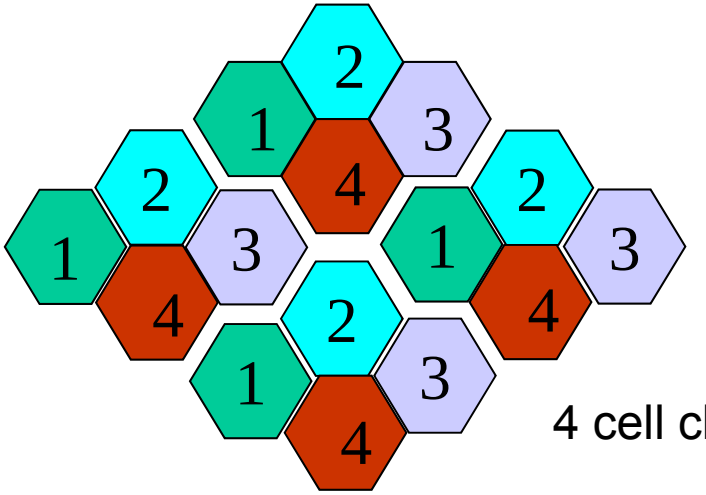


Frequency Planning (2/2)

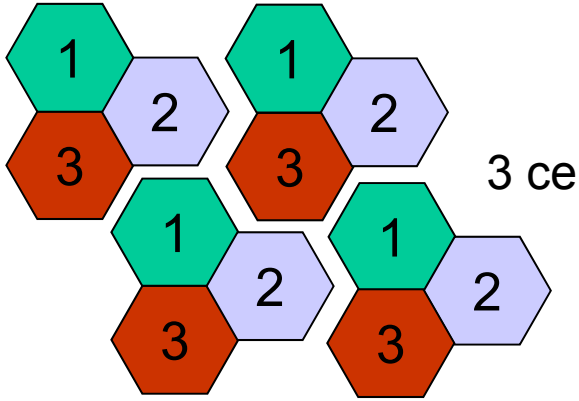
- Total set is allocated to each cluster consisting of N cells
  - 1/N is called “reuse factor”



7 cell cluster



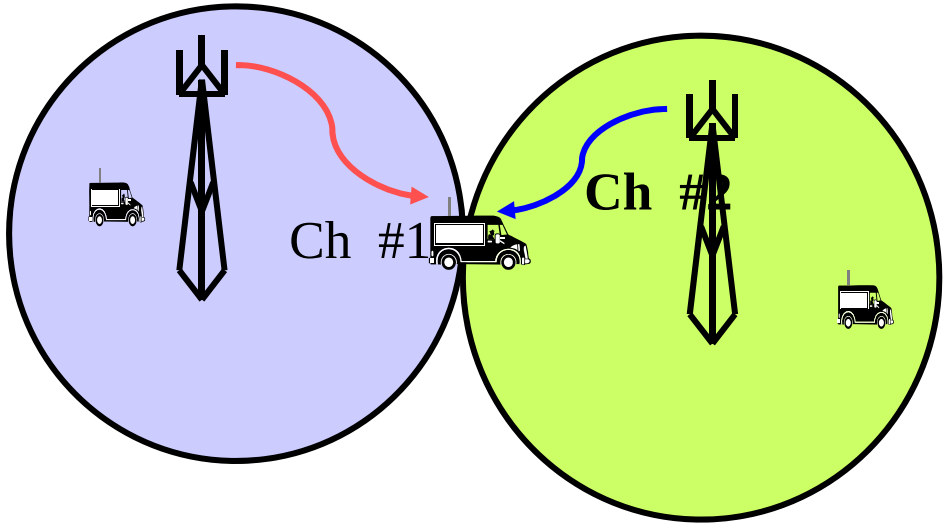
4 cell cluster



3 cell cluster

Hand Off

- Transfer of MH to a new cell when it crosses cell boundary during a call → identify new BS & assign new channel



Handoff

- Handoff should be initiated at a carefully chosen signal level to avoid triggering handoff due to momentary fades
- Hard and soft handoff
  - hard handoff : old connection is broken before new connection is established (*Break-before-make*)
  - soft handoff : new connection is established before old connection is broken (*Make-before-break*)

Handoff Strategies

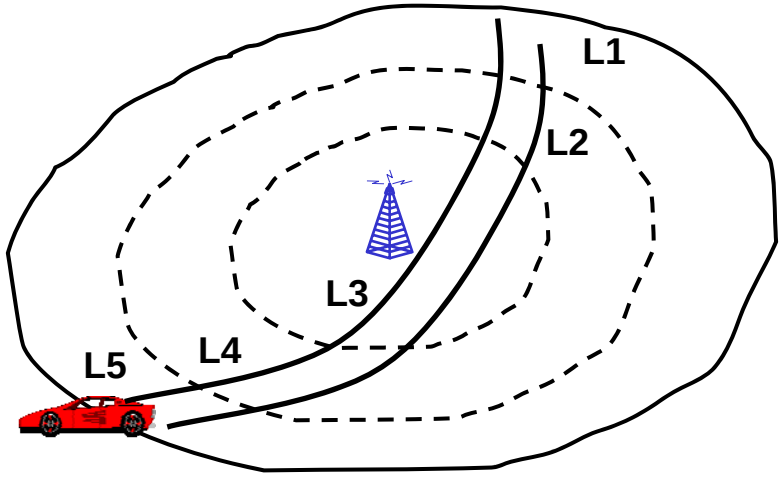
- Network Controlled Handoff (NCHO)
  - Used in 1G analog systems
  - Link quality is monitored by serving BS and surrounding BSs
  - Handoff decision is made by the network
- Mobile Assisted Handoff (MAHO)
  - Used in 2G digital systems
  - Both the MH and serving BS measure link quality, but only MH measures link quality of surrounding BSs
  - MH periodically sends link quality measurements to the serving BS
  - Handoff decision is made by the network
- Mobile Controlled Handoff (MCHO)
  - Used in some newer digital systems
  - Link quality measurements are done as in MAHO
  - Serving BS sends link quality measurements to MH
  - Handoff decision is made by the MH

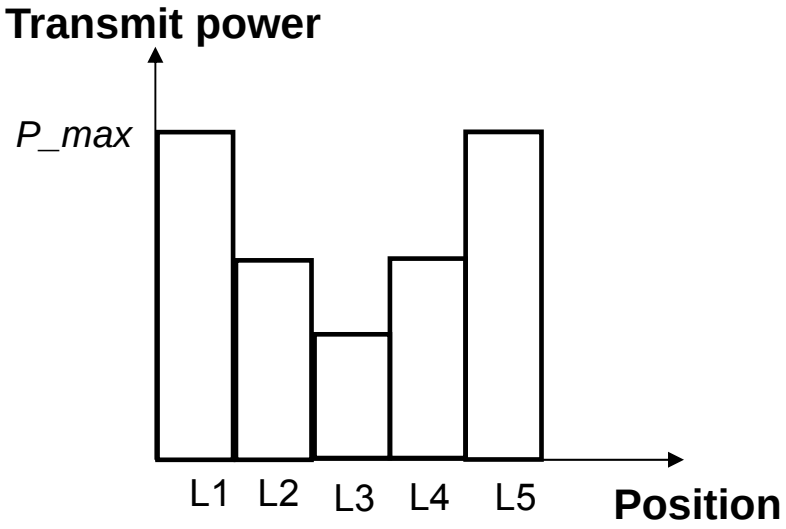
Handoff Triggering Strategies

- RSS (Relative signal strength) → choose strongest received BS
  - too many unnecessary handoffs
- Relative RSS with threshold → handoff if
  - *current* BS's *RSS < threshold &*
  - *current* BS's *RSS < other BS's RSS*
- Relative signal strength with handoff margin → handoff if
  - *(other BS's RSS - current* BS's *RSS) > handoff margin*
- Relative RSS with margin & threshold → handoff if
  - *current BS's RSS < threshold &*
  - *(other BS's RSS - current* BS's *RSS) > handoff margin*

Power Control (1/3)

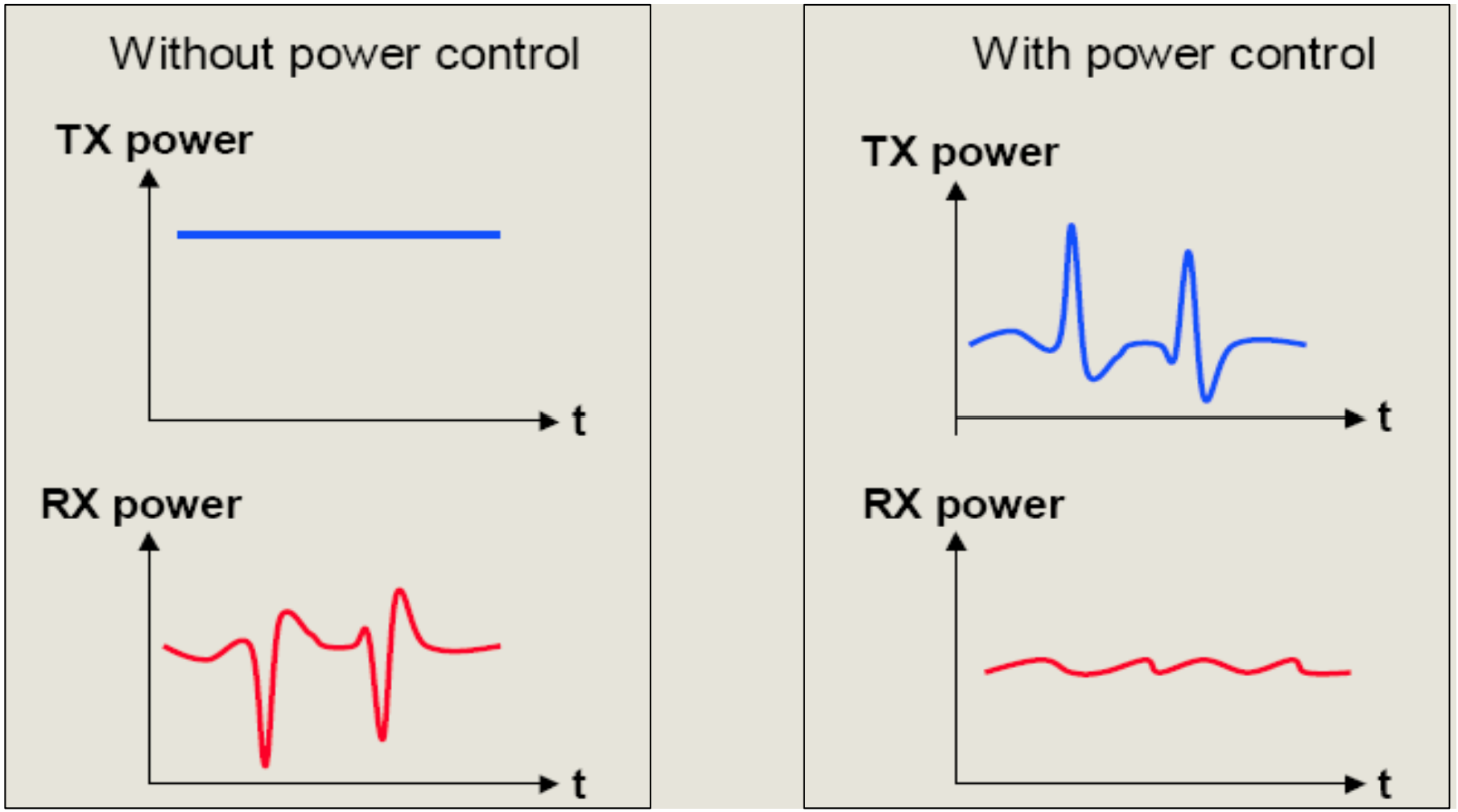
- Received transmit power may fluctuate due to propagation conditions and host mobility
- Power control from BS aims to adjust transmit power of mobile hosts to maintain an approximately equal receive level
- A mobile adjusts its transmit power within a predefined limit, *P_max*





Power Control (2/3)

- Effect of power control
  - Power Control “Removes” Fading



Power Control (3/3)

- Open-loop power control
  - Achieved by using channel estimation in accordance with characteristics of received signal
  - No feedback info, thus may not accurate
  - Simple and quick control possible
- Closed-loop power control
  - Decision is based on the real measurements
  - BS and mobile exchange measured link quality
  - More accurate power control possible

Channel Allocation (1/3)

- How to assign channels to a requesting call?
- Goal : maximize spectral efficiency
  - probability of new call blocking
  - probability of forced termination
  - link quality
- Channel Allocation schemes
  - Fixed Channel Allocation
  - Dynamic Channel Allocation
  - Flexible Channel Allocation

Channel Allocation (2/3)

- Fixed Channel Allocation
  - Each cell is statically allocated a subset of channels
  - A requesting call is blocked if no available channel in the cell
  - Simplified channel management
  - Allocated channels have optimum reuse distance
  - Good when traffic pattern is statistically unchanging

- Dynamic Channel Allocation
  - Channels are not allocated to cells permanently
  - MSC (mobile switching center) allocates a channel to a call from the global pool
  - Reduces probability of blocking and increases system capacity → all channels available to all cells

Channel Allocation (3/3)

- Flexible Channel Allocation
  - Combine aspects of FCA and DCA
  - Each cell is assigned a fixed set of channels
  - A pool of channels is reserved for flexible assignment

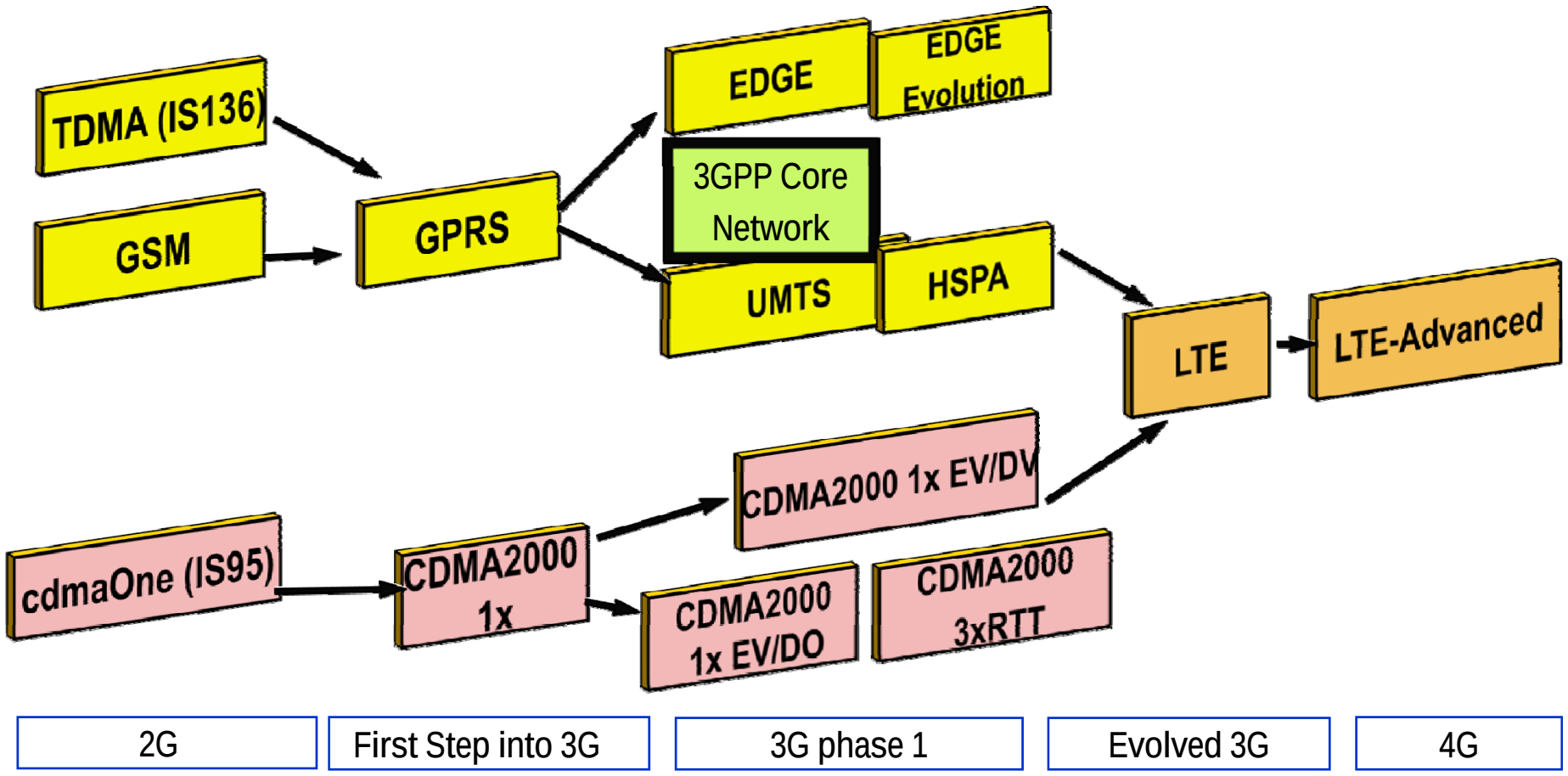
    → MSC assigns these channels

Cellular Systems

Cellular Generations

- 1G
  - Analog, circuit-switched
- 2G
  - Digital, circuit-switched,10 Kbps
- 2.5G
  - Digital, packet-switched, 40-400 Kbps
- 3G
  - Digital, packet-switched, 0.4 – 2 Mbps
- 4G
  - Data rate 1Gbps

Cellular Generations (continued)



1G Cellular Systems

- Analog telecommunications standards that were introduced in the 1980s
- Used FDMA and FDD (allocate 25 MHz bandwidth in each direction)
- Spectra in the 800 and 900 MHz bands.
- No vision for a universal service, hence different countries adopted different standards.

- 1G often refers to analog cellular services
- Some well known systems:
  - AMPS (US), NMT (Sweden), E-TACS (UK)

2G Cellular Systems

- Digital systems
- Introduce data services for mobile - SMS (short message service)

- Major standards:
  - TDMA based:
    - GSM (EU, Asia): accounts for over 80% of all subscribers
    - IS-136 (North American TDMA) : once prevalent in USA but most have migrated to GSM
  - CDMA based:
    - IS-95 (US, Asia) : accounts for about 17% of all subscribers

2G Cellular Systems - GSM

- Global System for Mobile communications
- The most popular standard for mobile telephony systems in the world
- Joint European effort beginning in 1982 to develop a standard for a mobile telephone system that could be used across Europe (i.e., seamless roaming across Europe)
- Pioneered low-cost implementation of SMS that has seen spectacular success by teenagers
- Services first launched in Finland (1991)

2G Cellular Systems - IS-95

- Interim Standard 95, aka cdmaOne as the brand name
- 1st CDMA-based digital cellular standard by Qualcomm
- First deployment in Hong Kong in1994
- Major success in Korea (1M subscribers by 1996)
- Used by Verizon and Sprint in US
- Evolution fixes bugs and adds data
  - IS-95A provides data rates up to 14.4 kbps
  - IS-95B provides data rates up to 64 kbps

2.5G Cellular Systems

- Once the world view was simple: go from 2G to a wonderful suite of new services under the umbrella of “3G”
- The schedule for 3G did not meet the demand for new services
- So interim solutions were devised for high-speed data transfer over upgraded existing 2G networks – called 2.5G
  - 1x-RTT for CDMA2000
  - GPRS (2.5G) and EDGE (2.75G) for GSM

Why 3G?

2G digital cellular is already very popular and successful.

Why further changes?

- Lack of a single worldwide radio band
- Lack of a single worldwide technology
- Circuit-switched service uses spectrum resources inefficiently for bursty data
  - Internet popularity motivates packet technology
  - Voice via packet transmission gaining interest

3G Vision

- *Universal global roaming*
- Voice quality comparable to the public switched telephone network
- Multimedia (voice, data & video) support
- Increased data rates: 2 Mbps
- Support for both packet switched and circuit switched data
- More efficient use of the available spectrum

3G Partnership Projects

- A collaboration among groups of telecommunications associations to make a globally applicable 3G mobile phone system specification

- 2 Partnership Projects
  - 3GPP (3G Partnership Project)
    - Standardization group for UMTS, the set of 3G standards based on earlier 2G GSM technology.
    - Leverages GSM's dominant position
  - 3GPP2 (3G Partnership Project 2)
    - The standardization group for CDMA2000, the set of 3G standards.
    - Evolution from original Qualcomm CDMA (cdmaOne or IS-95)

3G Transitional (3.5G, 3.75G, 3.9G) Systems

- 3GPP family
  - HSPA
    - HSDPA
    - HSUPA – named by Nokia. 3GPP uses another name - Enhanced Uplink (EUL)
  - HSPA+
  - LTE (3.9G)
- 3GPP2 family
  - EV-DO Rev. A, EV-DO Rev. B
- Other
  - Mobile WiMAX (IEEE 802.16e)

4G Systems

- LTE Advanced
  - The first release LTE does not meet the requirements defined by ITU such as peak data rates up to 1 Gbps
  - Industry and standardization organizations therefore started to work on 4G access technologies

- WiMAX family
  - IEEE 802.16m - Advanced air Interface with data rates of 100 Mbps mobile and 1 Gbps fixed

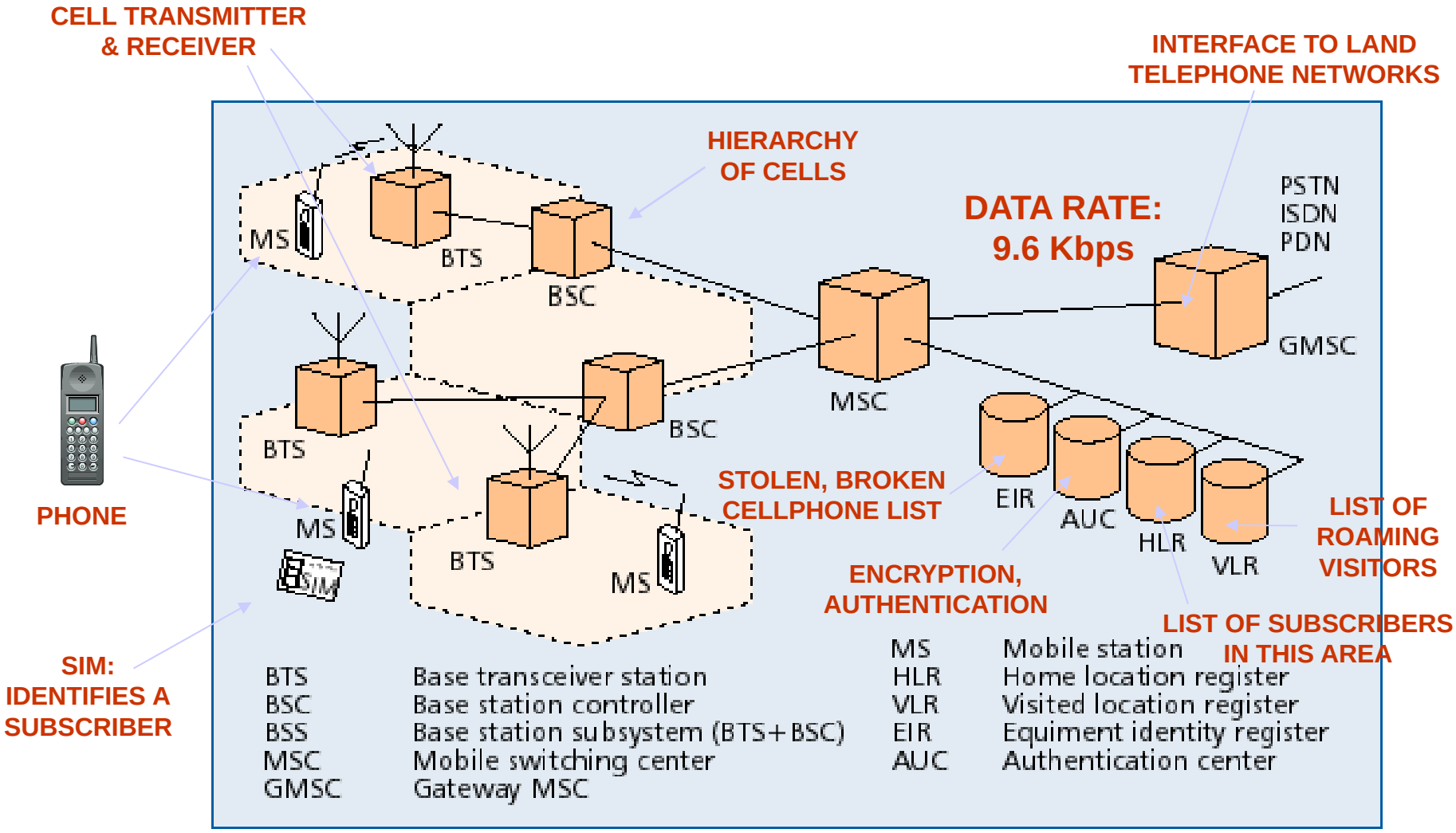
GSM

Architecture of GSM system

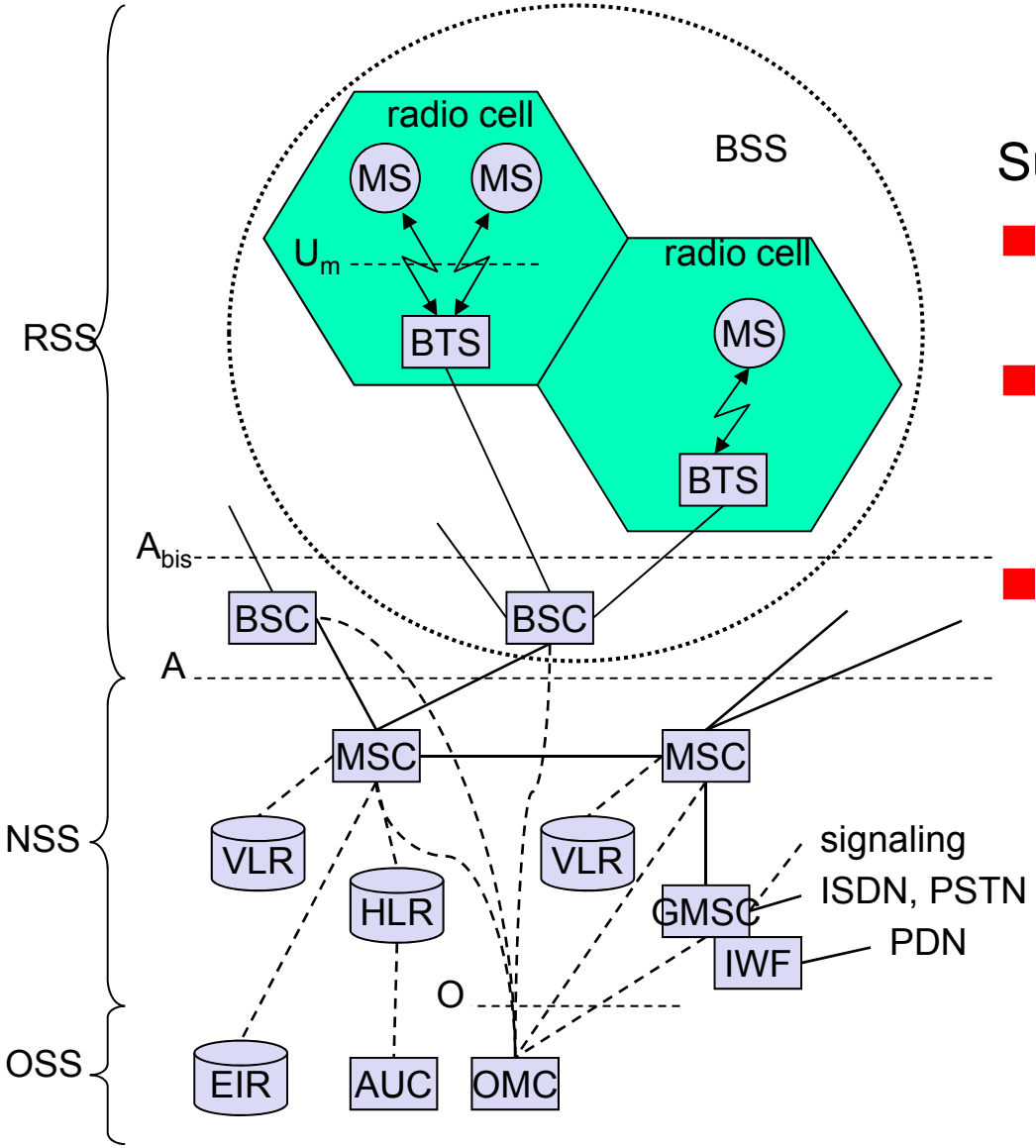
- Components
  - MS (mobile station)
  - BS (base station)
  - MSC (mobile switching center)
  - LR (location register)

- Subsystems
  - RSS (radio subsystem): covers all radio aspects
  - NSS (network and switching subsystem): call forwarding, handover, switching
  - OSS (operation subsystem): management of the network

GSM Architecture



GSM Architecture (continued)



Subsystems

- RSS (radio subsystem): covers all radio aspects
- NSS (network and switching subsystem): call forwarding, handover, switching
- OSS (operation subsystem): management of the network

GSM - Radio Subsystem (RSS)

- Radio Subsystem (RSS) comprises the cellular mobile network up to the switching centers
- Components
  - *MS* (Mobile Station)
    - Communicates across air interface with BTS
  - *BSS* (Base Station Subsystem)
    - *BTS* (Base Transceiver Station) - radio components including sender, receiver, antenna
    - *BSC* (Base Station Controller) - switching between BTSs, controlling BTSs, managing of network resources

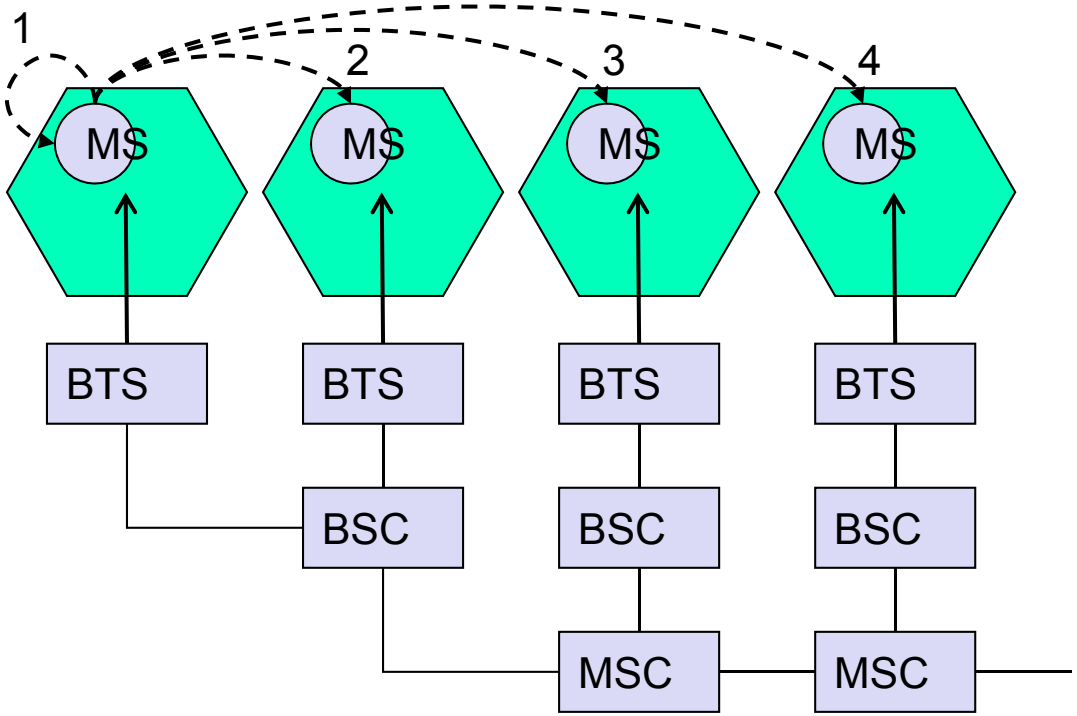
GSM - Network and Switching Subsystem (NSS)

- NSS is the main component of GSM - switching, mobility management, interconnection to other networks, system control
- Components
  - Mobile Services Switching Center (MSC)
    - switching functions
    - additional functions for mobility support
    - management of network resources
    - interworking functions via Gateway MSC (GMSC)
    - integration of several databases
    - several BSCs can belong to a MSC
  - Home Location Register (HLR)
    - central master database containing user data, permanent and semi-permanent data of all subscribers assigned to the HLR
    - one provider can have several HLRs
  - Visitor Location Register (VLR)
    - local database for data about all users currently in the domain of VLR
    - under control of MSC

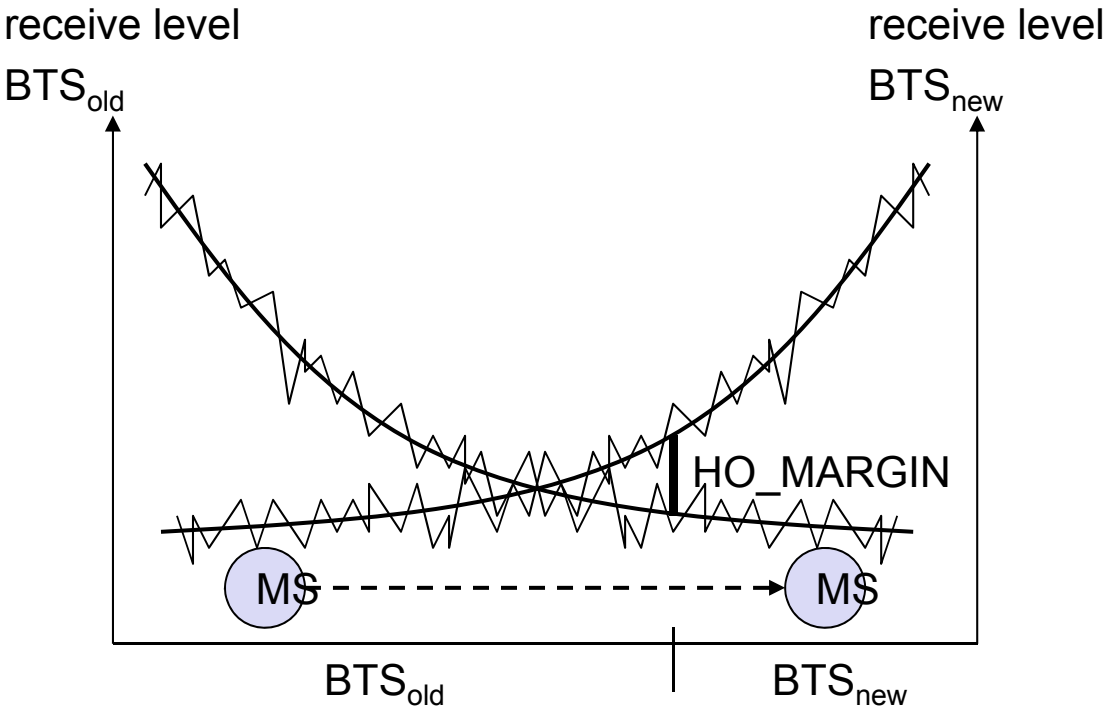
GSM - Operation Subsystem (OSS)

- OSS enables centralized operation, management, and maintenance of all GSM subsystems
- Components
  - Authentication Center (AUC)
    - generates user specific authentication parameters on request of VLR
    - authentication parameters used for authentication of mobile terminals and encryption of user data on the air interface
  - Equipment Identity Register (EIR)
    - registers GSM mobile stations and user rights
    - stolen or malfunctioning mobile stations can be locked
  - Operation and Maintenance Center (OMC)
    - Traffic monitoring, status report of network entity, billing,….

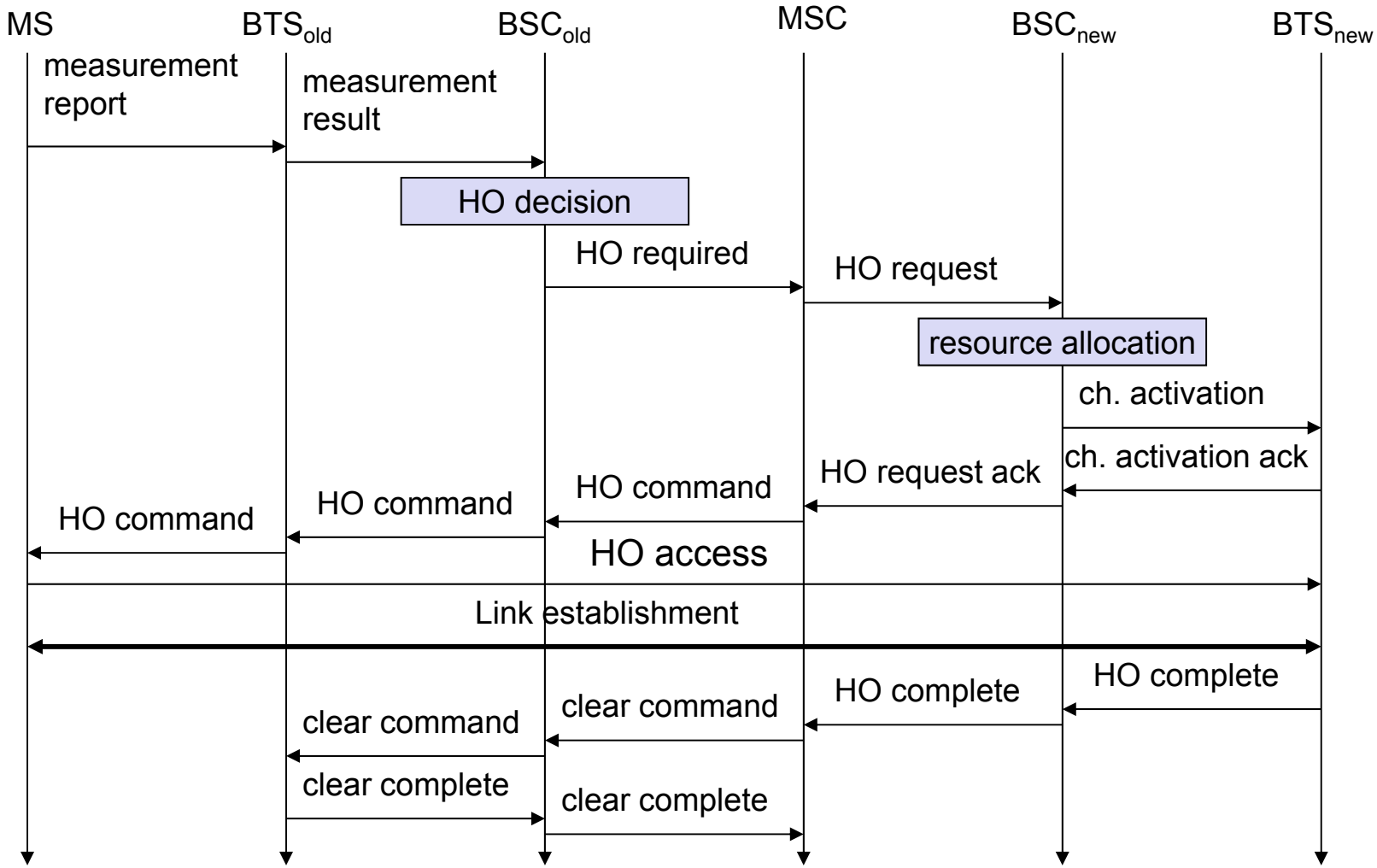
4 types of handover



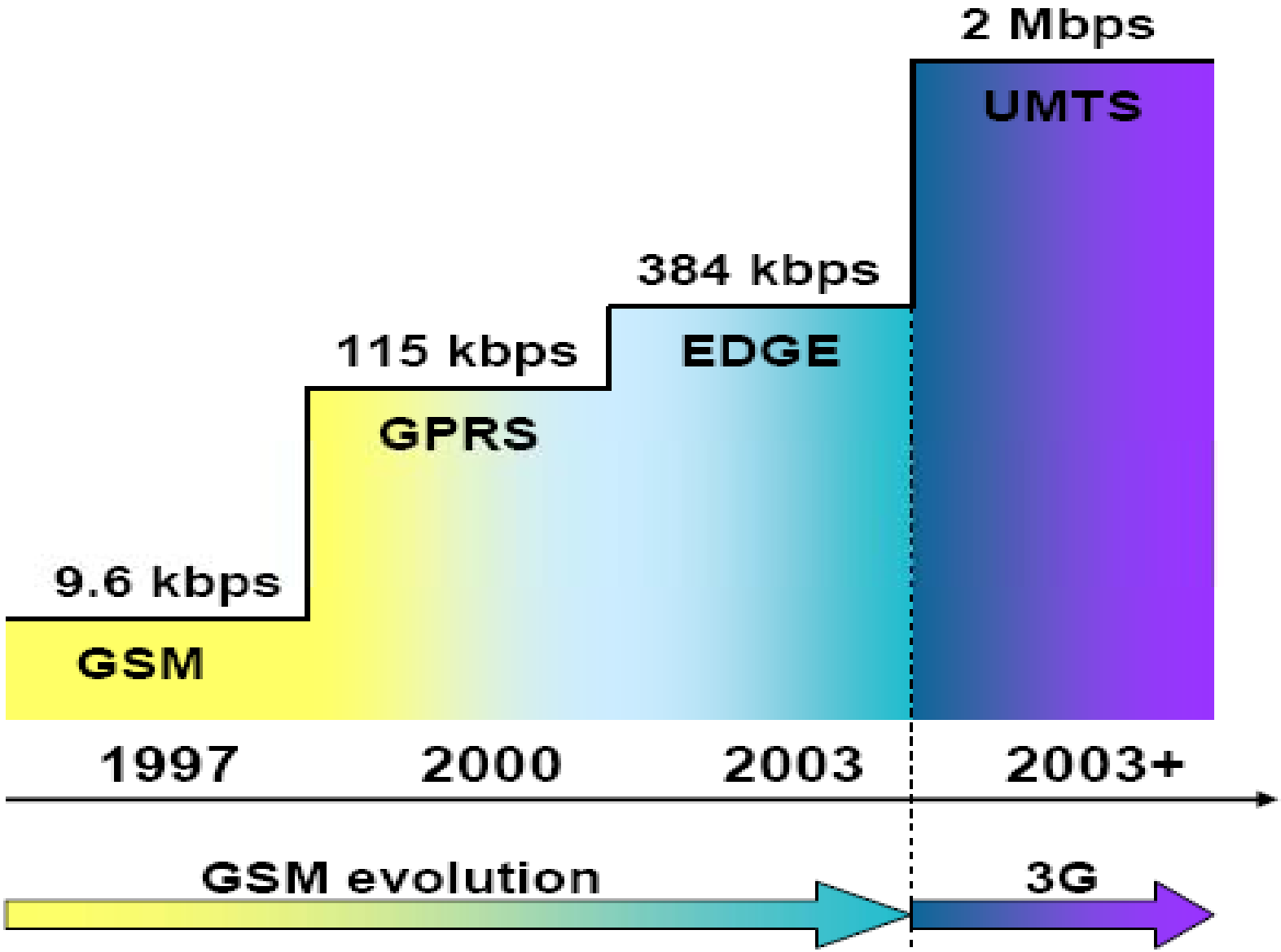
Handover decision



GSM - Handoff Procedure



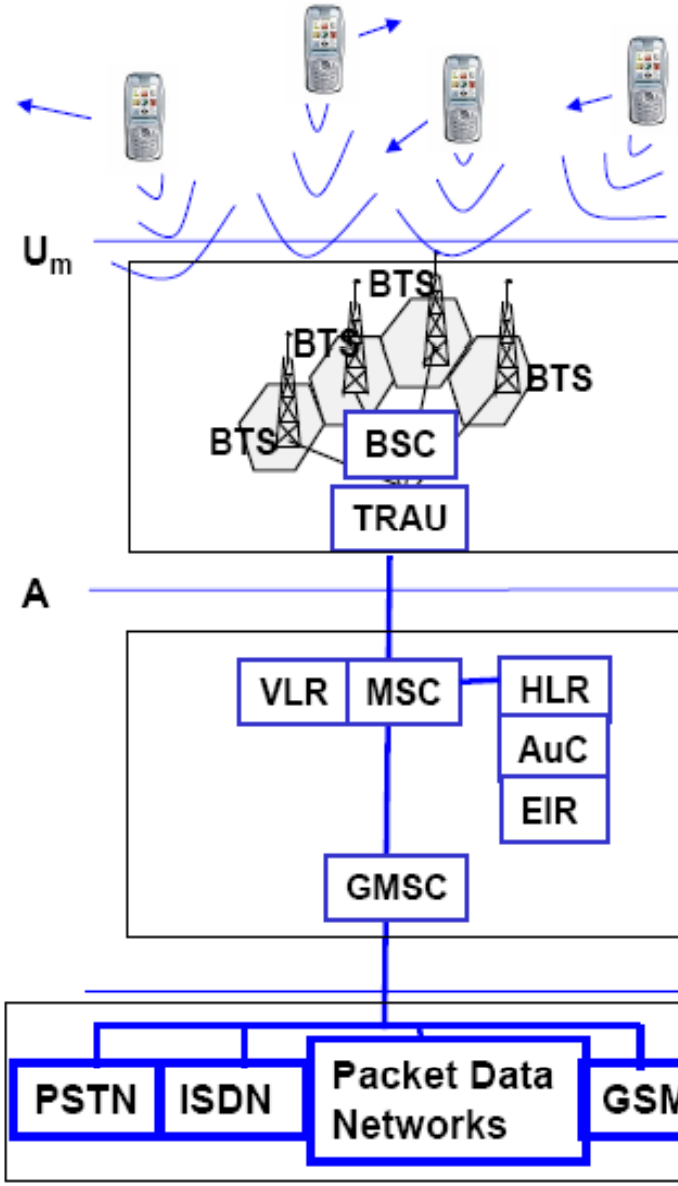
GSM Evolution for Data Access



Comparisons - GSM

- GSM is a circuit switched network
  - opposed to packet switched networks based on IP
  - for all services (e.g. voice, fax, wap) an end-to-end connection is established
  - all services are reserved the identical bandwidth → wasteful
  - all services are charged on a per-time unit basis

Simplified GSM architecture



Mobile Station (MS)

- User interface and Radio interface
- Service control
- User Identity Module (SIM, unique identification of user)

Base Station Subsystem (RAN)

- receive / send data from / to MS via radio link (BTS)
- control Radio specific signaling (BSC)
- Radio resource management (BSC)
- Transcoding and rate adaptation (TRAU)
  - Transform e.g. voice coding from one digital format into another one, e.g. ISDN to GSM

Core Network (CN)

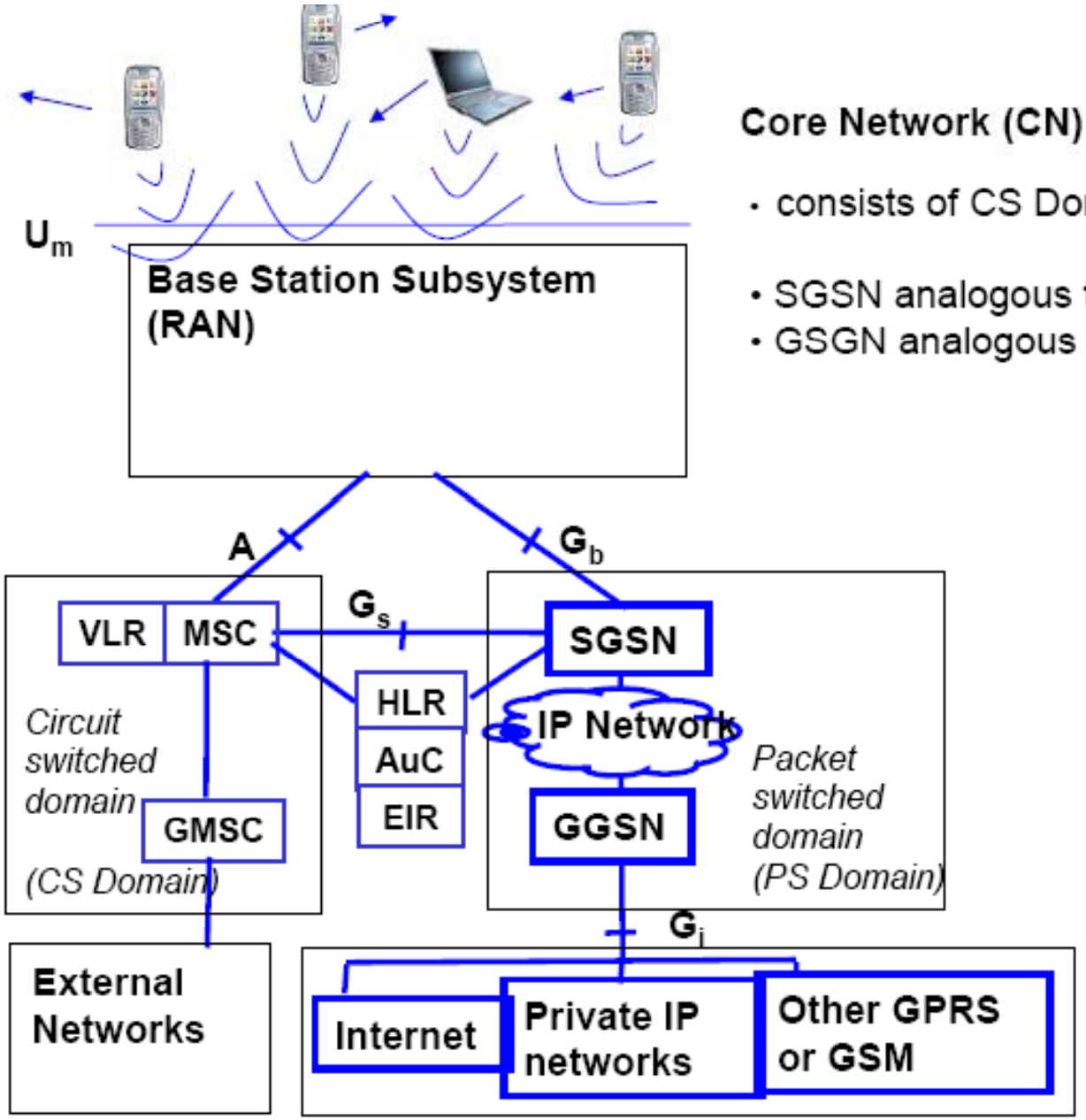
- Routing (MSC)
- Mobility management (MSC)
- Collection of charging information (MSC)
- Subscriber management (MSC)
- Interworking with external networks (GMSC)
- Data storage, e.g. suscriber profiles, current MSC (HLR, AuC, EIR / VLR)

External Networks

Comparisons - GPRS

- Since an overall increase of data traffic is expected, GSM was evolved to become more flexible → GPRS (General Packet Radio Service)
- GPRS adds technology for supporting data traffic:
  - Packet switched domain to core network
  - Shared channel on the radio link
    - Shared channel means several users share the same radio channel → opposed to a dedicated channel in GSM
    - More efficient usage of resources
    - Efficient for applications with variable rates
  - Higher transmission rates
  - Allows a direct connection to the Internet
  - Charging per data volume possible → GSM always charging per time unit

Simplified GPRS architecture



Core Network (CN)

- consists of CS Domain and PS Domain in parallel

- SGSN analogous to MSC; but packet switched
- GSGN analogous to GMSC, but packet switched

Comparisons - EDGE

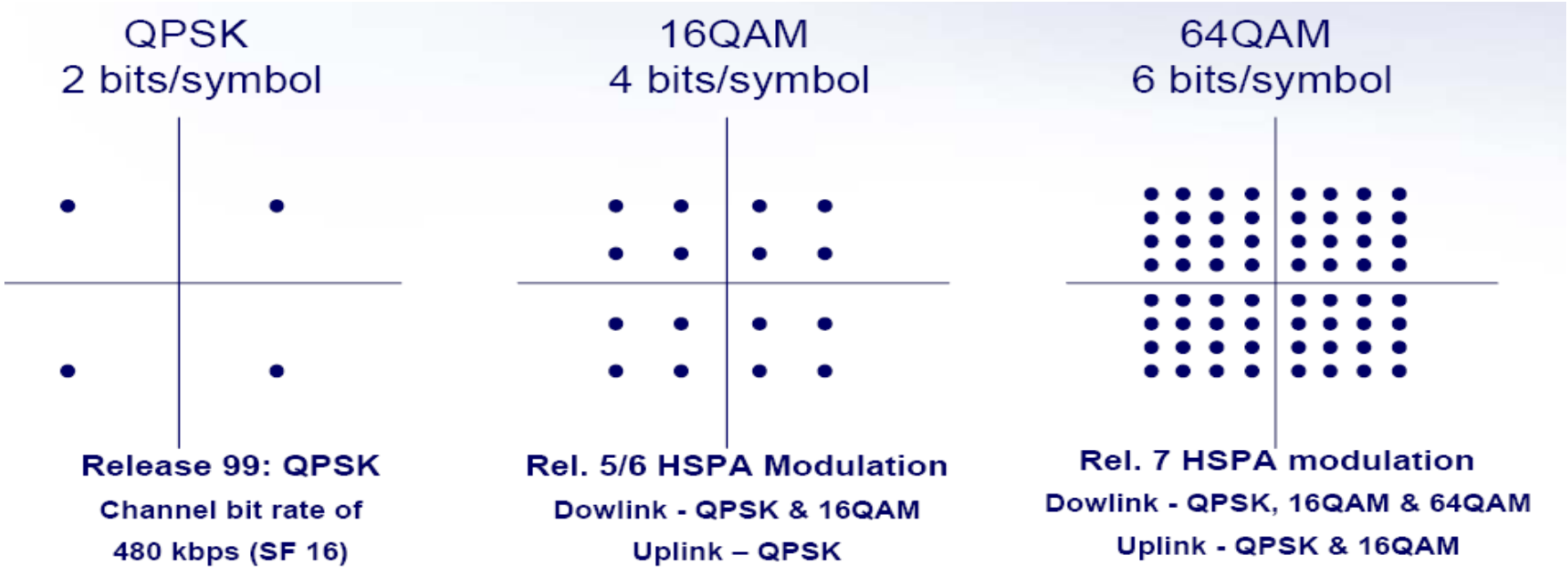
- Enhanced Data rates for Global Evolution
- Added on to GPRS to get increased data rate using advanced technologies (e.g, adaptive modulation and coding)
- Uses 9 Modulation coding schemes (MCS1-9) that supports 8.8 kbps (MCS1) to 59.2kbps (MCS9)
- Requires new terminal equipment and modifications in BS
  - Core network and the rest remains the same

Adaptive modulation and coding

- Depending on the channel condition, the best modulation technique is selected to provide the most efficient spectral efficiency possibly with current signal-to-noise ratio
  - Codes with lower rates are used in poor channel conditions
  - Codes with higher rates are used in good channel conditions.

  ⇒ Improved user data rate, higher overall throughput

ex: UMTS



UMTS

Universal Mobile Telecommunications System (UMTS)

- Add a new radio access network→ UTRAN (UMTS Terrestrial Radio Access Network)
- UTRAN and GSM radio access network can coexist and connect to the same Core Network
- CS Domain may also be based on packet based transport
  - High Speed Circuit-Switched Data (HSCSD)
    - A specification for data transfer over GSM networks.
    - Utilizes multiple time slots per user
- Introduction of IMS (IP Multimedia Subsystem)
  - Supports IP-based multimedia services

Simplified UMTS architecture

User Equipment (UE)

Base Station Subsystem from GSM

UMTS Radio Access Network (UTRAN)

Radio Access Network (RAN)

Radio link between UTRAN and UE is called UTRA

A

$I_{u\text{-}ps}$

$I_{u\text{-}cs}$

G_b

Core Network (CN)

circuit switched domain **CS Domain**

packet switched domain **PS domain**

G_i

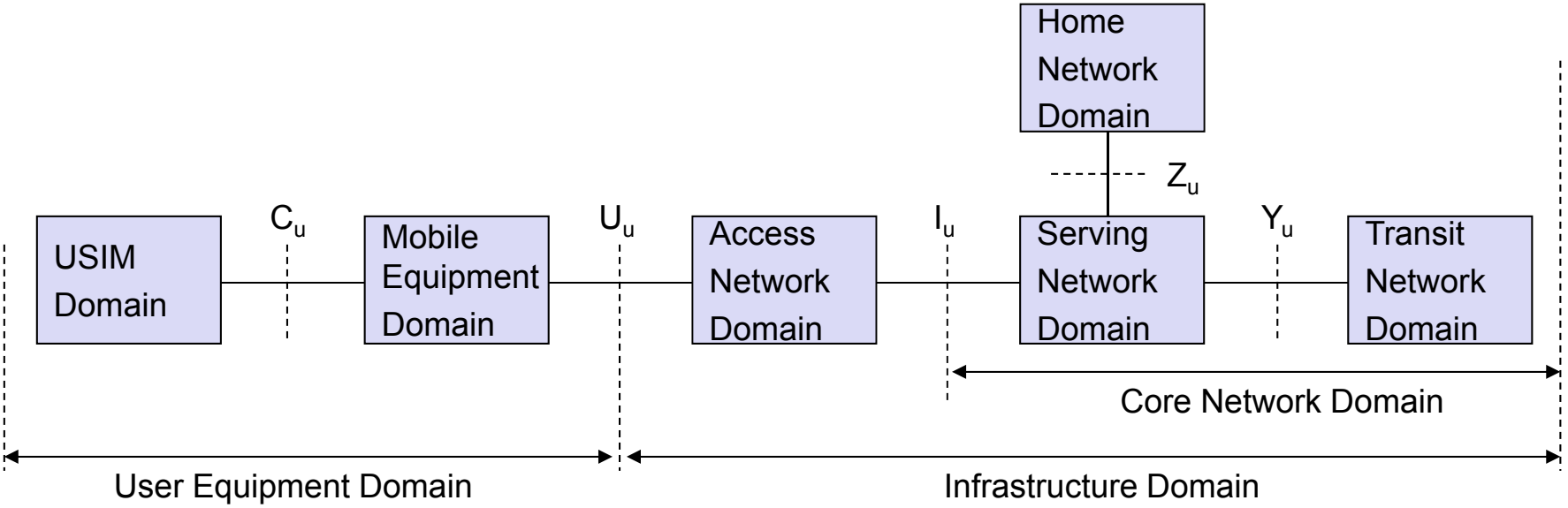
G_i

IP Multimedia Subsystem (IMS)

External Networks (Internet, PSTN,...)

UMTS domains

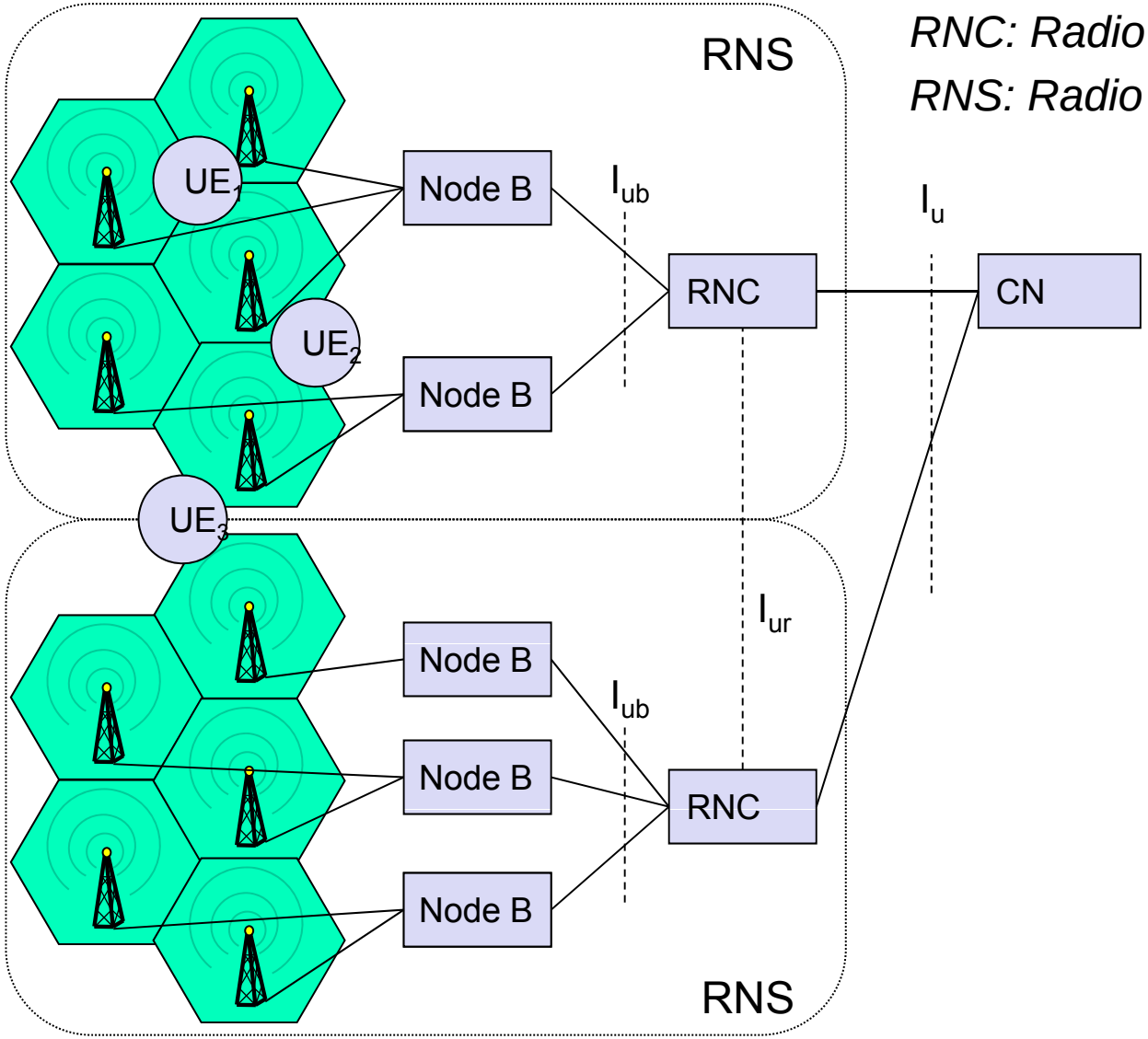
- User Equipment Domain
  - Assigned to a single user in order to access UMTS services
- Infrastructure Domain
  - Shared among all users
  - Offers UMTS services to all accepted users



UMTS domains (continued)

- Universal Subscriber Identity Module (USIM)
  - Functions for encryption and authentication of users
  - Inserted into a mobile equipment
- Mobile Equipment
  - Functions for radio transmission
  - User interface for establishing/maintaining end-to-end connections
- Access Network Domain
  - Access network dependent functions
- Core Network Domain
  - Access network independent functions

UTRAN architecture



RNC: Radio Network Controller

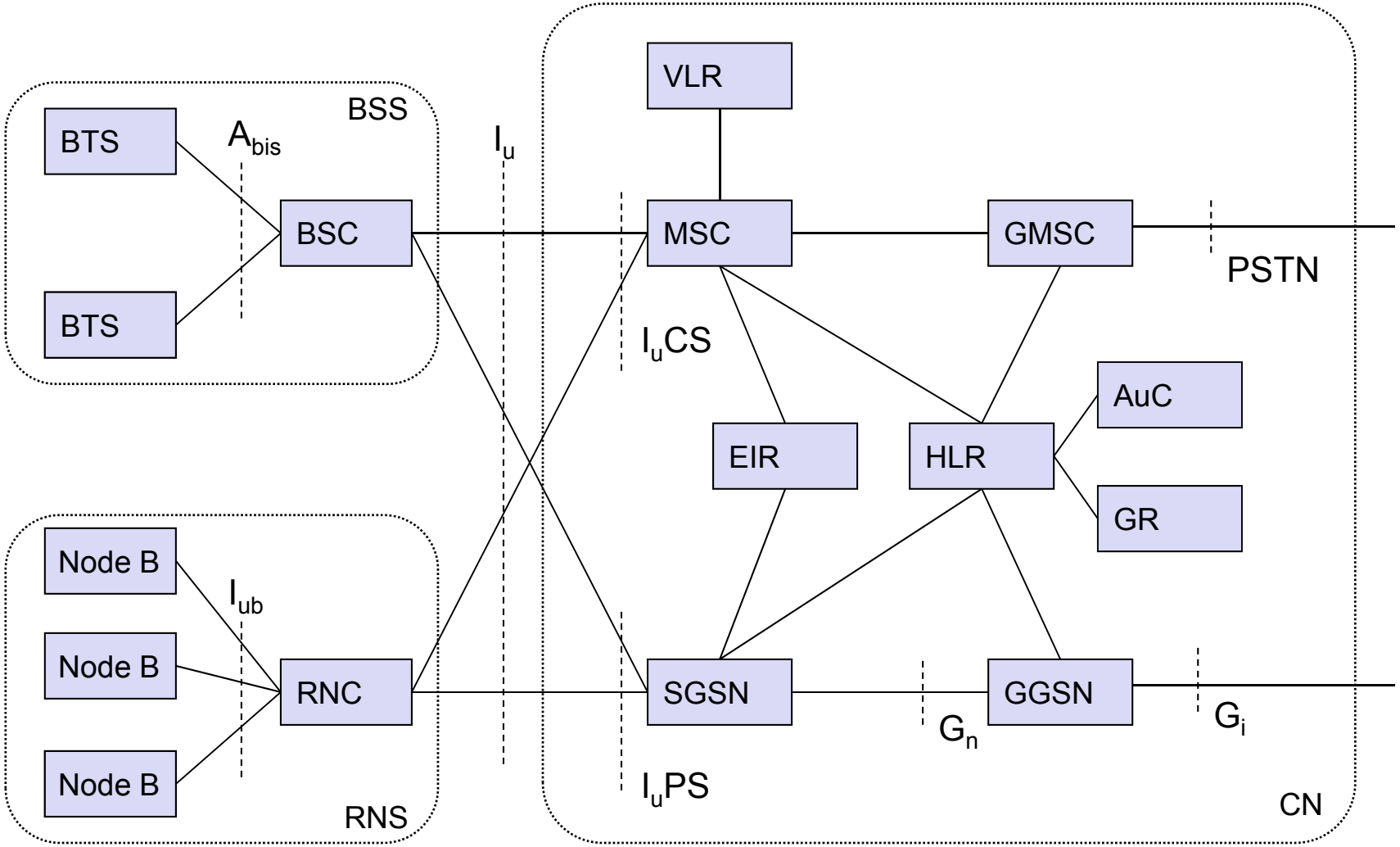
RNS: Radio Network Subsystem

UTRAN

- Provides air interface access method for UE
- Base Station is referred to as Node-B and control equipment for several Node-B's is called Radio Network Controller (RNC).

- Functions of Node–B
  - Air Interface for Tx/Rx
  - Modulation / Demodulation
- Functions of RNC
  - Radio Resource Control
  - Channel Allocation
  - Power Control Settings
  - Handover Control

Core network: architecture



Core network

- Provides switching, routing and transit for user traffic
- Separated into two logical domains: Circuit Switched Domain and Packet Switched Domain

- Circuit Switched Domain (CSD)
  - Circuit switched service
  - Resource reservation at connection setup
  - GSM components (MSC, GMSC, VLR)

- Packet Switched Domain (PSD)
  - GPRS components (SGSN, GGSN)

3G Transitional and 4G Systems

- HSPA (High-Speed Packet Access)
  - HSDPA / HSUPA
- HSPA+ (*Evolved* High-Speed Packet Access)
- LTE
- LTE Advanced

HSPA / HSPA+

- HSPA
  - Provides increased performance by using improved modulation schemes and by refining protocols
  - Supports increased peak data rate up to 14 Mbps in downlink and 5.76 Mbps in uplink
- HSPA+
  - Provides further increased performance by using higher order modulation (64QAM) and antenna array technologies such as beam-forming (focuses the transmitted power of an antenna in a beam towards the user's direction) and Multiple-input multiple-output communications (MIMO) that uses multiple antennas at the sending and receiving side
  - Supports increased peak data rate up to 56 Mbps in downlink and 22 Mbps in uplink

LTE

3GPP Long Term Evolution (LTE) - Motivation

- Need for PS optimized system
  - Evolve UMTS towards packet only system
- User demand for higher data rate and QoS
- Part of the LTE standard is the System Architecture Evolution (SAE)
  - Flat IP-based network architecture designed to replace GPRS Core Network and ensure support for some legacy or non-3GPP systems (for example GPRS and WiMax respectively)

3GPP LTE - Key Features

- High spectral efficiency
  - OFDM - offers robustness against multipath interference and high affinity to advanced techniques (e.g., MIMO)
- Very low latency
  - Short setup time & Short transfer delay
  - Short HO latency and interruption time
- Support of variable bandwidth - 1.4, 3, 5, 10, 15, 20 MHz
- Simple protocol architecture
  - PS mode only with VoIP capability
- Simple Architecture
  - eNodeB as the only E-UTRAN (Evolved Universal Terrestrial Radio Access Network) node

3GPP LTE - Key Features (cont'd)

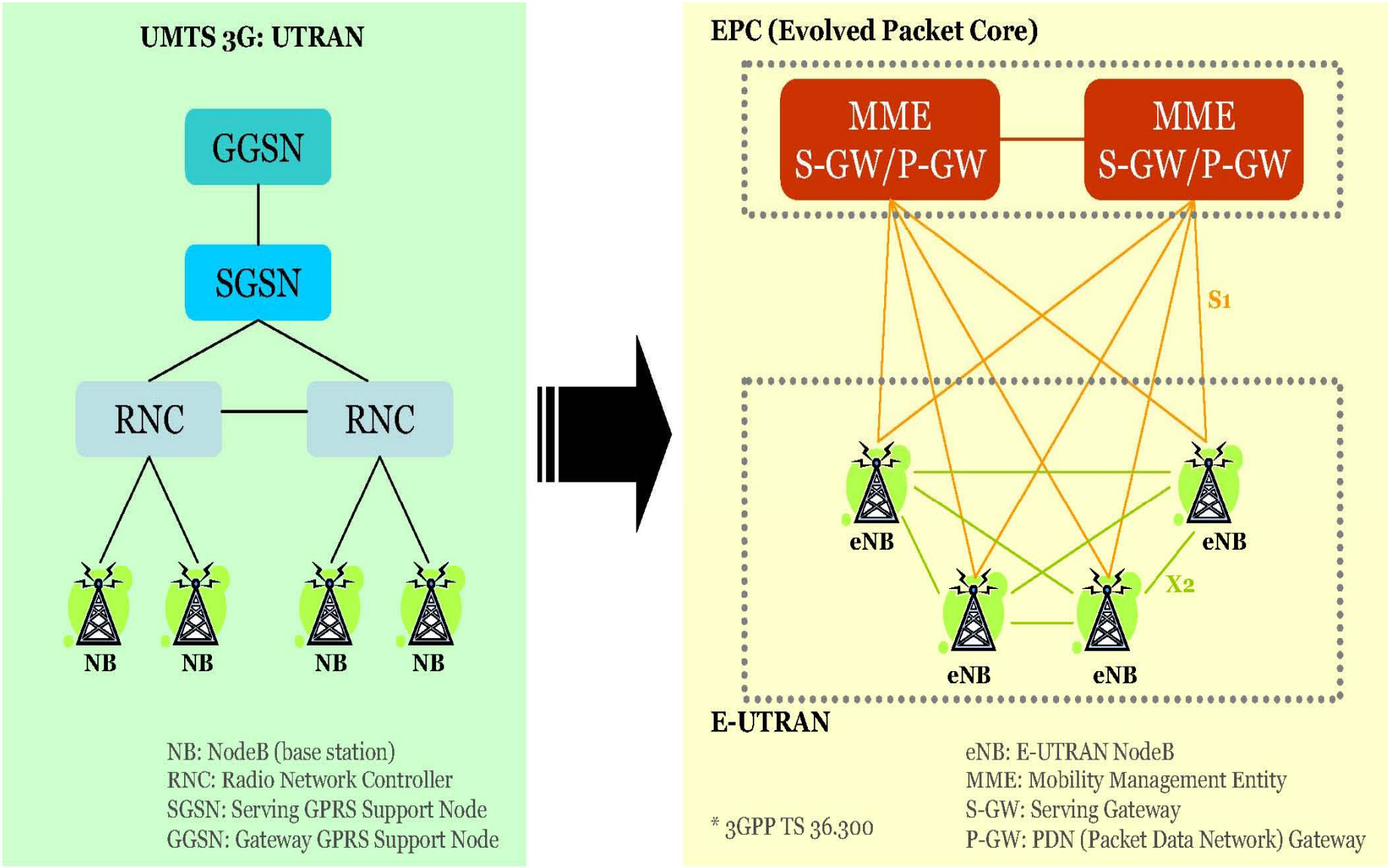
- Compatibility and inter-working with earlier 3GPP Releases
- Inter-working with other systems (e.g. cdma2000)

3GPP LTE - E-UTRAN Architecture

- No more RNC

  → RNC layers / functionalities moves in eNB
- X2 interface for handover preparation and forwarding of user data
  - Target eNB prepares handover by sending required information to UE transparently through source eNB as part of the Handover Request Acknowledge message
  - Buffered and new data is transferred from source to target eNB until path switch → prevents data loss

3GPP LTE – E-UTRAN Architecture (cont'd)

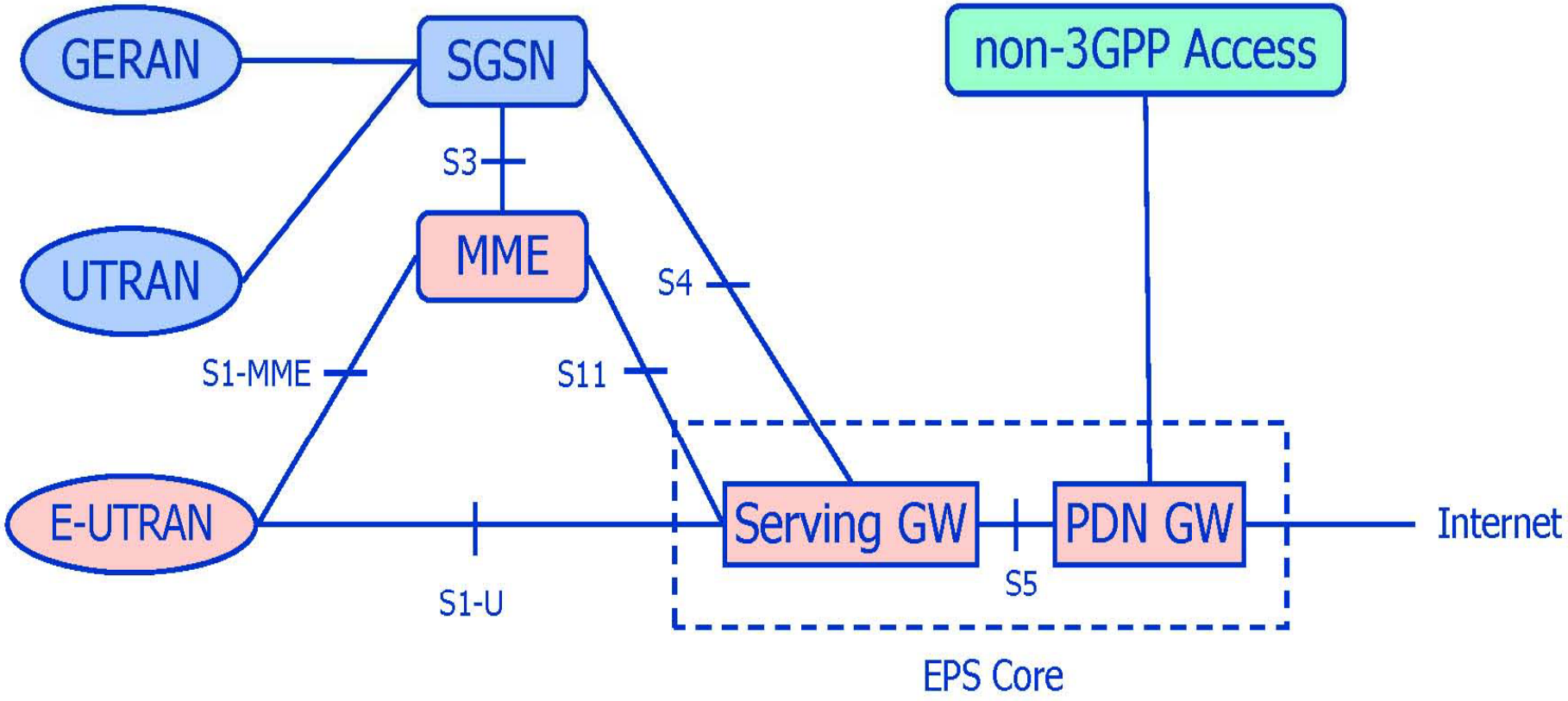


3GPP LTE – E-UTRAN Architecture (cont'd)

- eNB (E-UTRAN NodeB)
  - All radio interface-related functions
- MME (Mobility Management Entity)
  - Control plane functions
  - UE authentication, authorization, mobility management
  - S-GW/PDN-GW selection
- S-GW (Serving Gateway)
  - Local mobility anchor for inter-eNB handovers
  - Anchors mobility for intra-LTE handover between e-NBs as well as mobility between 3GPP access systems
  - Packet routing and forwarding

3GPP LTE – E-UTRAN Architecture (cont'd)

- P-GW
  - Mobility anchor between 3GPP and non-3GPP access (SAE anchor function)
  - Connectivity to packet data network



3GPP LTE – System Architecture Evolution (SAE)

- Core network architecture of 3GPP's future LTE wireless communication standard.
- Main principles and objectives of LTE-SAE architecture
  - Common anchor point and gateway (GW) node for all access technologies
  - IP-based protocols on all interfaces;
  - Simplified network architecture
  - All IP network
  - All services are via Packet Switched domain
  - Support mobility between heterogeneous RATs, including not only legacy systems as GPRS but also non-3GPP systems (say WiMAX)

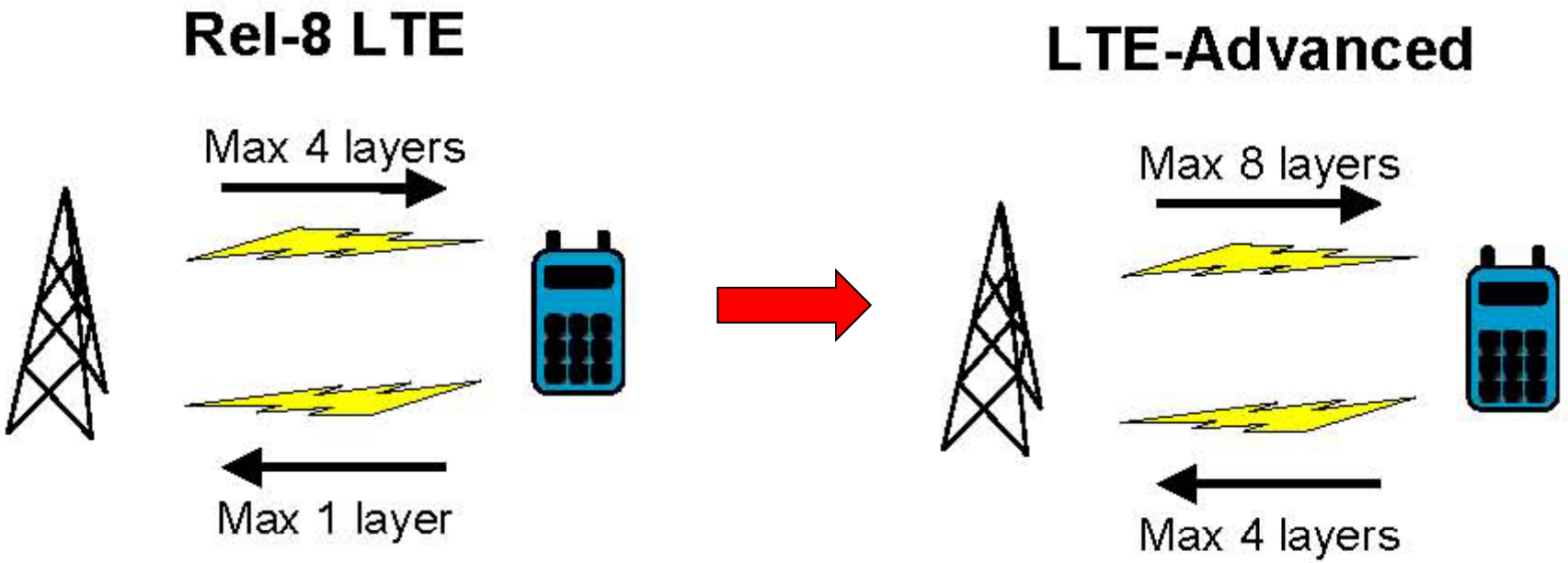
LTE - Advanced

LTE Advanced - Requirements

- Requirements for IMT-Advanced (4G) by ITU-R
  - Compatibility of services within IMT and with fixed networks
  - Capability of interworking with other radio access systems
  - High quality mobile services
  - User-friendly applications, services and equipment
  - Worldwide roaming capability
  - Enhanced peak data rates to support advanced services and applications (100 Mbps for high and 1 Gbps for low mobility)
- 3GPP stated intention is to meet or exceed IMT-Advanced requirements

LTE Advanced - Key Features

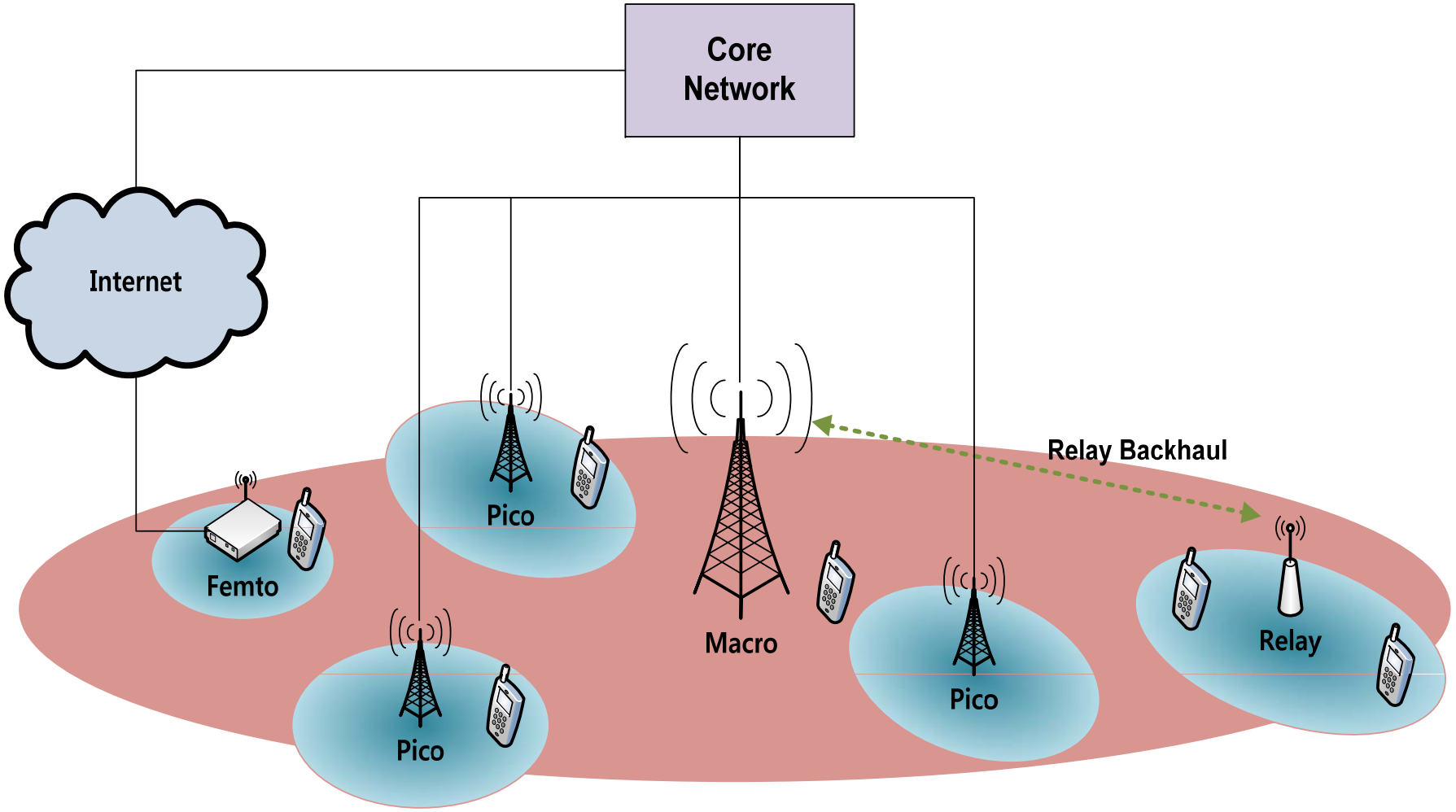
- Advanced MIMO (Higher order MIMO) techniques - improve peak data rate and spectrum efficiency
  - Up to 8x8 Downlink (from 4x2 for LTE)
  - Up to 4x4 Uplink (from 1x2 for LTE)



LTE Advanced - Key Features

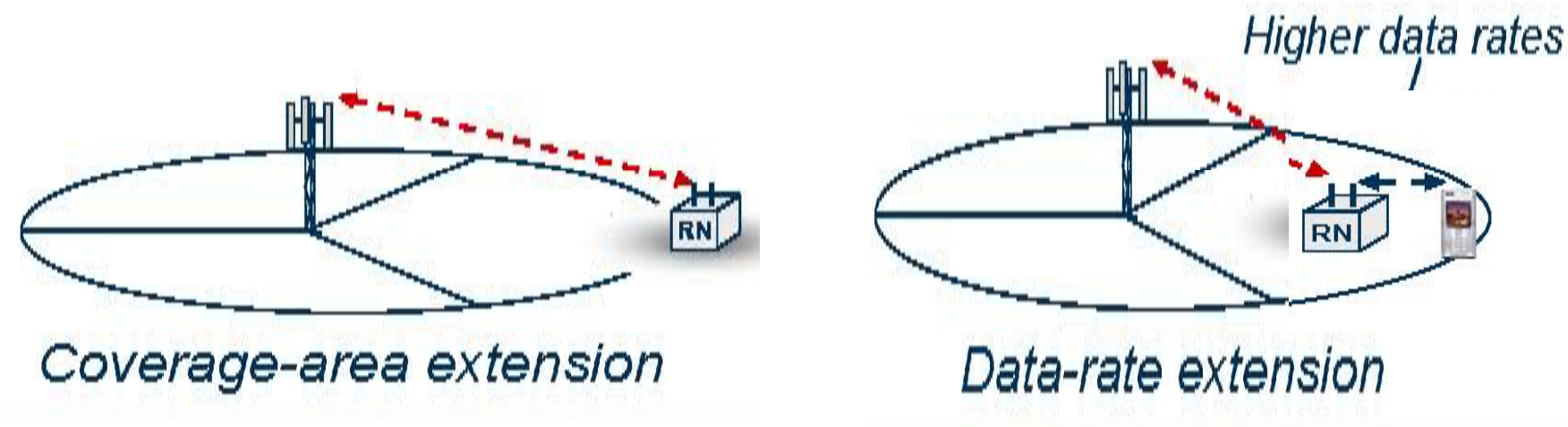
- Heterogeneous network
  - A combination of Macro, micro (<2km), pico (<200m), femto (<10m), relay nodes creates heterogeneous network with ongoing need for advanced radio resource management
- Femto cell
  - Small base station used in home and small business
  - Access to core network via broadband internet (e.g. DSL or cable)
  - Used mainly for indoor coverage
  - Extend service coverage, especially where access would otherwise be limited or unavailable (rural area)
  - Requires interference coordination for overlaid deployment of cells with different Tx power

LTE Advanced - Key Features

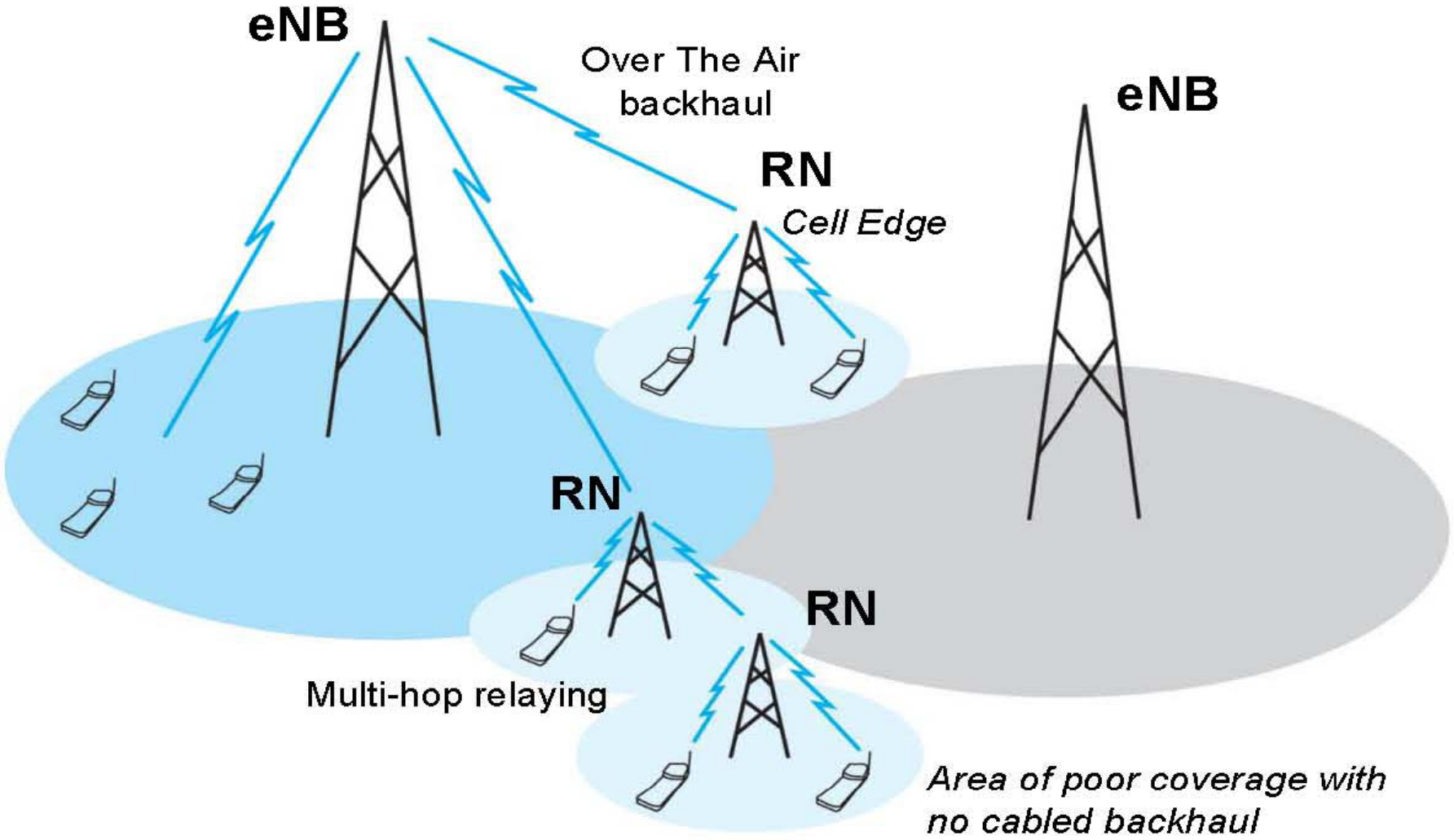


LTE Advanced - Key Features

- Relaying
  - Uses a relay node (RN) that receives, amplifies and then retransmits DL and UL signals
  - Ease of deployment and reduced deployment cost compared to a regular BS
  - Considered as a tool for lower-cost coverage extension
    - Coverage-area extension
    - Data-rate extension



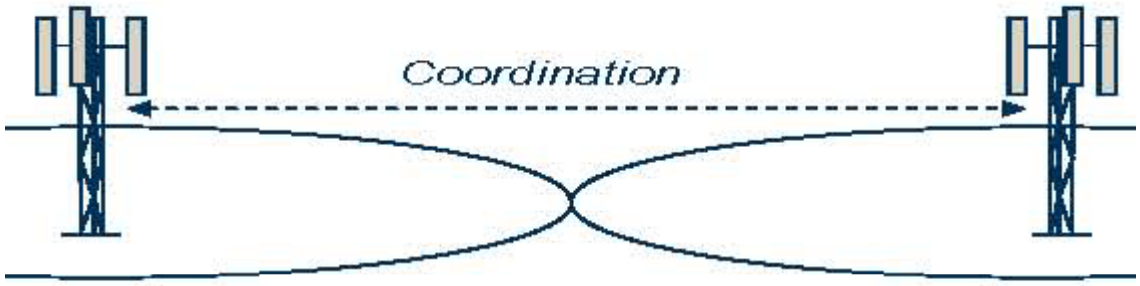
LTE Advanced - Key Features



LTE Advanced - Key Features

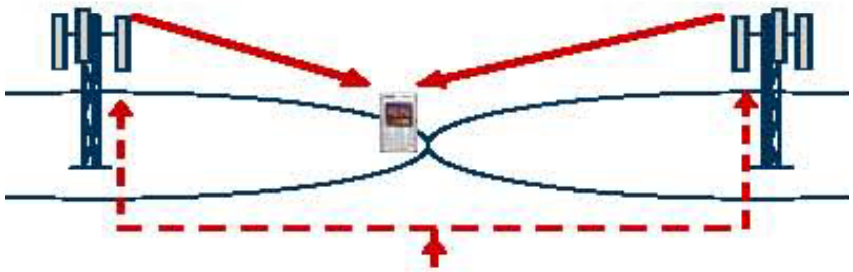
- Coordinated multipoint transmission/reception (CoMP)
  - Dynamic coordination in transmission / reception between cells
  - What to achieve?
    - Reduced inter-cell interference
    - Improved signal strength in downlink and uplink

    → *Enhanced service provisioning, especially for cell-edge users*

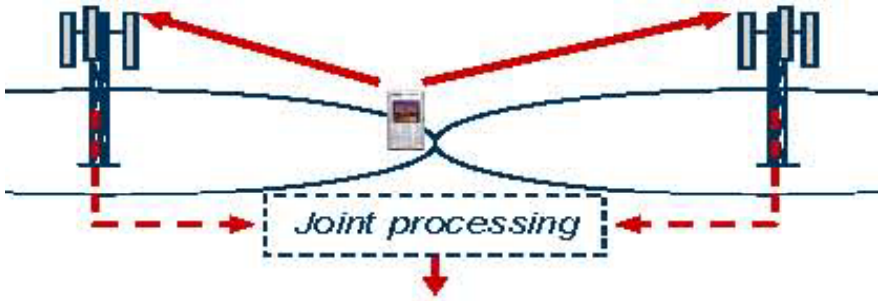


LTE Advanced - Key Features

- **Joint coherent processing**
  - Joint transmission from multiple geographically separated eNB (DL)
  - Reception and joint processing of signals received at multiple geographically separated eNB (UL)
  - Payload data is required at all transmitting eNB



DL



UL