Basic Introduction to LTE

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Topics

- Very Brief History (GSM -> LTE)
- LTE and LTE-Advanced
- Basic LTE Architecture Components
- Data Path
  - PDNs, Bearers, Network Roaming
  - Protocols and Layers
- Air Interface
  - Channels, PHY, Resource Grid, Scheduler
- Security
  - Air Interface, EPC
- Voice Overview
  - IMS, Circuit Switched Fall-back,

Very Brief History

- 3GPP (3rd Generation Partnership Project)
  - Combination of standards bodies to develop mobile telecom standards from GSM
- GSM (Global System for Mobile Communications)
  - “2G” circuit switched
- UMTS (Universal Mobile Telecommunications System)
  - “3G” Updated air interface - not backwards compatible
  - Retained GSM core network - circuit switched
  - HSPA (High Speed Packet Access)
    - “3.5G” Enhanced core network to support high speed data
    - Same channel for voice and data
  - Wideband CDMA w/ 5 MHz channels
    - Issue w/ NA market
- LTE (Long Term Evolution)
  - “4G” - 1st deployed in 2009 in Sweden and Norway
  - No backwards compatibility requirements - fully packet switched
  - Uses UMTS basic core architecture

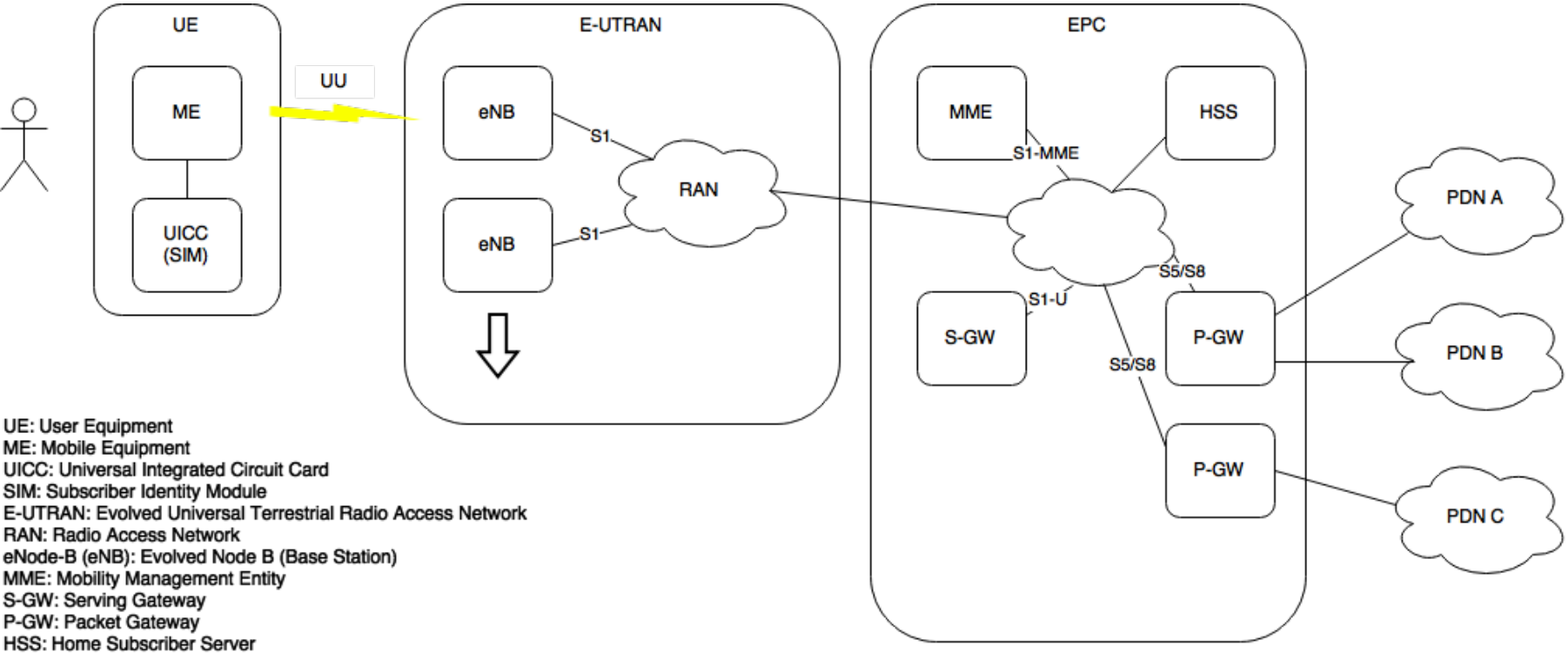
Very Brief History

- 3GPP2 (3rd Generation Partnership Project 2)
  - Combination of standards bodies to develop mobile telecom standards from IS-95 (cdmaOne)
- IS-95 (cdmaOne)
  - “2G” circuit switched
- CDMA2000
  - “3G” w/ 1.25 MHz channels - works better for NA market
  - Backwards compatible
  - EV-DO (Evolution Data - Optimized)
    - “3.5G” Support high speed data
    - Different channels for voice and data
- UMB (Ultra Mobile Broadband)
  - “4G” standard abandoned by Qualcomm in 2008 when it became clear that LTE had won the race

LTE and LTE-Advanced

- LTE specifications include
  - Minimum of 100 Mbps DL and 50 Mbps UL w/ 20 MHz channel - not seen in practice
  - Maximum of 5 ms latency from mobile to network boundary
  - Mobile transition from IDLE to ACTIVE less than 100 ms
  - Mobile speeds up to 350 kph (215 mph) w/ reduced performance
- LTE-Advanced
  - Response to ITU requirements for “4G” systems
  - Channel multiplexing and combining
  - Minimum of 1000 Mbps DL and 500 Mbps UL w/ 5x20 MHz channel - not seen in practice
  - Cooperative interference mitigation between eNB’s (base stations)
  - Other advanced eNB cooperative actions

LTE Architecture Components

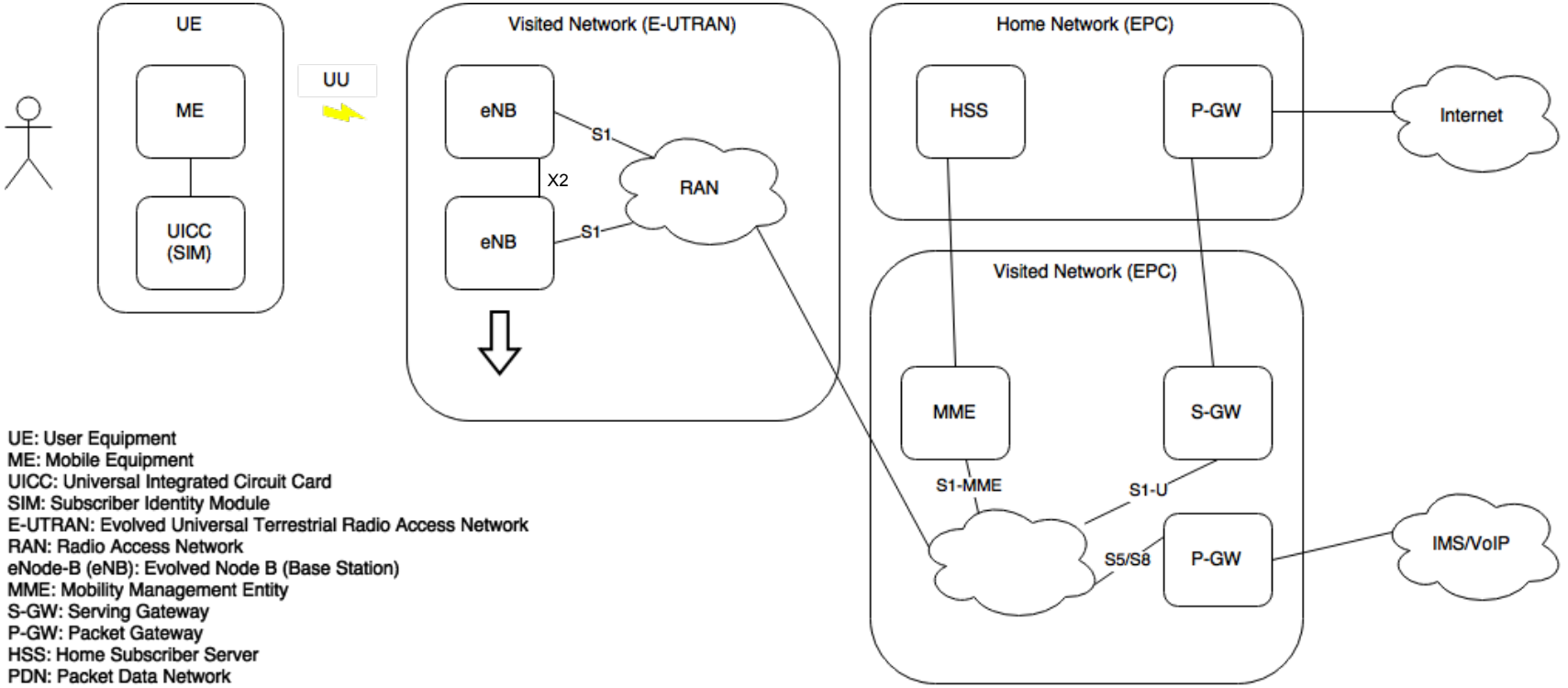


UE: User Equipment
ME: Mobile Equipment
UICC: Universal Integrated Circuit Card
SIM: Subscriber Identity Module
E-UTRAN: Evolved Universal Terrestrial Radio Access Network
RAN: Radio Access Network
eNode-B (eNB): Evolved Node B (Base Station)
MME: Mobility Management Entity
S-GW: Serving Gateway
P-GW: Packet Gateway
HSS: Home Subscriber Server
PDN: Packet Data Network
EPC: Evolved Packet Core

Data Path

- User data is placed on ‘bearers’
  - Provide capability to roam between eNB at high rate
  - Provide SLA/QoS by user and data class
    - Guaranteed average bit rate
  - Bi-directional data pipe
    - Between UE and P-GW if using GTP-U
    - Between UE and S-GW if using GRE
  - Within the EPC, bearers are identified by a 32-bit ‘Tunnel Endpoint ID’ (TEID)
  - Maximum of 11 bearers per UE
- User data is tunnelled on bearers through the EPC to external packet data networks PDNs which provide services
  - P-GW is the gateway to the external user networks
  - Internet access, private corporate networks, VoIP service (IMS), etc. - Identified by Access Point Name (APN) - Associated to UE in HSS record
  - UEs are connected to PDNs and are assigned IP addresses (per PDN) based on the profile in the HSS - static, dynamic

Network Roaming



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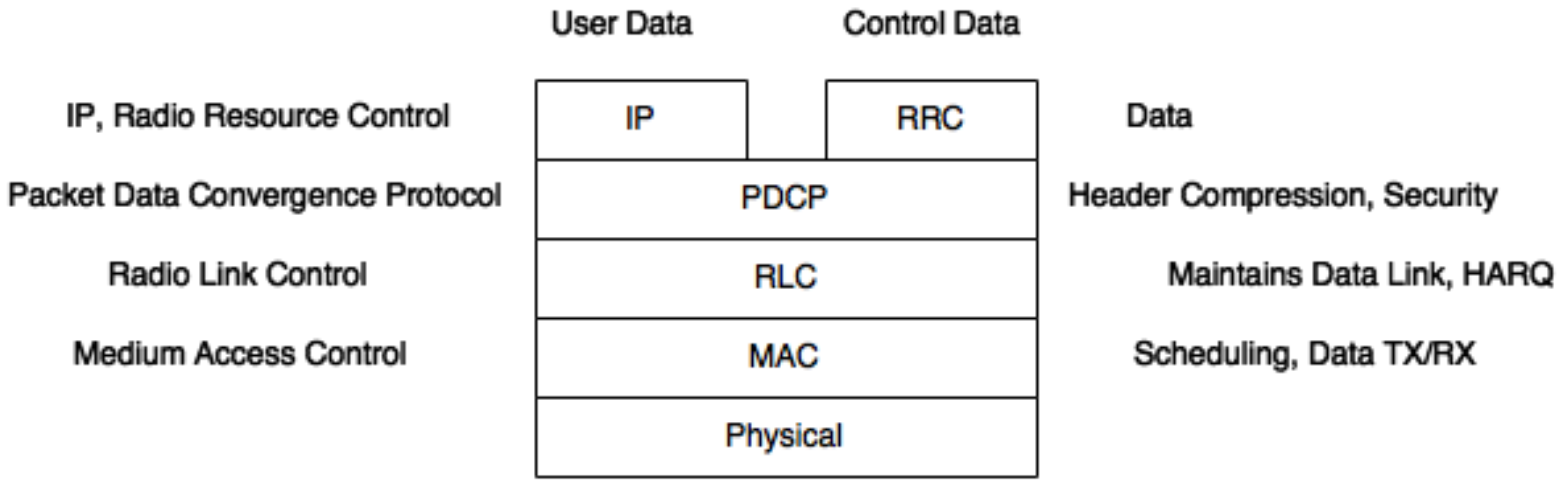
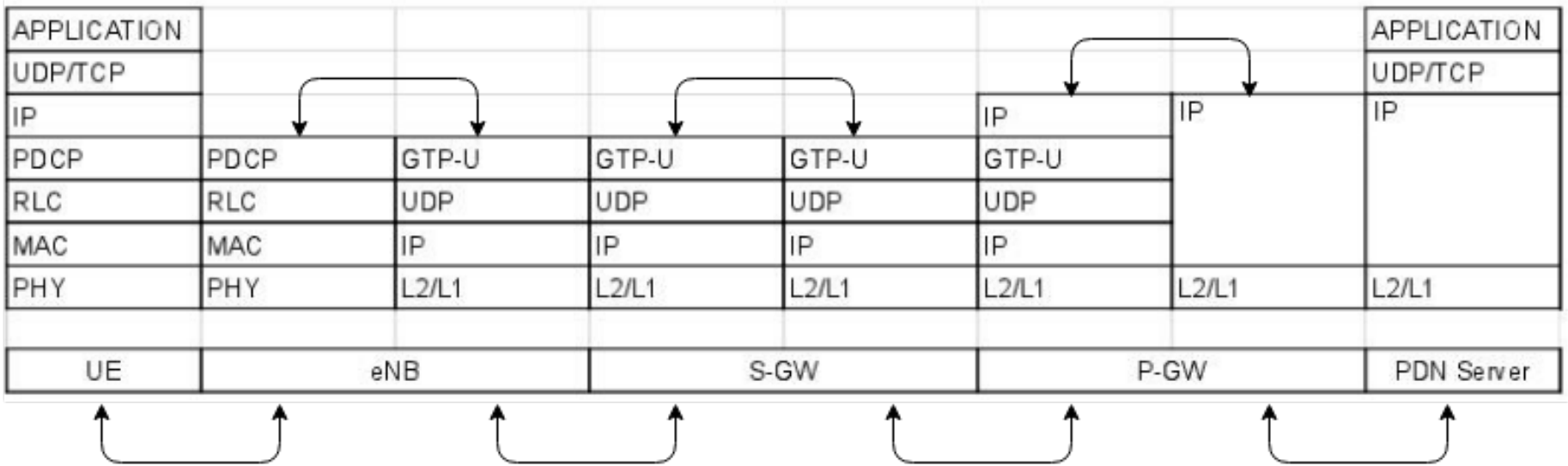
Transport Protocol Features

- Air Interface
  - Custom radio control protocols
  - Hybrid Automatic Repeat Request (HARQ) to assist with maintaining an error-free datalink
    - Only request repeat of specific sub-frames that fail error check (CRC)
    - Continuous feedback (fixed delay of 4 sub-frames) of acknowledgements on radio control channels (RLC)
  - Data Scheduler
    - Many inputs to determine data priority and is a differentiator among manufacturers
  - Header compression
    - Compresses repeated headers
  - Security
- Packet Core
  - Native IP
  - UDP is used for all user traffic transport and most internal signalling traffic
  - GPRS Tunneling Protocol (GTP)
    - User and Control types
    - Used to define user data bearers across the EPC

Air Interface Protocols



User Data Protocols



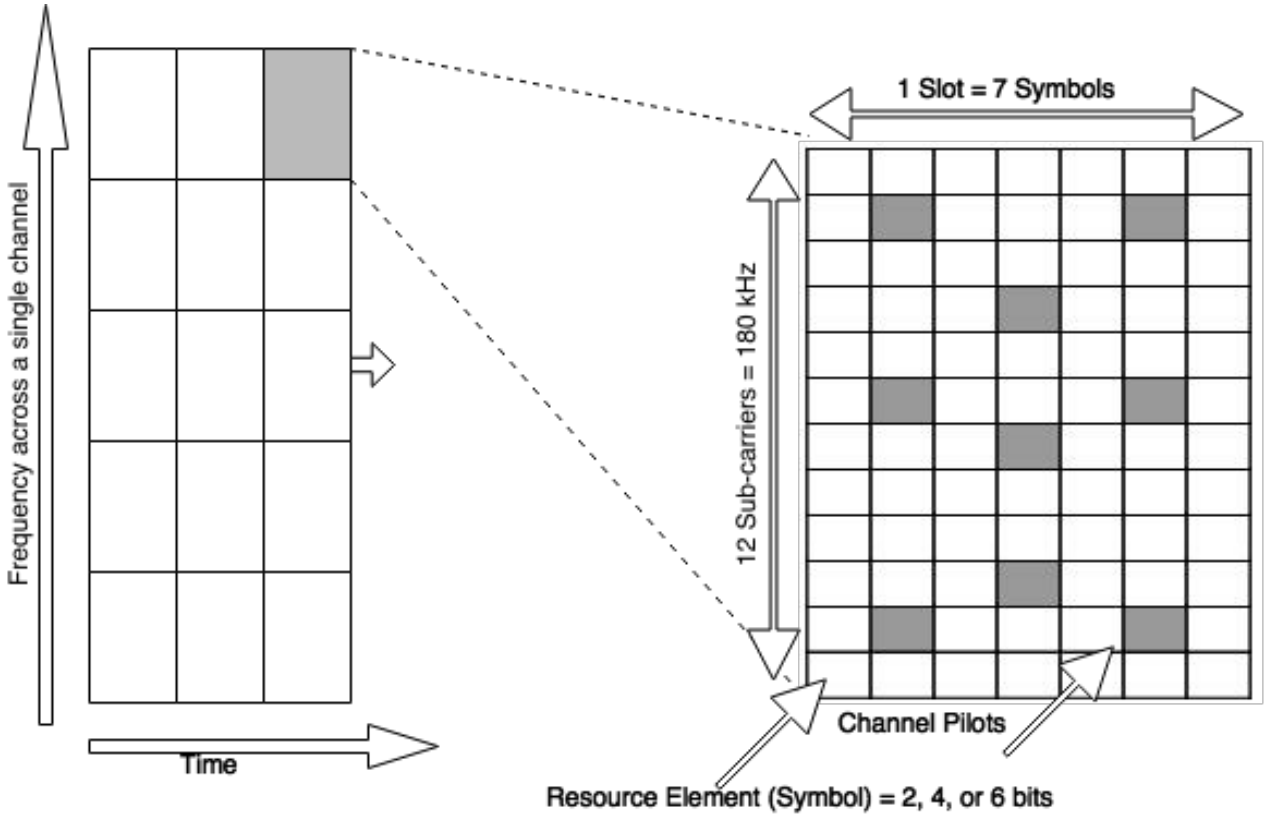
Air Interface PHY

- Downlink (DL): Base Station (eNB) -> User Equipment
  - OFDMA
  - Data transmissions to UEs uses resource blocks (12 sub-carriers) as the fundamental scheduling unit
- Uplink (UL): User Equipment -> Base Station (eNB)
  - SC-FDMA: Small peak-to-average power ratio helps with inexpensive transmitters
  - Cannot span discontiguous sub-carrier blocks
- FDD and TDD
  - FDD is the primary use in US
  - Supported channels span from 1.4 MHz to 20 MHz wide
- Frequency specific scheduling
  - Uses pilot carriers on the DL to assist UE with channel estimation
  - UE provides channel estimation feedback to eNB
  - eNB uses per-UE feedback as input to the DL scheduler to select minimally faded sub-carriers
  - eNB schedules all UL and DL transmissions and publishes the schedule every 1 ms

Air Interface PHY

- Fractional frequency reuse
  - In FDD mode, LTE cells typically use the same frequency channels
  - Every eNB can use the same set of frequencies, but allocate the sub-carriers in a flexible way
  - 100% reuse on ‘near’ UEs while avoiding sub-carriers being used by adjacent eNBs for ‘far’ UEs that may overlap adjacent eNB coverage area
  - Possible for adaptive coordination with adjacent eNBs for scheduling
- Adaptive modulation
  - Per resource block (12 sub-carriers)
  - QPSK: 2 bit/symbol, QAM16: 4 bit/symbol, QAM64: 6 bit/symbol
- MIMO
  - More on another slide…
- Timing advance
  - ‘far’ EU UL TX before ‘near’ EU UL TX and even before the final DL TX symbol boundary
  - Ensures all EU UL TX arrive at eNB at the same time
  - Diferent timing advance assigned per UE - eNB synchronization and roaming

Resource Grid



Symbol Time (Ts) = 66.7 us
Slot Time = 0.5 ms
Subframe = 2 Slots = 1 ms
Frame = 10 Subframes = 10 ms

*Subframes are the smallest resource time to be scheduled.

*Frames are used for TX of system information and reference signals for random access procedures.

MIMO

- LTE expects at least 2 antennas on the EU (usually different polarizations due to close proximity)
- RX Diversity at the eNB
  - Helps with UL fade resistance
- TX Diversity at the eNB
  - Closed loop - phase shift applied based on feedback from EU, only good for slow moving EU
  - Open loop - Alamouti technique using coding with block transmissions (space-time block code)
- Single User Spatial Multiplexing “traditional MIMO”
  - Parallel data streams using uncorrelated RF channels, not good for LOS propagation
  - Increases data speed, not eNB capacity
- Multi User MIMO - UL
  - Subset (typically 2) of UEs TX simultaneously using uncorrelated RF channels on same frequency without pre-coding
  - Increases eNB capacity, not data transfer speed

MIMO

- Beamforming
  - If appropriate, the eNB can be configured to use beamforming instead of spatial multiplexing for LOS geometries (e.g. rural hilltop)
  - Requires physically different antenna separation configuration than spatial multiplexing
  - Increases system gain resulting in increased coverage and higher modulation modes

Air Interface Security

- Authentication
  - Both the UE and the network confirm identities when joining
- User Confidentiality
  - Protect user identity from cloning
  - Use of temporary IDs across the air interface derived from common algorithms and pre-shared permanent IDs
- Encryption
  - All keys derived from shared secret key which is derived from the International Mobile Subscriber Identity (IMSI) on the UICC/SIM card
  - Keys stored on UICC and HSS server
  - Prevents replay attacks
  - All interface data is encrypted* including RCC signalling at the PDCP air interface layer
  - 128 bit keys (taken from LSB of 256 bit key) - capable of being increased to 256 bit in the future
  - Approved encryption algorithms are: SNOW 3G (legacy), AES, ZUC (China), *NULL
    - If NULL is used, the user is supposed to be notified

EPC Security

- IKE/IPSec on transport data streams
- Security Domains - usually different network operators
- Signalling Encryption
  - Required between Security Domains, optional internal to a Security Domain
- User Data
  - No encryption is required internal to a Security Domain or between Security Domains
  - Standards assume that security will be handled at the application level for user data
  - Why do you think this is the case?

Voice Service

- IP Multimedia System (IMS) - Entire books cover this topic...
  - External network with signalling to create bearers with correct QoS
  - Subscribes to subscriber location information service
  - Long-term integration solution
- 3rd Party VoIP
  - May not be associated with a bearer with correct QoS
  - May not receive subscriber location information from the network
- Dual Radio (2/3G and LTE)
  - Expensive - used as a CDMA transition feature in some phones
- Circuit Switched Fallback
  - Most used solution at the current time, but being phased out
  - When UE initiates a voice call, the network moves the UE to a 2/3G base station and onto the existing circuit switched voice system
  - When the call is completed the UE is moved back to the LTE eNB for high speed data
  - Complicated dance of signalling to handle the hand-offs