UMTS and LTE

References

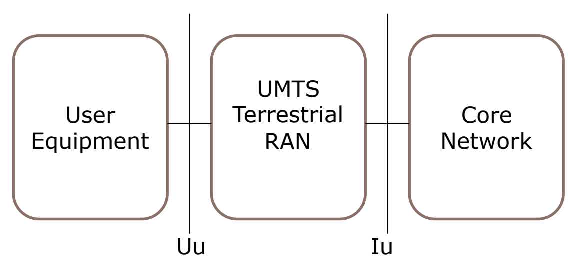
- Material Related to LTE comes from
  - "3GPP LTE: System Overview, Product Development and Test Challenges," *Agilent Technologies Application Note*, 2008.
  - IEEE Communications Magazine, February 2009
  - IEEE Communications Magazine, April 2009
  - Bell Labs Technical Journal, Vol. 13, No. 4, 2009
  - LTE: The UMTS Long Term Evolution, *Ed. S. Sesia et al*, John Wiley and Sons, 2011

What is UMTS?

- UMTS stands for Universal Mobile Telecommunications System
  - 3G cellular standard in the US, Europe, and Asia
- Outcome of several research activities in Europe
  - Assisted the standardization efforts
- Most of the standardization work was focused in 3GPP (3rd Generaration Partnership Project)
  - 3GPP refers to the physical layer as UTRA – UMTS Terrestrial Radio Access
  - There are two modes – FDD and TDD

UMTS Architecture

- The UMTS System
  - Consists of many logical network elements similar to the 2G systems
  - Logical network elements have "open interfaces"
- There are three components
  - User Equipment (UE)
  - UMTS Terrestrial Radio Access Network (UTRAN)
  - Core Network (CN)
    - Heavily borrows from GSM



Detailed Network Elements

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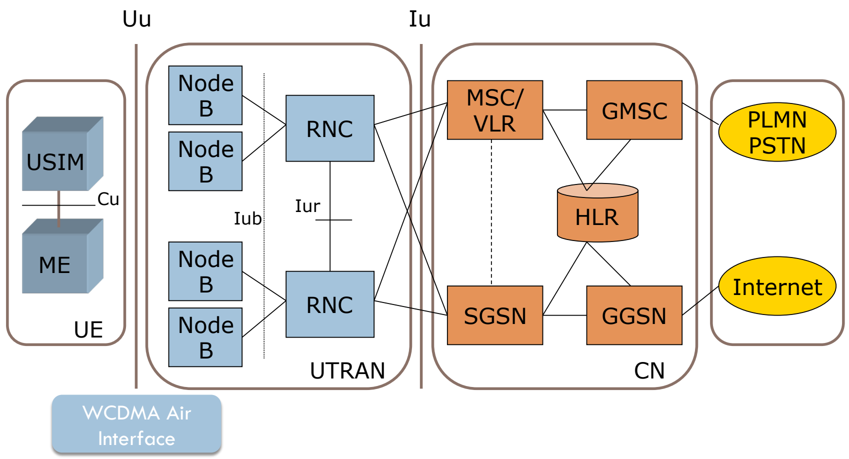

Summary of WCDMA – I

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- WCDMA is somewhat different compared to IS-95
- It is a "wideband" direct sequence spread spectrum system
  - Supports up to 2 Mbps using
    - Variable spreading
    - Multicode connections
- The chip rate is 3.84 Mcps
  - Approximate bandwidth is 5 MHz
  - Supports higher data rates/capacity

Summary of WCDMA – II

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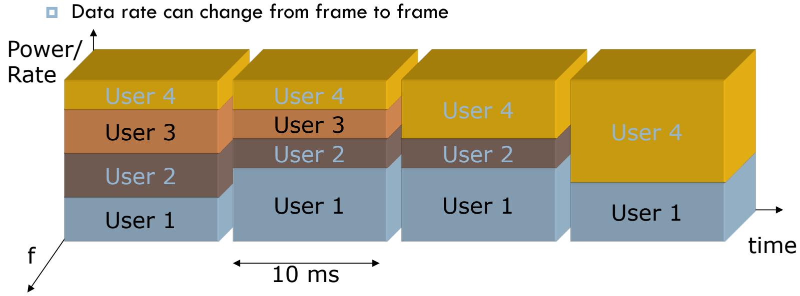
- Supports variable data rates or *bandwidth on demand*
  - Transmissions are in frames of 10 ms
  - The data rate is constant for 10 ms
  - Data rate can change from frame to frame



Long Term Evolution (LTE)

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- It is an *evolution* of UMTS
- Many terms, ideas, entities, borrowed from UMTS
  - Simplified architecture compared to UMTS
- Protocol stack is similar to UMTS

LTE – Summary

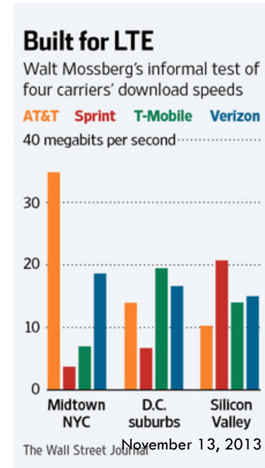
- Only packet data traffic on the air (no circuit switching)
- All IP core network that can interface better with technologies such as WiFi and WiMax
- Use of OFDMA as the medium access/modulation scheme
- Flexibility to deploy it in as little spectrum as 1.4 MHz and as much as 20 MHz of spectrum
- Support for true "broadband" with improved spectrum efficiency

Expected Downlink Data Rates in LTE

FDD Downlink Peak Data Rates Using 64 QAM			
Antenna Configuration	SISO	2 × 2 MIMO	4 × 4 MIMO
Data Rate (Mbps)	100	172.8	326.4

Mossberg's Measurements

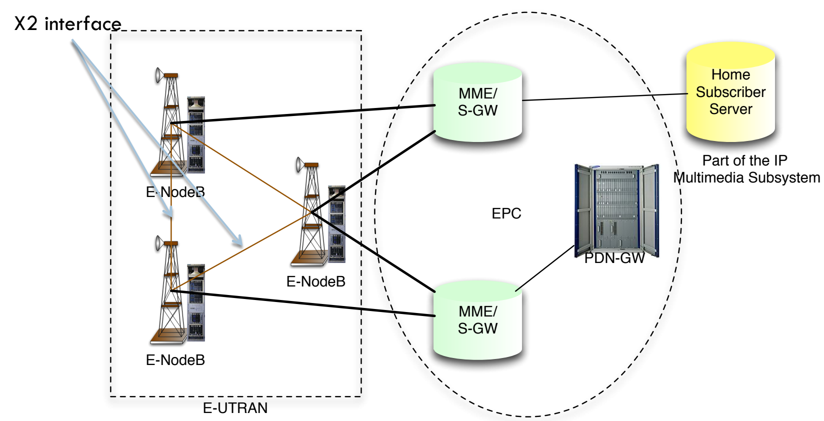
- Average using different versions of iPhone 5S, 20 downloads per phone
- Sprint Spark in 2015



LTE Network Architecture

- Evolved Packet System (EPS) consists of two parts
  - E-UTRAN – Evolved UMTS Terrestrial Radio Access Network
  - EPC – Evolved Packet Core
- E-UTRAN
  - Consists of only one kind of node: eNode-B
- EPC
  - Fully based on IP – consists of elements
    - MME – Mobility Management Entity (like SGSN)
    - S-GW & PDN-GW: Serving and Packet Data Network Gateways
    - Home subscriber server (HSS)
  - Voice and real-time applications will make use of the IP Multimedia Subsystem (IMS)

LTE Network Architecture



Channel Bandwidths

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- Can vary from 1.4 MHz to 20 MHz
- Resource Block (RB)
  - 180 kHz wide and 0.5ms long
  - 12 subcarriers spaced at 15 kHz (24 at 7.5 kHz possible later)
- Data rate limited by User Equipment (UE) categories

Channel BW (MHz)	1.4	3.0	5	10	15	20
Resource Blocks	6	15	25	50	75	100

Orthogonal Frequency Division Multiplexing

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- Idea in frequency domain:
  - Coherence bandwidth limits the maximum data rate of the channel
  - Send data in several parallel sub-channels each at a lower data rate and different carrier frequency
- Idea in time domain:
  - By using several sub-channels and reducing the data rate on each channel, the symbol duration in each channel is increased
  - If the symbol duration in each channel is larger than the multipath delay spread, we have few errors
- OFDM enables
  - Spacing carriers (sub-channels) as closely as possible
  - Implementing the system completely in digital

What is OFDM?

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- Modulation/Multiplexing technique
- Usual transmission
  - Transmits single high-rate data stream over a single carrier
- With OFDM
  - Multiple parallel low-rate data streams
  - Low-rate data streams transmitted on orthogonal subcarriers
  - Allows spectral overlap of sub-channels

OFDM Advantages

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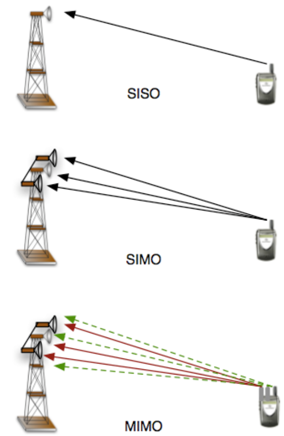
- Bandwidth efficiency
- Reduction of ISI
  - Needs simpler equalizers
- Robust to narrowband interference and frequency selective fading
- Possibility of improving channel capacity using adaptive bit loading over multiple channels

How can we increase data rates?

- Traditional ways
  - Reduce the symbol duration
    - Needs larger bandwidth
    - Leads to a wideband channel and frequency selectivity - irreducible error rates
  - Increase the number of bits/symbol
    - Error rates increase with M for the same E_b/N_0
- MIMO systems
  - There is no need to increase the bandwidth or power
    - But what are the limitations?
  - Use multiple transmit (Tx) and receive (Rx) antennas
  - Increases spectral efficiency to several tens of bps/Hz

What is MIMO?

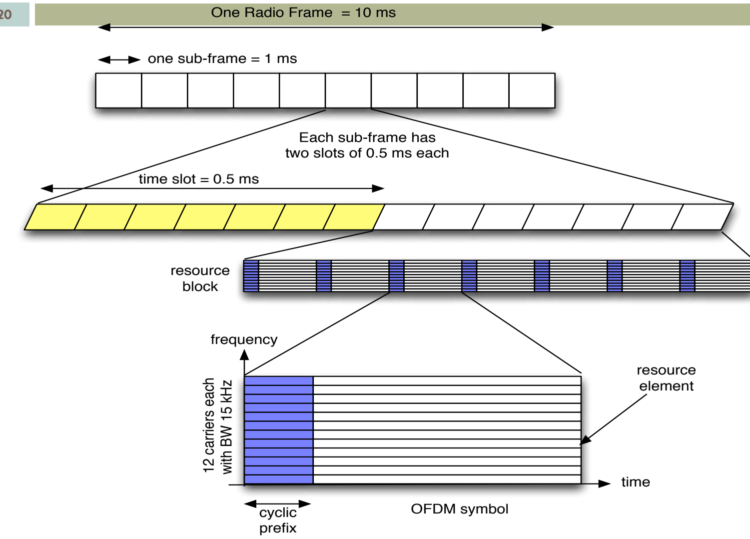
- So far we have considered Single Input Single Output or SISO systems
  - Both transmitter and receiver have one antenna each
  - Simplest form of transceiver architecture
- Single input multiple-output (SIMO) systems
  - Receiver has multiple antennas
- Multiple input multiple output (MIMO) systems
  - Both transmitter and receiver have multiple antennas
  - Strictly: Each antenna has its own RF chain (modulator, encoder and so on)



Performance enhancements due to MIMO

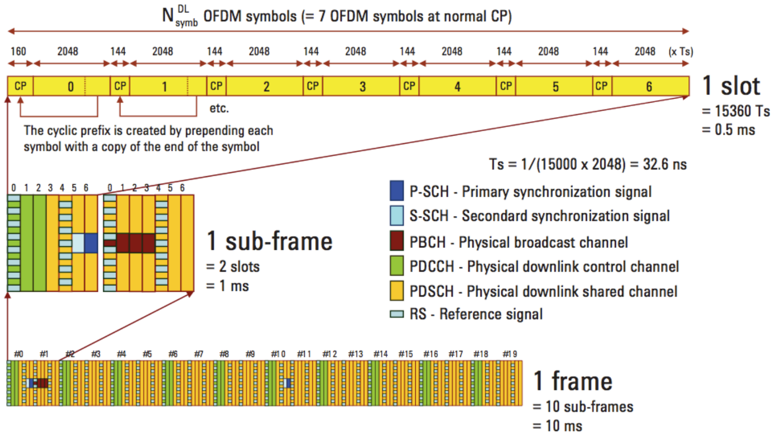
- Diversity gain
  - Ability to receive multiple copies of the signal with independent fading
- Spatial multiplexing gain
  - Send different information bits over different antennas and recover the information
- Interference reduction
  - Reduce the region of interference thereby increasing capacity

LTE Frame Structure



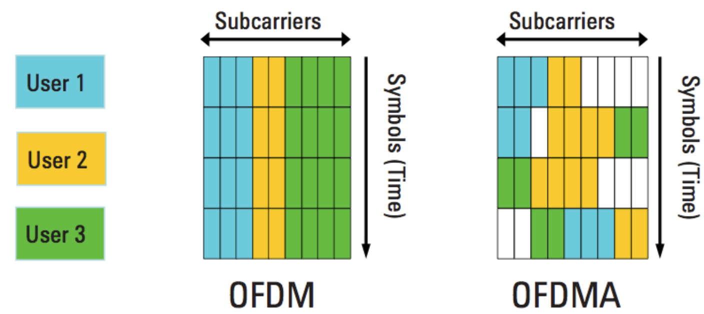
Detailed Downlink Frame Structure (FDD)

Source: Agilent Application Note



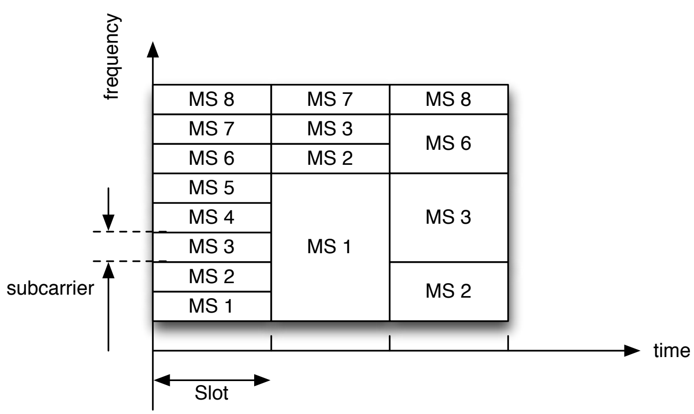
Downlink Multiple Access: OFDMA

Note users don't have to be assigned resource blocks that are together

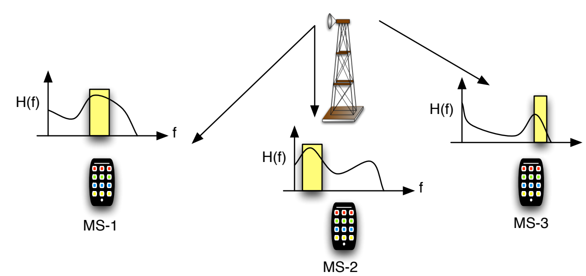


Source: Agilent Application Note

Flexible Resource Allocation in OFDMA



Multi-user Diversity with OFDMA

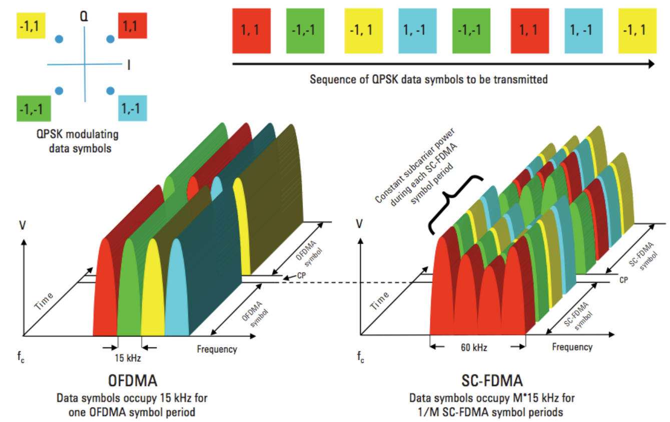


- Allocate subsets of carriers to users over different times
  - Preferably, allocate carriers that have good channel characteristics

Other Downlink Features

- Support for MIMO
  - Transmit diversity
  - Beamforming
  - Spatial multiplexing
  - Combos
- Link adaptation
  - Various modulation schemes and code rates
- Frequency and time selective scheduling
  - MS reports channel quality for resource blocks
- Fractional frequency reuse (FFR)
  - A fraction of frequency resources are not reused in every cell (or are used with low transmit power)

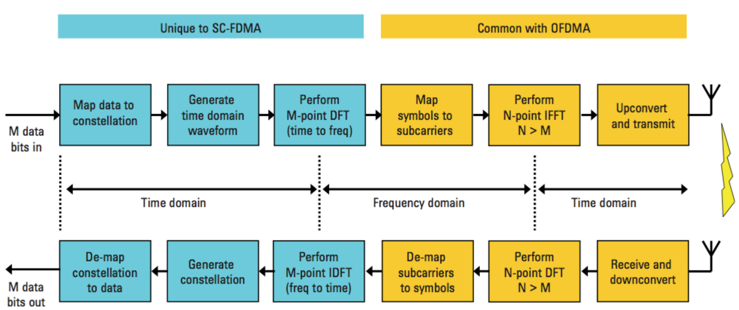
Uplink Multiple Access: Single Carrier FDMA



Source: Agilent Application Note

Why SC-FDMA

- Avoid high peak-to-average power ratio (PAPR) in MS

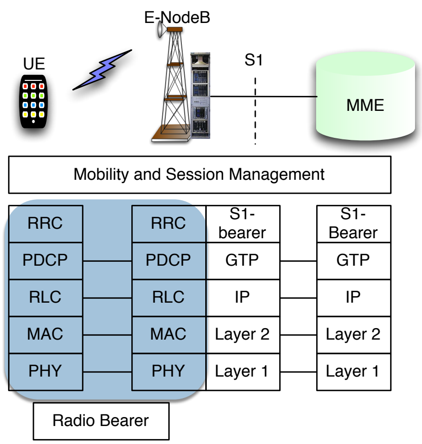


Source: Agilent Application Note

Other Uplink Features

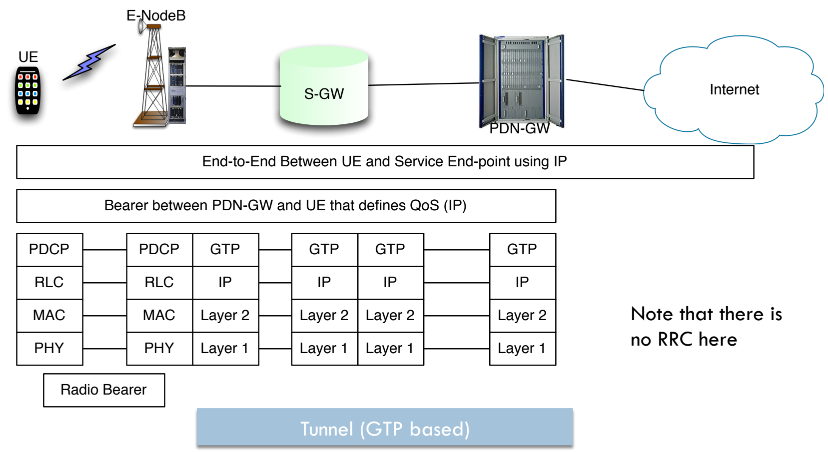
- Intra-cell orthogonality
  - Unlike CDMA, there is only interference from outside the cell, not within the cell
  - No need for fast power control (compare with CDMA)
    - Still has slow power control
- Frequency and time selective scheduling using wideband channel sounding signal by mobile stations
- Mobile is always "online"
  - Has idle and connected states

LTE Simplified Protocol Stack (Control Information)



- Shaded stack is called the "access stratum" - AS, upper layers are called "non-access stratum" – NAS
- RRC = Radio Resource Control
  - Includes measurements on signals
- PDCP = Packet Data Convergence Protocol
- RLC = Radio Link Control
- GTP = GPRS Tunneling Protocol

Flow of user data ("our data")



Note that there is no RRC here

LTE Physical Signals

DL signals	Full name	Purpose
P-SCH*	Primary synchronization signal	Used for cell search and identification by the UE. Carries part of the cell ID (one of three orthogonal sequences)
S-SCH*	Secondary synchronization signal	Used for cell search and identification by the UE. Carries the remainder of the cell ID (one of 168 binary sequences)
RS	Reference signal (Pilot)	Used for DL channel estimation. Exact sequence derived from cell ID (one of 3 X 168 = 504 pseudo random sequences)

UL signals	Full name	Purpose
RS	Reference signal (Demodulation and sounding)	Used for synchronization to the UE and UL channel estimation

Source: Agilent Application Note

LTE Physical Channels

Source: Agilent Application Note

DL channels	Full name	Purpose
PBCH	Physical broadcast channel	Carries cell-specific information
PMCH	Physical multicast channel	Carries the MCH transport channel
PDCCH	Physical downlink control channel	Scheduling, ACK/NACK
PDSCH	Physical downlink shared channel	Payload
PCFICH	Physical control format indicator channel	Defines number of PDCCH OFDMA symbols per sub-frame (1, 2, or 3)
PHICH	Physical hybrid ARQ indicator channel	Carries HARQ ACK/NACK

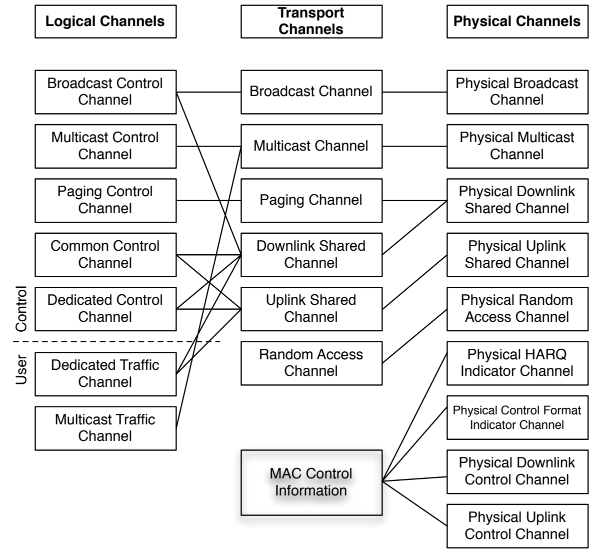
UL channels	Full name	Purpose
PRACH	Physical random access channel	Call setup
PUCCH	Physical uplink control channel	Scheduling, ACK/NACK
PUSCH	Physical uplink shared channel	Payload

Transport Channels in LTE

Transport channel type		Functions
Downlink		
Downlink shared channel	DL-SCH	Support for HARQ, dynamic link modulation, dynamic and semi-static resource allocation, UE discontinuous reception, and MBMS transmission Possibility to be broadcast in entire cell coverage area to allow beamforming
Broadcast channel	PBCH	Fixed transport format Must be broadcast in entire cell coverage area
Paging channel	PCH	Support for UE discontinuous reception Must be broadcast in entire cell coverage area, mapped to physical resources
Multicast channel	MCH	Support for MBSFN, semi-static resource allocation Must be broadcast in entire cell coverage area
Uplink		
Uplink shared channel	UL-SCH	Support for dynamic link adaptation, HARQ, dynamic, and semi-static resource allocation Possibility to use beamforming
Random access channel	RACH	Limited control information, collision risk

Compare with Transport Channels In UMTS

Source: *Agilent Application Note*



Mapping between Logical, Transport, and Physical Channels

Mapping from Transport to Physical Channels

Downlink	
TrCH	**Physical channel**
DL-SCH	PDSCH
BCH	PBCH
PCH	PDSCH
MCH	PMCH
Control information	**Physical channel**
CFI	PCFICH
HI	PHICH
DCI	PDCCH
Uplink	
TrCH	**Physical channel**
UL-SCH	PUSCH
RACH	PRACH
Control information	**Physical channel**
UCI	PUCCH

Source: *Agilent Application Note*

Medium Access in LTE

- Problem
  - ARQ between mobile and RNC incurs delays
  - ACKs/NACKs are at the RLC layer
- Solution
  - Do the scheduling and ARQ between mobile and Node-B
  - ARQ at Layer 1
    - Hybrid ARQ to improve success rate
- Hybrid ARQ
  - Combines erroneous frames with retransmitted frames to achieve **diversity**
- Fast scheduling
  - Instead of signaling from the RNC, a Node-B is allowed to make decisions on the **maximum data rates** that a MS can use to transmit packet data
  - Uses adaptive multi-rate transmission

Similar ideas were adopted in LTE

Link Adaptation in LTE

- Uses a "channel quality indicator" or CQI
- Sent by a mobile on an uplink control channel (PUCCH or PUSCH) for periodic or aperiodic reporting of CQI
- CQI values can be for
  - Entire system bandwidth
  - Mobile picks a subset of the bandwidth
  - eNode-B picks a subset of the bandwidth

CQI Index	Modulation Scheme	Code Rate
1	QPSK	0.076
4	QPSK	0.3
8	16-QAM	0.48
11	64-QAM	0.55
15	64-QAM	0.93

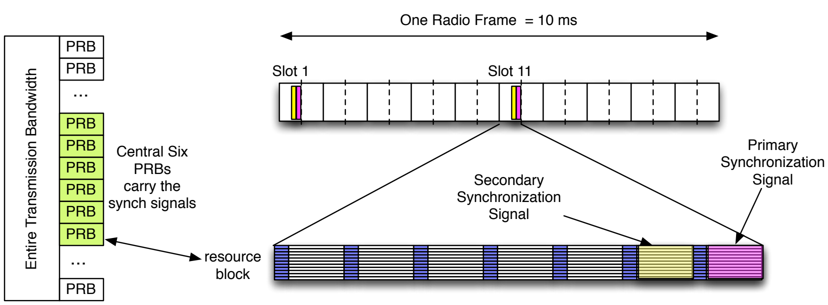
Sample adaptive transmission rates in LTE and their mapping to CQI values

Mobile uses block error rate thresholds to determine the CQI

In Brief: Cell Search in LTE

- OFDMA and time/frequency resource blocks (RBs)
- Problems
  - Different bandwidths supported in LTE (1.25, 2.5, 5, 10, 20 MHz)
  - Need smaller delay for cell search
- Sync Channel
  - Uses "central" 1.25 MHz bandwidth
  - Comprises of 76 sub-carriers with a spacing of 15 kHz
  - Within these, a primary (P-SCH) and secondary (S-SCH) synchronization channel is transmitted
    - Each carries part of the Cell-ID
- Reference Signal (RS)
  - Used for downlink channel estimation

Cell Search in LTE



Random Access

- Uplink transmissions in a cell must be orthogonal
  - They are aligned with frame timing of an e-NodeB
- When a MS powers up or after a long period of inactivity, this alignment is lost
- RA Procedure
  - MS sends one of several preambles (shared) with a guard period
  - E-NodeB detects preamble, estimates MS's timing, and responds with a correct timing advance and uplink resource
  - MS sends its identity in this allocated resource + some data
  - E-NodeB echos the MS identity

More on RA Procedure

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- RA procedure must be repeated if the echoed identity is not correct
  - Due to a collision of the preambles
- Backoff indication from e-NodeB can be used to reduce contention
- After an inter-eNodeB handoff, an RA procedure is imminent
  - Contention free RA procedure is possible
  - **Unique preamble** is assigned to the MS

Obtaining Uplink Resources

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- If a MS has data to send, it can send a single "scheduling request" (SR) bit using
  - The RA Procedure OR
  - Dedicated SR on the PUCCH
- In the first allocated resource, the MS sends a buffer status report that has more information about how much data it wants to send
- E-NodeB allocates resources on a per sub-frame basis (every ms!)
  - Scheduler is responsible for handling QoS

Mobility Management in LTE

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- Two scenarios
- When the E-Node B's are connected
- When the E-Node B's are not connected
- Recall flat architecture

Simplified Handoff – BSs connected

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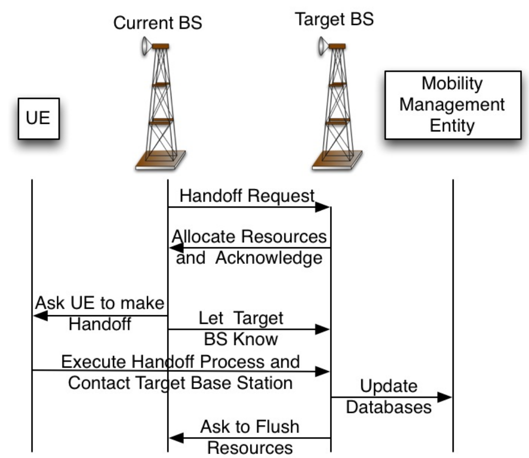

Simplified Handoff – BSs are not connected