ΤΕΙ ΣΕΡΡΩΝ
Technological Educational Institute of Serres

Department of Informatics & Communications

M.Sc. in Communication and Information Systems

Thesis Title:

“Study and simulation of LTE physical uplink shared channel (PUSCH)”

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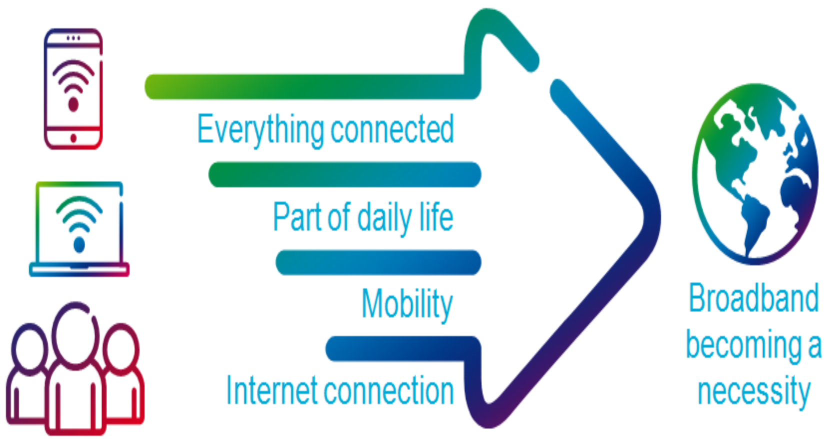
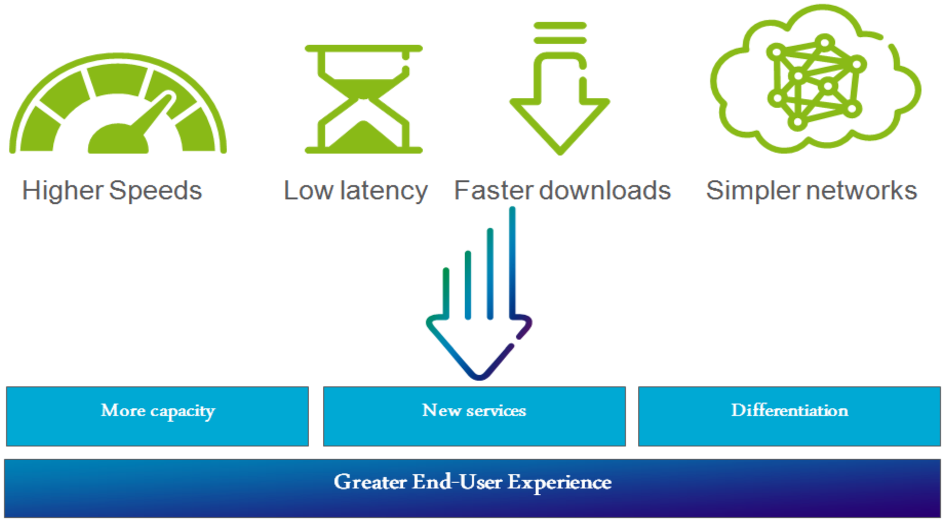
Introduction

- LTE stands for Long Term Evolution
- LTE is based on standards developed by 3rd Generation Partnership Project (3GPP)
- LTE standards are described in Release 8
- LTE is next stage of mobile communication which will enable things like IP based voice, high data streaming, on portable devices
- LTE is the first step towards IMT-Advanced (“4G”)

The Need for LTE





- Packet Switched data is becoming more and more dominant
- VoIP is the most efficient method to transfer voice data
- Amount of data is continuously growing
- Need for higher data rates at lower cost and spectral efficiency
- Users demand better quality to accept new services
- Need for cheaper infrastructure
- LTE will enhance the system to satisfy these requirements.

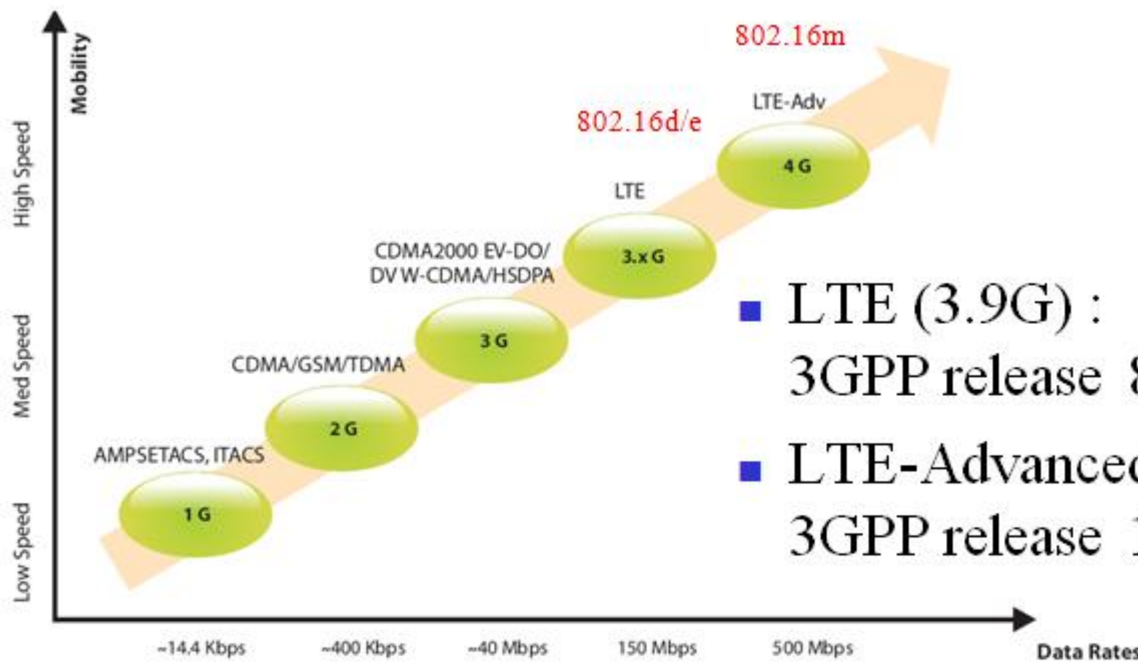
Advantages and Evolution of LTE

for Network Operators

- High network throughput
- Low latency
- Plug & Play architecture
- Low Operating Costs
- All-IP network
- Simplified upgrade path from 3G networks

for End Users

- Faster data downloads/uploads
- Improved response for applications
- Improved end-user experience



- LTE (3.9G) : 3GPP release 8~9
- LTE-Advanced : 3GPP release 10+

What is 3GPP ?
&
What does 3GPP produce?

- 3GPP Stands for 3rd Generation Partnership Project*
- The Partners are Standards Developing Organizations, SDOs:

ARIB (Japan) | CCSA (China) | TTA (Korea)

atis (USA) | ETSI World Class Standards (Europe) | TTC Telecommunication Technology Committee (Japan)

- 3GPP is a 'company contribution' driven organization…companies participate in 3GPP through their membership of one of the Partner SDOs
- Currently over 350 Individual Members (Operators, Vendors, Regulators)
- 13 Market Representation Partners (giving perspectives on market needs and drivers)
- Technical Specifications and Technical Reports for 3G Mobile (WCDMA, HSPA, LTE) and 4G Mobile (LTE-Advanced) Radio Interfaces and Service Layers. Also, the systems architecture evolution that goes with it
- Evolved GSM specifications (GPRS, EDGE)
- Revised versions of 3GPP specifications are published following the quarterly Technical Specification Group plenary meetings

*3GPP is not constrained to 3rd Generation. It includes work on both 2nd and 4th generation technologies.

The 3GPP Specifications for LTE

- LTE introduced in Rel 8
  - Minor improvements in Rel 9 and Rel 10
- Scalable channel bandwidths of 1.4, 3, 5, 10, 15 and 20 MHz allocations
- Support both paired (FDD) and unpaired (TDD) spectrum as well as half duplex FDD
- IP Packet switched radio interface
- Simplified architecture: The network side of E-UTRAN is composed only of eNodeBs
- Reasonable power consumption for the mobile terminal
- Flexible use of new and existing frequency bands
- Support for inter-operation and co-existence with legacy standards while evolving toward an all-IP network
- Supports at least 200 active users in every 5 MHz cell
- Significantly increased average user throughput and spectrum efficiency
  - Downlink target 3-4 times greater than HSDPA Release 6
  - Uplink target 2-3 times greater than HSUPA Release 6
- Increased data rates 10 times more than HSPA Release 6 technology
  - Downlink Peak Data Rate: 100Mbit/s in a 20MHz downlink spectrum (i.e. 5 bit/s/Hz)
  - Uplink: 50Mbit/s in a 20MHz uplink spectrum (i.e. 2.5 bit/s/Hz)
- Significantly reduced latencies
- High level of mobility and security. Optimized for low mobility(0-15km/h) but supports high speed.
- LTE coverage is optimized for cell sizes up to 5 km, works with slight degradation of performance up to 30 km cells. Also cell range up to 100 km not precluded.
- RAN (Radio Access Network) round-trip times of less than 10ms
- Co-existence with legacy standards

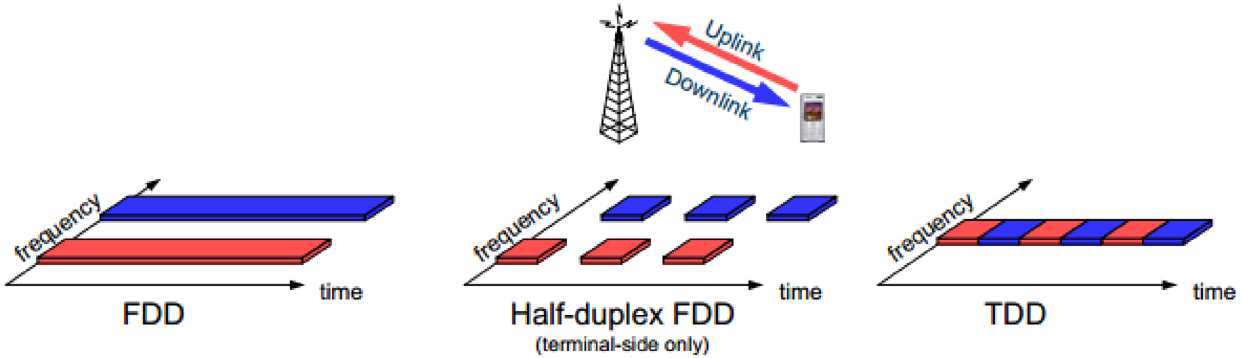
Spectrum and Frequency Bands for LTE

- Seamless integration with previous mobile systems and new frequency bands that may be identified
- Support both paired and unpaired spectrum allocations

- FDD for paired spectrum, enables simultaneous transmission on two different sufficiently separated frequencies: one for DL and one for UL.

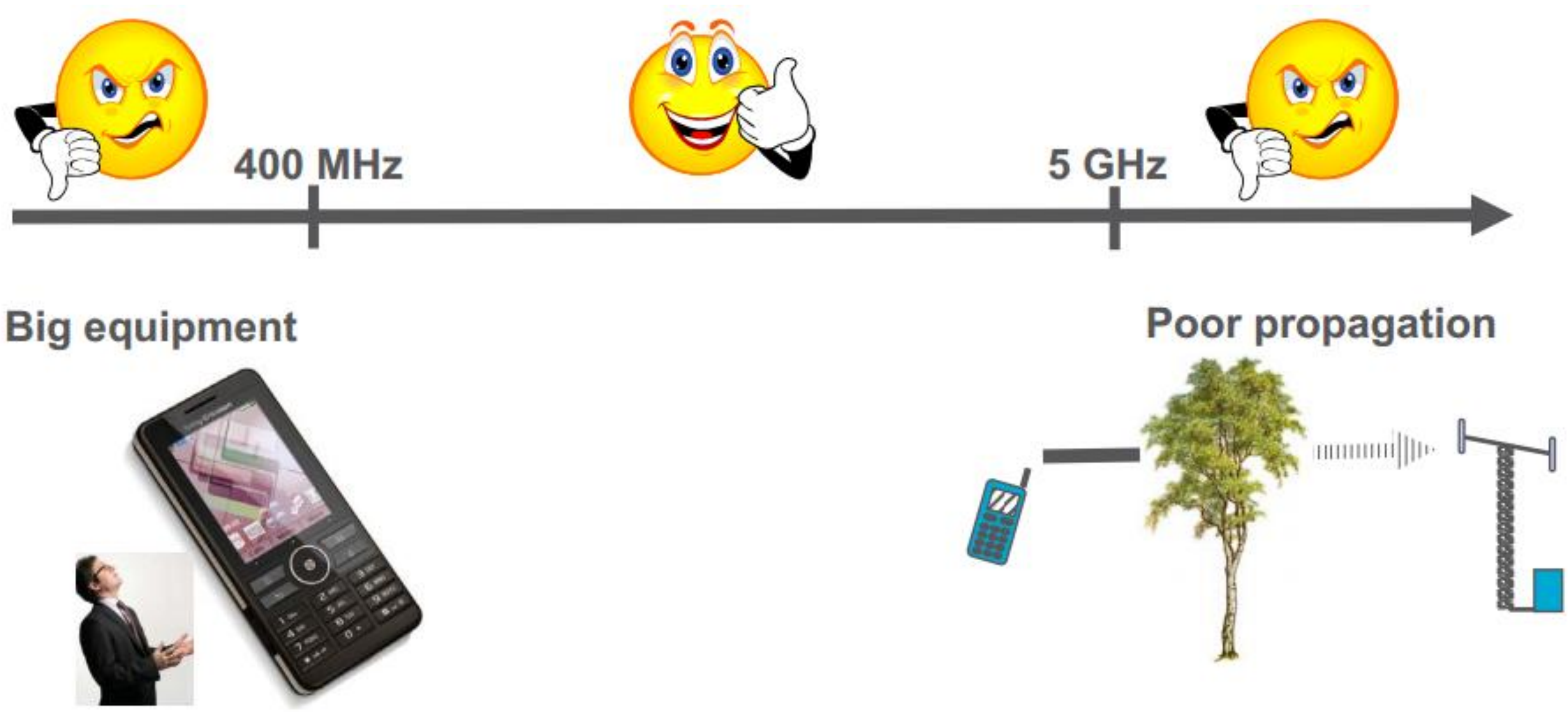
- TDD for unpaired spectrum, DL and UL transmissions share the same channel and carrier frequency. Transmissions are time multiplexed.

- Half-duplex FDD at the terminal, transmission and reception separated in both frequency and time.



- 29 FDD and 12 TDD Frequency Bands
- High degree of commonality between the bands is desired to enable global roaming.
- WRC '07 identified additional frequency bands for IMT, e.g. 450-470MHz, 698-806MHz, 3400-3600MHz

Good Spectrum



LTE Supported Frequency Bands

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
4	1710 MHz – 1755 MHz	2110 MHz – 2155 MHz	FDD
5	824 MHz – 849 MHz	869 MHz – 894MHz	FDD
6[1]	830 MHz – 840 MHz	875 MHz – 885 MHz	FDD
7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
9	1749.9 MHz – 1784.9 MHz	1844.9 MHz – 1879.9 MHz	FDD
10	1710 MHz – 1770 MHz	2110 MHz – 2170 MHz	FDD
11	1427.9 MHz – 1447.9 MHz	1475.9 MHz – 1495.9 MHz	FDD
12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
13	777 MHz – 787 MHz	746 MHz – 756 MHz	FDD
14	788 MHz – 798 MHz	758 MHz – 768 MHz	FDD
15	Reserved	Reserved	FDD
16	Reserved	Reserved	FDD
17	704 MHz – 716 MHz	734 MHz – 746 MHz	FDD
18	815 MHz – 830 MHz	860 MHz – 875 MHz	FDD
19	830 MHz – 845 MHz	875 MHz – 890 MHz	FDD
20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
21	1447.9 MHz – 1462.9 MHz	1495.9 MHz – 1510.9 MHz	FDD
22	3410 MHz – 3490 MHz	3510 MHz – 3590 MHz	FDD
23	2000 MHz – 2020 MHz	2180 MHz – 2200 MHz	FDD
24	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
26	814 MHz – 849 MHz	859 MHz – 894 MHz	FDD
27	807 MHz – 824 MHz	852 MHz – 869 MHz	FDD
28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
29	N/A	717 MHz – 728 MHz	FDD[2]
...			
33	1900 MHz – 1920 MHz	1900 MHz – 1920 MHz	TDD
34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
35	1850 MHz – 1910 MHz	1850 MHz – 1910 MHz	TDD
36	1930 MHz – 1990 MHz	1930 MHz – 1990 MHz	TDD
37	1910 MHz – 1930 MHz	1910 MHz – 1930 MHz	TDD
38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
41	2496 MHz 2690 MHz	2496 MHz 2690 MHz	TDD
42	3400 MHz – 3600 MHz	3400 MHz – 3600 MHz	TDD
43	3600 MHz – 3800 MHz	3600 MHz – 3800 MHz	TDD
44	703 MHz – 803 MHz	703 MHz – 803 MHz	TDD

NOTE 1: Band 6 is not applicable

NOTE 2: Restricted to E-UTRA operation when carrier aggregation is configured. The downlink operating band is paired with the uplink operating band (external) of the carrier aggregation configuration that is supporting the configured Pcell.

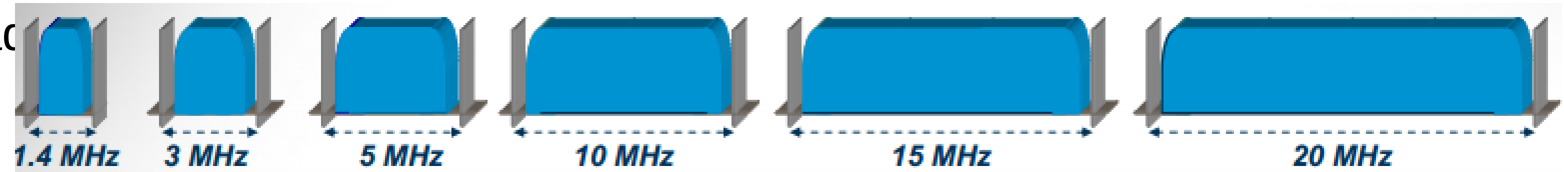
3GPP TS 36.101 version 11.7.0 Release 11

LTE Spectrum and Bandwidth Flexibility

- Operation in differently sized spectrum allocations and in diverse frequency ranges
- RF requirements to achieve operation in different frequency bands

- Coexistence between operators in the same geographical area in the band
- Co-location of base station equipment between operators
- Coexistence with services in adjacent frequency bands and across country borders
- Coexistence between operators of TDD systems in the same band
- Release-independent frequency-band principles

- Transmission in different bandwidths on both DL and UL
- Baseband specifications support from 1.4MHz to 20MHz
- Rad



Key Features of LTE

Downlink: OFDMA

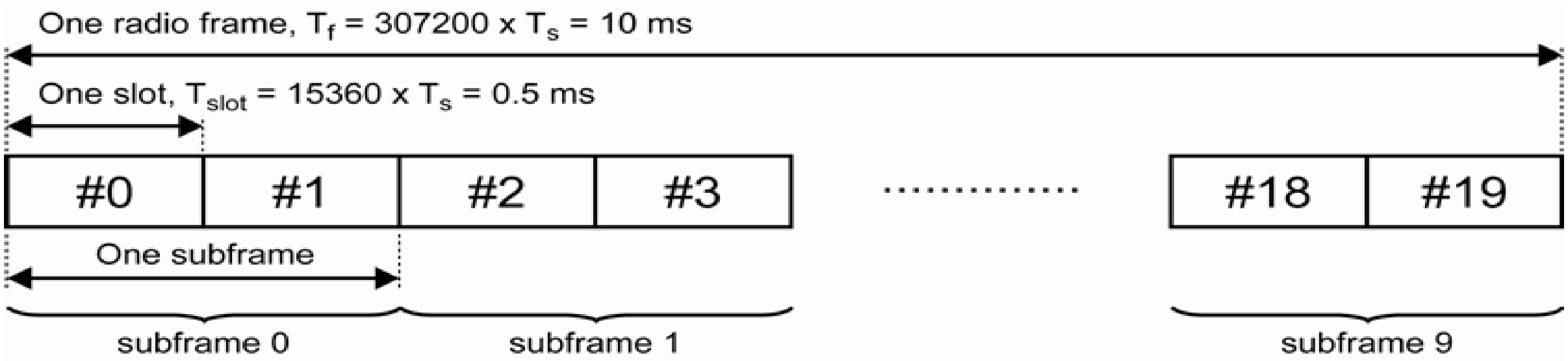
- High spectral efficiency
- Robust against frequency-selectivity / multi-path interference
- Inter-symbol interference contained within cyclic prefix
- Supports flexible bandwidth deployment
- Facilitates frequency-domain scheduling
- Well suited to advanced MIMO techniques

Uplink: SC-FDMA

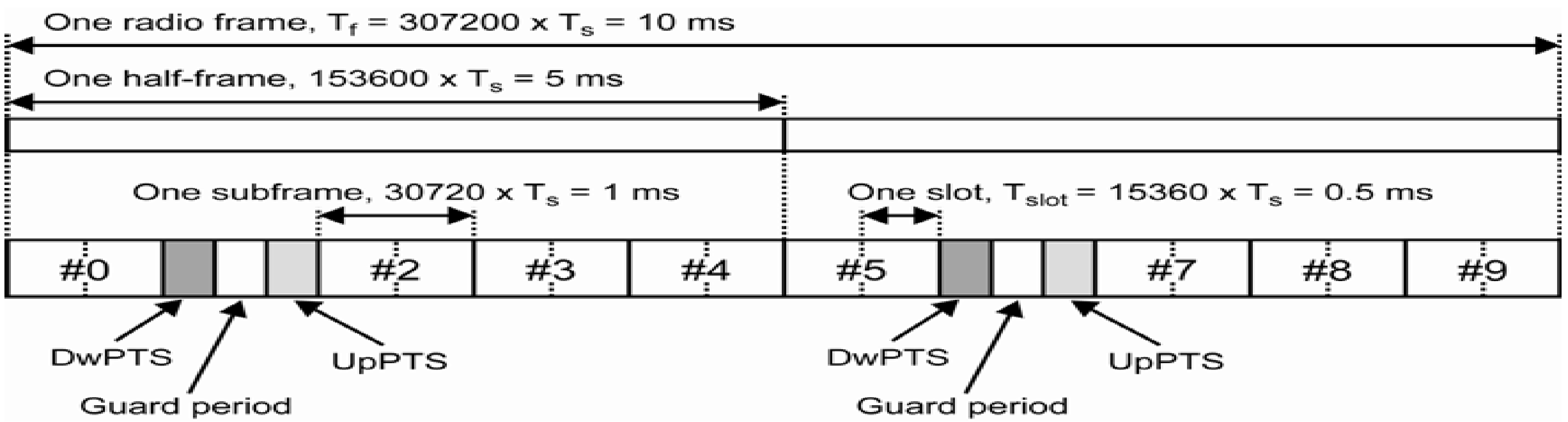
- Based on OFDMA with DFT precoding
- Common structure of transmission resources compared to downlink
- Cyclic prefix facilitates frequency-domain equalisation at eNodeB
- Low PAPR for efficient transmitter design (mobile power saving)

Frame Structure

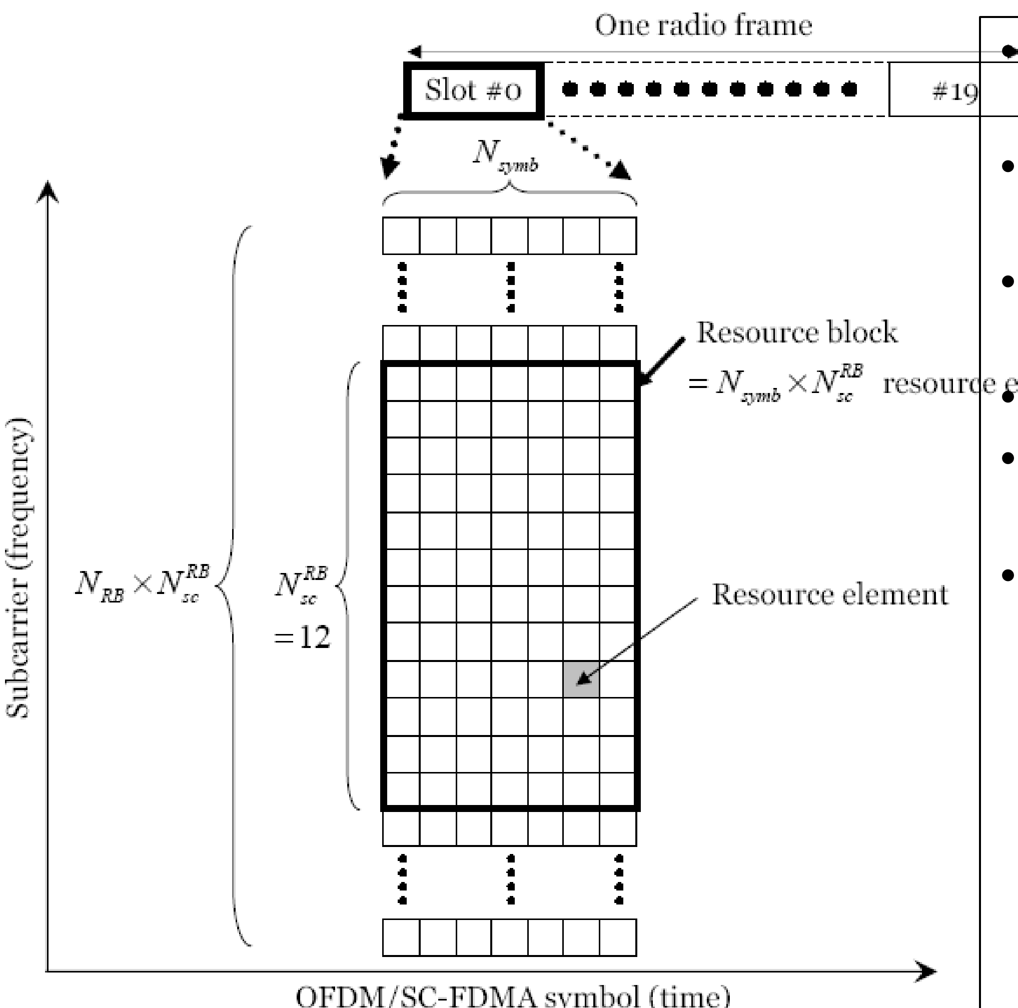
Frame Structure Type 1 (FDD and Half-duplex FDD)



Frame Structure Type 2 (TDD)



Resource Grid



- One frame is 10ms
  → 10 subframes
- 6 or 7 SC-FDMA symbols in one slot
- One subframe is 1ms
  → 2 slots
- Subcarrier spacing = 15 kHz
- One slot contains *N* Resource Blocks (6 < N < 110)
- Block of 12 SCs in 1 slot = 1 RB
  - 0.5 ms x 180 kHz
  -Smallest unit of allocation

LTE Uplink Physical Layer

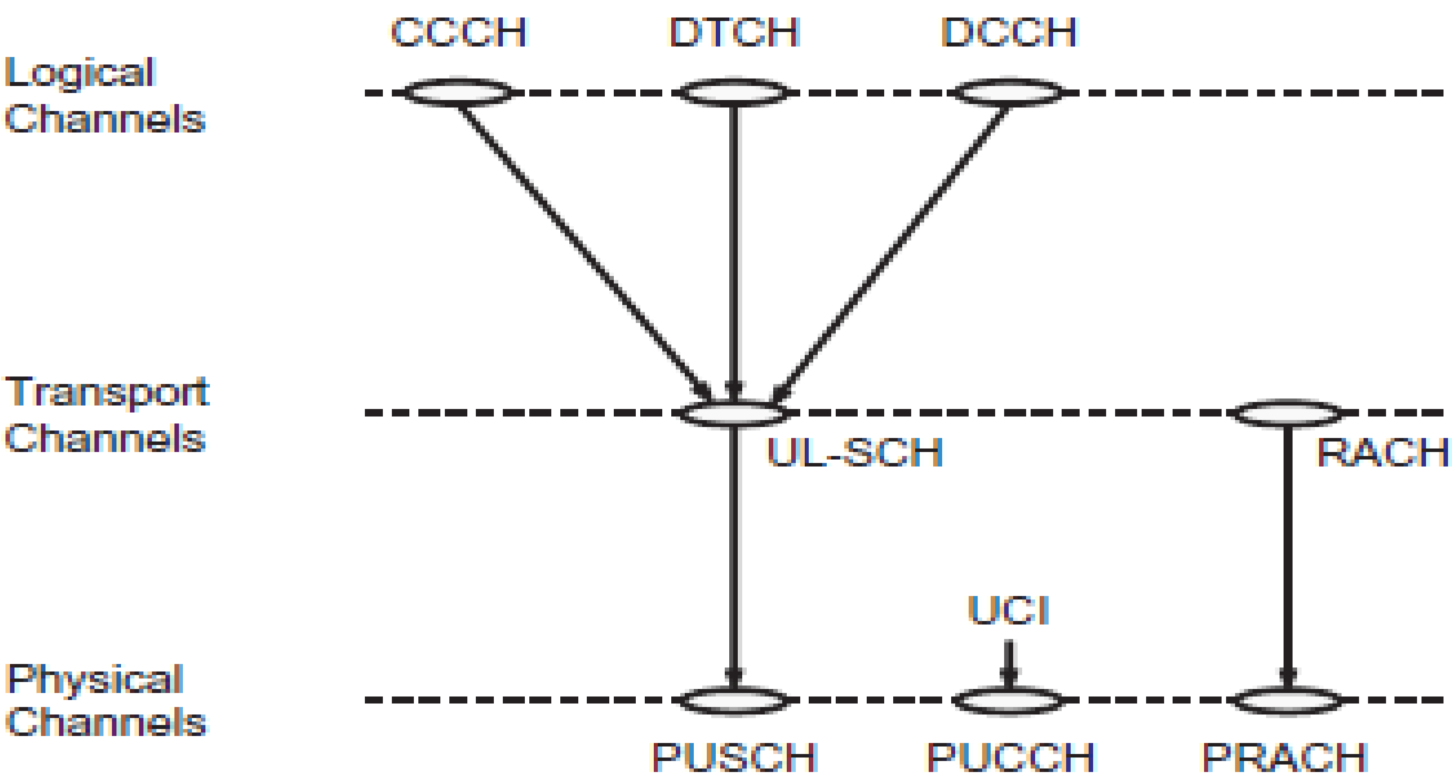
- The physical layer is defined taking bandwidth into consideration, allowing the physical layer to adapt to various spectrum allocations.

- The modulation schemes supported in the downlink are QPSK, 16QAM and 64QAM, and in the uplink QPSK, 16QAM and 64-QAM.The Broadcast channel uses only QPSK.

- The channel coding scheme for transport blocks in LTE is Turbo Coding with a coding rate of R=1/3, two 8-state constituent encoders and a contention-free quadratic permutation polynomial (QPP) turbo code internal interleaver.

- Trellis termination is used for the turbo coding. Before the turbo coding, transport blocks are segmented into byte aligned segments with a maximum information block size of 6144 bits. Error detection is supported by the use of 24 bit CRC.

LTE Uplink Channels



LTE Uplink Transport Channels

Random Access Channel (RACH)

- Channel carries minimal information
- Transmissions on the channel may be lost due to collisions

Uplink Shared Channel (UL-SCH)

- Optional support for beam forming
- Supports dynamic link adaptation by varying the transmit power and potentially modulation and coding
- Supports Hybrid ARQ
- Supports dynamic and semi-static resource allocation

Uplink Physical Channels

Physical Radio Access Channel (PRACH)	• Carries the random access preamble • The random access preambles are generated from Zadoff-Chu sequences with zero correlation zone, generated from one or several root Zadoff-Chu sequences.
Physical Uplink Shared Channel (PUSCH)	• Carries the UL-SCH • QPSK, 16-QAM, and 64-QAM Modulation
Packet Uplink Control Channel (PUCCH)	• Carries Hybrid ARQ ACK/NAKs in response to downlink transmission • Carries Scheduling Request (SR) • Carries CQI reports • BPSK and QPSK Modulation

Physical Uplink Shared Channel (PUSCH)

- Data transmissions on Physical Uplink Shared Channel (PUSCH)
  - In centre of uplink bandwidth
  - Minimizes out-of-band emissions from wide-bandwidth data transmissions
  - 1 transport block per TTI
  - Same channel coding / rate matching as PDSCH
  - Modulation QPSK, 16QAM, 64QAM

- When PUSCH is transmitted, any control signalling is multiplexed with data to maintain single carrier structure

- When no PUSCH, control signalling is on Physical Uplink Control Channel (PUCCH)
  - Usually at edges of system bandwidth
  - PUCCH hops from one side of the carrier to the other to maximize frequency diversity

Control Signalling on PUSCH

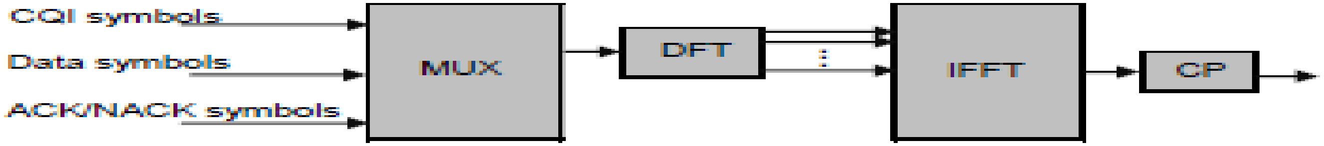
- PUSCH carries the uplink L1/L2 control signals in the presence of uplink data
- CQI/PMI transmitted on PUSCH uses the same modulation scheme as data
- ACK/NACK and RI are transmitted so that the coding/scrambling/modulation maximize the Euclidean distance at the symbol level. The outermost constellation points are used to signal these for 16-QAM and 64-QAM
- Different channel coding approaches are applied with control signals transmitted on PUSCH:

  - 1-bit ACK/NACK: repetition coding

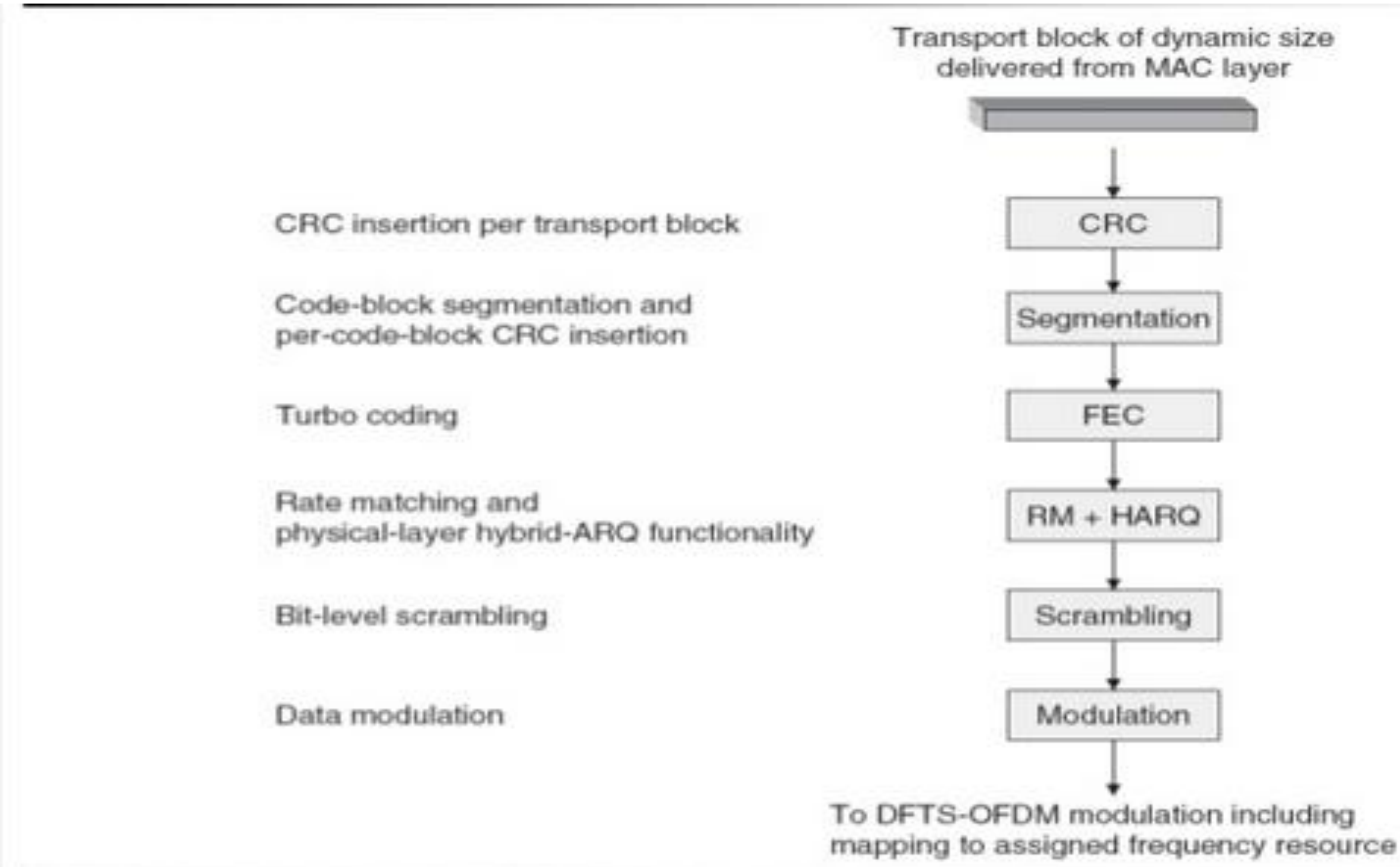
  - 2-bit ACK/NACK/RI: simplex coding

  - CQI/PMI < 11 bits: (32,N) Reed-Muller coding

  - CQI/PMI > 11 bits: tail-biting convolutional coding (1/3)
- An important issue related to control signaling on PUSCH is how to keep the performance of control signaling at the target level.



PUSCH Processing



PUSCH Frequency Hopping

- PUSCH Transmission

  - Localized transmission w/o frequency hopping

    -> Frequency Selective Scheduling Gain

  - Distributed transmission with “frequency hopping”

    -> Frequency Diversity Gain, Inter-cell Interference Randomization

- Two types of PUSCH frequency hopping

  - Sub-band based hopping according to cell-specific hopping patterns

  - Hopping based on explicit hopping information in the scheduling UL grant

Uplink Physical Signals

- UL Physical Signals

  - An uplink physical signal is used by the physical layer but does not carry information originating from higher layers
- Two types of reference signals

  - UL Demodulation Reference Signal (DRS) for PUSCH, PUCCH

  - UL Sounding Reference Signal (SRS) not associated with PUSCH, PUCCH transmission

LTE Key Parameters

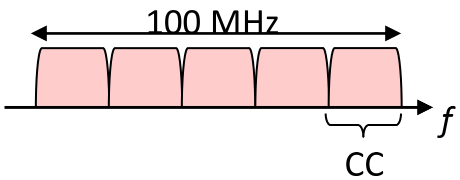
Frequency Range	UMTS FDD bands and UMTS TDD bands					
Bandwidth (MHz)	1.4	3	5	10	15	20
Number of Resource Blocks (N_{RB}). 1 Resource Block=180kHz	6	15	25	50	75	100
Modulation Schemes	Downlink: QPSK, 16QAM, 64QAM					
	Uplink: QPSK, 16QAM, 64QAM (optional for handset)					
Multiple Access	Downlink: OFDMA (Orthogonal Frequency Division Multiple Access)					
	Uplink: SC-FDMA (Single Carrier Frequency Division Multiple Access)					
MIMO Technology	Downlink: Wide choice of MIMO configuration options for transmit diversity, spatial multiplexing, and cyclic delay diversity (max. 4 antennas at base station and handset)					
	Uplink: Multi user collaborative MIMO					
Peak Data Rate	Downlink: 150Mbps (UE category 4, 2x2 MIMO, 20MHz) 300Mbps (UE category 5, 4x4 MIMO, 20MHz)					
	Uplink: 75Mbps (20MHz)					
IDFT (Tx) / DFT (Rx) size	128	256	512	1024	1536	2048
Number of used subcarriers	72	180	300	600	900	1200
Number of data subcarriers	60	150	250	500	750	1000
Number of pilot subcarriers	12	30	50	100	150	200
Number of guard subcarriers (including DC subcarrier)	56	76	212	424	636	848
Number of total subcarriers (rest zero padded)	128	256	512	1024	1536	2048
Samples per slot	960	1920	3840	7680	11520	15360
Sample Rate (MHz)	1.92	3.84	7.68	15.36	23.04	30.72
OFDM Symbols / Subframe	7/6 (Normal / Extended CP)					

LTE-Advanced

Support of Wider Bandwidth(Carrier Aggregation)

- Use of multiple component carriers(CC) to extend bandwidth up to 100 MHz
- Common physical layer parameters between component carrier and LTE Rel-8 carrier

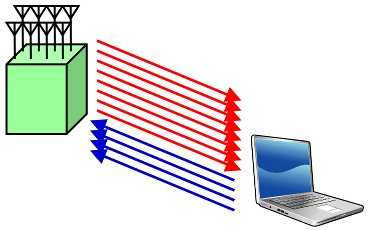
→ Improvement of peak data rate, backward compatibility with LTE Rel-8



Advanced MIMO techniques

- Extension to up to 8-layer transmission in downlink
- Introduction of single-user MIMO up to 4-layer transmission in uplink
- Enhancements of multi-user MIMO

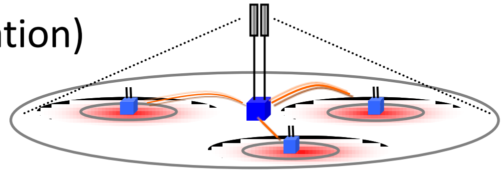
→ Improvement of peak data rate and capacity



Heterogeneous network and eICIC(enhanced Inter-Cell Interference Coordination)

- Interference coordination for overlaid deployment of cells with different Tx power

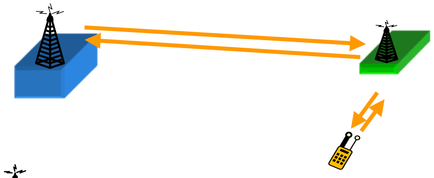
→ Improvement of cell-edge throughput and coverage



Relay

- Type 1 relay supports radio backhaul and creates a separate cell and appear as Rel. 8 LTE eNB to Rel. 8 LTE Ues

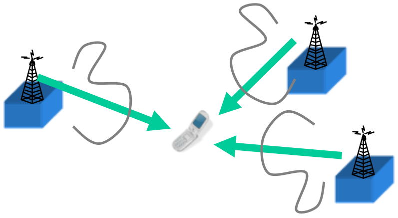
→ Improvement of coverage and flexibility of service area extension



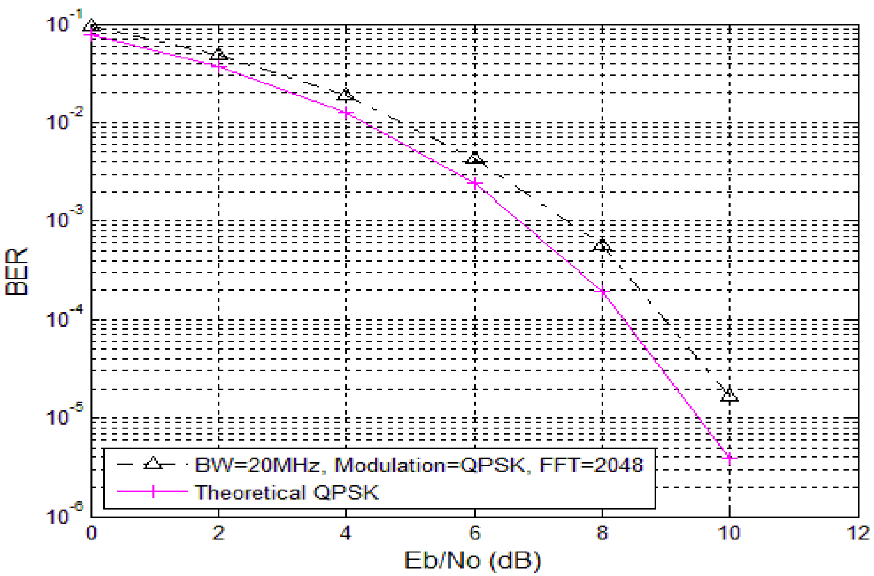
Coordinated Multi-Point transmission and reception (CoMP)

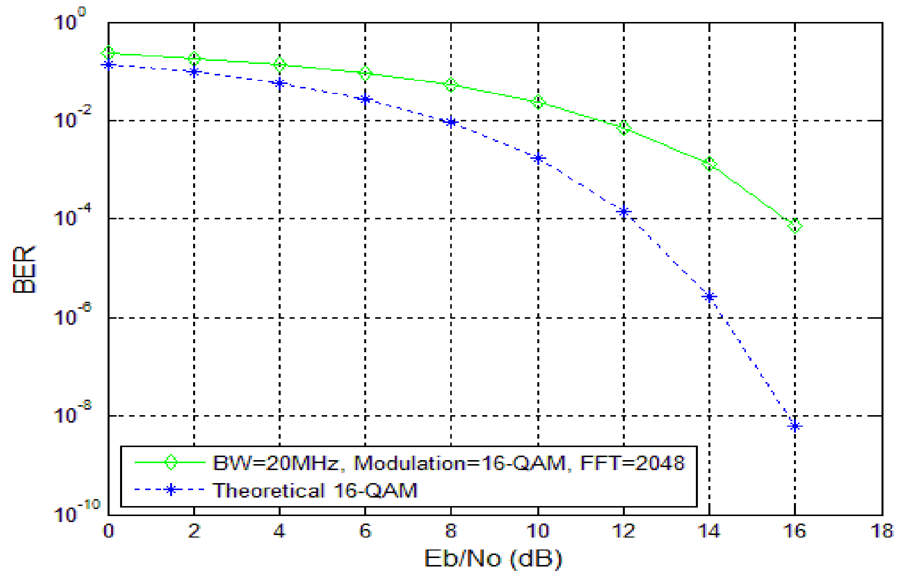
- Support of multi-cell transmission and reception

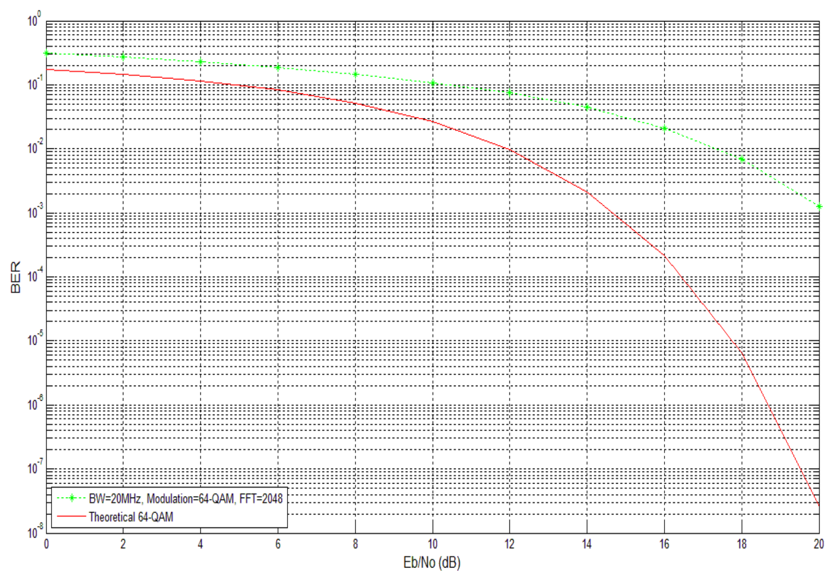
→ Improvement of cell-edge throughput and coverage

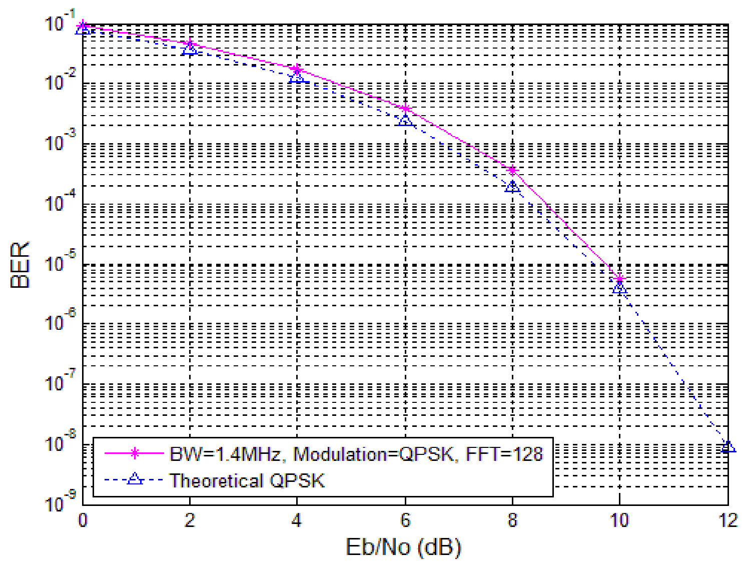


Simulation Results





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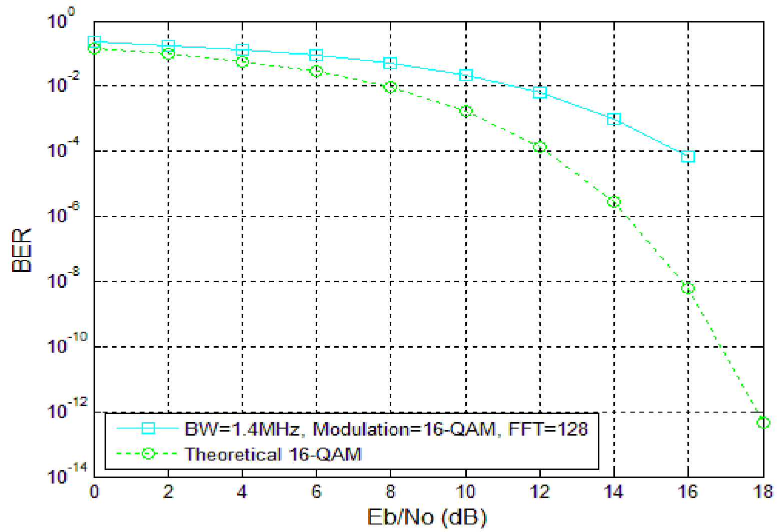
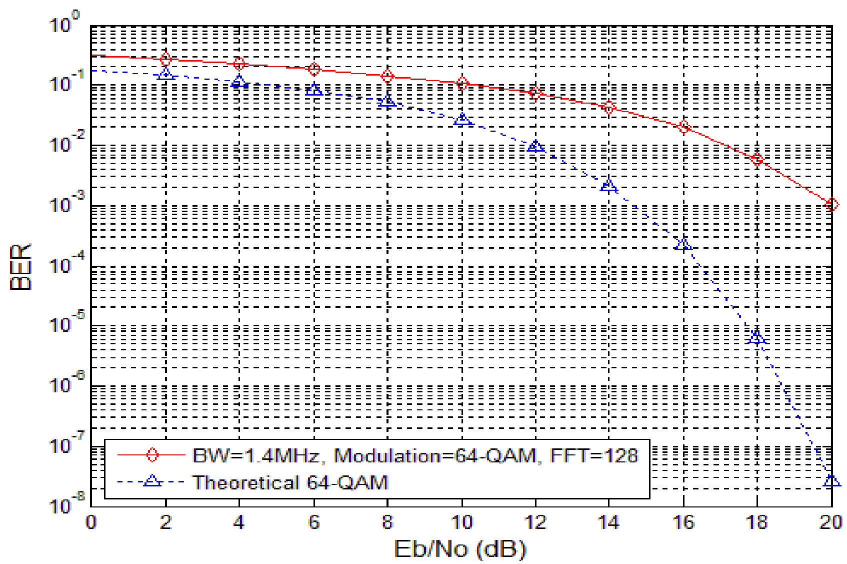
Eb/No (dB)
BW=1.4MHz, Modulation=QPSK, FFT=128
Theoretical QPSK


BER
Eb/No (dB)
BW=1.4MHz, Modulation=16-QAM, FFT=128
Theoretical 16-QAM


BER
Eb/No (dB)
BW=1.4MHz, Modulation=64-QAM, FFT=128
Theoretical 64-QAM