What LTE parameters need to be Dimensioned and Optimized

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Presenter

- ## Leonhard Korowajczuk
  - CEO/CTO CelPlan International
  - 45 years of experience in the telecom field (R&D, manufacturing and service areas)
  - Holds13 patents
  - Published books
    - "Designing cdma2000 Systems"
      - published by Wiley in 2006- 963 pages, available in hard cover, e-book and Kindle
    - "LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis "
      - published by Wiley in June 2011- 750 pages, available in hard cover, e-book and Kindle
  - Books in Preparation:
    - LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis
      - second edition (2014) LTE-A and WiMAX 2.1(1,000+ pages)
    - Network Video: Private and Public Safety Applications (2014)
    - Backhaul Network Design (2015)
    - Multi-Technology Networks: from GSM to LTE (2015)
    - Smart Grids Network Design (2016)

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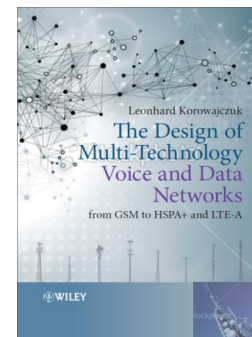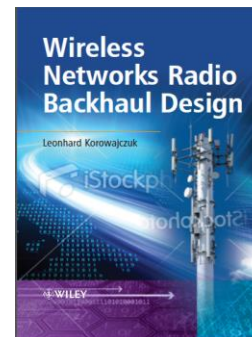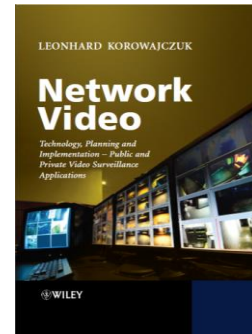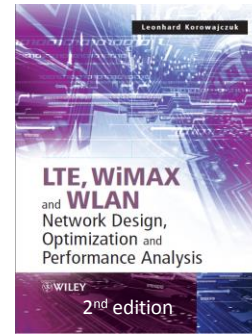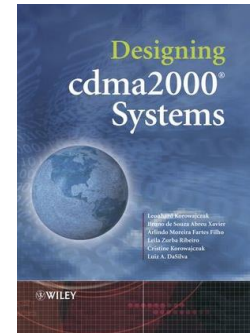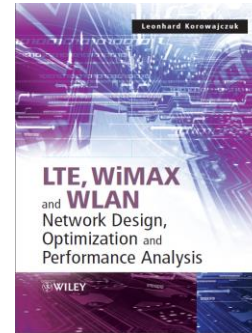
- Employee owned enterprise with international presence
  - Headquarters in USA
  - 450 plus employees
  - Twenty (20) years in business
- Subsidiaries in 6 countries with worldwide operation
- Vendor Independent
- Network Design Software (CelPlanner Suite/CellDesigner)
- Network Design Services
- Network Optimization Services
- Network Performance Evaluation

- Services are provided to equipment vendors, operators and consultants
- High Level Consulting
  - RFP preparation
  - Vendor interface
  - Technical Audit
  - Business Plan Preparation
  - Specialized (Smart Grids, Aeronautical, Windmill, …)
- Network Managed Services
- 2G, 3G, 4G, 5G Technologies
- Multi-technology / Multi-band Networks
- Backhaul, Small cells, Indoor, HetNet, Wi-Fi offloading

CelPlan Webinar Series

- **How to Dimension user Traffic in 4 G networks**
  - May 7th 2014
- **How to Consider Overhead in LTE Dimensioning and what is the impact**
  - June 4th 2014
- **How to Take into Account Customer Experience when Designing a Wireless Network**
  - July 9th 2014
- **LTE Measurements what they mean and how they are used?**
  - August 6th2014
- **What LTE parameters need to be Dimensioned and Optimized? Can reuse of one be used? What is the best LTE configuration?**
  - September 3rd 2014
- **Spectrum Analysis for LTE Systems**
  - October 1st 2014
- **MIMO: What is real, what is Wishful Thinking?**
  - November 5th 2014
- **Send suggestions and questions to: webinar@celplan.com**

Webinar 1 (May 2014)
How to Dimension User Traffic in 4G Networks

Participants from 44 countries
Youtube views: 572

User Traffic

1. How to Dimension User Traffic in 4G Networks

2. How to Characterize Data Traffic

3. Data Speed Considerations

4. How to calculate user traffic?

5. Bearers

6. User Applications Determination

7. User Distribution

Webinar 2 (June 2014)
How to consider overhead in LTE dimensioning
and what is the impact

Participants from 49 countries
Youtube views: 285

Overhead in LTE

1. Reuse in LTE
2. LTE Refresher
   1. Frame
   2. Frame Content
   3. Transmission Modes
   4. Frame Organization
      1. Downlink Signals
      2. Uplink Signals
      3. Downlink Channels
      4. Uplink Channels
   5. Data Scheduling and Allocation
   6. Cellular Reuse
3. Dimensioning and Planning
4. Capacity Calculator

Webinar 3 (July 2014)
How to consider Customer Experience when designing a wireless network

Participants from 40 countries
Youtube views: 230

Customer Experience

1. How to evaluate Customer Experience?
2. What factors affect customer experience?
3. Parameters that affect cutomer experience
4. SINR availability and how to calculate it
5. Conclusions
6. New Products

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Webinar 4 (August 6th, 2014)
LTE Measurements
What they mean?
How are they used?

Participants from 44 countries
Youtube views: 245

LTE Measurements

1. Network Measurements
   1. UE Measurements
      - RSRP
      - RSSI and its variations
      - RSRQ and its variations
      - RSTD
      - RX-TX Time Difference
   2. Cell Measurements
      - Reference Signal TX Power
      - Received Interference Power
      - Thermal Noise Power
      - RX-TX Time Difference
      - Timing Advance
      - Angle of Arrival
   3. Measurement Reporting
      - Intra-LTE
      - Inter-RAT
      - Event triggered
      - Periodic

2. Field Measurements
   1. 1D Measurements
      - RF propagation model calibration
      - Receive Signal Strength Information
      - Reference Signal Received Power
      - Reference Signal Received Quality
      - Primary Synchronization Signal power
      - Signal power
      - Noise and Interference Power
      - Fade Mean
   2. 2D Measurements
      - Primary Synchronization Signal Power Delay Profile
   3. 3D measurements
      - Received Time Frequency Resource Elements
      - Channel Frequency response
      - Channel Impulse Response
      - Transmit Antenna Correlation
      - Traffic Load
   4. Measurement based predictions

Next Events

Webinar 6
Spectrum Analysis for LTE Systems

October 1st 2014

Registration is open

Spectrum Analysis for LTE Systems

- LTE is an OFDM broadband technology, with very wide channels. Narrow band channels present similar fading characteristics in its bandwidth, with variations restricted only to time dimension. Wide band channels vary in the frequency domain also. The designer has to have a full understanding of this variations and this information is not available with traditional test gear

- Until today designers had to guess multipath and fading performance, but the deployment of wide band channels and MIMO techniques require a precise understanding of this effect geographically

- Decisions as where to deploy cells, what number of antennas to use and parameter settings, can represent huge capital (CAPEX) savings and reduce operational costs (OPEX)

- RF Parameter Characterization in Broadband Channels
- Traditional Spectrum Analysis
- LTE Performance Spectrum Analysis
- Network Characterization though Drive Test
- Drive Test Devices
  - Software Defined Receivers
  - Spectrum recording
- Visualizing Measurements in Multiple Dimensions
  - 1 Dimension
  - 2 Dimensions
  - 3 Dimensions
- Measurement Interpolation and Area Prediction
- Explaining LTE Measurement Content
  - RX Signal Strength per RE
  - Noise Filtered Channel Response for each RS
  - RF Channel Response for RS carrying OFDM symbols
  - RF Channel Response for all OFDM symbols
  - Impulse Response for each RS Carrying OFDM symbol
  - Multipath Delay Spread
  - Reference Signal Received Power
  - Receive Signal Strength Indicator: full OFDM symbols
  - Receive Signal Strength Indicator: RS RE of OFDM symbols
  - Receive Signal Strength Indicator: PBCH
  - Reference Signal Received Quality: full OFDM symbols
  - Reference Signal Received Quality: RS RE of OFDM symbols
  - Reference Signal Received Quality: PBCH
  - PSS Power Distribution Profile
  - PSS Power
  - Frequency Fade Mean
  - Frequency Fade Variance
  - Signal power
  - Noise Power
  - Signal to Noise and Interference Ratio
  - Antenna Correlation
  - LTE Frame Traffic Load

4G Technologies Boot Camp Americas Region- Reston, VA

September 16 to 20, 2014

4G Technologies Boot Camp

Americas Region- Reston, VA (September 16 to 20)

- Designed to give CEOs, CTOs, managers, engineers, and technical staff the practical knowledge on 4G networks

- **Module A: Wireless Communications Fundamentals**
  - 4G Broadband Wireless Systems use a whole new set of techniques and technological solutions that require the understanding of new concepts and terminologies. Students are presented with the basic principles of 4G technologies, from the mathematical basics to the specifics of each area. With this knowledge students will be able to understand the inner-workings of 4G technologies.
  - Wireless Network Mathematics Refresher
  - Signal Processing Fundamentals
  - The RF Communications Channel
  - Advanced Antenna Systems (MIMO and AAS)
  - Data and Internet Protocols

- **Module B: 4G Technologies in-depth Analysis (WLAN, WiMAX, LTE)**
  - 4G technologies are evolving at a fast pace. Many solutions exist in one technology but not in the others, so understanding all of them is essential to understand each one as its defined today, along with its possible evolution paths.
  - 4G Wireless Communication Channel
  - WLAN (Wi-Fi), WiMAX
  - LTE and LTE Advanced
  - Comparing 4G Technologies

- 4G Certification (Optional)

- Additional information, Pricing & Registration available at www.celplan.com

LTE Technology, Network Design & Optimization Boot Camp

December 8 to 12, 2014

at University of West Indies (UWI)

St. Augustine, Trinidad

LTE Technology, Network Design & Optimization Boot Camp

- December 8 to 12, 2014

- Based on the current book and updates from the soon-to-be published 2nd edition of, "***LTE, WiMAX, and WLAN: Network Design, Optimization and Performance Analysis***", by Leonhard Korowajczuk, this -day course presents students with comprehensive information on LTE technology, projects, and deployments.

- CelPlan presents a realistic view of LTE networks, explaining what are just marketing claims and what can be achieved in real life deployments. Each module is taught by experienced 4G RF engineers who design and optimize networks around the globe.

- The materials provided are based upon this experience and by the development of industry leading planning & optimization tools, such as the CelPlanner Software Suite, which is also provided as a 30-day demo to each student

- **Module A: LTE Technology**
  - Signal Processing Applied to Wireless Communications
  - LTE Technology Overview
  - Connecting to an LTE network: an UE point of view
  - How to calculate the capacity of an LTE cell and network
  - Understanding scheduling algorithms
  - LTE measurements and what they mean
  - Understanding MIMO: Distinguishing between reality and wishful thinking
  - Analyzing 3D RF broadband drive test

LTE Technology, Network Design & Optimization Boot Camp

- **Module B: LTE Network Design**
  - Modeling the LTE Network
  - Building Network Component Libraries
  - Modeling user services and traffic
  - Creating Traffic Layers
  - RF Propagation Models and its calibration
  - Signal Level Predictions
  - LTE Predictions
  - LTE Parameters
  - LTE Resource Optimization
  - LTE Traffic Simulation
  - LTE Performance
  - Interactive Workshop (sharing experiences)
- 4G Certification (Optional)
- Additional information, Pricing & Registration available at www.celplan.com

Today's Feature Presentation

Today's Webinar

What LTE parameters need to be Dimensioned and Optimized

September 3, 2014

Content

1. LTE Refresher

User Traffic Prediction (webinar 1)
Overhead Prediction (webinar 2)
Downlink Frame (webinar 2)
Uplink Frame (webinar 2)
Zadoff-Chu Sequences
Orthogonality
How to consider Interference

1.1 User Traffic

User Traffic Characterization

- Main network applications used in the network have to be identified
- QoS should be assigned to each application, so the most adequate bearer type is assigned
- Additional technical parameters have to be assigned to each application
- QoS characteristics are assigned to each service
  – QCI
  – GBR/MBR
  – AMBR
  – ARP
  – Packet Size
- Unitary Daily Tonnage are assigned for each service
  – DL
  – UL

CellDesigner - Tonnage Calculator

QCI Table | *QoS* | *Unitary* | *Tonnage*

Service Identification

	Name	QCI	GBR	MBR	APN	UE	Capability	Vulnerability	DL	UL
1	Conversational Voice	1	12.5	16			N	Y	320	320
2	Conversational Video (live streaming)	2	180	240			N	Y	760	64
3	Real Time Gaming	3	1.5	1.6			N	Y	80	24
4	Non conversational Video (buffered)	4	128	156			N	Y	1024	128
5	IMS signaling	5			64	32	Y	Y	128	32
6	Video (buffered streaming), TCP applications	6			128	256	Y	Y	1024	128
7	Voice, Video Live Streaming, Interactive Gaming	7			128	256	Y	Y	760	64
8	Video (buffered streaming), TCP applications	8			128	256	Y	Y	1024	128
9	Video (buffered streaming), TCP applications	9			128	256	Y	Y	1024	128
10	UTP based applications	5			32	64	Y	N	64	12
11	UTP based applications	6			48	128	Y	N	128	24
12	UTP based applications	7			64	128	Y	N	256	48

Data Rate (kbps) — GBR, MBR | AMBR (kbps) — APN, UE | ARP — Capability, Vulnerability | Packet Size (Bytes) — DL, UL

CellDesigner - Tonnage Calculator

QCI Table | *QoS* | *Unitary* | *Tonnage*

QCI Standard Values

QCI	Type	Priority	Delay	PER
1	GBR	2	100	10-2
2	GBR	4	150	10-3
3	GBR	3	50	10-3
4	GBR	5	300	10-6
5	NGBR	1	100	10-6
6	NGBR	6	300	10-6
7	NGBR	7	100	10-3
8	NGBR	8	300	10-6
9	NGBR	9	300	10-6
10	NGBR	10	100	10-2
11	NGBR	11	100	10-2
12	NGBR	12	100	10-2
13	NGBR	13	100	10-2
14	NGBR	14	100	10-2
15	NGBR	15	100	10-2
16	GBR	12	100	10-2

GBR - Guarantted Bit Rate
NGBR - Non Guarantted Bit Rate
Delay - Packet Delay Budget (ms)
PER - Packet Error Loss Rate

CellDesigner - Tonnage Calculator

QCI Table | *QoS* | *Unitary* | *Tonnage*

Unitary Daily Tonnage

Service Identification

Name	Unit type	Smartphone DL	Smartphone UL	Tablet DL	Tablet UL	USB DL	USB UL	Modem DL	Modem UL
e-mail	kB	2	8	2	8	2	8	2	8
web access	MB	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3
music streaming	MB/h	5	55	5	55	5	55	5	55
music download	MB	1	6	1	6	1	6	1	6
video streaming	MB/h	30	320	30	320	30	320	30	320
video calling	MB/h	30	450	30	450	30	450	30	450
photos download/upload	MB	0.5	3	0.5	3	0.5	3	0.5	3
navigation	MB/h	5	25	5	25	5	25	5	25
VoLTE	MB/h	10	10	10	10	10	10	10	10
4G VoIP	MB/h	15	15	15	15	15	14	15	15
4G VoIP with video	MB/h	100	100	100	100	100	100	100	100
Online gaming	MB/h	1	4	1	4	1	4	1	4

User Traffic Characterization UT1

- Main network applications used in the network have to be identified
- QoS should be assigned to each application, so the most adequate bearer type is assigned
- Additional technical parameters have to be assigned to each application
- Presents a mix of applications

CellDesigner - Tonnage Calculator

QCI Table | *QoS* | *Unitary* | **Tonnage**

Daily to Busy Hour Factor 0.33333   Number of UE 500000   Number of UE 100000   Number of UE 80000   Number of UE 40000

Service Identification

Name	Unit type	QoS	Smartphone Daily Usage	Smartphone Busy Hour (Mbps) DL	Smartphone Busy Hour (Mbps) UL	Tablet Daily Usage	Tablet Busy Hour (Mbps) DL	Tablet Busy Hour (Mbps) UL	USB Daily Usage	USB Busy Hour (Mbps) DL	USB Busy Hour (Mbps) UL	Modem Daily Usage	Modem Busy Hour (Mbps) DL	Modem Busy Hour (Mbps) UL
e-mail	Units	9	50	0.3034	0.0758	15	0.0910	0.0227	20	25.000	0.0303	25	0.1517	0.0379
web access	Pages	9	20	4.6603	1.5534	40	9.3206	3.1068	50	60.000	3.8836	60	13.981	4.6603
music streaming	Minutes	2	4	2.8479	0.2589	6	4.2719	0.3883	8	10.000	0.5178	10	7.1199	0.6472
music download	Tracks	7	5	23.301	3.8836	8	37.282	6.2137	10	12.000	7.7672	12	55.924	9.3206
video streaming	Minutes	4	2	8.2850	0.7767	3	12.427	1.1650	4	5.0000	1.5534	5	20.712	1.9418
video calling	Minutes	2	2	11.650	0.7767									
photos download/upload	Units	1	8	18.641	3.1068	10	23.301	3.8836	12	15.000	4.6603	15	34.952	5.8254
navigation	Minutes	1	2	0.6472	0.1294									
VoLTE	Minutes	5				9	1.1650	1.1650	10	15.000	1.2945	15	1.9418	1.9418
4G VoIP	Minutes	9				10	1.9418	1.9418	12	12.000	2.3301	12	2.3301	2.3301
4G VoIP with video	Minutes	9				10	12.945	12.945	12	15.000	15.534	15	19.418	19.418
Online gaming	Minutes	3				5	0.2589	0.0647	6	10.000	0.0776	10	0.5178	0.1294

Summary

DL	UL		Smartphone DL	Smartphone UL	Tablet DL	Tablet UL	USB DL	USB UL	Modem DL	Modem UL
91.766	18.378	**UE Tonnage @ BH (kbps)**	70.337	10.561	103.00	30.897	179.00	37.649	157.04	46.252
59.789	11.382	Backhaul Total Tonnage @ BH (Gbps)	35.168	5.2808	10.300	3.0897	14.320	3.0119	6.2819	1.8501
13.289	2.9838	UE Montly Tonnage (GB/Mo)	2.6530	0.3983	3.8852	1.1654	6.7516	1.4200	5.9236	1.7445
2.1507	0.4094	Network Montly Tonnage (PB/Mo)	1.2650	0.1899	0.3705	0.1111	0.5151	0.1083	0.2259	0.0665
7104	1088	**Weighted Packet Size (Bits)**								

User Traffic Characterization UT2

- Main network applications used in the network have to be identified
- QoS should be assigned to each application, so the most adequate bearer type is assigned
- Additional technical parameters have to be assigned to each application
- Voice users only

CellDesigner - Tonnage Calculator

QCI Table | QoS | Unitary | Tonnage

Daily to Busy Hour Factor **0.33333**   Number of UE **500000**   Number of UE **100000**   Number of UE **80000**   Number of UE **40000**

Service Identification			Smartphone			Tablet			USB			Modem		
Name	**Unit type**	**QoS**	**Daily Usage**	**Busy Hour (Mbps) DL**	**UL**	**Daily Usage**	**Busy Hour (Mbps) DL**	**UL**	**Daily Usage**	**Busy Hour (Mbps) DL**	**UL**	**Daily Usage**	**Busy Hour (Mbps) DL**	**UL**
e-mail	Units	9	50	0.3034	0.0758	15	0.0910	0.0227	20	25.000	0.0303	25	0.1517	0.0379
web access	Pages	9	20	4.6603	1.5534	40	9.3206	3.1068	50	60.000	3.8836	60	13.981	4.6603
music streaming	Minutes	2	4	2.8479	0.2589	6	4.2719	0.3883	8	10.000	0.5178	10	7.1199	0.6472
music download	Tracks	7	5	23.301	3.8836	8	37.282	6.2137	10	12.000	7.7672	12	55.924	9.3206
video streaming	Minutes	4	2	8.2850	0.7767	3	12.427	1.1650	4	5.0000	1.5534	5	20.712	1.9418
video calling	Minutes	2	2	11.650	0.7767									
photos download/upload	Units	1	8	18.641	3.1068	10	23.301	3.8836	12	15.000	4.6603	15	34.952	5.8254
navigation	Minutes	1	2	0.6472	0.1294									
VoLTE	Minutes	5				9	1.1650	1.1650	10	15.000	1.2945	15	1.9418	1.9418
4G VoIP	Minutes	9				10	1.9418	1.9418	12	12.000	2.3301	12	2.3301	2.3301
4G VoIP with video	Minutes	9				10	12.945	12.945	12	15.000	15.534	15	19.418	19.418
Online gaming	Minutes	3				5	0.2589	0.0647	6	10.000	0.0776	10	0.5178	0.1294

DL	UL	Summary										
91.766	18.378	**UE Tonnage @ BH (kbps)**	70.337	10.561		103.00	30.897		179.00	37.649	157.04	46.252
59.789	11.382	Backhaul Total Tonnage @ BH (Gbps)	35.168	5.2808		10.300	3.0897		14.320	3.0119	6.2819	1.8501
13.289	2.9838	UE Montly Tonnage (GB/Mo)	2.6530	0.3983		3.8852	1.1654		6.7516	1.4200	5.9236	1.7445
2.1507	0.4094	Network Montly Tonnage (PB/Mo)	1.2650	0.1899		0.3705	0.1111		0.5151	0.1083	0.2259	0.0665
7104	1088	**Weighted Packet Size (Bits)**										

1.2 Overhead

Overhead Calculator for UT 1

- Allows user to specify planned overheads
- Provides a quick calculation of cell limits, based on control and data traffic
- Limited to 18 users per cell due to data and signalling traffic

Overhead Calculator for UT 2

- Allows user to specify planned overheads
- Provides a quick calculation of cell limits, based on control and data traffic
- Limited to users per cell due to contol (mapping) capacity limitation

1.3 Downlink Frame

LTE Frame Downlink

- Example on left: 5 MHz Bandwidth
- Subcarrier Width: 15 kHz
  - Central subcarrier
  - Null subcarriers
- Frame: 10 ms
  - Subframe: 1 ms
  - Slot: 0.5 ms
  - Symbol: 66.66 µs
  - Normal Cyclic Prefix: µs
  - Extended Cyclic Prefix: µs
- Resource Element
  - 1 subcarrier x 1 symbol
- Resource Block
  - 12 subcarriers x 1 slot
- Transmission Time Interval
  - 1 subframe
- Central Sub-carrier is not used
- Allocation
  - Green: Synchronization signals
  - Orange: Master Information Block
  - Yellow: Control/Signalling
  - Reference Signals: Blue
  - Light Blue: Data and Control/Signalling

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LTE Frame Downlink

- Example on left: 5 MHz Bandwidth
- Subcarrier Width: 15 kHz
  - Central subcarrier
  - Null subcarriers
- Frame: 10 ms
  - Subframe: 1 ms
  - Slot: 0.5 ms
  - Symbol: 66.67 µs
  - Normal Cyclic Prefix: 5.2/ 4.7 µs
    - (1.4 km)
  - Extended Cyclic Prefix: 16.7 µs
    - (5 km)
- Resource Element
  - 1 subcarrier x 1 symbol
- Resource Block
  - 12 subcarriers x 1 slot
- Transmission Time Interval
  - 1 subframe
- Central Sub-carrier is not used
- Allocation
  - Green: Secondary Synchronization
  - Red : Primary Synchronization
  - Orange: Master Information Block
  - Yellow: Control/Signalling
  - Reference Signals: Blue
  - Light Blue: Data and Control/Signalling

Legend:
- PFICH/ PHICH/ PDCCH
- PBCH
- PDSCH / PMCH
- Primary Synchronization Signal
- Secondary Synchronization Signal
- Reference Signal
- Cyclic Prefix

1.4 Uplink Frame

LTE Frame Uplink (eNB view)

- Example on left: 5 MHz Bandwidth
- Subcarrier Width: 15 kHz
  - No central subcarrier
  - Null subcarriers
- Frame: 10 ms
  - Subframe: 1 ms
  - Slot: 0.5 ms
  - Symbol: 66.66 µs
  - Normal Cyclic Prefix: µs
  - Extended Cyclic Prefix: µs
- Resource Element
  - 1 subcarrier x 1 symbol
- Resource Block
  - 12 subcarriers x 1 slot
- Transmission Time Interval
  - 1 subframe
- Allocation
  - Green: Control
  - Light Red: DL Quality 1
  - Orange: ACK/NACK
  - Red: DL Quality 2
  - Light Blue: Not Used
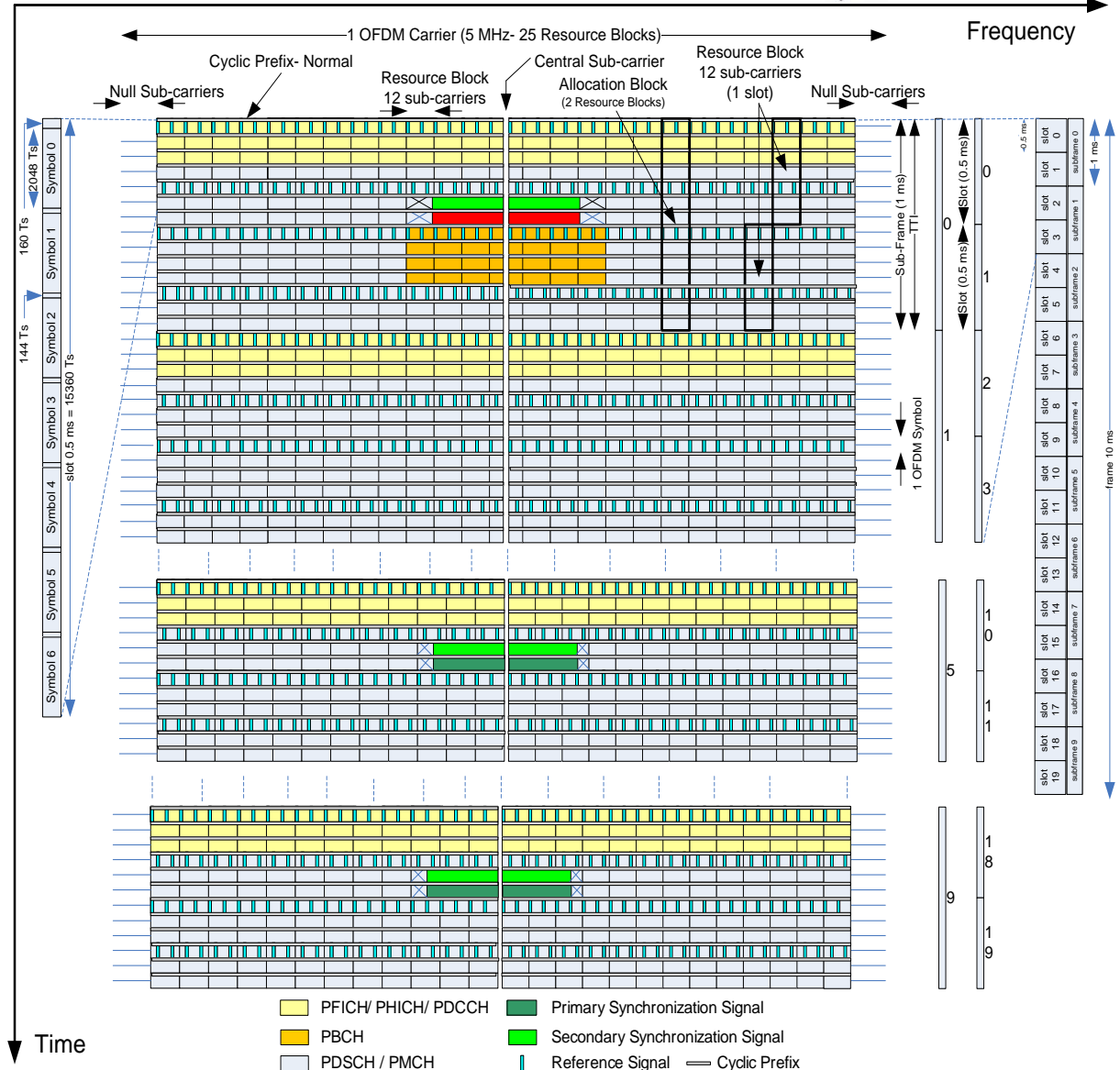 - Orange: Assigned Subcarriers
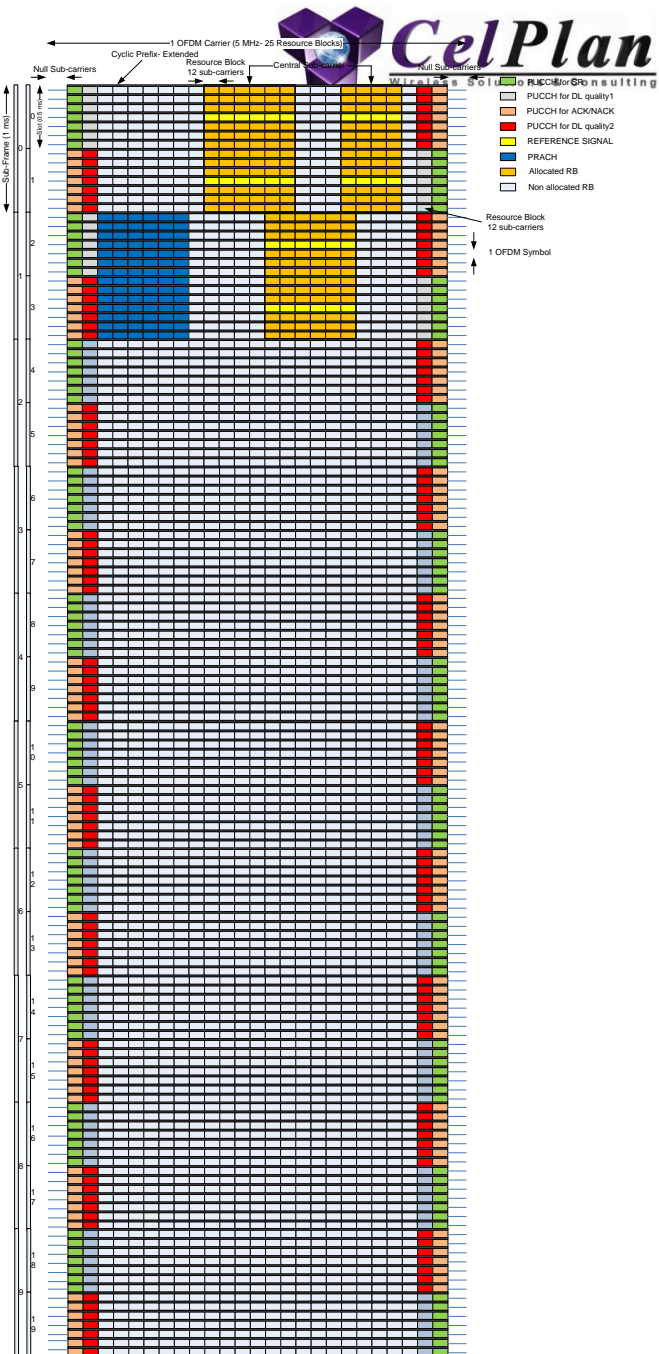
LTE Frame Uplink (eNB view)

- Example on left: 5 MHz Bandwidth
- Subcarrier Width: 15 kHz
  - No central subcarrier
  - Null subcarriers
- Frame: 10 ms
  - Subframe: 1 ms
  - Slot: 0.5 ms
  - Symbol: 66.66 μs
  - Normal Cyclic Prefix: μs
  - Extended Cyclic Prefix: μs
- Resource Element
  - 1 subcarrier x 1 symbol
- Resource Block
  - 12 subcarriers x 1 slot
- Transmission Time Interval
  - 1 subframe
- Allocation
  - Green: Control
  - Light Red: DL Quality 1
  - Orange: ACK/NACK
  - Red: DL Quality 2
  - Yellow: Reference Signal
  - Light Blue: Not Used
  - Orange: Assigned Subcarriers
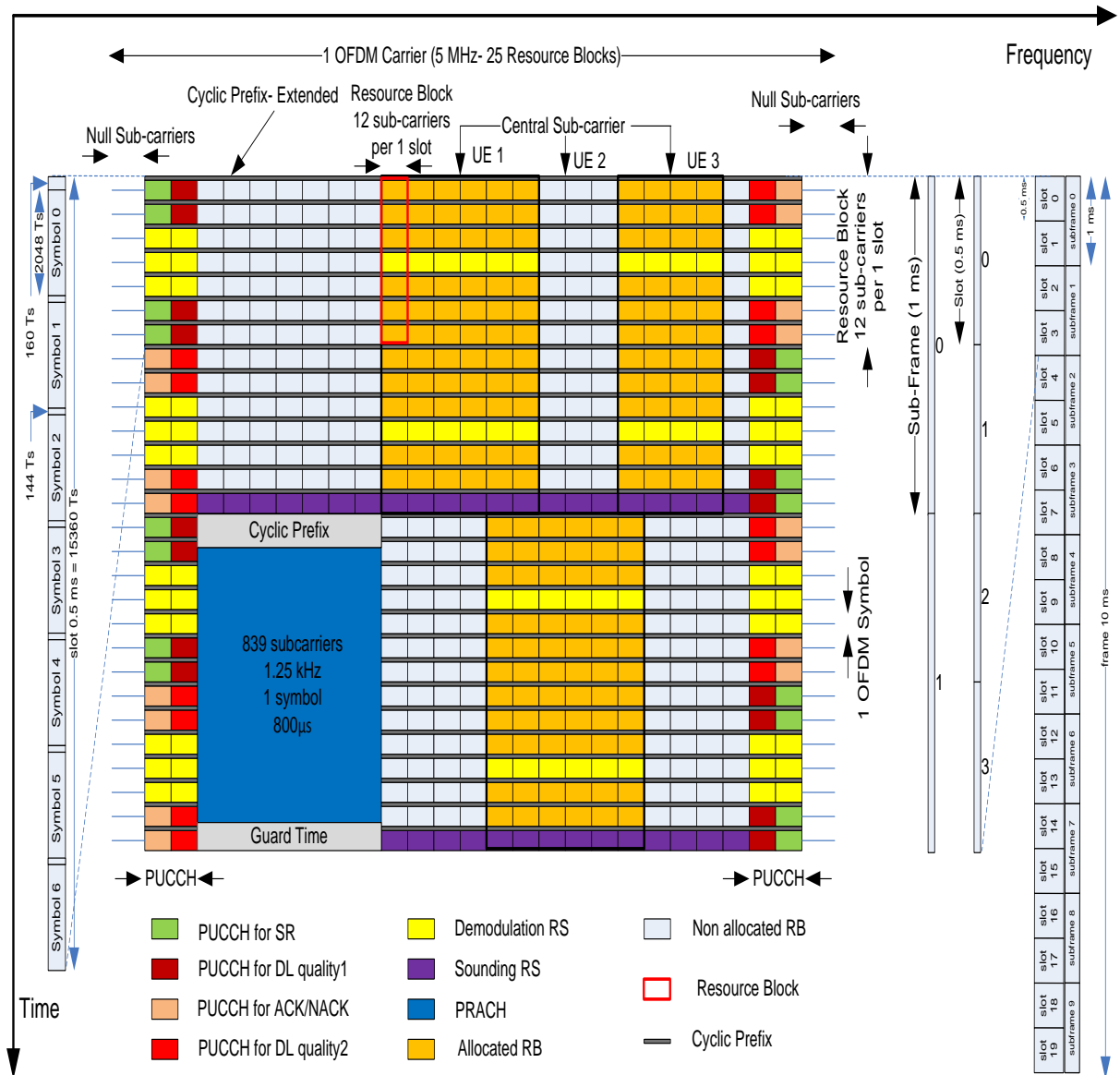
Frame Organization

- **Downlink**
  - Control area
  - Data area

- **Uplink**
  - Control area
  - RACH area
  - Data area

- **Transmit Time Interval (TTI)**
  - Data packet has to be transfered inside a TTI period
  - Several packets can be transfered within the same TTI
  - The downlink control area maps the data location in the data area for downlink and uplink
  - Control information location has to be found through blind search by the UE

Downlink

Subframe 0	Subframe 1	Subframe 2	Subframe 3	Subframe 4	Subframe 5	Subframe 6	Subframe 7	Subframe 8	Subframe 9

map   map   map

Subframe 0	Subframe 1	Subframe 2	Subframe 3	Subframe 4	Subframe 5	Subframe 6	Subframe 7	Subframe 8	Subframe 9

Uplink
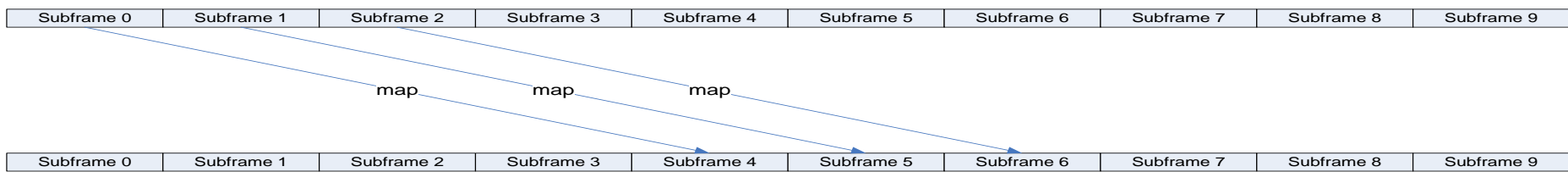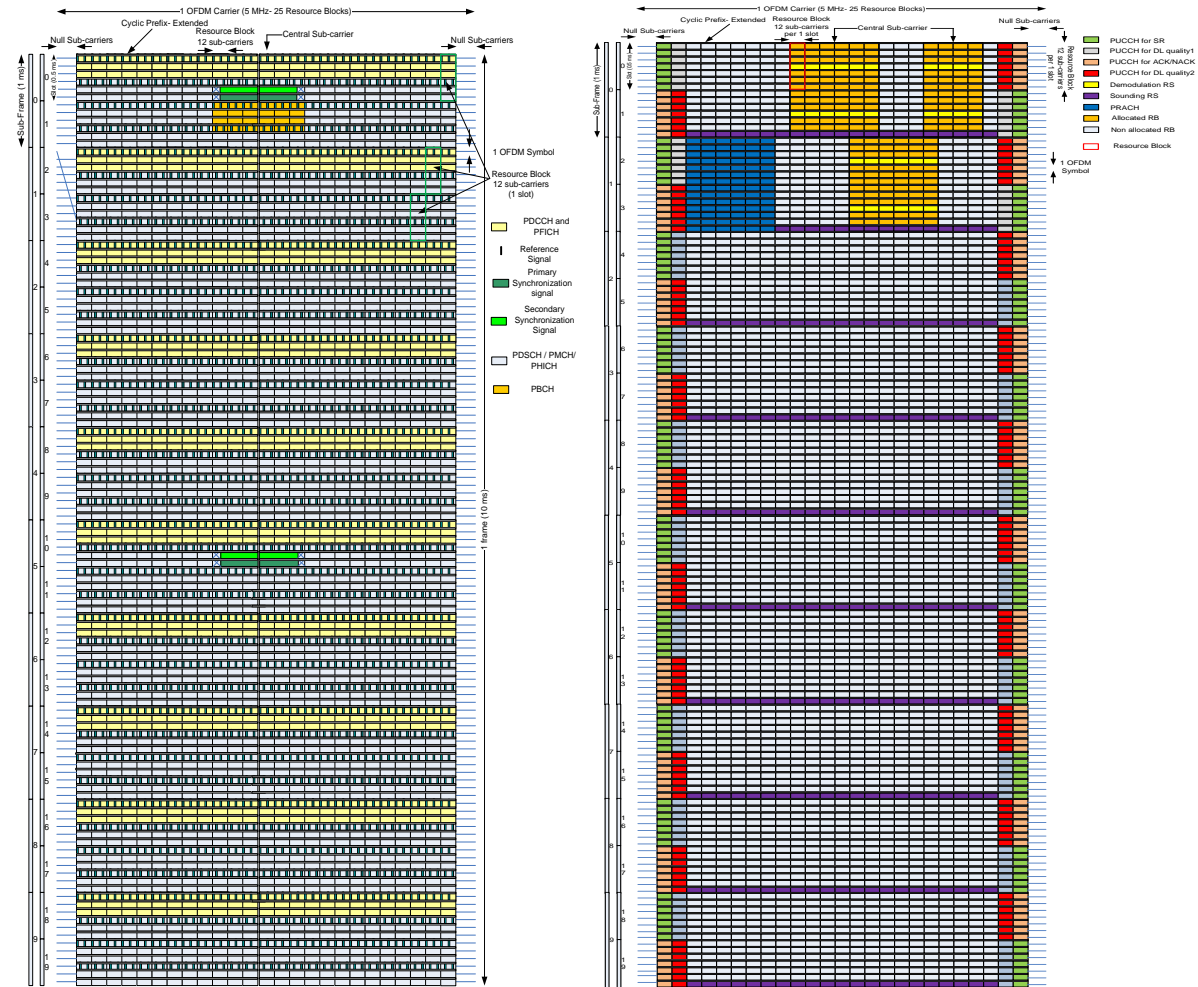
1.5 Zadoff Chu Sequences

Zadoff-Chu Sequence

- Wireless signals mix in the air, so there is a need for code sequences that can be uniquely identified
  - These codes should have low auto-correlation (correlation to shifted copies of themselves) and constant amplitude
  - CAZAC (Constant Amplitude Zero Auto Correlation) codes satisfy this property and Zadoff-Chu sequence is one of these codes
- A Zadoff–Chu (ZC) sequence is a complex-valued mathematical sequence which, when applied to radio signals, gives rise to an electromagnetic signal of constant amplitude
- A Zadoff–Chu sequence that has not been shifted is known as a "root sequence"
- Cyclic shifted versions of the sequence do not cross-correlate with each other when the signal is recovered at the receiver
- The sequence then exhibits the useful property in which cyclic-shifted versions of it remain orthogonal to one another, provided that each cyclic shift, when viewed within the time domain of the signal, is greater than the combined propagation delay and multi-path delay-spread of that signal between transmitter and receiver
  - M_{ZC} :Sequence length (preferably a prime number) =63
  - U: Sequence index, represented by integers prime to M_{ZC}
  - K: Sequence Shift
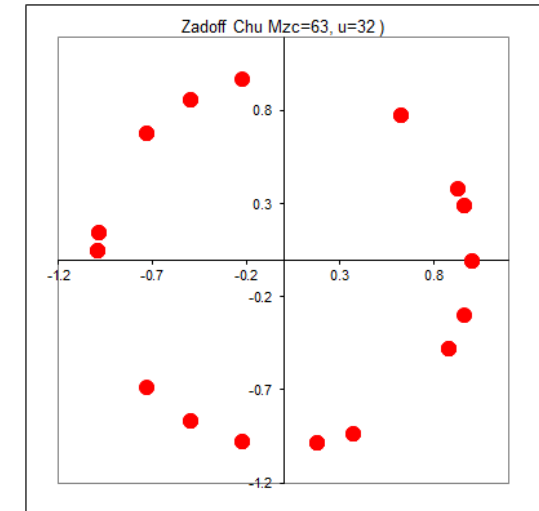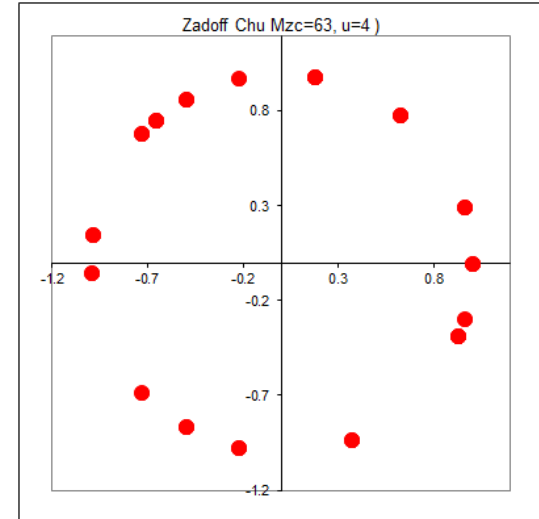
$$X_{ZC}^u(k) = e^{-j\pi u \frac{k(k+1)}{M_{ZC}}}$$

1.6 Orthogonality

Orthogonality

- In geometry, two Euclidean vectors are **orthogonal** if they are perpendicular, *i.e.,* they form a right angle

- Two vectors, *x* and *y*, in an inner product space, *V*, are *orthogonal* if their inner product is zero
  - This relationship is denoted $x \perp y$

- In linear algebra, an **inner product space** is a vector space with an additional structure called an **inner product**
  - This additional structure associates each pair of vectors in the space with a scalar quantity known as the inner product of the vectors
  - Inner products allow the rigorous introduction of intuitive geometrical notions such as the length of a vector or the angle between two vectors
  - They also provide the means of defining orthogonality between vectors (zero inner product)
  - Inner product spaces generalize Euclidean spaces (in which the inner product is the dot product, also known as the scalar product)

- In mathematics, the **dot product**, or **scalar product** (or sometimes **inner product** in the context of Euclidean space), is an algebraic operation that takes two equal-length sequences of numbers (usually coordinate vectors) and returns a single number
  - This operation can be defined either algebraically or geometrically.
    - Algebraically, it is the sum of the products of the corresponding entries of the two sequences of numbers
    - Geometrically, it is the product of the Euclidean magnitudes of the two vectors and the cosine of the angle between them
    - The name "dot product" is derived from the centered dot " · " that is often used to designate this operation; the alternative name "scalar product" emphasizes the scalar (rather than vectorial) nature of the result

Orthogonality

- Geometric interpretation of the angle between two vectors defined using an inner product

$$\theta = \arccos(x \cdot y / |x| \, |y|)$$

- Orthogonality and rotation of coordinate systems in Euclidean space through circular angle φ
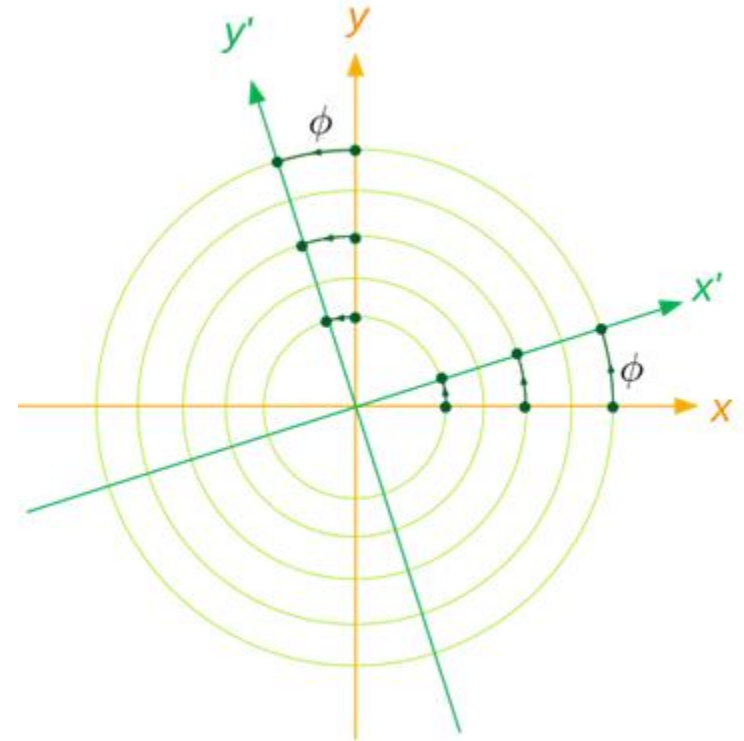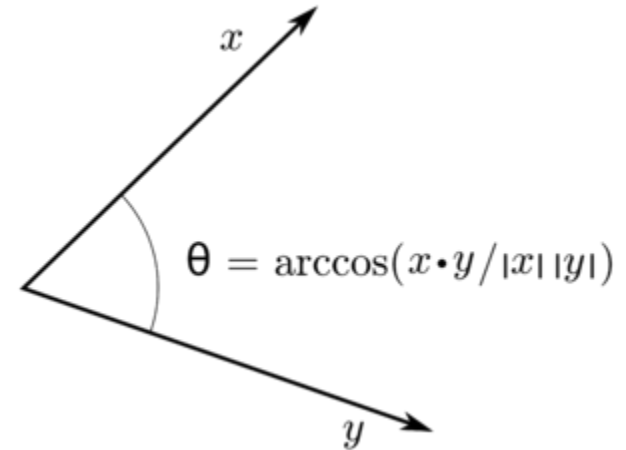
Dot Product Use Example

		TRANSMITTER										
		I					Q					
		P	D	D	P		P	D	D	P		
		1	0	0	1			1	1			
I		1	-1	-1	1			1	1			TX output
		iDFFT- I						iDFFT- Q				I+Q
angle	radians	p*cos f1	d*cos f2	d*cos f3	p*cos f4	sum I	p* sin f1	d* sin f2	d* sin f3	p* sin f4	sum Q	sum I+Q
7.5	0.1309	0.99144486	-0.965925826	-0.923879533	0.866025404	-0.03	0	0.258819	0.382683	0	0.642	0.609167
22.5	0.392699	0.92387953	-0.707106781	-0.382683432	6.12574E-17	-0.17	0	0.707107	0.92388	0	1.631	1.465076
37.5	0.654498	0.79335334	-0.258819045	0.382683432	-0.866025404	0.051	0	0.965926	0.92388	0	1.89	1.940998
52.5	0.916298	0.60876143	0.258819045	0.923879533	-0.866025404	0.925	0	0.965926	0.382683	0	1.349	2.274044
67.5	1.178097	0.38268343	0.707106781	0.923879533	-1.83772E-16	2.014	0	0.707107	-0.38268	0	0.324	2.338093
82.5	1.439897	0.13052619	0.965925826	0.382683432	0.866025404	2.345	0	0.258819	-0.92388	0	-0.665	1.6801
97.5	1.701696	-0.1305262	0.965925826	-0.382683432	0.866025404	1.319	0	-0.25882	-0.92388	0	-1.183	0.136043
112.5	1.963495	-0.3826834	0.707106781	-0.923879533	3.06287E-16	-0.6	0	-0.70711	-0.38268	0	-1.09	-1.68925
127.5	2.225295	-0.6087614	0.258819045	-0.923879533	-0.866025404	-2.14	0	-0.96593	0.382683	0	-0.583	-2.72309
142.5	2.487094	-0.7933533	-0.258819045	-0.382683432	-0.866025404	-2.3	0	-0.96593	0.92388	0	-0.042	-2.34293
157.5	2.748894	-0.9238795	-0.707106781	0.382683432	-4.28802E-16	-1.25	0	-0.70711	0.92388	0	0.217	-1.03153
172.5	3.010693	-0.9914449	-0.965925826	0.923879533	0.866025404	-0.17	0	-0.25882	0.382683	0	0.124	-0.0436
187.5	3.272492	-0.9914449	-0.965925826	0.923879533	0.866025404	-0.17	0	0.258819	-0.38268	0	-0.124	-0.29133
202.5	3.534292	-0.9238795	-0.707106781	0.382683432	5.51317E-16	-1.25	0	0.707107	-0.92388	0	-0.217	-1.46508
217.5	3.796091	-0.7933533	-0.258819045	-0.382683432	-0.866025404	-2.3	0	0.965926	-0.92388	0	0.042	-2.25883
232.5	4.057891	-0.6087614	0.258819045	-0.923879533	-0.866025404	-2.14	0	0.965926	-0.38268	0	0.583	-1.5566
247.5	4.31969	-0.3826834	0.707106781	-0.923879533	1.10253E-15	-0.6	0	0.707107	0.382683	0	1.09	0.490334
262.5	4.581489	-0.1305262	0.965925826	-0.382683432	0.866025404	1.319	0	0.258819	0.92388	0	1.183	2.50144
277.5	4.843289	0.13052619	0.965925826	0.382683432	0.866025404	2.345	0	-0.25882	0.92388	0	0.665	3.010221
292.5	5.105088	0.38268343	0.707106781	0.923879533	-9.8001E-16	2.014	0	-0.70711	0.382683	0	-0.324	1.689246
307.5	5.366887	0.60876143	0.258819045	0.923879533	-0.866025404	0.925	0	-0.96593	-0.38268	0	-1.349	-0.42317
322.5	5.628687	0.79335334	-0.258819045	0.382683432	-0.866025404	0.051	0	-0.96593	-0.92388	0	-1.89	-1.83861
337.5	5.890486	0.92387953	-0.707106781	-0.382683432	8.57495E-16	-0.17	0	-0.70711	-0.92388	0	-1.631	-1.7969
352.5	6.152286	0.99144486	-0.965925826	-0.923879533	0.866025404	-0.03	0	-0.25882	-0.38268	0	-0.642	-0.67384
367.5	6.414085	0.99144486	-0.965925826	-0.923879533	0.866025404	-0.03	0	0.258819	0.382683	0	0.642	0.609167
382.5	6.675884	0.92387953	-0.707106781	-0.382683432	-7.34981E-16	-0.17	0	0.707107	0.92388	0	1.631	1.465076
397.5	6.937684	0.79335334	-0.258819045	0.382683432	-0.866025404	0.051	0	0.965926	0.92388	0	1.89	1.940998

Dot Product Use Example

|		DECODER 1- Applied on transmitted signal (no distortion)							
		I				Q			
		P	D	D	P	P	D	D	P
		1	0	0	1		1	1	
		1	-1	-1	1		1	1	
		DFFT- I				DFFT- Q			
alpha	radians	(I+Q)*f1	(I+Q)*f2	(I+Q)*f3	(I+Q)*f4	(I+Q)*f1	(I+Q)*f2	(I+Q)*f3	(I+Q)*f4
7.5	0.1309								
22.5	0.392699								
37.5	0.654498								
52.5	0.916298	1.38435019	-0.588565861	-2.10094258	-1.969379753	1.80412	2.196558	0.870239	-1.13702
67.5	1.178097	0.89474949	-1.653281482	-2.160116355	-4.29677E-16	2.160116	1.653281	-0.89475	-2.33809
82.5	1.439897	0.2192971	-1.622852335	-0.642946575	1.455009599	1.665727	0.434842	-1.55221	-0.84005
97.5	1.701696	-0.0177572	-0.131407474	0.052061413	0.117816718	0.134879	-0.03521	-0.12569	0.068022
112.5	1.963495	0.64644661	1.194477583	-1.560660172	-5.17394E-16	-1.56066	1.194478	0.646447	-1.68925
127.5	2.225295	1.65771199	0.70478748	-2.515806852	2.358264869	-2.16037	2.630303	-1.04208	-1.36154
142.5	2.487094	1.85876937	-0.606394262	-0.896599543	2.029034747	-1.42628	2.263094	-2.16458	1.171464
157.5	2.748894	0.95300957	-0.72940195	0.394749491	4.42322E-16	-0.39475	0.729402	-0.95301	1.03153
172.5	3.010693	0.04322835	-0.042115684	0.040282408	-0.037759889	-0.00569	0.011285	-0.01669	0.021801
187.5	3.272492	0.28883777	-0.281403305	0.269153952	-0.252299301	0.038026	-0.0754	0.111487	-0.14567
202.5	3.534292	1.35355339	-1.035964915	0.560660172	-8.07721E-16	0.56066	-1.03596	1.353553	-1.46508
217.5	3.796091	1.79205424	-0.584629499	-0.864418703	1.95620843	1.375092	-2.18187	2.086891	-1.12942
232.5	4.057891	0.94760104	0.402879001	-1.438115432	1.34805941	1.234938	-1.50356	0.595687	0.778302
247.5	4.31969	-0.1876427	-0.346718518	0.453009574	5.40606E-16	-0.45301	0.346719	0.187643	-0.49033
262.5	4.581489	-0.3265035	-2.416205676	0.957259715	2.166310745	-2.48004	0.64742	2.311029	-1.25072
277.5	4.843289	0.39291273	-2.907650537	-1.151961835	2.606928153	-2.98447	-0.7791	2.781082	1.505111
292.5	5.105088	0.64644661	-1.194477583	-1.560660172	-1.65548E-15	-1.56066	-1.19448	0.646447	1.689246
307.5	5.366887	-0.2576124	0.10952566	0.390962403	0.366480002	0.335727	0.408755	0.161942	-0.21159
322.5	5.628687	-1.4586698	-0.47586807	0.703606747	1.592285596	1.119277	1.775964	1.698657	0.919307
337.5	5.890486	-1.6601164	-1.27059805	-0.68764271	-1.54083E-15	0.687643	1.270598	1.660116	1.796897
352.5	6.152286	-0.6680728	-0.650877113	-0.62254474	-0.583560455	0.087953	0.174402	0.257866	0.336919
367.5	6.414085	0.60395587	0.588410509	0.562797278	0.52755443	0.079512	0.157664	0.233118	0.304584
382.5	6.675884	1.35355339	1.035964915	0.560660172	-1.0768E-15	0.56066	1.035965	1.353553	1.465076
397.5	6.937684	1.53989699	0.502367167	-0.742787655	-1.680953302	1.181605	1.87486	1.793248	0.970499
		12	-12	-12	12	-2.2E-15	12	12	-9.5E-15

1.7 How to Consider Interference

How to consider Interference

- Resource Planning should not be done by just considering the geographical proximity between cells

- It is essential that the interference potential be considered

- Interference is expressed in SNR, but this is a measurement that can not be aggregated

- The best way to express the amount of interference is to consider its statistical probability of occurrence over time, what is called availability

  - Network availability can be expressed for a target SNR level

  - Availability can be aggregated and can be traffic weighted, expressing the real network performance

   - Performance can be expressed at a pixel, cell, BTS or network level

Availability and Outage

- Availability and outage are complementary, so both can be used to express the network performance or the relationship between entities

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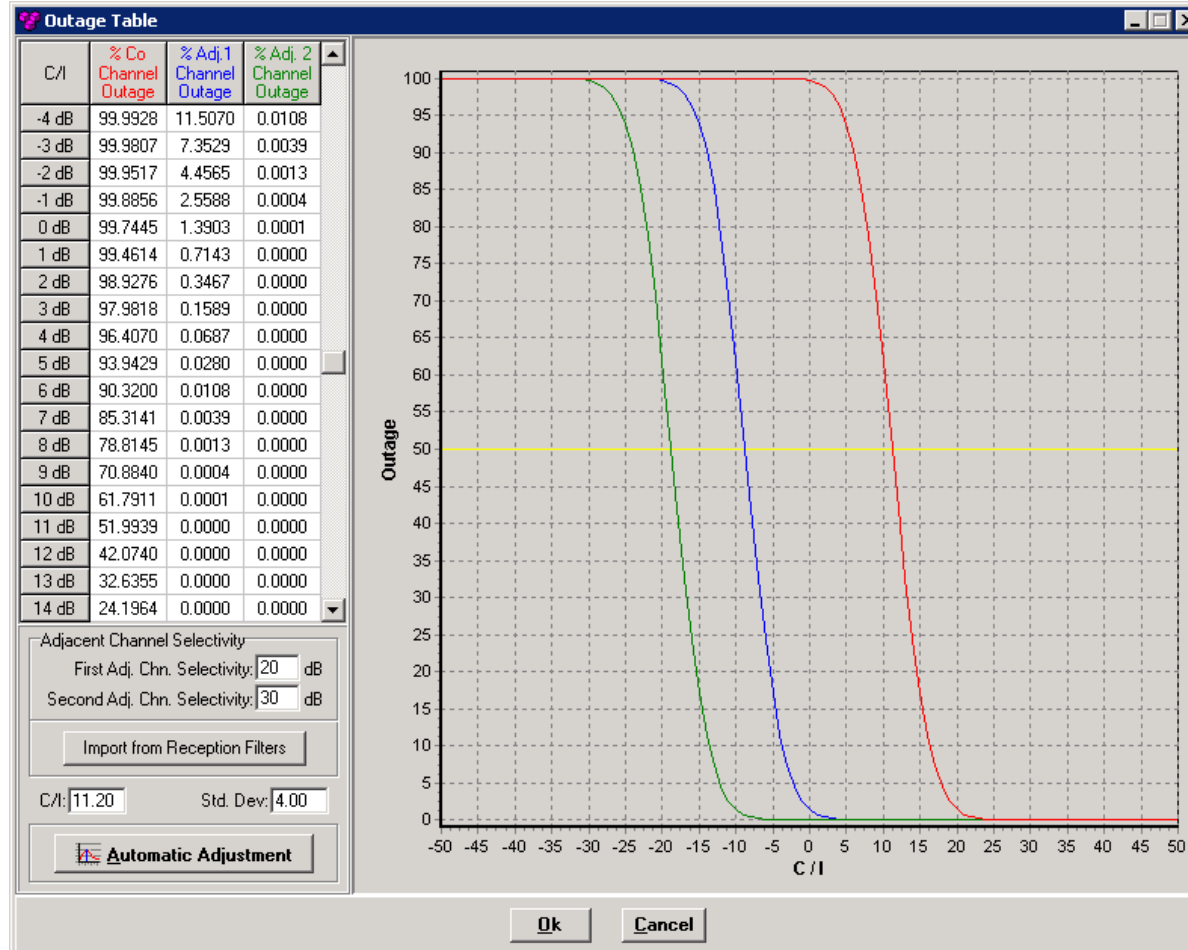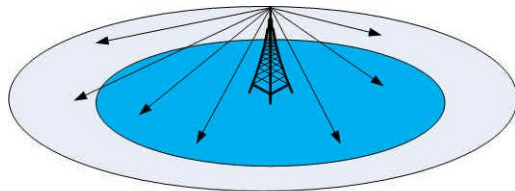
Interference Outage Matrix

- The Outage matrix calculates outages for all sectors pairs
  - Pairs assume that sectors use the same resources, and the outage is multiplied by the affected traffic
- Expressing interference by traffic outage allows us to add interference contributions
  - A special algorithm is used to calculate overlaps
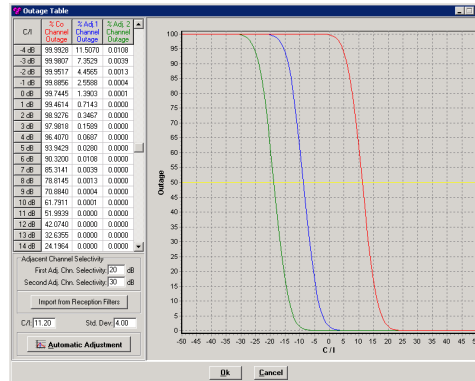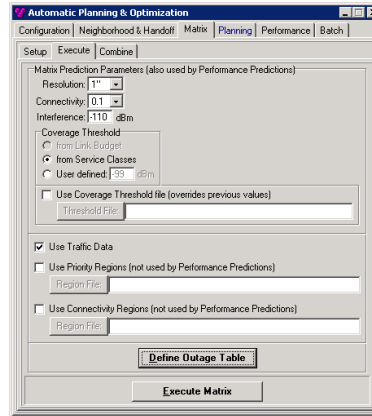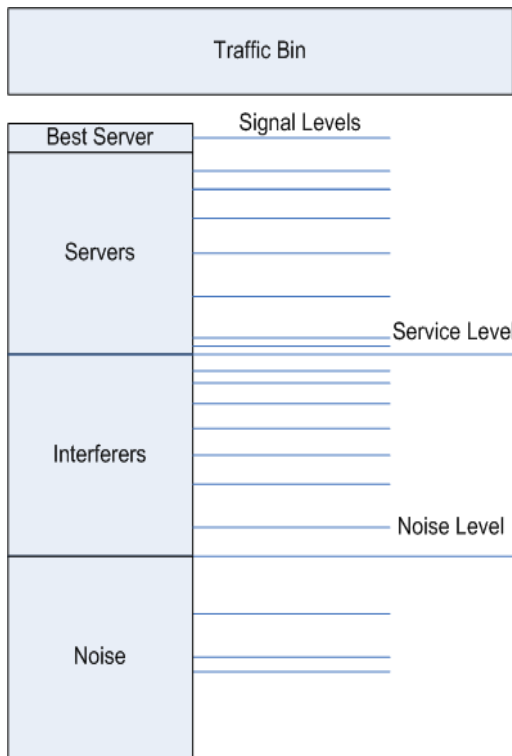
	S1	S2	S3	:	Sn
S1	$O_{1,1}$	$O_{1,2}$	$O_{1,3}$	:	$O_{1,n}$
S2	$O_{2,1}$	$O_{2,2}$	$O_{2,3}$	:	$O_{2,n}$
S3	$O_{3,1}$	$O_{3,2}$	$O_{3,3}$	:	$O_{3,n}$
:	:	:	:	:	:
Sn	$O_{n,1}$	$O_{n,2}$	$O_{n,3}$	:	$O_{n,n}$

Statistical Interference Considerations

- To do Resource Optimization Software has to know the interference between any pair of sectors
- The best way to express interference is as an outage against an SNIR
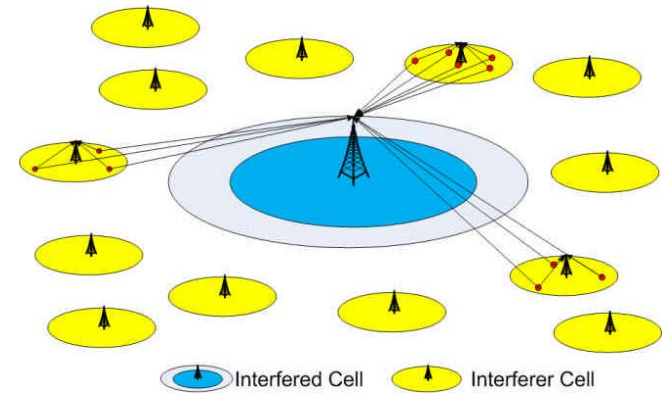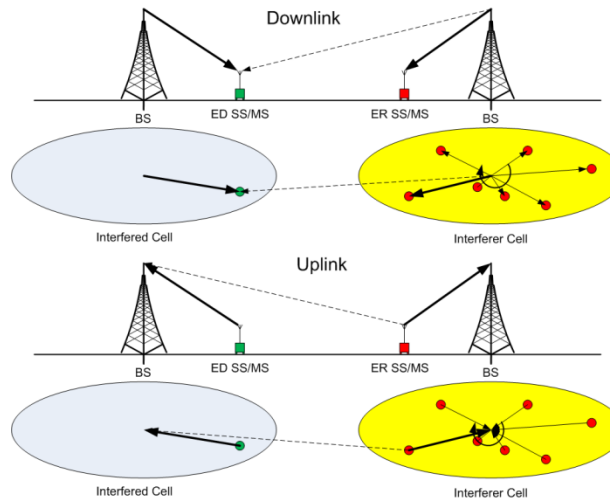
Uplink Interference from multiple cells
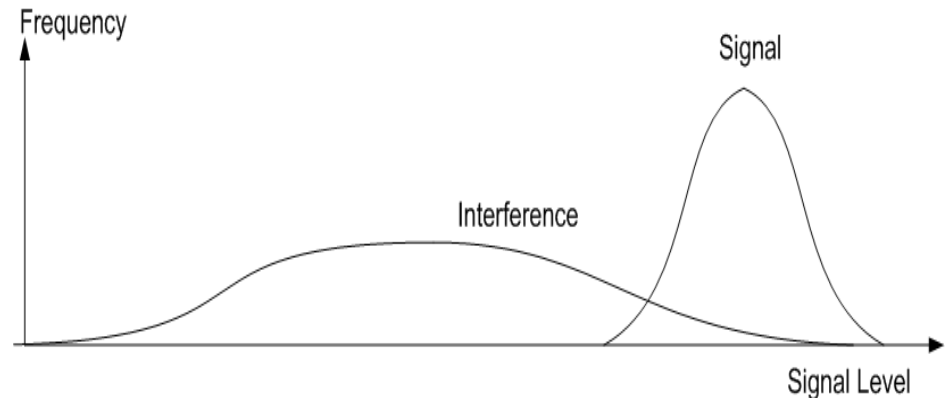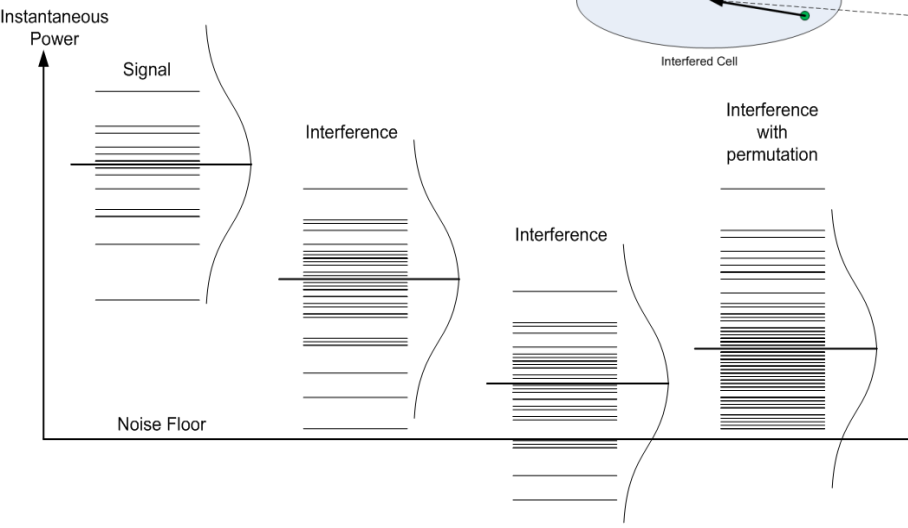
Interference Outage Matrixes

- Matrixes are calculated for each service class, co-channel, adjacent channel, downlink, uplink…

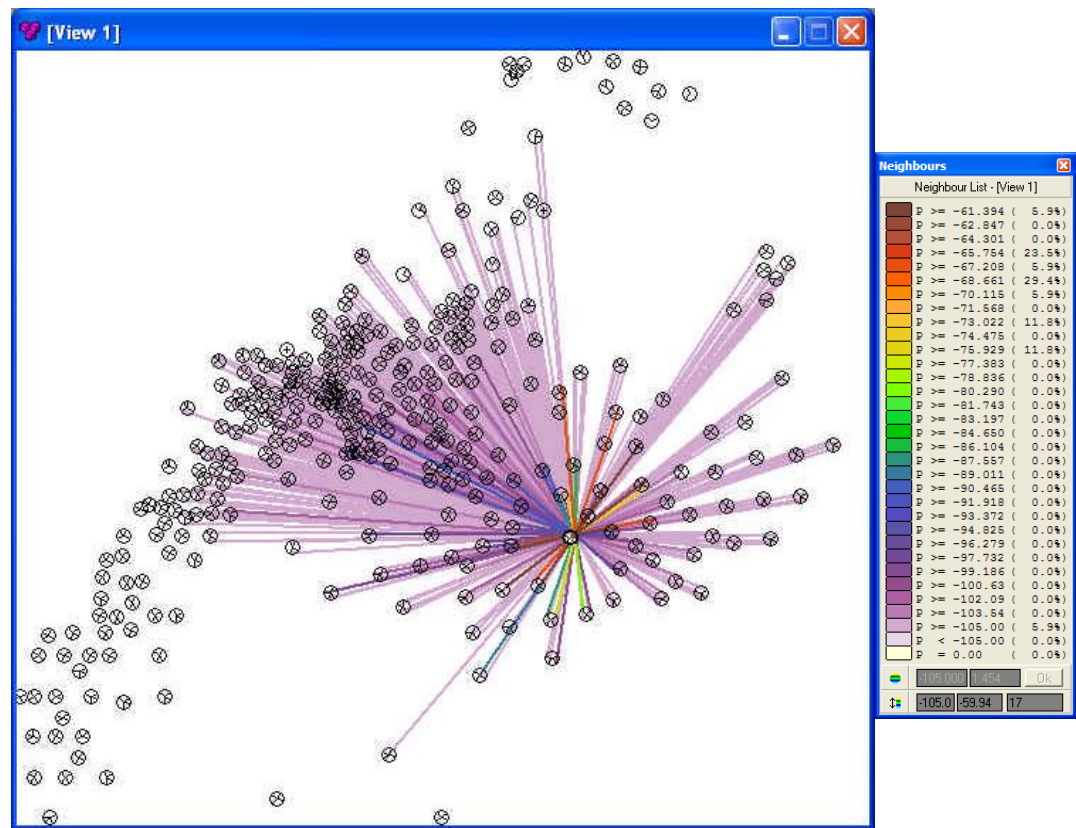# 2. Network Planning

BTS and Cell ID
Link Budget
Channel Assignment
Neighborhood
Tracking Area

2.1 BTS and Cell ID

BTS (eNB) and CellID (E-UTRAN cell)

- eNB represents a Base Station (BTS), which can have multiple cells
- The standard assumes that the controller is at BTS level, running different instances for each cell
- Cells are identified by the E-UTRAN Cell Global Identifier (ECGI)
  - Mobile Country Code (MCC) and Mobile Network Code (MNC) uniquely identify the operator
  - Public Land Mobile Network (PLMN)= MCC+MNC
  - E-UTRAN Cell Identifier (ECI) identify the cell
    - Short eNB (20 bit) can identify 1,048,576 cells
      - Allows 256 cells per eNB
      - Use for macro and micro BTS
    - Long eNB (28 bit) can identify 268, 435, 456 cells
      - Allows 1 cell per eNB
      - Used for pico, nano and femto cells
- Cell IDs can be grouped according to carrier bands and cell types

E-UTRAN Cell Global Identity (ECGI)		
MCC (10 bit)	MNC (10 bit)	E-UTRAN Cell Identifier (28 bit)
		Short eNB Identifier / Cell ID
		Long eNB Identifier
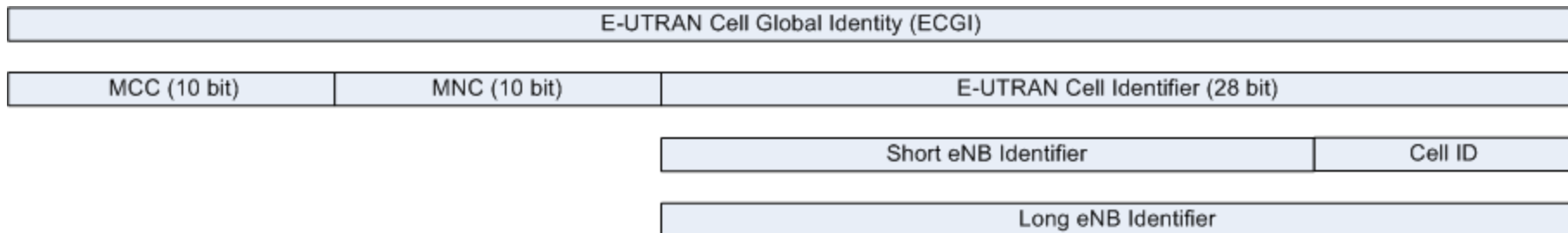
2.2 Cell Link Budget

What is in a Link Budget?

Power Budget and Noise Budget

- A link budget analyzes two paths
  - One is the power budget (in blue) from the Transmitter to the Receiver
  - Another is the noise budget (in green) from the Thermal Noise Floor to the CNIR ratio required for a certain receive probability
  - The difference between both budgets establishes the service margin
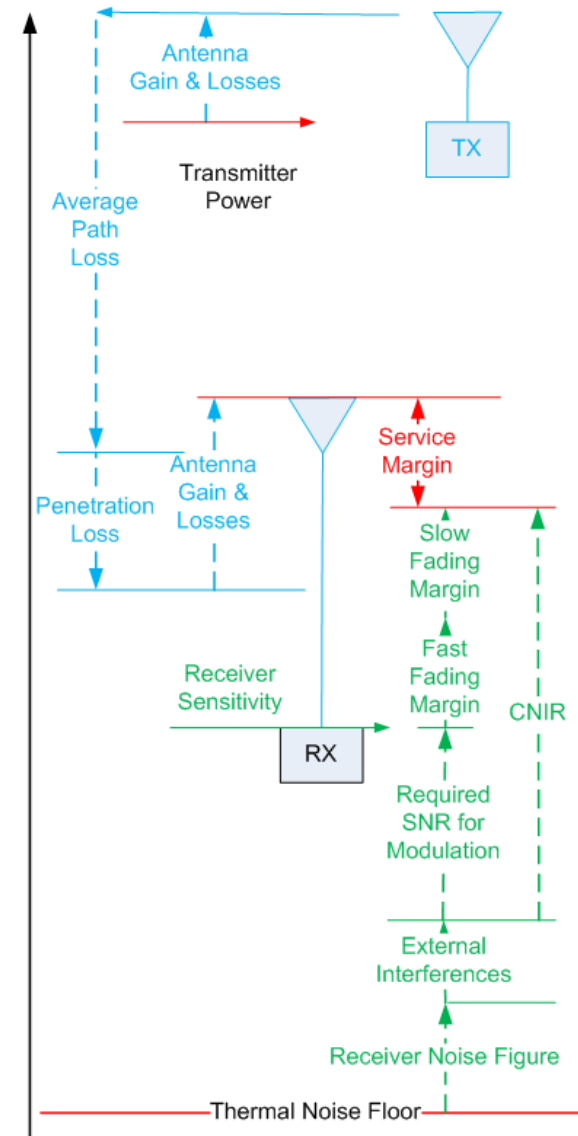
2.3 Channel and Resource Assignment

2.3.1 Channel and Resource Assignment Strategy

Spectrum and Resource Assignment Strategy

- Designer has to ponder the different alternatives available to him when developing a resource allocation strategy
- There is not a best solution, as each deployment has its own characteristics and will require different strategies
- A decision requires a deep knowledge of:
  - Technology
  - Deep understanding of the equipment functionality and parameters
  - User traffic characteristics and tonnage
  - Proper market modeling
  - Proper equipment modeling
  - Proper cell modeling
- Resource Strategy ponders
  - What reuse factor should be used?
  - What are the limits of each cell, considering all bottlenecks?
  - How resources should be distributed?

2.3.2 Scenarios Testing

Experimenting with Multiple Scenarios

- The easiest way to test scenarios is to minimize the number of inputs to it. Here's a quick network set up for testing purposes:
  - No GIS databases
  - Free space propagation
  - Sites uniformly spaced
  - Sites radii = smallest expected radius in final deployment
  - Uniform traffic distribution considering average density in area
- Configuring scenarios – assume the operator has 20 + 20 MHz of spectrum
  - 1 FDD channel of 20 MHZ
  - 2 FDD channels of 10 MHz
  - 4 FDD channels of 5 MHz
  - 2 TDD channels of 20 MHz
  - 4 TDD channels of 10 MHz
  - 8 TDD channels of 5 MHz
- After channel size is selected, designers must analyze sectorization and whether reuse areas will be used
  - Omni cells
  - Three sectors, no reuse areas
  - Six sectors, no reuse areas
  - Three sectors, split in reuse areas
  - Six sectors, split in reuse areas
- Only after these decisions are made can a designer select channel frequencies

2.3.3 Spectrum Usage Strategy

Spectrum Usage Strategy

- Wireless broadband allows for different channel bandwidths

- The decision process is fairly complex
  - Different markets have different constraints
  - Designer may need to experiment with different scenarios
  - Service classes defined in market modeling must be considered

- Broadband networks still have RF propagation characteristics and interference issues similar to 2G/3G cellular networks
  - In cellular, a reuse of 7 (or more) is required to control interference
  - Same principle is valid in broadband, when not achievable, techniques such as interference avoidance and interference averaging should be employed

- Out of band attenuations and external interference must be considered
  - Drive test should be performed to look for interferers (other markets, fluorescent lights (700MHz!), cordless phones, etc)
  - Test at different days of the week and different times of day (busy hours)

Channel and Resource Planning

- ## Strategies
  - Frequency channels can be reserved for point to point connections
  - Frequency channels can be reserved for the cell core coverage
  - Frequency channels can be partially used (segmentation, resource block sharing)
  - Frequency channels can be allocated by reuse areas
    - FFR (Fractional Frequency Reuse)
  - Frequency channels can be partially loaded when using interference averaging

- ## Frequency reuse and partitioning scheme (N_c, N_s, N_f, N_{pt})
  - N_c is the number of cell sites per cluster, i.e., number of BTSs needed to consume all available spectrum (frequency channels)
  - N_s is the number of sectors per BTS
  - N_f is the number of frequencies available
  - N_{pt} is the number of partitions used for each frequency
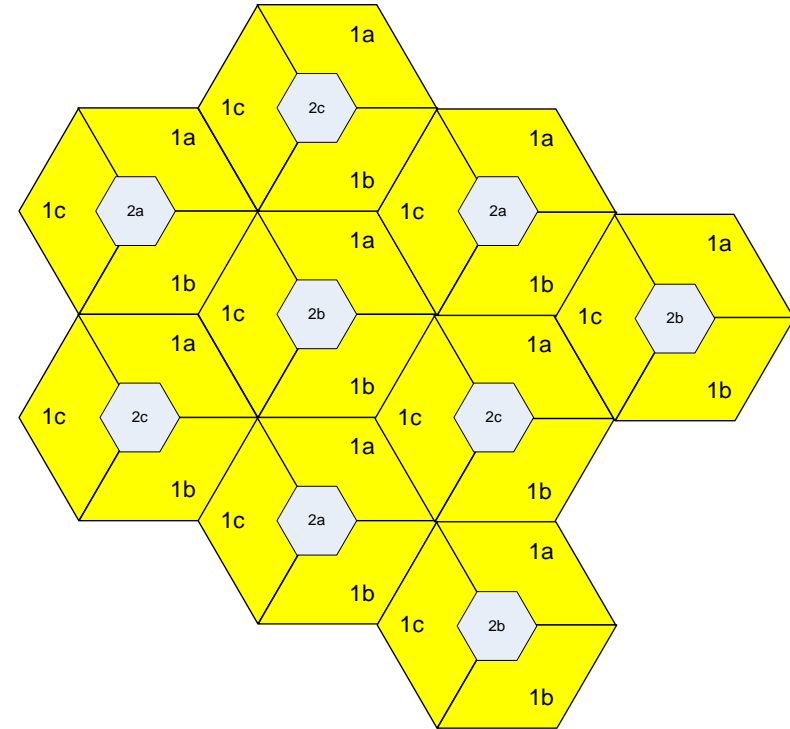
2.3.4 Fractional Frequency Reuse

Fractional Frequency Reuse (FFR)

- Scenario 1- all resources are used in each cell
- Scenario 2- resources are segmented in 3
- Scenario 3- resources are segmented in 3 in the periphery and fully used in center of cell
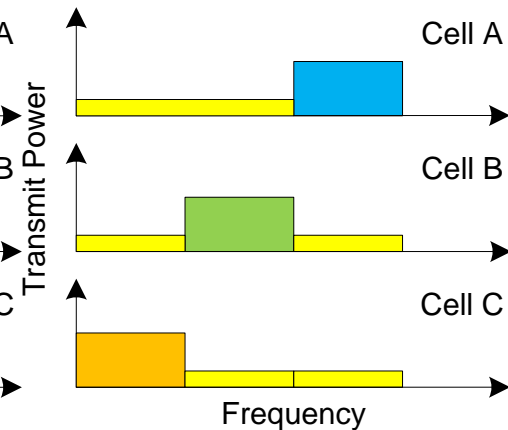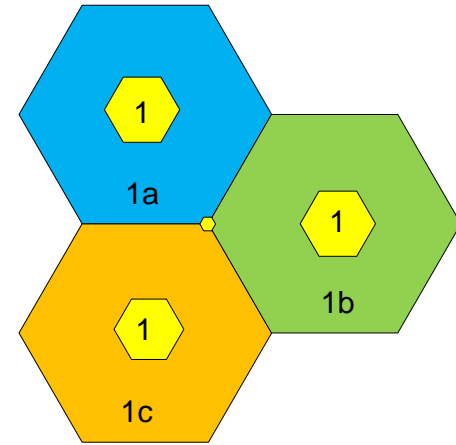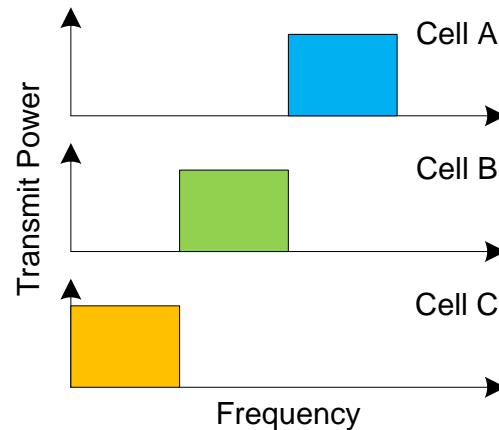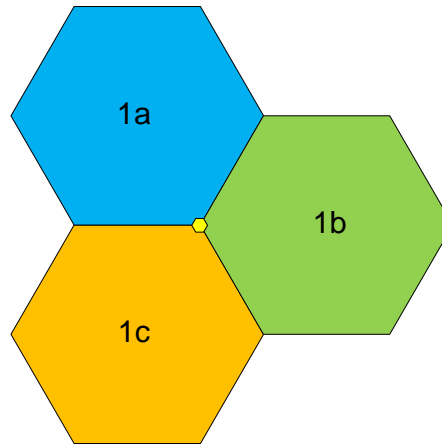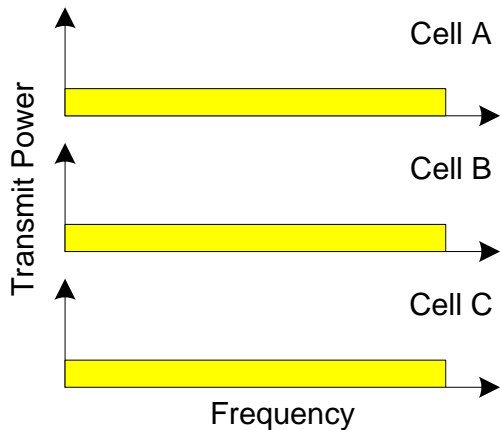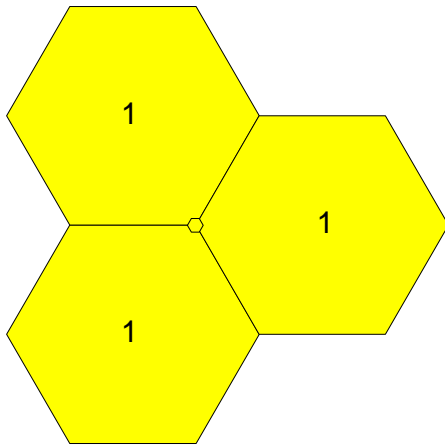
2.3.5 Single Carrier Scenarios

Scenario A – One carrier available (reuse of 1)

- Reuse (1,3,1,1)
- This is the scenario LTE was conceived for
- LTE replaces resource reuse by stronger forward error correcting codes
- It can be shown that this approach is similar to regular resource reuse and in a regular scenario does produce a higher throughput (as shown later)
- This was the reasoning adopted by 3GPP
- Unfortunately this is not the case for non-uniform traffic distribution, neither for broadcasted signals, like control and signalling
- 3GPP is trying to fix the issues, without great success, as the issues arise from the basic concepts
    - 3GPP hopes rely on approaches that can better allocate resources, but this meaning that the reuse of 1 is being partially abandoned
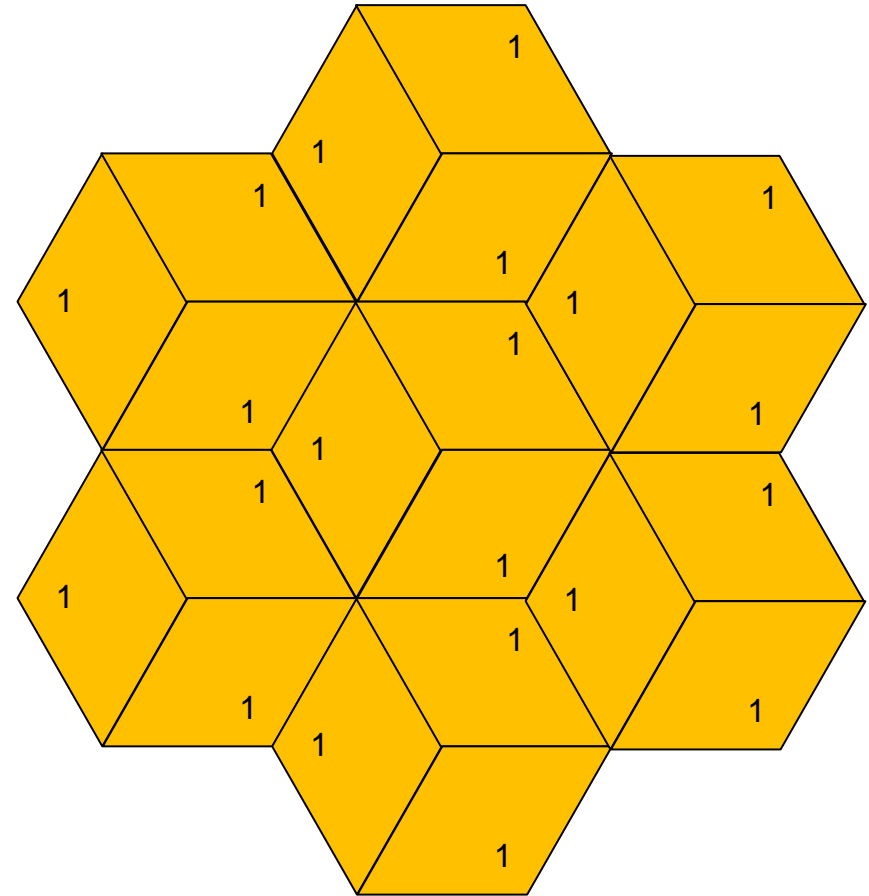
Scenario A – One carrier available (reuse of 3)

- Reuse (1,3,1,3)

- Most realistic scenario, that provides some interference relief for control and signalling channels

- 3GPP does not provide direct support for it, but the formats available do support it

- Vendors have to implement this kind of usage though
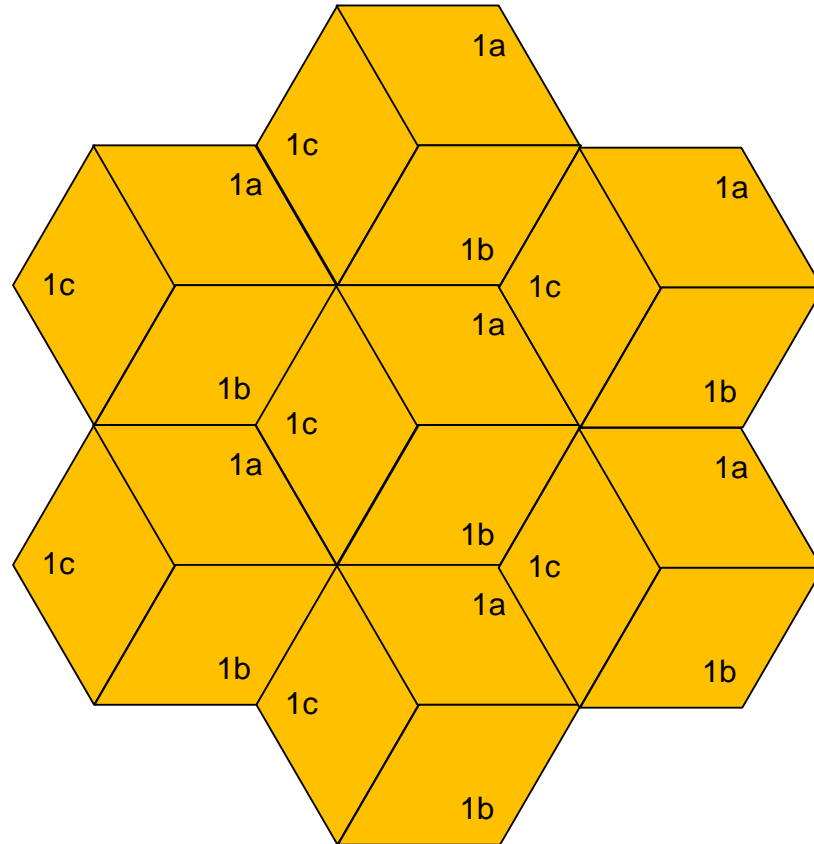
Scenario A – One carrier available fractional reuse
(reuse of 1 in the center a reuse 3 in the periphery)

- 3 GPP evolved solution

- It accepts the reuse 3 in the periphery (cell edge), but applies reuse 1 in the middle (cell center)

- Note that what is called cell center is not where the BTS tower is, but the center of the cell coverage

  - This applies to omni cells

  - For sector cells this solution requires a different strategy when locating cells and will most likely result in a single cell per tower

- The difficulty of implementing this solution is to find where the UE is located
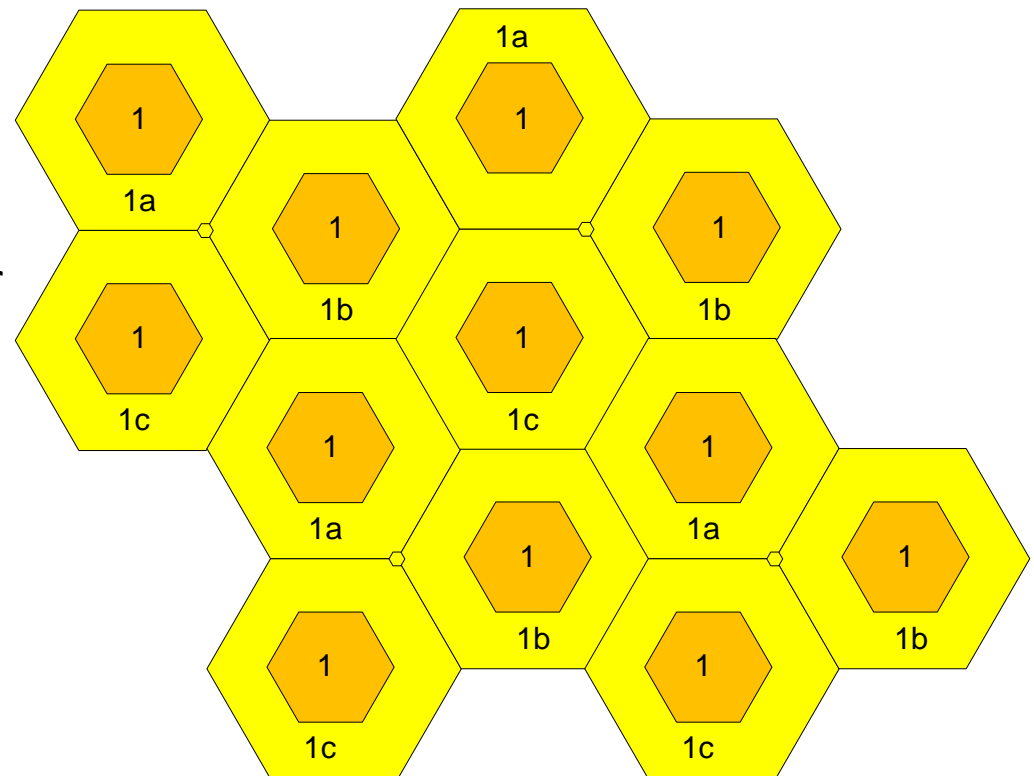
2.3.6 Three Carrier Scenarios

Scenario B – Three carriers available (reuse of 3)

- Requires carrier planning

- Reuse (1,3,3,1)

- This configuration is a good compromise, but needs to be supported by vendor

- Does not maximize user data throughput

- Should be considered when control is the bottleneck
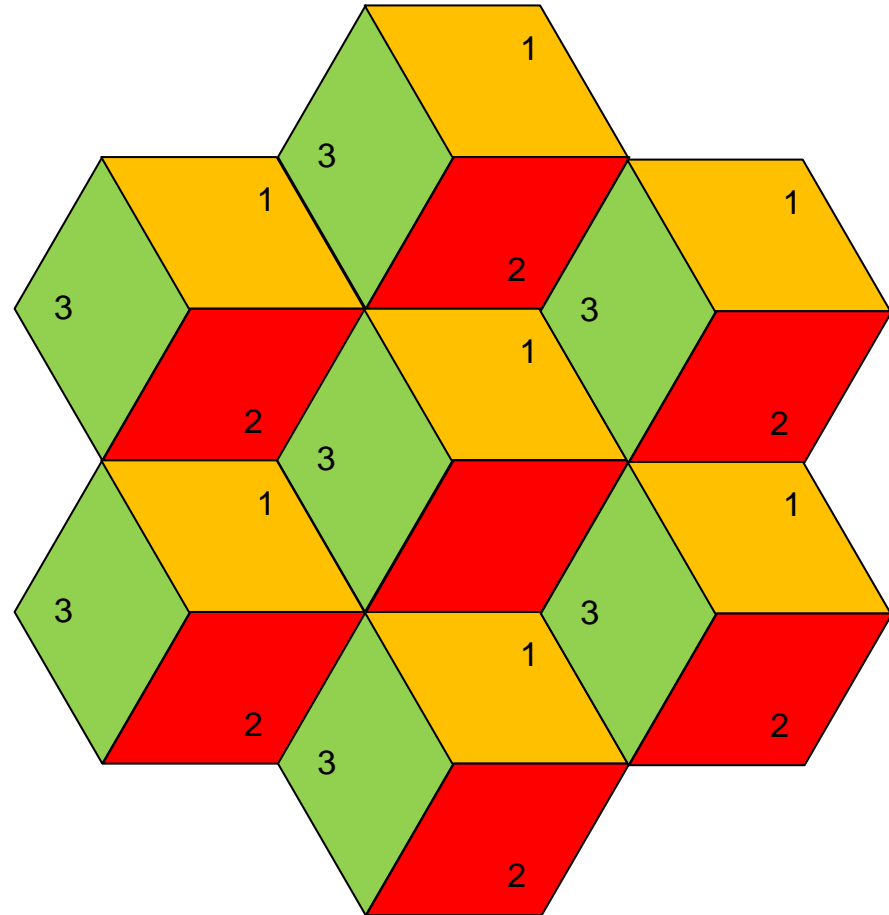
Scenario B – Three carriers available (reuse of 9)

- Requires carrier planning
- Reuse (1,3,3,2)
- This configuration is a good compromise, but needs to be supported by vendor
- Does not maximize user data throughput
- Should be considered when the intercell interference is very high and control is the bottleneck
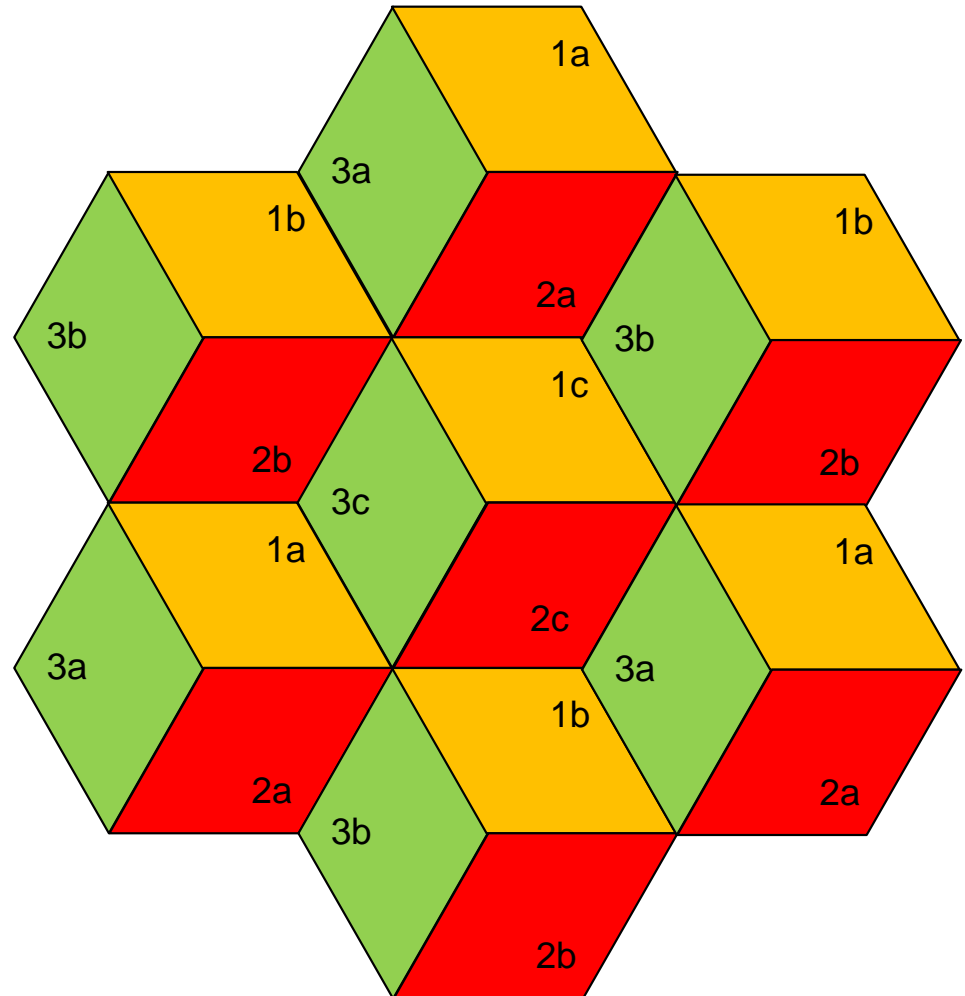
Scenario B – Three carriers available (mixed reuse)

- In this example three carriers are available
  - Carrier three is used for point-to-point rooftop connections (not in picture)
  - Carrier two is used for coverage close to the cell (may or may not be partitioned)
    - It assumes that the eNBs will coordinate the allocation between themselves
  - Carrier one is used in the outskirts of the cell to avoid interference between adjacent cells.
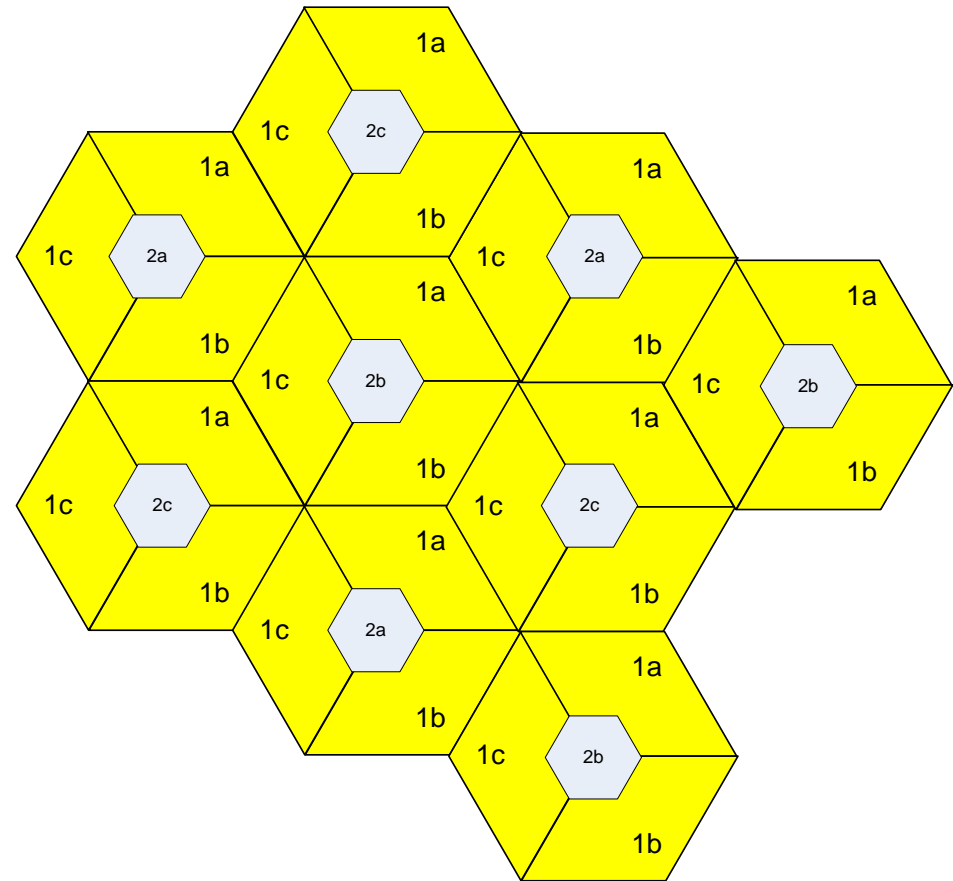
2.4 Neighborhood

Neighborhood Determination

- Neighbors are picked from the interference matrix based on their capability of interfering
- Topological neighbors are added due to handover considerations
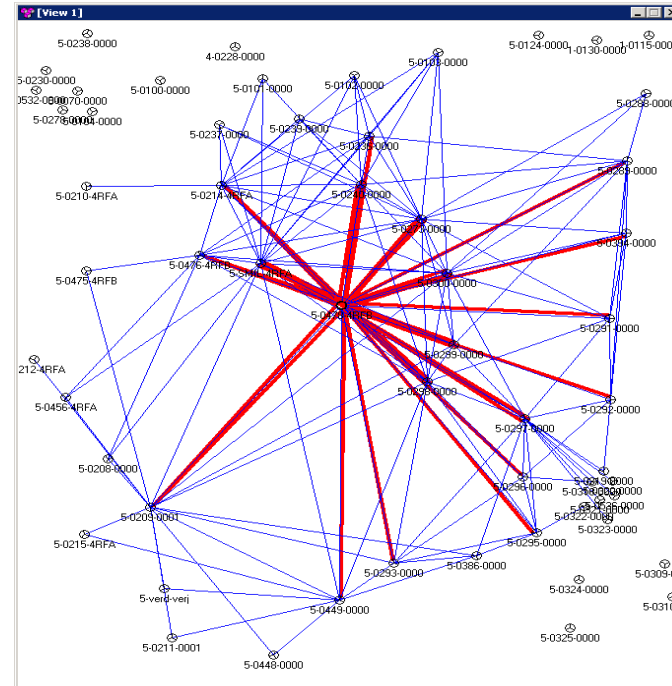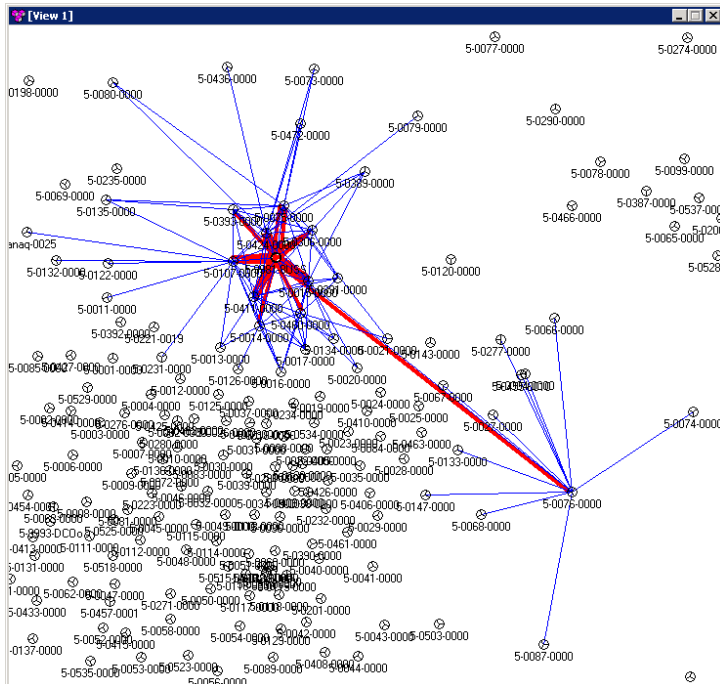
Red- Primary Neighbors   Blue- Secondary neighbors

Handover Calculation

- Ideal handover thresholds are calculated on a neighbor basis
  - Recommended handover thresholds are based on the border signals between two sectors
  - Recommended Handover Hysteresis is based on Standard Deviation of the border signals between two sectors

A/B average signal
level: -78 dBm
Std: 6 dB

A/C average signal
level : -75 dBm
Std: 3 dB

B/C average signal
level: -85 dBm
Std: 4 dB
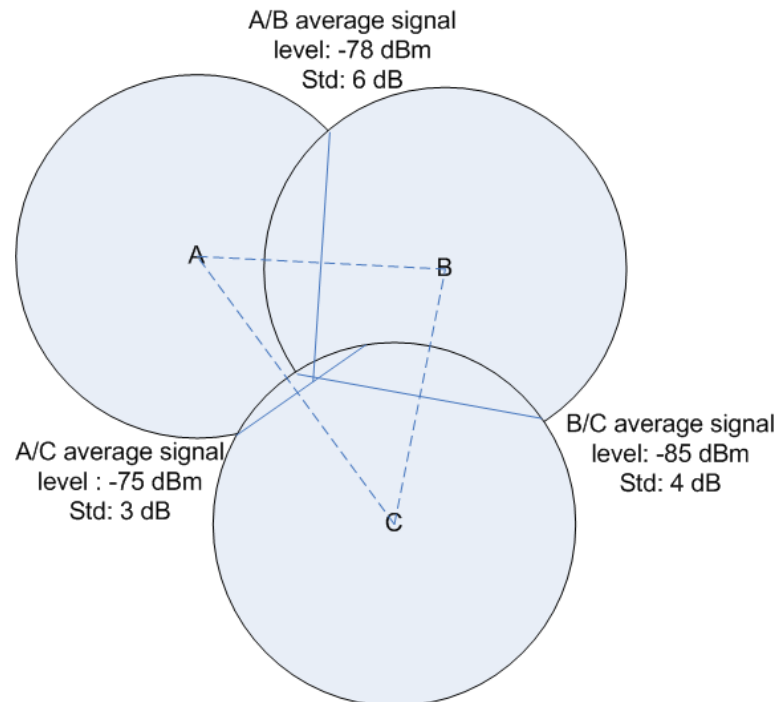
2.5 Tracking Area

Tracking Area (TA)

- Cell Tracking Area Code (TAC) is broadcast in SIB 1
- TA Identity (TAI)= MCC+MNC+TAC
- A cell can have up to 6 PLMN (MCC+MNC), so it can have up to 6 TAI
- UEs can register with multiple TAs while in idle mode
- Paging messages are broadcast across all TAs where the UE is registered
- TAs can coincide with 2G and 3G routing and location areas
- Large TA have as drawback excessive paging load, reducing network capacity
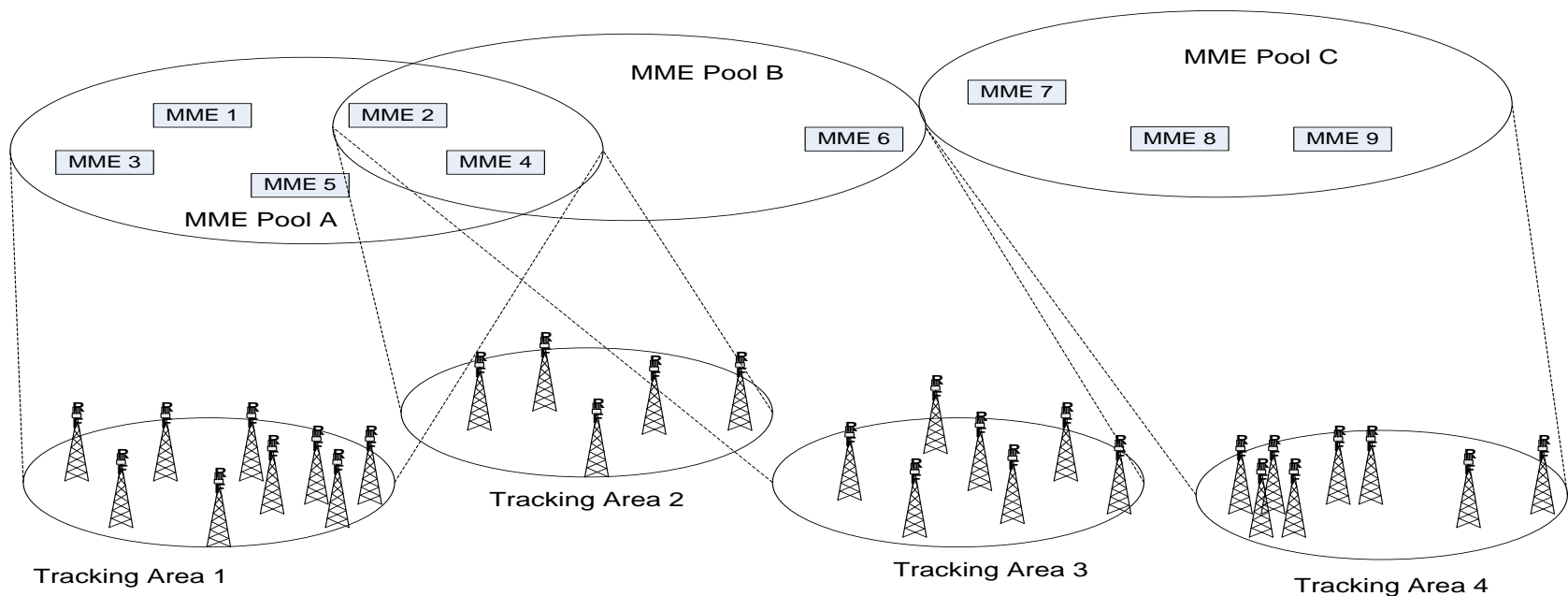
2.6 Frequency and Resource Allocation Tools

Automatic Resource Planning

- Advance Algorithms are used to assign channels automatically

- Advanced Simulated Annealing

- Scored best in several benchmark tests
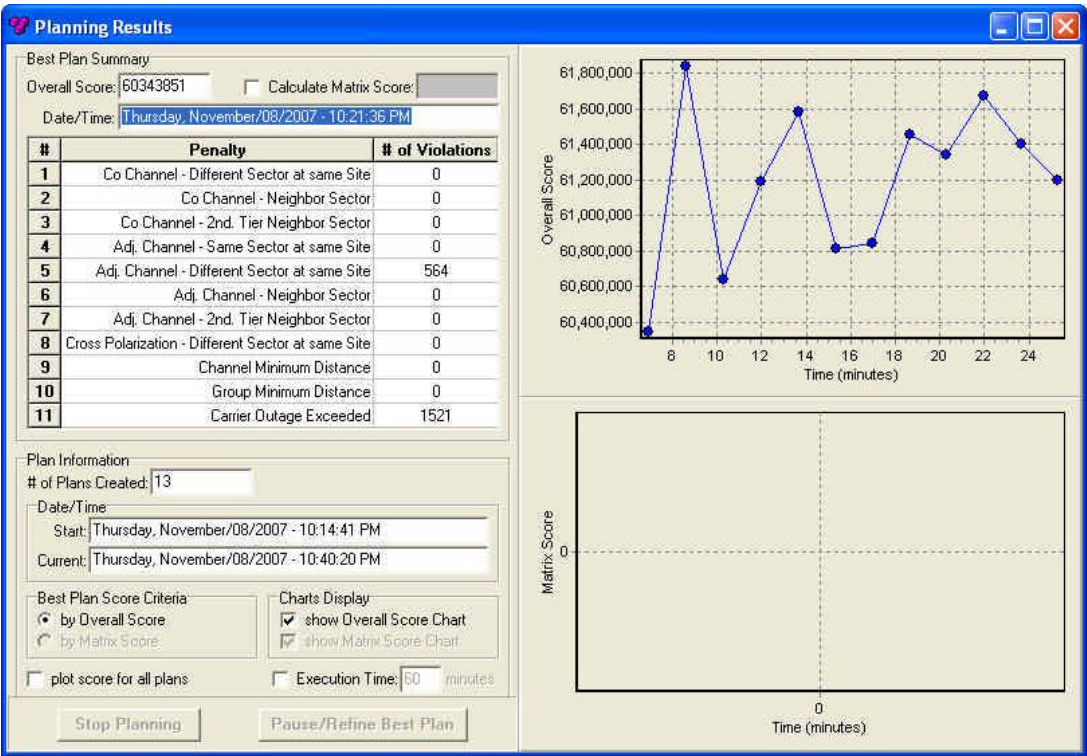
Code Optimization

- The Interference Matrix is used as an input to the parameter planning process. CelOptima picks the best values automatically

- Code optimization distributes codes to minimize possibility of interference, by considering geographical neighborhood, as well as, interference neighborhood
  - Code optimization uses the concept of availability
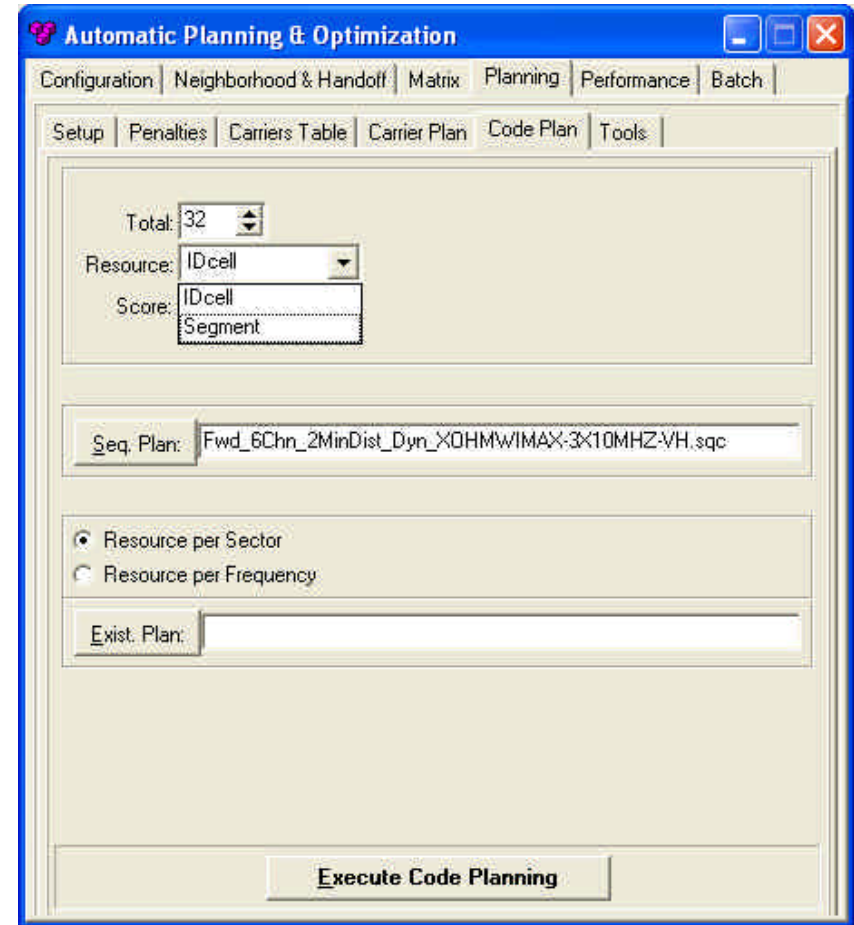
Channel, Code and Segment Plans

- It is important to visualize the assignments graphically, to verify any inconsistencies

- Channel Plan
- PCI Plan
- Segment Plan

3. DOWNLINK
Dimensioning and Planning

3.1 Physical Cell ID (PCI) Planning

PSS (reuse of 3)

SSS (reuse of 168)

Cell RS (reuse of 6)

Uplink Group Base Sequence (reuse of 30)

PCI Planning

- Physical Cell Identity (PCI) differs from Cell ID, and is used to differentiate one cell from the others while providing configuration information
- There are 504 PCI codes in an LTE network
  - They are organized in 168 groups of 3
- PCI is used to index many different network parameters and information location, as:
  - Primary Synchronization Signal (PSS)
  - Secondary Synchronization Signal (SSS)
  - Cell Reference Signal (CRS)
  - Uplink Group Base Sequence (GBS)

3.1.1 Primary Synchronization Signal

PSS

Primary Synchronization Signal

- Defines the Primary Cell Identity (PCI) Group by one of three Zadoff-Chu root sequences, based on the CellID (mod3)

- It uses QPSK modulation

- It is sent on the last symbol of slot 0 and 10 of every frame

- It is sent over the central 72 sub carriers, using 62 symbols and blanking the remaining 10 symbols

- Frame synchronization and type of cyclic prefix used can not be defined

- The good correlation properties of the Zadoff-Chu sequence assures that it can be received even with low SINR
  - A Zadoff Chu sequence uses orthogonal sequences of 4 complex values

- PSS detection allows for:
  - Center of the channel bandwidth in frequency domain
  - symbol, slot, subframe synchronization in time domain
  - Extract the two least significant digits of the CellID (mod3)

- Requires a reuse of 3

Zadoff Chu Mzc=72, u=1

Zadoff Chu Mzc=72, u=2

Zadoff Chu Mzc=72, u=3

72 central sub-carriers; 6 Resource Blocks; 2 antennas; PCI=1; PHICH Scaling=1; PHICH duration=normal

| CRS | DTX | PFICH | PHICH | PDCCH | SSS | PSS | MIB | PDSCH |

Note: Central Carrier is not Depicted   Resource Element (RE)   Resource Element Group (REG) or Quadruplet
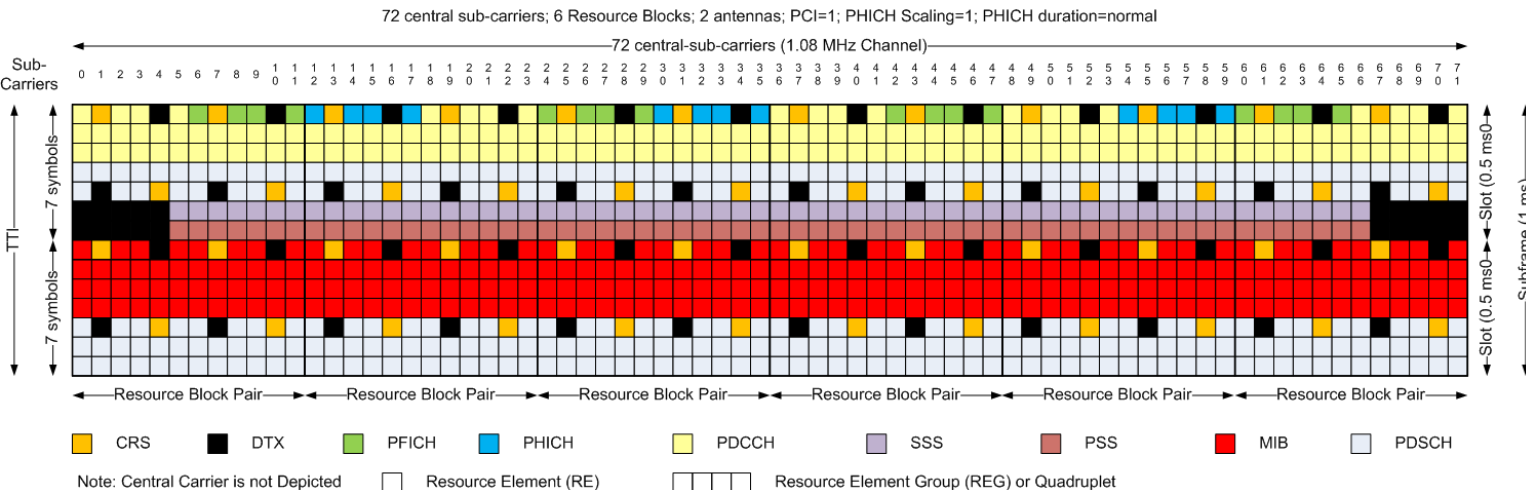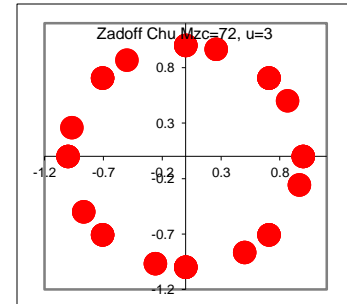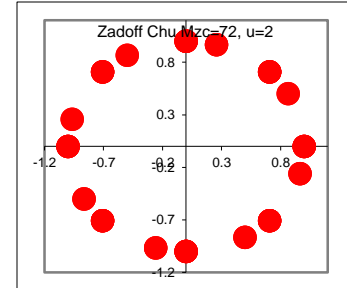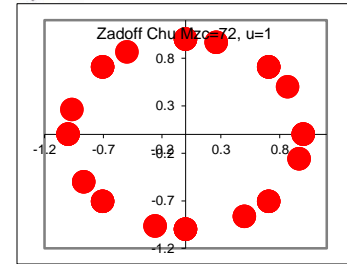
3.1.2 Secondary Synchronization Signal

SSS

Secondary Synchronization Signal (SSS)

- Carries one of 168 pseudo-random Gold sequences in the first frame occurrence and a different one in the second frame occurrence
  - defines the Primary Cell Identity (PCI) value within each PCI group (defined by PSS)
  - defines the cyclic prefix used, though the time distance between both sequences
  - Defines the beginning of each frame is sent one symbol before the last symbols of slot 0 and 10 of every frame

- Uses QPSK modulation

- It is an interleaved concatenation of two length 31 binary sequences, scrambled with a scrambling sequence defined by the primary synchronization signal.

- It is sent over the central 72 sub carriers, using 62 symbols and blanking the remaining 10 symbols

- Ideally 150 codes fit into the required reuse of 3, 6, 30
  - 18 codes can be used for small cells or to fill in irregular cell clusters

72 central sub-carriers; 6 Resource Blocks; 2 antennas; PCI=1; PHICH Scaling=1; PHICH duration=normal

Legend: CRS, DTX, PFICH, PHICH, PDCCH, SSS, PSS, MIB, PDSCH

Note: Central Carrier is not Depicted   Resource Element (RE)   Resource Element Group (REG) or Quadruplet
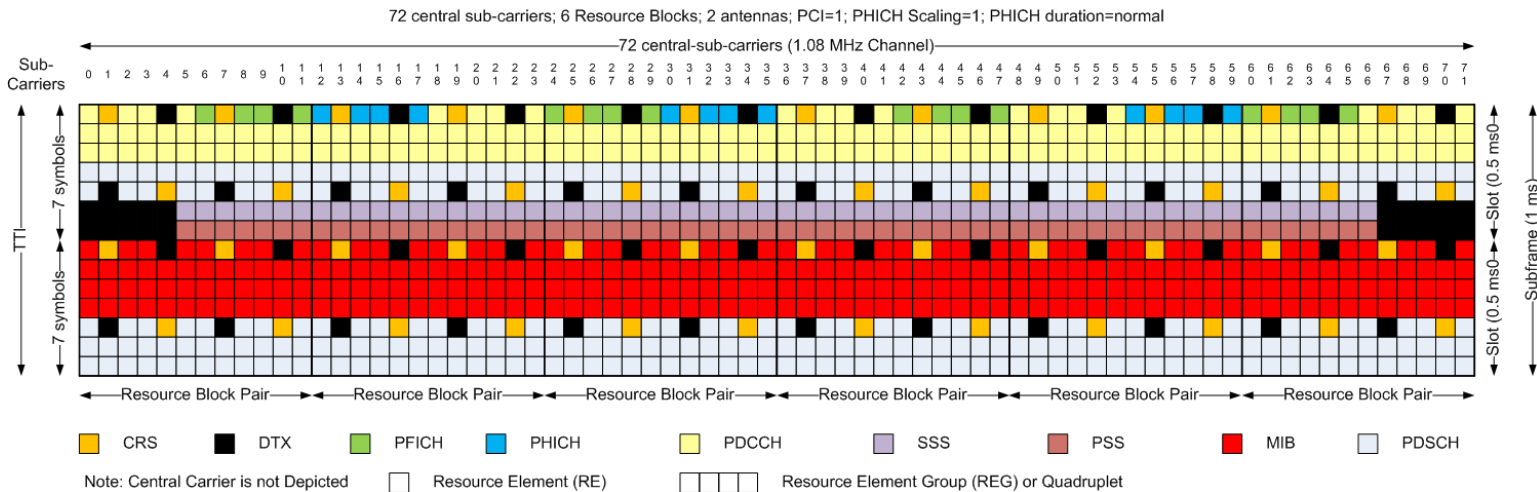
3.1.3 Cell Reference Signals

CRS

Reference Signals

- Reference Signals
  - Cell Specific Reference Signals (CRS)
  - MBSFN Reference Signals (MBSFN-RS)
  - UE Specific Reference Signals (UE-RS)
  - Positioning Reference Signals (PRS)
  - Channel State Information Reference Signals (CSI)
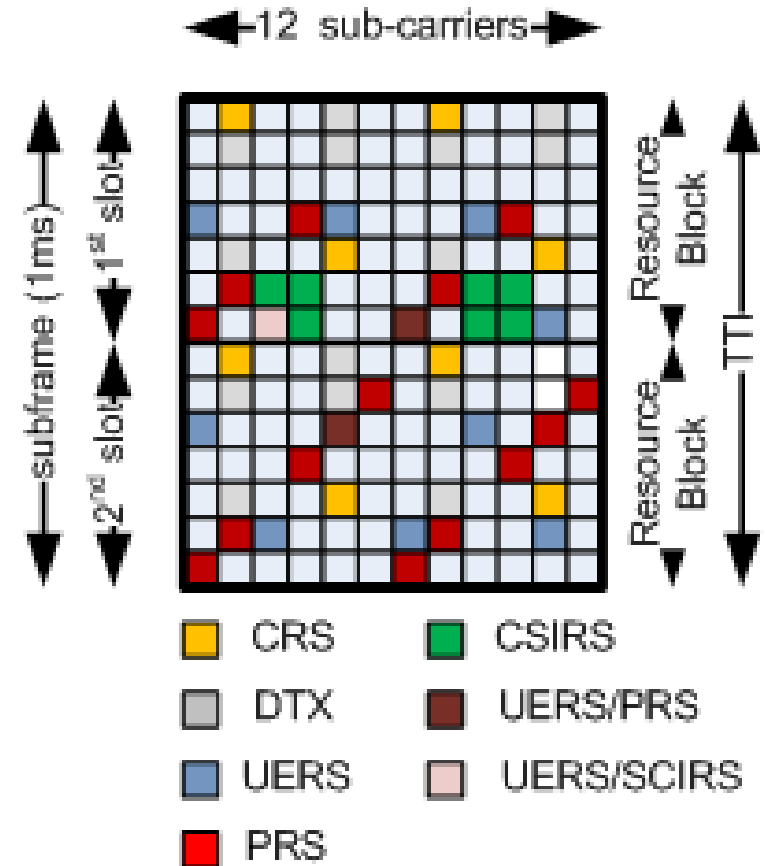
Resource Block with all possible Reference Signals assigned for a network with 4 antennas

Cell Specific Reference Signals (CRS)

- Carries one of 168 length-31 pseudo-random Gold sequences
- Antenna port 0 and 1 have 4 RS each per RB
- Antenna port 2 and 3 have 2 RS each per RB
- Each antenna sends DRX in the other antennas RS positions
- Subcarriers are selected according to PCI (mod6)
- Used to estimate RF channel response for each transmit antenna
- Power boosting can be applied to RE with CRS
- Requires a reuse of 6

Port 0   Port 2
Port 1   Port 3

PIC (mod 0)
PCI (mod 1)
PCI (mod 2)
PCI (mod 3)
PCI (mod 4)
PCI (mod 5)

Reference Signal   DTX   All sub-carriers
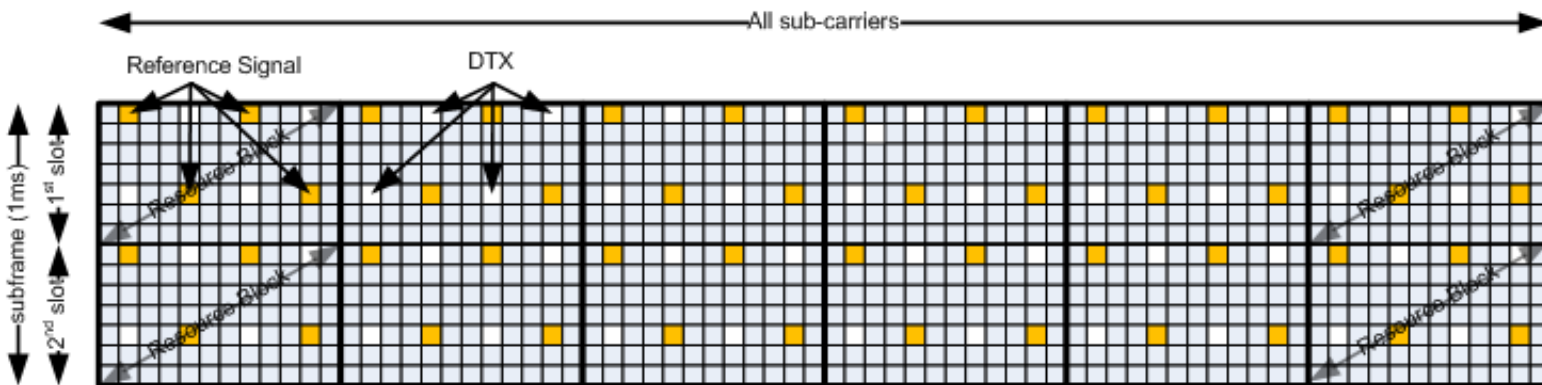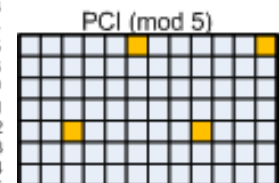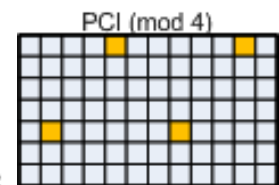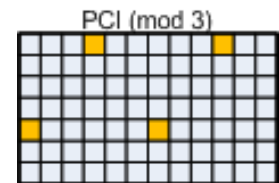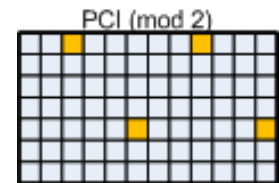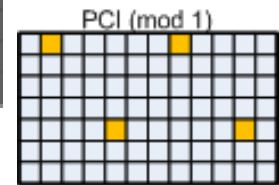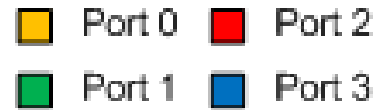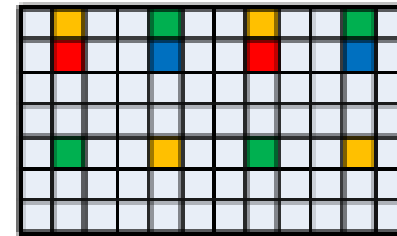
3.1.4 Uplink Group Base Sequence

GBS

Uplink Base Group Sequence

- There are 30 groups of base sequences available for PUCCH DMRS, PUSCH DMRS, SRS and PUCCH.
- Each group has 1 sequence available up to a length of 5 and two sequences for each length afterwards
- Same groups should not be used in neighbor cells and group allocation per cell should be done
- Groups can be use the PCI as a reference and assign the group with mod (PIC, 30)
- The standard has provision for an additional parameter used to assign PUSCH DMRS
  - This parameter is called PUSCH Group Assignment, is represented by Δ_{ss} and is broadcast in SIB2
  - The group assignment for PUSCH DMRS is then given by:
    - $mod(mod(PCI, 30) + \Delta_{ss}, 30)$
- As an alternative to planning group hopping can be used
  - It is not such a good alternative, though as periodic conflicts will still arise

Uplink Groups of Base Sequences
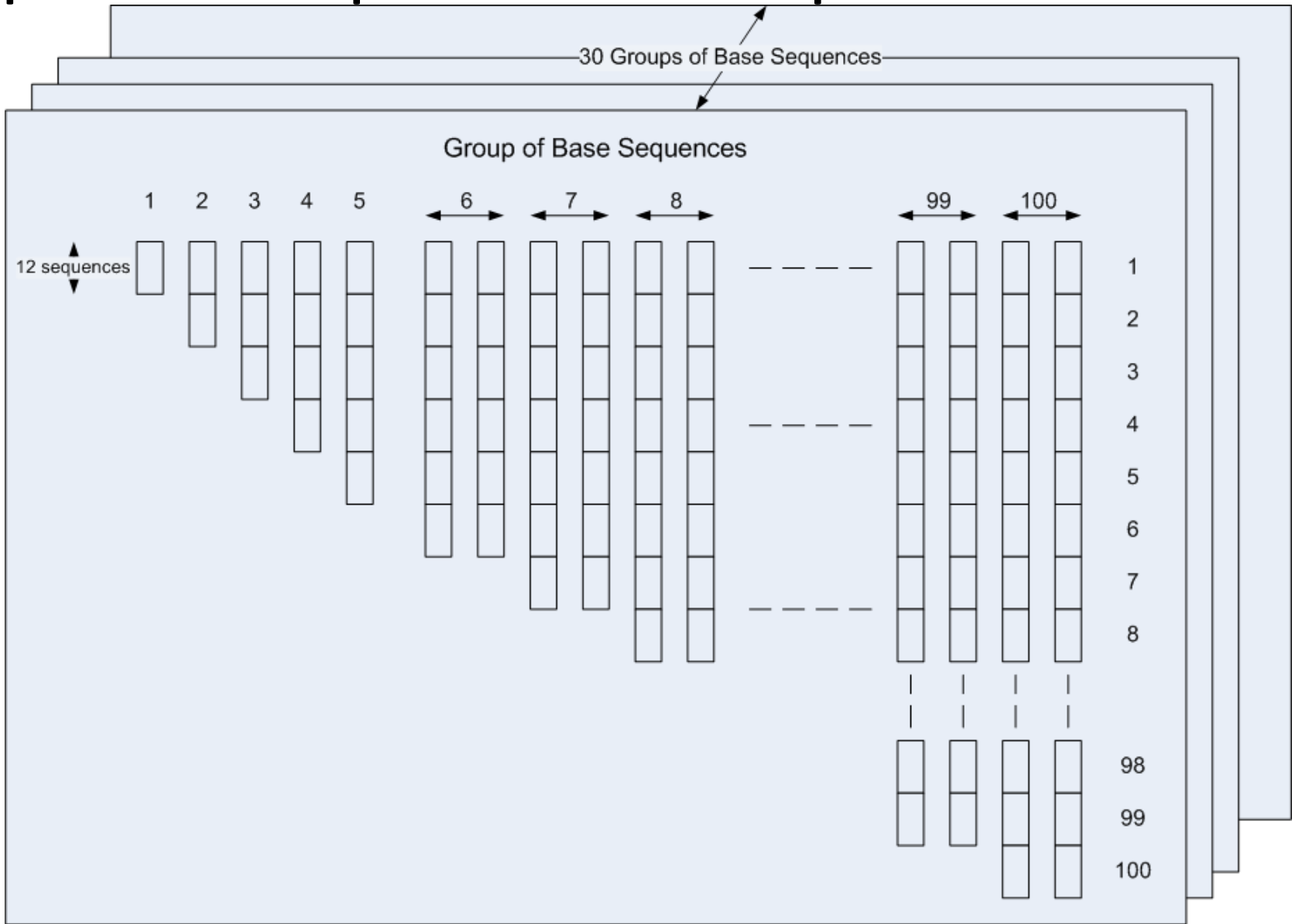
3.1.5 PCI Planning

PCI Planning

- Apply reuse of 3 (PCI mod 3)

  – Clusters of 3 cells

  – Different codes for each three sectored eNB

- Apply reuse 6 (PCI mod 6)

  – Clusters of 6 cells

- Apply reuse 30

  – Clusters of 30 cells

- CellDesigner considers RF interference and geometry to automatically populate PCIs

  – Some PCIs should be reserved for small cells (suppose 18 groups of 3)
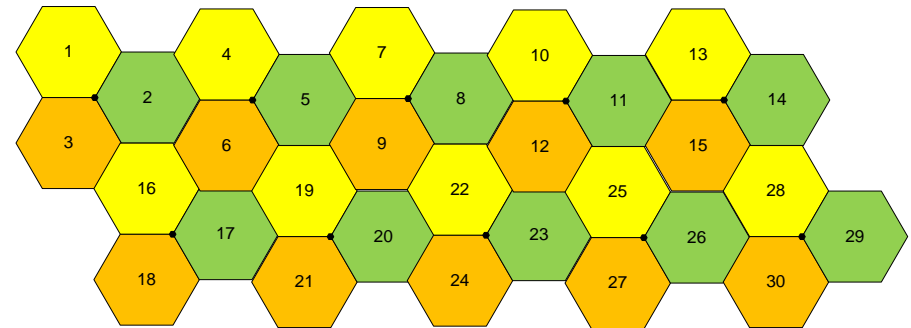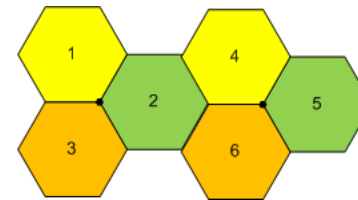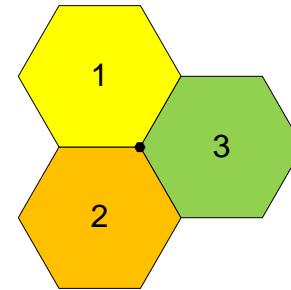
3.2 Downlink Dimensioning

Cyclic Prefix (CP)

PFICH

PHICH

PDCCH

CCE

PDSCH

RBG

3.2.1 Cyclic Prefix

CP

Cyclic Prefix (CP)

- A cyclic prefix is a multipath guard band at the start of each symbol

- Properly designed it eliminates multipath, increasing throughput, but excessive cycle prefix represents an overhead that reduces throughput

- LTE has only two options of Cyclic prefix, as shown in the table below

- The difficulty is to measure multipath on a cell basis

- CellSpectrum is an equipment that allows to measure the multipath delay spread for various attenuation levels, so the designer can dimension CP properly

	T_s	µs	km
Cyclic Prefix= Normal	160/144	5.2/4.7	1.4
Cyclic Prefix= Extended	512	16.7	5.0

$$T_s = 1/(15{,}000 * 2048) = 32.55\ ns$$

CelSpectrum™

- Wireless Spectrum Analysis Platform
  - 100 kHz to 8 GHz tuning and 200 GHz/sec scan
  - 70 dBc at 100 MHz IBW and 100 dBc at 200 kHz
  - Real-time triggering and capture
  - Network efficient and standard APIs
  - Low power and small form-factor
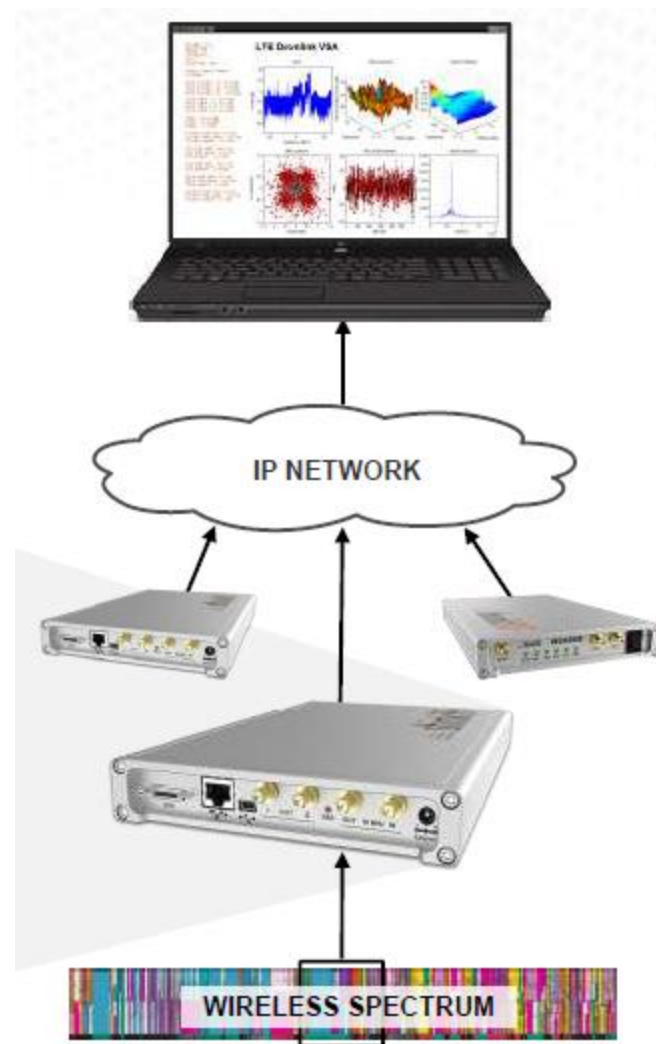
Primary Synchronization Signal Power Delay Profile (PSS PDP)
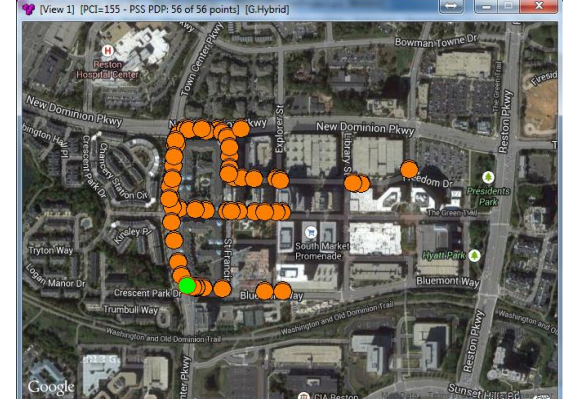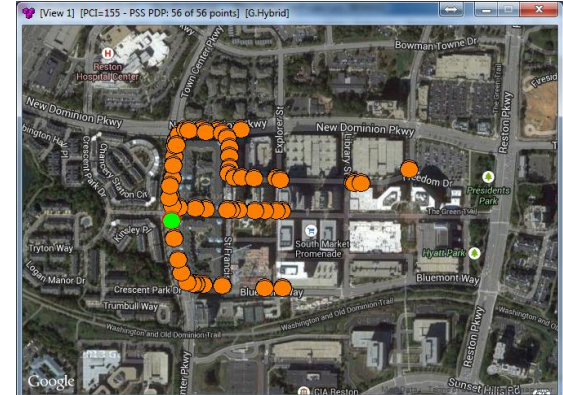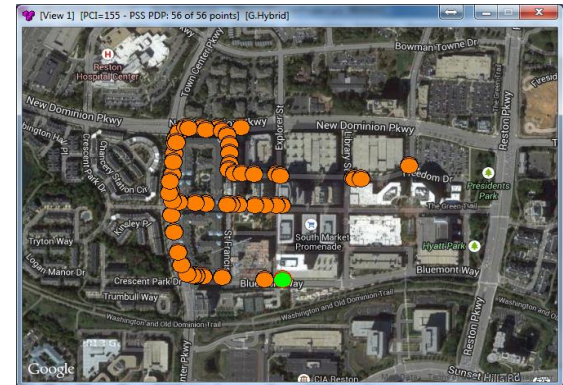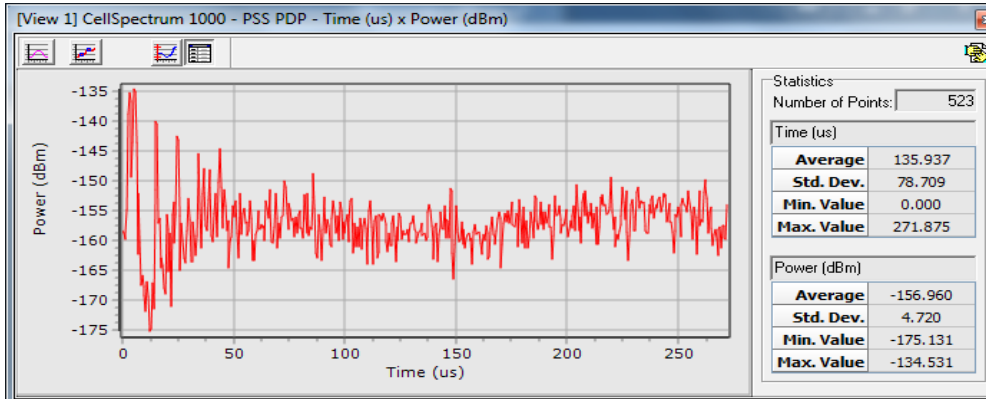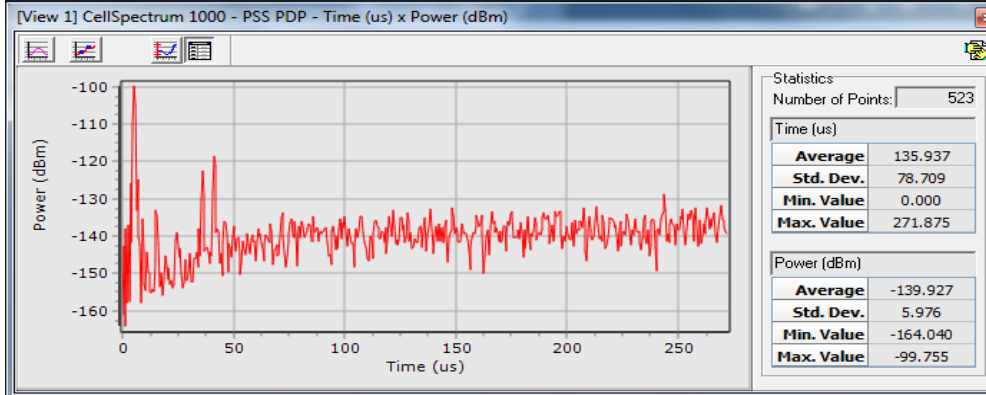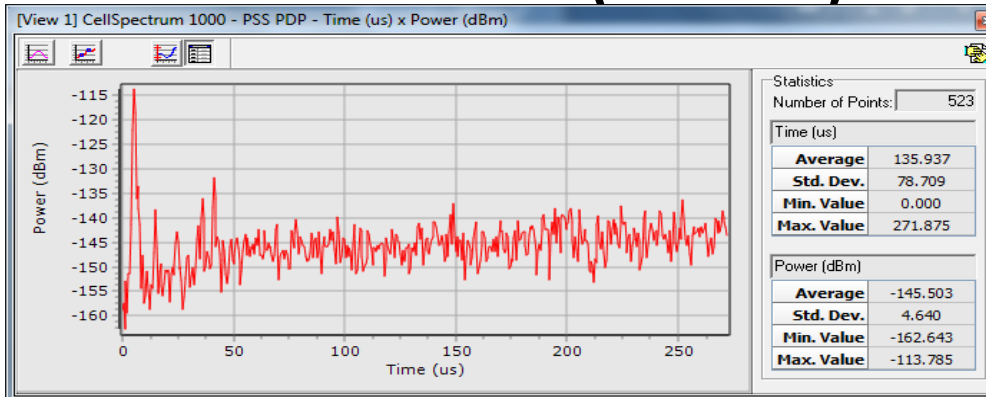
3.2.2 Physical Control Format Indicator Channel

PFICH

Number of Control Symbols

Physical Control Format Indicator Channel (PCFICH)

- This channel signal every subframe the number of OFDM symbols used for PDCCH
  - It carries the CFI (Channel Format Indicator) which signals that 1, 2 or 3 frames are used (2 bit)
  - This information is spread by a cell specific length-31 pseudo random Gold Sequence
- It is sent over 4 Resource Elements Groups (REG-RE quadruplets), sent in the first symbol of each subframe, on subcarriers not reserved for RS
  - Exact REG position depends on bandwidth and CellID
  - Uses QPSK modulation (16 RE=16 Symbols= 32 bit)

72 central sub-carriers; 6 Resource Blocks; 2 antennas; PCI=1; PHICH Scaling=1; PHICH duration=normal

Note: Central Carrier is not Depicted. Resource Element (RE) Resource Element Group (REG) or Quadruplet

Legend: CRS, DTX, PFICH, PHICH, PDCCH, SSS, PSS, MIB, PDSCH

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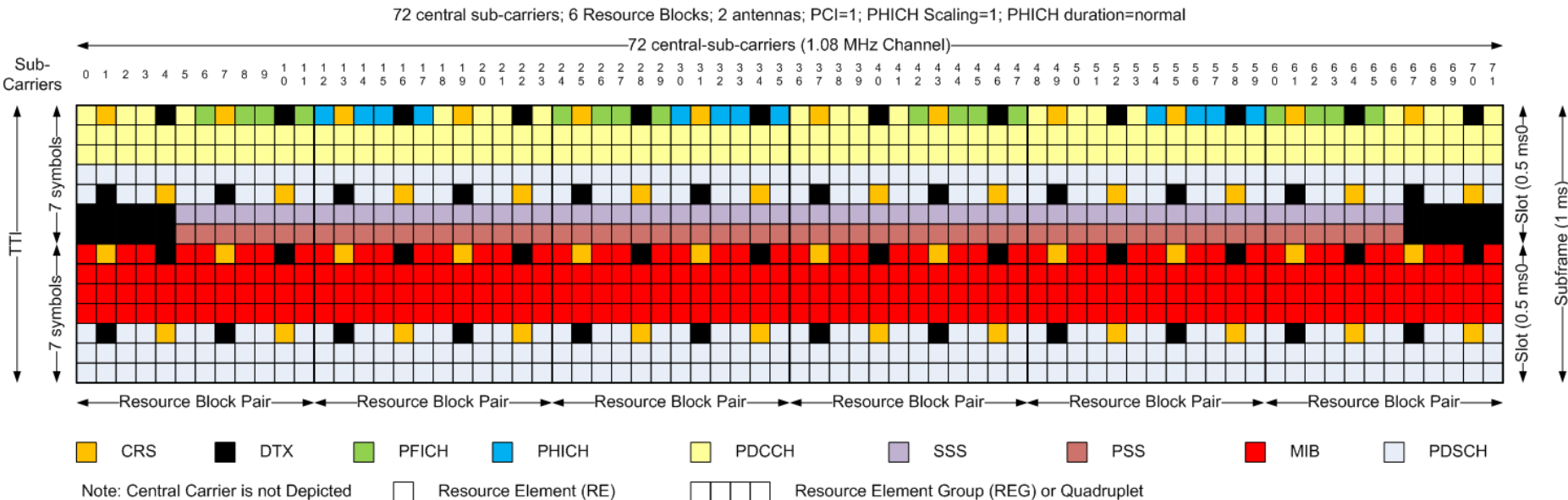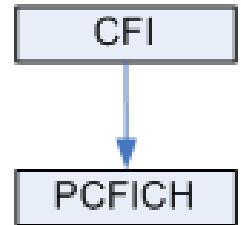
3.2.3 Physical Hybrid ARQ Indication Channel

PHICH

Scaling Factor

PHICH Location

Physical Hybrid ARQ Indication Channel (PHICH)

- This channel is used to signal ACK/NACK for uplink data transferred on PUSCH

- MIB defines the PHICH configuration
  - PHICH location
    - Normal: first OFDM subframe symbol
    - Extended: first 3 OFDM subframe symbols
  - PHICH Group Scaling Factor(1/6, 1/2,1,2)
    - Defines the number of PHICH groups

- Each group data is sent over 3 REG (Resource Element Groups)
  - REG is a quadruplet of consecutive symbols, avoiding RS and PPCFICH symbols

- The exact position of the REGs depends on the bandwidth and CellID

- REG vary between 1 and 50

- Each group is shared between 8 UEs, by the use of orthogonal sequences
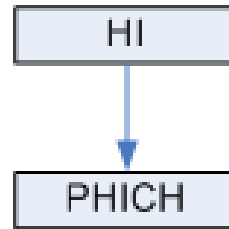
PHCIH Groups (NCP, double for ECP)						
PHICH Group Scaling Factor (normal CP)	Bandwidth (MHz)					
	1.4	3	5	10	15	20
1/6	1	1	1	2	2	3
1/2	1	1	2	4	5	7
1	1	2	4	7	10	13
2	2	4	7	13	19	25

72 central sub-carriers; 6 Resource Blocks; 2 antennas; PCI=1; PHICH Scaling=1; PHICH duration=normal

Legend: CRS, DTX, PFICH, PHICH, PDCCH, SSS, PSS, MIB, PDSCH

Note: Central Carrier is not Depicted — Resource Element (RE) — Resource Element Group (REG) or Quadruplet

PCFICH and PHICH allocation

Allocation of PCFICH and PHICH on the quadruplets of the first symbol of every subframe (5 MHz bandwidth, Normal Cyclic Prefix)

Legend:
- PCFICH (yellow)
- PHICH 1/6 scale (light blue)
- PHICH 1/2 scale (green)
- PHICH 1 scale (blue)
- PHICH 2 scale (red)

3.2.4 Physical Downlink Control Channel

PDCCH
Number of Control Channel Symbols in TTI
DCI
CCE

CONTROL

| Transmission Mode | Downlink Control Information (DCI) Format | Physical Downlink Control Channel (PDCCH) Data Mapping Info | PDCCH Format Coding Rate | Number of Common Channel Elements (CCE) | CCE Allocation |

| Transport Block +CRC | Code Blocks +CRC | MCS TBS Index | Number of Resource Block Pairs to be Used | PDSCH Format | TBG Allocation | Code Word Assembly |

USER and SIGNALING DATA
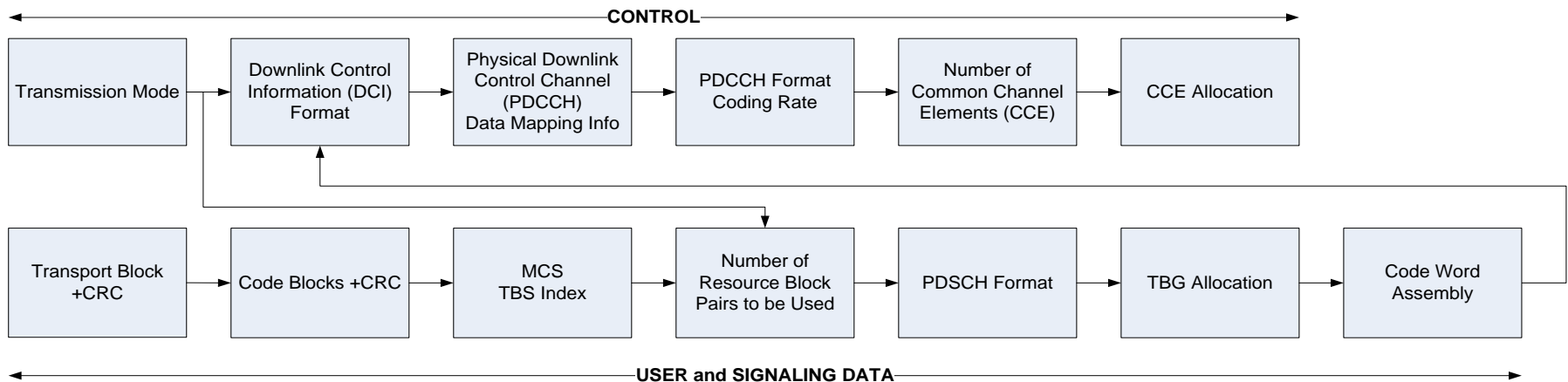
Physical Downlink Control Channel (PDCCH) 1

- This channel is used to transfer Downlink Control Information (DCI): Data mapping allocation
- PDCCH uses the first OFDM symbols of each subframe
  - PCFICH specifies the number of OFDM symbols used
- PDCCH is sent with QPSK in a single antenna or using receive diversity
- PDCCH information is mapped to Control Channel Elements (CCE)
  - Each CCE is made of 9 REG (quadruplets)
    - 1 CCE= 9 REG= 36 symbols = 72 bit
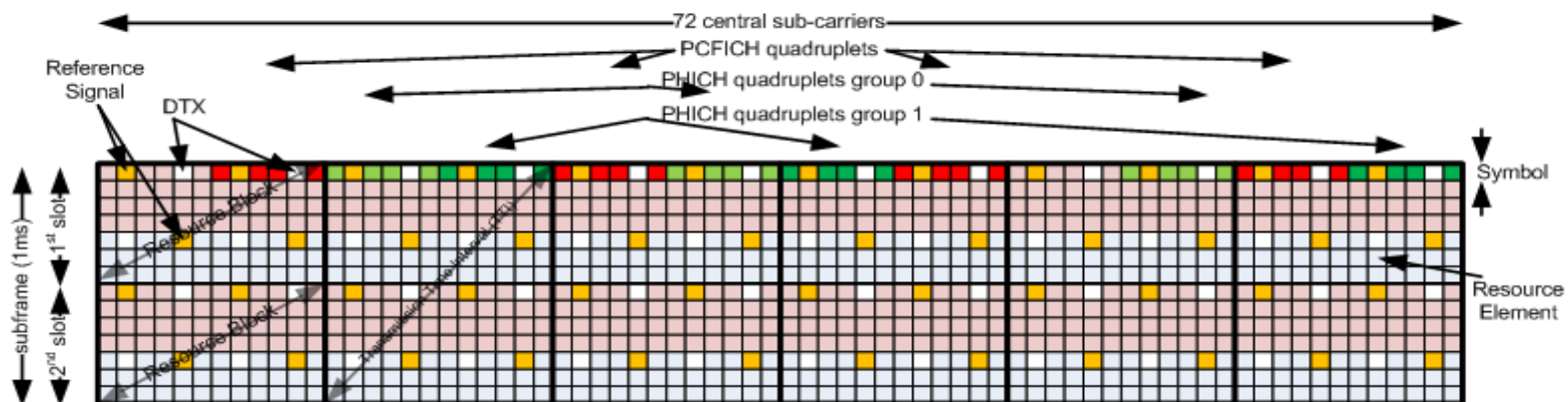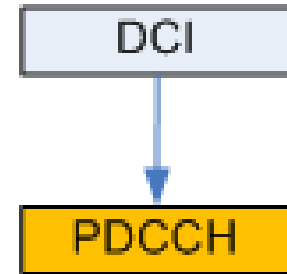
Physical Downlink Control Channel (PDCCH) 2

- Four PDCCH formats are specified in the table
- PDCCH format is selected according to DCI size and puncturing allowed by the channel conditions
  - There are 13 DCI formats and the formats are used for:
    - System Information Broadcast
    - Paging purposes
    - Power Control
    - Notifying allocation of users data
  - DCI information is added a 16 bit CRC and 1/3 FEC
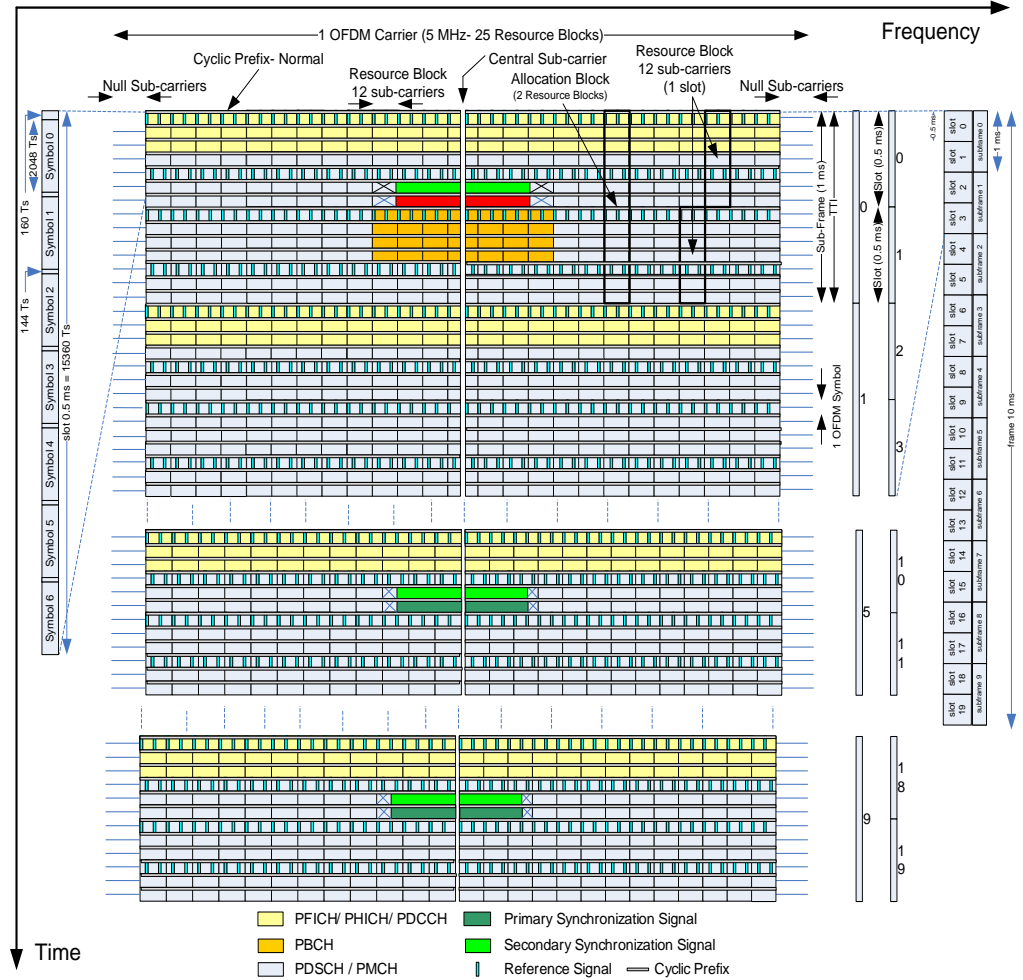
PDCCH Format	Number of CCE	Number of RE Quadruplets	Number of Bit
0	1	9	72
1	2	18	144
2	4	36	288
3	8	72	576

Physical Downlink Control Channel (PDCCH) 3

- PDCCH is transmitted using QPSK on a single antenna or using receive diversity
- DCI format is chosen according to the type of message being sent
- Once the DCI format is chosen it is added a 16 bit CRC, which is scrambled by a Temporary Identifier (RNTI)
  - See next slide for RNTI definition
- PHY adds a 1/3 FEC code
- The PDCCH format is chosen according to the coding rate allowed by the RF channel
- The PDCCH format chosen defines the number of CCEs assigned
- PDCCH are grouped in search spaces
  - 2 common search spaces (16 CCE each)
  - 4 UE specific search spaces (6, 12, 8 and 16 CCE)
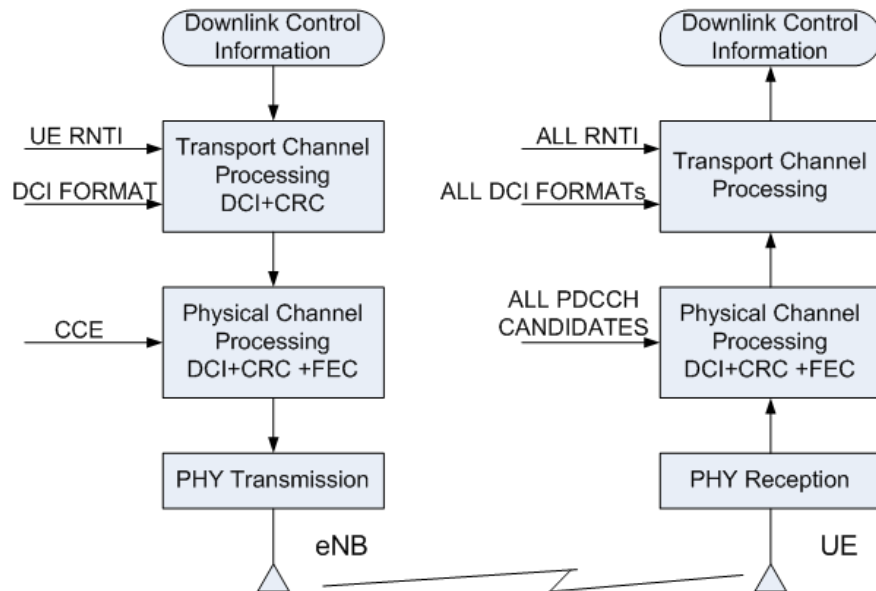
Search Space	CCE	Aggregation Level	Number of PDCCH candidates
Common	16	4	4
	16	8	2
UE Specific	6	1	6
	12	2	6
	8	4	2
	16	8	2

eNB side:

Downlink Control Information → UE RNTI, DCI FORMAT → Transport Channel Processing DCI+CRC → CCE → Physical Channel Processing DCI+CRC +FEC → PHY Transmission → eNB

UE side:

Downlink Control Information ← ALL RNTI, ALL DCI FORMATs ← Transport Channel Processing ← ALL PDCCH CANDIDATES ← Physical Channel Processing DCI+CRC +FEC ← PHY Reception ← UE

- The UEs are assigned an UE specific search space

- Each UE accesses the common search spaces and blindly detects each message by descrambling the CRC with all pre-defined RNTI values

- Next the UE accesses its specific search space and blindly detects each message by descrambling the CRC with its assigned RNTIs

- ## PDCCH constitution
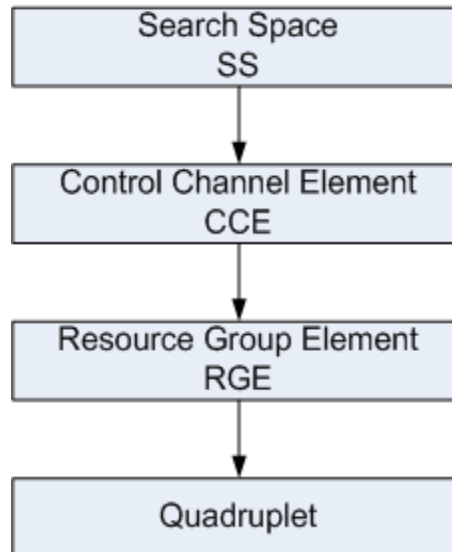
3.2.4.1 Radio Network Temporary Identifier

RNTI

Nicknames

Identification and their context
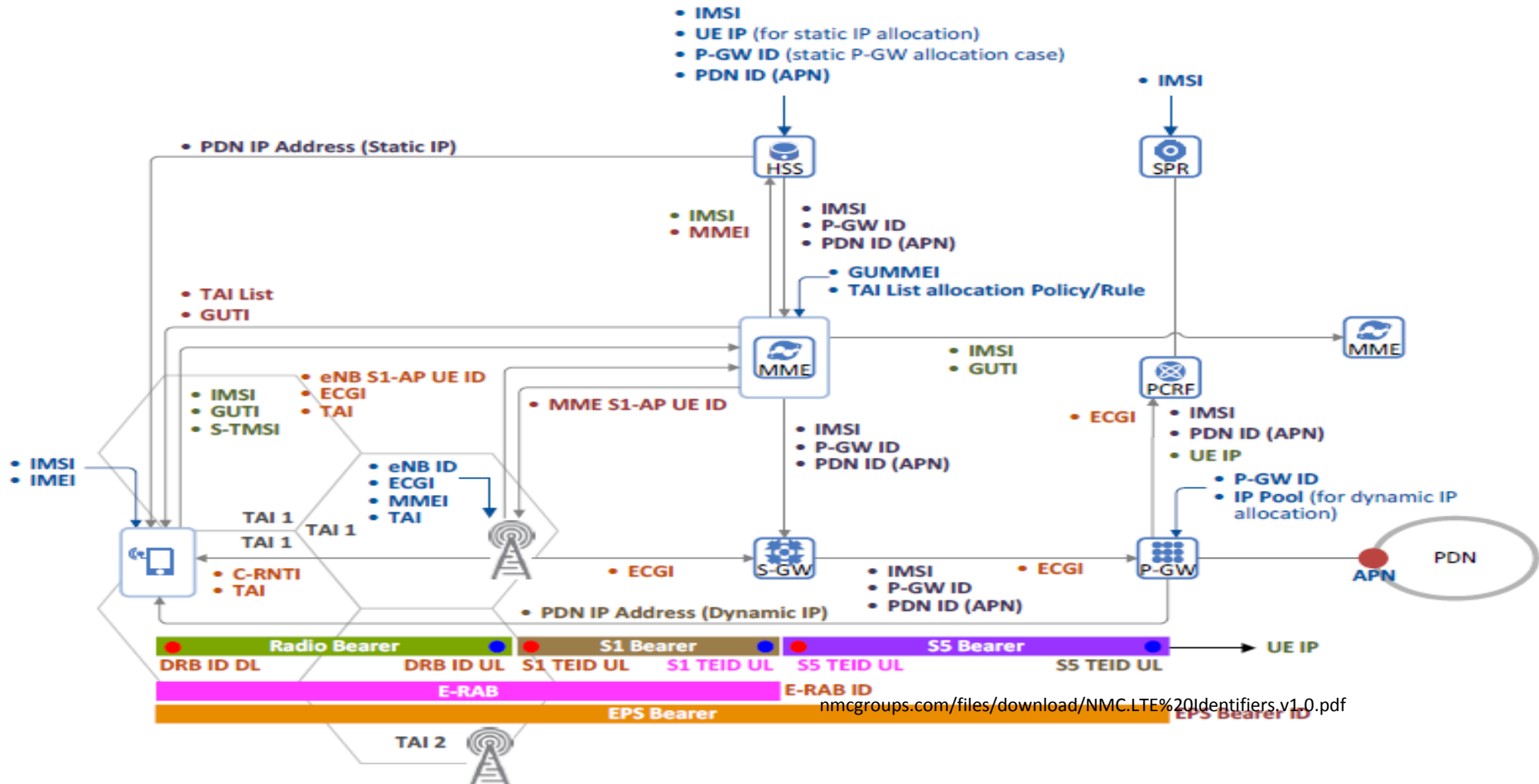
nmcgroups.com/files/download/NMC.LTE%20Identifiers.v1_0.pdf
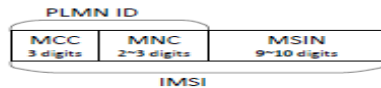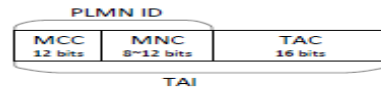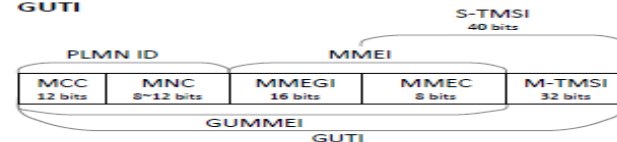
Identification List

Acronym	Name	Description	Composition
IMSI	International Mobile Sunscriber Identity	Unique identification of mobile (LTE) subscriber . Network (MME) gets the PLMN of the subscriber.	IMSI=PLMN ID+MSIN=MCC+MNC+MSN (≤ 15 digit)
PLMN ID	PubliC Land Mobile Network identifier	Unique Identification of PLMN	PLMN ID= MCC+NCC (≤ 6 digit)
MCC	Mobile Country Code	Assigned by ITU	3 digit
MNC	Mobile Network Code	Assigned by National Authority	2 or 3 digit
MSIN	Mobile Subscriber Identification Number	Assigned by Operator	9 or 10 digit
GUTI	Globally Unique Temporary Identification	Identifies an UE between UE and MME on behalf of IMSI for security reasons	GUTI=GUMMEI+M-TMSI (≤ 80 bit)
TIN	Temporary Identity used in Next Update	TIN stores UE's GUTI within MME, to indicate which temporay ID will be used in next update	TIN=GUTI
S-TMSI	SAE Temporary Mobile Subscriber Identity	Short UE identification within an MME group (unique within MME pool)	S-TMSI=MMEM-TMSI (40 bit)
M-TMSI	MME Mobile Subscriber Identity	Unique within an MME	32 bit
GUMMEI	Global Unique MME Identity	Uniquely identifies globally an MME	GUMMEI=PLMN ID +MMEI (≤ 48 bit)
MMEI	MME Identifier	Identifies an MME uniquely within a PLMN	MMEI=MMEGI + MMEC (24 bit)
MMEGI	MME Group Identifier	Unique withn a PLMN	16 bit
MMEC	MME Code	Identifies an MME uniquely within an MME Group	8 bit
C-RNTI	Cell-Radio Network Temporary identifier	Identifies an UE uniquely in a cell	0x0001 to 0xFFF3 (16 bit)
eNB S1AP UE ID	eNB S1 Application Protocol UE ID	Identifies UE uniquely in an eNB S1-MME interface	32 bit integer
MME S1AP UE ID	MME S1 Application Protocol UE ID	Identifies UE uniquely in an MME S1-MME interface	32 bit integer
IMEI	InternationalMobile Equipment Identity	Identifies uniquely an ME (mobile equipment)	IMEI=TAC+SNR+CD (15 digit)
IMEI/SV	IMEi/Software Version	Identifies uniquely an ME (mobile equipment)	IMEI/SV=TAC+SNR+SVN (16 digit)
ECGI	E-UTRAN Cell Global Identifier	Idetifies a cell uniquely in a global setting	ECGI=PLMN ID+ECI (≤ 52 bit)
ECI	E-UTRAN Cell Identifier	Identifies a cell within a PLMN	Global eNB ID= PLMN ID +eNB ID (≤ 44 bit)
Global eNB ID	Global eNB Identifier	Identifies an eNB within a PLMN	20 bit
eNB ID	eNodeB ID	Identifies an eNB in aa global scale	IP address (4 bytes) +FQDN (variable length) Fully Qualified Domain Name
P-GW ID	PDN GW Identity	Identifies a specific PDN GW	TAI (≤28 bit)=PLMN ID +TAC
TAI	Tracking Area Identity	Identifies Tracking Area	16 bit
TAC	Tracking Area Code	Indicates to which Tracking Area an eNB belongs	TAI (≤28 bit)TAC
TAI List	Tracking Area Identity	UE can move into cell in the list without a location update (TA update)	PDN Identity= APN=APN.NI+APN.OI (variable length)
PDN ID	Packet Data Network Identity	Identifies PDN (IP Network) that mobile data will be sent to	4 bit
EPS Bearer ID	Evolved Packet System Bearer Identifier	Identifies an EPS bearer (default or dedicated) per UE	4 bit
E-RAB ID	E-UTRAN Radio Access Bearer Identifier	Identifies E-RAB per UE	4 bit
DRB ID	Data Radio Bearer Identifier	Identifies DRB per UE	4 bit
LBI	Linked EPS Bearer ID	Identifies default bearer associated with dedicated EPS	4 bit
TEID	Tunnel End Point Identifier	Identifies end point of GTP tunnel	32 bit

Radio Network Temporary Identifier

- RNTI is used to address specific UEs and at the same identify the type of message that is being sent
  - Some messages are addressed to all UEs and have fixed identification values
    - SI-RNTI
    - P-RNTI
    - M-RNTI
  - The remaining messages are sent to specific UEs
    - RA-RNTI
    - C-RNTI (temporary)
    - C-RNTI
    - SPS-C-RNTI
    - TPC-PUCCH-RNTI
    - TPC-PUSCH-RNTI

RNTI type	Type of Information	Hex value	Values
RA-RNTI	Random Access Response	0001 to 003C	60
C-RNTI (Temporary)	Random Access Contention Resolution	003D to FFF3	65463
C-RNTI	Downlink or Uplink transmission (one)		
SPS-C-RNTI	Semi-persistent scheduling		
TPC-PUCCH-RNTI	PUCCH TX Power Comand		
TPC-PUSCH-RNTI	PUSCH TX Power Comand		
M-RNTI	MBMS notification	FFFD	1
P-RNTI	Paging	FFFE	1
SI-RNTI	System information message	FFFF	1

3.2.4.2 Common Channel Element

CCE

Common Channel Element (CCE)

- A CCE is an aggregation of 9 consecutive quadruplets (4 REs)
  - REs carrying RS, PCFICH and PHICH are disregarded

CCE numbering in a 5 MHz channel, 2 antennas, Normal Cyclic Prefix, Cell ID=0

Common Channel Elements (CCE)

Antennas=4, Cyclic Prefix=extended, PCFICH=1 , PHICH scaling=2						
	Channel Bandwidth (MHz)					
	1.4	3	5	10	15	20
RB	6	15	25	50	75	100
REs/symbol	72	180	300	600	900	1200
RSs per RB symbol 0 of subframe	4	4	4	4	4	4
RSs per RB symbol 1 of subframe	4	4	4	4	4	4
RS per RB symbol 2 of subframe	0	0	0	0	0	0
RS per RB symbol 3 of subframe	0	-	-	-	-	-
Symbol 0 available REs	48	120	200	400	600	800
Symbol 1 available REs	48	120	200	400	600	800
Symbol 2 available REs	72	180	300	600	900	1200
Symbol 3 available REs	72	-	-	-	-	-
Total available REs	96	120	200	400	600	800
REGs	24	30	50	100	150	200
PCFICH (REG)	4	4	4	4	4	4
PHICH (REG)	3	3	3	3	3	3
PHICH TOTAL REG	12	24	42	78	114	150
PHICH TOTAL bit	96	192	336	624	912	1200
Free REGS	8	2	4	18	32	46
CCEs	0	0	0	2	3	5

Four antenna, Extended Cyclic Prefix, PCFICH=1, PHICH=2						
Channel Bandwidth (MHz)						
	1.4	3	5	10	15	20
4 antenna, Extended CP, PCFICH=1, PHICH=2						
Free REGS	8	2	4	18	32	46
CCEs	0	0	0	2	3	5

One antenna, Normal Cyclic Prefix, PCFICH=3, PHICH=1/6						
Channel Bandwidth (MHz)						
	1.4	3	5	10	15	20
1 antenna, Normal CP, PCFICH=3, PHICH=1/6						
Free REGS	62	120	205	415	627	837
CCEs	6	13	22	46	69	93

3.2.5 Physical Downlink Shared Channel

PDSCH

Number of Resource Block Groups

Physical Downlink Shared Channel (PDSCH) 1
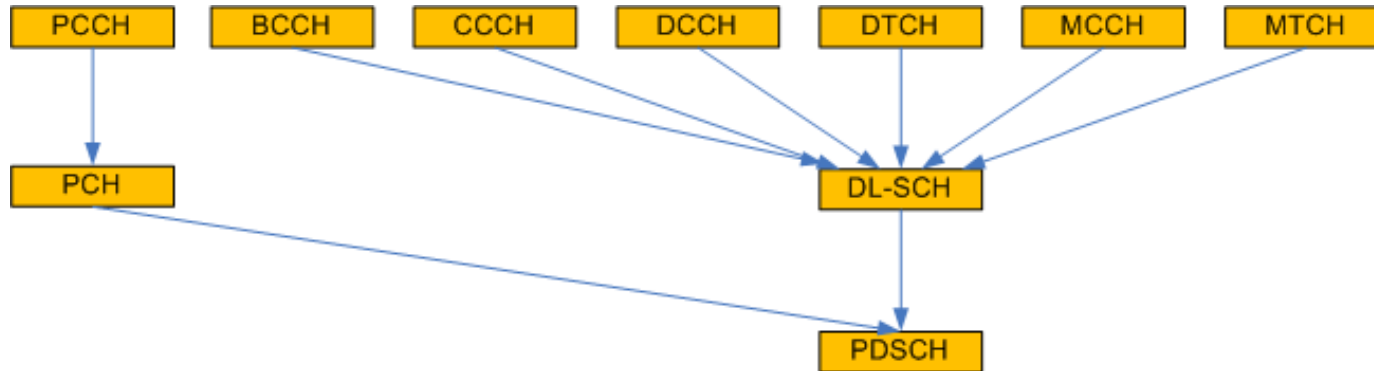
- This is a shared channel is used to:
  - Broadcast System Information Blocks (SIB)
  - Broadcast Paging messages
  - Downlink RRC signalling messages:
    - Signalling Radio Bearers (SRB)
      - Every connection has it own set of SRB
- Downlink Control Information formats (DCI) are used to allocate PDSCH resources
- System and paging messages use QPSK
- Radio Bearers use QPSK, 16 QAM or 64 QAM, base don the link adaptation requirements

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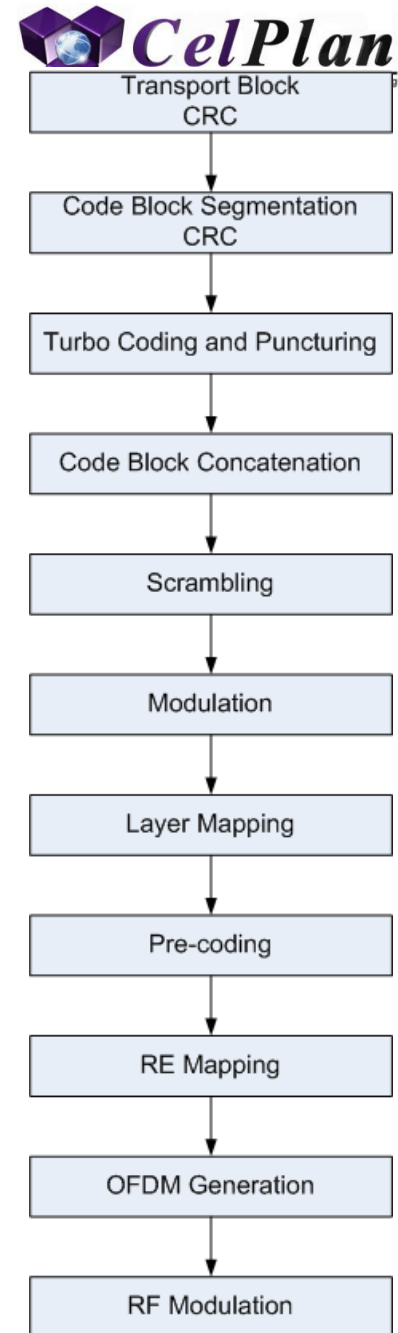
Physical Downlink Shared Channel (PDSCH) 2

- Paging Control Channel (PCCH)
  - Paging can be used for:
    - Initiate a mobile terminating PS data connection
    - Initiate a mobile terminating SMS connection
    - Initiate a mobile terminating CS fallback connection
    - Trigger an UE to reacquire System Information
    - Provide Earthquake and Tsunami Warning System (ETWS) notification
    - Provide a Commercial Mobile Alert Service (CMAS) notification
  - Paging procedure can be initiated by MME or eNB
  - UE Paging Identity is defined by the UE Identity Index and is used to calculate the Paging Frame (PF)
    - UE Index Identity= UE IMSI (mod 1024)

- Paging Channel (PCH)
  - Uses QPSK modulation
  - PCH codeword is transferred during one subframe at the paging occasion of each DRX cycle

PCH Transport Block

↓

24 bit CRC

↓

Filler bits (40 bits)

↓

Turbo Code 1/3

↓

Rate Matching to Link Conditions

↓

PCH Codeword
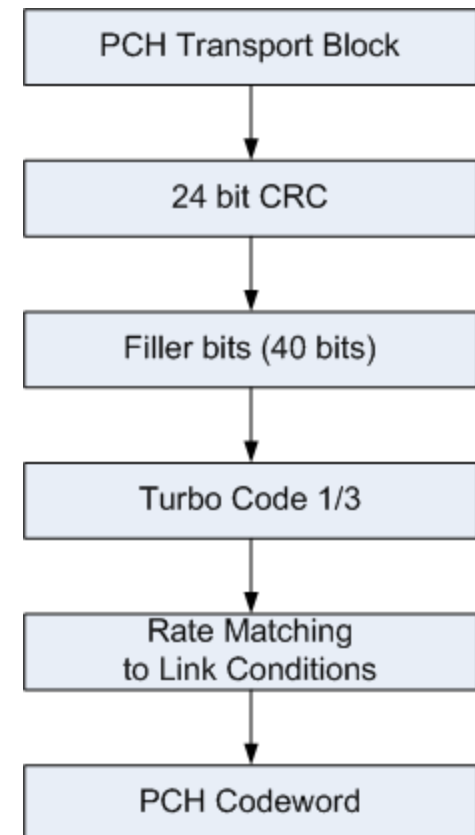
Physical Downlink Shared Channel (PDSCH) 3

- Downlink Shared Channel (DL-SCH)
  - It is a shared channel used for:
    - Transfer BCCH System Information Blocks (SIB)
    - Transfer RRC Signalling conveyed by CCCH, DCCH, MCCH
    - Transfer Application Data conveyed by DTCH, MTCH
  - Channel allocation is conveyed to the UE by the PDCCH DCI
  - The DL-SCH can transfer up to 2 transport blocks per subframe per connection
  - Downlink procedure is illustrated in figure
  - QPSK, 16 QAM and 64QAM modulations are used according to RF link conditions
  - A DL-SCH codeword has to be transferred in a 1 ms subframe
  - MCCH and MTCH details are given in PMCH

DL-SCH Transport Block

↓

24 bit CRC

↓

Segment (6120 bit)

↓

Add Segment 24 bit CRC

↓

Filler bits (40 bit)

↓

Turbo Code 1/3

↓

Interleaving and Scrambling

↓

Rate Matching to Link Conditions

↓

DL-SCH Codeword
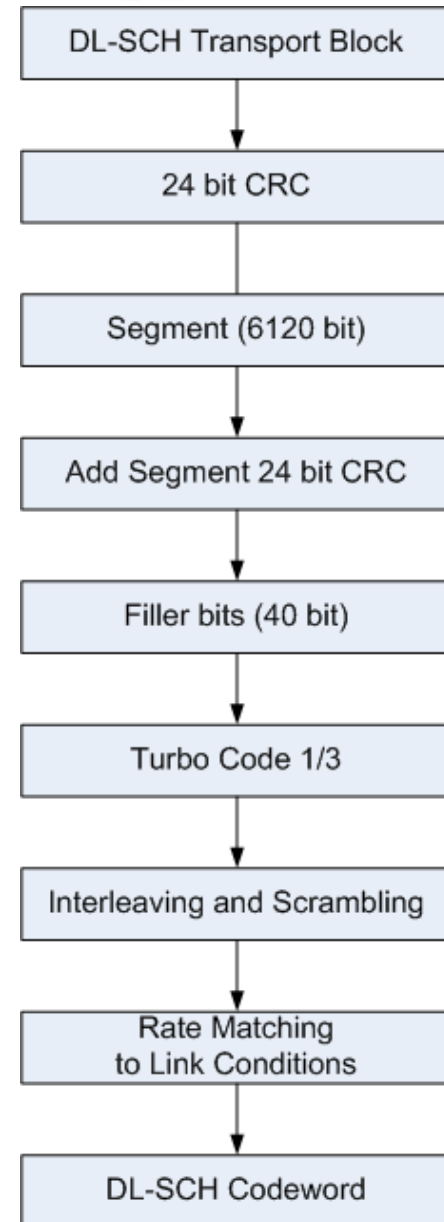
3.2.6 PDSCH Resource Allocation

RBG

PDSCH Resource Allocation

CONTROL

| Transmission Mode | Downlink Control Information (DCI) Format | Physical Downlink Control Channel (PDCCH) Data Mapping Info | PDCCH Format Coding Rate | Number of Common Channel Elements (CCE) | CCE Allocation |

| Transport Block +CRC | Code Blocks +CRC | MCS TBS Index | Number of Resource Block Pairs to be Used | PDSCH Format | TBG Allocation | Code Word Assembly |

USER and SIGNALING DATA

3.2.6.1 Resource Block Group

Resource Block Groups (RBG)

- Resource Allocation is done in Resource Block Groups (RBG), each one corresponding to a certain number of Resource Block Pairs

- RBGs size varies from 1 to 4, depending on the channel bandwidth

Resource Block Group	Bandwidth (MHz)					
	1.4	3	5	10	15	20
Total Number of RBs	6	15	25	50	75	100
RBG Size (RB)	1	2	2	3	4	4
Total Number of RBGs	6	8	13	17	19	25
Bit map size (bit)	6	8	13	17	19	25

RBG Numbering

5 MHz Resource Block Group (RBG) numbering

PRBs

00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Frequency

sub-frame

00	01	02	03	04	05	06	07	08	09	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24	25
26	27	28	29	30	31	32	33	34	35	36	37	38
39	40	41	42	43	44	45	46	47	48	49	50	51
52	53	54	55	56	57	58	59	60	61	62	63	64
65	66	67	68	69	70	71	72	73	74	75	76	77
78	79	80	81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100	101	102	103
104	105	106	107	108	109	110	111	112	113	114	115	116
117	118	119	120	121	122	123	124	125	126	127	128	129

frame

Time

3.2.6.2 PDSCH Resource Allocation

PDSCH Resource Allocation

- The smallest allocation unit is a Resource Block Group (RBG), defined by 3GPP for each bandwidth

- PDSCH Allocation Type is informed in DCI

- LTE suffers of intrinsic lack of diversity, and the different allocation types are trying to make up for it

- This affected the uplink due to the SC-OFDMA restriction, which was lifted in Release 10

- This different allocations require extensive mapping, so several schemes were devised to reduce the number of bits required to inform the allocation (bit scrubbing), resulting in added complexity

Resource Block Group	Bandwidth (MHz)					
	1.4	3	5	10	15	20
Total Number of RBs	6	15	25	50	75	100
RBG Size (RB)	1	2	2	3	4	4
Total Number of RBGs	6	8	13	17	19	25
Bit map size (bit)	6	8	13	17	19	25

PDSCH	Allocation Type	Characteristic
Downlink	0	Direct bit mapping of RBGs
	1	Divides each RBG in two subsets
	2 contiguous	Uses a RIV (Resource Indication Value) to indicate the start and end of allocation
	2 distributed	Uses a look up table to allocate RBGs
Uplink	Type 0 Non Hopping	Uses a RIV (Resource Indication Value) to indicate the start and end of allocation
	Type 0 Hopping Type 1	Divides the set of contiguous RBs in groups and alternating these groups between the two slots of the subframe
	Type 0 Hopping Type 2	The number of sub-bands is specified by the network, through an RCC command
	Type 1	Allows for non contiguous allocation of RBs using binomial coefficients (Release 10)

Physical Resource Blocks (PRB)	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Resource Block Groups (RBG)	0		1		2		3		4		5		6		7		8		9		10		11		12

LTE Modulation and Coding Schemes (MCS)

UE Reported Measurements

CQI Index	Modulation	Coding Rate	Bits per Symbol
0	Out of range		
1	QPSK	0.08	0.16
2	QPSK	0.12	0.24
3	QPSK	0.19	0.38
4	QPSK	0.30	0.60
5	QPSK	0.44	0.88
6	QPSK	0.59	1.18
7	16QAM	0.37	1.48
8	16QAM	0.48	1.92
9	16QAM	0.60	2.40
10	64QAM	0.46	2.76
11	64QAM	0.55	3.30
12	64QAM	0.65	3.90
13	64QAM	0.75	4.50
14	64QAM	0.85	5.10
15	64QAM	0.93	5.58

Control Messages MCS (QPSK)

	Format 0	Format 1	Format 2	Format 3
Average MCS for Control Information	0.569	0.285	0.142	0.071

Data and Signaling Messages MCS

MCS	SNIR	Modulation	Spectral Efficiency	Repetition
0	-5	QPSK	0.234	8.5
1	-4	QPSK	0.307	6.5
2	-3	QPSK	0.377	5.3
3	-3	QPSK	0.490	4.1
4	-2	QPSK	0.602	3.3
5	-1	QPSK	0.740	2.7
6	0	QPSK	0.877	2.3
7	1	QPSK	1.027	1.9
8	2	QPSK	1.176	1.7
9	3	QPSK	1.326	1.5
10	4	16QAM	1.328	3.0
11	5	16QAM	1.477	2.7
12	5	16QAM	1.695	2.4
13	6	16QAM	1.914	2.1
14	7	16QAM	2.160	1.9
15	8	16QAM	2.406	1.7
16	9	16QAM	2.570	1.6
17	10	64QAM	2.572	2.3
18	11	64QAM	2.730	2.2
19	12	64QAM	3.029	2.0
20	13	64QAM	3.322	1.8
21	13	64QAM	3.609	1.7
22	14	64QAM	3.902	1.5
23	15	64QAM	4.213	1.4
24	16	64QAM	4.523	1.3
25	17	64QAM	4.816	1.2
26	18	64QAM	5.115	1.2
27	19	64QAM	5.332	1.1
28	20	64QAM	5.555	1.1

3.2.7 Downlink Power Allocation

Power Boost: P_b

Downlink Power Allocation

- Downlink Power can be equally divided between all subcarriers or can be scaled between RS carrying symbols and the remaining symbols
  - This scaling is defined by the Energy per Resource Element (EPRE), using two parameters

$$P_a = RS_{power}/RE_{non\ RS\ symbol\ power}$$

$$P_b = RS_{power}/RE_{RS\ symbol\ power}$$

RE Power
Carrying RS
RSpower

RE Power in an OFDM Symbol that does not carry RS
RE(non RS Symbol) power

ρa

RE Power in an OFDM Symbol that carries RS
RE (RS symbol)power

ρb

ρa and ρb are power ratios
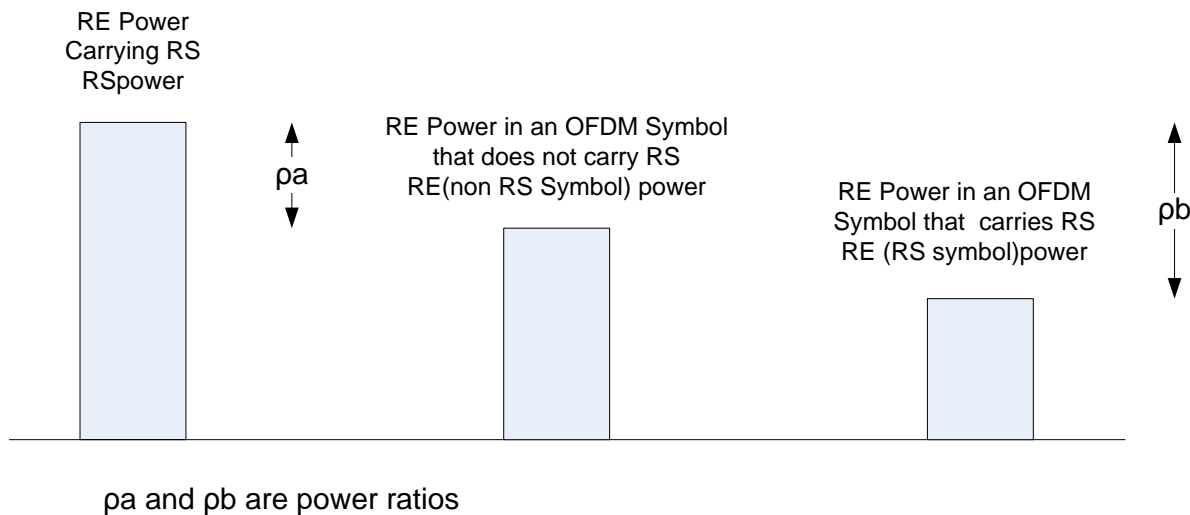
Downlink Power Allocation

- The ratio ρ_b / ρ_a is informed by the parameter Power Boost: P_b in SIB2 for each UE, according to the table below
  - P_b can take integer values from 0 to 3

P_b	ρ_b/ρ_a (linear)	
	One antenna port	Two/Four antenna port
0	1	5/4
1	4/5	1
2	3/5	3/4
3	2/5	1/2
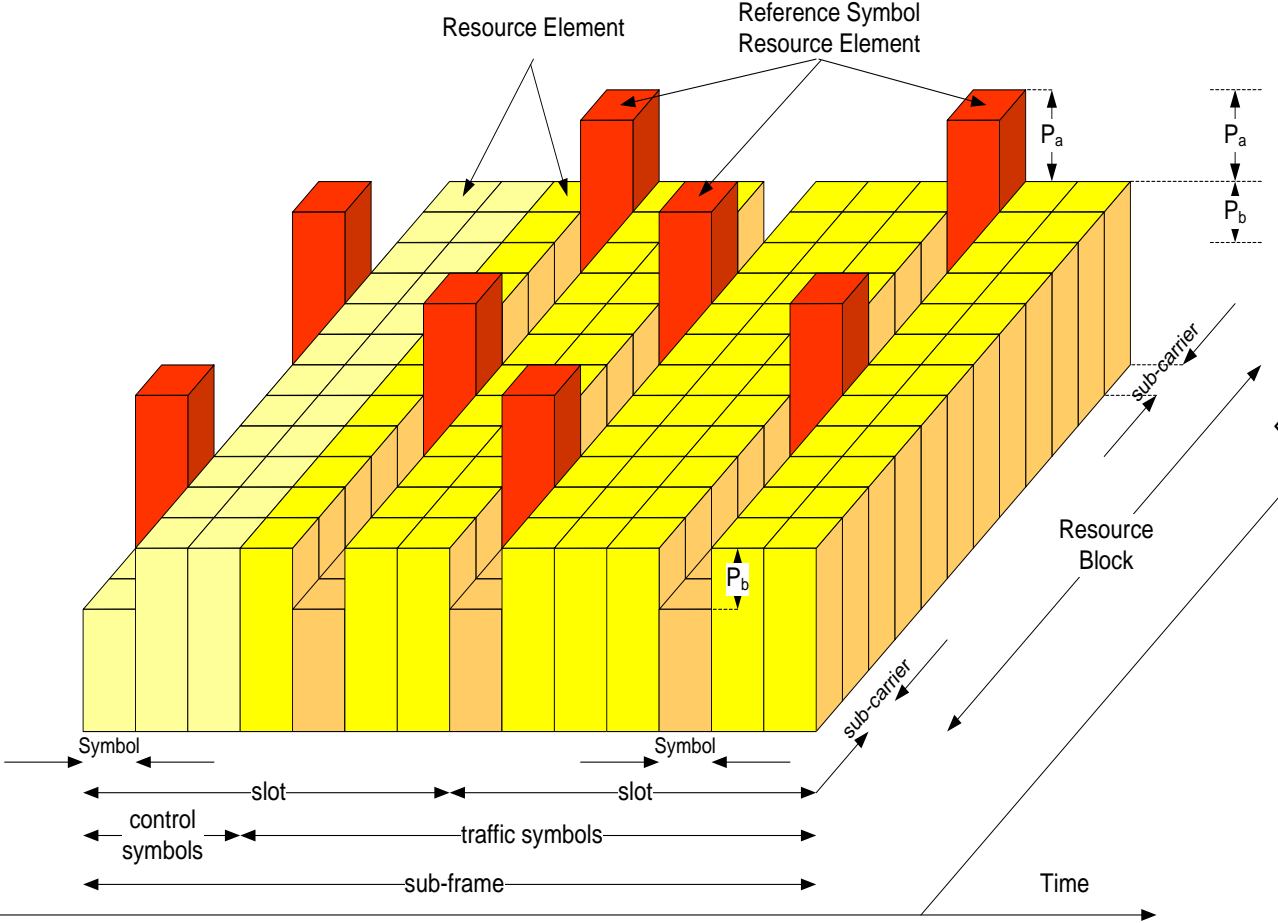
3.3 Traffic Allocation Procedures

RRM
RRC
PDCP
RLC
MAC
PHY

E-UTRAN Protocol Layers

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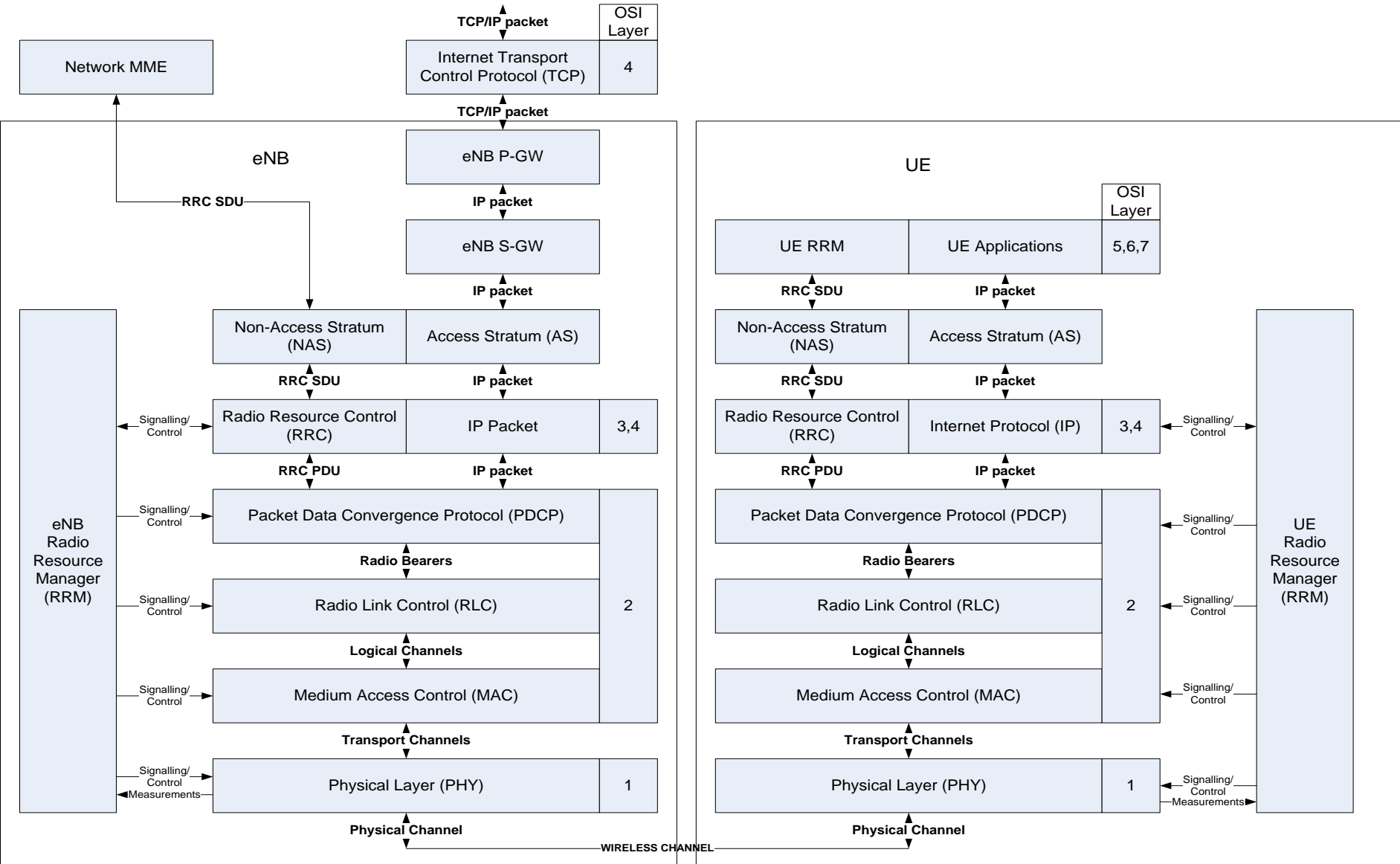
Enhanced NodeB (eNB)

- The eNB informs UEs of its presence by broadcasting access information
  - The initial access is standardized, so UEs can perform it by detecting only the central 1MHz of the RF channel bandwidth
  - The synchronization and basic broadcast information is sent in the central 1 MHz bandwidth
  - This information is enough for the UE to synchronize itself and find out the bandwidth and eNB frame structure organization
- In this bandwidth the eNB send the Synchronization Signals (Primary and Secondary). The synchronization signals are sent twice per frame (every 0.5 ms)
- This is enough for an UE to identify the eNB presence and its signal strength and ID.
- In the same bandwidth the eNB sends the Master Information Block (MIB), so the UE can find out the channel bandwidth and frame organization.
  - This information is sent once per frame, and repeated in 4 consecutive frames.
- The eNB sends additional System Information Blocks (SIBs) which provide additional instructions about the network to the UE.
  - There are 16 SIBs sent with different periodicities
  - SIB 1 informs the scheduling of other SIBs
  - SIB 2 provides access and configuration information
  - SIB 3 provides cell reselection (handover) information
  - SIB 4 provides a neighbor list

Send Synchronization Signals
(twice per frame)

↓

Send Master Information Block and
sub-frame organization information

↓

Send System Information Blocks (SIB)

↓
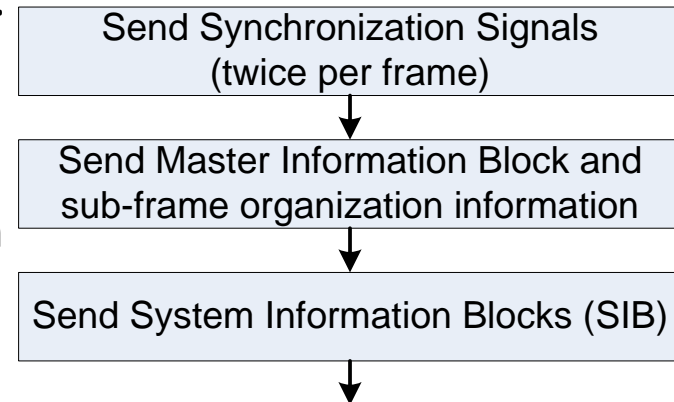
3.3.1 Radio Resource Management

RRM

E-UTRAN Protocol Layers
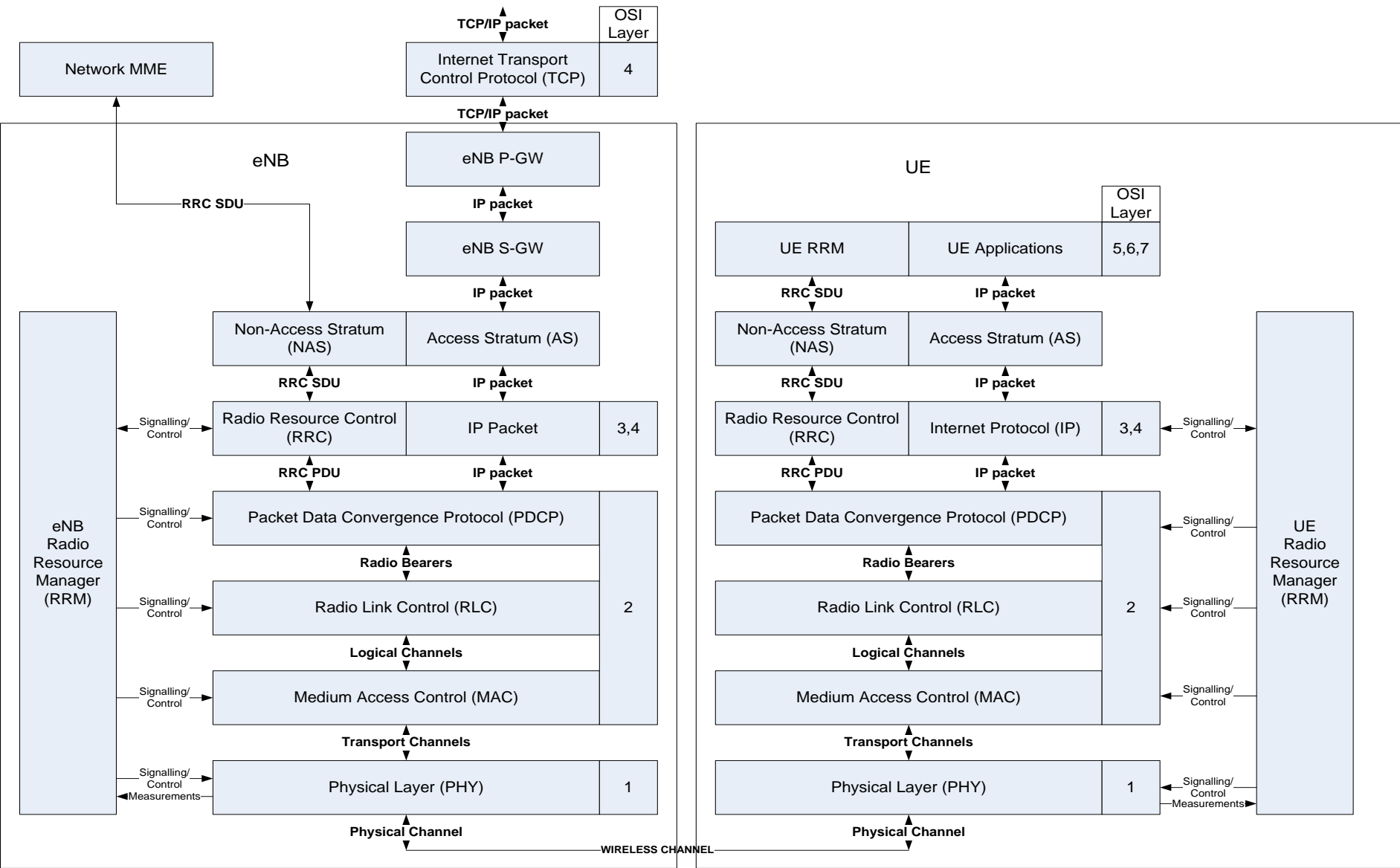
Radio Resource Management (RRM)

- The eNB has its own version of RRM that implements the MME RRM policies at local level
- RRM implements a set of queues that store packets according to their QoS Class Identifier (QCI)
  - The messages are then scheduled according to policies defined for the RRM
- Packet arrival procedure follows the following steps:
  - IP packet arrives (has destination IP address and port number)
  - IP address is matched against registered UE IPs
  - UE temporary identification is retrieved and associated to the packet
  - A QCI is associated to the packet based on a predefined Flow Template (destination and origin address, protocol and port number)
  - A compatible existing bearer is assigned or if not available one is created
  - A service flow is assigned to the packet, or a new one is created
  - Packet is placed in the appropriate queue
- Scheduler analyzes the queues and prepares UEs scheduling sequence, according to scheduling policy.
- Scheduling is revised every 1 ms (Transmission Time Interval-TTI)
- PDCP and RLC instances are assigned to the service flow.
- The availability of a transmission opportunity is described next.
  - MAC schedules HARQ retransmissions and other low level messages (RAR messages)
  - Resource Allocation gets next scheduled UE information
  - Resource Allocation defines the size of the transmission opportunity based on UE MCS and availability in the 1 ms TTI (defines Transport Block Size)
  - UE packets are segmented and concatenated to fill in the transmission opportunity (Transport Block)
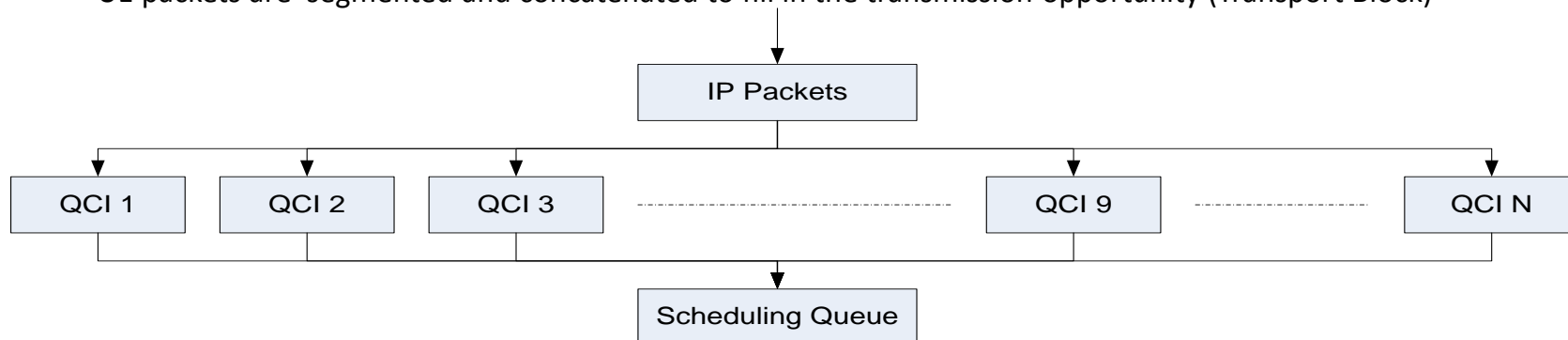
3.3.2 Radio Resource Controller

RRC

E-UTRAN Protocol Layers
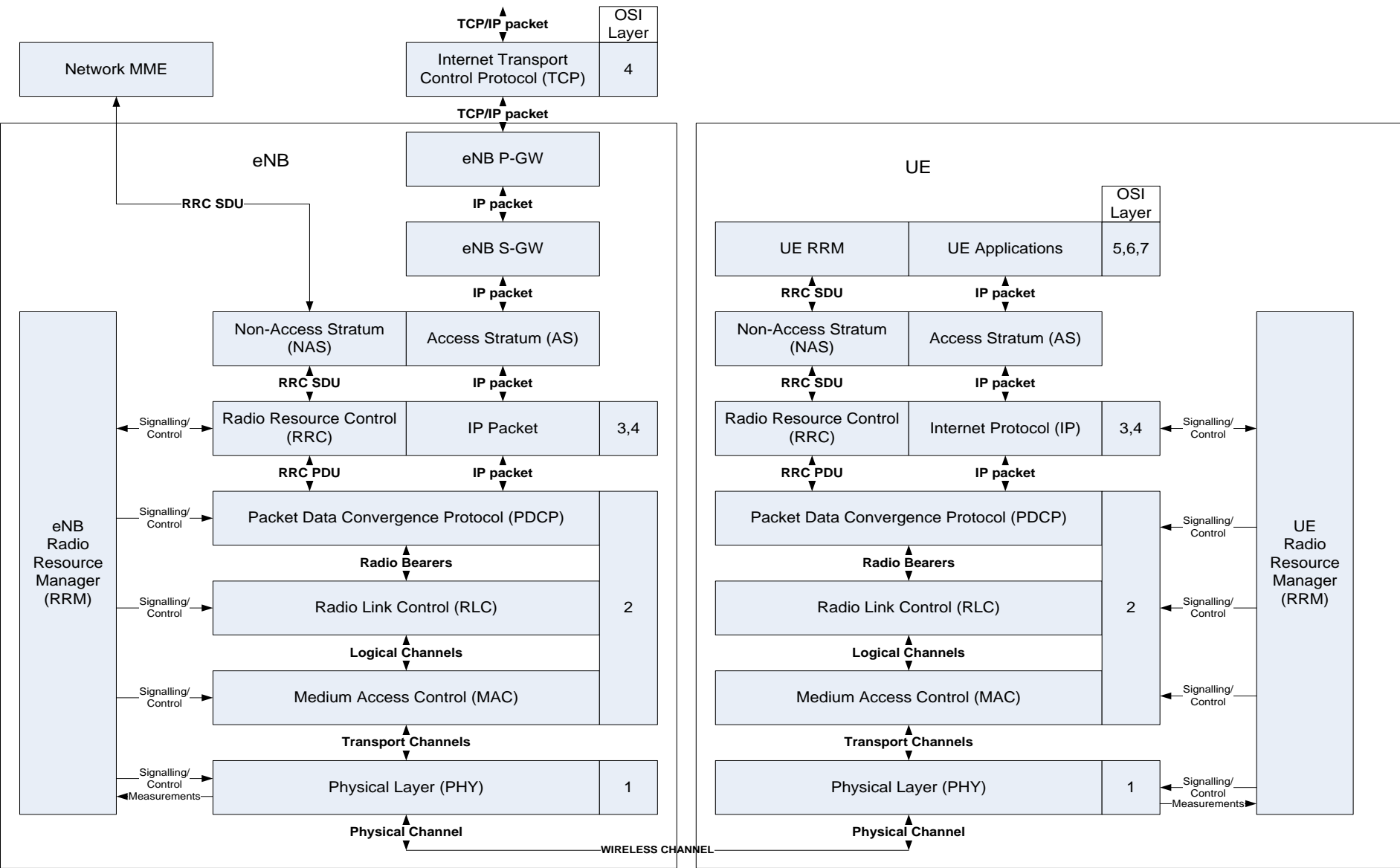
Radio Resource Controller (RRC)

- RRC handles all the NAS messages and its main function is to establish, maintain, modify and release connections.
  - UE state transitions and radio bearer configurations are done at the RRC layer
- RRC messages have high reliability as they use ARQ and HARQ functionality provided by the lower levels (RLC and MAC respectively).
  - At the eNB RRC is responsible for broadcasting the System Information and page UEs
  - At the UE RRC is responsible for PLMN cell selection, cell reselection and Radio Link Failure (RLF) detection
- RRC implements a set of timers that define when certain procedures should be started or terminated
- RRC message structure is encoded using Abstract Sintax Notation One (ASN.1) standardized in ISO 8824, ISO 8825 (3GPP X680, X681, X691)

3.3.3 Packet Data Convergence Protocol

PDCP

E-UTRAN Protocol Layers
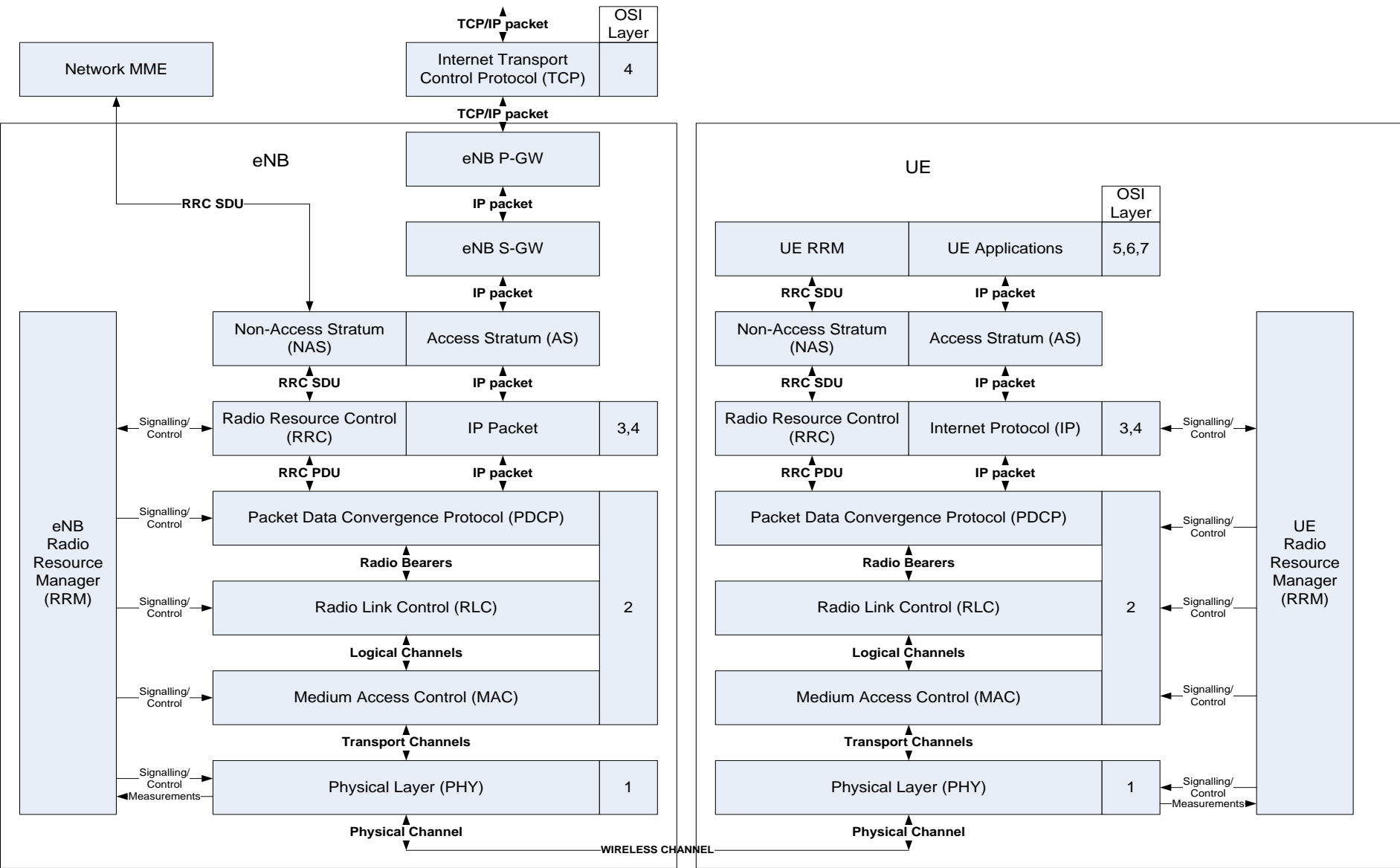
Packet Data Convergence Protocol (PDCP)

- Protocol Architecture
  - Uses different procedures for user and control data
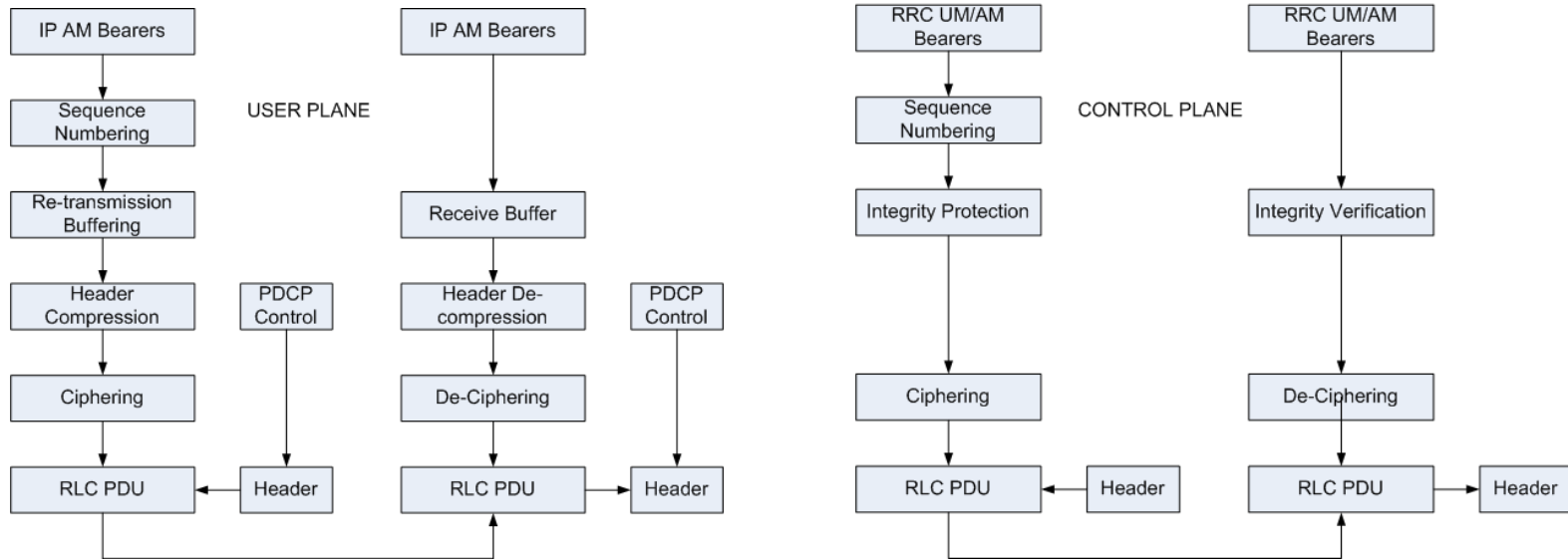
- Header Compression
  - An IP header has from 40 to 60 bytes
  - An VoIP data packet has in average 31 bytes
  - PDCP uses IETF Robust Header Compression (ROHC)
    - The full header is sent in the first packet
    - Following packets send only the header differences (1 to 3 bytes)
- Ciphering and integrity protection
- Prevention of Packet Loss During Handover
  - eNBs exchange PDCP data about sent packets, stored packets and received confirmations

Packet Data Convergence Protocol (PDCP)

- PDCP has different functionalities for NAS and AS messages
  - In the NAS it is responsible for ciphering and integrity protection of control plane messages
  - In the AS it is responsible for IP header compression according to RFC 3095 from IETF (Internet Engineering task Force) Robust Header Compression (ROHC)
- There is one PDCP entity per radio bearer configured for an UE
- PDCP AS header overhead can be 1 or 2 bytes wide, depending if the PDCP sequence number is 7 or 12 bit wide
- PDCP check the messages sequence number and if some sequences are missing it notifies the lower level.
- IP header compression reduces the IP header from 40 bits for IPV4 and 80 bits for IPv6 to few bits

| PDCP PDU | n | n+1 | n+2 | n+3 |

| PDCP SDU RLC PDU | PDCP Header | n | PDCP Header | n+1 | PDCP Header | n+2 | PDCP Header | n+3 |
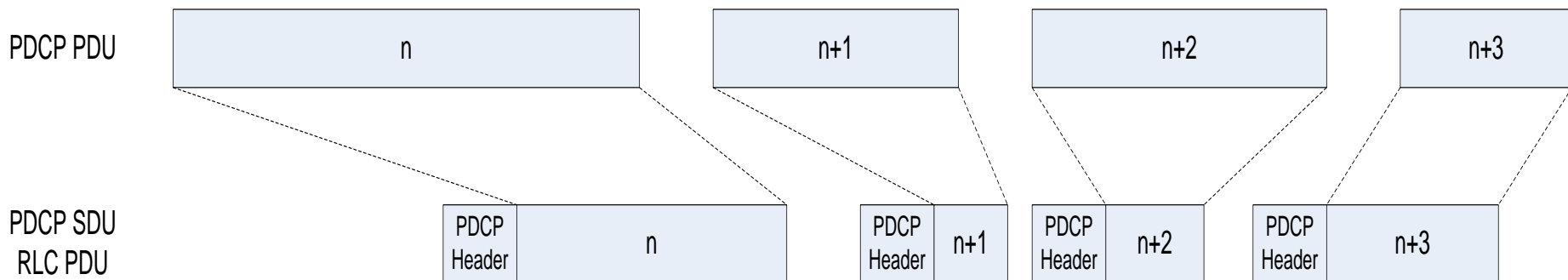
3.3.4 Radio Link Controller

RLC

E-UTRAN Protocol Layers
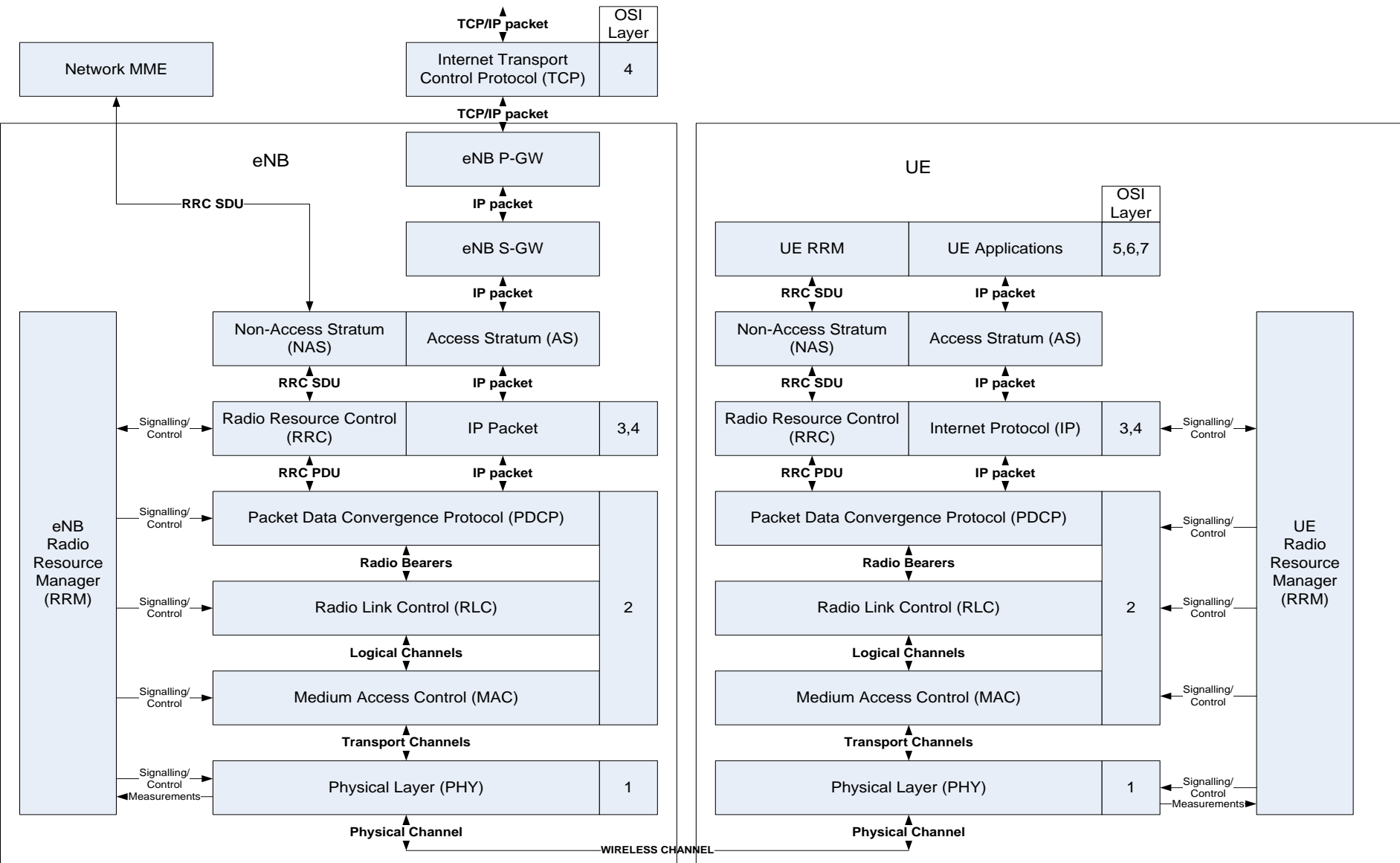
Radio Link Controller (RLC)

- Protocol Architecture
  - Is responsible for the layer 2 data link integrity between eNB and UE
  - Operates in three modes
  - Transparent Mode ™
    - System Information, Paging Messages and Paging Control Messages
    - Messages are sent to MAC without any overhead
  - Unacknowledged mode (UM)
    - Handles data streams to which timely delivery is more important than reliability, like VoIP and streaming video
    - MAC requests PDUs of a certain size and the RLC is responsible for segmentation and concatenation of data Payloads
    - RLC is responsible for packet sequence
      - RLC uses HARQ process to achieve this goal
  - Acknowledged mode (AM)
    - Similar to UM mode, but it is also responsible for data integrity
    - Transmitted data is stored in a re-transmission buffer until a receipt acknowledgement is received
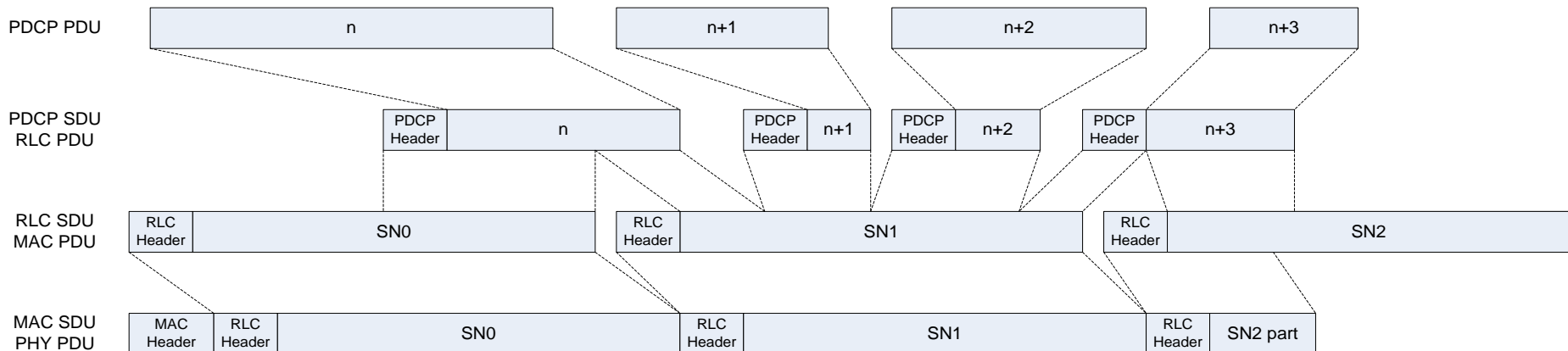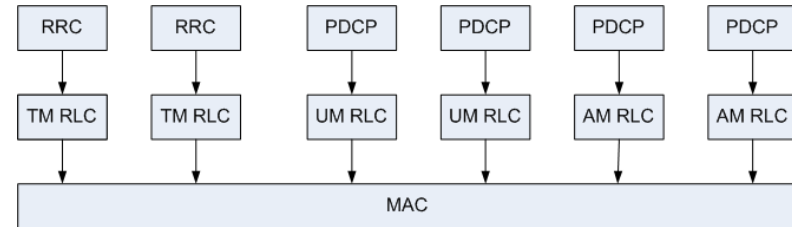
3.3.4 Medium Access Controller

MAC

E-UTRAN Protocol Layers
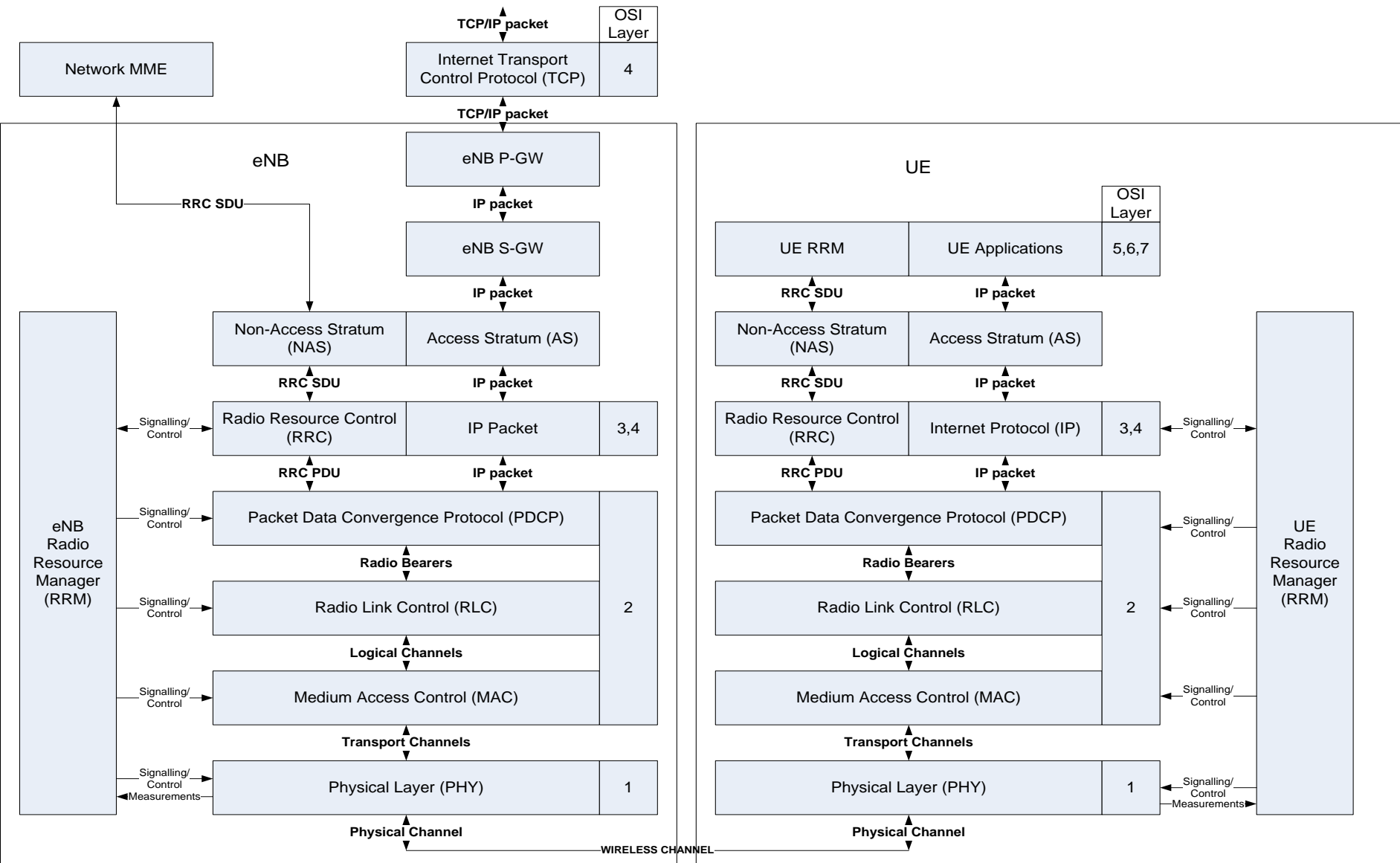
Medium Access Controller (MAC)

- RLC PDUs represent logical channels, which are mapped by MAC to transport channels
- MAC can also segment and concatenate RLC PDUs, but for this to happen there must be availability of several RLC PDUs destined to the same UE
- MAC is responsible for the HARQ (Hybrid ARQ) process
- UE MAC is responsible to convey information about the uplink buffer status and the uplink power headroom.
- MAC is responsible for the random access procedures and timing alignment procedures in the uplink
- MAC can concatenate and disaggregate PDCP packets, to better use the transmission opportunity
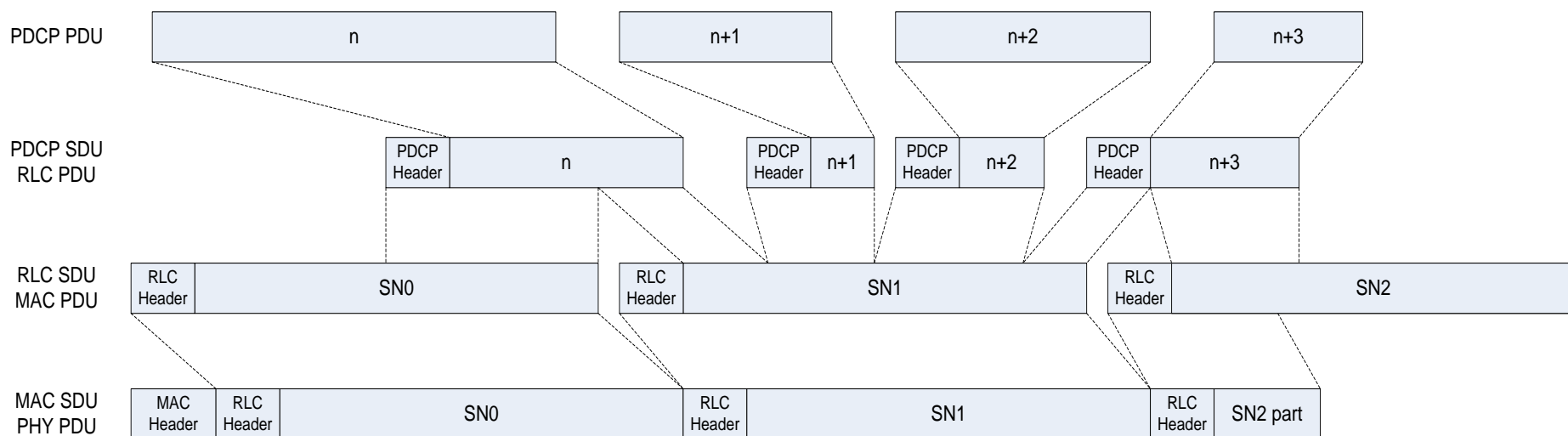
3.3.5 Physical Layer

PHY
Transmission Modes
PDCC Coding Rate
MCS
TBS

E-UTRAN Protocol Layers
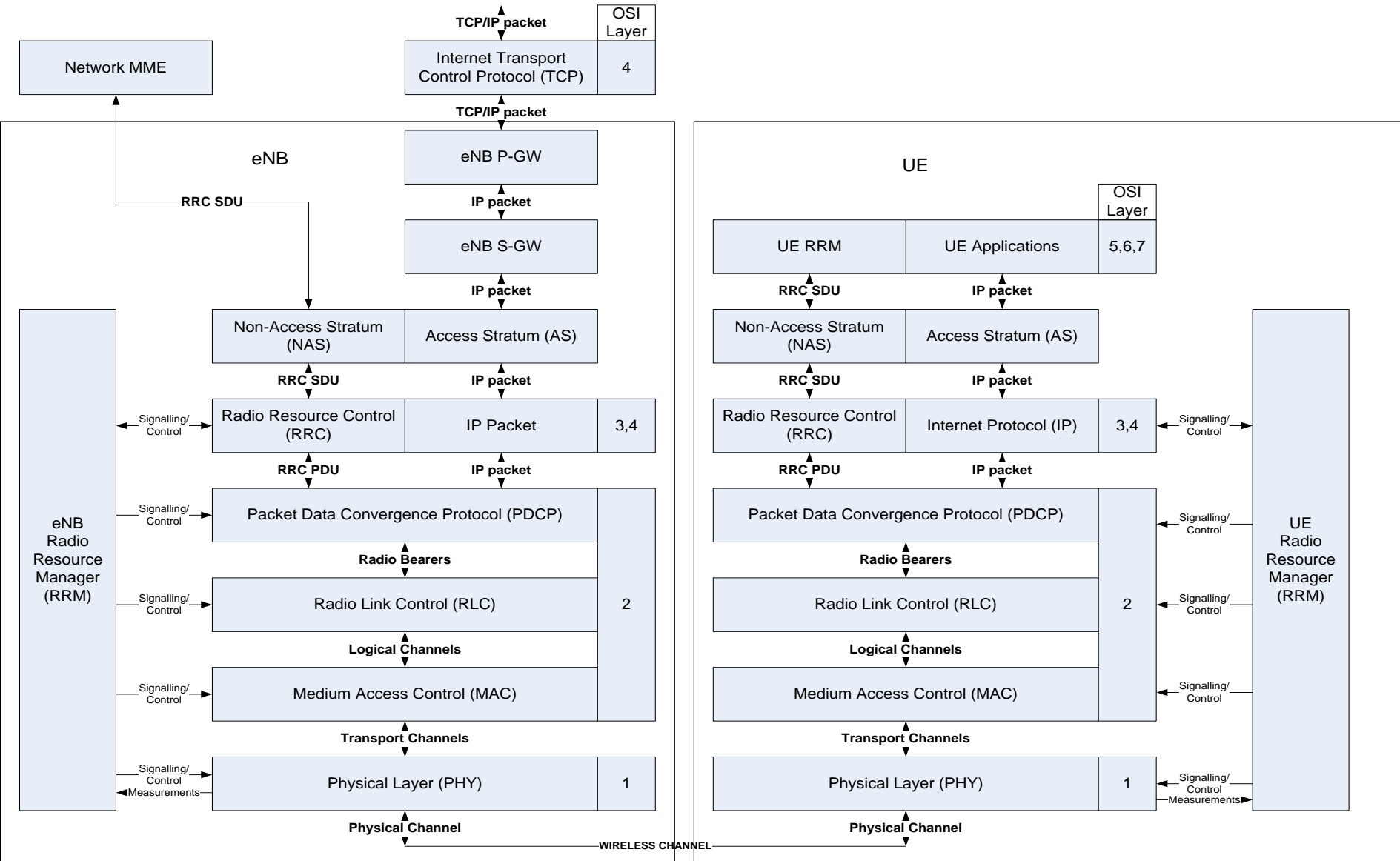
Physical Layer (PHY)

- The PHY layer receives from the MAC layer a wireless packet as a Transport Block (TB)

- All wireless transmissions must start and finish inside a Transmission Time Interval (TTI), which corresponds to a sub-frame and has duration of 1 ms

- The subframe is divided in two blocks of symbols:
  - The first 1 to 3 symbols carry what is called by 3GPP as control information, but basically corresponds to mapping information of the data portion
  - The remaining symbols carry the data, being it NAS signaling or AS user data

- The control area carries the mapping information for the data being sent in the downlink in the same TTI and mapping for the uplink data to be sent 4 TTI's later (FDD)

- It is important to note that the in FDD the downlink and uplink frames are synchronized at the Base Station

- The UE has gathered enough information from the System Information Broadcasts (SIBs) to fully understand the eNB downlink and uplink frame organization
  - This allows the UE to work in tune with the eNB

Frame Organization

- **Downlink**
  - Control area
  - Data area

- **Uplink**
  - Control area
  - RACH area
  - Data area

- **Transmit Time Interval (TTI)**
  - Data packet has to be transfered inside a TTI period
  - Several packets can be transfered within the same TTI
  - The downlink control area maps the data location in the data area for downlink and uplink
  - Control information location has to be found through blind search by the UE

Downlink

| Subframe 0 | Subframe 1 | Subframe 2 | Subframe 3 | Subframe 4 | Subframe 5 | Subframe 6 | Subframe 7 | Subframe 8 | Subframe 9 |

map   map   map

| Subframe 0 | Subframe 1 | Subframe 2 | Subframe 3 | Subframe 4 | Subframe 5 | Subframe 6 | Subframe 7 | Subframe 8 | Subframe 9 |
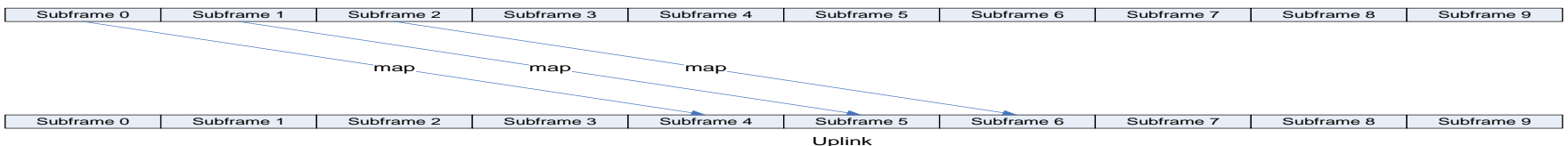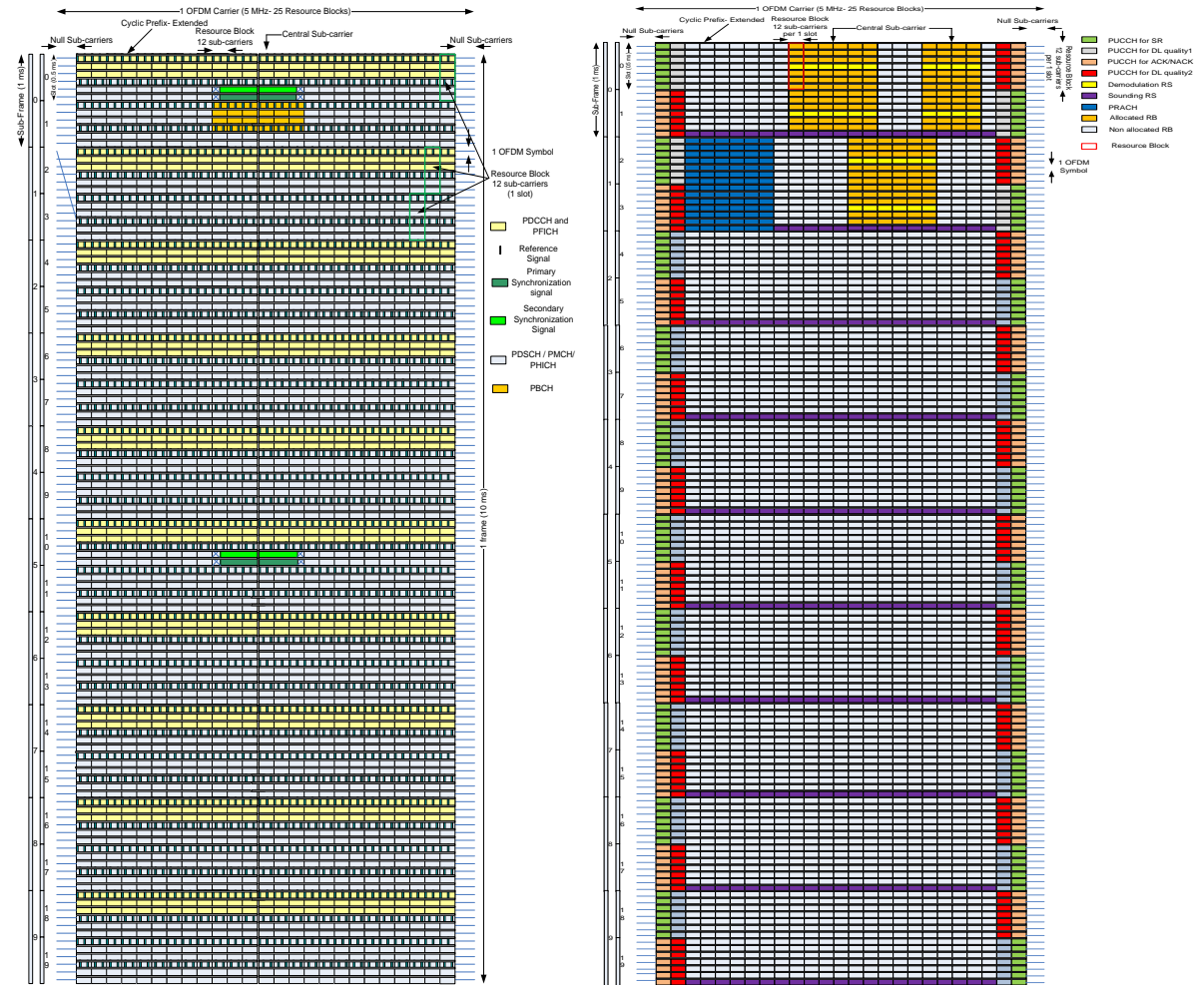
Uplink

3.3.5.1 Transmission Modes

Transmission Modes

- LTE specifies 9 Transmission Modes (TM) for the downlink and 2 for the uplink
  - Each transmission mode has different mapping (control) requirements, so 11 Dowlnik Control Information (DCI) formats are specified and asociated to the different modes
    - The purpose of this variety of DCIs is to save bits whenever possible, to achieve higher throughputs (bit scrubbing)

Mode	PDSCH Transmission Mode (using C-RNTI to address UE)	DCI Format	Search Space	Channel State Information (UE feedback)	Antenna Ports	Release
1	Single antenna port (port 0)	1A	Common and UE specific	CQI		8
		1	UE specific		0	
2	Transmit Diversity	1A	Common and UE specific	CQI	0, (0,1), (0,1,2,3)	8
		1	UE specific			
3	Transmit Diversity	1A	Common and UE specific	CQI, RI	0, (0,1), (0,1,2,3)	8
	Open Loop Spatial Multiplexing or Transmit Diversity	2A	UE specific			
4	Transmit Diversity	1A	Common and UE specific	CQI, RI, PMI	0, (0,1), (0,1,2,3)	8
	Closed Loop Spatial Multiplexing or Transmit Diversity	2	UE specific			
5	Transmit Diversity	1A	Common and UE specific	CQI, PMI	0, (0,1), (0,1,2,3)	8
	Multi-user MIMO	1D	UE specific			
6	Transmit Diversity	1A	Common and UE specific	CQI, PMI	0, (0,1), (0,1,2,3)	8
	Closed Loop Spatial Multiplexing using Single Transmission Layer	1B	UE specific			
7	Single antenna port (port 0) or Transmit Diversity	1A	Common and UE specific	CQI	0, (0,1), (0,1,2,3)	8
	Single antenna port (port 5)	1	UE specific			
8	Single antenna port (port 0) or Transmit Diversity	1A	Common and UE specific	CQI	0, (0,1), (0,1,2,3)	9
	Dual layer transmission or single antenna port (port 7 and 8)	2B	UE specific	PMI, RI if instructed by eNB	7,8	
9	Single antenna port (port 0) or Transmit Diversity	1A	Common and UE specific	CQI	0, (0,1), (0,1,2,3)	10
	Up to 8 layers transmission (port 7 to 14)	2C	UE specific	PTI, PMI, RI if instructed by eNB	(7,8,9,10), (7 to 14)	

Mode	PUSCH Transmission Scheme	DCI Format	Search Space	Antenna Ports	Release
1	Single Antenna port	0	Common and UE specific	10	8
2	Single Antenna port	0	Common and UE specific	10	10
	Closed Loop Spatial Multiplexing	4	UE specific	(20,21), (40,41,42,43)	

3.3.5.2 PHY PDCCH Control (Mapping) Resource Allocation

PDCCH

DCI

| Transmission Mode | → | Downlink Control Information (DCI) Format | → | Physical Downlink Control Channel (PDCCH) Data Mapping Info | → | PDCCH Format Coding Rate | → | Number of Common Channel Elements (CCE) |

LTE Frame Downlink

- Example on left: 5 MHz Bandwidth
- Subcarrier Width: 15 kHz
  - Central subcarrier
  - Null subcarriers
- Frame: 10 ms
  - Subframe: 1 ms
  - Slot: 0.5 ms
  - Symbol: 66.67 µs
  - Normal Cyclic Prefix: 5.2/ 4.7 µs
    - (1.4 km)
  - Extended Cyclic Prefix: 16.7 µs
    - (5 km)
- Resource Element
  - 1 subcarrier x 1 symbol
- Resource Block
  - 12 subcarriers x 1 slot
- Transmission Time Interval
  - 1 subframe
- Central Sub-carrier is not used
- Allocation
  - Green: Secondary Synchronization
  - Red : Primary Synchronization
  - Orange: Master Information Block
  - Yellow: Control/Signalling
  - Reference Signals: Blue
  - Light Blue: Data and Control/Signalling

Legend:
- PFICH/ PHICH/ PDCCH
- PBCH
- PDSCH / PMCH
- Primary Synchronization Signal
- Secondary Synchronization Signal
- Reference Signal — Cyclic Prefix

PHY PDCCH Control (Mapping) Resource Allocation

- The eNB has chosen and informed the UE of the transmission modes to be used between them
  - This is during the RRC Connection set-up, RRC Connection Reconfiguration or RRC Connection re-establishment process
  - There are 9 modes for the downlink and 2 modes in the uplink
  - A transmission mode does support more than one transmission capability which is adapted according to the type of information and the channel quality
  - The reasons for so many transmission modes are the different combinations of transmit diversity, spatial multiplexing, beamforming and MU-MIMO.
- Each mode defines the Downlink Control Information (DCI) format to be used in the control channel
  - There are 11 DCI formats for the downlink mapping and 2 DCI formats for the uplink mapping, which are associated with the transmission modes
  - The reason for so many DCI formats is the requirement of minimizing the size of the DCI, so it can be heavily repeated, as there is no protection against interference

Physical Layer (PHY)

- The DCI information in the TTI control area has to be blindly detected by the UE, as there is no mapping for it
  - Based on the downlink frame organization the UE can figure out the control data transmission location possibilities and has to try all of the locations to verify if data is being broadcasted or sent specifically to it
  - This is done by analyzing a 16 bit CRC added to the DCI format and is scrambled by the destination temporary identity
  - The channel used to convey the control information (DCI) is called Physical Downlink Control Channel (PDCCH)
  - The CRC is scrambled with the appropriate destination RNTI avoiding the need of an additional address field
- The control data transmission possibilities are defined by Control Channel Elements (CCE), a set of 36 in-line Resource Elements each
- The number of CCEs used to send a DCI, depends on the PDCCH format used (there are 4 formats), which defines the coding rate applied to the QPSK modulation.
- UE has to do a blind search of PDCCH locations, by verifying all possible assigned CCEs and decoding the CRC with the temporary IDs assigned
- Once the control information is detected the location of the NAS /AS messages/data can be established

PDCCH Coding Rate

PDCCH Coding Rate				PDCCH Format 0	PDCCH Format 1	PDCCH Format 2	PDCCH Format 3
Number of CCE				1	2	4	8
Number of Quadruplets				9	18	36	72
Number of coded bits				72	144	288	576
DCI Format	Channel Bandwidth (MHz)	DCI data bits	DCI bits after CRC	Spectral Efficiency			
0/ 1A/ 3 /3A	5	35	41	0.569	0.285	0.142	0.071
	10	37	43	0.597	0.299	0.149	0.075
	20	38	44	0.611	0.306	0.153	0.076
1	5	37	43	0.597	0.299	0.149	0.075
	10	41	47	0.653	0.326	0.163	0.082
	20	49	55	0.764	0.382	0.191	0.095
1B	5	37	43	0.597	0.299	0.149	0.075
	10	38	44	0.611	0.306	0.153	0.076
	20	40	46	0.639	0.319	0.160	0.080
1C	5	22	28	0.389	0.194	0.097	0.049
	10	23	29	0.403	0.201	0.101	0.050
	20	25	31	0.431	0.215	0.108	0.054
1D	5	37	43	0.597	0.299	0.149	0.075
	10	38	44	0.611	0.306	0.153	0.076
	20	40	46	0.639	0.319	0.160	0.080
2	5	49	55	0.764	0.382	0.191	0.095
	10	53	59	0.819	0.410	0.205	0.102
	20	61	67	0.931	0.465	0.233	0.116
2A/2B	5	46	52	0.722	0.361	0.181	0.090
	10	51	57	0.792	0.396	0.198	0.099
	20	58	64	0.889	0.444	0.222	0.111
2C	5	48	54	0.750	0.375	0.188	0.094
	10	52	58	0.806	0.403	0.201	0.101
	20	60	66	0.917	0.458	0.229	0.115
4	5	44	50	0.694	0.347	0.174	0.087
	10	46	52	0.722	0.361	0.181	0.090
	20	48	54	0.750	0.375	0.188	0.094

Coding Rate	Equivalent Repetition	SNR gain (dB)
0.05	20.0	13.0
0.06	16.7	12.2
0.07	14.3	11.5
0.08	12.5	11.0
0.09	11.1	10.5
0.10	10.0	10.0
0.12	8.3	9.2
0.14	7.1	8.5
0.16	6.3	8.0
0.18	5.6	7.4
0.20	5.0	7.0
0.22	4.5	6.6
0.24	4.2	6.2
0.26	3.8	5.9
0.28	3.6	5.5
0.30	3.3	5.2
0.32	3.1	4.9
0.33	3.0	4.8
0.34	2.9	4.7
0.36	2.8	4.4
0.38	2.6	4.2
0.40	2.5	4.0
0.42	2.4	3.8
0.44	2.3	3.6
0.46	2.2	3.4
0.48	2.1	3.2
0.50	2.0	3.0
0.55	1.8	2.6
0.60	1.7	2.2
0.65	1.5	1.9
0.70	1.4	1.5
0.75	1.3	1.2
0.80	1.3	1.0
0.85	1.2	0.7
0.90	1.1	0.5
0.95	1.1	0.2
1.00	1.0	0.0

3.3.5.3 PHY PDSCH Resource Allocation

PDSCH

MCS

TBS

| Transport Block | → | Code Blocks | → | MCS TBS index | → | TBP | → | PDSCH format | → | TBG Allocation | → | Code Words | → | DCI mapping |

LTE Frame Downlink

- Example on left: 5 MHz Bandwidth
- Subcarrier Width: 15 kHz
  - Central subcarrier
  - Null subcarriers
- Frame: 10 ms
  - Subframe: 1 ms
  - Slot: 0.5 ms
  - Symbol: 66.67 µs
  - Normal Cyclic Prefix: 5.2/ 4.7 µs
    - (1.4 km)
  - Extended Cyclic Prefix: 16.7 µs
    - (5 km)
- Resource Element
  - 1 subcarrier x 1 symbol
- Resource Block
  - 12 subcarriers x 1 slot
- Transmission Time Interval
  - 1 subframe
- Central Sub-carrier is not used
- Allocation
  - Green: Secondary Synchronization
  - Red : Primary Synchronization
  - Orange: Master Information Block
  - Yellow: Control/Signalling
  - Reference Signals: Blue
  - Light Blue: Data and Control/Signalling

Legend:
- PFICH/ PHICH/ PDCCH
- PBCH
- PDSCH / PMCH
- Primary Synchronization Signal
- Secondary Synchronization Signal
- Reference Signal — Cyclic Prefix

Physical Layer (PHY)

PDCP PDU

| n | n+1 | n+2 | n+3 |

PDCP SDU
RLC PDU

| PDCP Header | n | PDCP Header | n+1 | PDCP Header | n+2 | PDCP Header | n+3 |

RLC SDU
MAC PDU

| RLC Header | SN0 | RLC Header | SN1 | RLC Header | SN2 |

MAC SDU
PHY PDU

| MAC Header | RLC Header | SN0 | RLC Header | SN1 | RLC Header | SN2 part |

| MAC Transport Block | CRC 24 bit |

PHY SDU

| Code Block | CRC 24 bit | Code Block | CRC 24 bit |

PHY PDSCH Resource Allocation

- There are 3 downlink Data Resource Allocation Types and 4 uplink Resource Allocation Types
  - The reason for the different types is to provide some degree of diversity to the data allocation, although the diversity provided is still a cry away from the one provided in WiMAX
- In line with the DCI format bit saving strategy, the size of the Transport Block is not informed directly, instead a convoluted method is used to provide this information.
- 3GPP publishes a table that associates MCS Index to a TBS index (just a mapping)
  - The MCS/TBS index defines the modulation scheme and loosely a coding rate.
  - This table associates then the TBS index and the Number of Resource Blocks (RBs) used to the amount of data being sent in bits
  - To do this it considers as the available number of Resource Elements (RE) in a Resource Block pair (RBP) as being 120 RE
- By standardizing this it is not necessary to inform the TB size to the UE, as the MCS index is informed and the number of RBPs and its location also

Modulation and Coding Scheme (MCS)

- UE does quality measurements and report them through a Channel Quality Indicator (CQI) value (webinar 4)

- eNB uses CQI values as an orientation together with other factors and chooses a MCS to transit to the UE and another to receive from the UE

- MCSs are used to send user data to the UEs

- There are 28 MCS values with the spectral efficiency, expressed i bits/symbol varying from 5.55 to 0.234

- The spectral efficiency is much higher than the one used for the control channel, as it is expected that some interference mitigation measures will be taken, like resource partitioning

CQI	MCS Index	Modulation Sceme	Modulated bit	Coding Rate * 1024	Spectral Efficiency	Coding Gain (dB)	DL Req. SINR (dB) 10% BLER	UL Req. SINR (dB) 10% BLER
2	0	QPSK	2	120	0.234	9.3	-2.8	-2.5
	1	QPSK	2	157	0.307	8.1	-2.5	-2.0
3	2	QPSK	2	193	0.377	7.2	-2.0	-1.4
	3	QPSK	2	251	0.490	6.1	-1.3	-0.4
4	4	QPSK	2	308	0.602	5.2	-0.5	0.0
	5	QPSK	2	379	0.740	4.3	0.5	0.9
5	6	QPSK	2	449	0.877	3.6	0.8	1.9
	7	QPSK	2	526	1.027	2.9	2.0	2.7
6	8	QPSK	2	602	1.176	2.3	2.8	3.2
	9	QPSK	2	679	1.326	1.8	3.8	4.3
	10	QPSK	2	340	1.328	4.8	4.8	5.1
7	11	16QAM	4	378	1.477	4.3	5.0	6.0
	12	16QAM	4	434	1.695	3.7	6.0	7.0
8	13	16QAM	4	490	1.914	3.2	7.0	7.9
	14	16QAM	4	553	2.160	2.7	7.3	8.5
9	15	16QAM	4	616	2.406	2.2	8.3	9.3
	16	16QAM	4	658	2.570	1.9	9.0	9.8
	17	16QAM	4	439	2.572	3.7	10.3	11.0
10	18	16QAM	4	466	2.730	3.4	11.5	11.5
	19	16QAM	4	517	3.029	3.0	11.8	13.5
11	20	16QAM	4	567	3.322	2.6	12.5	14.5
	21	64QAM	6	616	3.609	2.2	13.3	14.3
12	22	64QAM	6	666	3.902	1.9	14.3	15.3
	23	64QAM	6	719	4.213	1.5	15.3	16.3
13	24	64QAM	6	772	4.523	1.2	16.3	17.3
	25	64QAM	6	822	4.816	1.0	16.8	17.8
14	26	64QAM	6	873	5.115	0.7	17.8	18.8
	27	64QAM	6	910	5.332	0.5	18.8	19.8
15	28	64QAM	6	948	5.555	0.3	20.0	21.0

Physical Layer (PHY)

- The TBS table and procedure is the same for the eNB (downlink) and UE (uplink), as it is defined by the eNB for both. In the uplink the size of the TBS is defined by the eNB based on the buffer size report sent in the uplink map. The procedure is the following:

- PHY analyzes the MCS index required for the downlink or uplink transmission to/from an UE

- PHY looks up the Transport Block Table (TBS) for the TBS index associated with the MCS and finds the number of RBs required to send the TB

- If the actual TB size does not find an exact match in the table, the closest larger value is chosen and the remaining bits are padded. This bits will be discarded by the MAC, which carries the exact size of its constituents

- PHY adds a 24 bit CRC to the TB for error detection

- PHY segments the TB in Code Blocks (CB) with a maximum size of 6,120 bits, due to limitations of 6,144 bits in the turbo code implementation

- PHY adds a 24 bit CRC to each CB, resulting in the maximum size of 6,144 bit

- PHY calculates the actual code rate to be used, based on the actual REs available in the RBPs

- The procedure in the receive side (eNB or UE) is the reverse.
  - The actual number of REs available in the RBPs is calculated
  - The total size of the CBs is calculated
  - The coding rate is obtained

Transport Block Size (TBS) Index

- eNB does not inform directly the MCS, but refers to a TBS which can be mapped to a MCS

- Data scrambled by RA-RNTI, SI-RNTI or P-RNTI, considered signalling data, does not use the TBS table and is always QPSK modulated

- TBS index is informed in the DCI message and is uplicable to downlink and uplink allocations (mapping)

- The TBS index is used in conjunction with a TBS table explained next

Downlink

MCS Index	Modulation Order	TBS Index
0	2	0
1	2	1
2	2	2
3	2	3
4	2	4
5	2	5
6	2	6
7	2	7
8	2	8
9	2	9
10	4	9
11	4	10
12	4	11
13	4	12
14	4	13
15	4	14
16	4	15
17	6	15
18	6	16
19	6	17
20	6	18
21	6	19
22	6	20
23	6	21
24	6	22
25	6	23
26	6	24
27	6	25
28	6	26
29	2	
30	4	reserved
31	6	

Uplink

MCS Index	Modulation Order	TBS Index	Redundancy Version
			rv_{idx}
0	2	0	0
1	2	1	0
2	2	2	0
3	2	3	0
4	2	4	0
5	2	5	0
6	2	6	0
7	2	7	0
8	2	8	0
9	2	9	0
10	2	10	0
11	4	10	0
12	4	11	0
13	4	12	0
14	4	13	0
15	4	14	0
16	4	15	0
17	4	16	0
18	4	17	0
19	4	18	0
20	4	19	0
21	6	19	0
22	6	20	0
23	6	21	0
24	6	22	0
25	6	23	0
26	6	24	0
27	6	25	0
28	6	26	0
29			1
30	reserved		2
31			3

Transport Block Size (TBS) Table

- In the TBS Table the TBS index, correponds to a certain modulation and points to arow with the number of bits that should be placed in the number of Transport Blocks (TBs) specified in each column

- This is necessary as the number of bits being sent is not specified in the DCI

- Transport Blocks have different number of available symbols, depending of their location, number of signals and other channels being carried and so the number of bits would vary between RBs

- The TBS table standardizes the number of bits so the eNB and the UE can figure out the number of bits sent, by just analyzing the TBS index and the number of Transport Blocks (pairs) allocated to the transmission

- The exact number of bits is adjusted through the rate matching mecahnism used at the Turbo Code output

- The actual table goes up to 110 RB, while we show an extract up to 16 RBs

I_{TBS}	1	2	3	4	5	6	7	8	9	10	11	12	-----	98	99	100
0	16	32	56	88	120	152	176	208	224	256	288	328	----	2,728	2,728	2,792
1	24	56	88	144	176	208	224	256	328	344	376	424	----	3,624	3,624	3,624
2	32	72	144	176	208	256	296	328	376	424	472	520	----	4,392	4,392	4,584
3	40	104	176	208	256	328	392	440	504	568	616	680	----	5,736	5,736	5,736
4	56	120	208	256	328	408	488	552	632	696	776	840	----	6,968	6,968	7,224
5	72	144	224	328	424	504	600	680	776	872	968	1,032	----	8,760	8,760	8,760
6	328	176	256	392	504	600	712	808	936	1,032	1,128	1,224	----	10,296	10,296	10,296
7	104	224	328	472	584	712	840	968	1,096	1,224	1,320	1,480	----	11,832	12,216	12,216
8	120	256	392	536	680	808	968	1,096	1,256	1,384	1,544	1,672	----	13,536	14,112	14,112
9	136	296	456	616	776	936	1,096	1,256	1,416	1,544	1,736	1,864	----	15,264	15,840	15,840
10	144	328	504	680	872	1,032	1,224	1,384	1,544	1,736	1,928	2,088	----	16,992	17,568	17,568
11	176	376	584	776	1,000	1,192	1,384	1,608	1,800	2,024	2,216	2,408	----	19,848	19,848	19,848
12	208	440	680	904	1,128	1,352	1,608	1,800	2,024	2,280	2,472	2,728	----	22,152	22,920	22,920
13	224	488	744	1,000	1,256	1,544	1,800	2,024	2,280	2,536	2,856	3,112	----	25,456	25,456	25,456
14	256	552	840	1,128	1,416	1,736	1,992	2,280	2,600	2,856	3,112	3,496	----	28,336	28,336	28,336
15	280	600	904	1,224	1,544	1,800	2,152	2,472	2,728	3,112	3,368	3,624	----	30,576	30,576	30,576
16	328	632	968	1,288	1,608	1,928	2,280	2,600	2,984	3,240	3,624	3,880	----	31,704	31,704	32,856
17	336	696	1,064	1,416	1,800	2,152	2,536	2,856	3,240	3,624	4,008	4,392	----	35,160	35,160	36,696
18	376	776	1,160	1,544	1,992	2,344	2,792	3,112	3,624	4,008	4,392	4,776	----	39,232	39,232	39,232
19	408	840	1,288	1,736	2,152	2,600	2,984	3,496	3,880	4,264	4,776	5,160	----	42,368	42,368	43,816
20	440	904	1,384	1,864	2,344	2,792	3,240	3,752	4,136	4,584	5,160	5,544	----	45,352	46,888	46,888
21	488	1,000	1,480	1,992	2,472	2,984	3,496	4,008	4,584	4,968	5,544	5,992	----	48,936	48,936	51,024
22	520	1,064	1,608	2,152	2,664	3,240	3,752	4,264	4,776	5,352	5,992	6,456	----	52,752	52,752	55,056
23	552	1,128	1,736	2,280	2,856	3,496	4,008	4,584	5,160	5,736	6,200	6,968	----	57,336	57,336	57,336
24	584	1,192	1,800	2,408	2,984	3,624	4,264	4,968	5,544	5,992	6,712	7,224	----	59,256	61,664	61,664
25	616	1,256	1,864	2,536	3,112	3,752	4,392	5,160	5,736	6,200	6,968	7,480	----	61,664	63,776	63,776
26	712	1,480	2,216	2,984	3,752	4,392	5,160	5,992	6,712	7,480	8,248	8,760	----	73,712	73,712	75,376

Table of Allocated Resource Blocks

Physical Layer (PHY)

- The procedure in the receive side (eNB or UE) is the reverse
  - The actual number of REs available in the RBPs is calculated
  - The total size of the CBs is calculated
  - The coding rate is obtained
- The acknowledgement that a TB or CB was properly received is sent in a special channel in the downlink, PHCIH (Physical Hybrid-ARQ Indicator Channel) for uplink acknowledgements, and in the uplink PUCCH (Physical Uplink Control Channel)
- Each acknowledgement is modulated using BPSK to generate 3 modulation symbols 000 for negative ACK and 111 for positive ACK
  - These modulation symbols are spread using an appropriate orthogonal sequence. A Spreading Factor (SF) of 4 is used when the cyclic prefix is normal and SF of 2 when the cyclic prefix is extended
- The downlink acknowledgement for uplink data is sent 4 subframes after the transmission and it is assigned to a PHICH group and Orthogonal Sequence Index inside the group
  - This assignment is based on the lowest PRB index assigned to the data transmission, the Demodulation Reference Signal (DMRS) shift signaled within the DCI and the number of PHICH groups defined by the SIBs
- The uplink acknowledgement for downlink data is sent 4 subframes after the transmission and is defined by the PUCCH format used
  - There are 7 formats available

Physical Layer (PHY)

- Up to release 10 only one transport block could be sent to an UE
  - After release 10 up to two transport blocks can be sent to the same UE
- A negative acknowledgement triggers the Hybrid-ARQ process
- There are 3 HARQ types
  - HARQ type 1(Full Redundancy): When a wireless packet (Transport Block or Code Block) is detected in error (CRC does not match), it is discarded and a negative acknowledgement is sent (NACK).
    - The whole packet is then retransmitted
  - HARQ type 2 (Full Incremental Redundancy): When a retransmission is required a different set of code bits is generated and sent
    - The receiver combines the two transmissions obtaining additional parity bits and getting a better probability of correcting the error
  - HARQ type 3 (Partial Incremental Redundancy or Chase Combining): Only additional parity bits are sent, so a stronger code can be formed.

3.4 Downlink Dimensioning and Planning Summary

Planning

Dimensioning

Downlink Planning

- Physical Cell Identity (28 bit or 20+8 bit)
- Primary Synchronization Signal (PSS) (reuse of 3)
- Secondary Synchronization Signal (SSS) (reuse of 168)
  - Consider a reuse of 150
- Cell Reference Signal (CRS) (reuse of 6)
- Uplink Group Base Sequence (GBS) (reuse of 30)

Downlink Dimensioning

- Control Symbols (CFI)
  - Control Format Indicator (CFI 1, 2, or 3)
    - Based on number of Transport Blocks
- ACK/NACK quadruplets
  - PHICH Scaling Factor (1/6, 1/2, 1 or 2)
    - Based on number of Code Blocks
  - PHICH Location (Normal or Extended)
- Control Channel Elements (CCE)
  - Based on Number of Downlink and Uplink Codewords and respective PDCCH formats
- User Traffic
  - Based on number of Resource Block Groups (RBG) used and respective MCS