What LTE parameters need to be Dimensioned and Optimized

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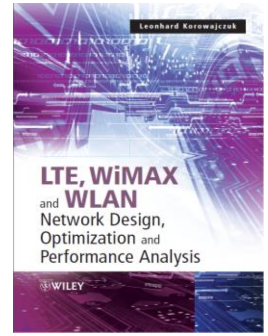
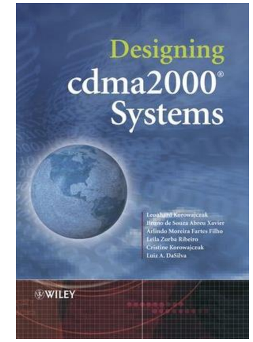
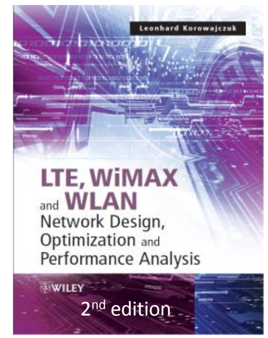
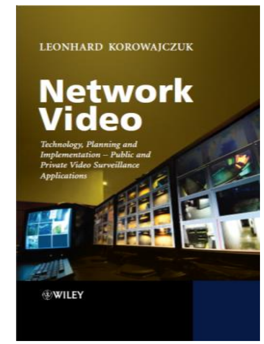
Presenter

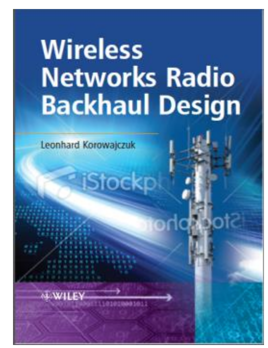
- **Leonhard Korowajczuk**
  - CEO/CTO CelPlan International
  - 45 years of experience in the telecom field (R&D, manufacturing and service areas)
  - Holds13 patents
  - Published books
    - "Designing cdma2000 Systems"
      - published by Wiley in 2006- 963 pages, available in hard cover, e-book 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)

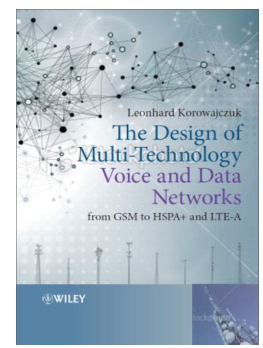












CelPlan International

- 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/ September 17th, 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: 821

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: 430

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: 315

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

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

Participants from 44 countries
Youtube views: 373

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

Webinar 5 (September 3rd, 2014)

What LTE parameters need to be Dimensioned and Optimized

Part 1- Downlink

Participants from 69 countries

Youtube views: 574

Webinar 5 (September 16th, 2014)

What LTE parameters need to be Dimensioned and Optimized

Part 2- Uplink

Today

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
  - This requires 2D and 3D analysis
- 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

Webinar 7
MIMO
What is Real?
What is Wishful Thinking?

November 5th 2014

Registration is open

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 Part 2- Uplink

September 17, 2014

Content

4. Uplink Dimensioning

Random Access

Control and Data

4.1 Random Access Area

Random Access Process

- Random Access is a process used by UEs to access packet networks
  - Ethernet uses Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
  - Wi-Fi uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
- 3GPP specified for LTE uplink a Random Access procedure
- LTE UEs access to the uplink frame is done through a contention process
  - LTE dedicates a portion of the uplink frame for the contention to happen
  - This portion is called Physical Random Access Channel (PRACH)
- In LTE Random Access process is used for:
  - Initial access to eNB: RRC Idle Mode to RRC Connected Mode transition
  - Provide information for eNB to calculate the Timing Advance to be used by the UE
  - Request eNB for uplink resource allocation
  - Complete and intra-system handover
- Random Access parameters are broadcasted by eNB in SIB1 (System information Block 1) and SIB2 (System Information Block 2), which should be read by the UE before accessing the network
  - These parameters should be dimensioned by the network designer

SIB1 Random Access Parameters

SIB 1 parameters for Random Access	
Maximum UE transmit Power	≤ 23 dBm
System Information Periodicity	8, 16, 32, 64, 128, 256, 512 frames
SIB mapping	1 to 32 instances

SIB2 Random Access Parameters

- System Information Block 2, broadcasted Random Access Parameters
  - SIB 2 periodicity is scheduled in SIB 1 (8, 16, 32, 64,128, 256, 512 frames)

PDSCH Configuration	Range
Reference Signal Power	-50 to -60 dBm
Power Boost (P_B)	0 to 3

RACH Configuration	Range	Step
Number of RA Preambles	4 to 64	4
Size of RA Preamble Group A	4 to 60	4
Message Size Group A	56, 144, 208, 256 bit	
Message Power Offset Group B	-∞. 0, 5, 8, 10, 12, 15, 18 dB	
Power Ramping Step	0, 2, 4, 6 dB	
Preamble Initial Received Target Power	-120 to -90 dBm	2 dB
Preamble Maximum Transmissions	3, , 5, 6, 7, 8, 10, 20, 50, 100, 200	
RA Response Window Size	2, 3, 4, 5, 6, 7, 8, 10 subframes	
MAC Contention Resolution Timer	8, 16, 24, 32, 40, 48, 56, 64 subframes	
Maximum HARQ Message Transmissions	1 to 8	1

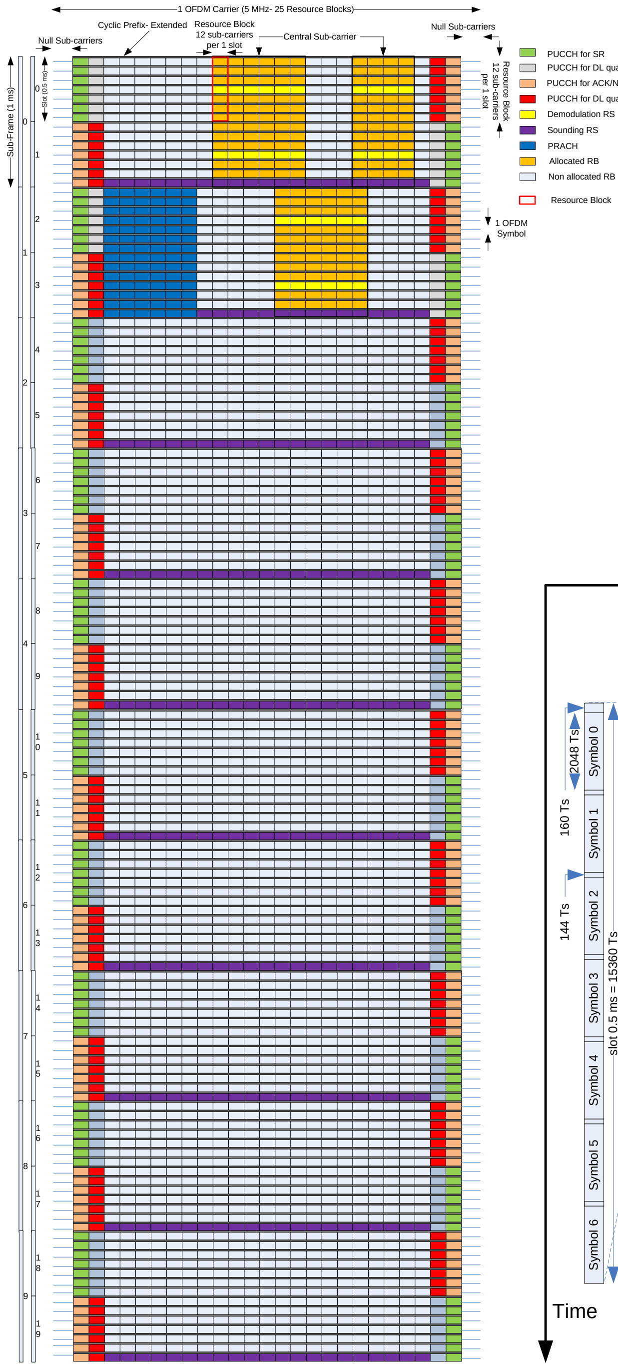
PRACH Configuration Parameters	Range
Root Sequence Index	0 to 837
PRACH Configuration Index	0 to 63
High Speed Flag	true/false
Zero Correlation Zone Configuration	0 to 15
PRACH Frequency Offset	0 to 94 RB

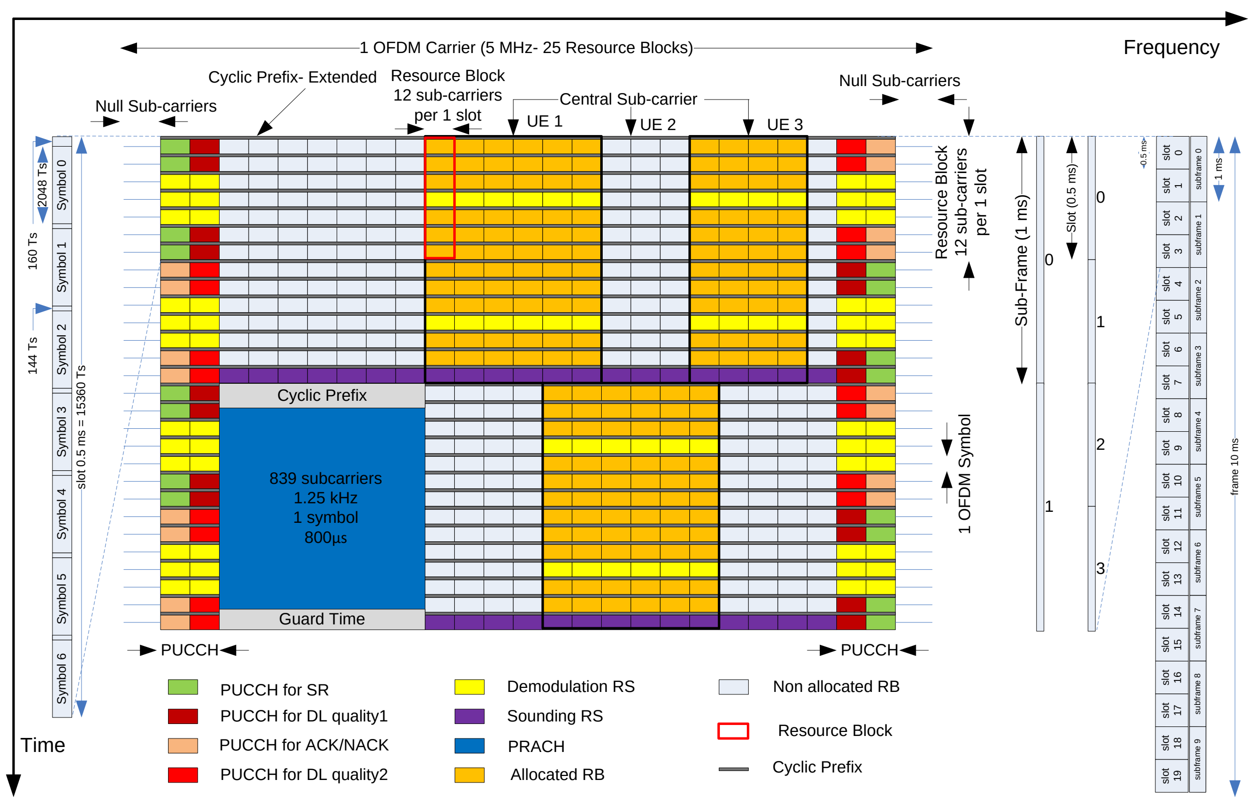
Random Access Area Design

- PRACH area has to accommodate requests from all UEs connected to eNB
- Several UEs will access PRACH at the same time
  - 3GPP designed PRACH to provide 64 codes for simultaneous access
  - The codes do not carry any information besides:
    - An UE is requesting access, has chosen the code it is accessing and requests its timing advance information
- The PRACH area removes capacity from the uplink access
- 3GPP reserved 6 PRBs x 1 to 3 subframes for the Random Access
  - The uplink frame is formed at the eNB antenna by the contribution of UEs that are accessing it at that time
  - UEs assume that they are close to the eNB when accessing PRACH, so they transmit based synchronized in time with when they receive the eNB transmitted downlink frame
  - UEs transmissions will arrive delayed in time, proportionally to its distance to eNB (2 µs per 300 m)
    - An UE at 3 km from cell center, will arrive with a delay of 20 µs
  - The orthogonal codes should accommodate this delay, so 3GPP selected the Zadoff-Chu code for the access
  - A Zadoff-Chu (ZC) sequence is orthogonal to its time shifted sequences, although ZC sequences are not orthogonal between themselves
- 3GPP had to consider:
  - A Cyclic Prefix (CP)area that would accommodate the round trip between eNB and UE
  - A Preamble (P) area that would carry the Zadoff-Chu code
  - A Guard Time (GT)at the end of the symbol that would avoid interference outside the subframe
- The basic PRACH was designed for a cell range of 15 km, which leads to a CP and GT of approximately 100 µs
- This left inside the subframe 800 µs for the Preamble symbol, which corresponds to a symbol width in frequency of 1.25 KHz

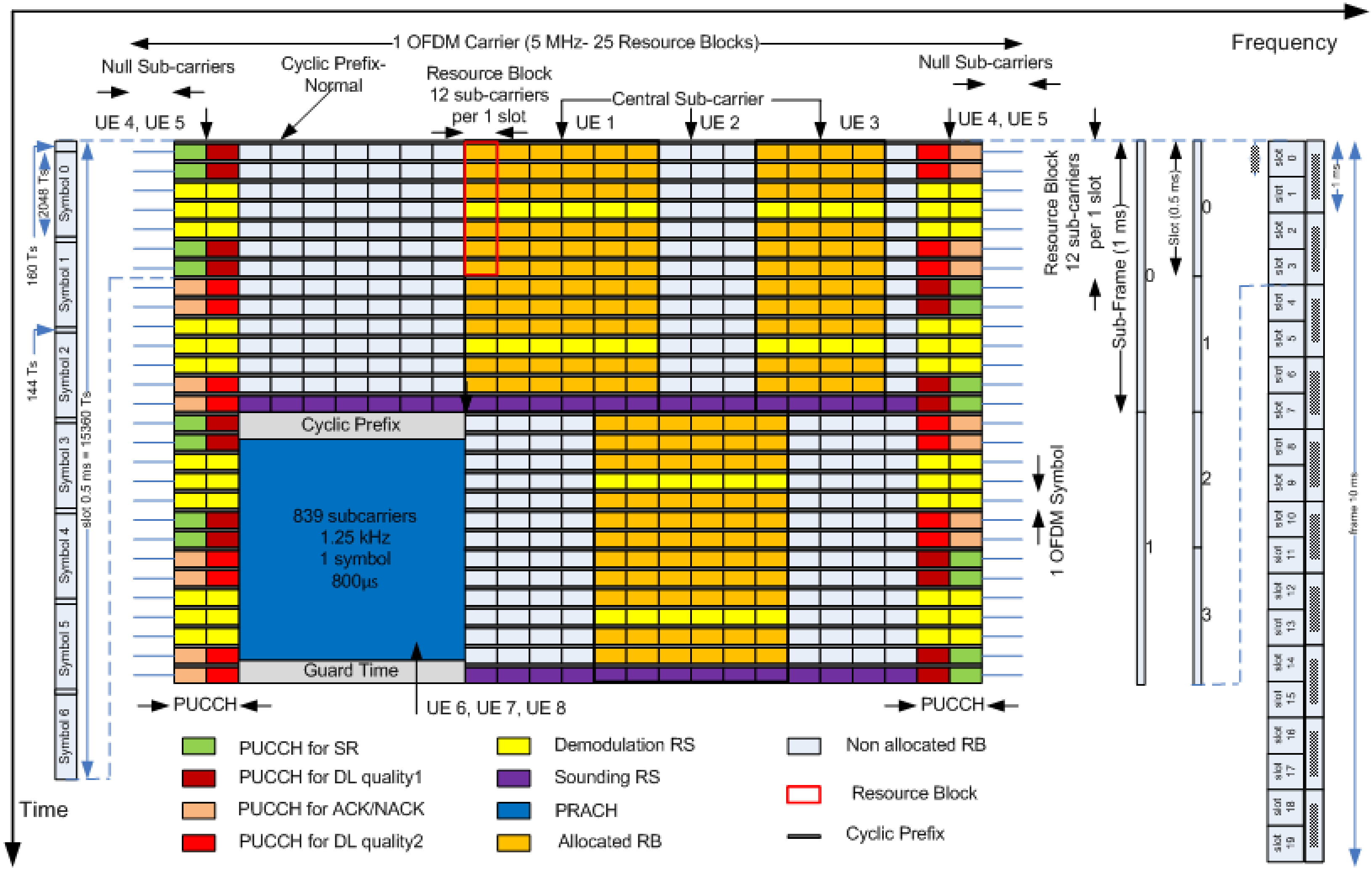
LTE Frame UL

- Allocation
  - Green: Control
  - Light Red: DL Quality 1
  - Orange: ACK/NACK
  - Red: DL Quality 2
  - Blue: Random Access
  - Light Blue: Not Used
  - Orange: Assigned Subcarriers





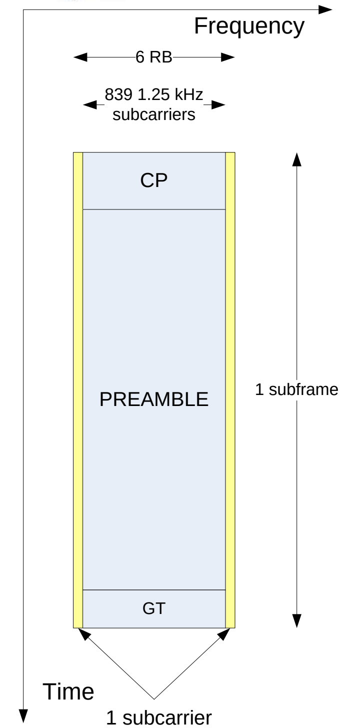
PRACH



1 OFDM Carrier (5 MHz- 25 Resource Blocks)
Frequency
Null Sub-carriers
Cyclic Prefix-Normal
Resource Block 12 sub-carriers per 1 slot
Central Sub-carrier
Null Sub-carriers
UE 4, UE 5
UE 1
UE 2
UE 3
UE 4, UE 5
Cyclic Prefix
839 subcarriers
1.25 kHz
1 symbol
800µs
Guard Time
PUCCH
UE 6, UE 7, UE 8
PUCCH
Resource Block 12 sub-carriers per 1 slot
Sub-Frame (1 ms)
1 OFDM Symbol
Symbol 0
Symbol 1
Symbol 2
Symbol 3
Symbol 4
Symbol 5
Symbol 6
2048 Ts
160 Ts
144 Ts
slot 0.5 ms = 15360 Ts
Time
PUCCH for SR
PUCCH for DL quality1
PUCCH for ACK/NACK
PUCCH for DL quality2
Demodulation RS
Sounding RS
PRACH
Allocated RB
Non allocated RB
Resource Block
Cyclic Prefix

Random Access Area Design

- 3GPP specifies 5 Formats for the PRACH area, denominated PRACH Configuration Indexes (PRACHCI)
- To accommodate larger cells a 2 and 3 subframes formats were created
- In some of the formats the preamble symbol is repeated twice, so it can be more easily detected
- The last format was developed for small TDD cells, allocating PRACH during the TDD special frames

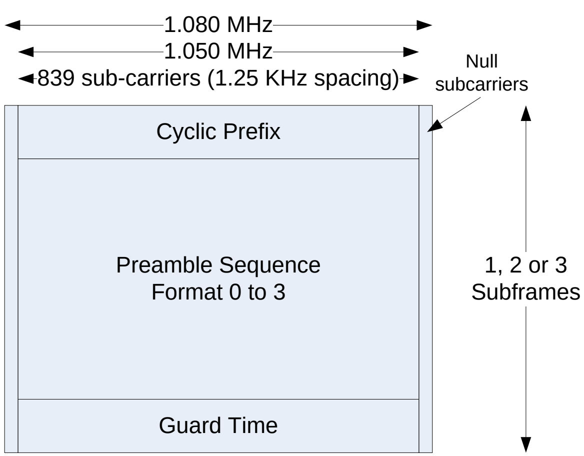


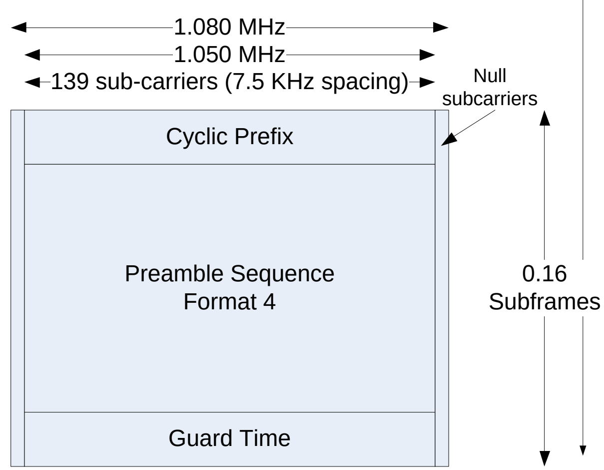
Number of Root Sequences	
Preamble Formats 0 to 3	Preamble Format 4
838	138

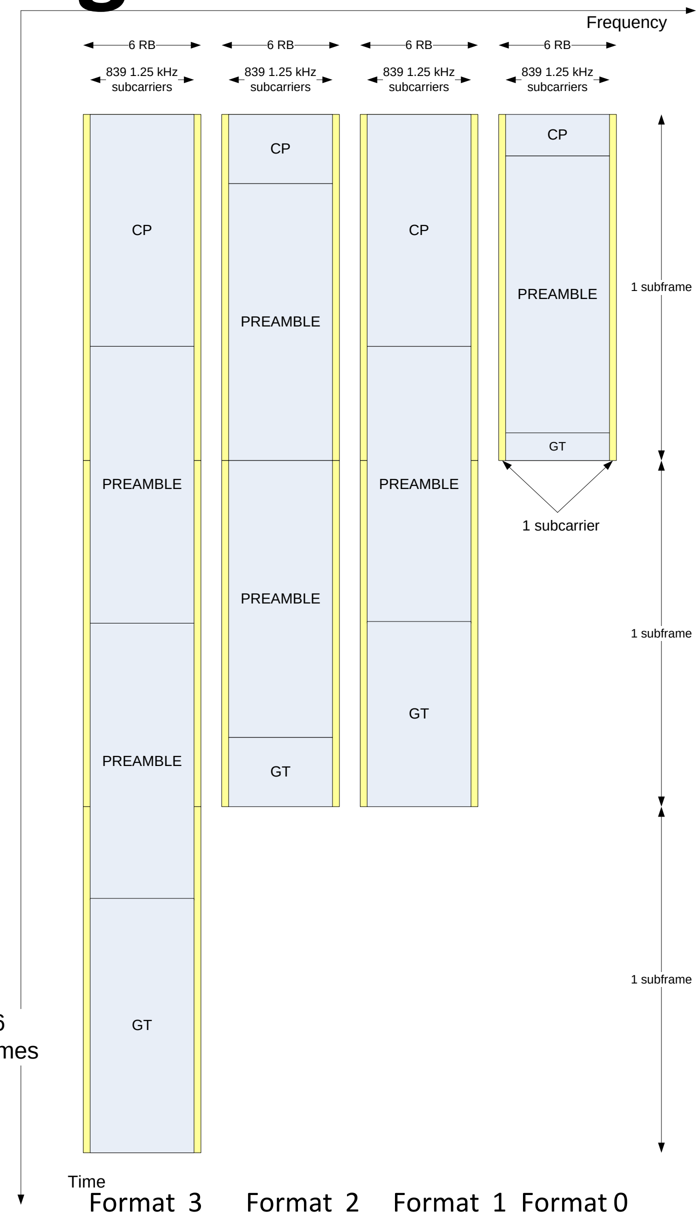
Preamble Format	Duplex	RACH sub-carriers	Sub-carrier width (kHz)	Total width (kHz)	Cell sub-carriers	RBs	PRACH CP (µs)	PRACH Symbols	Sequence (us)	Guard Time (µs)	Total duration (µs)	Sub-frames	Maximum Cell Range (km)	Cell size
0	FDD & TDD	839	1.25	1,049	69.92	6	103.13	1	800	96.88	1000	1	14.5	medium cells
1	FDD & TDD	839	1.25	1,049	69.92	6	684.38	1	800	515.63	2000	2	77.3	very large cells
2	FDD & TDD	839	1.25	1,049	69.92	6	203.13	2	1600	196.88	2000	2	29.5	large cells
3	FDD & TDD	839	1.25	1,049	69.92	6	684.38	2	1600	715.63	3000	3	107.3	extra large cells
4	TDD	139	7.5	1,043	69.50	6	14.58	0.17	133.33	9.38	157	0.16	1.4	small cells

Random Access Area Design

- The picture on the left depicts respectively the PRACH Configuration indexes 3, 2, 1 and 0
- The picture below depicts the dimensions of the PRACH area in frequency and time

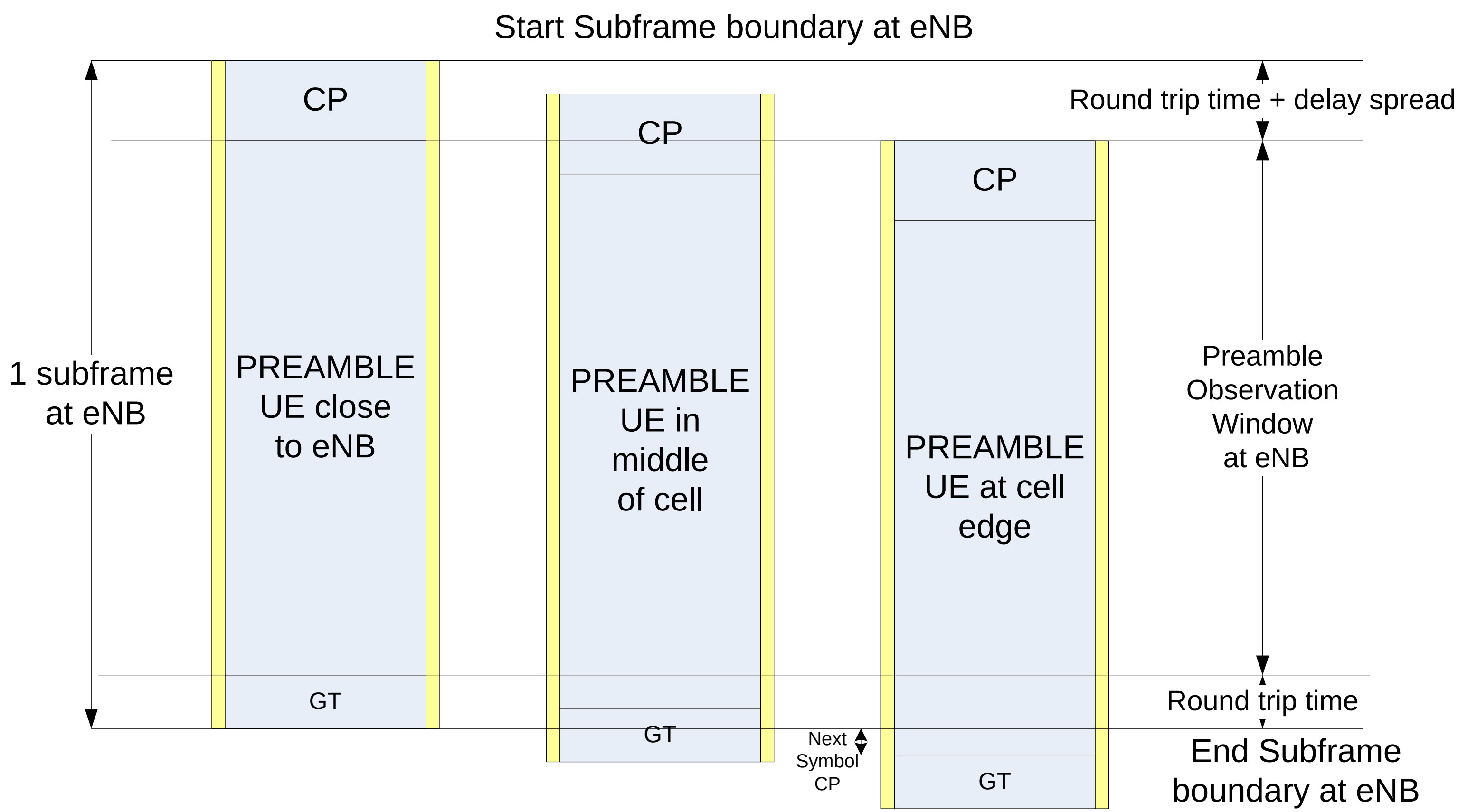






Preamble Detection

- eNB detects the preamble based on a fixed window that initiates a cyclic prefix after the subframe boundary
- This implies that UEs that are distant from eNB will be detected with a phase shift proportional to the UE distance from cell center
- This cell shift should be considered when allocating Random Area codes



RA area according to 3GPP

- 3GPP choose the Zadoff-Chu (ZC) code to provide orthogonallity
  - A ZC code is orthogonal to its shifted copies
  - Different ZC codes are not fully orthogonal
  - ZC code travel time adds to the original shift
- Neighbor cells should use different orthogonal codes to avoid intercell interference
- 3GPP assumed that a cell should have 64 codes available for random access, that the maximum cell radius supported is 120 km and that a reuse of 12 should be sufficient to avoid interference
  - The 120 km lead to a symbol size of 800 µs, equivalent to a sub-carrier spacing of 1.25 kHz
  - The number of subcarriers should be at least 64*12= 768, which would require 6 regular RBs, which could accommodate in theory 864 subcarriers
  - 3GPP choose 839 subcarriers and consequently 838 ZC code shifts
  - A cyclic prefix has to be added to the beginning of the RA symbol and a guard time at the end of it to accommodate for the travel time to the UE
- 3GPP standardized the Random Access area as 6 Resource Blocks wide (in frequency), with a duration of 1, 2 or 3 subframes
  - 1,080 KHz by 1, 2 or 3 ms

4.1.1 Random Access Procedure

Part 1

Random Access

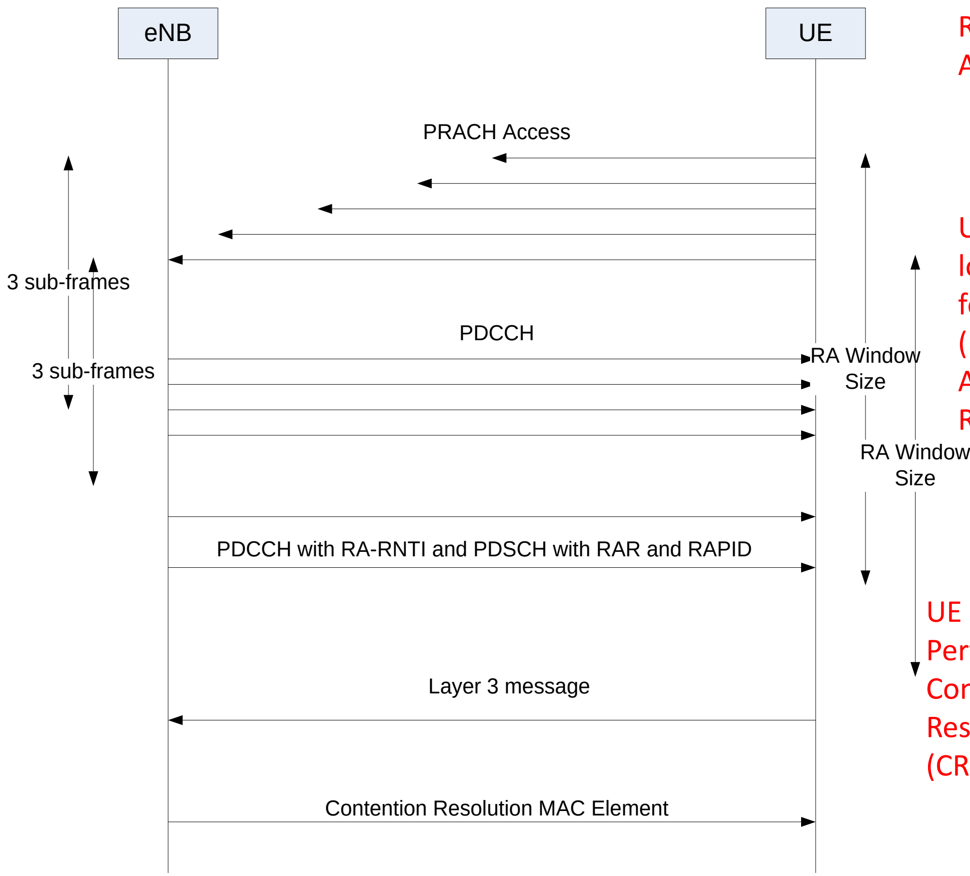
LTE Random Access Procedure

- An UE starts the access targeting an RX Receive Power Level specified in SIB2 and if no reply is received it increases the level by a step size specified in SIB2
  - RX Power level: -120 to -90 dBm (designer dimensioned), with a ramping step size of 0, 2, 4, 6 dB (designer dimensioned)
- The maximum number of UE access tries is specified in SIB2
  - 3, 4, 5, 6, 7, 8, 10, 20, 50, 100, 200 (designer dimensioned)
- UE should expect a reply to its random access from the eNB in a SIB2 specified window in subframes after the UE access
  - Response window size in subframes: 2, 3, 4, 5, 6, 7, 8, 10

RACH Configuration in SIB 2	Range	Step
Number of RA Preambles	4 to 64	4
Size of RA Preamble Group A	4 to 60	4
Message Size Group A	56, 144, 208, 256 bit	
Message Power Offset Group B	-∞. 0, 5, 8, 10, 12, 15, 18 dB	
Power Ramping Step	0, 2, 4, 6 dB	
Preamble Initial Received Target Power	-120 to -90 dBm	2 dB
Preamble Maximum Transmissions	3, , 5, 6, 7, 8, 10, 20, 50, 100, 200	
RA Response Window Size	2, 3, 4, 5, 6, 7, 8, 10 subframes	

Random Access Procedure

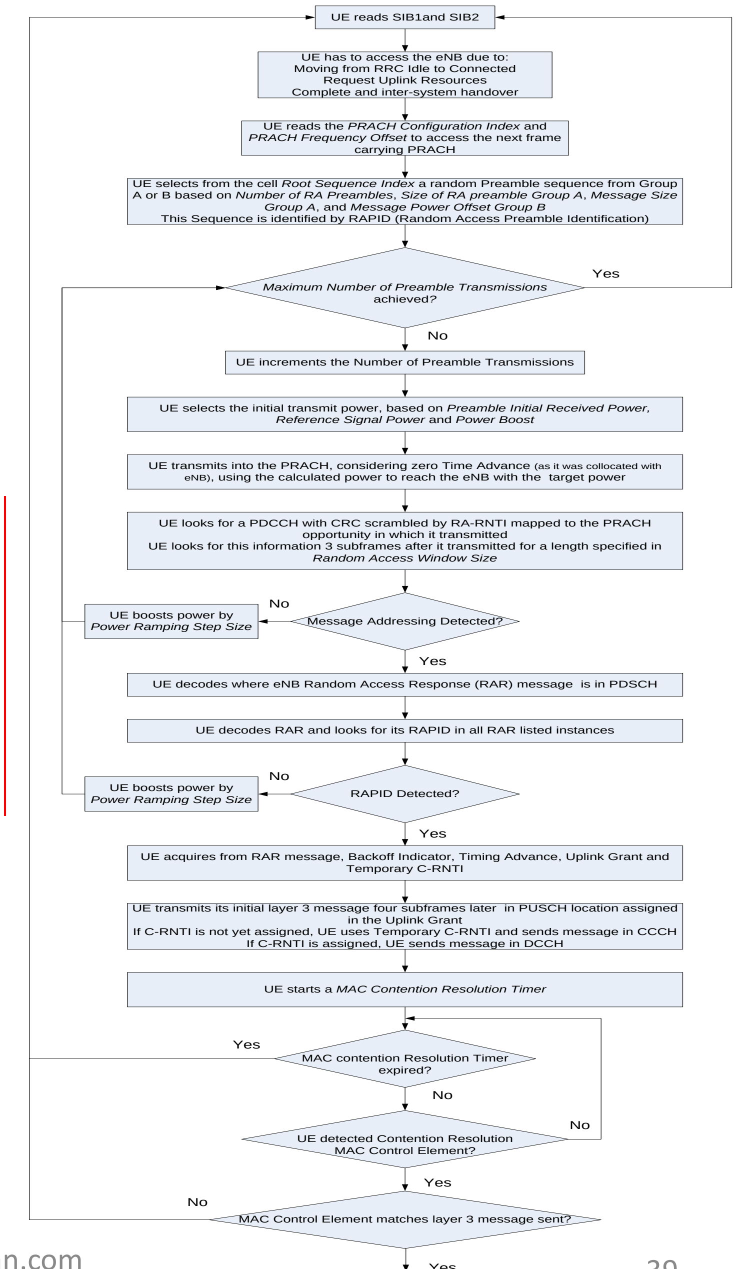
- Procedure Flow
  1. UE Performs Random Access
  2. UE Looks for eNB RAR message
  3. UE Performs Contention Resolution
- Messages Sequence



UE Performs Random Access

UE looks for RAR (Random Access Response)

UE Performs Contention Resolution (CR)

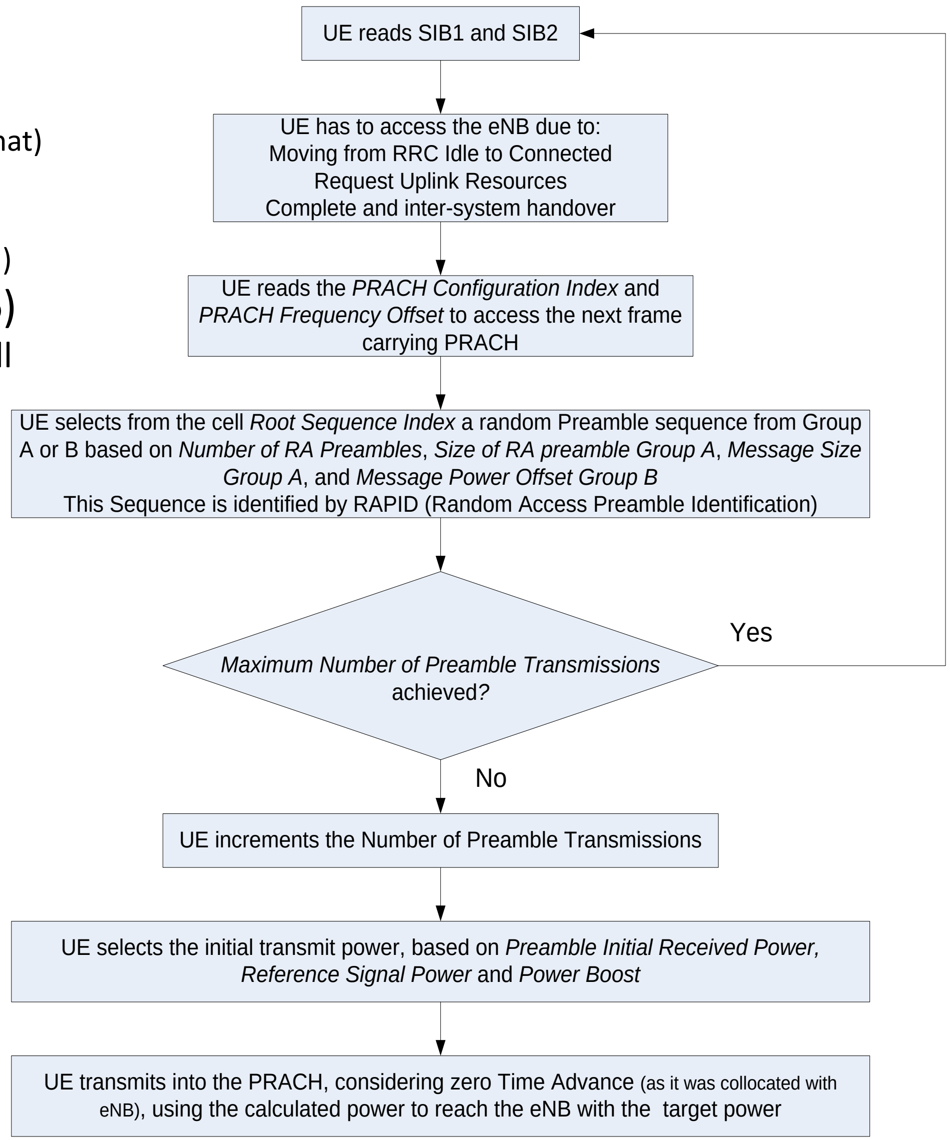


Random Access Procedure

- Parameters
  - PRACH Configuration Index (0 to 63)
    - Preamble Format (0 to 4)
      - Cell Range
    - Preamble Density (0.5 to 10 per frame)
      - Traffic
    - Preamble Version (up to 16 configurations per format)
      - Subframe Numbers (1 to 5 subframes per frame)
  - PRACH Frequency Offset
    - Location in a subframe (0 to 94, adjacent to PUCCH)
  - Zero Correlation Zone (0 to 15) or (0 to 6)
    - Number of Root Sequences required per cell
      - 1 shift ≈ cell range of 143 m
      - High Speed Flag (≥200 km/h)
  - Root Sequence Index
    - Preambles Format 0 to 3: 838
    - Preamble Format 4: 138
  - Random Sequence Group
    - Group A (4 to 60)
      - Small Message Size or poor coverage
    - Group B (4 to 64)
      - Large Message Size and good coverage
    - Non Contention Group

PRACH Configuration Parameters	Range
Root Sequence Index	0 to 837
PRACH Configuration Index	0 to 63
High Speed Flag	true/false
Zero Correlation Zone Configuration	0 to 15/ 0 to 6
PRACH Frequency Offset	0 to 94 RB

UE Performs Random Access



4.1.2 Physical Random Access Channel (PRACH)

RACH
PRACH Format
Configuration Index
Frequency Offset
Zero Correlation Zone
High Speed Flag
Root Sequence Index

4.1.2.1 Random Access Channel

RACH

Random Access Channel (RACH)

- RACH is a transport channel used to transfer Random Access Preamble Control information between MAC and PHY
- RACH does not transfer any higher layer messages
- PHY is responsible for:
  - Calculate PRACH transmit power
  - Select Preamble Sequence
  - Transmit PRACH

PRACH Transmit Power

- SIB 2 parameters

Power Ramping Step	0, 2, 4, 6 dB	
Preamble Initial Received Target Power	-120 to -90 dBm	2 dB
Preamble Maximum Transmissions	3, , 5, 6, 7, 8, 10, 20, 50, 100, 200	

- Power Calculation

$$PRACH\ Preamble\ Transmit\ Power = \min(Pcmax, PL + Preamble\ RX\ Target\ Power)$$

$$\begin{aligned} Preamble\ Rx\ Target\ Power \\ &= Preamble\ Initial\ Received\ Target\ Power + Delta\ Preamble \\ &+ (Preamble\ Transmission\ counter - 1) * Power\ Ramping\ Step \end{aligned}$$

- PL: Downlink Path Loss
- P_{cmax}= UE maximum transmit power
- Delta Preamble= 0 dB for Preamble Format 0 and 1
- Delta Preamble= -3 dB for Preamble Format 2 and 3

Physical Random Access Channel (PRACH)

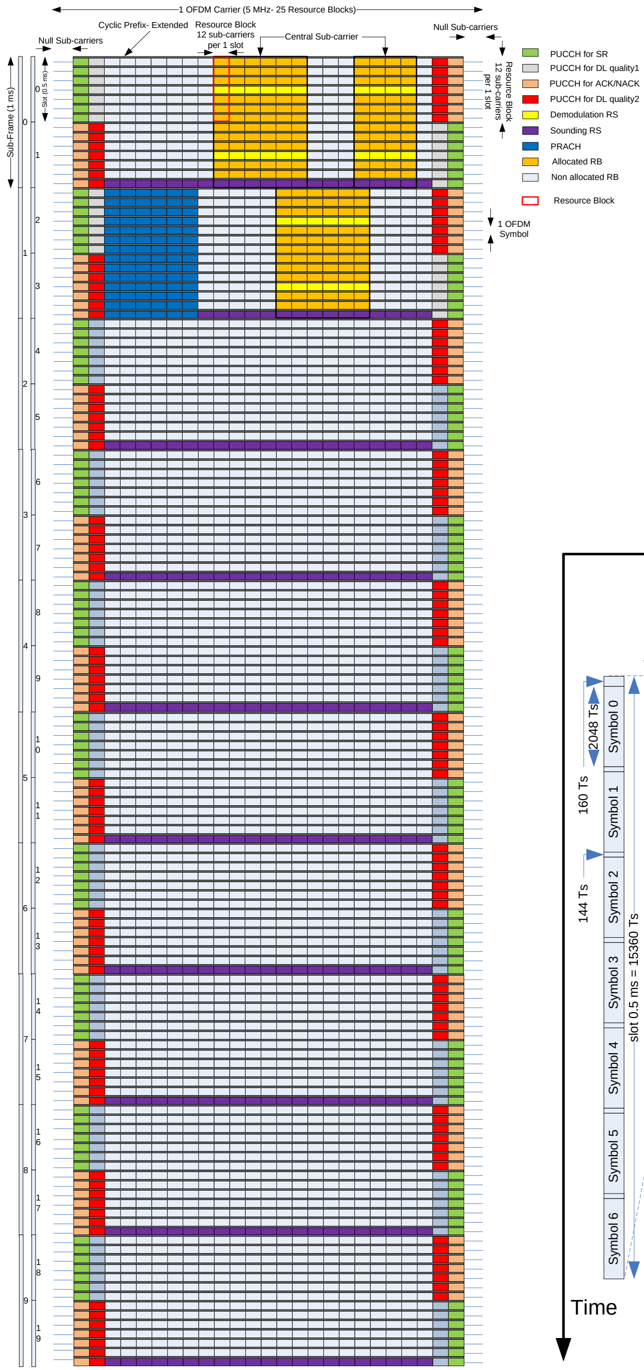
- Preamble Format (PF)
- Root Sequence Index (RSI)
  - RSI can be calculated after the following parameters are defined:
    - PRACH Configuration Index
    - Zero Correlation Zone Value
    - High Mobility Flag
  - PRACH configuration index defines the number of sequences required (from 836 or 138)
  - Zero Correlation Zone Value defines the number of sequences required by each cell
  - High Mobility Flag defines if Doppler effect has to be taken into account
- The planning tool should then allocate the required number of sequences using logical sequence numbering
  - The logical numbering can then be mapped according a table in 3GPP TS 36.211

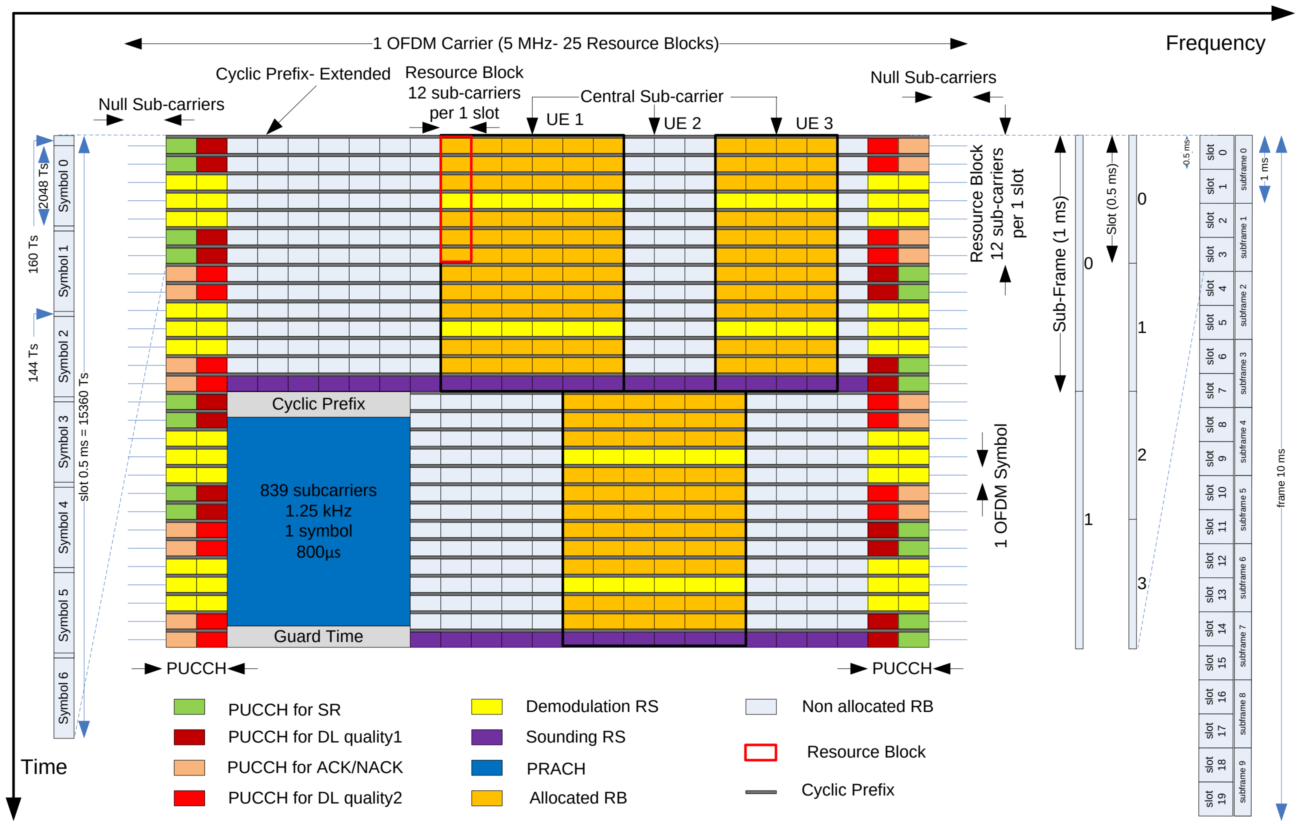
4.1.2.2 Physical Random Access Channel Format

PRACH Format

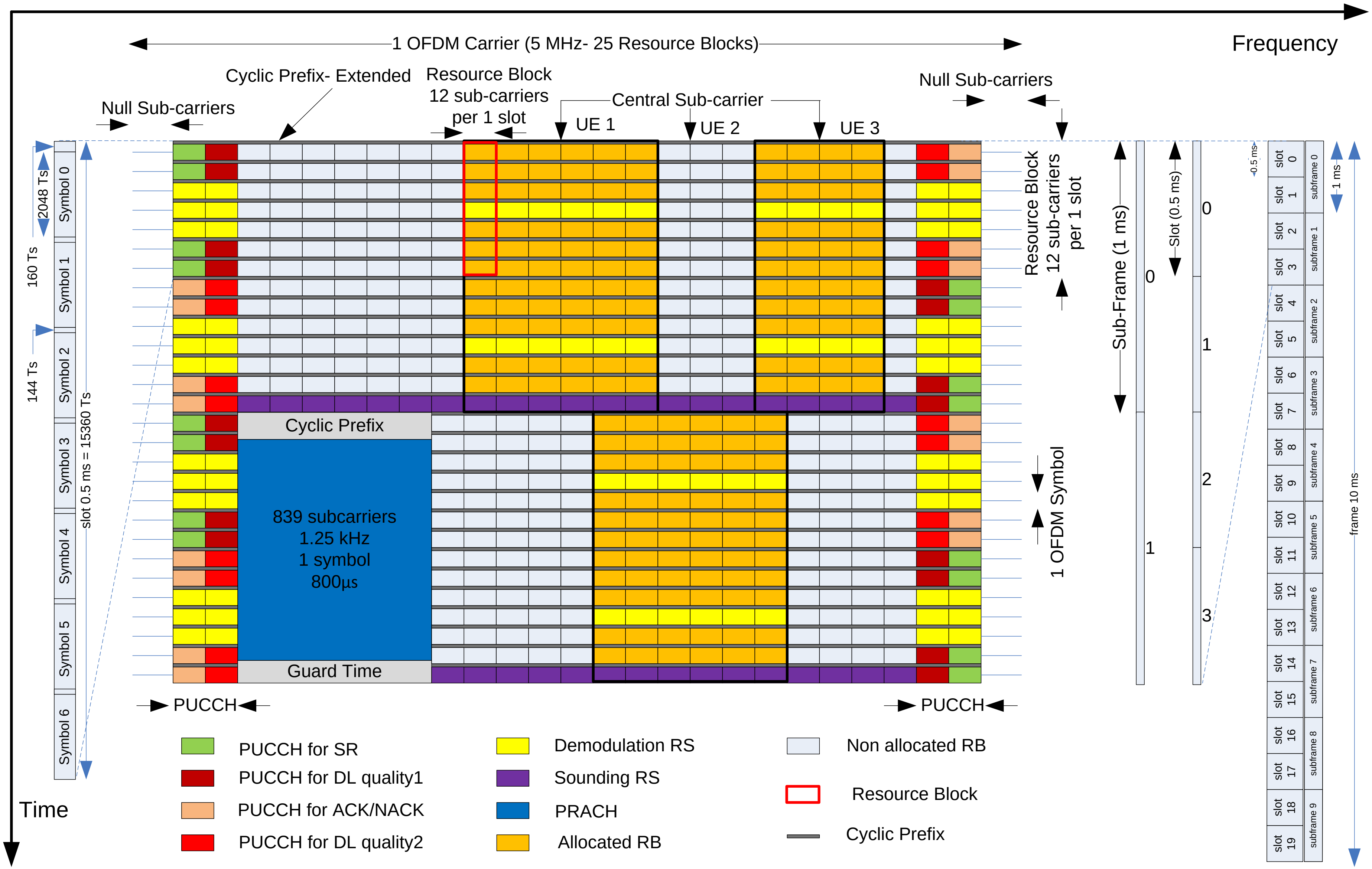
LTE Frame UL

- Allocation
  - Green: Control
  - Light Red: DL Quality 1
  - Orange: ACK/NACK
  - Red: DL Quality 2
  - Blue: Random Access
  - Light Blue: Not Used
  - Orange: Assigned Subcarriers





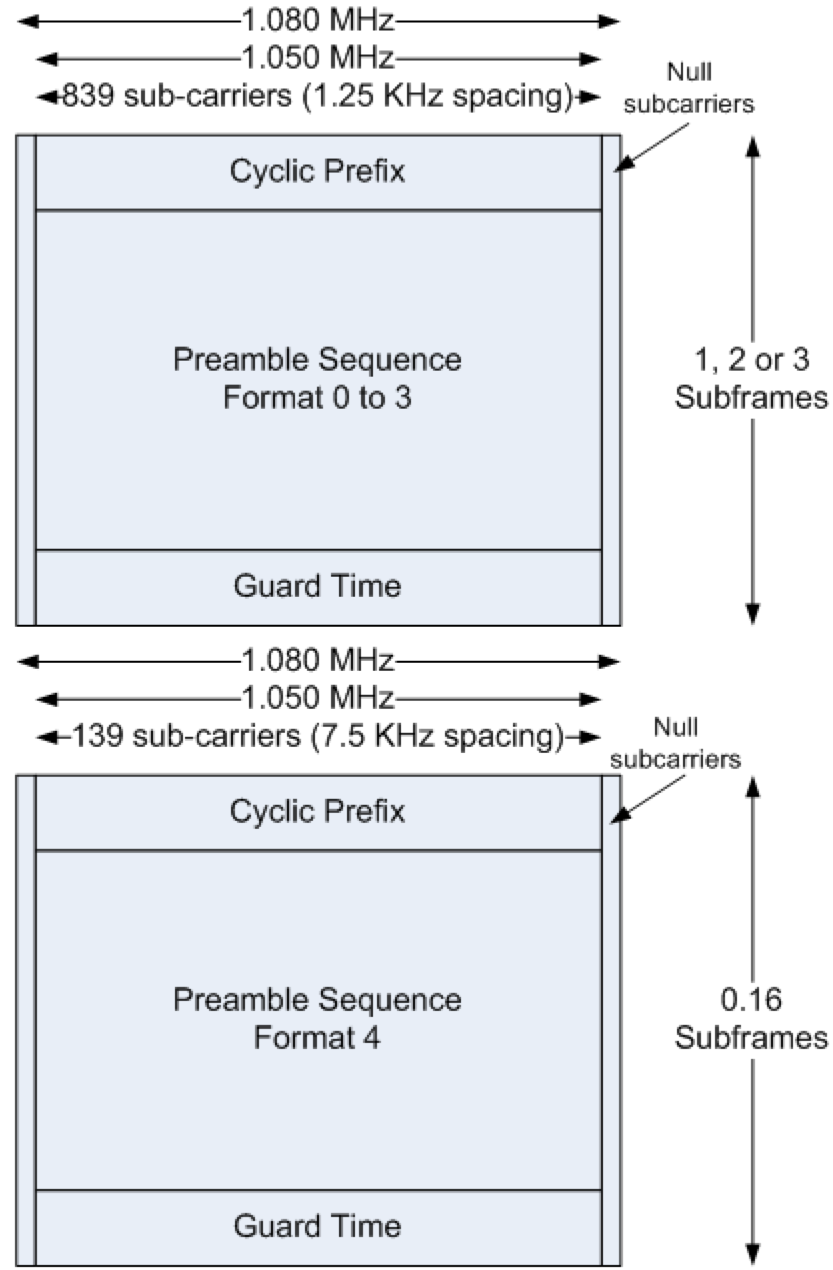
PRACH



1 OFDM Carrier (5 MHz- 25 Resource Blocks)
Frequency
Cyclic Prefix- Extended
Resource Block
12 sub-carriers
per 1 slot
Central Sub-carrier
Null Sub-carriers
Null Sub-carriers
UE 1
UE 2
UE 3
Symbol 0
Symbol 1
Symbol 2
Symbol 3
Symbol 4
Symbol 5
Symbol 6
2048 Ts
160 Ts
144 Ts
slot 0.5 ms = 15360 Ts
Cyclic Prefix
839 subcarriers
1.25 kHz
1 symbol
800µs
Guard Time
PUCCH
PUCCH
Resource Block
12 sub-carriers
per 1 slot
1 OFDM Symbol
Sub-Frame (1 ms)
Slot (0.5 ms)
0.5 ms
1 ms
frame 10 ms
Time
PUCCH for SR
PUCCH for DL quality1
PUCCH for ACK/NACK
PUCCH for DL quality2
Demodulation RS
Sounding RS
PRACH
Allocated RB
Non allocated RB
Resource Block
Cyclic Prefix

Physical Random Access Channel (PRACH) 1

- PRACH is used to transfer random access preambles to initiate network access procedure
  - PRACH does not transfer any RRC or application data
  - It is performed when:
    - UE wakes up from sleep mode
    - UE performs handoff
    - UE losses uplink timing synchronization
- UE has to acquire network synchronization and System Information before trying to access the system
  - Network defines frame and sub-frames used for Random Access (RA)
    - A bandwidth of 72 regular sub-carriers (six RB) are reserved for RA
    - One to three sub-frames are reserved for RA
- PRACH structure includes:
  - A Cyclic Prefix
  - A Preamble Sequence
  - A Guard Time



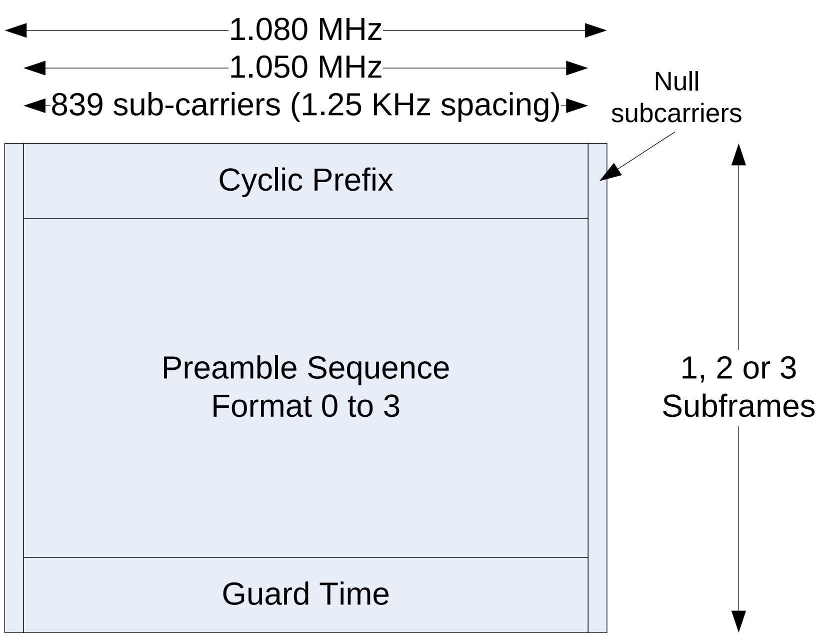
Physical Random Access Channel (PRACH) 2

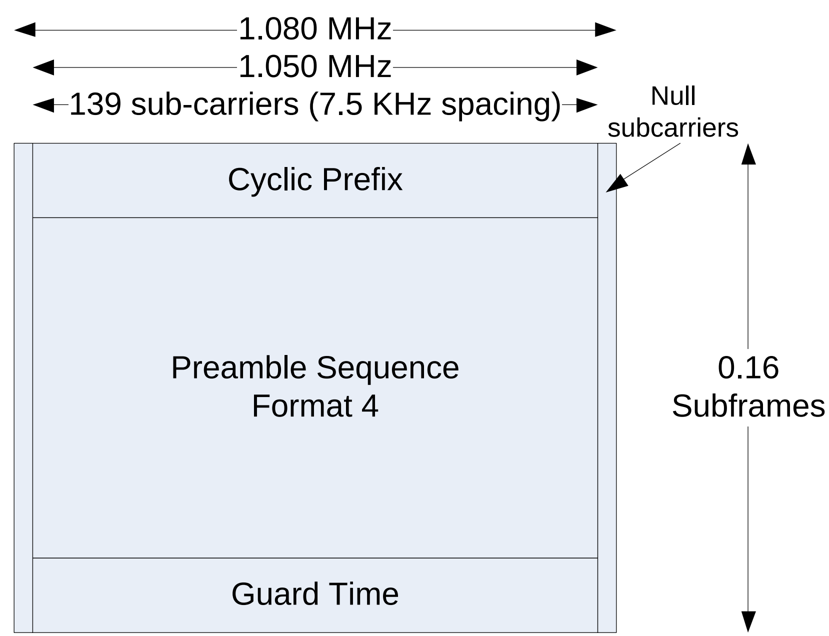
- PRACH is shared by several UEs, so orthogonal codes are used to individualize them
  - Regular 72 subcarriers do not allow for enough orthogonal codes
  - An UE sends a preamble corresponding to a specific orthogonal code
  - Each cell supports 64 preamble sequences
    - Sequences are divided in contention (2 groups) and non-contention
    - Once a group is selected the UE chooses at random a preamble
- Four formats are specified based on turnaround distance

Preamble Format	Application	Cyclic Prefix Duration (µs)	Sequence Duration (µs)	Guard Time (µs)	Total Duration (ms)	Maximum Cell Range (km)	Subcarriers	Subcarrier Bandwidth (kHz)	Symbol Duration (µs)
0	FDD & TDD	103.12	800	96.88	1	14.5	839	1.25	800
1	FDD & TDD	684.38	800	515.62	2	77.3	839	1.25	800
2	FDD & TDD	203.12	1600	196.88	2	29.5	839	1.25	800
3	FDD & TDD	684.38	1600	715.62	3	102.7	839	1.25	800
4	TDD	14.58	133.33	9.38	0.157	1.4	139	7.5	133.33

PRACH Format

PRACH Format	Duplex	RACH sub-carriers	Sub-carrier width (kHz)	Total width (kHz)	Cell sub-carriers	RBs	PRACH CP (µs)	PRACH Symbols	Sequence (us)	Guard Time (µs)	Total duration (µs)	Sub-frames	Maximum Cell Range (km)	Cell size
0	FDD & TDD	839	1.25	1,049	69.92	6	103.13	1	800	96.88	1000	1	14.5	medium cells
1	FDD & TDD	839	1.25	1,049	69.92	6	684.38	1	800	515.6	2000	2	77.3	very large cells
2	FDD & TDD	839	1.25	1,049	69.92	6	203.13	2	1600	196.8	2000	2	29.5	large cells
3	FDD & TDD	839	1.25	1,049	69.92	6	684.38	2	1600	715.6	3000	3	107.3	extra-large cells
4	TDD	139	7.5	1,043	69.50	6	14.58	0.17	133.33	9.38	157	0.16	1.4	small cells





4.1.2.3 PRACH Configuration Index

LTE Random Access Procedure

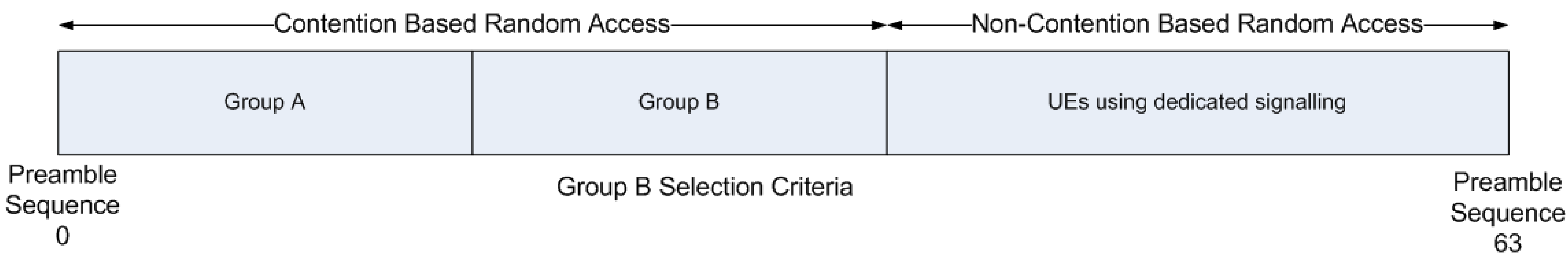
- 3GPP designed the RA area to support simultaneous access to several UEs, by providing orthogonal codes for the UE access
  - Each UE chooses randomly one of the codes to perform its access
  - 3GPP specifies that 64 codes should be available for the UEs in each access
  - The 64 codes are assigned to three groups
    - Contention Group A: to be used by UEs that have messages to be sent smaller than a threshold specified in SIB2 or path loss larger than a value calculated from parameters sent in SIB2
      - 4 to 60 codes (designer dimensioned), with a step of 4
    - Contention Group B:To be used by UEs that do not satisfy the conditions of Group A
      - 4 to 64 codes (designer dimensioned), with a step of 4
    - Non Contention Group: This codes are assigned by eNB to UEs during handover procedures, to avoid contention in this process
      - Remaining codes, can be none

LTE Random Access Procedure

- Each cell has 64 Preamble Sequences and Network Designer can group them in
  - Contention based Random Access Sequences
    - Group A: Small message or large Path Loss
    - Group B: Large messages and small path loss
  - Non-contention based Random Access Sequences
- UE should select the appropriate group B if equations below are satisfied by applying the parameters send in SIB 2, otherwise it should select Group A
  - Group A Message Size Threshold
  - Pmax
  - Target Rx Power
  - Preamble to Msg Delta
  - Group B offset
- UE will use the Non Contention Group only under direction of eNB, mainly during handover procedures
  - This trims the access timing during handover procedures
  - The network can be configured without the non-contention area

$$Message\ Size > Group\ A\ Message\ Size\ Threshold \quad AND$$

$$Path\ Loss < P_{max} - Target\ Rx\ Power - Preamble\ to\ Msg\ Delta - Group\ B\ Offset$$



LTE Random Access Procedure

- Random Access SIB 2 parameters are listed below, with respective ranges

RACH Configuration	Range	Step
Number of RA Preambles	4 to 64	4
Size of RA Preamble Group A	4 to 60	4
Message Size Group A	56, 144, 208, 256 bit	
Message Power Offset Group B	-∞. 0, 5, 8, 10, 12, 15, 18 dB	
Power Ramping Step	0, 2, 4, 6 dB	
Preamble Initial Received Target Power	-120 to -90 dBm	2 dB
Preamble Maximum Transmissions	3, , 5, 6, 7, 8, 10, 20, 50, 100, 200	
RA Response Window Size	2, 3, 4, 5, 6, 7, 8, 10 subframes	
MAC Contention Resolution Timer	8, 16, 24, 32, 40, 48, 56, 64 subframes	
Maximum HARQ Message Transmissions	1 to 8	1

PDSCH Configuration	Range
Reference Signal Power	-50 to -60 dBm
Power Boost (P_B)	0 to 3

PRACH Configuration Parameters	Range
Root Sequence Index	0 to 837
PRACH Configuration Index	0 to 63
High Speed Flag	true/false
Zero Correlation Zone Configuration	0 to 15
PRACH frequency Offset	0 to 94 RB

PRACH Configuration Index (0 to 63)

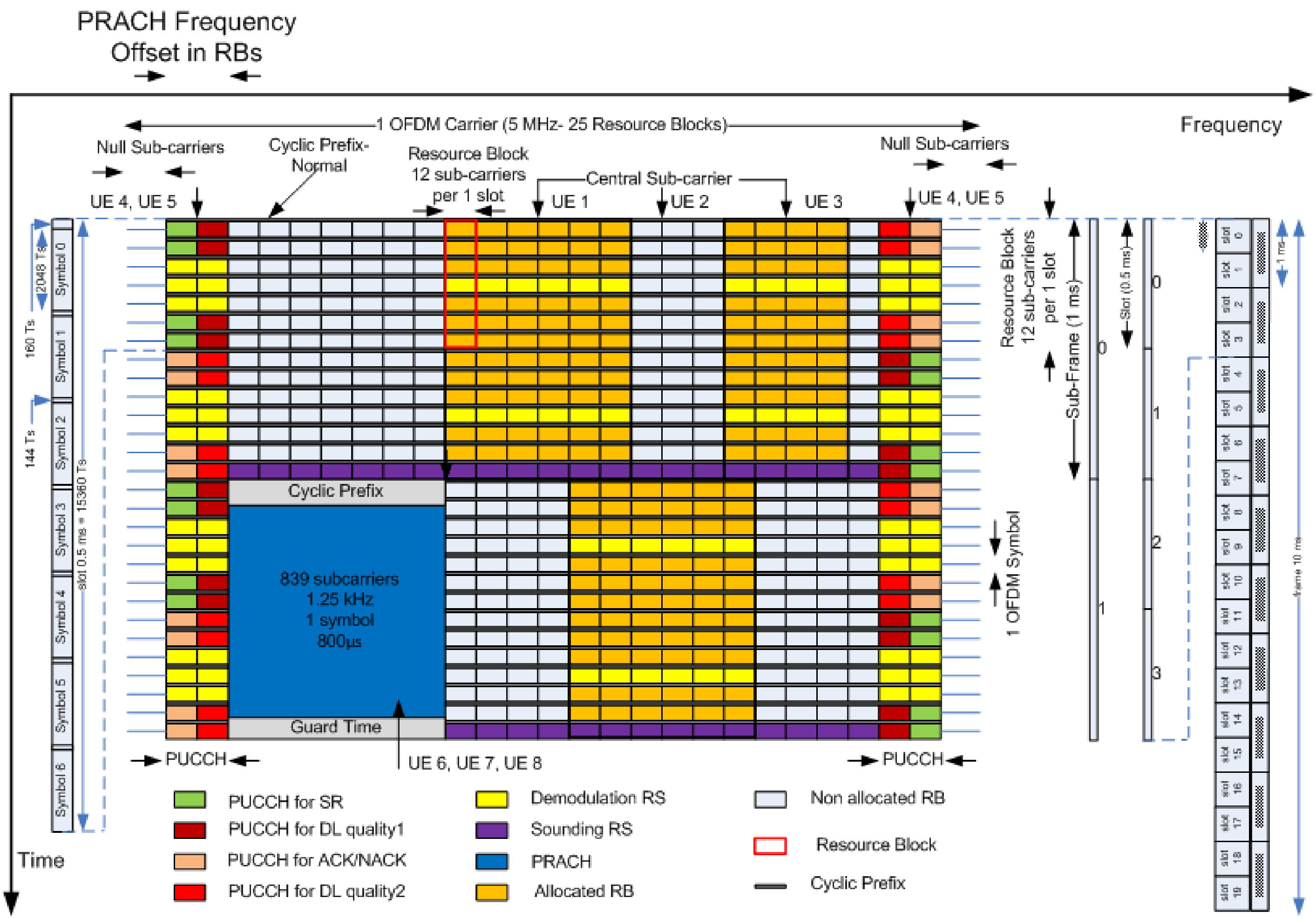
PRACH Configuration Index				
Configuration Index	Preamble Format	SFN	Subframe number	RACH density per frame
0	0	Even	1	0.5
1	0	Even	4	0.5
2	0	Even	7	0.5
3	0	Any	1	1
4	0	Any	4	1
5	0	Any	7	1
6	0	Any	1, 6	2
7	0	Any	2, 7	2
8	0	Any	3, 8	2
9	0	Any	1, 4, 7	3
10	0	Any	2, 5, 8	3
11	0	Any	3, 6, 9	3
12	0	Any	0, 2, 4, 6, 8	5
13	0	Any	1, 3, 5, 7, 9	5
14	0	Any	0 to 9	10
15	0	Even	9	0.5
16	1	Even	1	0.5
17	1	Even	4	0.5
18	1	Even	7	0.5
19	1	Any	1	1
20	1	Any	4	1
21	1	Any	7	1
22	1	Any	1, 6	2
23	1	Any	2, 7	2
24	1	Any	3, 8	2
25	1	Any	1, 4, 7	3
26	1	Any	2, 5, 8	3
27	1	Any	3, 6, 9	3
28	1	Any	0, 2, 4, 6, 8	5
29	1	Any	1, 3, 5, 7	4
30	-	-	-	
31	1	Even	9	0.5

PRACH Configuration Index				
Configuration Index	Preamble Format	SFN	Subframe number	RACH density per frame
32	2	Even	1	0.5
33	2	Even	4	0.5
34	2	Even	7	0.5
35	2	Any	1	1
36	2	Any	4	1
37	2	Any	7	1
38	2	Any	1, 6	2
39	2	Any	2, 7	2
40	2	Any	3, 8	2
41	2	Any	1, 4, 7	3
42	2	Any	2, 5, 8	3
43	2	Any	3, 6	2
44	2	Any	0, 2, 4, 6, 8	5
45	2	Any	1, 3, 5, 7	4
46	-	-	-	-
47	2	Even	9	0.5
48	3	Even	1	0.5
49	3	Even	4	0.5
50	3	Even	7	0.5
51	3	Any	1	1
52	3	Any	4	1
53	3	Any	7	1
54	3	Any	1, 6	2
55	3	Any	2, 7	2
56	3	Any	3	1
57	3	Any	1, 4, 7	3
58	3	Any	2, 5	2
59	3	Any	3, 6,	2
60	-	-	-	-
61	-	-	-	-
62	-	-	-	-
63	3	Even	9	0.5

4.1.2.4 PRACH Frequency Offset

PRACH Frequency Offset

- PRACH frequency offset specifies the first Resource Block to be used for the preambles
- This offset is applicable to all subframes
- FDD can only have one PRACH position per subframe
- TDD can have multiple PRACH positions per subframe



4.1.2.5 PRACH Zero Correlation Zone

Zero Correlation Zone

- 3GPP specifies 838 root sequences (with 839 symbols each)
- Each cells has 64 preamble sequences, created by equally spaced shifts
  - There are 838 cyclic shifts of a Root Sequence (1 shift ≈ cell range of 143 m)
  - To generate 64 sequences the shift between sequences must be 13 sub-carrier symbols
  - This corresponds to a cell size of 0.76 km
- Larger cell sizes require the use of more than one Root Sequence
- Zero Correlation Zone Index defines the relationship between the index, Number of Sequences and Cell Range (shown in table below for preamble formats 0 to 3)

Zero Correlation Zone High Speed Flag= false		Preamble sequences per Root Sequence	Root Sequences Required per Cell	Root Sequence reuse pattern	Cell Range (km)
Index	Cyclic shift				
1	13	64	1	838	0.76
2	15	55	2	419	1.04
3	18	46	2	419	1.47
4	22	38	2	419	2.04
5	26	32	2	419	2.62
6	32	26	3	279	3.47
7	38	22	3	279	4.33
8	46	18	4	209	5.48
9	59	14	5	167	7.34
10	76	11	6	139	9.77
11	93	9	8	104	12.20
12	119	7	10	83	15.92
13	167	5	13	64	22.78
14	279	3	22	38	38.80
15	419	2	32	26	58.83
0	838	1	64	13	118.8

Zero Correlation Zone

- Zero Correlation Zone Index is shown below for preamble format 4
- The high speed flag is set to false for this and the previous table
- High Speed Flag (HSF) is set to true for speeds exceeding 250 km/h
- When HSF is set to true the Doppler effect should be taken into account and the Cyclic shifts varies with the root sequence

Format 4						
Zero Correlation zone cyclic shift (High Speed Flag= false)		Preamble Sequences per Root Sequence	Root Sequences Required per Cell	Root Sequences Reuse Pattern	Cell Range (km)
Index	Actual value				
0	2	69	1	138	0.14
1	4	34	2	69	0.43
2	6	23	3	46	0.72
3	8	17	4	34	1.00
4	10	13	5	27	1.29
5	12	11	6	23	1.58
6	15	9	8	17	2.01

4.1.2.6 PRACH High Speed Flag

PRACH High Speed Flag

- High Speed flag is intended to notify that high speeds can generate Doppler offset and impact the preamble detection performance
- High speed train areas would require the setting of this flag as on, when speeds pass 250 km/h
- In this case the Zero Correlation zone table is modified to take into consideration the Doppler shift

4.1.2.7 PRACH Root Sequence Index

Root Sequence Index

- Root Sequence Index is assigned considering:
  - PRACH Configuration Index: defines the Preamble format
  - High Mobility Flag: defines if Doppler should be taken into account
  - Zero Correlation Zone Value: defines the number of cell sequences required, based on the cell range
- Network Planner should allocate the number of Root Sequences required for each, following a sequential numbering (logical numbering)
  - Logical Root Sequence Allocations should space same numbers as far apart as possible
  - 3GPP specifies a lookup table that maps the logical allocations to physical ones (see next slide)

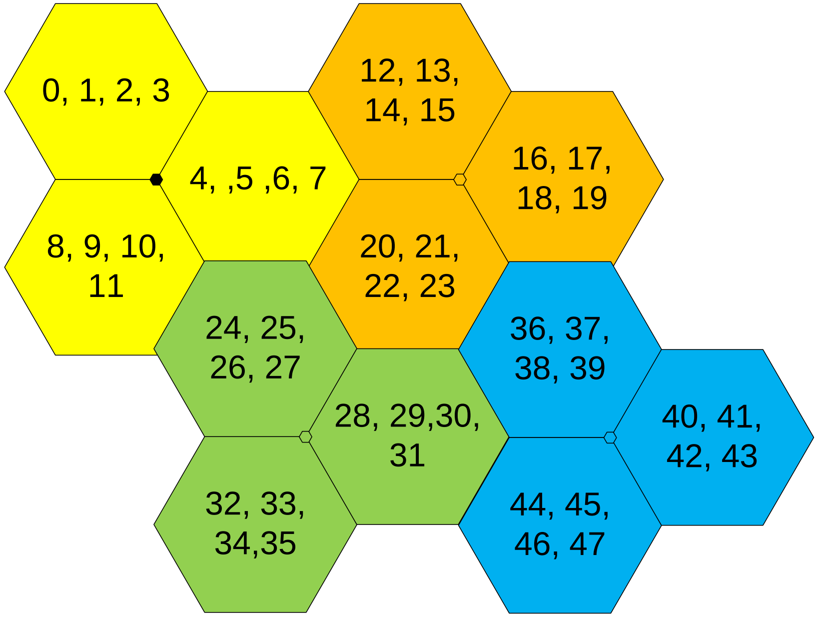
Logical to Physical Root Sequence Mapping

Logical root sequence number	Physical root sequence number u for formats 0 to 3 (in increasing order of the corresponding logical sequence number)
0–23	129, 710, 140, 699, 120, 719, 210, 629, 168, 671, 84, 755, 105, 734, 93, 746, 70, 769, 60, 779, 2, 837, 1, 838
24–29	56, 783, 112, 727, 148, 691
30–35	80, 759, 42, 797, 40, 799
36–41	35, 804, 73, 766, 146, 693
42–51	31, 808, 28, 811, 30, 809, 27, 812, 29, 810
52–63	24, 815, 48, 791, 68, 771, 74, 765, 178, 661, 136, 703
64–75	86, 753, 78, 761, 43, 796, 39, 800, 20, 819, 21, 818
76–89	95, 744, 202, 637, 190, 649, 181, 658, 137, 702, 125, 714, 151, 688
90–115	217, 622, 128, 711, 142, 697, 122, 717, 203, 636, 118, 721, 110, 729, 89, 750, 103, 736, 61, 778, 55, 784, 15, 824, 14, 825
116–135	12, 827, 23, 816, 34, 805, 37, 802, 46, 793, 207, 632, 179, 660, 145, 694, 130, 709, 223, 616
136–167	228, 611, 227, 612, 132, 707, 133, 706, 143, 696, 135, 704, 161, 678, 201, 638, 173, 666, 106, 733, 83, 756, 91, 748, 66, 773, 53, 786, 10, 829, 9, 830
168–203	7, 832, 8, 831, 16, 823, 47, 792, 64, 775, 57, 782, 104, 735, 101, 738, 108, 731, 208, 631, 184, 655, 197, 642, 191, 648, 121, 718, 141, 698, 149, 690, 216, 623, 218, 621
204–263	152, 687, 144, 695, 134, 705, 138, 701, 199, 640, 162, 677, 176, 663, 119, 720, 158, 681, 164, 675, 174, 665, 171, 668, 170, 669, 87, 752, 169, 670, 88, 751, 107, 732, 81, 758, 82, 757, 100, 739, 98, 741, 71, 768, 59, 780, 65, 774, 50, 789, 49, 790, 26, 813, 17, 822, 13, 826, 6, 833
264–327	5, 834, 33, 806, 51, 788, 75, 764, 99, 740, 96, 743, 97, 742, 166, 673, 172, 667, 175, 664, 187, 652, 163, 676, 185, 654, 200, 639, 114, 725, 189, 650, 115, 724, 194, 645, 195, 644, 192, 647, 182, 657, 157, 682, 156, 683, 211, 628, 154, 685, 123, 716, 139, 700, 212, 627, 153, 686, 213, 626, 215, 624, 150, 689
328–383	225, 614, 224, 615, 221, 618, 220, 619, 127, 712, 147, 692, 124, 715, 193, 646, 205, 634, 206, 633, 116, 723, 160, 679, 186, 653, 167, 672, 79, 760, 85, 754, 77, 762, 92, 747, 58, 781, 62, 777, 69, 770, 54, 785, 36, 803, 32, 807, 25, 814, 18, 821, 11, 828, 4, 835
384–455	3, 836, 19, 820, 22, 817, 41, 798, 38, 801, 44, 795, 52, 787, 45, 794, 63, 776, 67, 772, 72 767, 76, 763, 94, 745, 102, 737, 90, 749, 109, 730, 165, 674, 111, 728, 209, 630, 204, 635, 117, 722, 188, 651, 159, 680, 198, 641, 113, 726, 183, 656, 180, 659, 177, 662, 196, 643, 155, 684, 214, 625, 126, 713, 131, 708, 219, 620, 222, 617, 226, 613
456–513	230, 609, 232, 607, 262, 577, 252, 587, 418, 421, 416, 423, 413, 426, 411, 428, 376, 463, 395, 444, 283, 556, 285, 554, 379, 460, 390, 449, 363, 476, 384, 455, 388, 451, 386, 453, 361, 478, 387, 452, 360, 479, 310, 529, 354, 485, 328, 511, 315, 524, 337, 502, 349, 490, 335, 504, 324, 515
514–561	323, 516, 320, 519, 334, 505, 359, 480, 295, 544, 385, 454, 292, 547, 291, 548, 381, 458, 399, 440, 380, 459, 397, 442, 369, 470, 377, 462, 410, 429, 407, 432, 281, 558, 414, 425, 247, 592, 277, 562, 271, 568, 272, 567, 264, 575, 259, 580
562–629	237, 602, 239, 600, 244, 595, 243, 596, 275, 564, 278, 561, 250, 589, 246, 593, 417, 422, 248, 591, 394, 445, 393, 446, 370, 469, 365, 474, 300, 539, 299, 540, 364, 475, 362, 477, 298, 541, 312, 527, 313, 526, 314, 525, 353, 486, 352, 487, 343, 496, 327, 512, 350, 489, 326, 513, 319, 520, 332, 507, 333, 506, 348, 491, 347, 492, 322, 517
630–659	330, 509, 338, 501, 341, 498, 340, 499, 342, 497, 301, 538, 366, 473, 401, 438, 371, 468, 408, 431, 375, 464, 249, 590, 269, 570, 238, 601, 234, 605
660–707	257, 582, 273, 566, 255, 584, 254, 585, 245, 594, 251, 588, 412, 427, 372, 467, 282, 557, 403, 436, 396, 443, 392, 447, 391, 448, 382, 457, 389, 450, 294, 545, 297, 542, 311, 528, 344, 495, 345, 494, 318, 521, 331, 508, 325, 514, 321, 518
708–729	346, 493, 339, 500, 351, 488, 306, 533, 289, 550, 400, 439, 378, 461, 374, 465, 415, 424, 270, 569, 241, 598
730–751	231, 608, 260, 579, 268, 571, 276, 563, 409, 430, 398, 441, 290, 549, 304, 535, 308, 531, 358, 481, 316, 523
752–765	293, 546, 288, 551, 284, 555, 368, 471, 253, 586, 256, 583, 263, 576
766–777	242, 597, 274, 565, 402, 437, 383, 456, 357, 482, 329, 510
778–789	317, 522, 307, 532, 286, 553, 287, 552, 266, 573, 261, 578
790–795	236, 603, 303, 536, 356, 483
796–803	355, 484, 405, 434, 404, 435, 406, 433
804–809	235, 604, 267, 572, 302, 537
810–815	309, 530, 265, 574, 233, 606
816–819	367, 472, 296, 543
820–837	336, 503, 305, 534, 373, 466, 280, 559, 279, 560, 419, 420, 240, 599, 258, 581, 229, 610

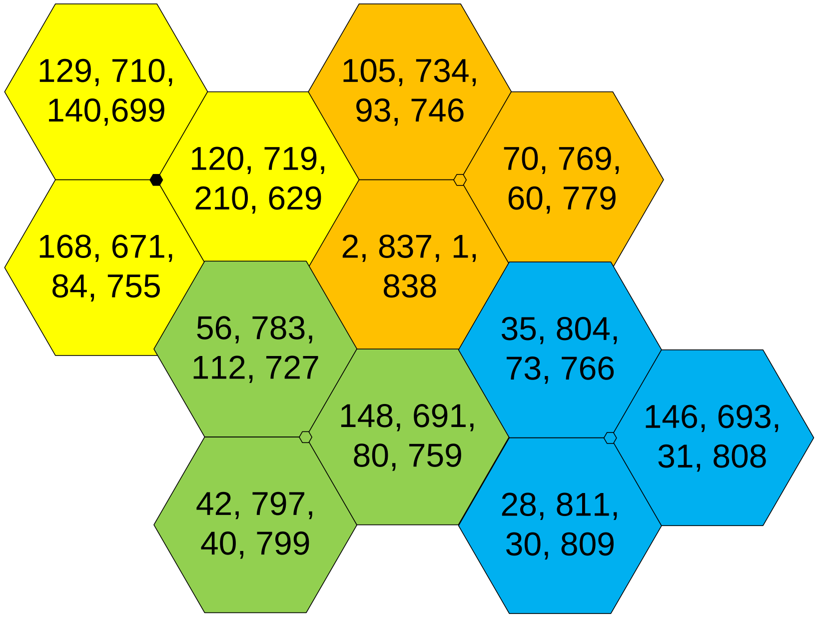
Logical and Physical Allocation of Root Sequence Numbers

- A Cell Range of 5 km requires
  - Preamble Format 0
  - Zero Correlation Zone 8
  - 4 Root Sequences per cell
  - Resulting in a reuse pattern of 209

Logical Allocation of Root Sequence Numbers



Physical Allocation of Root Sequence Numbers



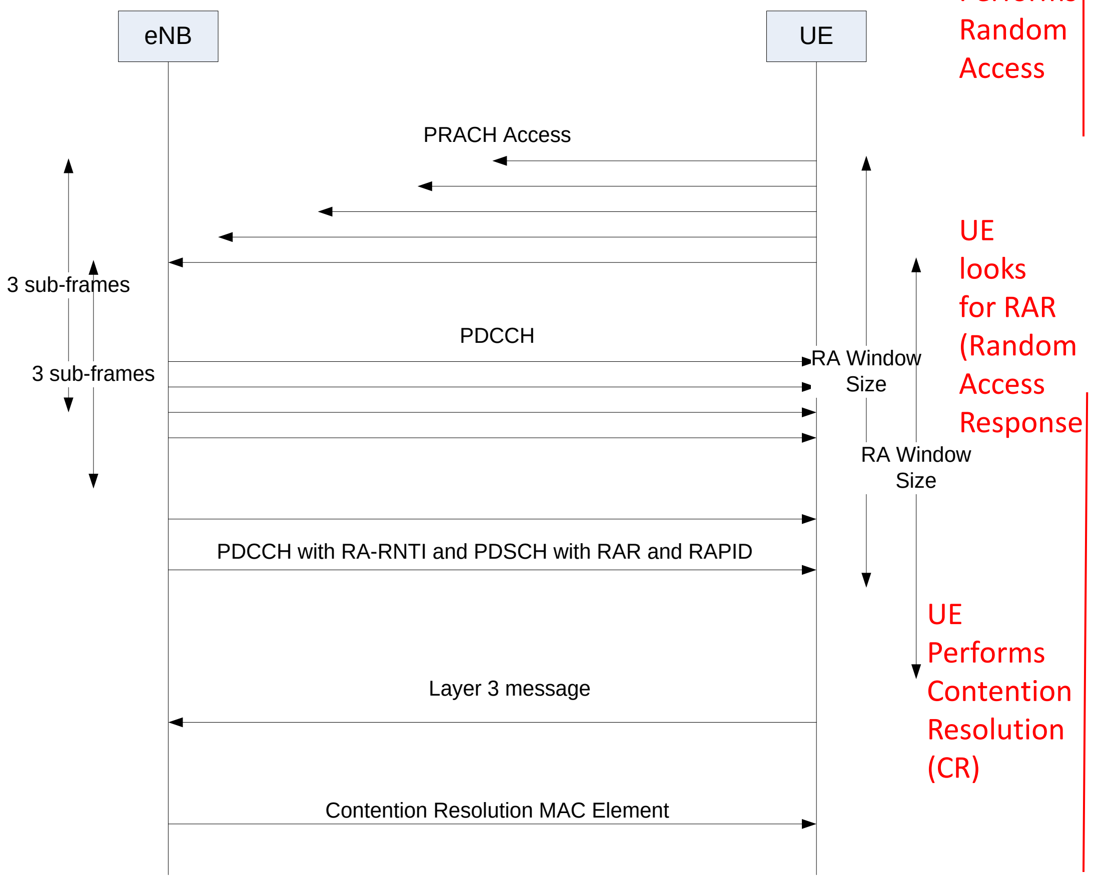
4.1.3 Random Access Procedure

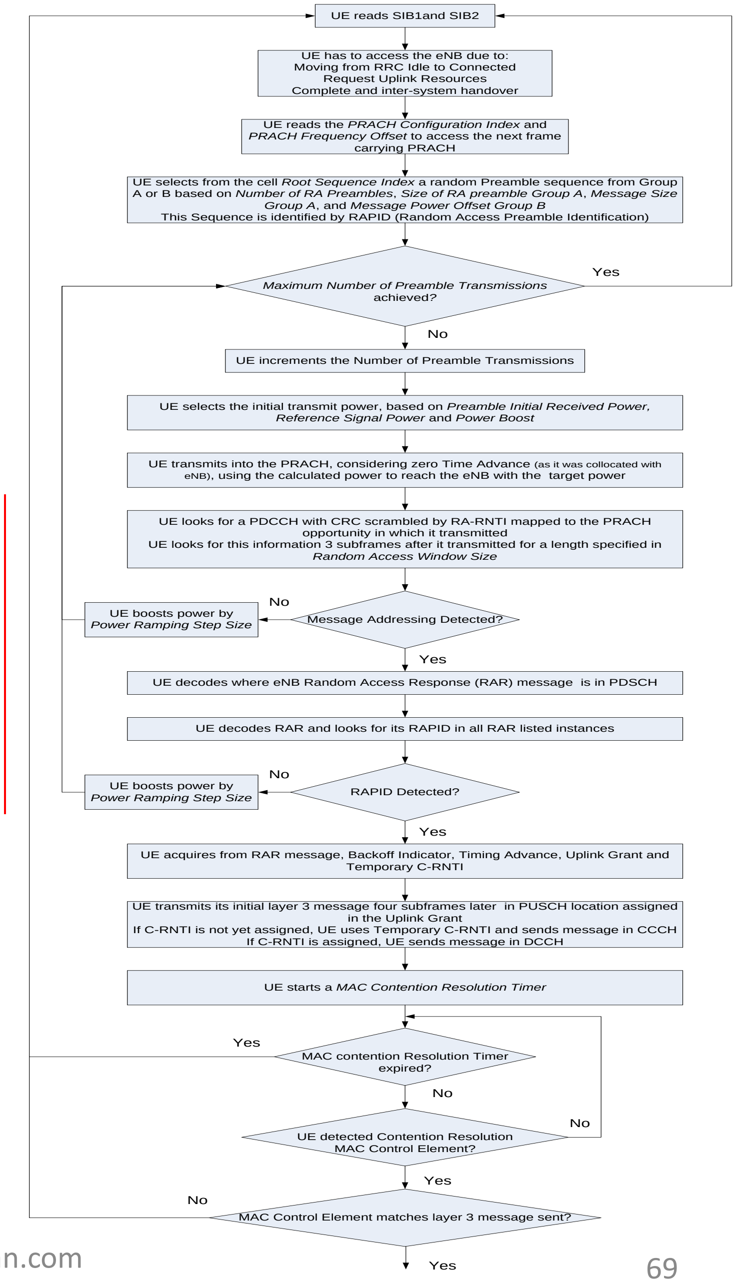
Part 2

Random Access Response

Random Access Procedure

- Procedure Flow
  1. UE Performs Random Access
  2. UE Looks for eNB RAR message
  3. UE Performs Contention Resolution
- Messages Sequence

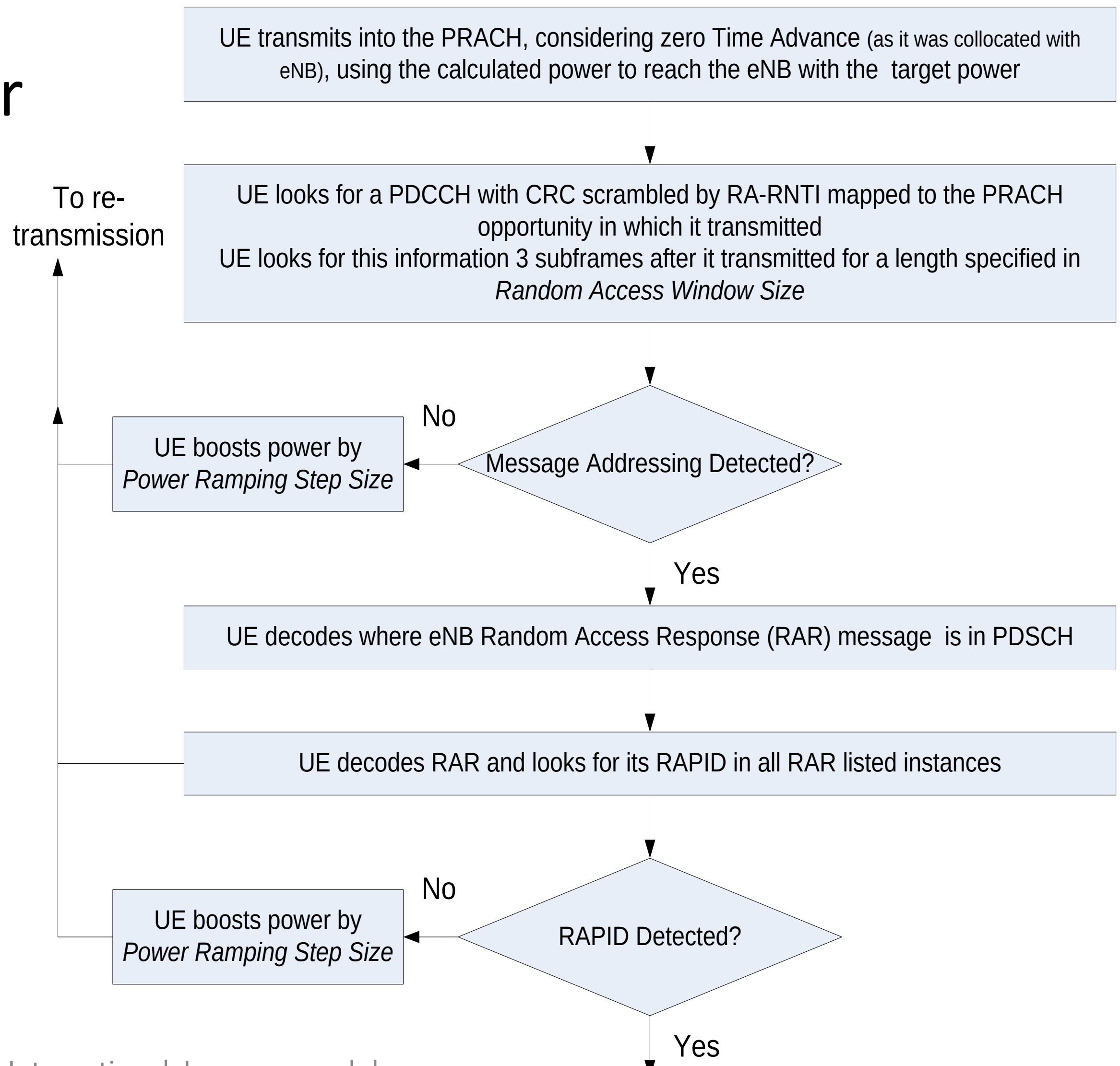




Random Access Procedure

- Parameters
  - Maximum Number of Preamble Transmissions
  - Preamble Initial Received Power
    - Reference Signal Power
    - Power Boost
  - Power Ramping Step

UE Looks for eNB RAR message



RAR Message

- eNB responds to Random Access in a specific Subframe with a Random Access Response (RAR) message
  - eNB responds to all detected accesses (up to 64) in the same message
  - Message location is specified in PDCCH using the RA-RNTI
    - RA-RNTI range goes from 0001 to 003C (60 values)
  - Temporary C-RNTI becomes C-RNTI if a successful contention resolution is done

$$RA\_RNTI = 1 + tid + (10 * fid)$$

$$tid = subframe\ PRACH\ index$$

$$fid = frequency\ PRACH\ index$$

$$0 \leq fid < 6$$

E/T/R/R/BI Subheader 8 bit	E/T/RAPID Subheader 1 8 bit	E/T/RAPID Subheader 2 8 bit	----	E/T/RAPID Subheader n 8 bit	Random Access Response 1 48 bit	Random Access Response 2 48 bit	----	Random Access Response n 48 bit

E/T/R/R/BI subheader

E	T	R	R	BI

E/T/RAPID subheader (n instances)

E	T	RAPID

Random Access Response Payload (n instances)

R	Timing Advance
Timing Advance	Uplink Grant
Uplink Grant	
Uplink Grant	
Temporary C-RNTI	
Temporary C-RNTI	

Backoff Indicator (BI)	Backoff (ms)
0	0
1	10
2	20
3	30
4	40
5	60
6	80
7	120
8	160
9	240
10	320
11	480
12	960
13	reserved
14	reserved
15	reserved

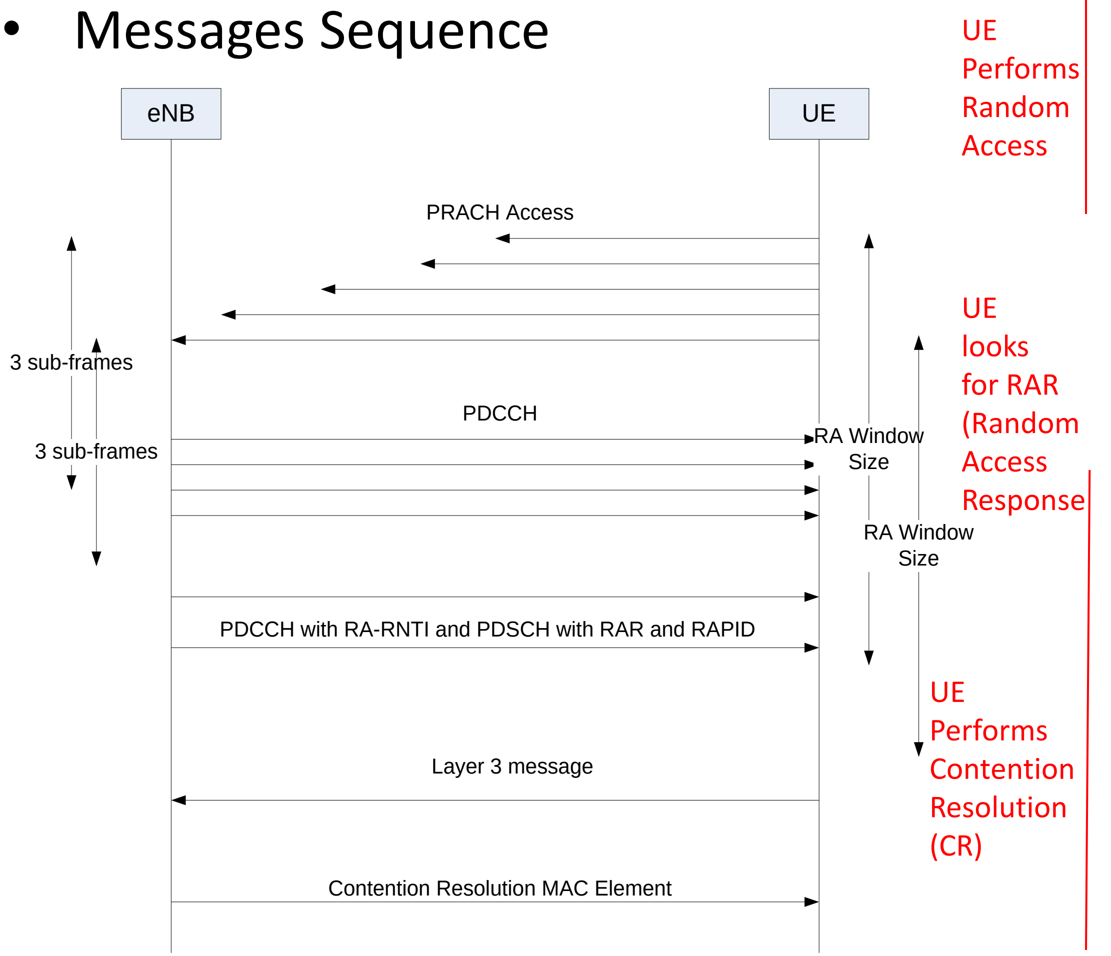
4.1.3 Random Access Procedure

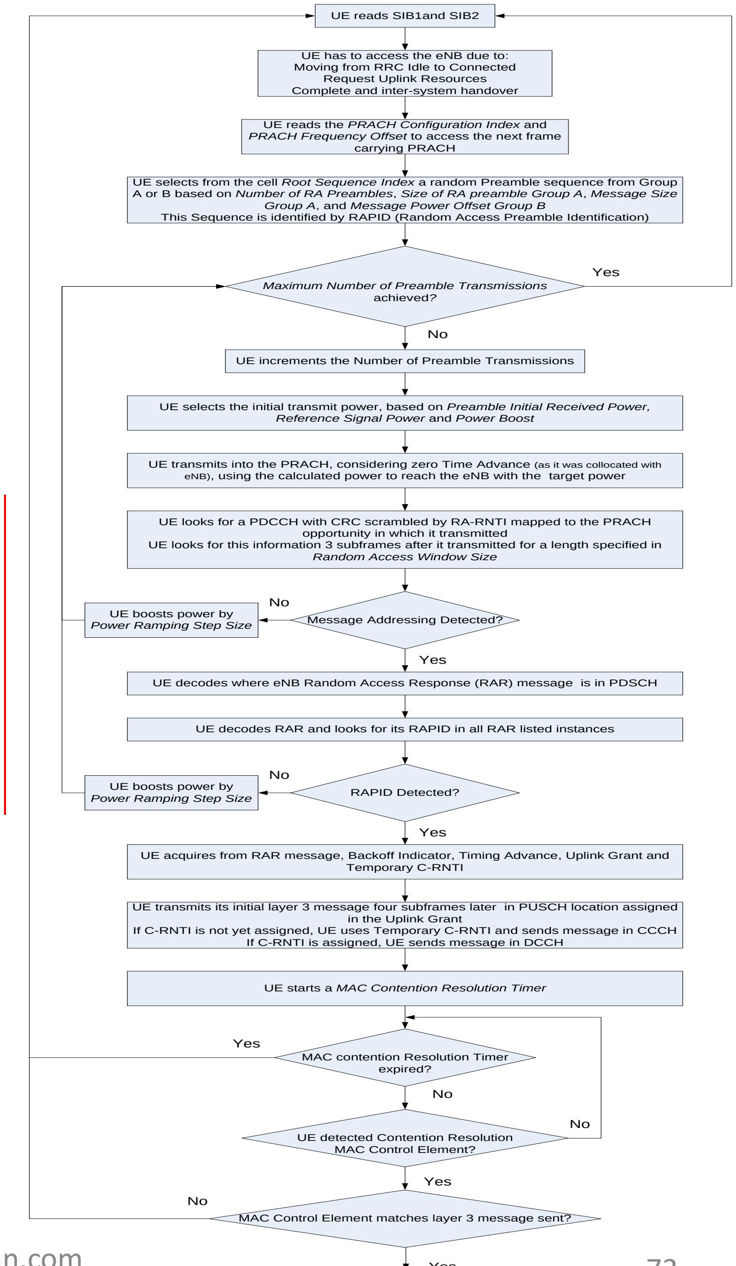
Part 3

Contention Resolution

Random Access Procedure

- Procedure Flow
  1. UE Performs Random Access
  2. UE Looks for eNB RAR message
  3. UE Performs Contention Resolution
- Messages Sequence

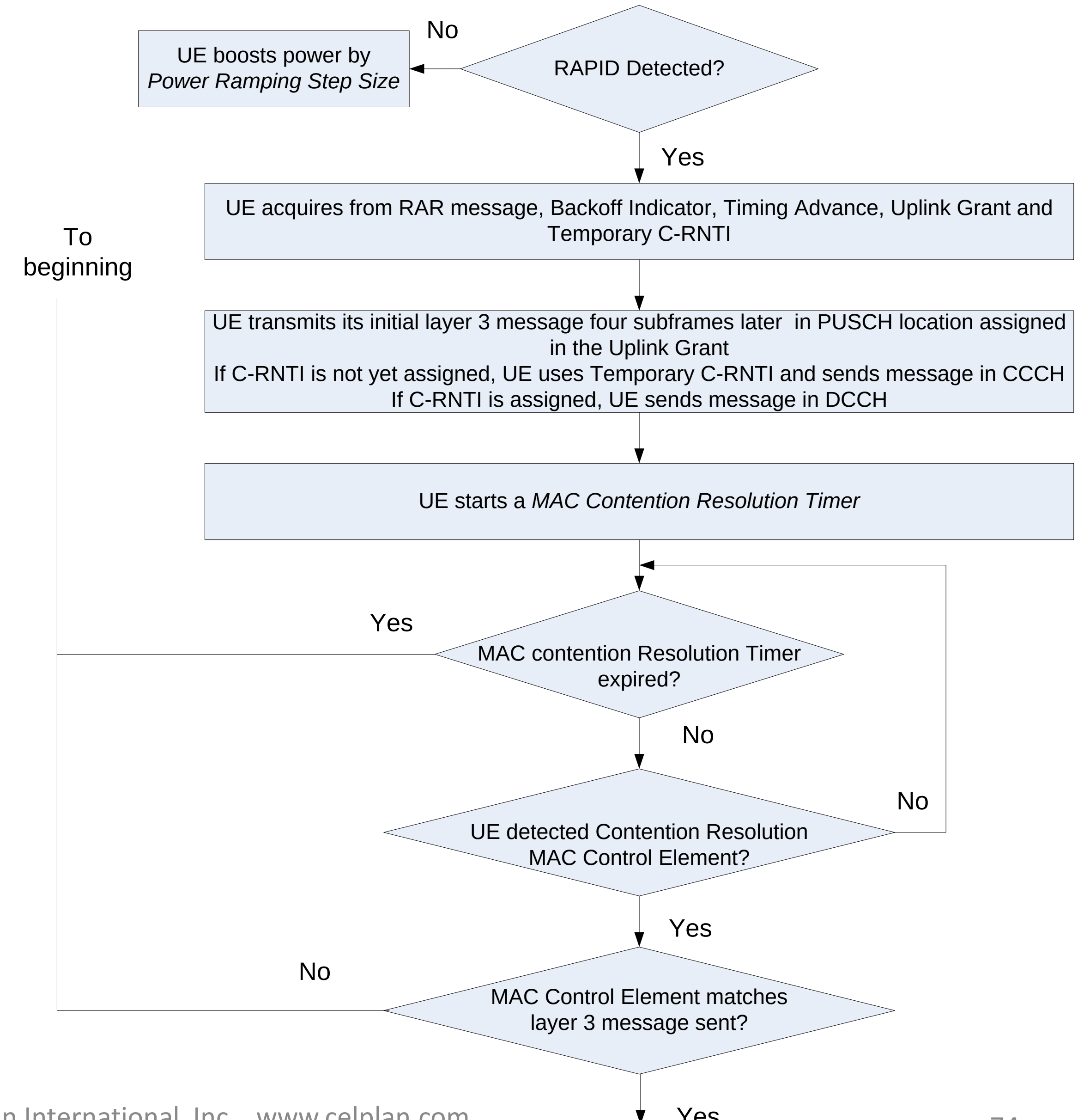




Random Access Procedure

UE Performs Contention Resolution

- RAR Message
- Contention Resolution MAC Control Element
- UE send its *Buffer status* in the MAC message, allowing eNB to provide the next Uplink Grant



UE Contention Resolution Identity MAC control element

- Contention Resolution starts by the UE sending a layer 3 message
  - CCCH and Temporary C-RNTI are used for RRC Connection Establishment or Re-Establishment
  - DCCH and C-RNTI are used for RRC Connection Reconfiguration Complete (Intra-system handover)
- This stage verifies if multiple UEs used the same combination of RA-RNTI and preamble sequence
- UE starts a contention resolution timer (send in SIB2), if timer expires the RA process starts from beginning
- eNB replies to UE layer 3 message with a Contention Resolution Identity (CRI) MAC control element, identified by LCID=11100
  - eNB resends in the body of the message the layer 3 message sent originally by the UE
- If UE decodes in the message successfully its original message, the random access procedure is successful and the Temporary C-RNTI becomes UEs C-RNTI
  - C-RNTI range is from 003C to FFF3 (65,463 values)

R	R	E	LCID (11100)	MAC subheader (8 bit)
UE Contention Resolution Identity				MAC Control Element (48 bit)
UE Contention Resolution Identity				
UE Contention Resolution Identity				
UE Contention Resolution Identity				
UE Contention Resolution Identity				
UE Contention Resolution Identity				

4.2 Uplink Control and Data Channels

DMRS- Demodulation Reference Signals
PUCCH- Physical Uplink Control Channel
PUSCH- Physical Uplink Shared Channel
SRS- Sounding Reference Signal

SIB 2 Uplink Configuration Parameters

- System Information Block 2, broadcasted Random Access Parameters
  - SIB 2 periodicity is scheduled in SIB 1 (8, 16, 32, 64,128, 256, 512 frames)

SIB 2 Information Elements for Uplink			Range
PUSCH Configuration	Nsb		1 to 4
	Hopping mode		inter-subframe, intra and inter sub-frame
	Hopping offset		0 to 98
	Enable 64 QAM		true/false
	Uplink Refence Signals	Group Hopping Enabled	true/false
		Group assignment	0 to 29
		Frequency Hopping Enabled (true/ false)	true/false
		Cyclic Shift	0 to 7
PUCCH Configuration	Delta PUCCH Shift		1 to 3
	N_{RB}^{2} CQI		0 to 98
	N_{CS}^{1}		0 to 7
	N_{PUCCH}^{1}		0 to 2047
Uplink Sounding Reference Signal Configuration	Setup	SRS Bandwidth Configuration	0 to 7
		SRS Subframe Configuration	0 to 15
		ACK/NACK SRS Simultaneous Transmissions	true/false
		Max UpPTS (TDD)	true/false

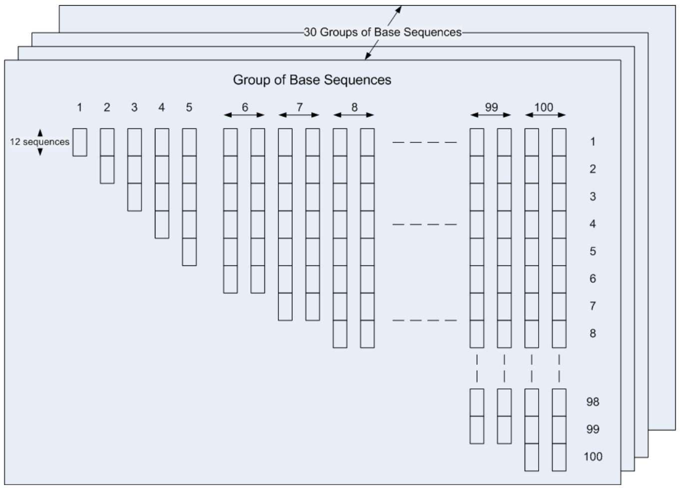
4.2.1 Demodulation Reference Signals (DMRS)

Demodulation Reference Signal (DMRS)

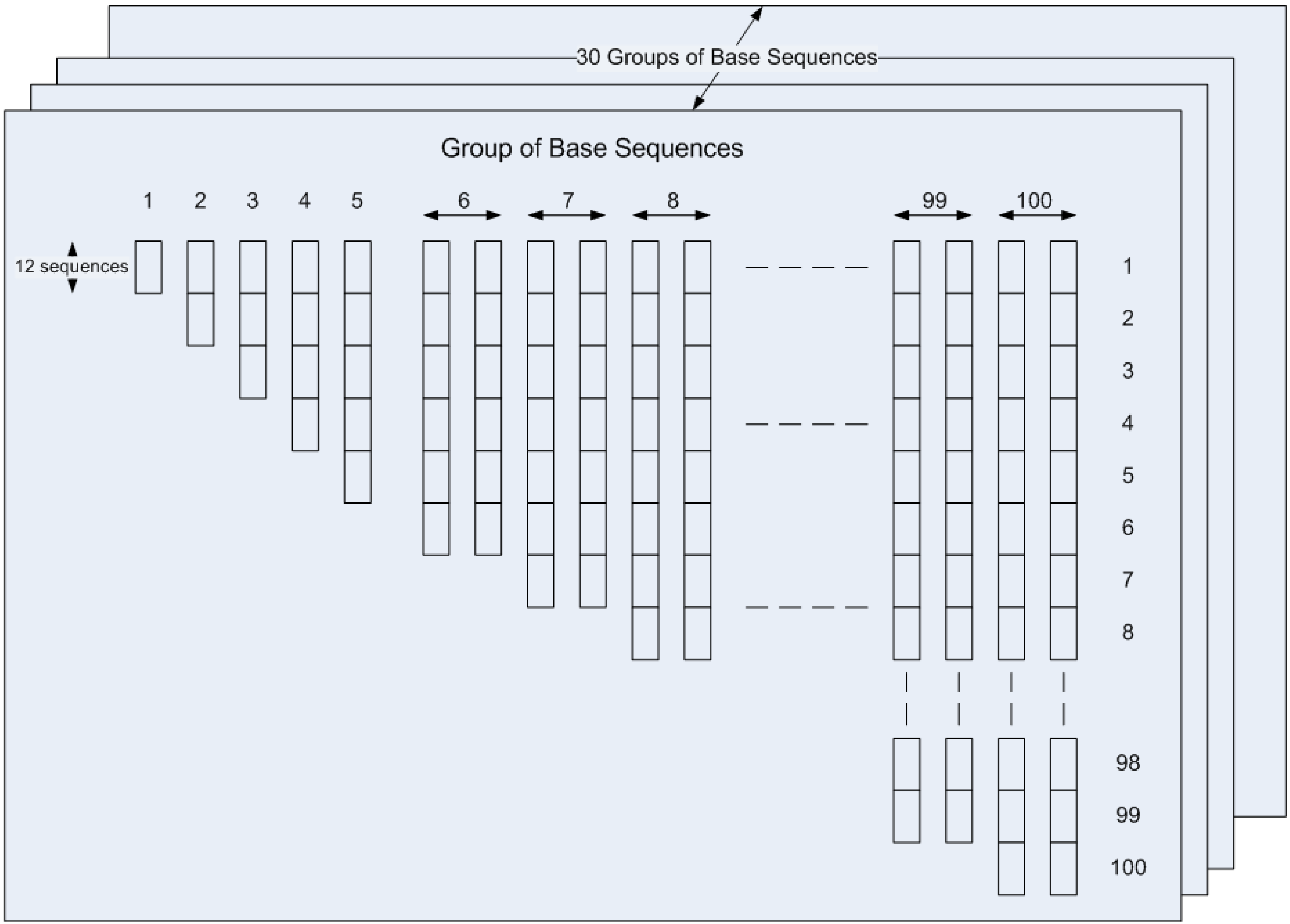
- DMRS are used for
  - Channel Estimation
  - Synchronization
- DMRS are used by
  - Physical Uplink Control Channel (PUCCH) and PUCCH DMRS
  - Physical Uplink Shared Channel (PUSCH) Demodulation Reference Signal
  - Sounding Reference Signal
- DMRS has 30 groups of Zadoff-Chu base sequences
  - Each group has 25 sequences
    - 5 base sequences (12, 24, 36, 48, 60) for 1 RB to 5 RB
    - 10 pairs of sequences for 6 RB to 15 RB
- UE selects one of the 30 groups of base sequences
- UE selects the group length based on the number of resource blocks to be transmitted
- For sequences larger than 60 (5 RB), UE selects one of the sequences in the pair
- Group hopping can be enabled by the system
  - 504 hopping patterns are used
    - 17 group hopping patterns
    - 30 sequence shift patterns
  - Group hopping can be aligned to PCI planning

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 (PCI, 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



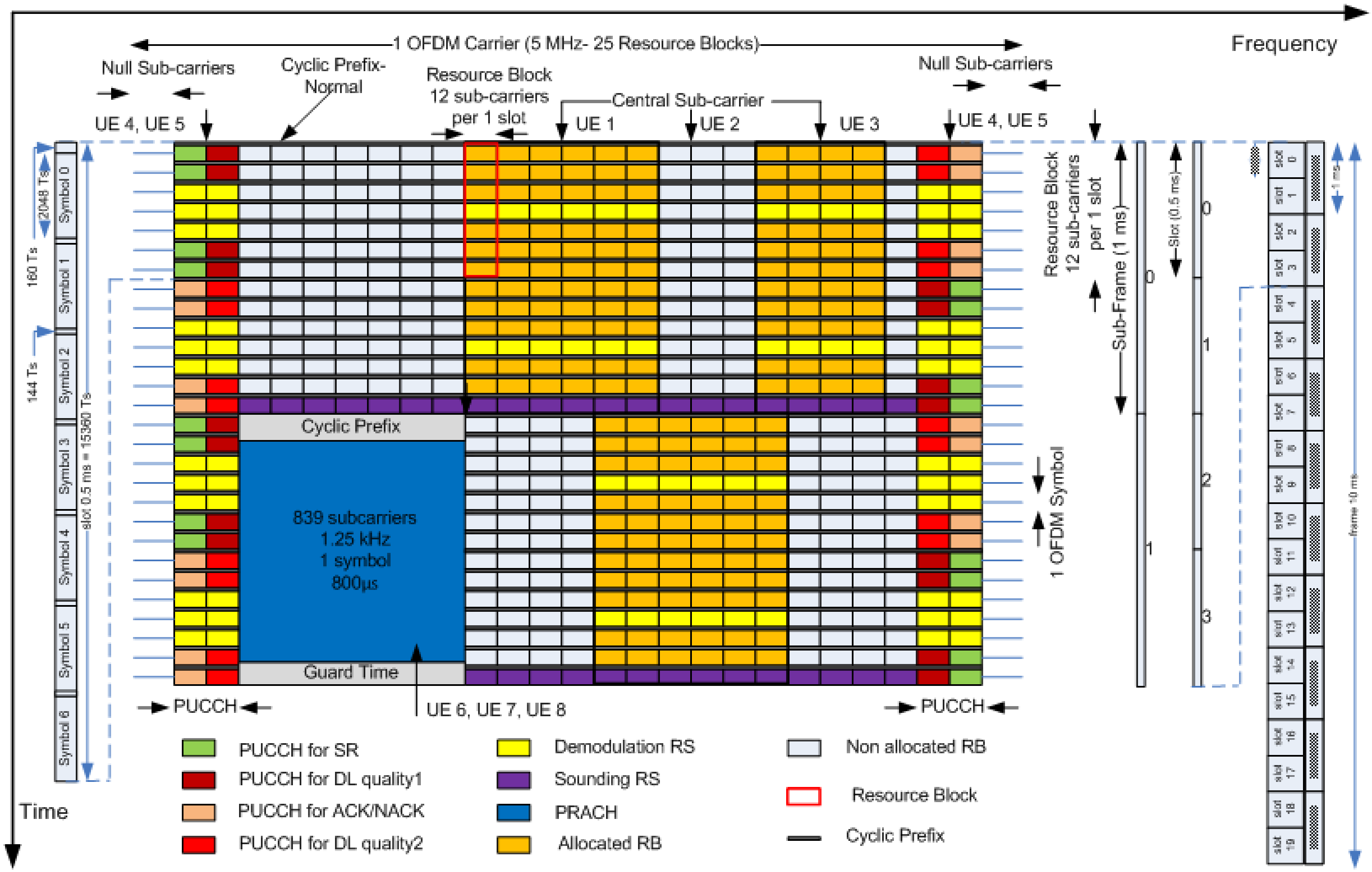
Uplink Base Group Sequence



4.2.2 Physical Uplink Control Channel

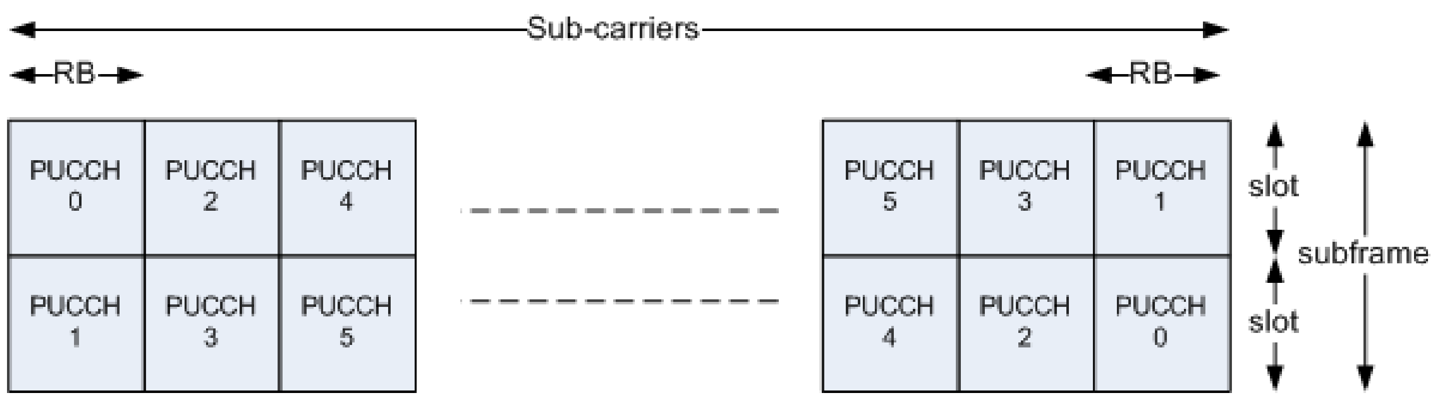
PUCCH

PUCCH


Frequency
1 OFDM Carrier (5 MHz- 25 Resource Blocks)
Null Sub-carriers
Cyclic Prefix-Normal
Resource Block 12 sub-carriers per 1 slot
Central Sub-carrier
Null Sub-carriers
UE 4, UE 5
UE 1
UE 2
UE 3
UE 4, UE 5
Resource Block 12 sub-carriers per 1 slot
Sub-Frame (1 ms)
1 OFDM Symbol
Cyclic Prefix
839 subcarriers
1.25 kHz
1 symbol
800µs
Guard Time
PUCCH
UE 6, UE 7, UE 8
PUCCH
Time
Symbol 0
Symbol 1
Symbol 2
Symbol 3
Symbol 4
Symbol 5
Symbol 6
2048 Ts
160 Ts
144 Ts
slot 0.5 ms = 15360 Ts
PUCCH for SR
PUCCH for DL quality1
PUCCH for ACK/NACK
PUCCH for DL quality2
Demodulation RS
Sounding RS
PRACH
Allocated RB
Non allocated RB
Resource Block
Cyclic Prefix

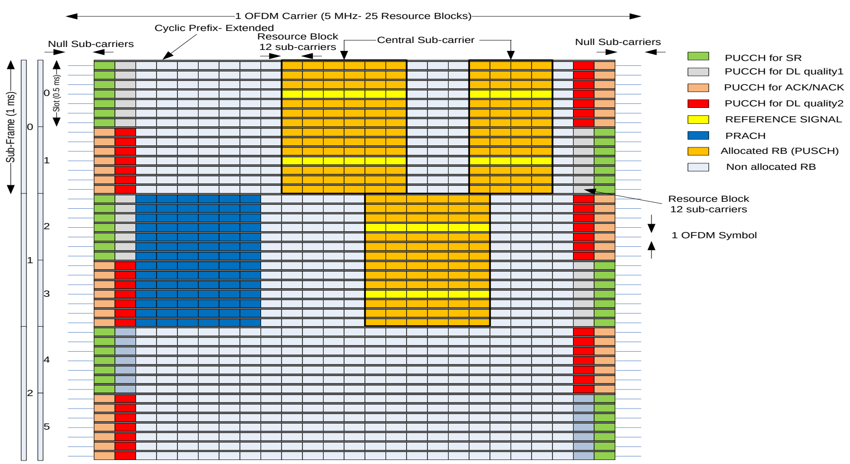
Physical Uplink Control Channel (PUCCH)

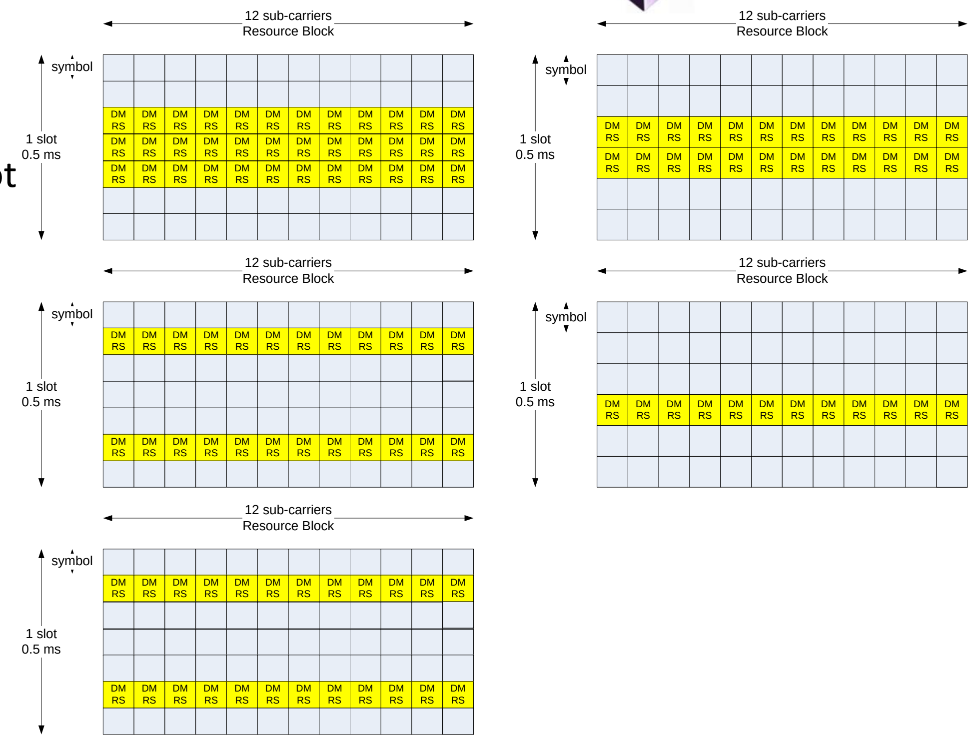
- The Uplink Control information (UCI) is sent over PUCCH or PUSCH
  - PUCCH is used before PUSCH establishment, after PUSCH is establishment UCI is sent using this channel
  - Release 10 allows for simultaneous transmission of PUCCH and PUSCH
- A single PUCCH occupies 2 RBs distributed across two time slots
- Each pair of Resource Blocks can be used simultaneously by multiple UEs
  - Different cyclic shifts and different orthogonal spreading codes allows the eNB to detect the transmission from multiple UEs sharing the same RBs
- PUCCH Resource Allocation
  - Number of allocated PUCCH depends on the number of UEs
  - PUCCH is allocated in pairs at the extreme edges of the eNB bandwidth
    - Format 2, if existent gets the most extreme Resource Blocks, followed by Format 1
    - When Format 3 is used the allocation of Resource Blocks has to be specified
- 2 to 8 RB can be allocated for PUCCH



Physical Uplink Control Channel (PUCCH)

- PUCCH transfers only control signalling (ACK/NACK, CSI (Channel State Information), SR (Scheduling Request)
- PUCCH occupies 1 RB on each extreme of a time slot
- There are 7 PUCCH DMRS formats





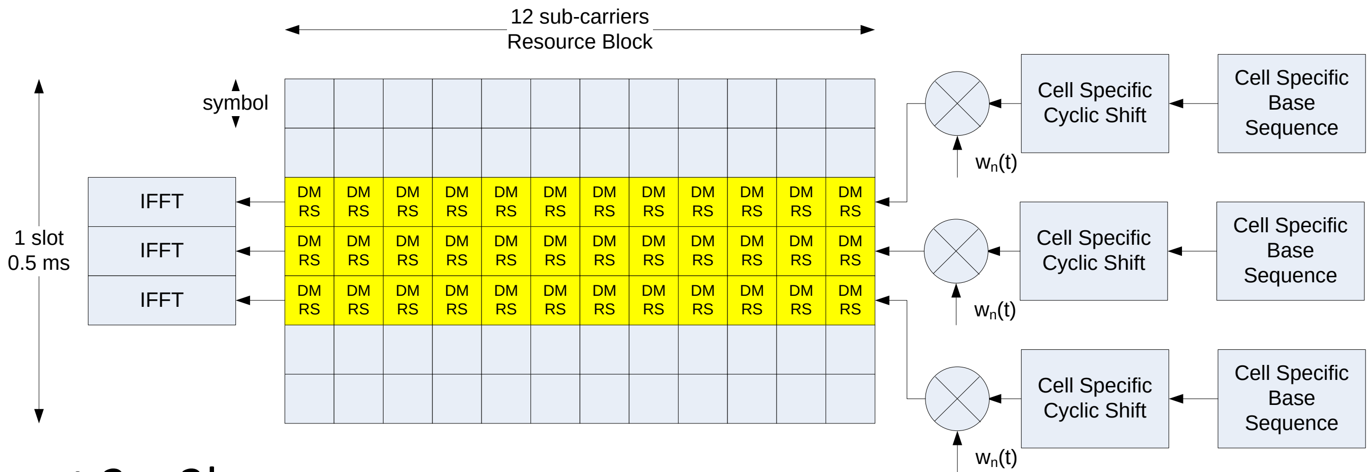
PUCCH					Normal CP			Extended CP			Spreading Factor
Format	Modulation Scheme	Data	Information	Bits per subframe	Total RE	DMRS RE	PUCCH RE	Total RE	DMRS RE	PUCCH RE	
1	N/A	No data, just channel presence	Scheduling Request (SR)	0	168	72	96	144	48	96	96
1a	BPSK	1 BPSK symbol	1 ACK/NACK	1	168	72	96	144	48	96	96
1b	QPSK	1 QPSK symbol	2 ACK/NACK	2	168	72	96	144	48	96	48
2	QPSK	10 QPSK symbols	CQI/PMI	20	168	48	120	144	24	120	6
2a	QPSK+BPSK	10 QPSK symbols + 1 BPSK symbol	CQI/PMI+1 ACK/NACK	21	168	48	120	144	24	120	5.7
2b	QPSK+QPSK	10 QPSK symbols + 1 QPSK symbol	CQI/PMI+2 ACK/NACK	22	168	48	120	144	24	120	5.5
3 FDD	QPSK	24 QPSK symbols	up to 10 x HARQ-ACK up to 10 HARQ-ACK+SR	48	168	48	120	144	24	120	2.5
3 TDD	QPSK	24 QPSK symbols	up to 20 x HARQ-ACK up to 20 HARQ-ACK+SR	48	168	48	120	144	24	120	2.5

PUCCH Demodulation Reference Signal (DMRS)

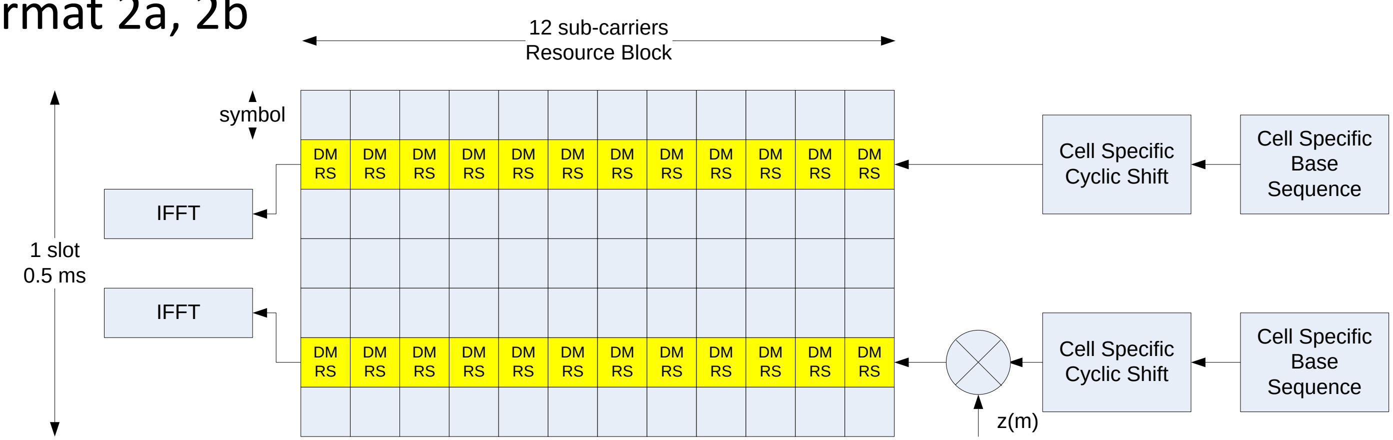
- The Demodulation Reference Signal is given by the equation
- $\bar{w}(m) \ * \ z(m) \ * \ r_{u,v}^{\propto}(n)$
  - $\bar{w}(m)$: applicable to format 1, and equal to 3 for normal CP and 2 for extended CP
    - m: references the DMRS symbol within PUCCH and varies between 0 and 2
  - $z(m)$: equal to 1
  - $r_{u,v}^{\propto}(n)$: represents the Demodulation Reference Signal sequence generated from the appropriate base sequence with a cyclic shift
    - α: is the cyclic shift applied to the base sequence (there are 12 shifts available)
    - u:is the base sequence Group Number (0 to 29)
    - v: is the index of the sequence with the appropriate length (0 or 1)
    - n: is the value of each subcarrier and varies from 0 to 11
- The Base Sequence Group Number is selected using the equation
- $u = (f_{gh} + \ f_{ss})mod30$
  - f_{gh}: equal to 0 if group hopping is disabled (according to SIB 2) and equal to a pseudo-random number between 0 and 29 if group hopping is enabled
    - The pseudo-random number is a function of PCI
  - f_{ss}: equal to PCI mod 30

PUCCH DMRS

- PUCCH DMRS is selected from 30 base sequences for PUCCH formats 1a, 1b,1c
  - The sequence is UE specific
- The cell specific cyclic shift (12 shifts available) is based on PCI (mod30) and helps to differentiate between UEs sharing the PUCCH
- There are 12 available cyclic shifts and 3 orthogonal codes



- Format 2a, 2b



Physical Uplink Control Channel (PUCCH)

- Format 1,1a,1b are used for Scheduling Request and 1 or 2 HARQ ACK
  - A single Symbol d(0) is used to convey the information
    - Format 1: no modulation (0 bit); Format 1a: BPSK (1 bit); Format 1b: QPSK (2 bit)
  - A cell specific Base Sequence is selected based on PCI
    - If group hopping is enabled the base sequence changes between time slots (no planning required, but conflict exists)
    - Group hopping randomizes intercell interference
  - d(0) is multiplied by the Base Sequence
  - A cyclic shift is applied to each symbol row
    - The number of available cyclic shifts is signaled in the RRC message and is defined by Delta PUCCH Shift
    - Larger the number of cyclic shift used smaller is the cell range
  - Time specific scrambling is applied (0° or 90 ° phase shift) to reduce inter code interference
  - An UE specific orthogonal code is applied, defined by a code index
  - The number of multiplexing possibilities is shown below

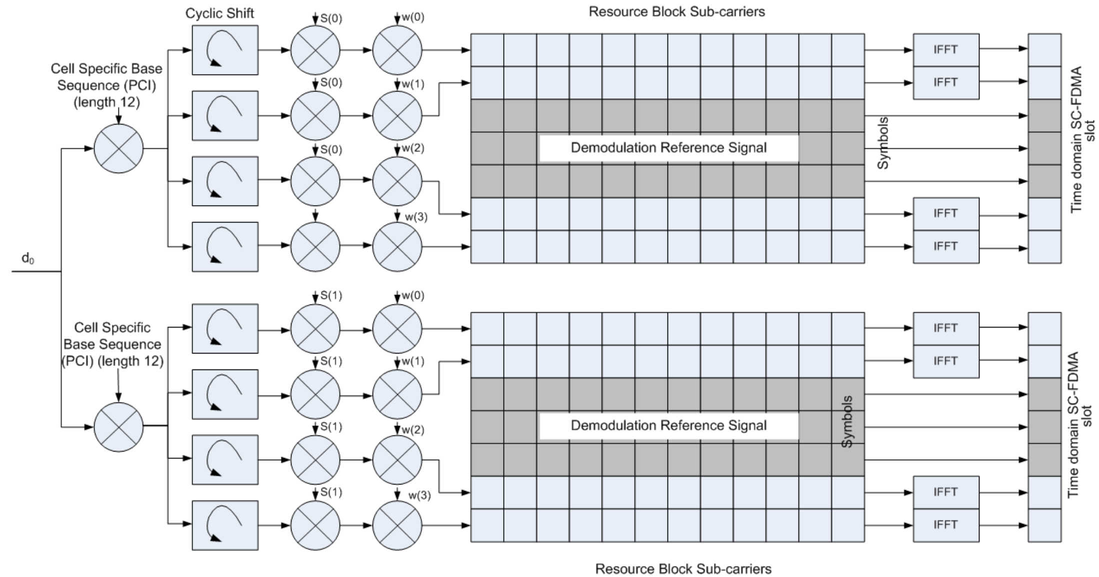
PUCCH delta shift	Total Cyclic shifts	Cell Range (km)
1	12	1.7
2	6	3.3
3	4	5.0

Code Index	w(0)	w(0)	w(0)	w(0)
0	1	1	1	1
1	1	-1	1	-1
2	1	-1	-1	1

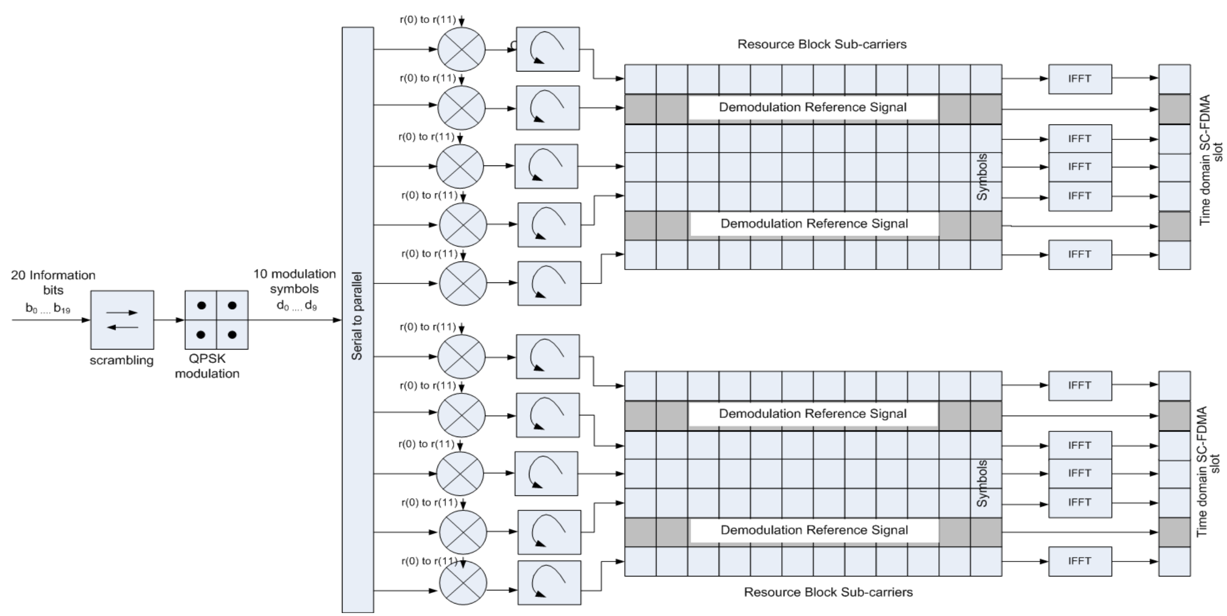
PUCCH delta shift	Total Cyclic shifts	Orthogonal codes	Resultant number of codes	Multipath delay (µs)	Multipath distance (km)
1	12	3	36	5.6	1.7
2	6	3	18	11.1	3.3
3	4	3	12	16.7	5.0

Physical Uplink Control Channel (PUCCH)

- Formats 1,1a,1b



- Formats 2,2a,2b

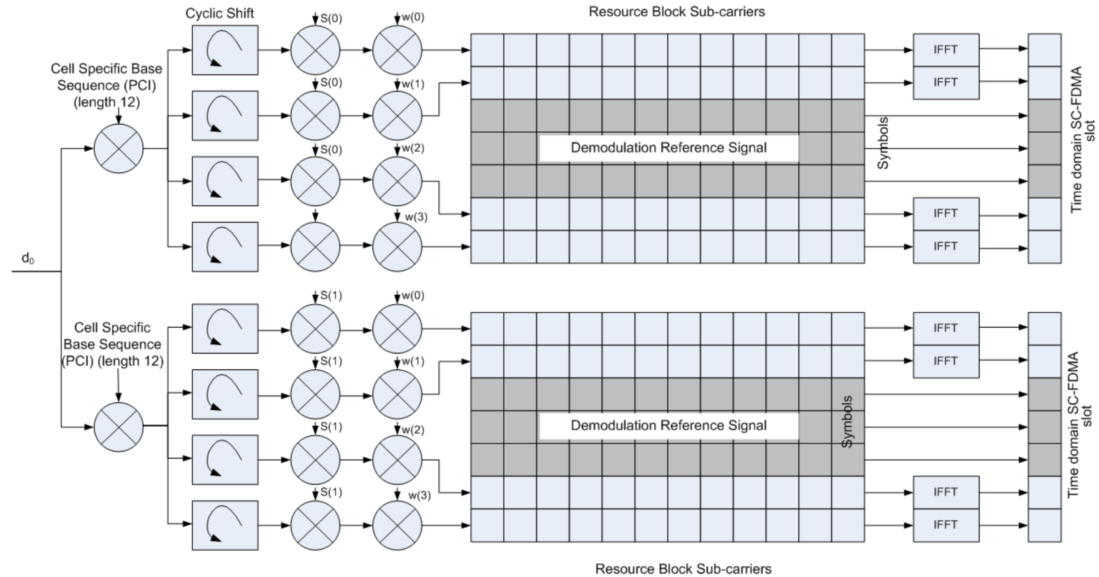


Physical Uplink Control Channel (PUCCH)

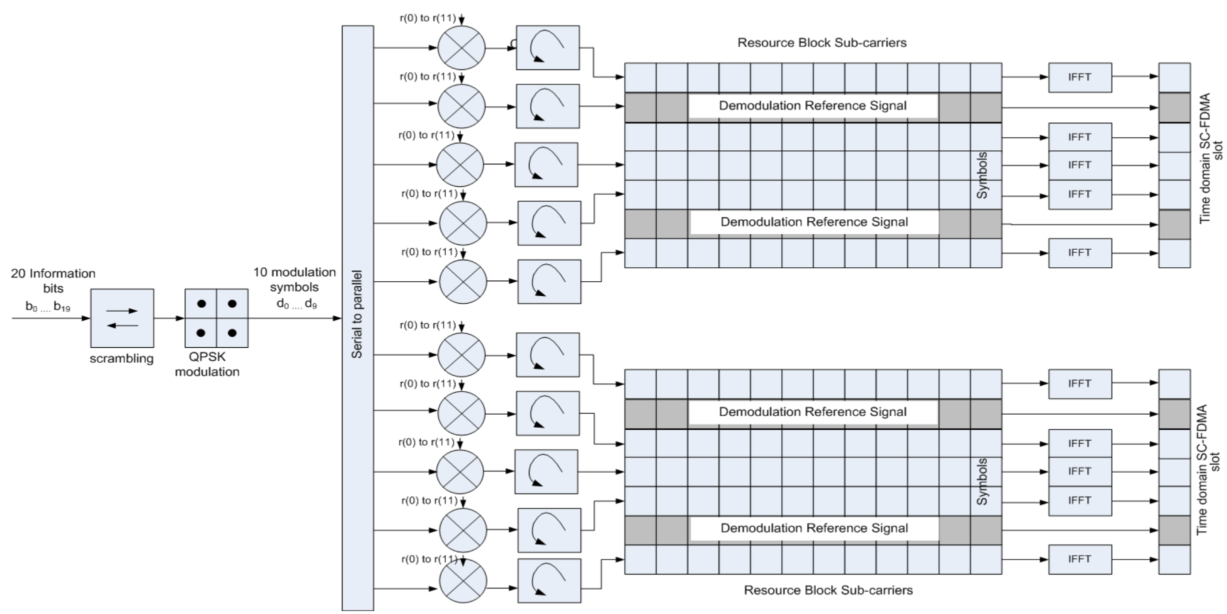
- Format 2, 2a, 2b is used for Channel State Information (CSI) report (20 to 22 bit)
  - Channel Quality Indicator (CQI)
  - Precoding Matrix Indicator (PMI)
  - Precoding Type Indication (PTI)
  - Rank Indication (RI)
- The HARQ bits are BPSK or QPSK coded and modulate the DMRS signal
- The 20 CSI bits are scrambled by a sequence based on the cell PCI and UE C-RNTI
- The 20 bits are then QPSK coded resulting in 10 symbols
- The 10 symbols are converted from serial to parallel and each multiplied cell specific Base Sequence of length 12
  - Group Base Sequence hopping can be applied
- Each sequence has a UE specific time domain cyclic shift applied

Physical Uplink Control Channel (PUCCH)

- Formats 1,1a,1b



- Formats 2,2a,2b

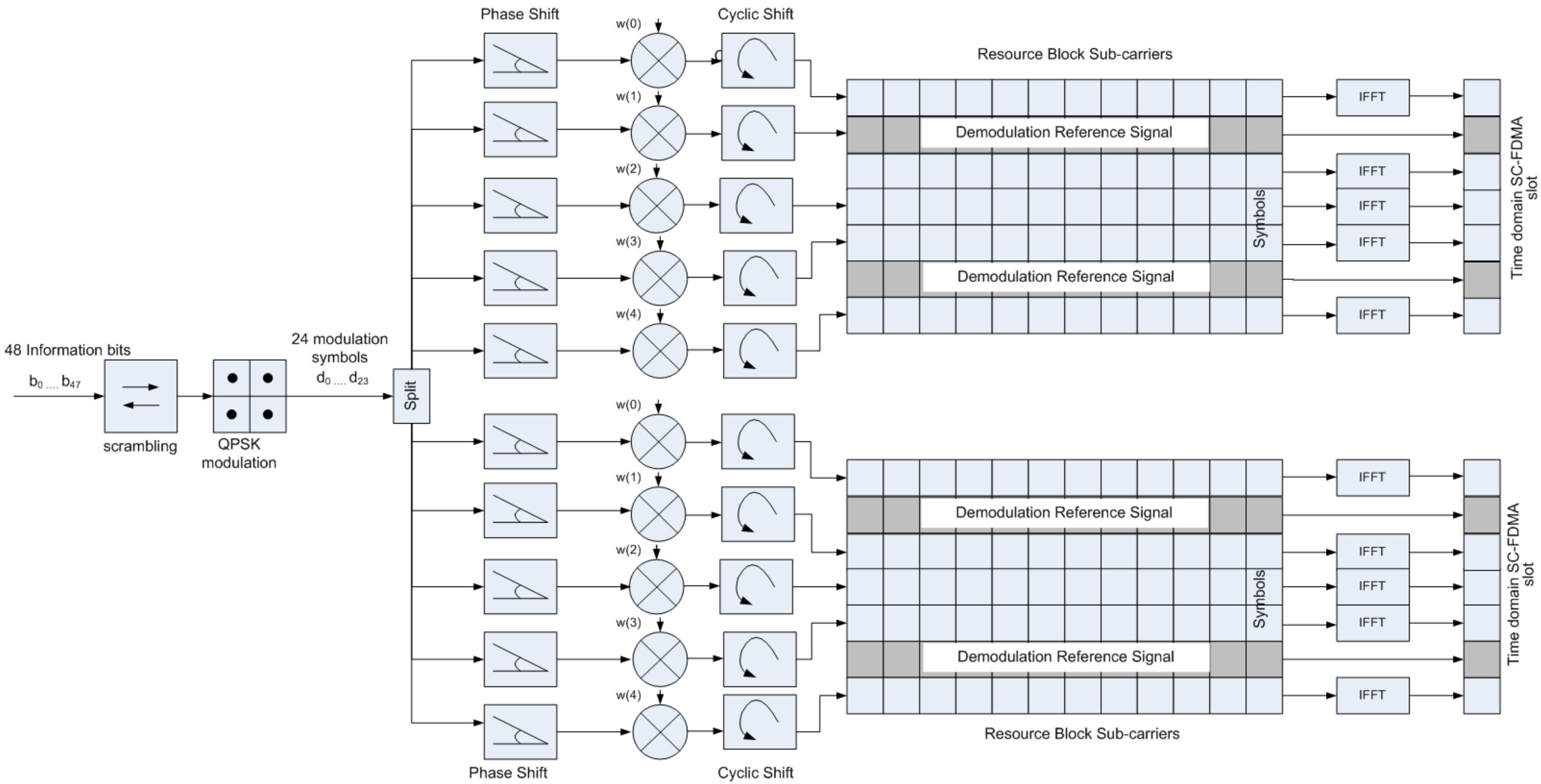


Physical Uplink Control Channel (PUCCH)

- Format 3 was introduced in Release 10, to support additional HARQ ACK requirements, besides the CSI information
  - FDD can have 2 HARQ ACK per subframe and up to 5 subcarriers
  - TDD PUCCH may have to acknowledge data sent over multiple downlink subframes, so it was designed to support up to 40 HARQ (by doing an AND of 20 HARQ)
- An SR can be also sent concatenated with the ACKs
- The 48 bits are scrambled with an UE specific sequence based on the cell PCI and UE C-RNTI
- The sequence is then QPSK modulated resulting in 24 symbols
- The symbols are then split in two sets of 12
  - Five duplicates are generated for each symbol and a phase shift is applied to each duplicate based on PCI and the symbol row
  - Each set of duplicates is multiplied by a different 5 bit orthogonal code
  - The orthogonal codes are UE specific and up to 5 UEs can be multiplexed on the same Resource Block
- Finally a set of time domain cyclic shifts is applied to the 10 sequences
  - This cyclic shifts are a function of PCI and the symbol row they are applied

Physical Uplink Control Channel (PUCCH)

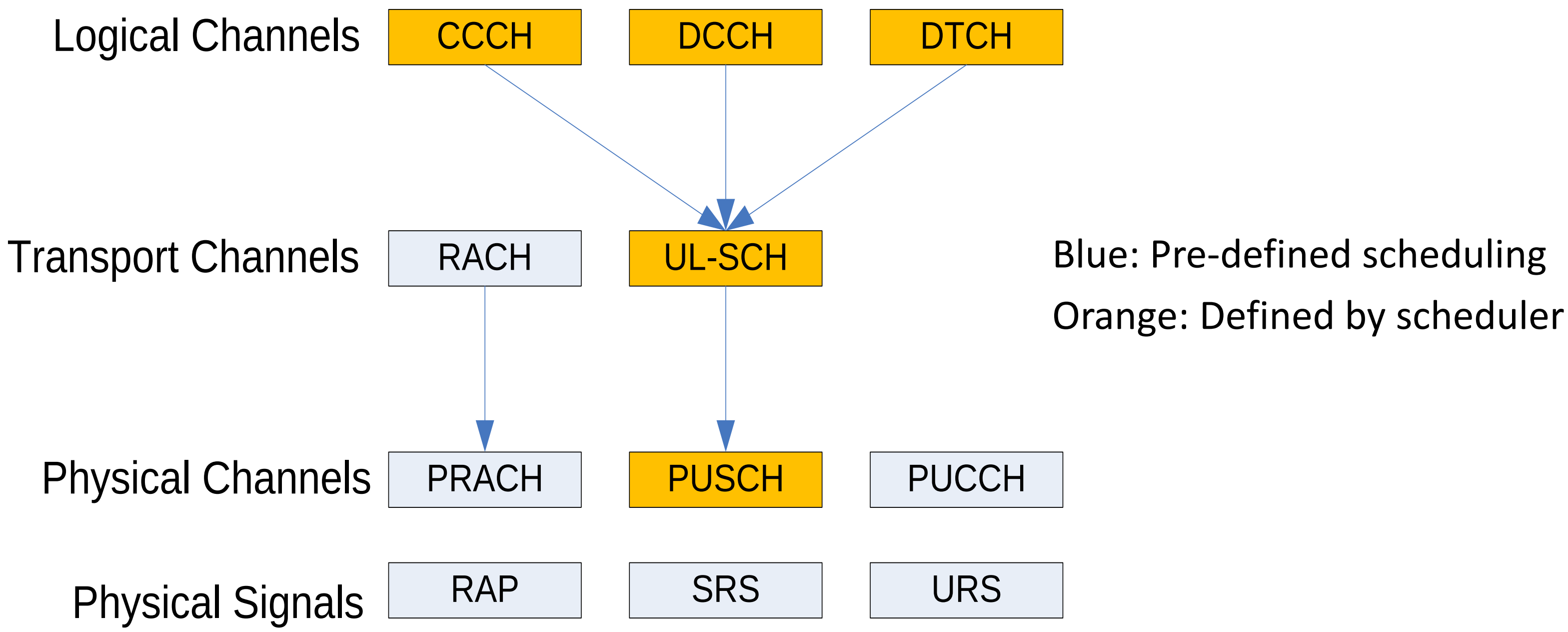
- Format 3



4.2.3 Physical Uplink Shared Channel

PUSCH

Uplink Channels



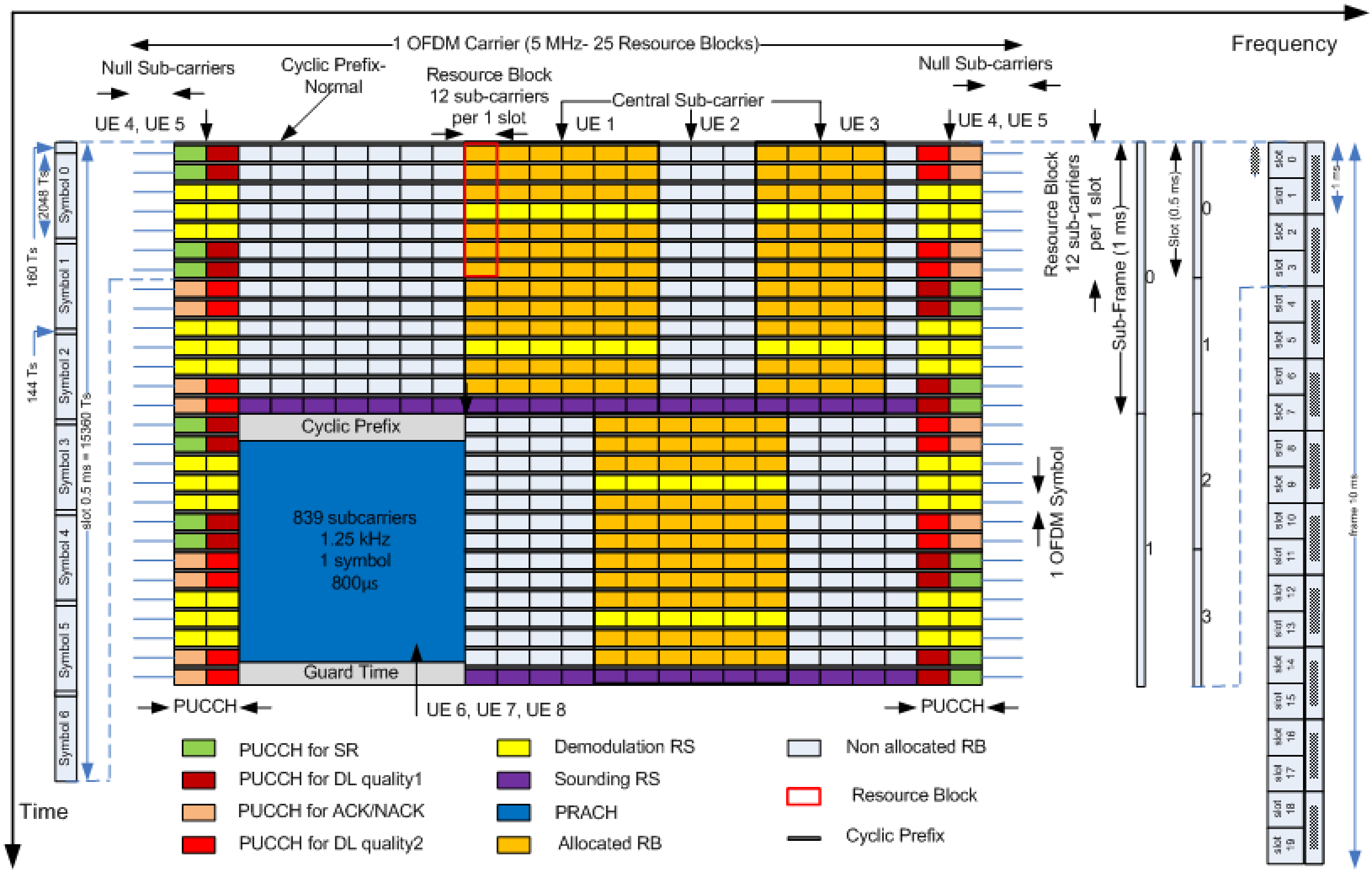
- CCCH: Common Control Channel
- DCCH: Dedicated Control Channel
- DTCH: Dedicated Traffic Channel
- PRACH: Physical Random Access Channel
- PUCCH: Physical Uplink Control Channel
- PUSCH: Physical Uplink Shared Channel
- PRACH: Physical Random Access Channel

- PRACH: Physical Random Access Channel
- PUCCH: Physical Uplink Control Channel
- PUSCH: Physical Uplink Shared Channel
- RACH: Random Access Channel
- RAP: Random Access Preamble
- SRS: Sounding Reference Signal
- UL: Uplink
- URS: Uplink Reference Signal

Physical Uplink Shared Channel (PUSCH)

- PUSCH carries:
  - RRC signalling messages (SRBs)
  - Uplink Control Information (UCI)
  - Application Data
- PUSCH uses QPSK, 16QAM, 64QAM if supported by UE
  - Modulation is indicated in DCI formats 0 to 4

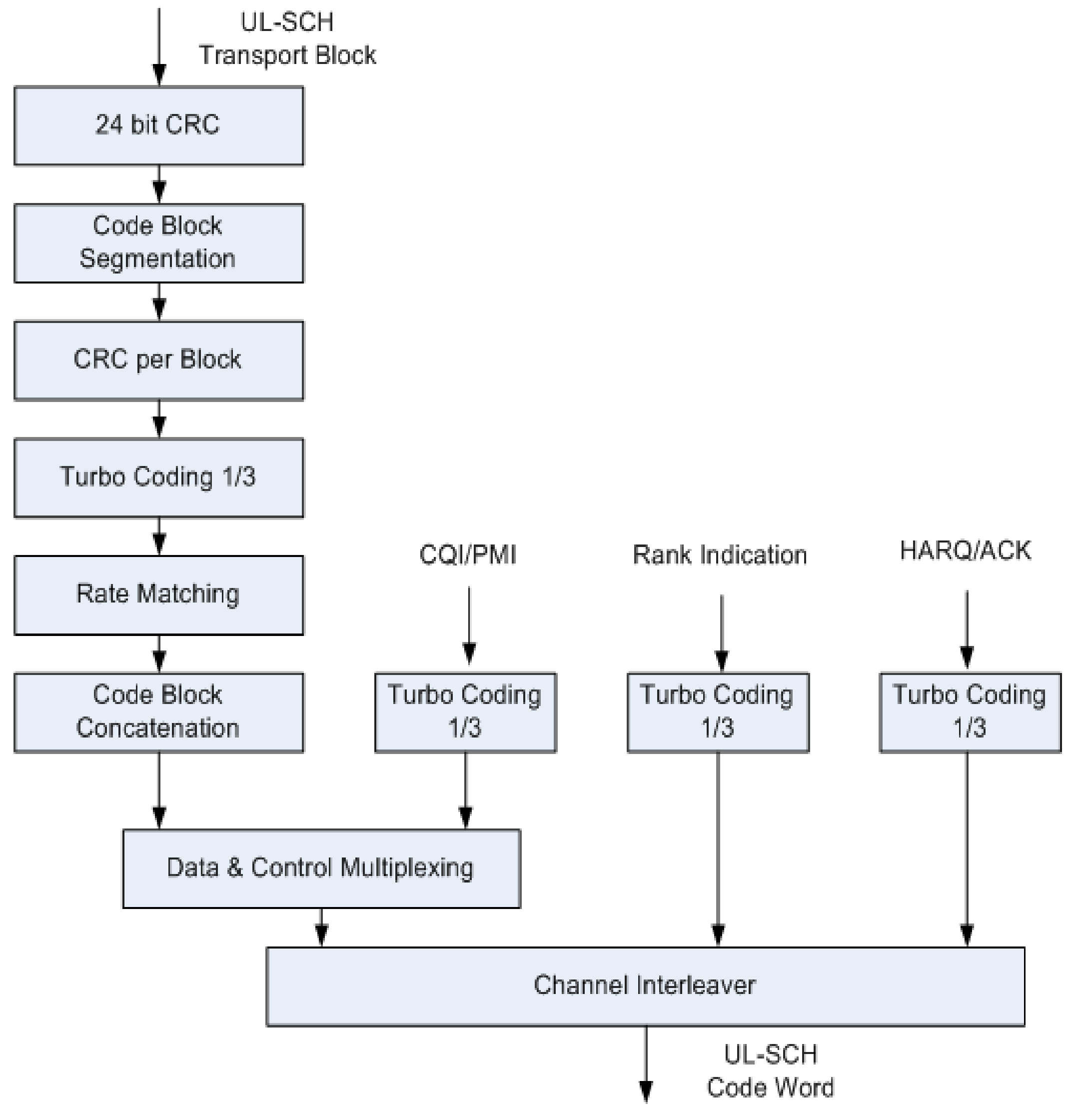
PUSCH



1 OFDM Carrier (5 MHz- 25 Resource Blocks)
Frequency
Null Sub-carriers
Cyclic Prefix-Normal
Resource Block 12 sub-carriers per 1 slot
Central Sub-carrier
Null Sub-carriers
UE 4, UE 5
UE 1
UE 2
UE 3
UE 4, UE 5
Symbol 0
Symbol 1
Symbol 2
Symbol 3
Symbol 4
Symbol 5
Symbol 6
2048 Ts
160 Ts
144 Ts
slot 0.5 ms = 15360 Ts
Cyclic Prefix
839 subcarriers
1.25 kHz
1 symbol
800µs
Guard Time
PUCCH
UE 6, UE 7, UE 8
PUCCH
Resource Block 12 sub-carriers per 1 slot
Sub-Frame (1 ms)
1 OFDM Symbol
Time
PUCCH for SR
PUCCH for DL quality1
PUCCH for ACK/NACK
PUCCH for DL quality2
Demodulation RS
Sounding RS
PRACH
Allocated RB
Non allocated RB
Resource Block
Cyclic Prefix

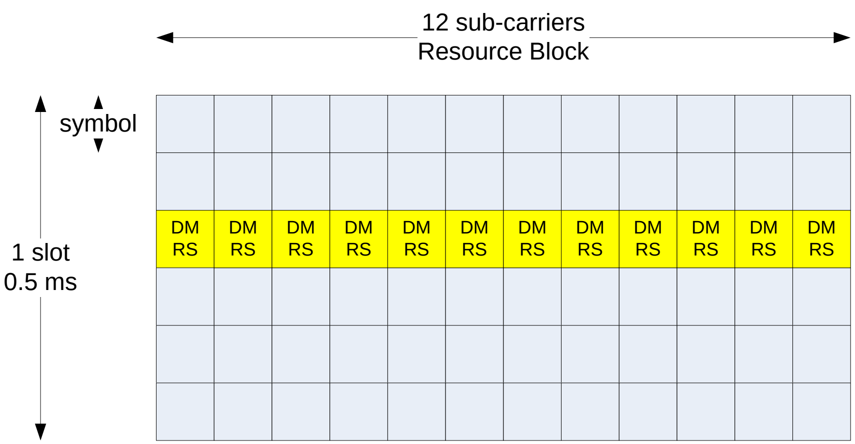
Uplink Shared Channel (UL-SCH)

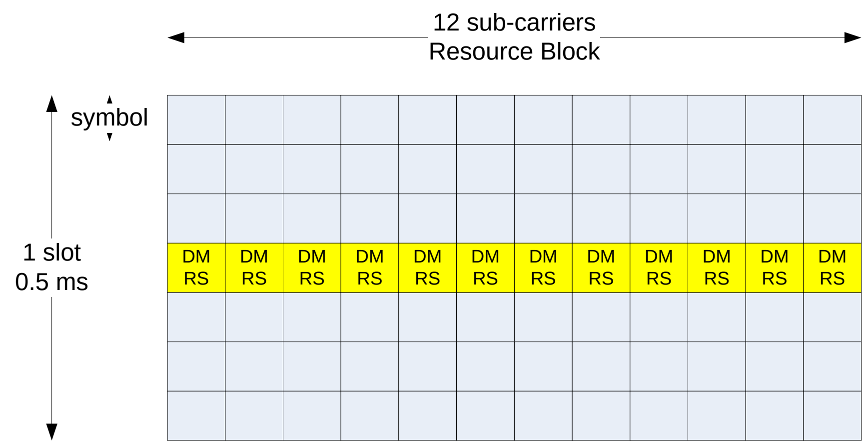
- UL-SCH is the transport channel for:
  - RRC (Radio Resource Control)
  - UCI (Uplink Control Information) data
- Maximum code word size is 6144 bit
- A UL-SCH codeword has to be transferred during a single subframe (1 ms)



PUSCH DMRS

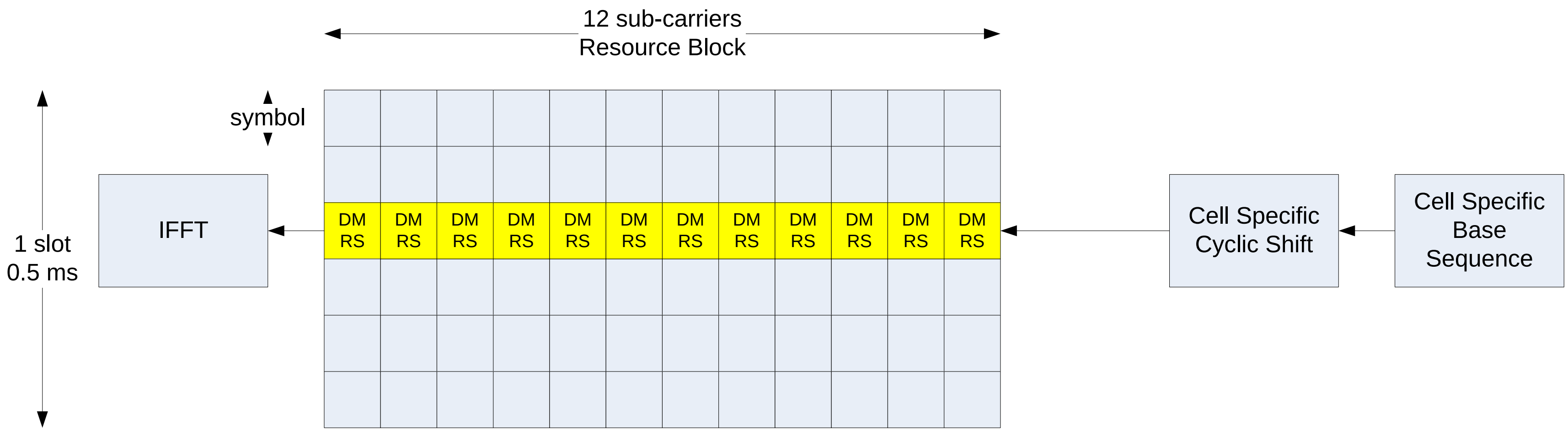
- R8 and R9 limit the transmission of PUSCH to a single antenna port
- The sequence choice is cell specific depends on
  - Physical Cell Identity (PCI)
  - Cell Specific Offset (Δ_{ss}) used if multi user MIMO is used, but only guarantees orthogonality if the UEs transmit same number of RBs
- R 10 fixes the issue above and allows the transmission over up to 4 antenna ports
  - Orthogonal Cover Code (OCC) is used to provide the additional dimensions of differentiation



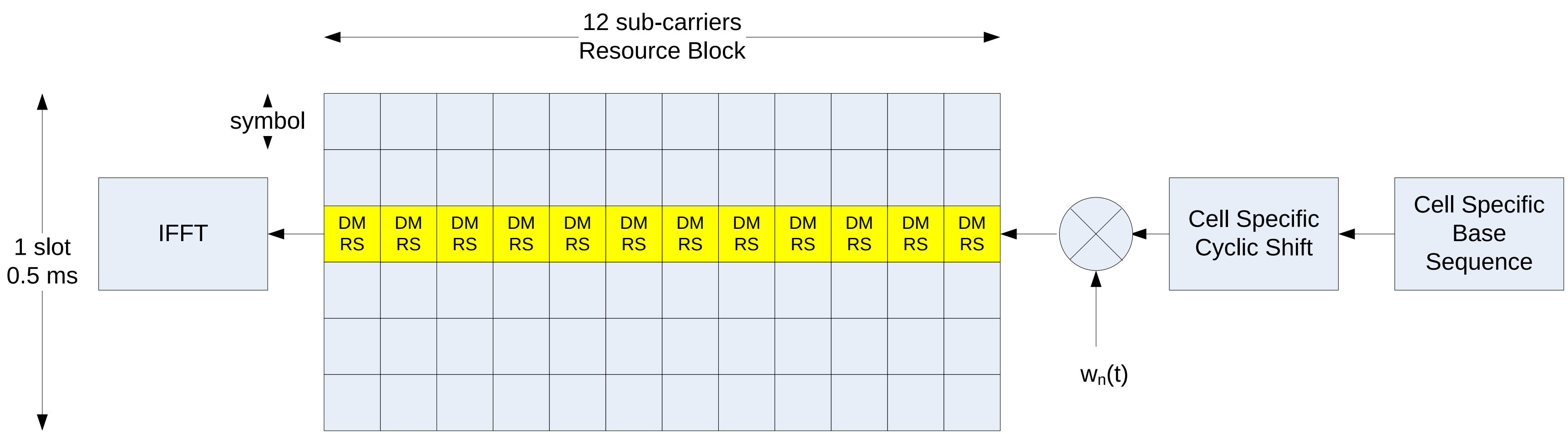


PUSCH DMRS

- R 8 and R9 PUSCH DMRS



- R 10 PUSCH DMRS (includes OCC-Orthogonal Cover Code)

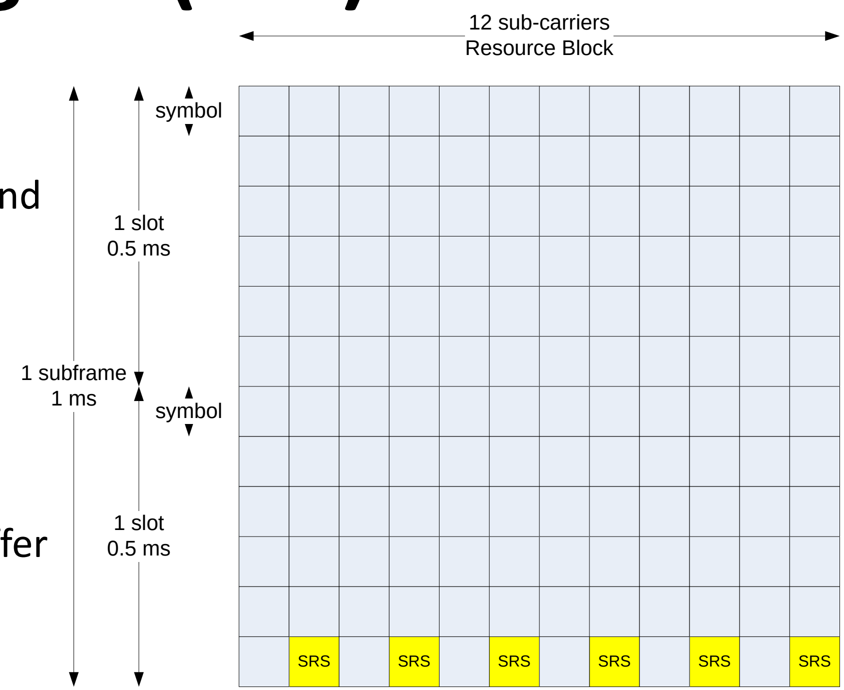


4.2.4 Sounding Reference Signal

SRS

Sounding Reference Signal (SRS)

- SRS is used to:
  - observe the channel quality over a bandwidth section and use the information for scheduling and link adaptation
  - Uplink timing estimation
  - Uplink power control
  - Angle of Arrival (AoA) measurements for beamforming
  - SRS has an advantage over CSR as it does not suffer interference from neighbor reference signals
- SRS bandwidth (# RB) is defined by:
  - 7 Cell Specific SRS Bandwidth configurations
  - Each configuration has 4 UE specific configurations
- SRS subframe configuration has:
  - 15 subframe configurations varying from 1 allocation per frame to 10 allocations per frame
- SRS Configuration Index
  - Defines SRS periodicity and frame offset
  - Varies from 0 to 636 subframes



SRS Configuration Index (I_{ss})	SRS Peridicity (ms)	SRS Subframe Offset
0 to 1	2	I_{ss}
2 to 6	5	I_{ss}-2
7 to 16	10	I_{ss}-7
17 to 36	20	I_{ss}-17
37 to 76	40	I_{ss}-37
77 to 156	80	I_{ss}-77
157 to 316	160	I_{ss}-157
316 to 636	320	I_{ss}-317

5 Resource Optimization

Reuse

Resource Assignment Planning

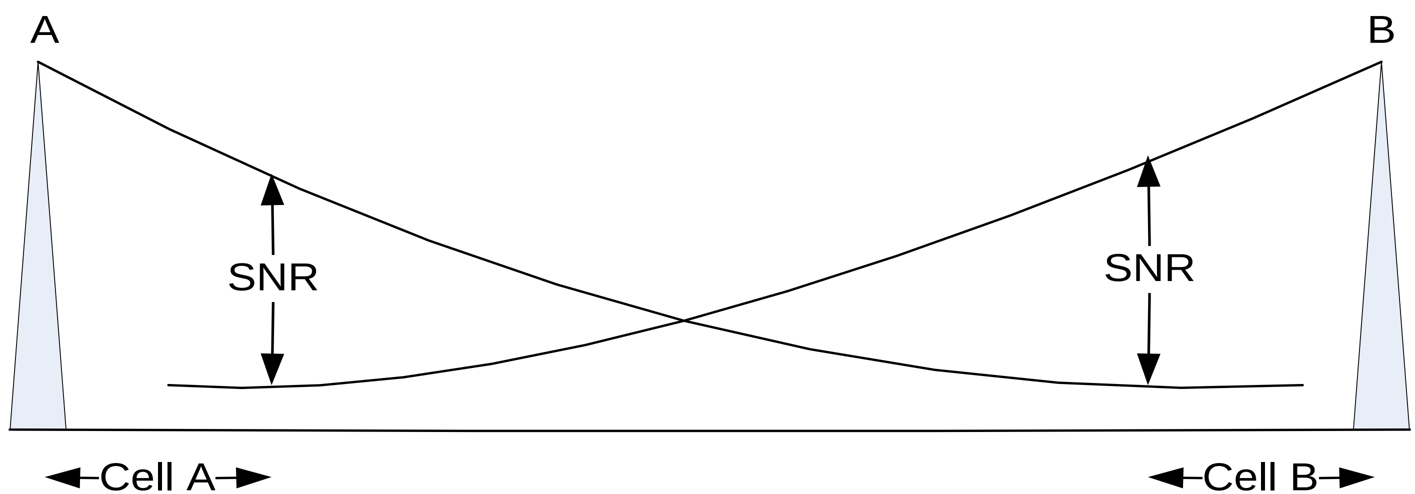
ICIC

5.1 Reuse in LTE

Reuse in LTE

- Reuse in Cellular
  - Load effect
  - Probabilistic conflit
- Reuse in LTE
  - Reuse 1
    - Actual reuse
  - Comparing reuse throughput

Required SNR (dB)			
	QPSK	16QAM	64 QAM
Gaussian	2.5	8.2	12.1
Rayleigh	15.7	21.3	25

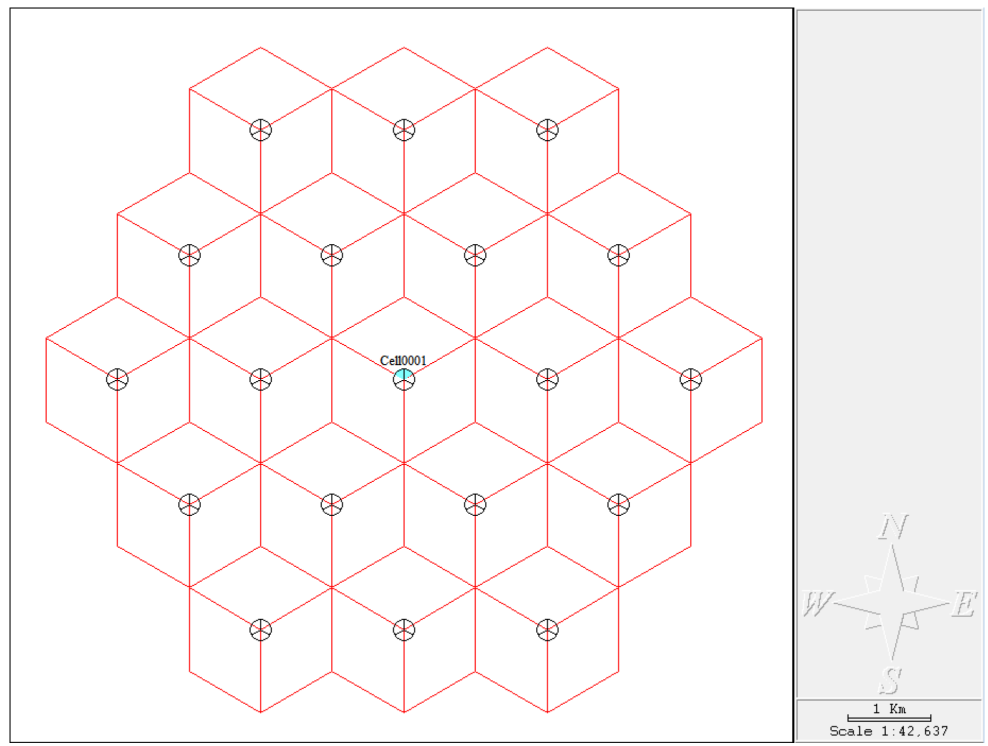


Reuse in LTE

- 3GPP designed LTE for a reuse of 1
  - Reuse of 1 creates significant interference
  - Interference has to be compensated by sending more robust signals
    - FEC detects and corrects signal errors
    - 3GPP choose a base FEC with a coding rate of 1/3 (spectral efficiency of 0.333) using a turbo encoder
    - Additonal strength is added by retransmitting the signal several times
    - Equivalent signal repetition varies from 8.5 times to 1.1 time
    - Repetition reduces capacity
  - Traditional reuses divide the resources in groups and also reduce capacity
- Which reuse will result in the highest throughput?

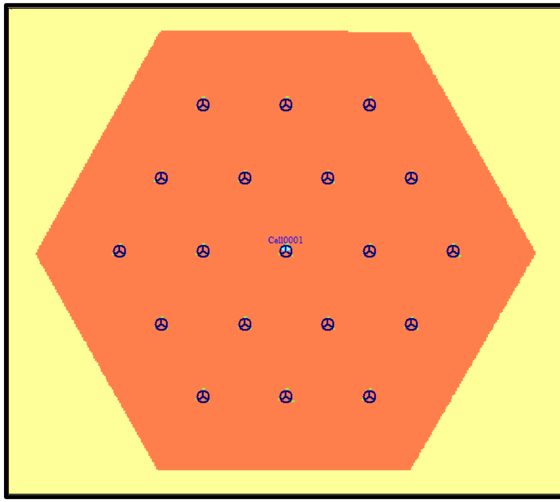
Reuse in LTE

- A theoretical experiment was set to find out which reuse will result in the highest throughput
- A cluster of 19 cells was arrnged with the following characteristics
  - Cell radius of 0.85 km
  - Tower height of 30 m
  - Flat terrain
  - No morphology
  - Propagation slope
    - 30 dB/decade

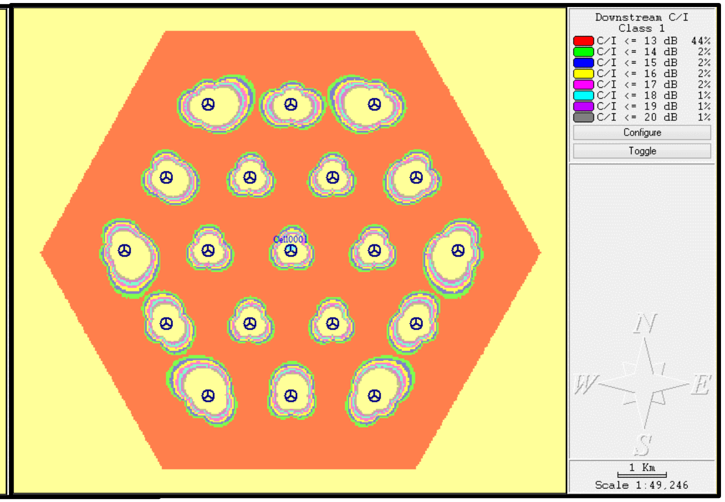


Downstream C/I for different reuses

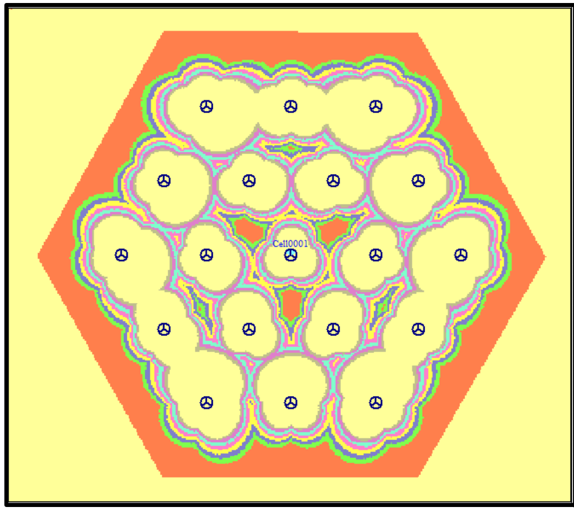
Reuse 1



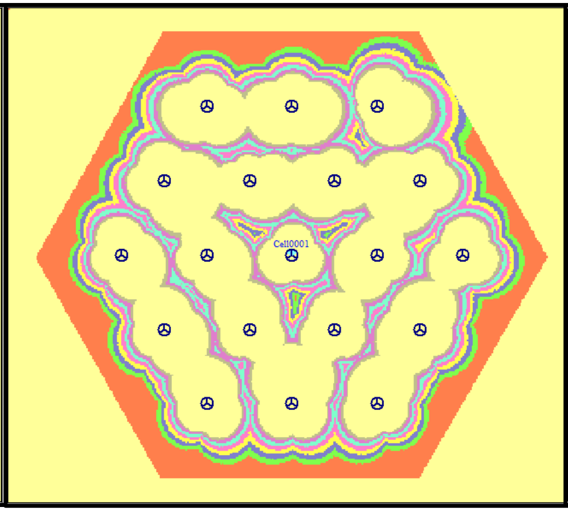
Reuse 3



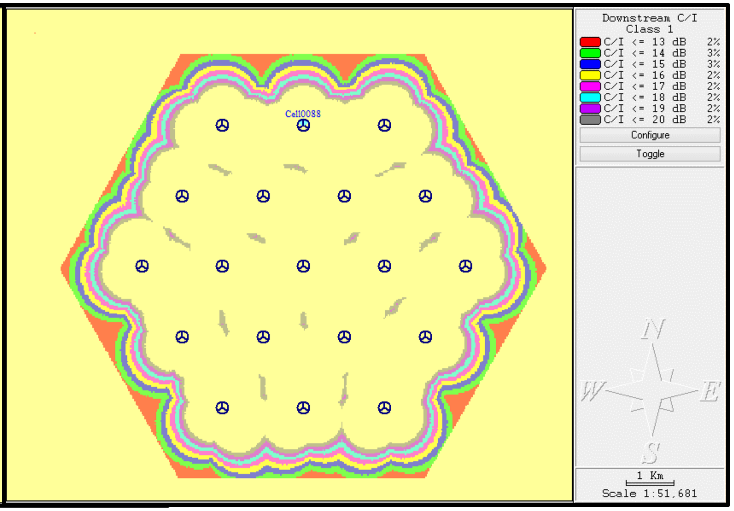
Reuse 9



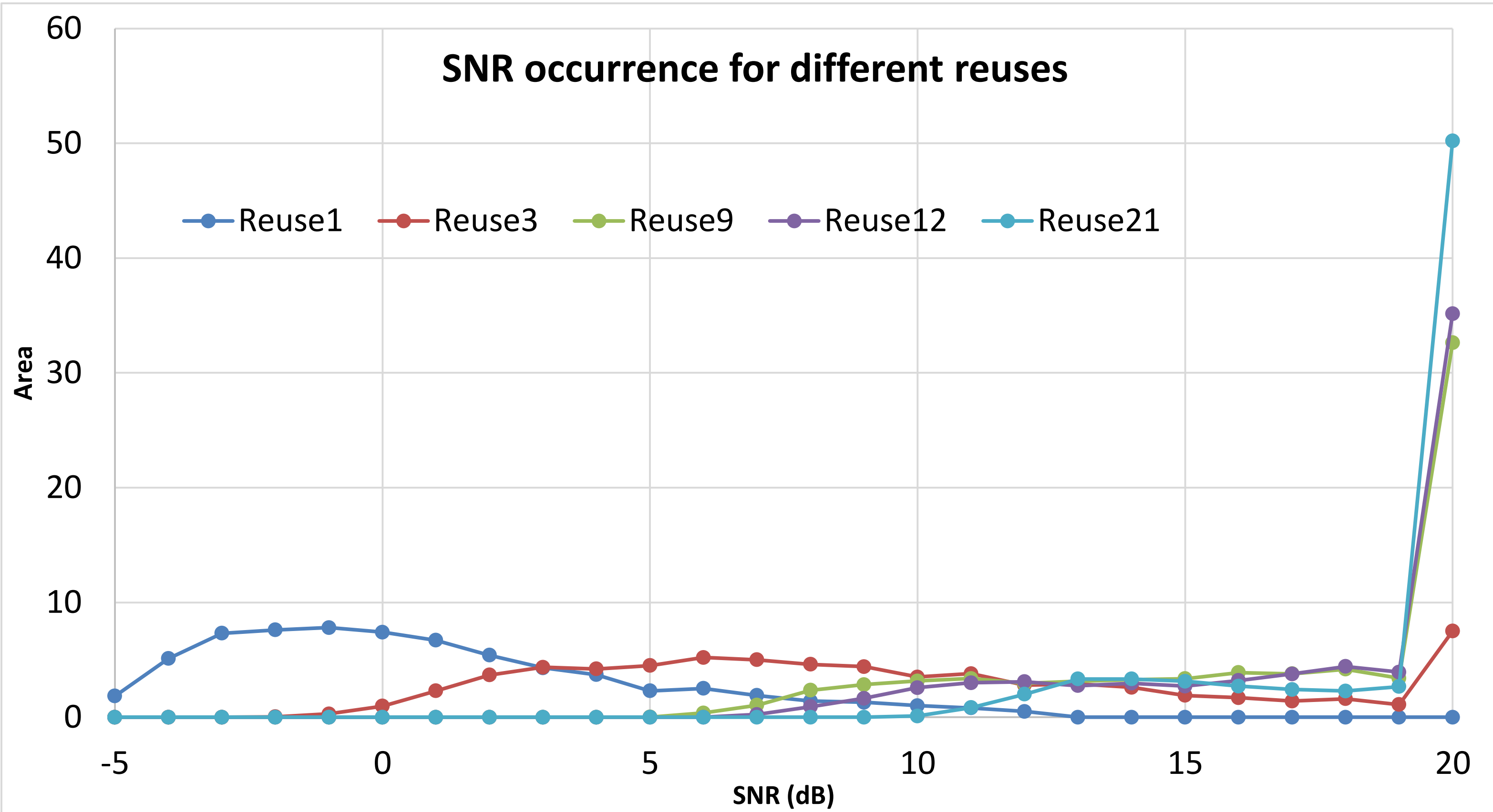
Reuse 12



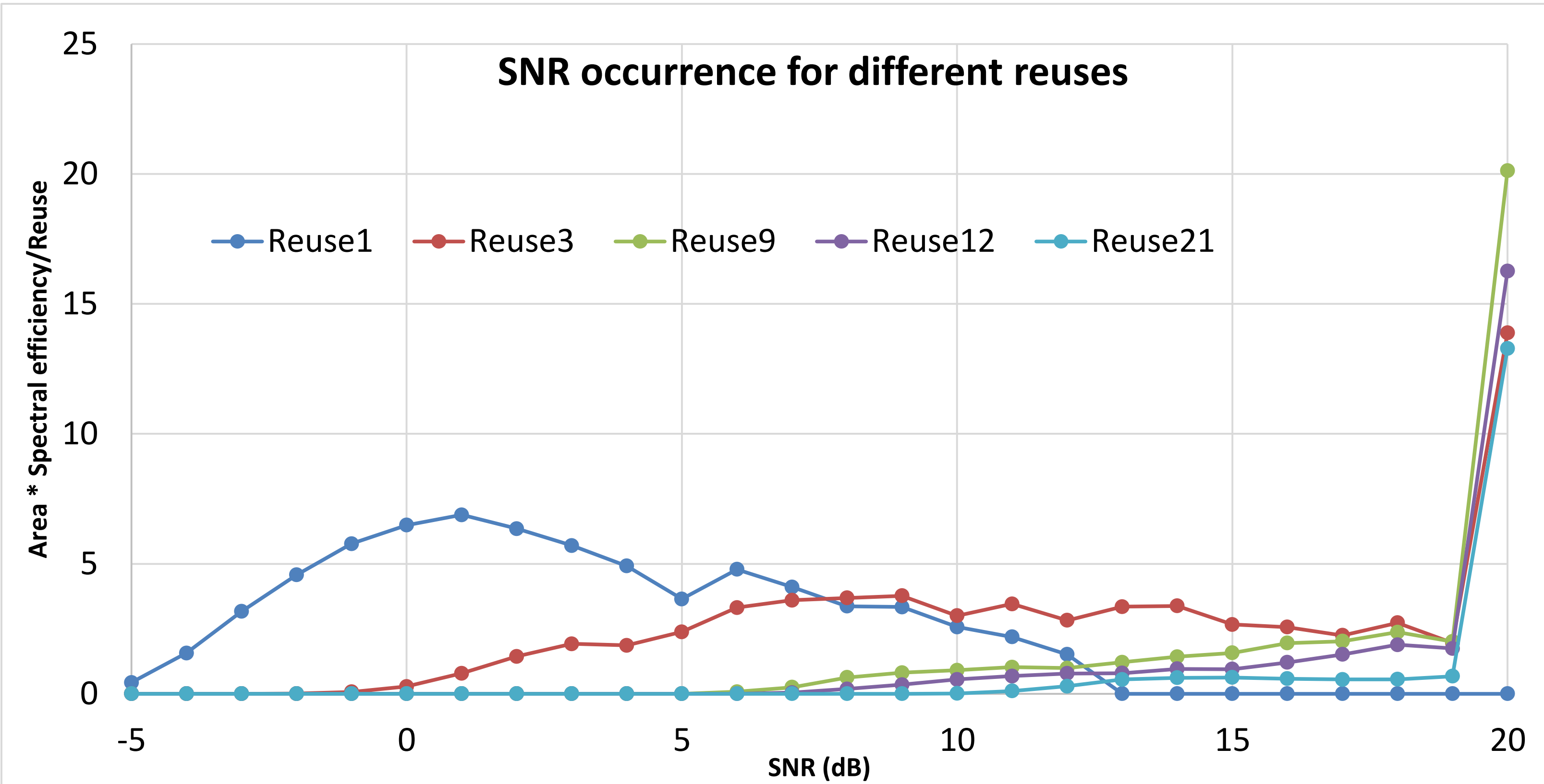
Reuse 21



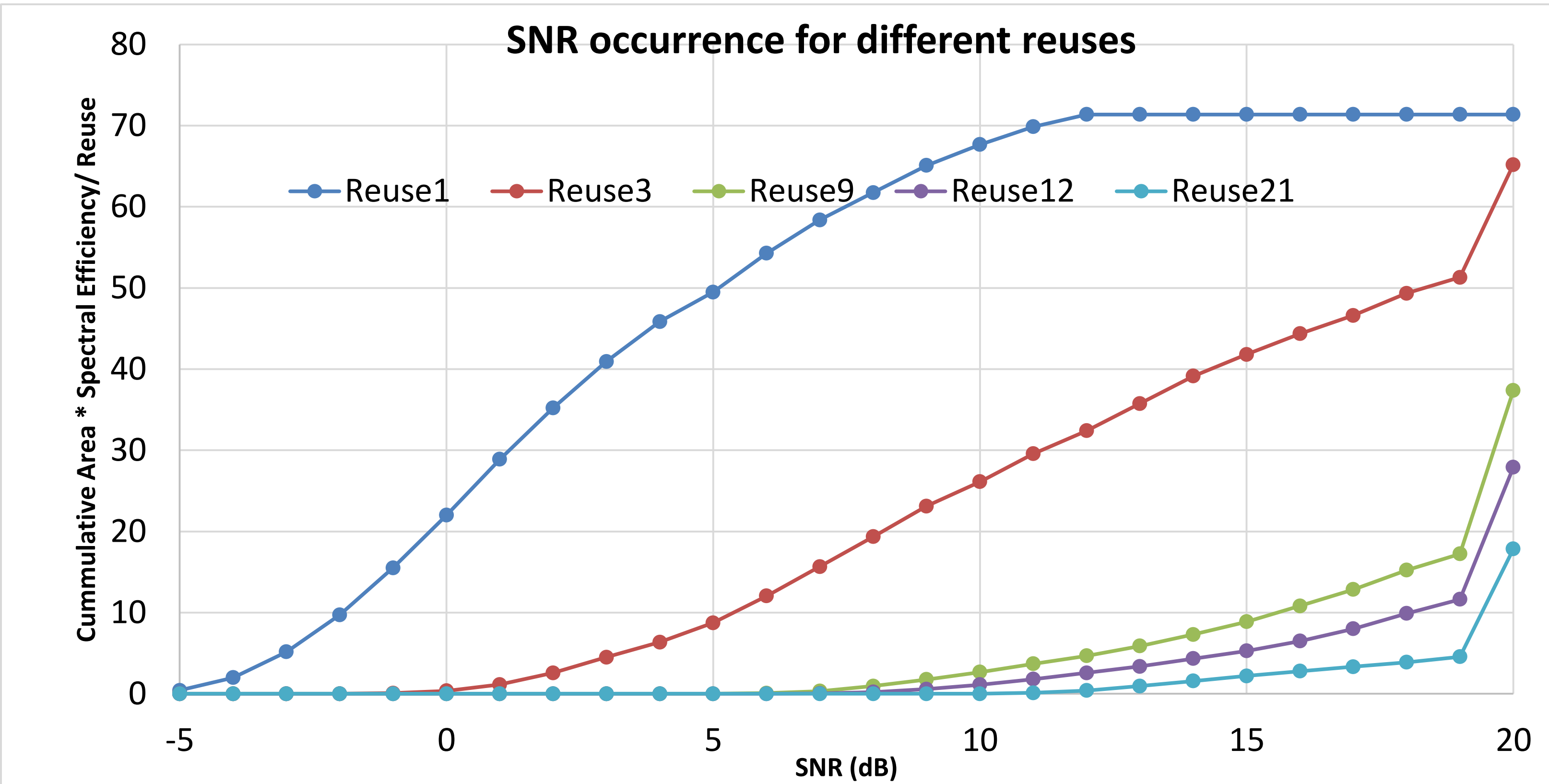
SNIR ocurrence per area



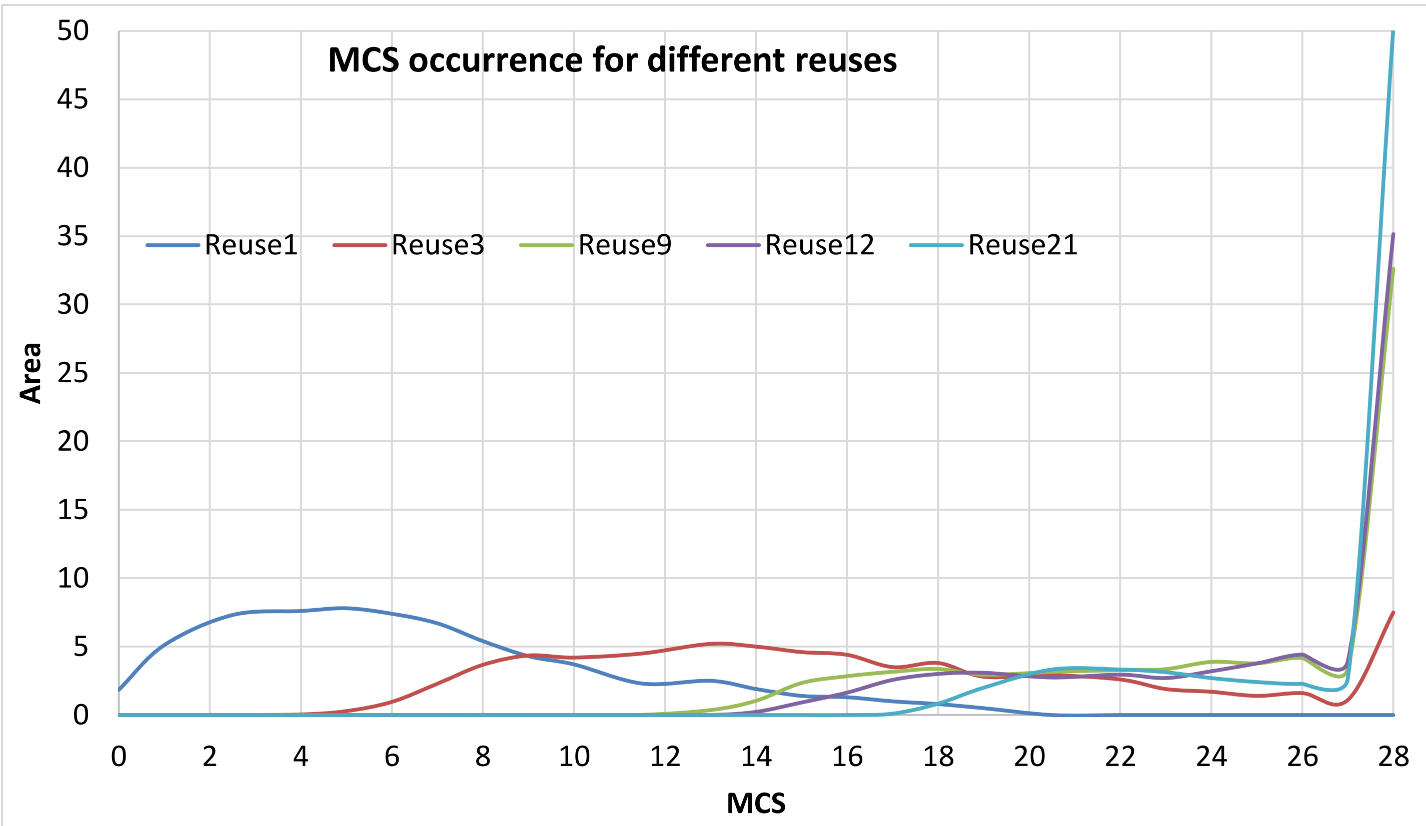
SNIR ocurrence per area*spectral efficiency/reuse



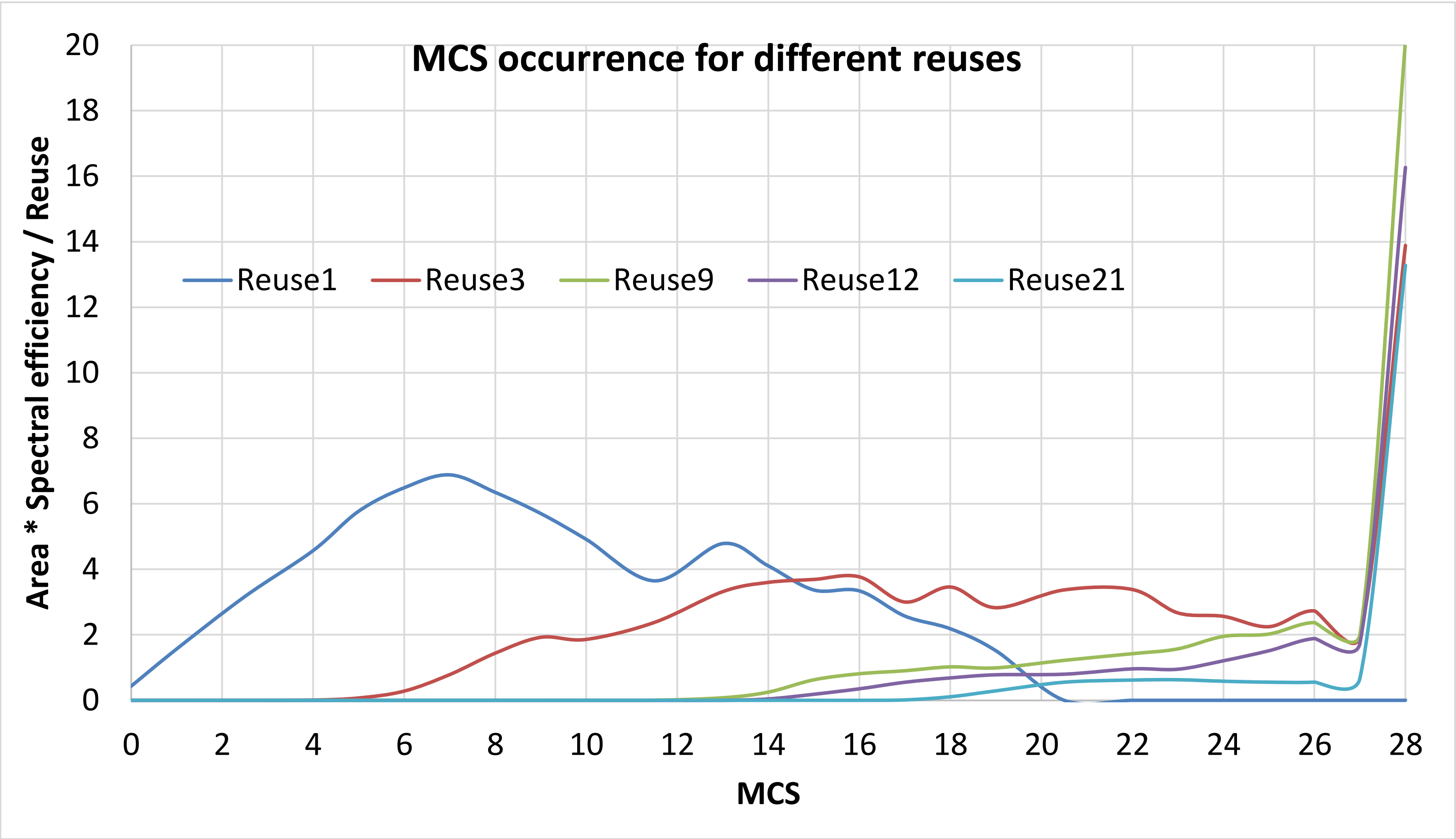
Cumulative SNIR ocurrence per area*spectral efficiency/reuse



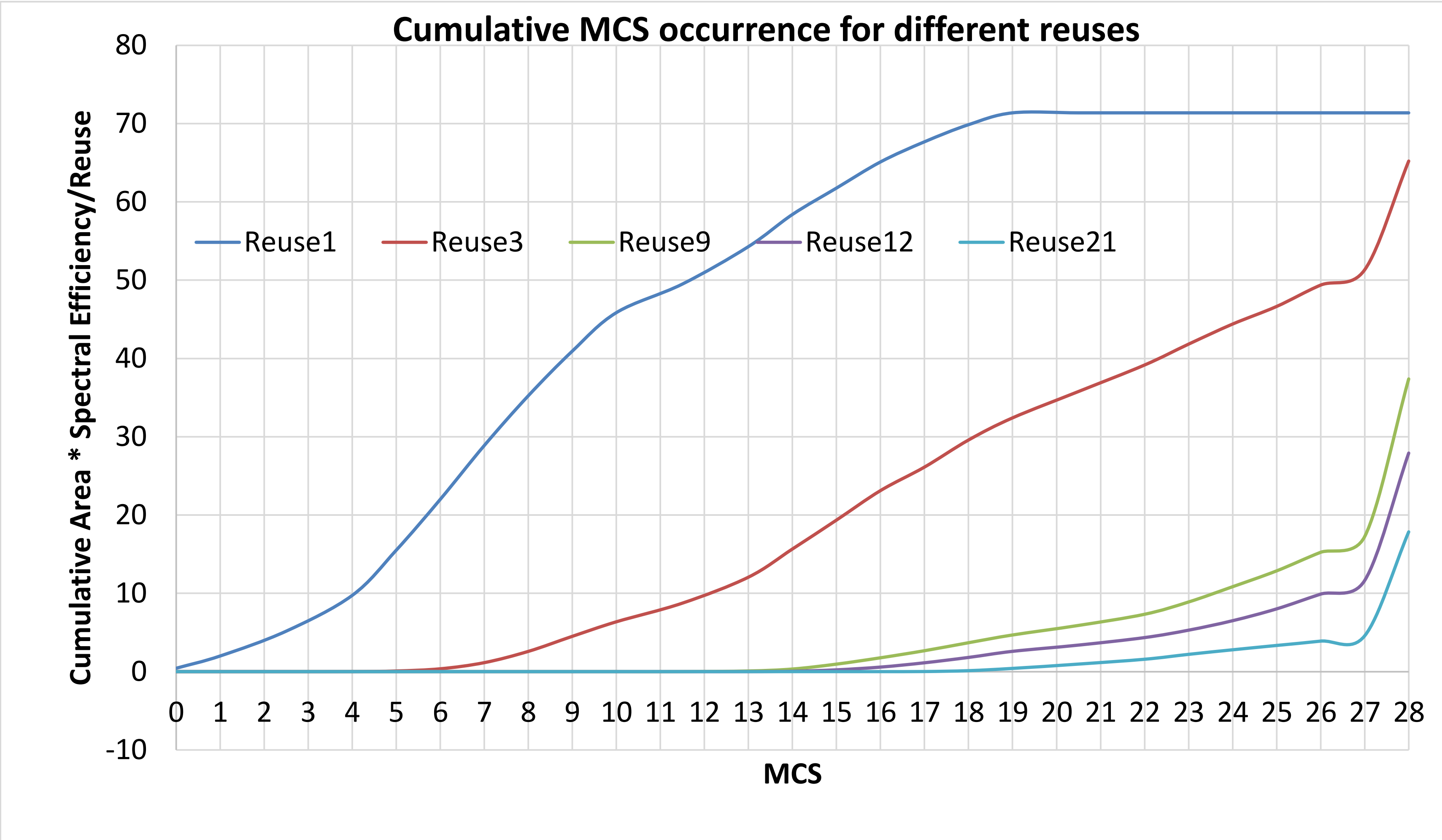
MCS ocurrence per area



MCS ocurrence per area*spectral efficiency/reuse



Cumulative MCS ocurrence per area*spectral efficiency/reuse



Observations

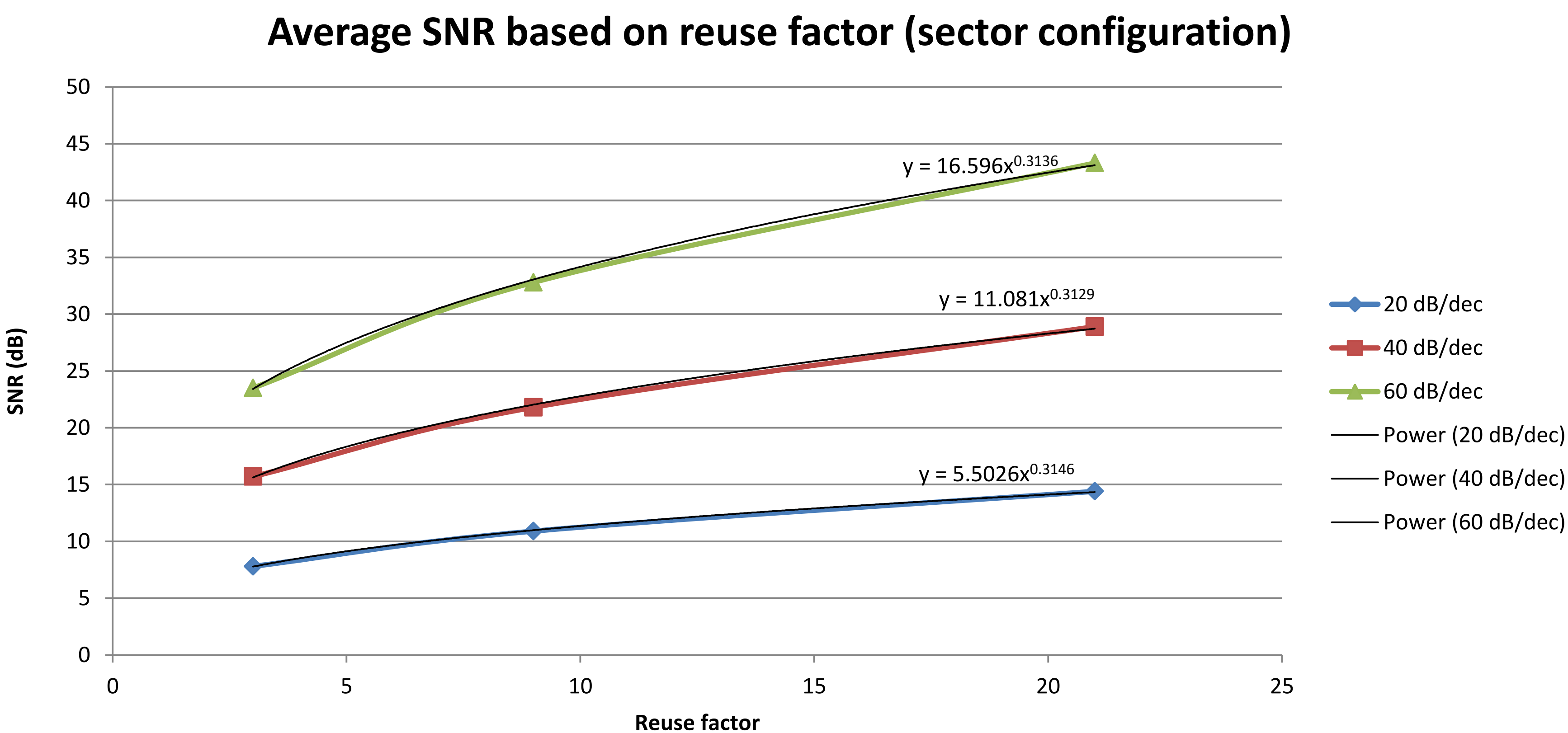
- Reuse 1 gave the highest throughput (19% above reuse 3)
- This assumes that repetition does increase the signal strength and that the interference is uncorrelated
  - The only mechanism to uncorrelate interference is fading
  - Actual result for reuse 1 should be worst than predicted
- Morphology will add losses and reuse 1 area will drop
  - Other reuses have a margin in the high MCSs
- Reuse 1 opeartes mainly in QPSK, all the other rueses operate mainly in 64QAM
- Traffic concentration in the center of the cell should favor the other reuses
- The most efficient reuse should be reuse 3

Reuse Modulation	1	3	9	12	21
QPSK	57%	7%	0%	0%	0%
16QAM	34%	29%	5%	2%	0%
64QAM	9%	65%	95%	98%	100%

	Reuse 1	Reuse 3	Reuse 9	Reuse 12	Reuse 21
Average Spectral Efficiency	1.41	3.53	4.87	5.00	5.25
Average Relative Throughput	1.41	1.18	0.54	0.42	0.25

Average SNR according to reuse factor

- The equations to find the reuse from the target SNR are:
- For 20 dB/dec: $$x = \left(\frac{SNR}{5.5026}\right)^{3.18877551}$$
- For 40 dB/dec: $$x = \left(\frac{SNR}{11.081}\right)^{3.195909}$$
- For 60 dB/dec: $$x = \left(\frac{SNR}{16.596}\right)^{3.17864}$$



5.2 Resource Assignment Planning

Resource Assignment Planning

- Resource Planning is still the sure way to maximize network throughput
- It also allows for the analysis of issue, which is impossible to do in a dynamically adjusted network
- The ideal Resource Planning unit is a Resource Block Group (RBG), numbered across a whole frame
  - This allows for optimum frequency and time domain allocation
- The resource scheduler can be one of three types:
  - Start-stop: a block of RBGs is assigned to each cell; partial overlap is allowed
  - Start: an RBG start location is assigned, so the initial allocations do not conflict between neighbor cells, but overlap may happen with high traffic
  - Random: cells choose their start point at random, avoiding planning; it is not recommended as it will worst performance than the other options

5.3 Small Cells and Hetherogeneous Networks

Small Cells

HetNet

Small Cells and HetNet

- Growing number of subscribers and demand for bandwidth → macro base stations can barely meet demand
- Introduction of Low Power Nodes (LPNs) = picocells, femtocells, and Relay Nodes (RNs).
- Network starts with macro cells for coverage, then LPNs are added for capacity, blind spots, and indoor coverage
- To expand LPN coverage – Cell Range Expansion (CRE)
  - Typically UE served by cell with strongest SINR
  - With LPNs this metric is <u>not</u> efficient; large disparity in transmit power between macro (46 dBm), pico cells (30 dBm) and femto cells (23 dBm)
  - CRE allows UEs to stay connect to cells with weaker power
  - Thus LPNs share more network load

Small Cell

- What is a small cell?
  - A micro cell
  - A metro cell/ Distributed Antenna System (DAS)
  - A pico cell
  - A repeater cell
    - Transparent to eNB
  - A relay cell
    - A new cell backhauled by eNB
  - A Cloud RAN
  - A femto cell
  - A Home eNB
  - A Wi-Fi hot spot

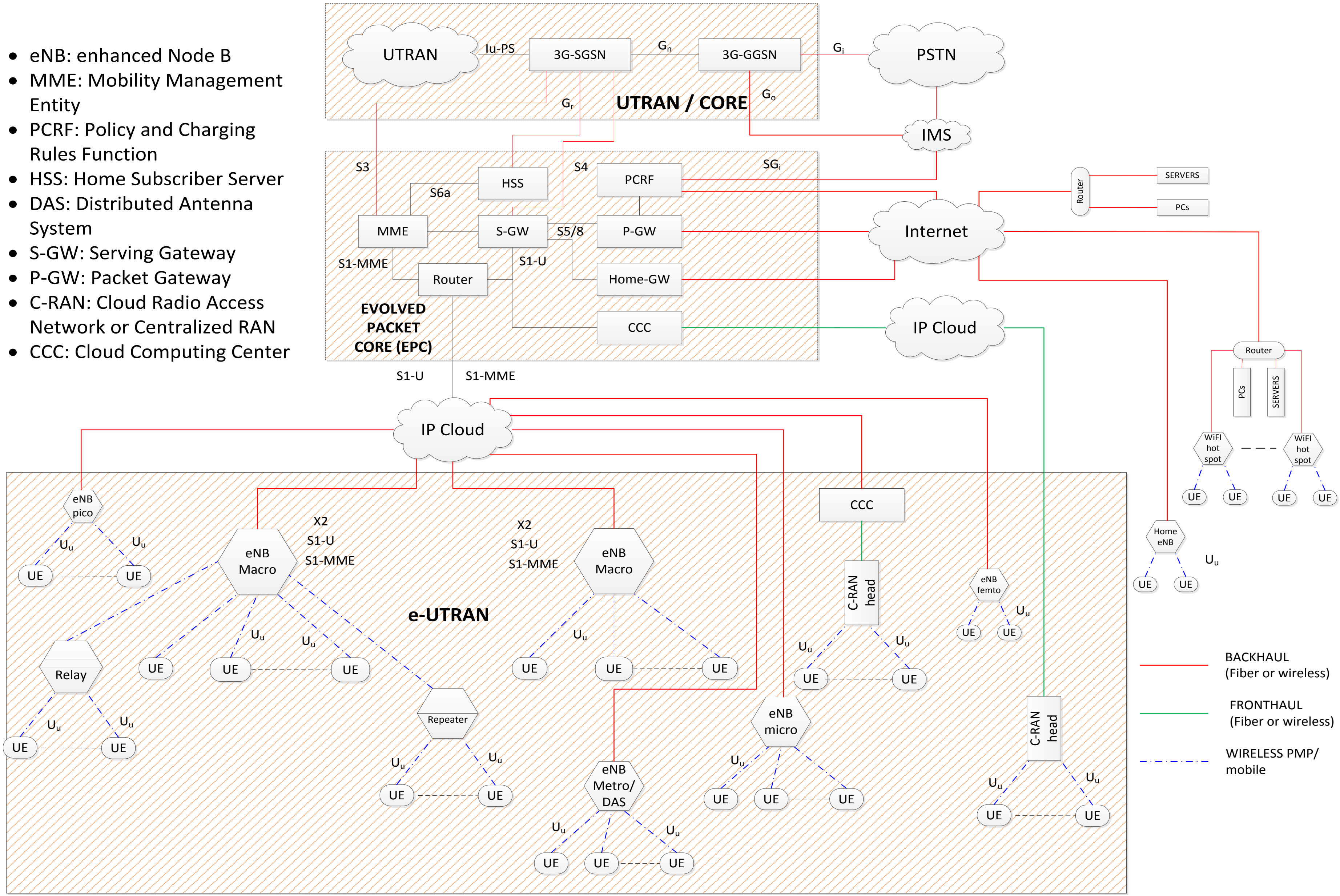
- What is a backhaul/ fronthaul?
  - A fiber or wireless connection from the cell towards the core
  - Fiber is terrestrial, wireless is aerial
  - Wireless can connection can be via:
    - eNB (repeater and relay)
    - Backhaul radio
  - Backhaul radios use adaptive modulation up to 1024QAM
    - Up to 5 bit/s/Hz

Heterogeneous Networks

- Wireline and wireless networks backhaul is becoming integrated by the use of IP
- Network users want seamless operation between wireline and wireless, with same performance
- Traffic from all kinds of wireless cells has to be combined with landline to reach private IP clouds or the Internet
- Backhaul planning has to consider the availability of fiber and complement it with wireless backhaul, in what we call metro fiber solution

Heterogeneous Network

- eNB: enhanced Node B
- MME: Mobility Management Entity
- PCRF: Policy and Charging Rules Function
- HSS: Home Subscriber Server
- DAS: Distributed Antenna System
- S-GW: Serving Gateway
- P-GW: Packet Gateway
- C-RAN: Cloud Radio Access Network or Centralized RAN
- CCC: Cloud Computing Center



Backhaul/ Fronthaul

- Backhaul interconnects RAN equipment to Core
- Fronthaul interconnects Remote Radio Units (RRU)to centralized Base Band Units (BBU)
  - Hoteling is the centralization of BBUs in a location (hotel)
  - More reliability, easy maintenance
- Backhaul design has to encompass traffic coming from all origins: wireline and wireless
- Backhaul design has to consider all types of backhaul: wireline and wireless
- Backhaul traffic has to be dimensioned properly
  - Large traffic can be consumed locally and do not reach the backhaul
  - Typical macro cell should be designed for 100 Mbit/s
- Backhaul should consider availability and reliability
  - Availability varies with the modulation and coding scheme used
  - Reliability depends on many factors, like power and vandalism
- Wireless backhaul operators can provide efficient backhaul sharing solutions

Heterogeneous Network

- eNB: enhanced Node B
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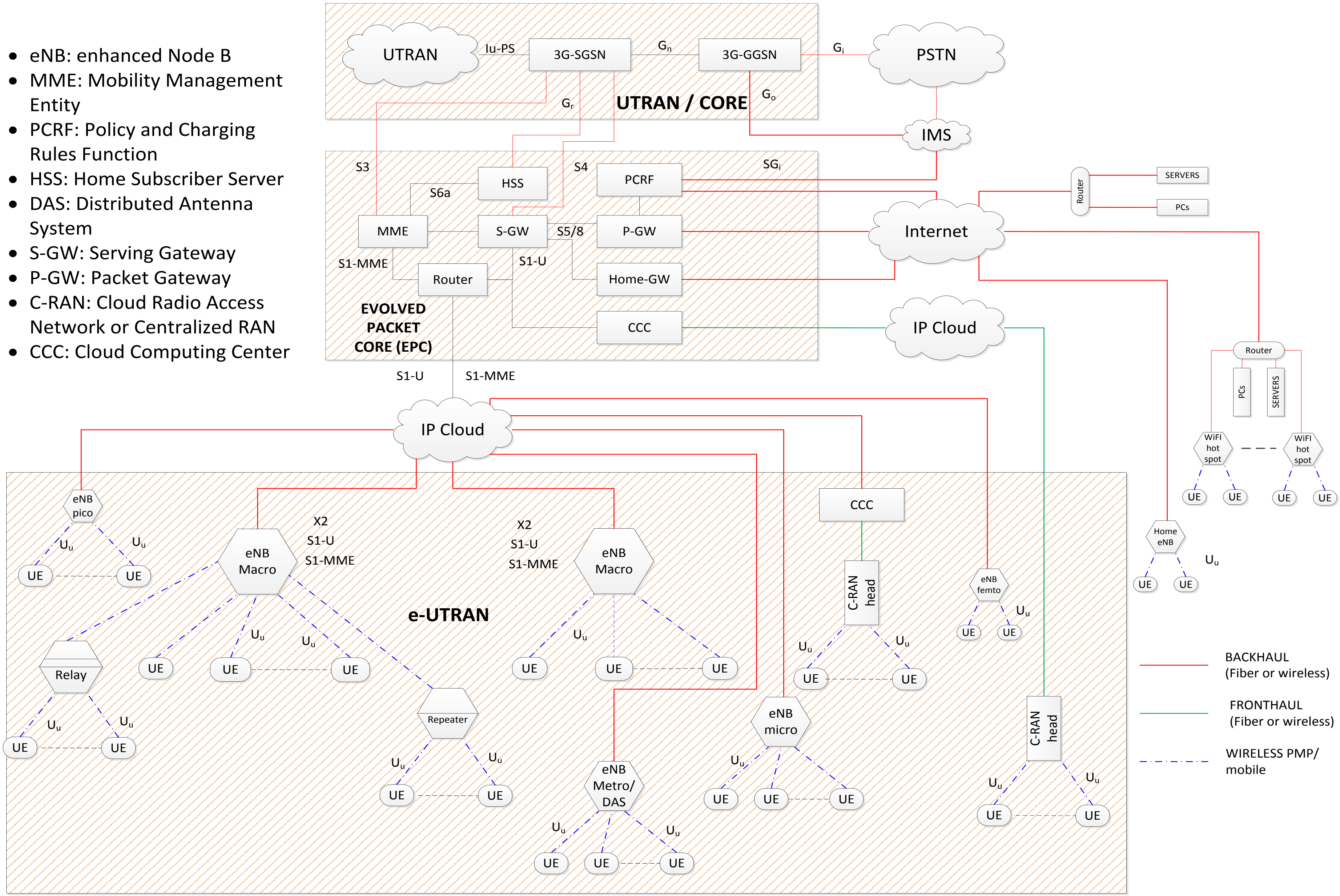


5.4 Intercell Interference Coordination (ICIC)

Inter Cell Interference Coordination

- LTE was designed with reuse of 1 as a basis
- Even so for lightly load cells, there should be a mechanism to avoid conflicts between adjacent cells
- Trying to avoid resource planning, 3GPP conceived the idea that cells could speak between themselves and decide how to use the resources in the best way, until conflict is unavoidable
- The implementation of this feature was left to the vendors, but 3GPP made available some features that could be used in the process

ICIC

- ICIC can be applied in frequency and time domains
  - In frequency domain some RBGs are prioritized
  - In time domain some sub-frames are prioritized
- ICIC is seen as essential in deployments with micro, pico and hetnets under a macro umbrella
  - Those cells should use exclusive resources to avoid interference from the more powerful macro cell

Features available for ICIC

- X2 interface that interconnects the eNBs
- X2 protocol messages
  - Uplink Interference Overload Indication
    - Reports uplink interference per Resource Block (high, medium, low)
  - Uplink High Interference Indication
    - Informs other eNBs then RBs it plans to use
  - Relative Narowband Transmit Power
    - Informs other eNBs which RBs will be transmitted with high power
  - Almost Blank Subframe Information (ABS)
    - Only Cell Reference Signals are transmitted in this frames, so they can be used by cells under the umbrella of the macrocell
  - Invoke Information
    - Used to request the macrocell to use ABS

LTE Rel 8 ICIC

- **3GPP Release 8 LTE ICIC**
  - Inter-Cell Inference Coordination
  - Optional implementation
  - Purpose is to decrease interference between neighboring <u>macro</u> base stations
  - Implemented by **lowering the power of part of the sub-channels in the frequency domain** which then can only be received close to the base station
  - ICIC can be static, semi-static, or dynamic
  - Can use fractional frequency reuse, soft frequency reuse, or full frequency reuse

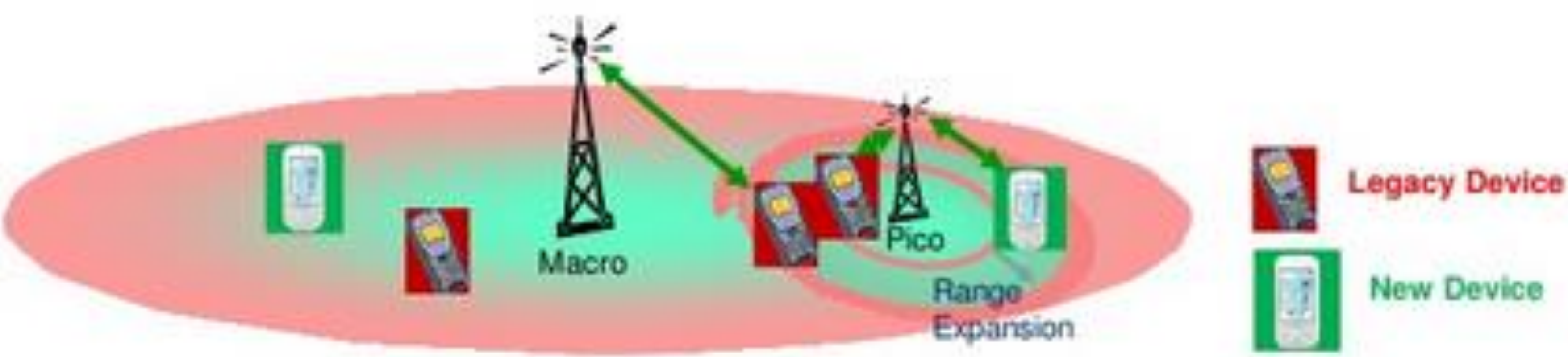
LTE-A Rel 10 eICIC

- **3GPP Release 10 LTE-Advanced eICIC**
  - Enhanced Inter-Cell Inference Coordination
  - Part of heterogeneous network (HetNet) approach - macro cells are complemented with LPNs inside their coverage area
  - Macro cells emit long range ,high power signals x LPNs emit low power signal over short distances
  - eICIC coordinates the **blanking of subframes in the time domain** in the macro cell to mitigate interference between the macro and small cells in its coverage area (i.e. macro cell transmits almost no data on these)
  - When several pico cells are used in the coverage area of a single macro cell overall system capacity is increased at the pico cells (as long as they do not overlap); downside is that macro cell capacity is diminished
  - Requires methods to quickly increase/decrease pico-exclusive subframes when traffic patterns change

- ICIC is a macro cell interference mitigation scheme; eICIC is designed as part of HetNet to reduce interference between macro and small cells

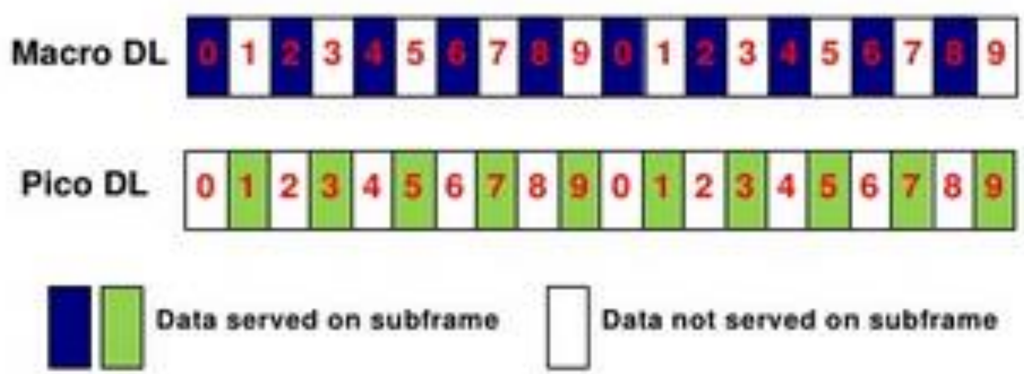
Almost Blank Sub-frames (ABS)

- Macro cell transmits:
  - Common reference signals
  - Sync signals
  - Primary broadcast signal
- Macro <u>does not</u> transmit any user specific traffic (data or control)
- Within CRE area, legacy devices are served by the macro cell



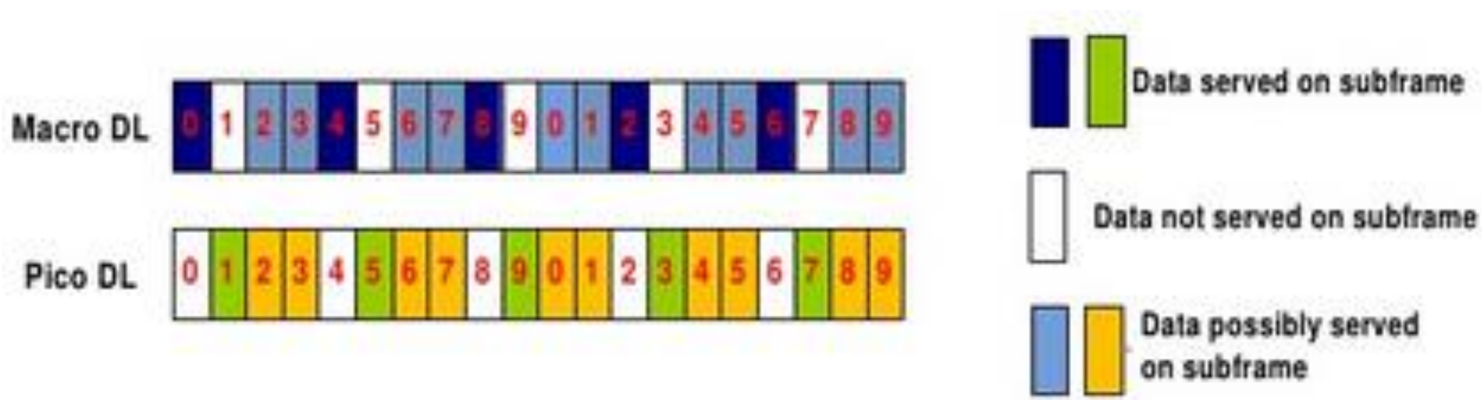
Inter-Cell Load Balancing

- Load balancing is done in time domain through partitioning
- Macro and pico cells negotiate partitioning and apply ABS
- ABS increases spatial reuse
  - Example in figure semi-static allocation (50% macros and 50% picos)



Adaptive Partitioning

- Traffic patterns change constantly in network
- Partitioning should be performed dynamically
- Certain ABS subframes can be “saved” for use on as needed basis
  - Example in figure adaptive allocation (25% fixed for macros and 25% fixed for pico; 50% adaptive subframes)



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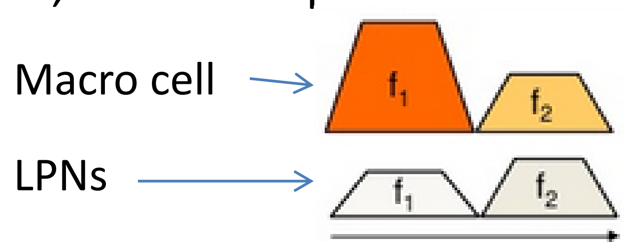
  - Almost Blank Subframe Information (ABS)
    - Only Cell Reference Signals are transmitted in this frames, so they can be used by cells under the umbrella of the macrocell
  - Invoke Information
    - Used to request the macrocell to use ABS

Frequency Domain Partitioning

- ABS is performed in Time Domain
- In Frequency Domain, macro and LPNs use separate frequencies (carriers)
  - Does not require synchronization
- Offers less granular resource allocation and lower flexibility
  - does not partition subframes
  - amount of LPNs does not change implementation
  - partitioning ratio is limited by number of carriers
- When Carrier Aggregation is used:
  - Macro cells transmit full power in one carrier, and lower power in second carrier
  - LPNs used second carrier as main carrier



ICIC Considerations

- ICIC helps with cell-edge throughput but only at low to moderate traffic load
  - It does not increase cell capacity!
  - Its gains are reduced with high load
- Dynamic ICIC (SON) ideally should be used to adapt to the cell’s varying traffic patterns
- eICIC should be used in HetNet deployments

ICIC Considerations

- 3GPP is looking for alternatives to make the network self adjusting
- This attempts are in very preliminary stages and are far away from replacing traditional resource planning
  - The risk with ICIC deployment is depicted below

6. Summary

Summary

- Dimensioning and planning an LTE network is not a trivial task
  - There are tens of important parameters that have to be properly dimensioned
- Overall throughput can be optimized by fine tuning all the parameters
- Knowledge of traffic characteristics is very important
- An advanced methodology and tool should be used to achieve desired results

7. CelPlan New Products

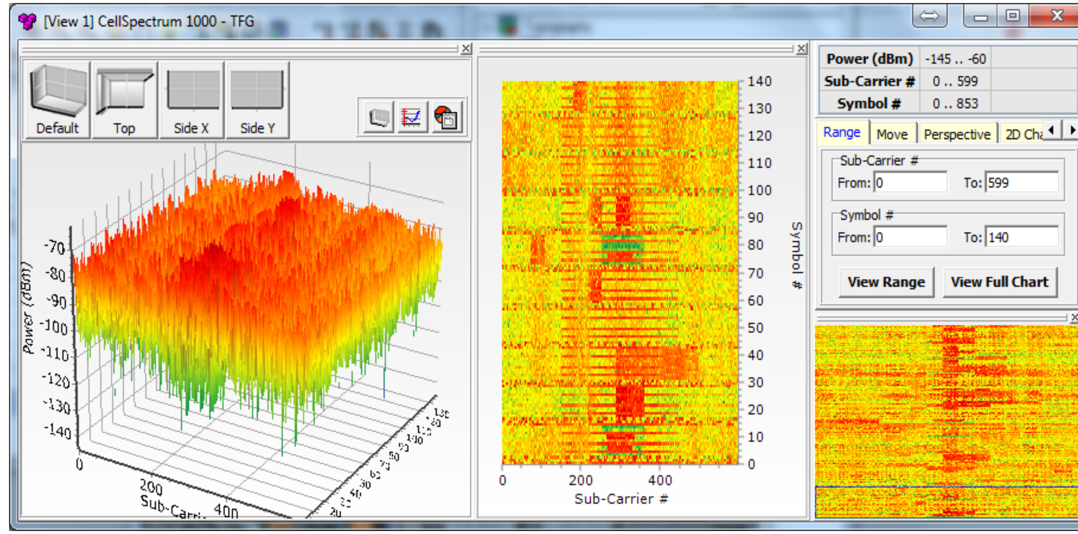
CellSpectrum

CellDesigner

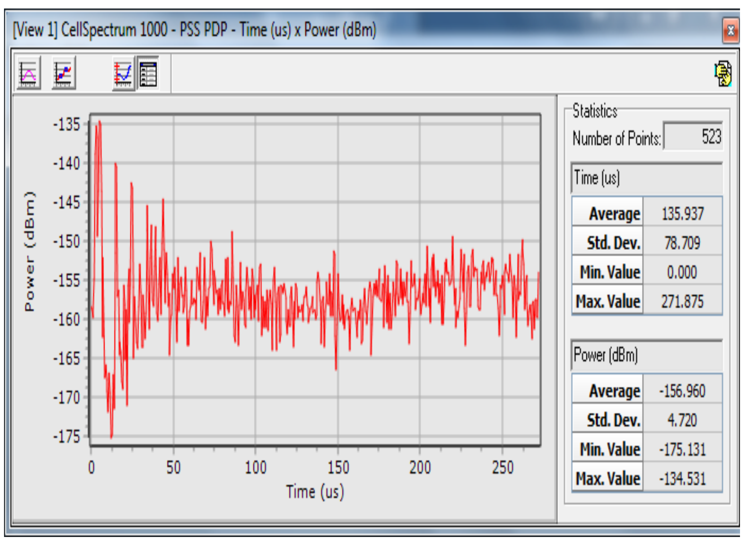
CellSpectrum

- A unique spectrum scanner for LTE channels
- Presents measurements in 1D (dimension), 2D and 3D at RE (Resource Element) level

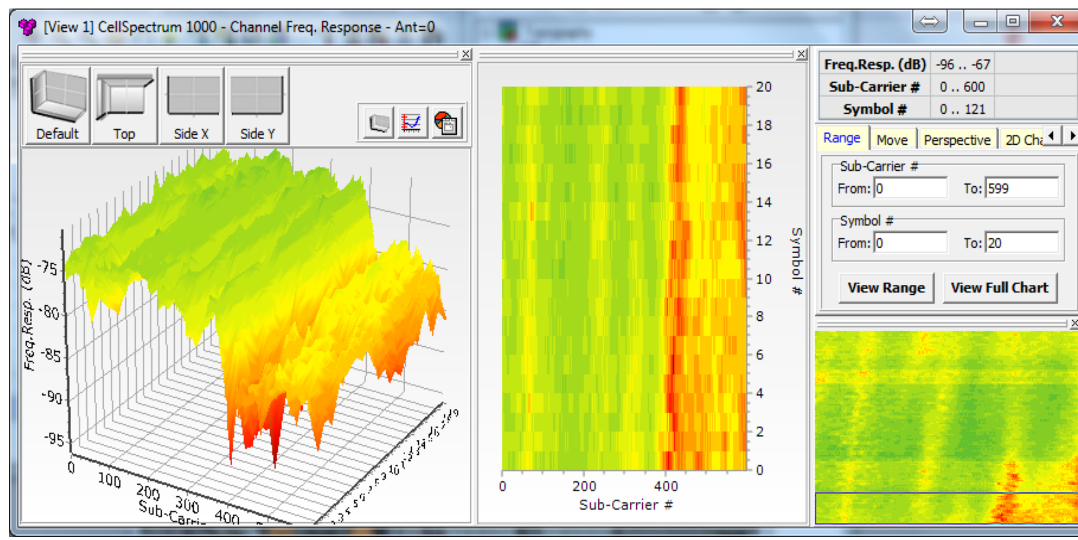
Received Signal level



Multipath



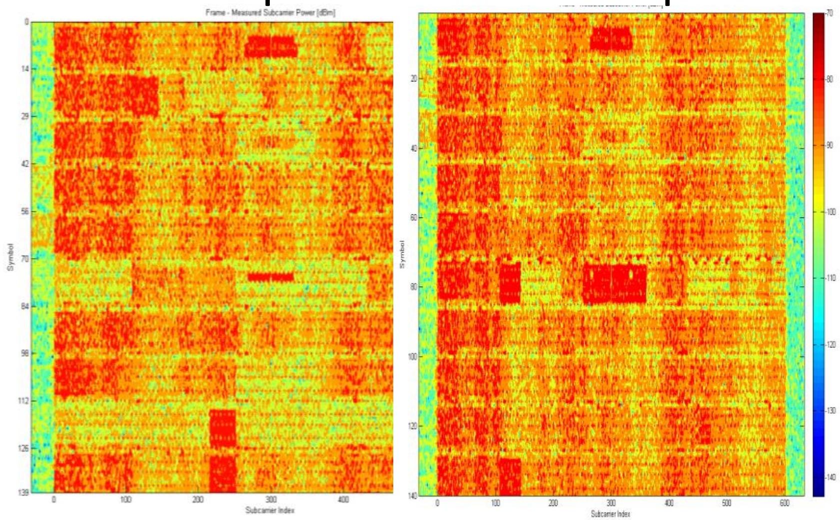
RF Channel Response



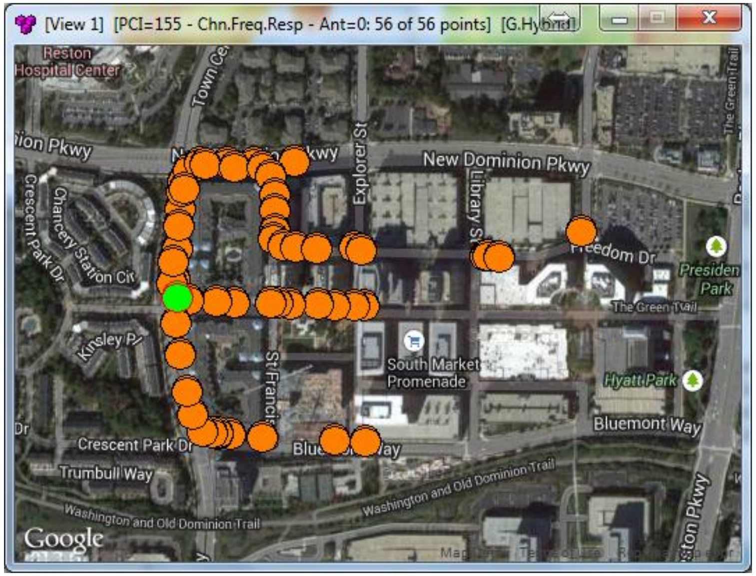
CellSpectrum

- Provides a unique antenna correlation analysis for MIMO estimation and adjustment

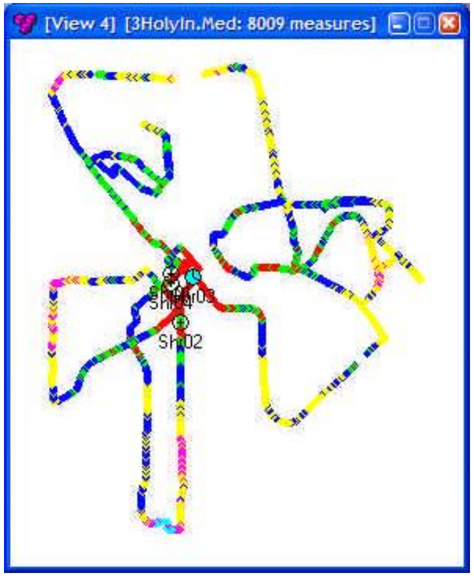
LTE frame port 0 LTE frame port 1

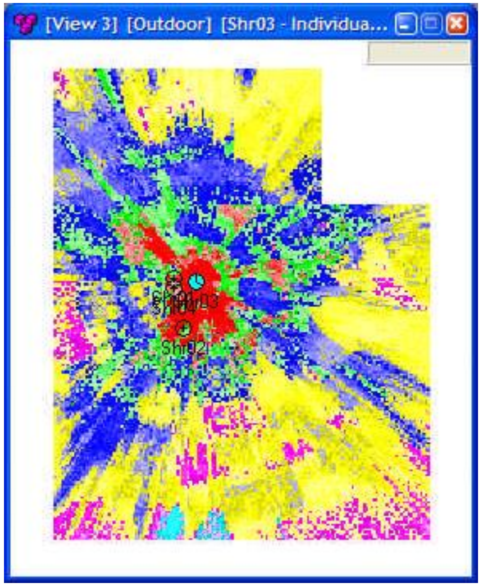


Drive Test



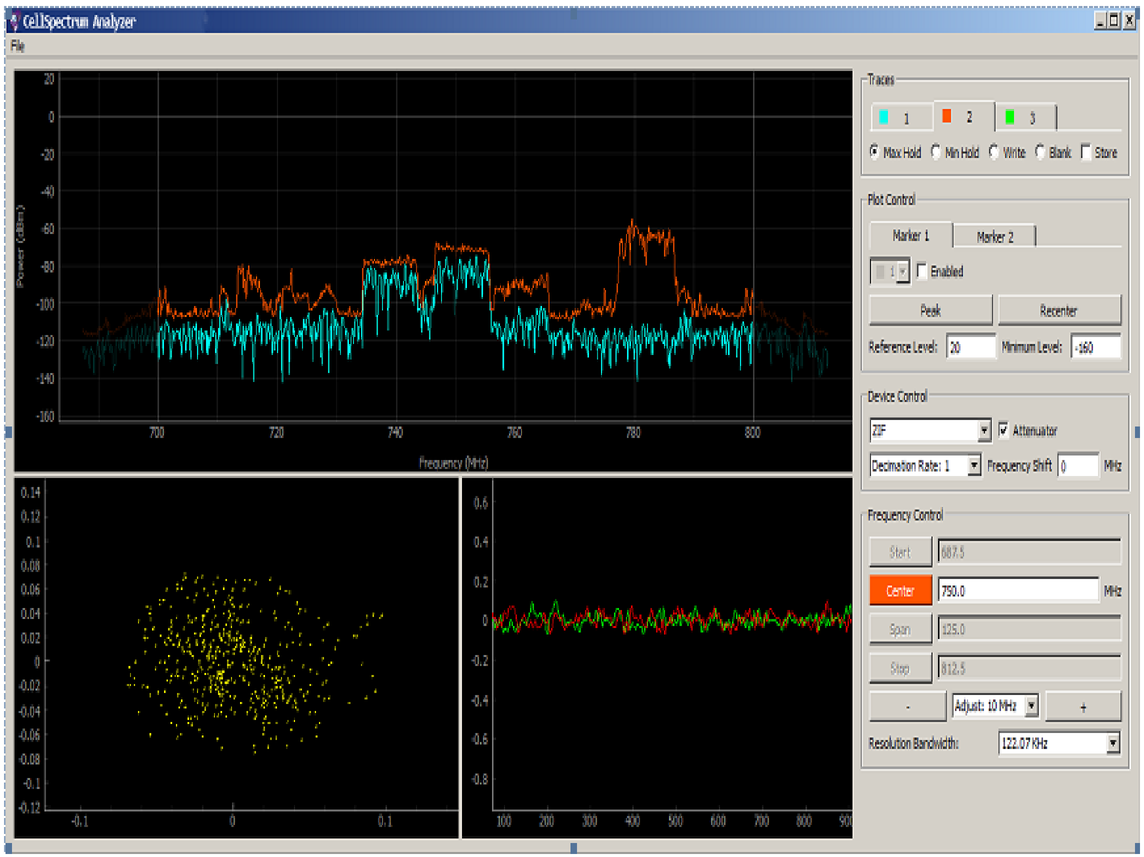
Measurement interpolation





CelSpectrum™ Analyzer

- Range: 100 MHz to 18 GHz
- Bandwidth: 125 MHz (IBW: 100 MHz)
- Decimation: 1, 4, 8, 16, 32, 64, 128, 256, 512, 1024
- Resolution Bandwidth: 976.562 KHz, 488.281 KHz, 244.1141 KHz, 122.07 kHz, 61.035 kHz, 30.518 kHz, 15.259 kHz, 7.62939 kHz, 3.815 kHz
- Display: Max hold, Min hold, Write, Blank
- Capture modes:
  - Sweep and Block



CellDesigner

A new Generation of Planning Tools

A collaborative work with operators

Your input is valuable

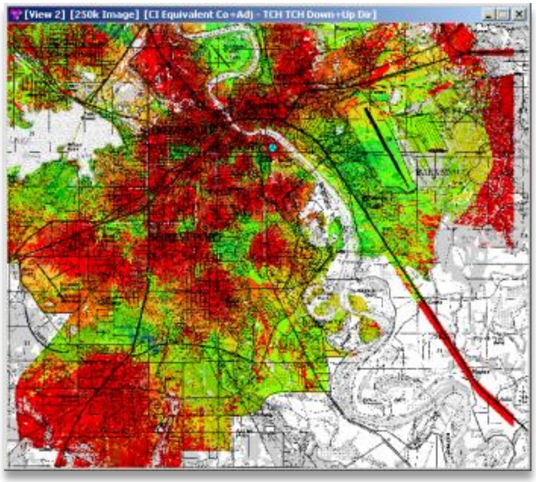
CellDesigner

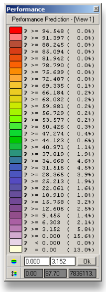
- CellDesigner is the new generation of Planning and Optimization tools
- Wireless networks became so complex that it requires a new generation of tools, capable of:
  - Documenting the physical deployments
  - Documenting network parameters for each technology
  - Flexible data traffic modelling (new services, new UE types)
  - Traffic allocation to different technologies
  - Fractional Resouce Planning
  - Performance evaluation
  - Integrated backhaul

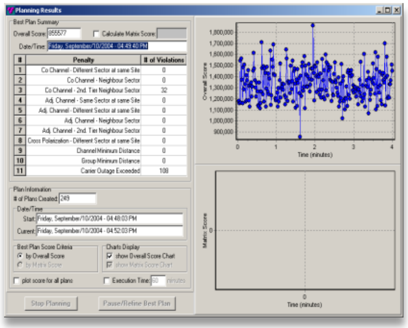
CellDesigner™

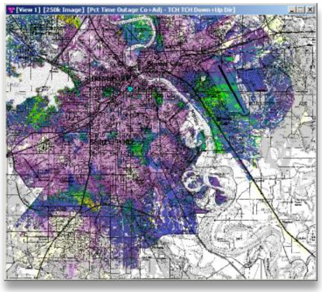
Simultaneous Multi-Technology Support

- Supports all wireless technology standards:
  - LTE–A (TDD and FDD), WiMAX, WI-FI, WCDMA (UMTS), HSPA, HSPA+, IS2000 (1xRTT, EVDO), GSM (including Frequency Hoping), GPRS, EDGE, EDGE-E, CDMA One, PMR/LMR (Tetra and P25), MMDS/LMDS, DVB-T/H, and Wireless Backhaul
- Full network representation
  - Site, Tower, Antenna Housing, Antenna System, Sector, Cell, Radio
  - Full network parameter integration
  - KPI integration
- Full implementation of the Korowajczuk 3D model, capable of performing simultaneously outdoor and indoor multi-floor predictions
- Multi-technology dynamic traffic simulation









CellDesigner™

Automatic Resource Planning (ARP)

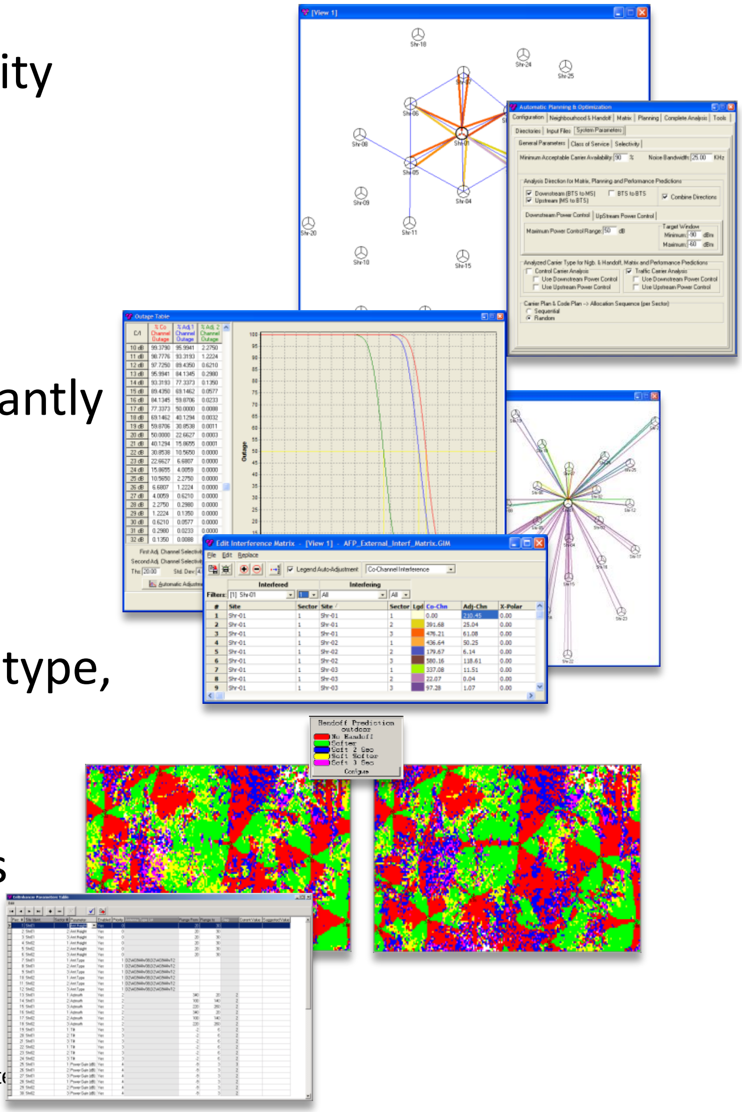
- Enables the dramatic increase of network capacity and performance
- Handover, Frequency and Code Optimization
- Automatically and efficiently optimizes handoff thresholds, neighbor lists, and frequency plans
- Patent-pending methodology capable of significantly increasing cell capacity (SON & ICIC)

Automatic Cell Planning (ACP)

- Footprint and interference enhancement
- Allows optimization of radiated power, antenna type, tilt, azimuth, and height

Performance Predictions

- Overall performance prediction per service class (bearer)



CellDesigner™

Google Earth Integration

- Capable of presenting predictions and measurements live in Google Earth's 3D environment

Network Master Plan (NMP)

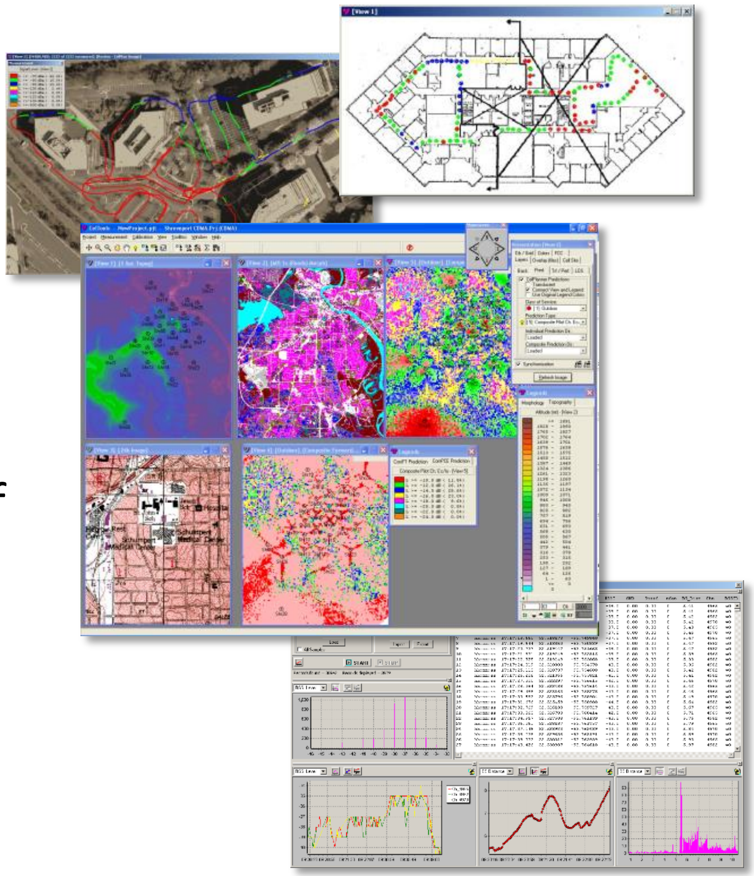
- Patent-pending methodology that simplifies SON and ICIC

Integration of Field Measurement Data

- Collection of data from virtually any type of measurement equipment and any format
- Automatic extraction of propagation parameters

Integration of KPIs

- Comparison reports between reported and calculated KPIS



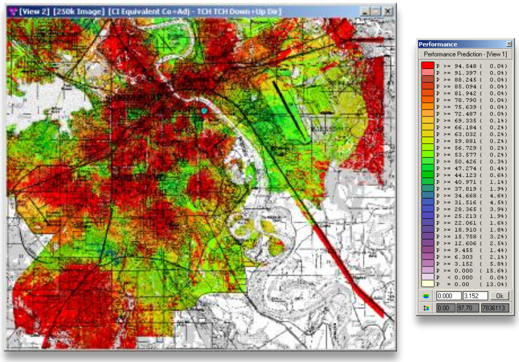
CellDesigner™

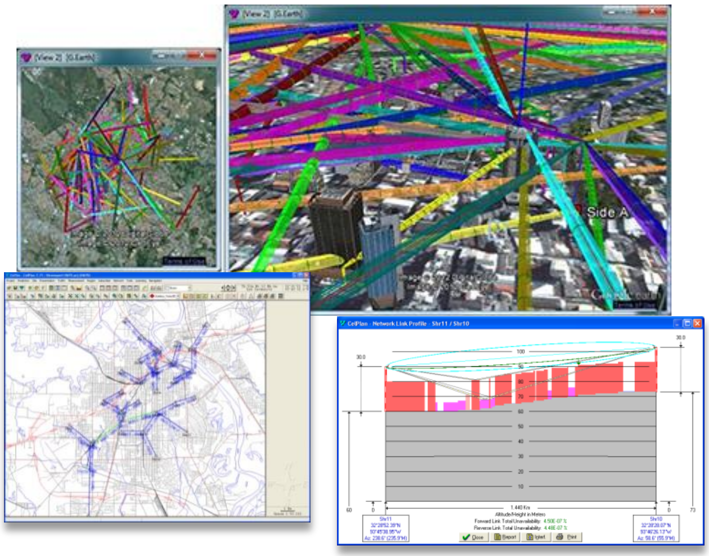
GIS Database Editor

- Allows the editing and processing of geographical databases

Backhaul Planning

- Calculates network interconnections, interference analysis & reporting for point-to-point, microwave transmission links
- Can display obstruction in Fresnel zones as well as the path loss
- Calculates attenuation caused by diffraction.
- Calculates rain attenuation for each link
- Provides link performance and compares against the requirements established by ITU-R





Thank You!

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Questions?