How to consider overhead in LTE dimensioning and what is the impact

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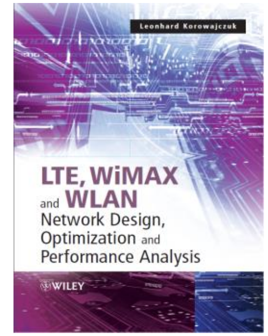
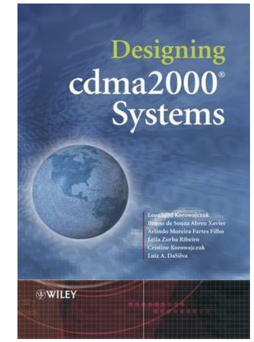
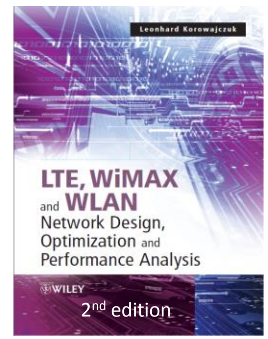
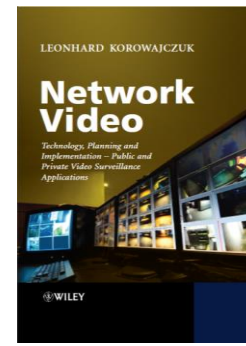
Presenter

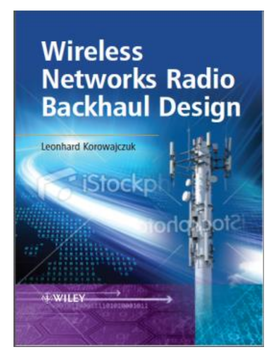
- **Leonhard Korowajczuk**
  - CEO/CTO CelPlan International
  - 45 years of experience in the telecom field (R&D, manufacturing and services areas)
  - Holds13 patents
  - Published books
    - "Designing cdma2000 Systems"
      - published by Wiley in 2006- 963 pages, available in hard cover, e-book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

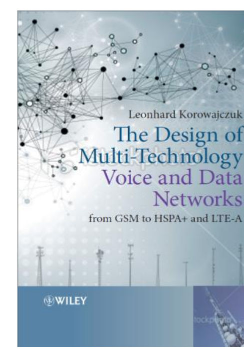












CelPlan International

- Employee owned enterprise with international presence
  - Headquarters in USA
  - 450 plus employees
  - Revenues of US$ 40M
  - 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?**
  - 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**

Today's Topic

How to consider overhead in LTE dimensioning and what is the impact

Content

How to Dimension user Traffic in 4 G networks

What was the outcome from the previous webinar

Challenge

More than 200 participants from 44 countries

Identify the country codes of participants of the last webinar

1	AE	ARE	
2	BD	BGD	
3	BG	BGR	
4	BI	BDI	
5	BR	BRA	
6	BW	BWA	
7	CA	CAN	
8	CG	COG	
9	DE	DEU	
10	DK	DNK	
11	EG	EGY	
12	ES	ESP	
13	FR	FRA	
14	GB	GBR	
15	GH	GHA	
16	GR	GRC	
17	HU	HUN	
18	IE	IRL	
19	IN	IND	
20	IT	ITA	
21	JO	JOR	
22	KW	KWT	

23	LB	LBN	
24	MA	MAR	
25	MV	MDV	
26	NG	NGA	
27	NL	NLD	
28	NO	NOR	
29	OM	OMN	
30	PK	PAK	
31	PT	PRT	
32	QA	QAT	
33	SA	SAU	
34	SE	SWE	
35	SG	SGP	
36	SI	SVN	
37	TJ	TJK	
38	TN	TUN	
39	TR	TUR	
40	TW	TWN	
41	TZ	TZA	
42	UA	UKR	
43	US	USA	
44	ZA	ZAF	

1. How to Dimension User Traffic in 4G Networks

CelPlan
Wireless Solutions & Consulting

- Service QoS
  - Services were identified and quality requirements established

CellDesigner - Tonnage Calculator

QoS | Unitary | Tonnage | QCI Table

Service Identification		Data Rate (kbps)		AMBR (kbps)		Alloc./Retent./Prior. ARP			Packet Size (Bytes)	
Name	QCI	GBR	MBR	APN	UE	Priority	Capabilit	Vulnerab	DL	UL
Conversational Voice	1	12.5	16			2	Yes	Yes	320	320
Conversational Video (live streaming)	2	180	240			2	Yes	Yes	760	64
Real Time Gaming	3	1.5	1.6			2	Yes	Yes	80	24
Non conversational Video (buffered)	4	128	156			2	Yes	Yes	1024	128
IMS signaling	5			64	32	2	Yes	Yes	128	32
Video (buffered streaming), TCP applications	6			128	256	2	Yes	Yes	1024	128
Voice, Video Live Streaming, Interactive Gaming	7			128	256	2	Yes	Yes	760	64
Video (buffered streaming), TCP applications	8			128	256	2	Yes	Yes	1024	128
Video (buffered streaming), TCP applications	9			128	256	2	Yes	Yes	1024	128
UTP based applications	5			32	64	2	Yes	Yes	64	12
UTP based applications	6			48	128	2	Yes	Yes	128	24
UTP based applications	7			64	128	2	Yes	Yes	256	48

CelPlan Wireless Solutions & Consulting

- Unitary Tonnage per Service
  - Data speed and tonnage concepts were defined
  - Tonnage per service was estimated

CellDesigner - Tonnage Calculator

QoS | Unitary | Tonnage | QCI Table

Unitary Daily Tonnage

Service Identification		Smartphone		Tablet		USB		Modem	
Name	Unit type	DL	UL	DL	UL	DL	UL	DL	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

QoS Class identifier (QoS)

- Default QCI values identified by 3GPP

CellDesigner - Tonnage Calculator

QoS | Unitary | Tonnage | QCI Table

QCI Standard Values

QCI	Type	Priority	Delay	PER
1	GBR	2	100	1:10
2	GBR	4	150	1:1000
3	GBR	3	50	1:1000
4	GBR	5	300	1:1000000
5	NGBR	1	100	1:1000000
6	NGBR	6	300	1:1000000
7	NGBR	7	100	1:1000
8	NGBR	8	300	1:1000000
9	NGBR	9	300	1:1000000

GBR - Guarantted Bit Rate

NGBR - Non Guarantted Bit Rate

Delay - Packet Delay Budget

PER - Packet Error Loss Rate

How to Dimension User Traffic in 4G Networks

CelPlan Wireless Solutions & Consulting

- Service tonnage per terminal type
  - Total network tonnage per terminal type was estimated

CellDesigner - Tonnage Calculator

QoS | Unitary | Tonnage | QCI Table

Daily to Busy Hour Factor: 0.33333

Service Identification			Smartphone			Tablet			USB			Modem		
			Number of UE: 500000			Number of UE: 100000			Number of UE: 80000			Number of UE: 40000		
			Daily Usage	Busy Hour (Mbps)		Daily Usage	Busy Hour (Mbps)		Daily Usage	Busy Hour (Mbps)		Daily Usage	Busy Hour (Mbps)	
Name	Unit type	QoS		DL	UL		DL	UL		DL	UL		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

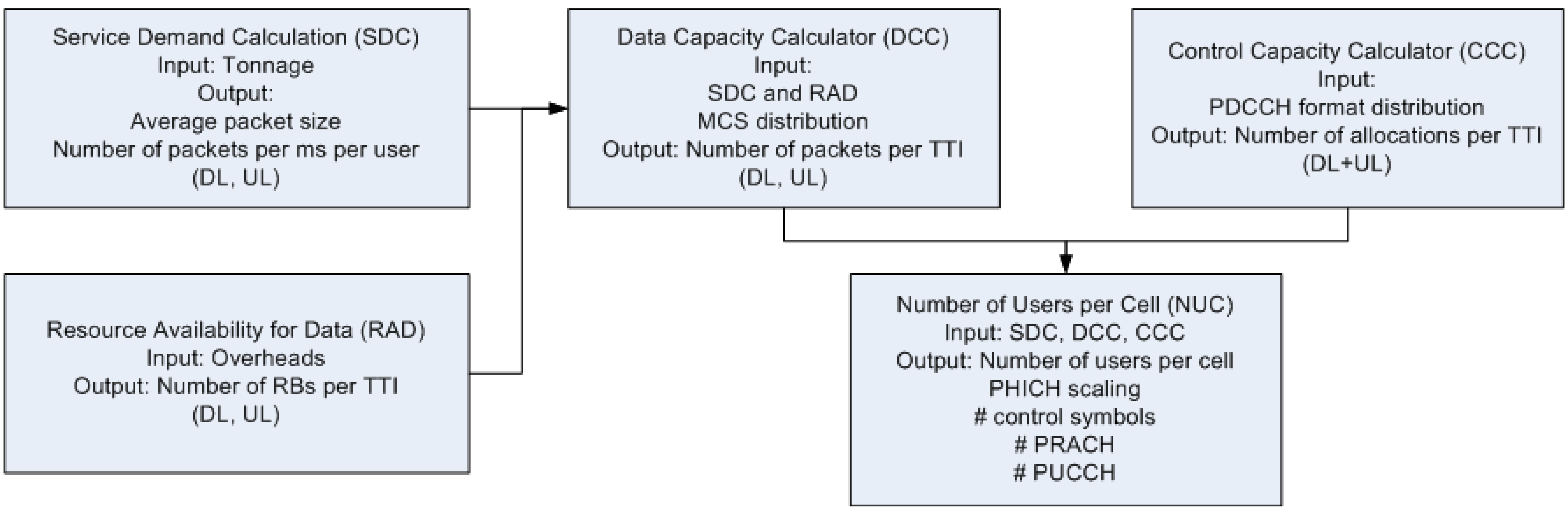
Summary

	Smartphone DL	Smartphone UL	Tablet DL	Tablet UL	USB DL	USB UL	Modem DL	Modem UL
UE Total Tonnage (kbps)	70.337	10.561	103.00	30.897	179.00	37.649	157.04	46.252
Backhaul Total Tonnage (Gbps)	35.168	5.2808	10.300	3.0897	14.320	3.0119	6.2819	1.8501
UE Montly Tonnage (GB/Mo)	2.6530	0.3983	3.8852	1.1654	6.7516	1.4200	5.9236	1.7445
Network Montly Tonnage (PB/Mo)	1.2650	0.1899	0.3705	0.1111	0.5151	0.1083	0.2259	0.0665

How to consider overhead in LTE dimensioning and what is the impact

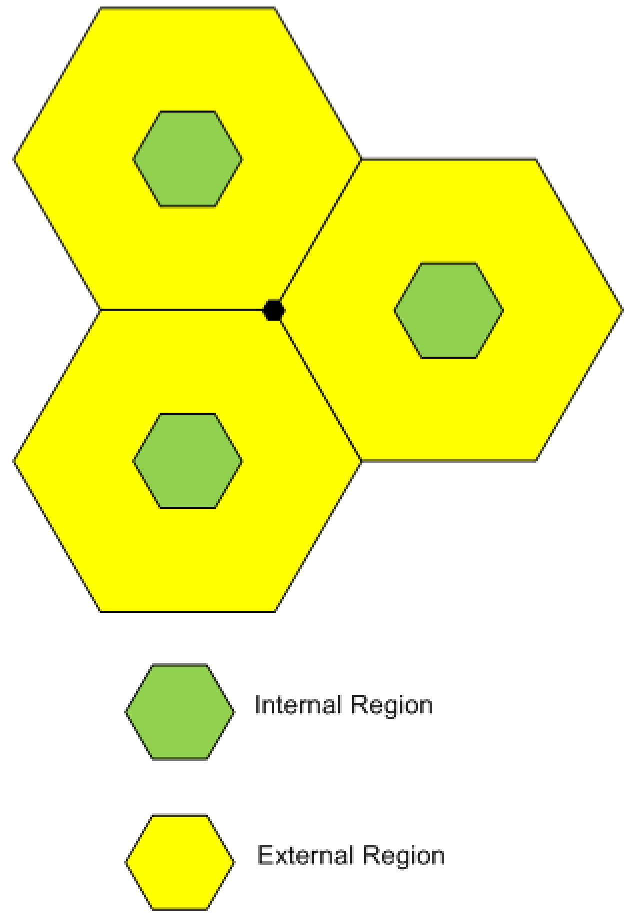
How to consider overhead in LTE dimensioning and what is the impact

- LTE cell capacity is limited by the network configuration and the user traffic characteristics
- The following items should be calculated for different scenarios
  - Service Demand
  - Resource Availability for data
  - Data Transfer Capacity
  - Control (mapping) Capacity
- Cell User Capacity can then be estimated and Pre-programed resources dimensioned



Reuse in LTE

- LTE was conceived for reuse 1
- A cell was divided in an interior (center) and and an exterior (edge) regions
- The exterior region would use very low coding rates (in the order of 0.07)
- The interior region would use higher coding rates
- No criteria was established to define exterior and interior regions
- Broadcast information has to use low coding rates
- Intercell Cell Interference Coordination (ICIC) was considered to improve the performance, four cases were proposed
  - No ICIC
  - Start-Stop Index (SSI)
  - Start Index (SI)
  - Random Start Index (RSI)
  - Start Index Geometry Weight (SIGW)
  - Random Index Geometry Weight (RIGW)



Bit scrubbing

- 3GPP decision of implementing a reuse of 1 in LTE implied in:
  - High repetition rates for control information
  - This lead to bit scrubbing (bit shaving) and complexity
    - Blind decoding, implicit addressing , multiple options
  - High data spread rates that trade reuse of 1 for low throughputs
  - Complex transmission modes
    - Some transmission modes can be practically used in few locations in the network (if at all)
- 3GPP provided mechanisms to avoid resource reuse conflicts
  - It suggested that interference is concentrated at cell edge and that reuse of 1 can be done in cell center
  - It did not specify how this should be done
    - Several implementation schemes have been suggested, none full proof
    - Traditional segmentation and zoning still being used

LTE Refresher

Focused on topics related to capacity and overhead

Single FDD Cell

5 MHz channel

Normal Cyclic Prefix

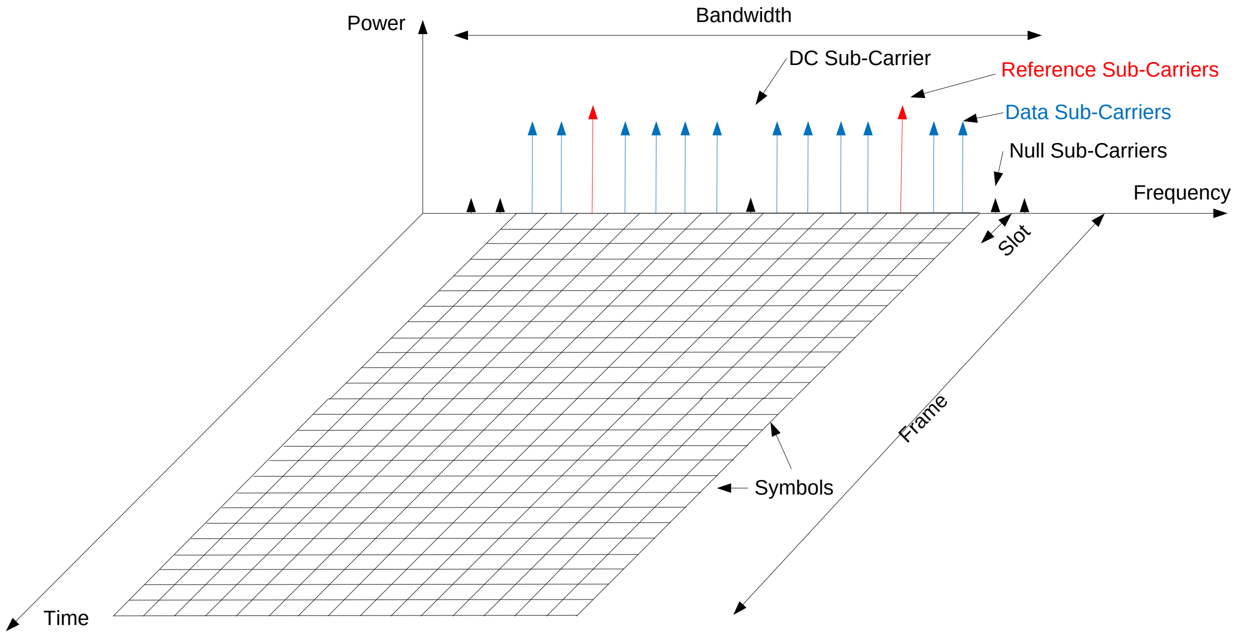
Frame

FDD will be covered in the seminar due to lack of time

LTE Frame

- An RF carrier modulated by a signal with a bandwidth B in the frequency domain, will generate a symbol of duration 1/B in the time domain
- LTE sub-carrier has a 15 kHz bandwidth
- LTE symbol has a duration of 1/15k
  - Ts= 66.66.. µs
- Time Base Unit

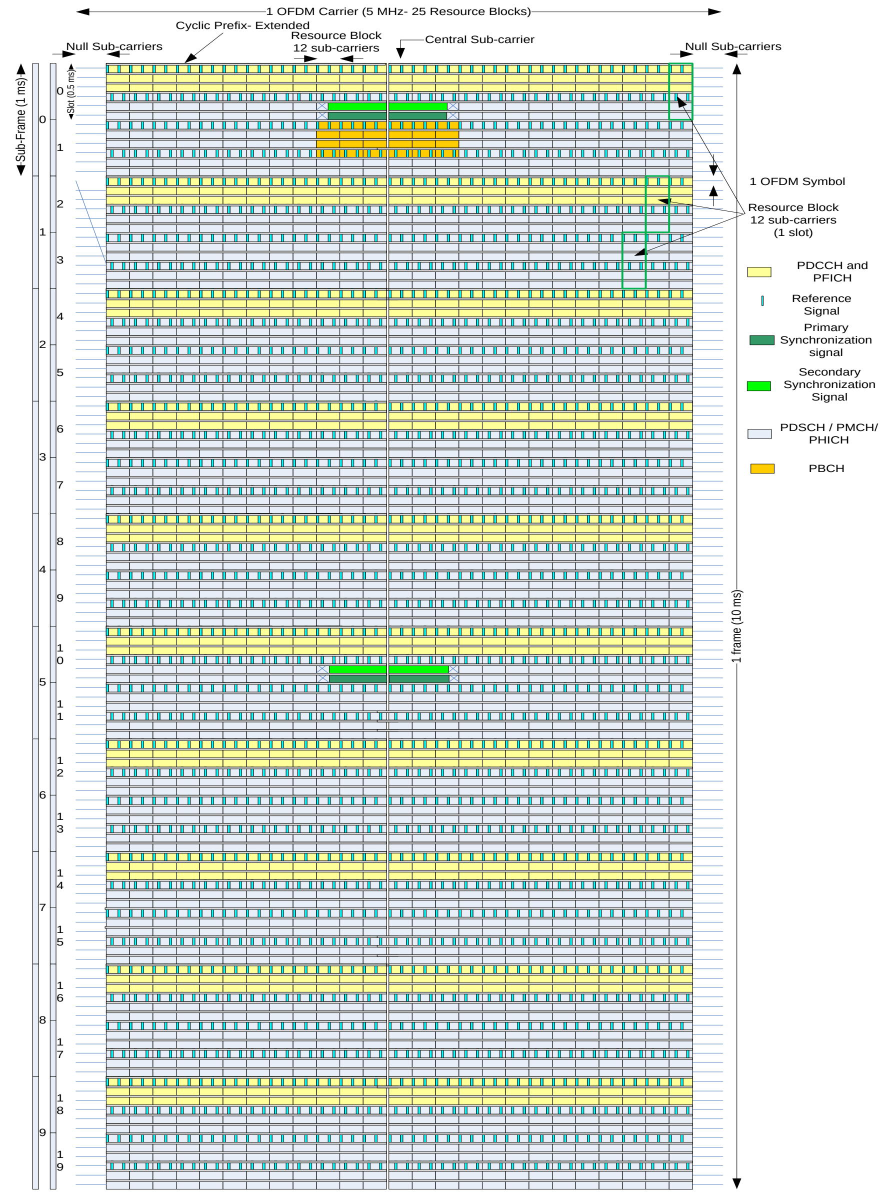
$$T_s = 1/(15{,}000 * 2048) = 32.55\ ns$$



Channel Bandwidth (MHz)	1.4	3	5	10	15	20
Sub-carrier Spacing (kHz)	15	15	15	15	15	15
FFT size	128	256	512	1024	1536	2048
Number of used sub-carriers	72	180	300	600	900	1,200
Number of Sub-carrier groups Resource Blocks (RB)	6	15	25	50	75	100

Downlink frame

- Frame Duration:10 ms
- Sub-frames: 10 (1 ms each)
- Slots: 20 (2 per sub-frame)
- Subcarrier: number is bandwidth dependent
- Resource Element (RE): symbol generated by a single subcarrier (15 kHz x 66.66.. µs)
- OFDM symbol: 66.66.. µs across the whole bandwidth
- Resource Block: 12 subcarriers per 1 slot (6 or 7 symbols)
- Resource Element Group (REG): 4 consecutive REs
- Transmit Time Interval (TTI): 1ms (1 subframe)

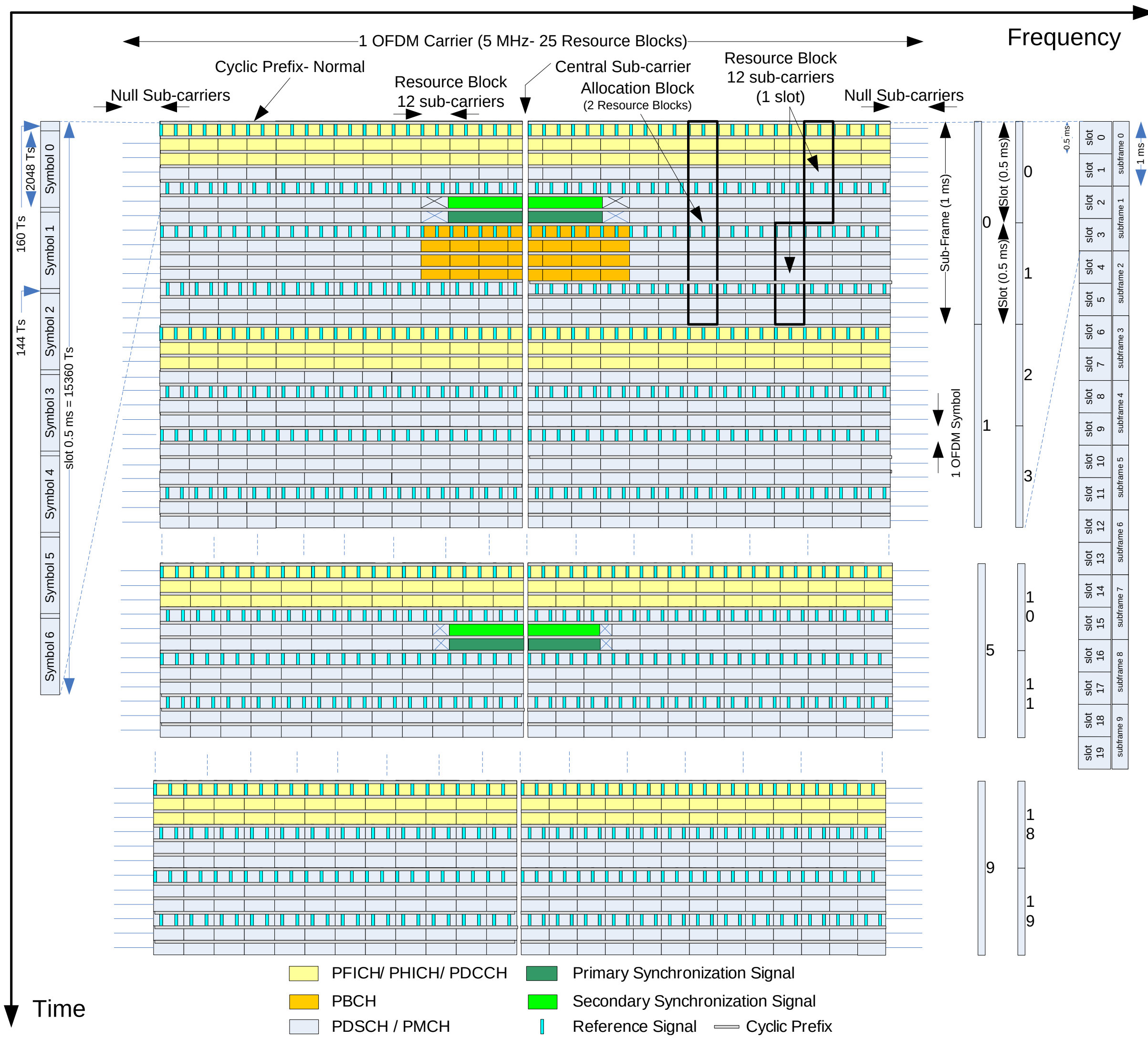


Downlink Frame

- Cyclic Prefix (CP)
  - addition to symbol duration that eliminates intersymbol interference due to multipath
- A slot can fit:
  - 7 symbols (normal CP)
  - 6 symbols (extended CP)

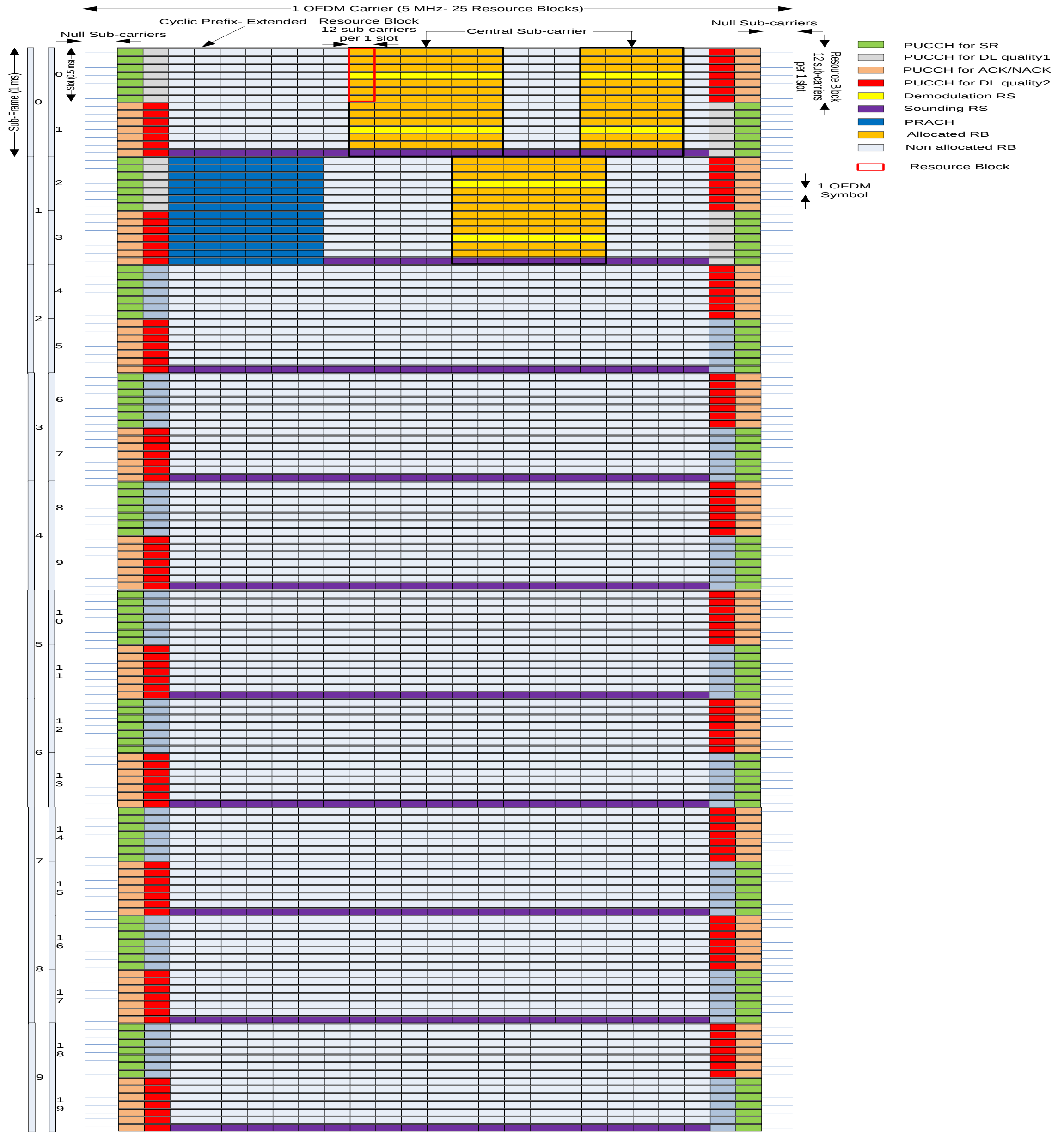
	Ts	µs	km
Cyclic Prefix= Normal	160/144	5.2/4.7	1.4
Cyclic Prefix= Extended	512	16.7	5.0

- TTI OFDM symbols are divided in two blocks
  - Control (yellow)
  - Data (blue)



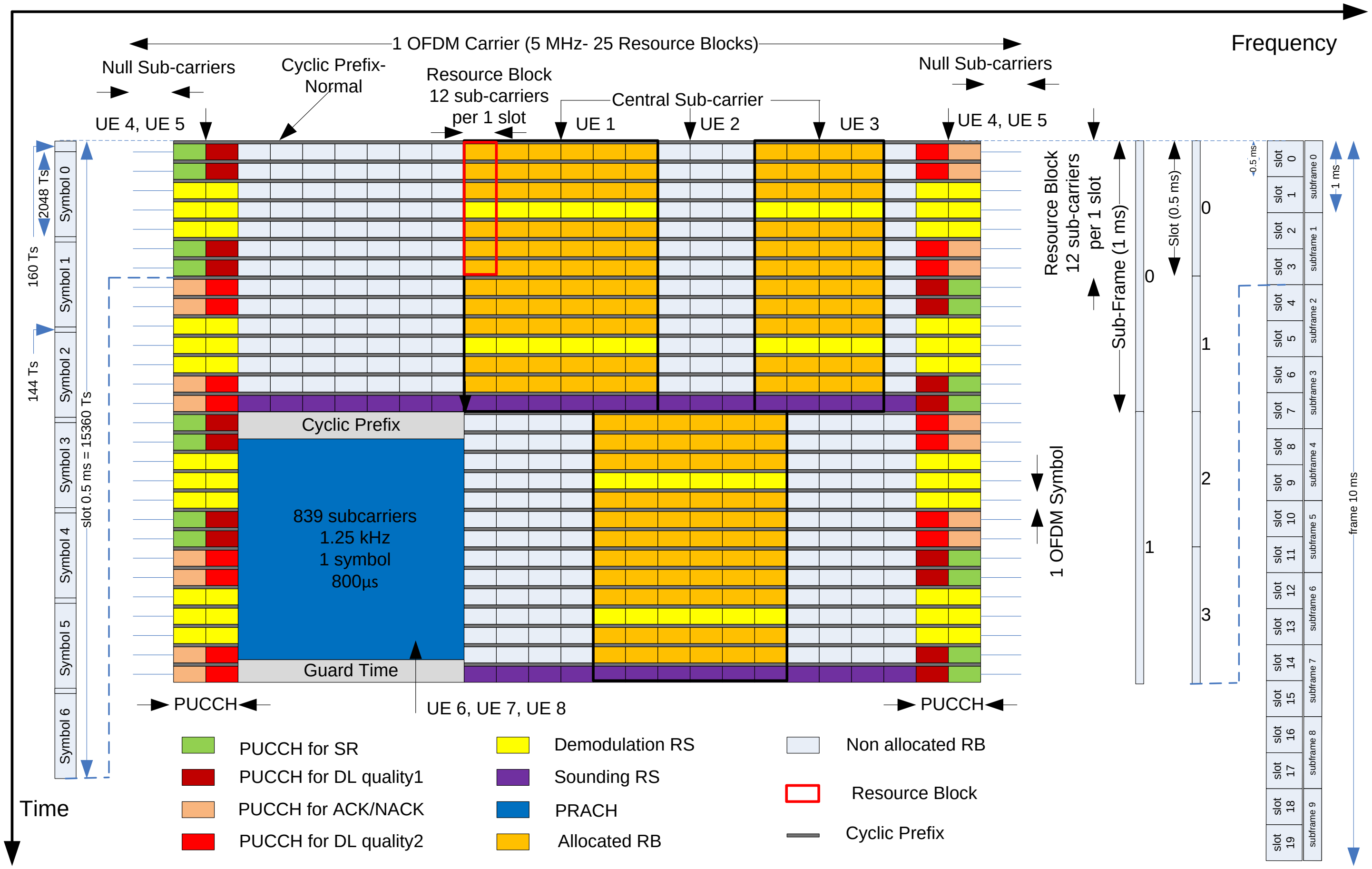
Uplink frame

- Downlink and Uplink frames are alligned at the eNB
- Uplink frame structure is the same as the downlink
  - Subframe, slot, RE (symbol), RB, TTI, CP
- Content is divided in:
  - Control (green, orange, red, gray)
  - Data (light blue)
  - Random Access (dark blue)



Uplink Frame

- Information set is a contiguous number of RBs
  - Control, Data or Random Access
- An UE can transmit per TTI
  - Release 8: 1 set of information
  - Release 10: 2 sets of information

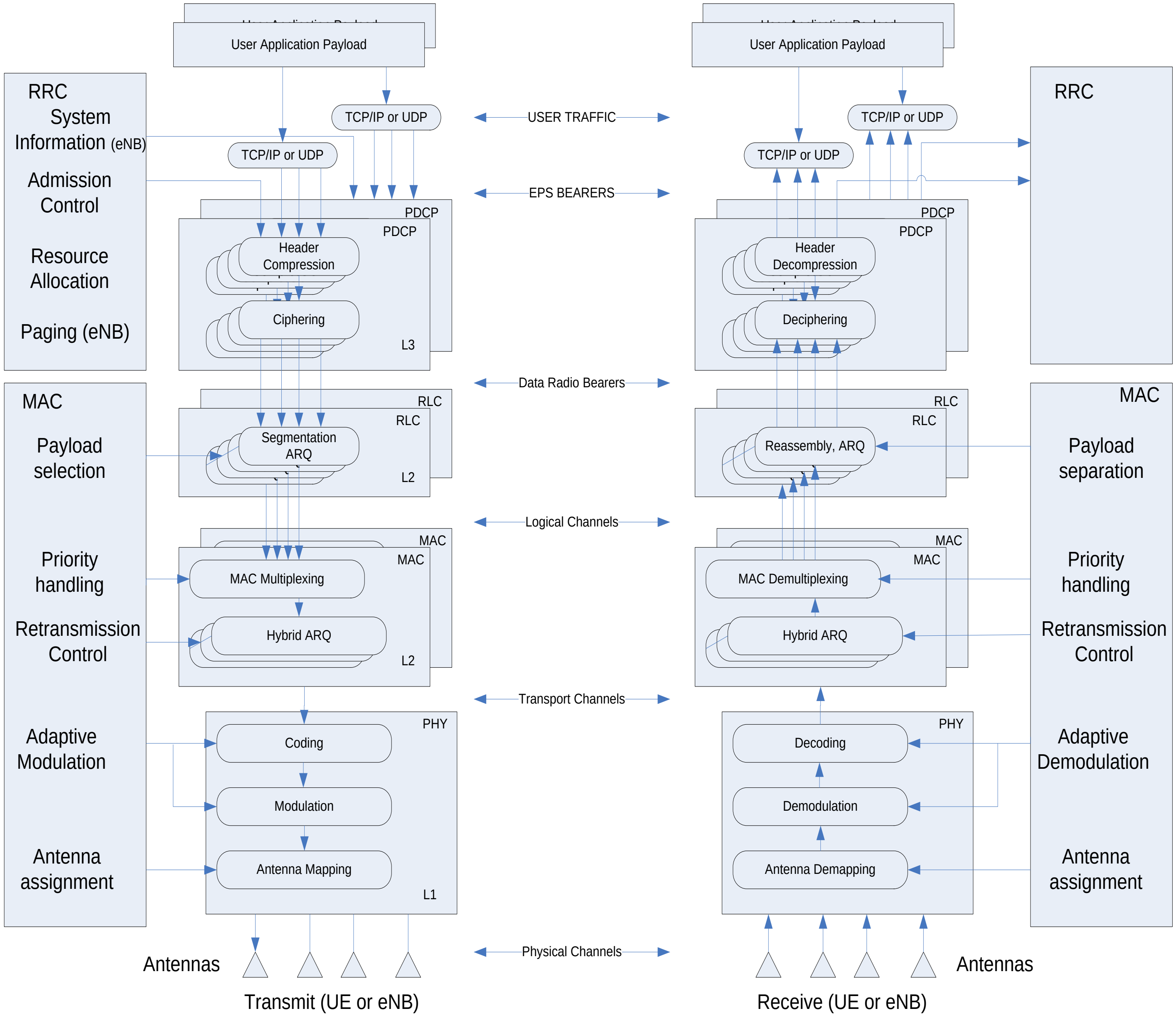


Frame Content

Signals and Channels

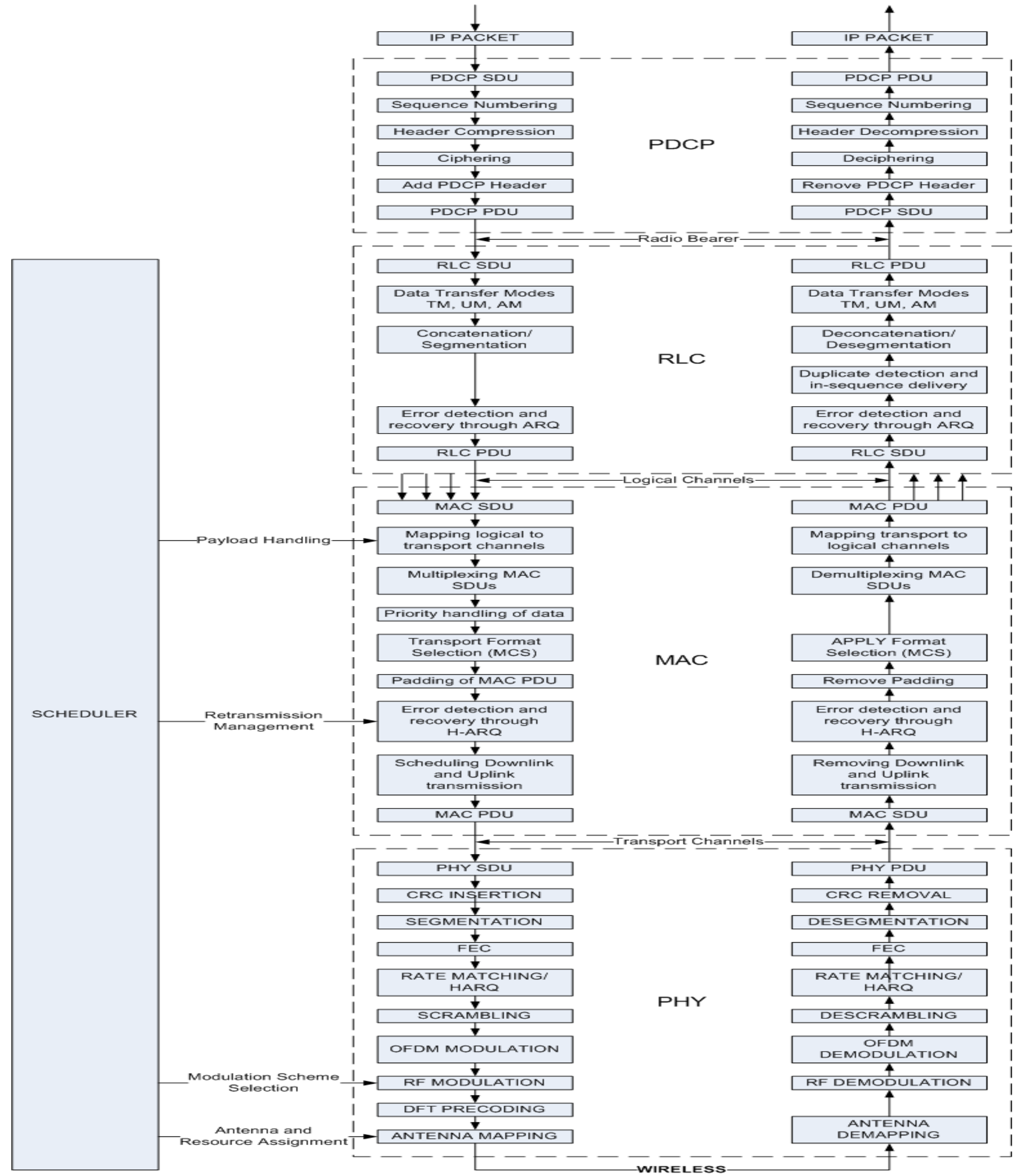
Protocol Layers

- **Management Layers**
  - Radio Resource Management (RRM)
  - Radio Resource Control (RRC)
  - Medium Access Control (MAC)
- **Protocol Layers**
  - Packet Data Convergence Protocol (PDCP)
  - Radio Link Control (RLC)
  - Medium Access Control (MAC)
  - Physical Layer (PHY)



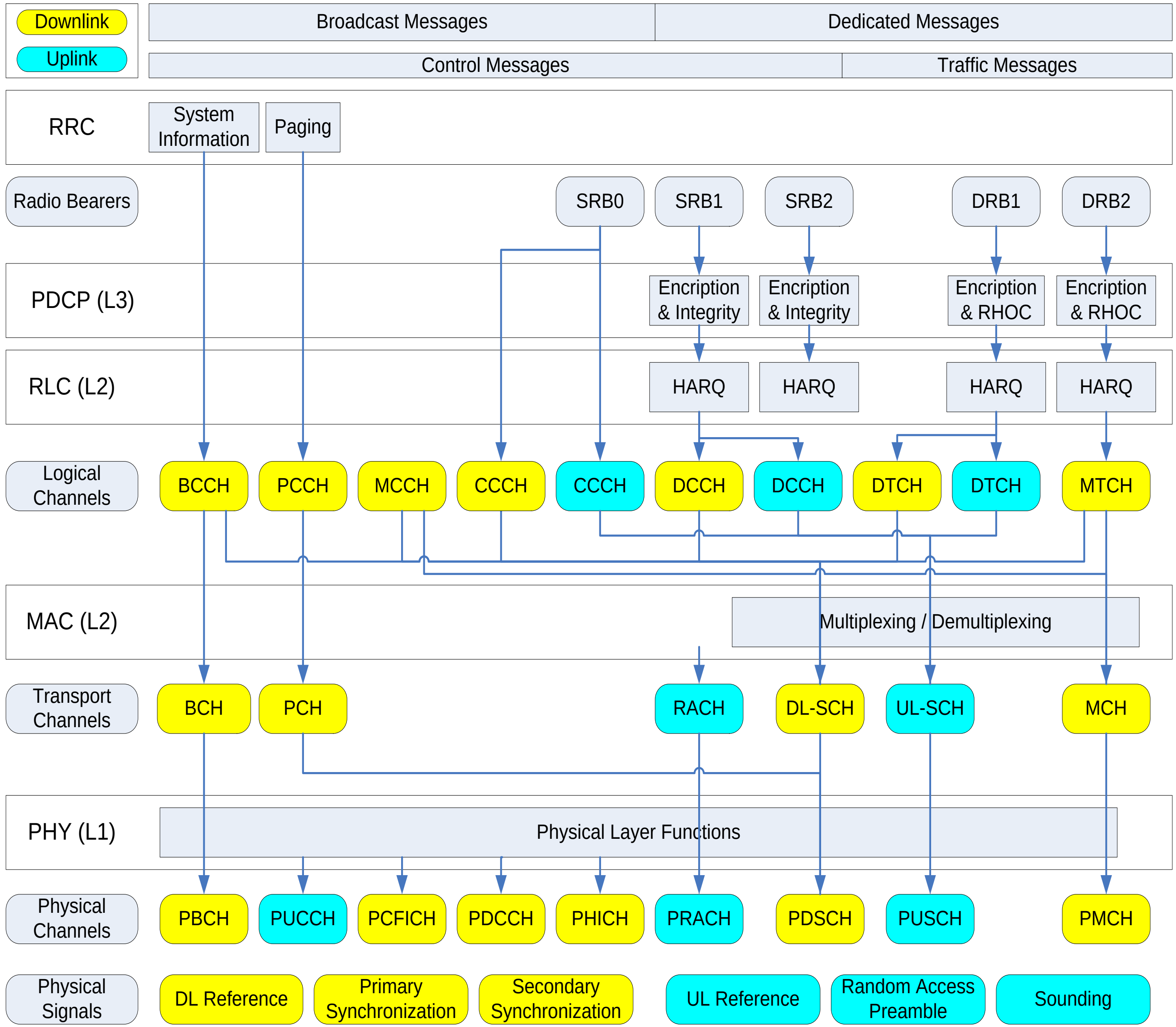
Protocol Overhead

- Packet Data Convergence Protocol (PDCP)
  - Adds 1 or 2 bytes
  - May remove 20/40 IP address bytes
- Radio Link Control (RLC)
  - Adds 1 or 2 bytes
- Medium Access Control (MAC)
  - Adds 5 bytes
- Physical Layer (PHY)
  - Adds 16 bit CRC
  - Adds 1/3 FEC
  - Does rate adjustment (repetition and puncturing)
  - Does Hybrid Repeat Request (HARQ)

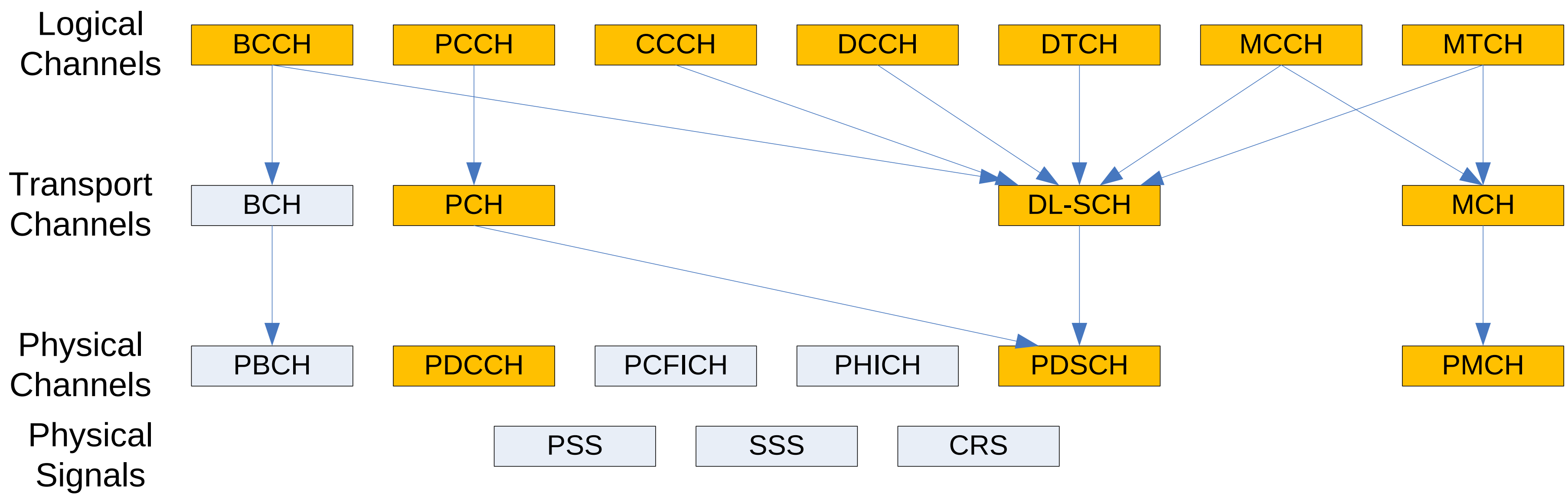


Channels and Signals

BCCH	Broadcast Control Channel
BCH	Broadcast Channel
CCCH	Common Control Channel
CRS	Cell Reference Signal
DCCH	Dedicated Control Channel
DL-SCH	Downlink Shared Channel
DRB	Data Radio Bearer
DRS	Demodulation Reference Signal
DTCH	Dedicated Traffic Channel
DwPTS	Downlink Pilot Timeslot
MCCH	Multicast Control Channel
MCH	Multicast Channel
MTCH	Multicast Traffic Channel
PBCH	Physical Broadcast Channel
PCCH	Physical Control Channel
PCFICH	Physical Control Information Channel
PCH	Paging Channel
PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
PHICH	Physical Hybrid Information Channel
PMCH	Physical Multicast Channel
PRACH	Physical Random Access Channel
PSS	Primary Synchronization Channel
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
RACH	Random Access Channel
RAP	Random Access Preamble
RLC	Radio Link Control
RRC	Radio Resource Control
SRB	Signaling Radio Bearer
SRS	Sounding Reference Signal
SSS	Secondary Synchronization Signal
UL-SCH	Uplink Shared Channel
UpPTS	Uplink Pilot Timeslot

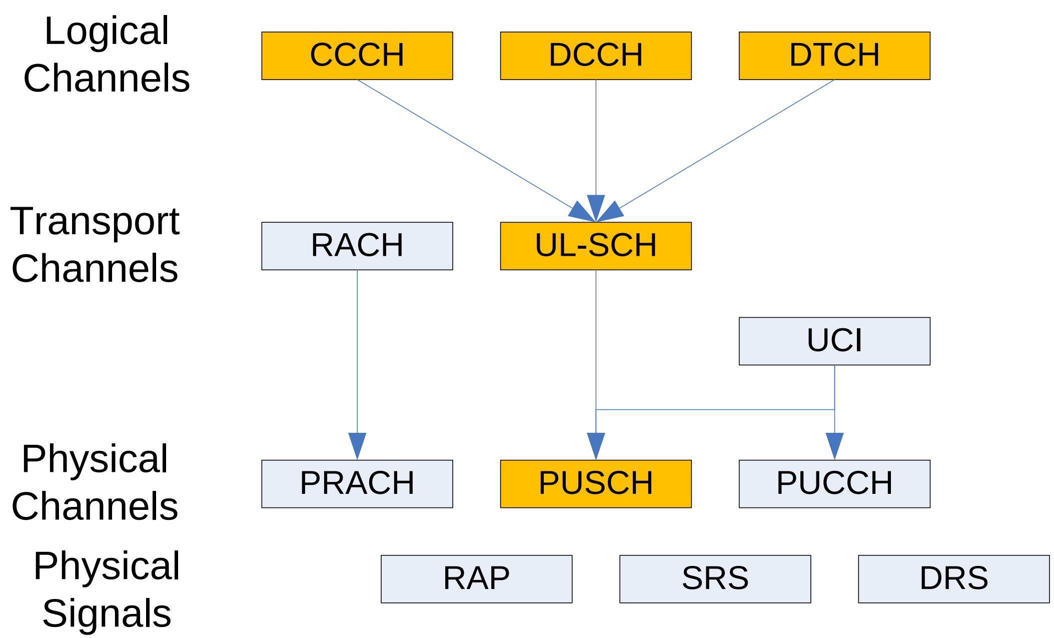


Downlink channels and signals



BCCH	Broadcast Control Channel	PCFICH	Physical Control Information Channel
BCH	Broadcast Channel	PCH	Paging Channel
CCCH	Common Control Channel	PDCP	Packet Data Convergence Protocol
CRS	Cell Reference Signal	PDSCH	Physical Downlink Shared Channel
DCCH	Dedicated Control Channel	PHICH	Physical Hybrid Information Channel
DL-SCH	Downlink Shared Channel	PMCH	Physical Multicast Channel
DRB	Data Radio Bearer	PSS	Primary Synchronization Channel
DTCH	Dedicated Traffic Channel	RLC	Radio Link Control
MCCH	Multicast Control Channel	RRC	Radio Resource Control
MCH	Multicast Channel	SRB	Signaling Radio Bearer
MTCH	Multicast Traffic Channel	SRS	Sounding Reference Signal
PBCH	Physical Broadcast Channel	SSS	Secondary Synchronization Signal
PCCH	Physical Control Channel		

Uplink Channels and Signals



DRB	Data Radio Bearer
DRS	Demodulation Reference Signal
DTCH	Dedicated Traffic Channel
DwPTS	Downlink Pilot Timeslot
PDCP	Packet Data Convergence Protocol
PRACH	Physical Random Access Channel
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
RACH	Random Access Channel
RAP	Random Access Preamble
RLC	Radio Link Control
RRC	Radio Resource Control
SRB	Signaling Radio Bearer
SRS	Sounding Reference Signal
UL-SCH	Uplink Shared Channel

Transmission Modes

Transmission Mode

- eNB and UE can communicate through different transmission modes, depending on:
  - UE capability
  - RF channel condition

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

Modulation and Coding Scheme

CelPlan Wireless Solutions & Consulting

- UE reports one of 15 CQI (Channel Quality Indicator)
- CQI values are mapped to 29 MCS (Modulation and Coding Scheme) indexes
- MCS indexes are mapped to 27 TBS (Transport Block Size) indexes

CQI	modulation	coding rate x 1024	Code Rate	efficiency	Adjusted	CR equiv.	MCS Index	modulation	coding rate x 1024	Code Rate	efficiency
2	QPSK	120	0.1172	0.2343750	0.2343750	120.00	0	2	120	0.1172	0.2344
	QPSK				0.3056641	156.50	1	2	157	0.1533	0.3066
3	QPSK	193	0.1885	0.3769531	0.3769531	193.00	2	2	193	0.1885	0.3770
	QPSK				0.4892578	250.50	3	2	251	0.2451	0.4902
4	QPSK	308	0.3008	0.6015625	0.6015625	308.00	4	2	308	0.3008	0.6016
	QPSK				0.7392578	378.50	5	2	379	0.3701	0.7402
5	QPSK	449	0.4385	0.8769531	0.8769531	449.00	6	2	449	0.4385	0.8770
	QPSK				1.0263672	525.50	7	2	526	0.5137	1.0273
6	QPSK	602	0.5879	1.1757813	1.1757813	602.00	8	2	602	0.5879	1.1758
	QPSK				1.3261719	679.00	9	2	679	0.6631	1.3262
	16QAM				1.3261719	339.50	10	4	340	0.3320	1.3281
7	16QAM	378	0.3691	1.4765625	1.4765625	378.00	11	4	378	0.3691	1.4766
	16QAM				1.6953125	434.00	12	4	434	0.4238	1.6953
8	16QAM	490	0.4785	1.9140625	1.9140625	490.00	13	4	490	0.4785	1.9141
	16QAM				2.1601563	553.00	14	4	553	0.5400	2.1602
9	16QAM	616	0.6016	2.4062500	2.4062500	616.00	15	4	616	0.6016	2.4063
	16QAM				2.5683594	657.50	16	4	658	0.6426	2.5703
	64QAM				2.5683594	438.33	17	6	439	0.4287	2.5723
10	64QAM	466	0.4551	2.7304688	2.7304688	466.00	18	6	466	0.4551	2.7305
	64QAM				3.0263672	516.50	19	6	517	0.5049	3.0293
11	64QAM	567	0.5537	3.3222656	3.3222656	567.00	20	6	567	0.5537	3.3223
	64QAM				3.6123047	616.50	21	6	616	0.6016	3.6094
12	64QAM	666	0.6504	3.9023438	3.9023438	666.00	22	6	666	0.6504	3.9023
	64QAM				4.2128906	719.00	23	6	719	0.7021	4.2129
13	64QAM	772	0.7539	4.5234375	4.5234375	772.00	24	6	772	0.7539	4.5234
	64QAM				4.8193359	822.50	25	6	822	0.8027	4.8164
14	64QAM	873	0.8525	5.1152344	5.1152344	873.00	26	6	873	0.8525	5.1152
	64QAM				5.3349609	910.50	27	6	910	0.8887	5.3320
15	64QAM	948	0.9258	5.5546875	5.5546875	948.00	28	6	948	0.9258	5.5547

Radio Network Temporary Identification (RNTI)

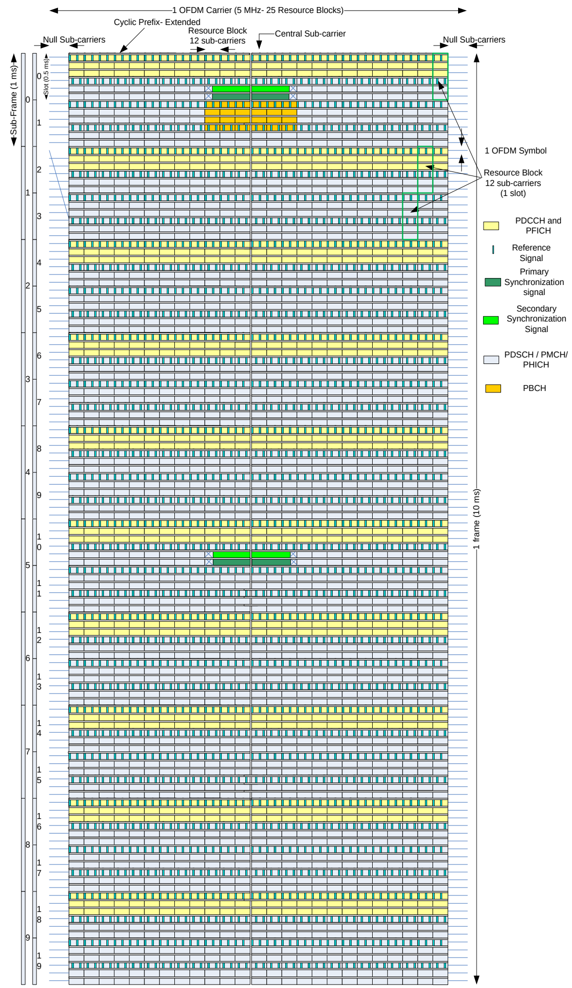
- eNB uses nicknames (RNTI) to identify UEs
  - RNTI is 16 bit long
  - Different RNTIs are assigned at different netwrok phases
  - RNTI is used as an address
  - It is scrambled with the 16 bit CRC added by PHY to the Transport Blocks (TB)

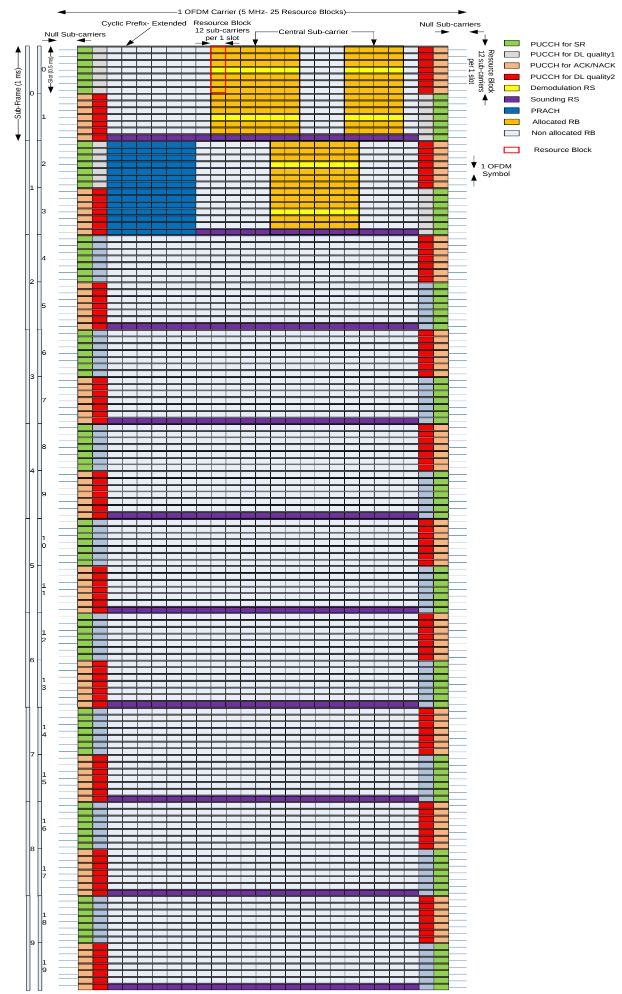
Radio Network Temporary Identifier	Network Operation	FDD		
		Range		Values
RA-RNTI	Random Access	0001	003C	60
C-RNTI				
Temporary C-RNTI				
Semi-Persistent Scheduling SPS-RNTI				
TPC-PUCCH-RNTI				
TPC-PUSCH-RNTI				
C-RNTI	Cell related	003D	FFF3	65463
Temporary C-RNTI				
Semi-Persistent Scheduling SPS-RNTI				
Transmit Power Control for UL TPC-PUCCH-RNTI				
Transmit Power Control for UL TPC-PUSCH-RNTI				
reserved	Reserved	FFF4	FFFC	9
M-RNTI	Multicast	FFFD		1
P-RNTI	Paging	FFFE		1
SI-RNTI	System Information	FFFF		1

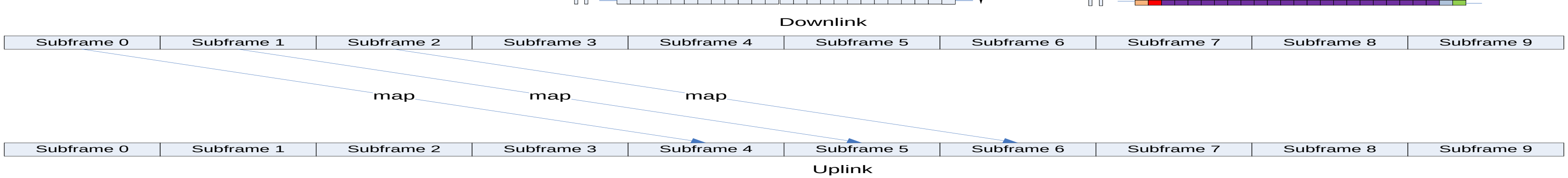
Frame Organization

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







Signals

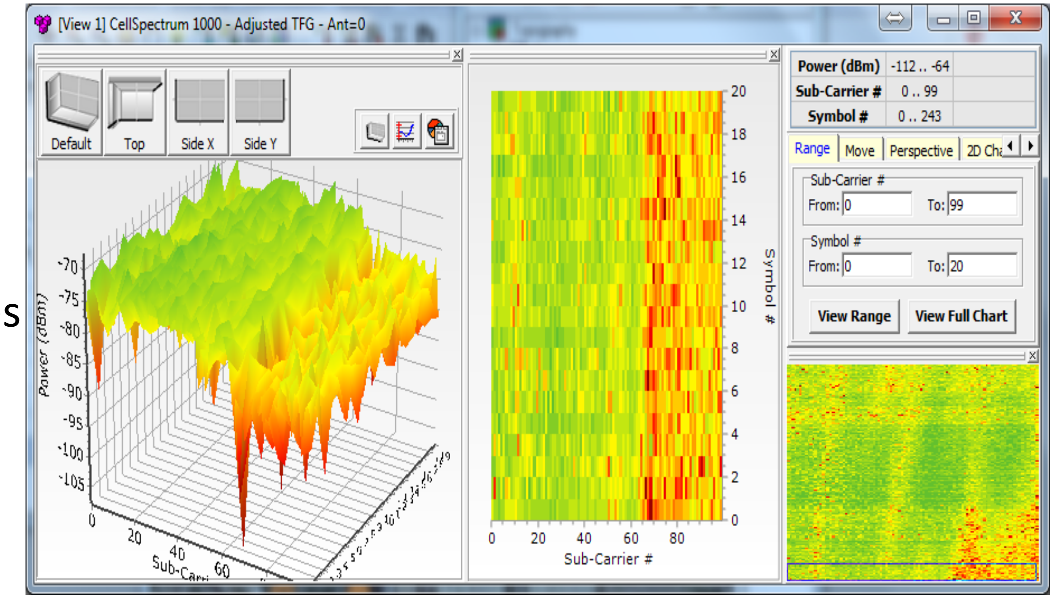
Signals

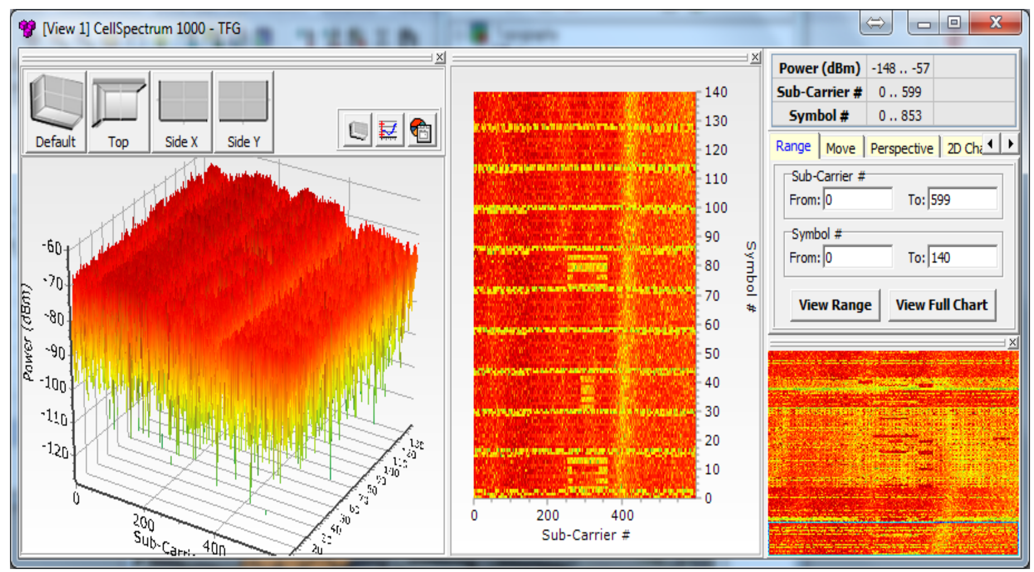
- Downlink
  - Primary Synchronization Signal (PSS)
  - Secondary Synchronization Signal (SSS)
  - Cell Reference Signal (CRS)
    - Location in frame is PCI dependent mod(PCI,6)
    - Each antenna has its own CRS and the antenna does not transmit when the other antennas are tranmittingg their CRSs
  - MBSFN (Multimedia Broadcast Single Frequency Network) Reference Signals (MBSFN-RS)
  - UE Specific Reference Signals (UE-RS) or Demodulation Reference Signals (DM-RS)
  - Positioning Reference Signals (PRS)
  - Channel State Information Reference Signals (CSI-RS)
- Uplink
  - Synchronization follows downlink synchronization
  - PUCCH Demodulation Reference Signal (PUCCH-DMRS)
  - PUSCH Demodulation Reference Signal (PUSCH-DMRS)
  - Sounding Reference Signal (SRS)

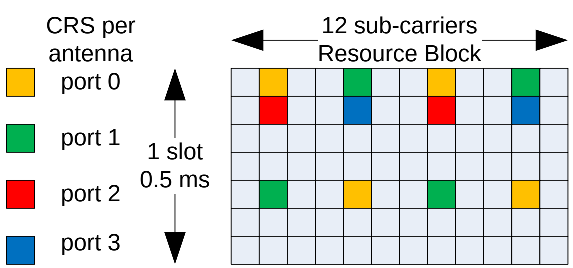
Channel Equalization

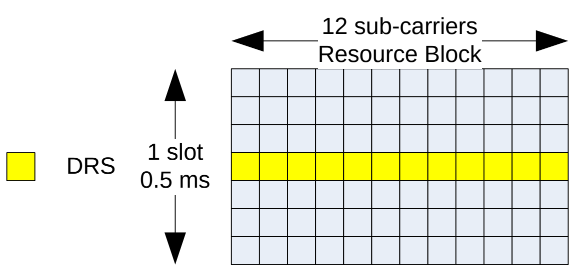
- A broadband channel has significant variations in frequency and time
- This variations have to be corrected before data is extracted
- Reference Signals are used for this purpose
- Reference Signals are known sequences that can be compared to a local reference
- Cell Reference Signals are used in the dowlink
- Demodulation Reference Signals are used in the uplink

CellSpectrum screen captures



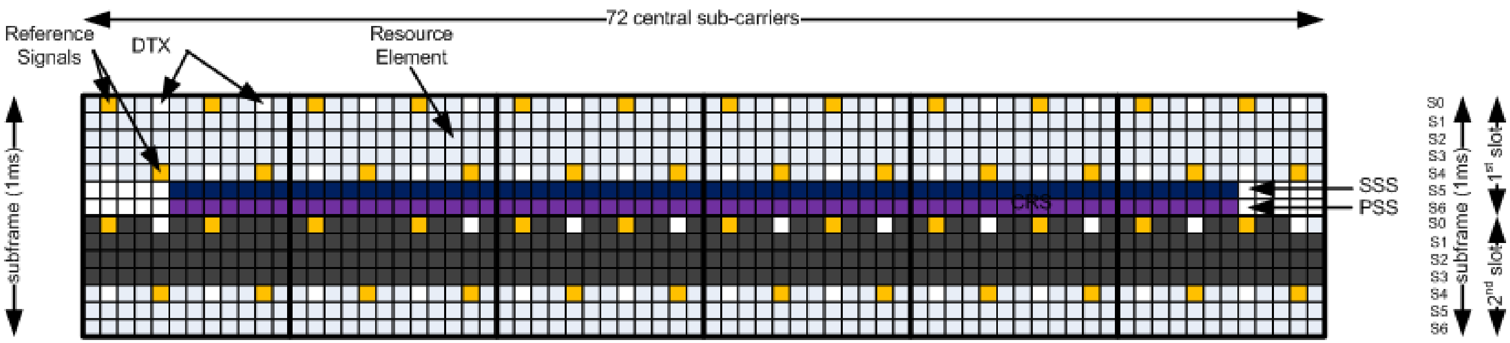


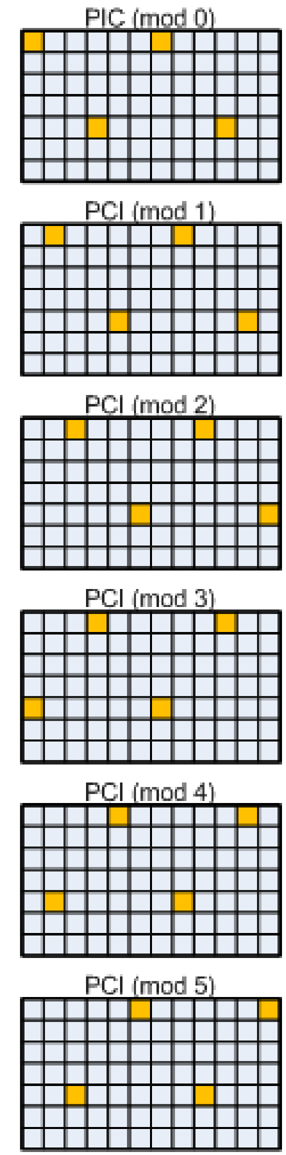




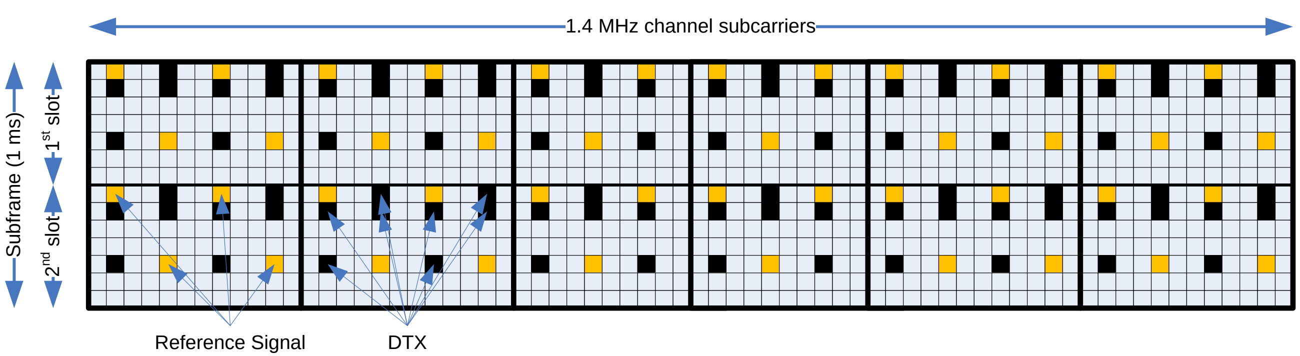
Downlink Signals

- Primary Synchronization Signal (PSS)
- Secondary Synchronization Signal (SSS)



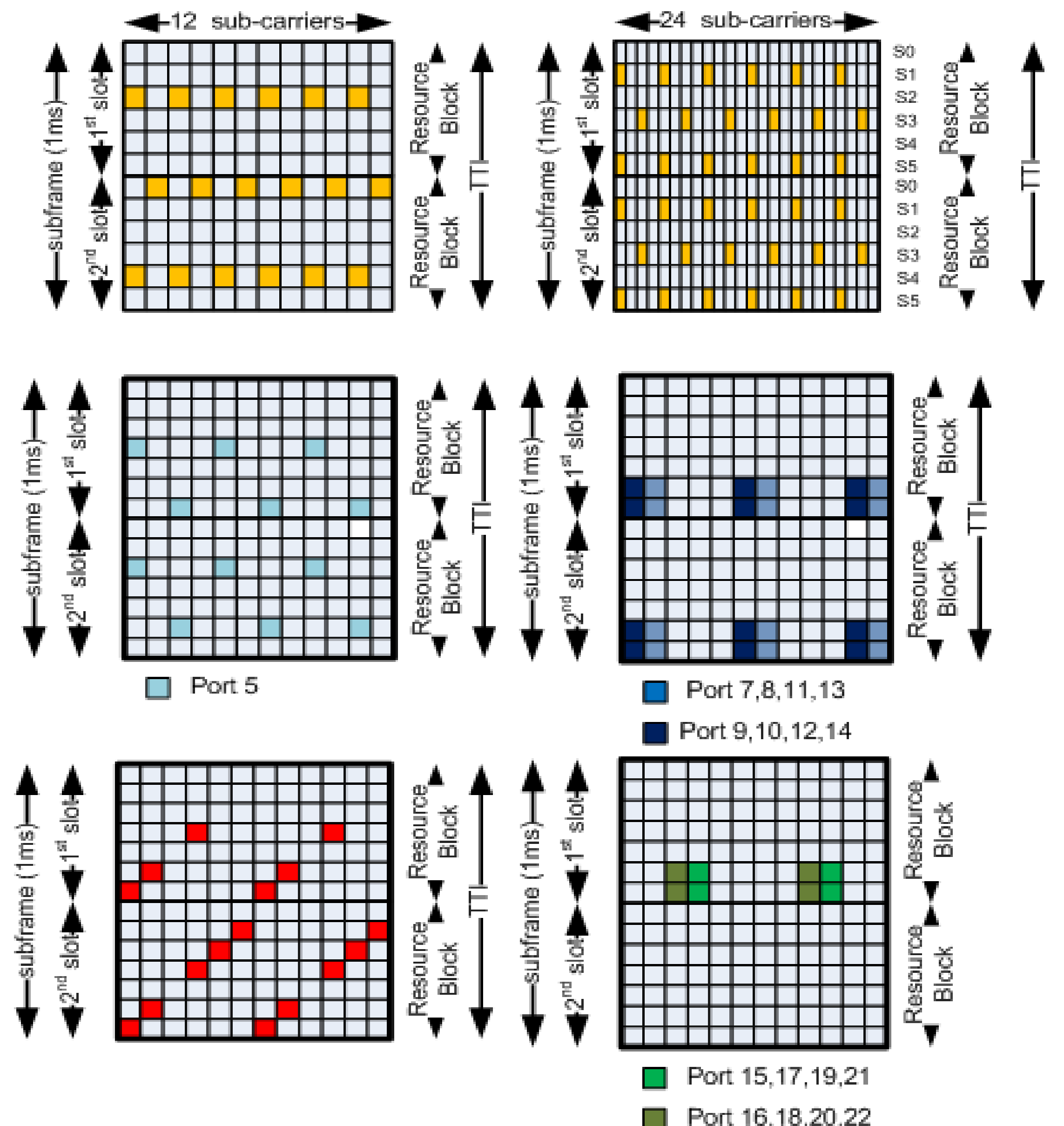


- Cell Reference Signal (CRS)



Other Downlink Signals Reference Signals

- MBSFN (Multimedia Broadcast Single Frequency Network) Reference Signals (MBSFN-RS)
- UE Specific Reference Signals (UE-RS) or Demodulation Reference Signals (DM-RS)
- Positioning Reference Signals (PRS)
- Channel State Information Reference Signals (CSI-RS)

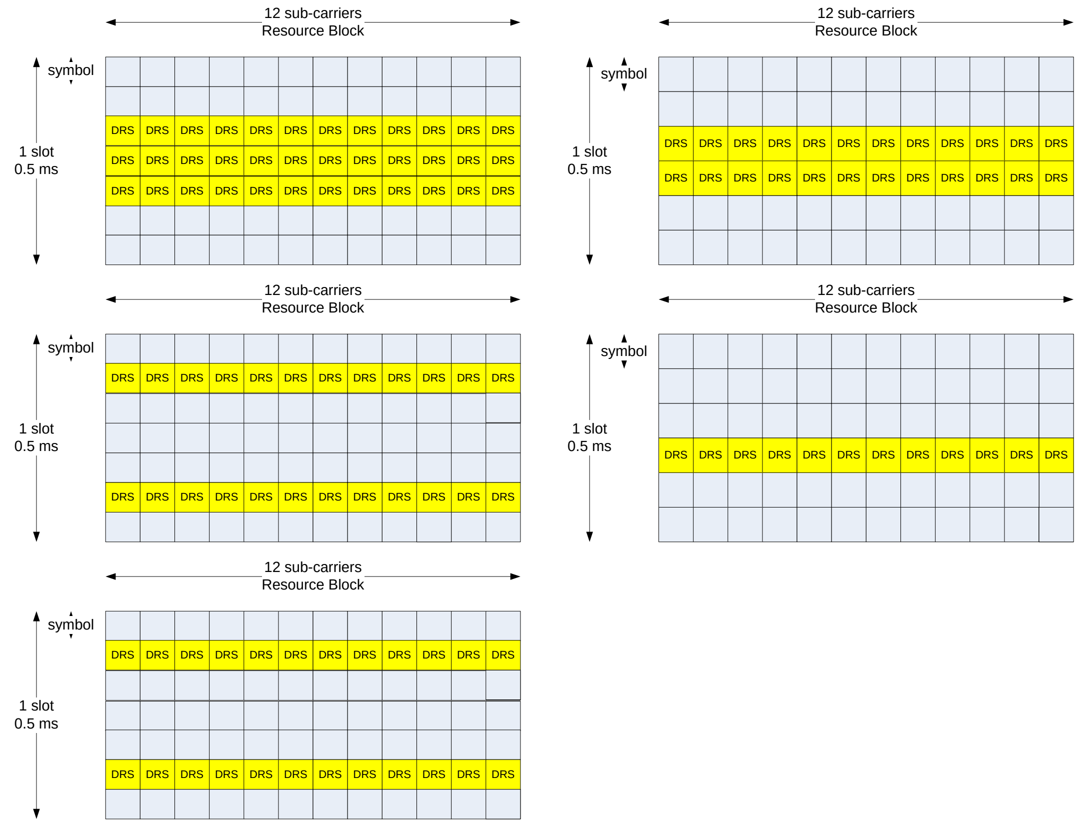


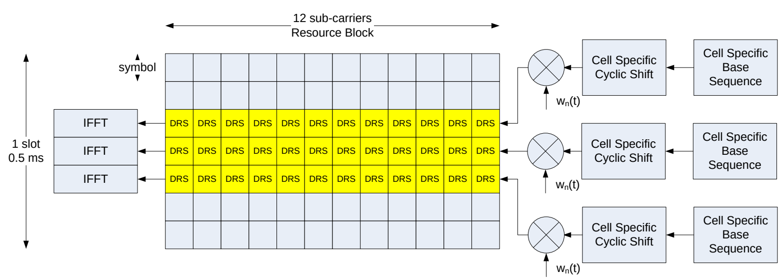
Uplink Signals

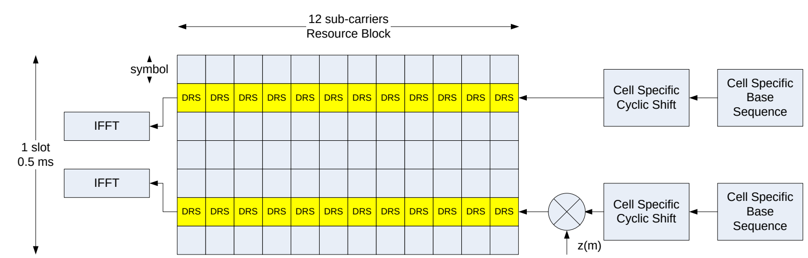
- Synchronization follows downlink synchronization
- PUCCH Demodulation Reference Signal (PUCCH-DMRS)
- PUSCH Demodulation Reference Signal (PUSCH-DMRS)
- Sounding Reference Signal (SRS)

PUCCH DMRS (Demodulation Reference Signals)

- DMRS is used to equalize the RF channel at the eNB
- There are 7 PUCCH formats
- These formats use different DMRS

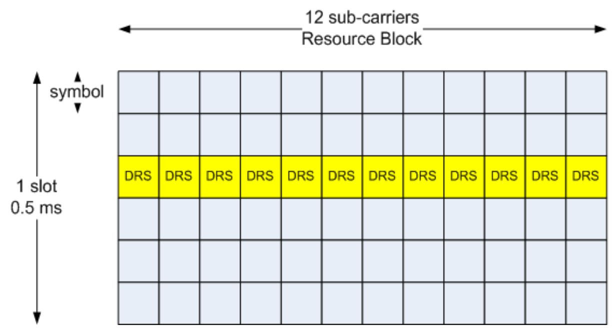


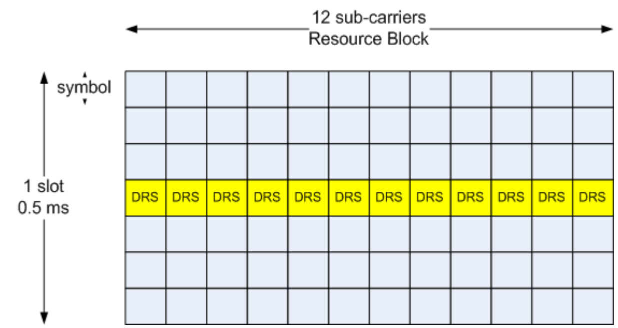


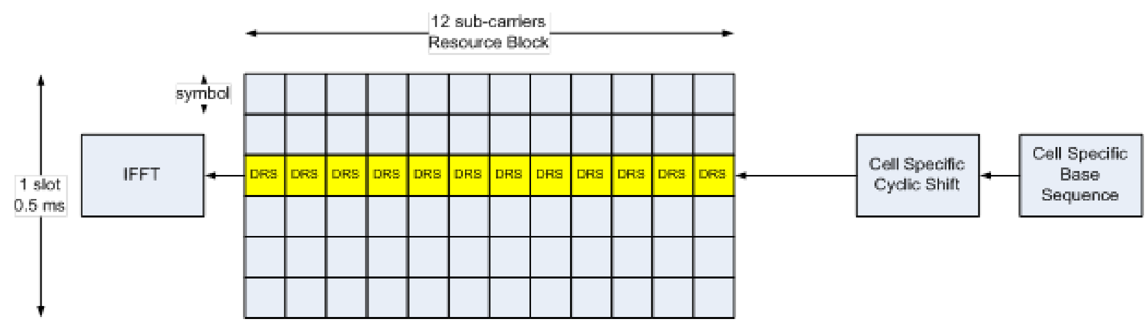


PUSCH DMRS (Demodulation Reference Signals)

- DMRS is used to equalize the RF channel at the eNB

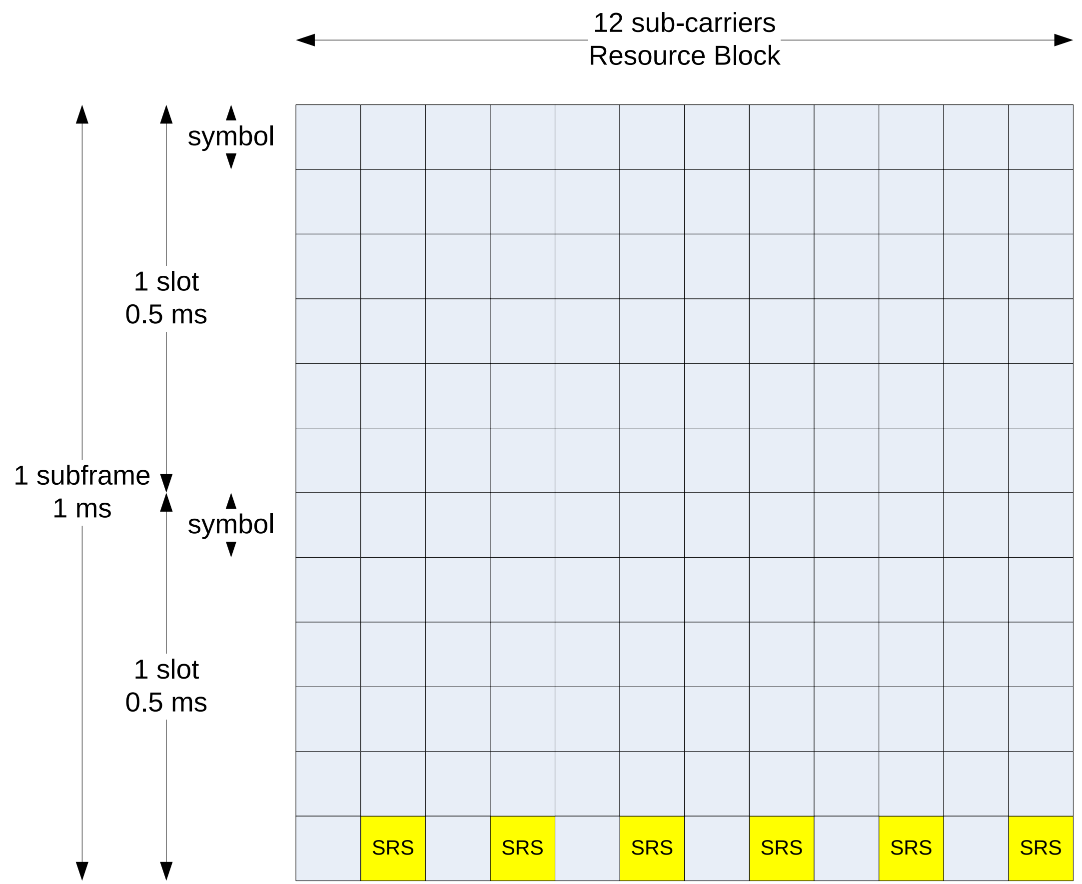






Sounding Reference Signal (SRS)

- SRS is sent to evaluate the RF channel performance outside the RBs used for UE transmission
- SRS uses resources normally available for PUSCH
- SRS periodicity is programmable



Channels

Downlink

Uplink

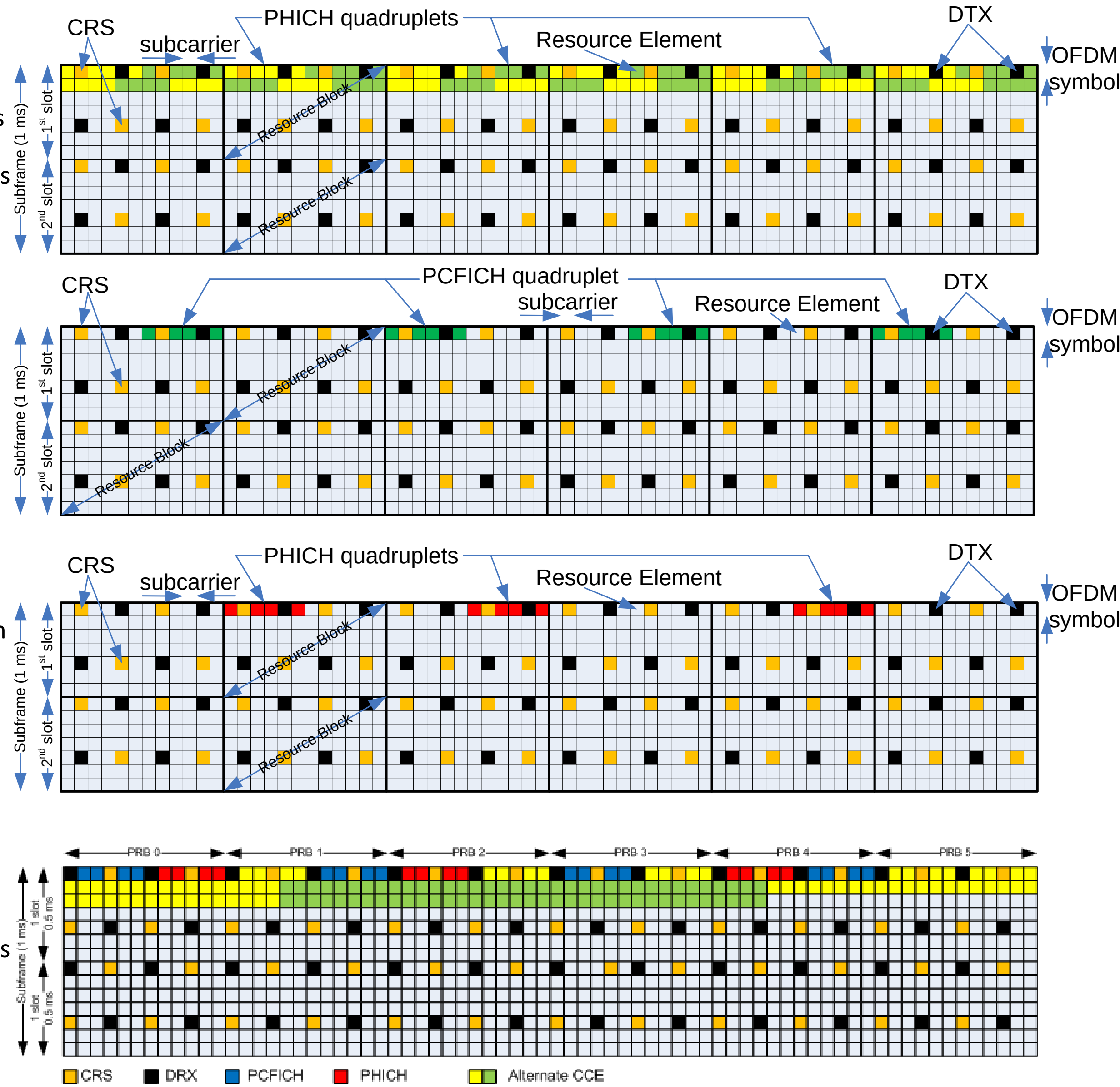
Downlink Channels

DL Channels

- Broadcast channel
  - PBCH (Physical Broadcast Channel)
    - Sent once a frame with basic channel information
- Subframe Control Area
  - PCFICH (Physical Control Format Indicator Channel)
    - Pre defined location, 4 REGs
  - PHICH (Physical Hybrid Indicator Channel)
    - Pre defined location, 3 REGs per group, scalable number of groups
  - PDCCH (Physical Downlink Control Channel)
    - Allocated to CCE in the remaining of the control area
    - One PDCCH for each PDSCH and PUSCH
- Subframe Data Area
  - PDSCH (Physical Downlink Shared Channel)
    - Location, size and characteristics defined by PDCCH
  - PMCH (Physical Multicast Channel)

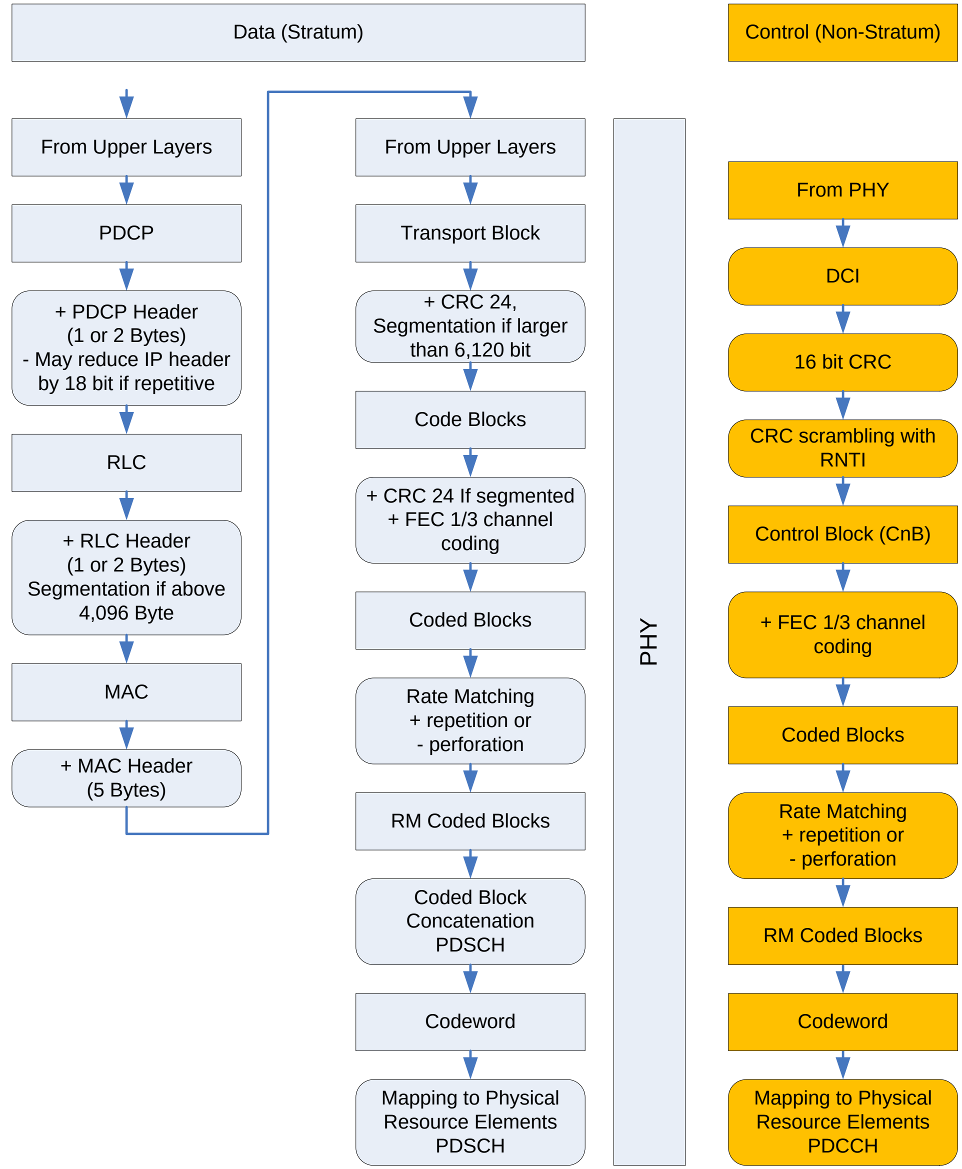
Downlink Control Area

- **Resource Element Group (REG)**
  - Set of 4 contiguous REs (ignoring RSs), its called quadruplet
  - Painted in sequence with alternate colors (yellow and green)
- **Physical Control Format indicator Channel (PCFICH)**
  - Set of 4 REGs
  - location varies with PCI
  - defines number of OFDM symbols in control area
- **Physical Hybrid Indication Control Channel (PHICH)**
  - PHCICH group is a set of 3 REGs
  - Number of groups varies with bandwidth and scaling factor (2 to 50)
  - Location varies with PCI
  - Carries ACK/NACK for UE messages
- **Control Channel Element (CCE)**
  - Set of 9 REGs
- **Search Area (SA)**
  - Set of CCEs for common use or cell specific use
  - Painted in sequence with alternate colors (yellow and green)



Downlink Control Area

- Downlink Control Information (DCI)
  - Informs how data is mapped in the TTI in terms of Resource Block Groups (RBG)
  - Informs the transmission characteristics of the data
  - Has several formats according to the transmission mode
    - Format is chosen according to the transmission mode and internal policy
- Physical Downlink Control Channel (PDCCH)
  - It uses QPSK modulation
  - Carries DCI information
  - It has 4 formats that are chosen according to RF channel condition
  - Each PDCCH format is allocated to a certain number of CCEs and consequently results in a different coding rate



Downlink Control Information (DCI)

- DCI carries mapping and transmit characteristics of each PDSCH (sent to one or more UEa) and PUSCH (to be received from an UE)

DCI	DCI Format	Application	RNTI
Uplink Resource Allocation	0	Single Antenna Port Scheduling of single PUSCH codeword	C-RNTI Temporary C-RNTI SPS-RNTI
Downlink Resource Allocation	1	Single Antenna Port or transmit diversity Scheduling of single PDSCH codeword	C-RNTI Temporary C-RNTI SPS-RNTI
	1A	Single Antenna Port or transmit diversity Compact scheduling of single PDSCH codeword or random Access Initiation	P-RNTI SI-RNTI RA-RNTI C-RNTI Temporary C-RNTI SPS-RNTI
	1B	Closed loop spatial multiplexing for a single codeword Compact scheduling of single PDSCH codeword with precoding information	C-RNTI
	1C	Single antenna port or transmit diversity Very compact Resource Block scheduling for single PDSC codeword	P-RNTI SI-RNTI RA-RNTI
	1D	Multi-user MIMO Compact scheduling of single PDSCH codeword with precoding and power offset information	C-RNTI
	2	Closed loop spatial multiplexing for a single codeword Scheduling of one or two PDSCH codewords	C-RNTI SPS-RNTI
	2A	Open loop spatial multiplexing for a single codeword Scheduling of one or two PDSCH codewords	
Transmit Power Control	3	TC command for PUCCH and PUSCH with 2 bit power adjustments	TPC-PUSCH-RNTI
	3A	TC command for PUCCH and PUSCH with 1 bit power adjustments	TPC-PUCCH-RNTI

Transmission Modes x DCI

- Each transmission mode supports one type of Downlink control Information (DCI)

Downlink Control Information (DCI) for downlink mapping	C-RNTI		SPS-C-RNTI	
Transmission Mode	Common Search Space	UE Search Space	Common Search Space	UE Search Space
Single Antenna	1A	1, 1A	1A	1
Transmit Diversity	1A	1, 1A	1A	1, 2A, 2
Open Loop Spatial Multiplexing	-	2A	-	-
Closed Loop Spatial Multiplexing	-	2	-	-
Multi-user MIMO	-	1D	-	-
Closed Loop Spatial Multiplexing, single layer	-	1B	-	-
Closed Loop Spatial Multiplexing, dual layer	-	2B	-	-
Closed Loop Spatial Multiplexing, eight layer	-	2C	-	-

PDCCH formats

- DCI size (in bit) depends on the DCI format and bandwidth
- Each DCI can be spread to the RF channel requirements according to the 4 PDCCH formats, resulting in different FEC spreading codes

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 bits				72	144	288	576
DCI Format	Channel Bandwidth (MHz)	DCI data bits	DCI bits after CRC				
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

PDCCH Allocation and Detection

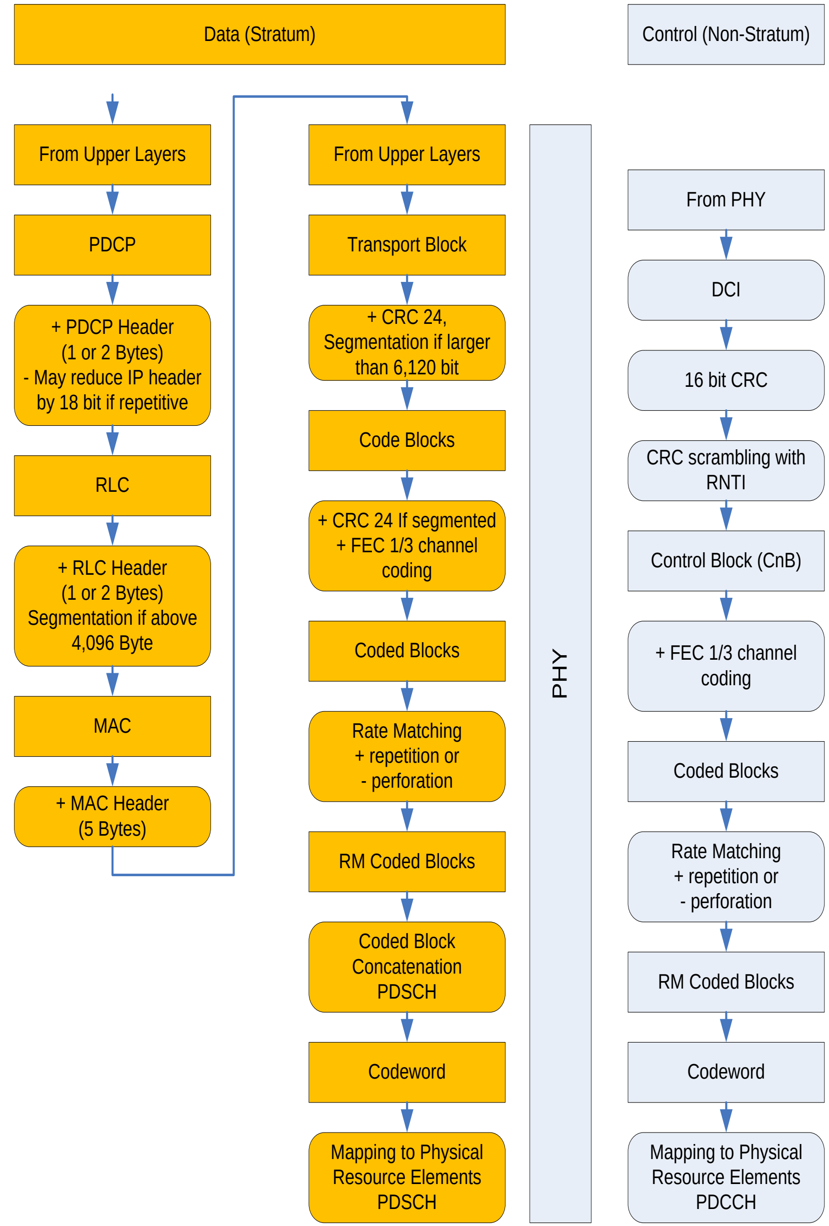
- eNB PDCCH assembly and allocation
  - PHY gets DCI information
  - PHY adds a 16 bit CRC
  - PHY scrambles CRC with UE RNTI, forming a Control Block (CnB)
  - PHY assigns a PDCCH format to the CnB according to RF channel requirements (MCS)
    - CnB is sent to 1/3 FEC Turbo Coder
    - Coded Block is rate matched to the PDCCH format size
  - PHY assigns PDCCH to a free set of CCEs
  - PHY maps PDCCH to CCE Resource Elements
- UE is not aware of a PDCCH allocation, but is aware of the frame area it is allocated
- UE blind searches all the CCE positions for a broadcasted or UE specific PDCCH
  - UE looks at every CCE position for a CRC and unscrambles with the broadcast and its RNTI and checks it validity
  - When successful UE found a valid PDCCH message

DL Data Area

- DL Data Allocation Types
  - Type 0- RBG allocation
  - Type 1- RBG subset allocation
  - Type 2- Virtual RBG allocation
    - Contiguous
    - Distributed

Downlink Data Area

- Transport Block (TB)
- Transport Block Size (TBS)
- Code Block (CB)
- Codeword (CW)
- Physical Downlink Shared Channel (PDSCH)



Data Allocation type 0

- Resource Block Group (RBG)
  - Set of contiguous PRBs
  - RBG size is bandwidth dependent
- Data Allocation type 0: simple RBG allocation
  - Bit map specifies the RBG allocation

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

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

Bit Map	0	1	1	0	0	1	0	0	0	1	1	0	0

Data Allocation type 1

- Data Allocation type 1: RBG subsets
  - Objective was to allow some resource segmentation between cells
  - Number of subsets is bandwidth dependable

Resource Allocation Type 1						
DCI formats: 1, 2, 2A, 2B, 2C	Bandwidth (MHz)					
	1.4	3	5	10	15	20
Total Number of RBs in frame	N/A	15	25	50	75	100
RBG Size (RB)	N/A	2	2	3	4	4
Total Number of RBGs	N/A	8	13	17	19	25
Number of RBG subsets	N/A	2	2	3	4	4
RBG subsets (bit)	N/A	1	1	2	2	2
Offset flag (bit)	N/A	1	1	1	1	1
Size of bit map (bit)	N/A	8	13	17	19	25

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
RBG subset 1	0				2				4				6				8				10				12
RBG subset 2			1				3				5				7				9				11		

Subset	1				
Offset flag	1				
Bit Map	0	1	0	0	0

Subset	2				
Offset flag	0				
Bit Map	1	1	0	1	0

Data Allocation type 2

- Data Allocation type 2: reduced mapping and added diversity
- Contiguous allocation
  - Resource Indication Value (RIV): indicates PRB start number and number of consecutive PRBs
- Distributed allocation
  - Resource Blocks are assigned to Virtual Resource Blocks
  - Interleaved in two (gap1) or four groups (gap2)
  - Then mapped to Physical Resource Groups
  - An RB pair is allocated with a separation (gap) between the first and second slot

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

RIV	127	
Number of RBs	Floor(RIV/Number of RBs)+1	6
Starting RB number	Mod(RIV, Number of RBs)	2

	write			
read	0	1	2	3
	4	5	6	7
	8	9	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	

Gap 1 = 27

RB	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
Slot 0	0	4	8	12	16	20	24	28	32	36	40	44	1	5	9	13	17	21	25	29	33	37	41		
Slot 1	2	6	10	14	18	22	26	30	34	38	42	45	3	7	11	15	19	23	27	31	35	39	43		

RB	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
Slot 0			2	6	10	14	18	22	26	30	34	38	42	45	3	7	11	15	19	23	27	31	35	39	43
Slot 1			0	4	8	12	16	20	24	28	32	36	40	44	1	5	9	13	17	21	25	29	33	37	41

	write			
read	0	1	2	3
	4	5	6	7
	8	9	10	11
	12	13	14	15
	16		17	

	write			
read	18	19	20	21
	22	23	24	25
	26	27	28	29
	30	31	32	33
	34		35	

Gap 2 = 9 Gap 2 = 9

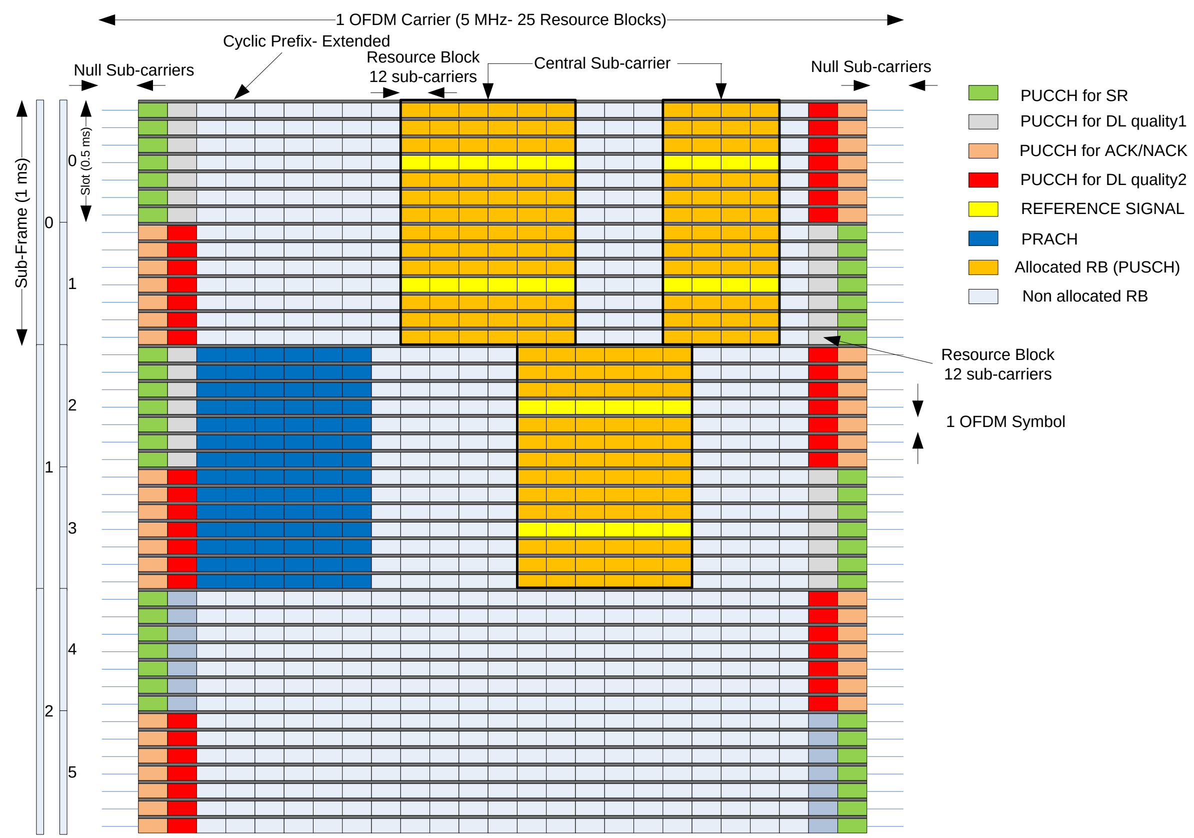
RB	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Slot 0	0	4	8	12	16	1	5	9	13	2	6	10	14	17	3	7	11	15	18	19	22	23	26	27	30
Slot 1	2	6	10	14	17	3	7	11	15	0	4	8	12	16	1	5	9	13	20	21	24	25	28	29	32

RB	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
Slot 0	31	34	20	21	24	25	28	29	32	33	35														
Slot 1	33	35	18	19	22	23	26	27	30	31	34														

Uplink Channels

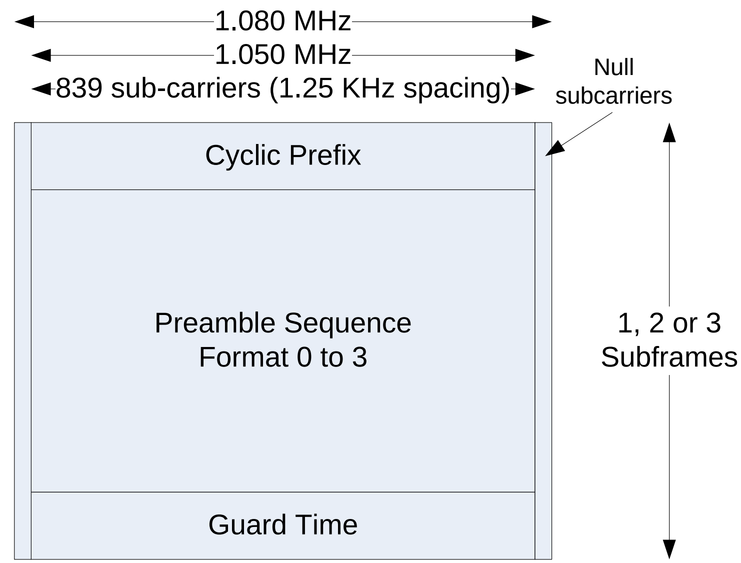
UL Channels

- Subframe Control Area
  - PUCCH
- Subframe Random Access Area
  - PRACH
- Subframe Data Area
  - PUSCH
  - PUMCH



Uplink RACH Area

- RACH areas are announced in SIB2
- There are 4 RACH area formats



RACH configuration	Range	Step
Number of RA preambles	4 to 64	4
Size of RA preamble Group A	4 to 60	
Message size Group A	56, 14, 208, 256 bit	
Message power offset Group B	0, 5, 8, 10, 12, 15, 18 dB	
Power ramping step size	0, 2, 4,6 dB	
Preamble initial received target power	-120 to -90 dBm	2
Maximum number of preamble transmissions	3, 4, 5, 6, 7, 8, 10, 20, 50, 100, 200	
Random Access 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 number of HARQ transmissions	1 to 8	1

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	515.63	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

PRACH

- There are 64 sequences that can be used for PRACH access
- These sequences are divided in:
  - Contention based
    - Group A
    - Group B
  - Non contention based

Contention Based Random Access		Non-Contention Based Random Access
Group A Poor coverage UE or low amount of data to be sent	Group B Good coverage UE or large amount of data to be sent	Handover UE
0	----------------- Sequence -----------------	63

PRACH configuration	Range	Configuration criteria
PRACH Configuration Index	0 to 63	Cell range PRACH preamble capacity eNB processing load RF channel performance
Zero correlation zone configuration	0 to 15	Cell Range Root-sequence index reuse pattern RF channel performance
High speed flag	false/true	UE mobility Root-sequence index reuse pattern
Root sequence index	0 to 837	Avoid reuse in neighbor cells
PRACH frequency offset	0 to 94	PUCCH Resource Block allocation Avoid PUSCH Resource Block fragmentation

Format 0 to 3					
Zero Correlation zone (high speed flag= false)		Preamble Sequences per Root Sequence	Root Sequences Required per Cell	Root Sequences Reuse Pattern	Cell Range (km)
Signaled value	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	12.2
12	119	7	10	83	15.9
13	167	5	13	64	22.8
14	279	3	22	38	38.8
15	419	2	32	26	58.8
0	838	1	64	13	118.8

Random Access Response (RAR)

- RAR provides UE Timing Advance and gives UE a resource grant in case it wants to send a message
- RAR provides a Temporary RNTI
- RAR provides a back off value

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

E/T/R/R/BI subheader				
E (extension)	T (type)	R (reserved)	R	BI
1 bit	1 bit	1 bit	1 bit	4 bit

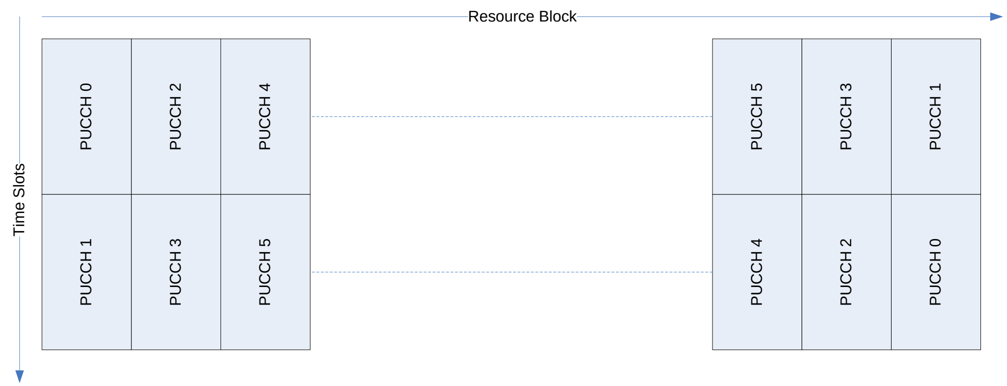
E/T/ RAPID (Random Access Preamble Identity)		
E (extension)	T (type)	RAPID
1 bit	1 bit	6 bit

Random Access Response (RAR) payload	
R (1 bit)	Timing Advance (7 bit)
+ Timing Advance (4 bit)	Uplink Grant (4 bit)
+ Uplink Grant (8 bit)	
+ Uplink Grant (8 bit)	
Temporary C-RNTI (8 bit)	
+ Temporary C-RNTI (8 bit)	

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

PUCCH

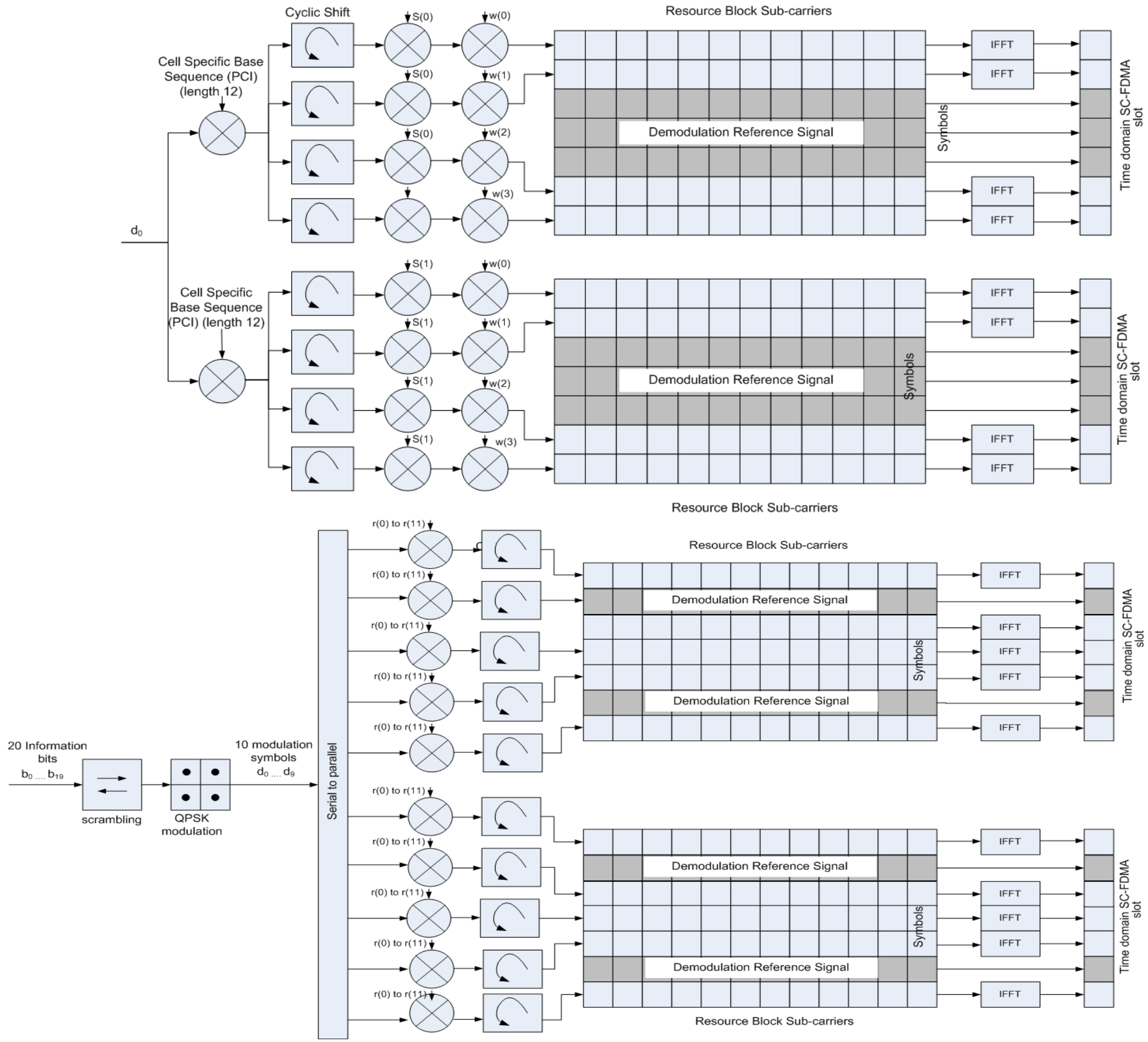
- Each PUCCH is assihned two RBs
- There are two types of PUCCH (standard and SR)
- Several UEs share the same RBs
- PUCCH has 7 formats and can signal, ACK, SR and CSI
- PUCCH uses a combination of base sequences, cyclic shifts and orhtogonal codes to differentitate between UEs



PUCCH Format	Release	Bits per Subframe	Duplex	Modulation Scheme	Number of RE		UCI data	
					Normal CP	Extended CP	Normal CP	Extended CP
1	8	0	FDD, TDD	-	48+48=96	48+36=84	Scheduling Request (SR)	
1a	8	1	FDD, TDD	BPSK			1HARQ - ACK	
			FDD				1HARQ-ACK +SR	
1b	8	2	FDD, TDD	QPSK			2HARQ-ACK, 2HARQ-ACK+SR, 4HARQ-ACK	
			FDD				4HARQ-ACK	
2	8	20	FDD, TDD	QPSK	60+60=120		CSI Report	CSI Report, CSI Report+2HARQ-ACK
2a	8	21	FDD, TDD	QPSK+BPSK	60+60=120	NA	CSI Report +1HARQ-ACK	NA
2b	8	22	FDD, TDD	QPSK+QPSK			CSI Report +2HARQ-ACK	NA
3	10	48	FDD	QPSK	60+60=120	60+48=108	10HARQ-ACK, 10HARQ-ACK+SR	
			TDD	QPSK			20HARQ-ACK, 20HARQ-ACK+SR	

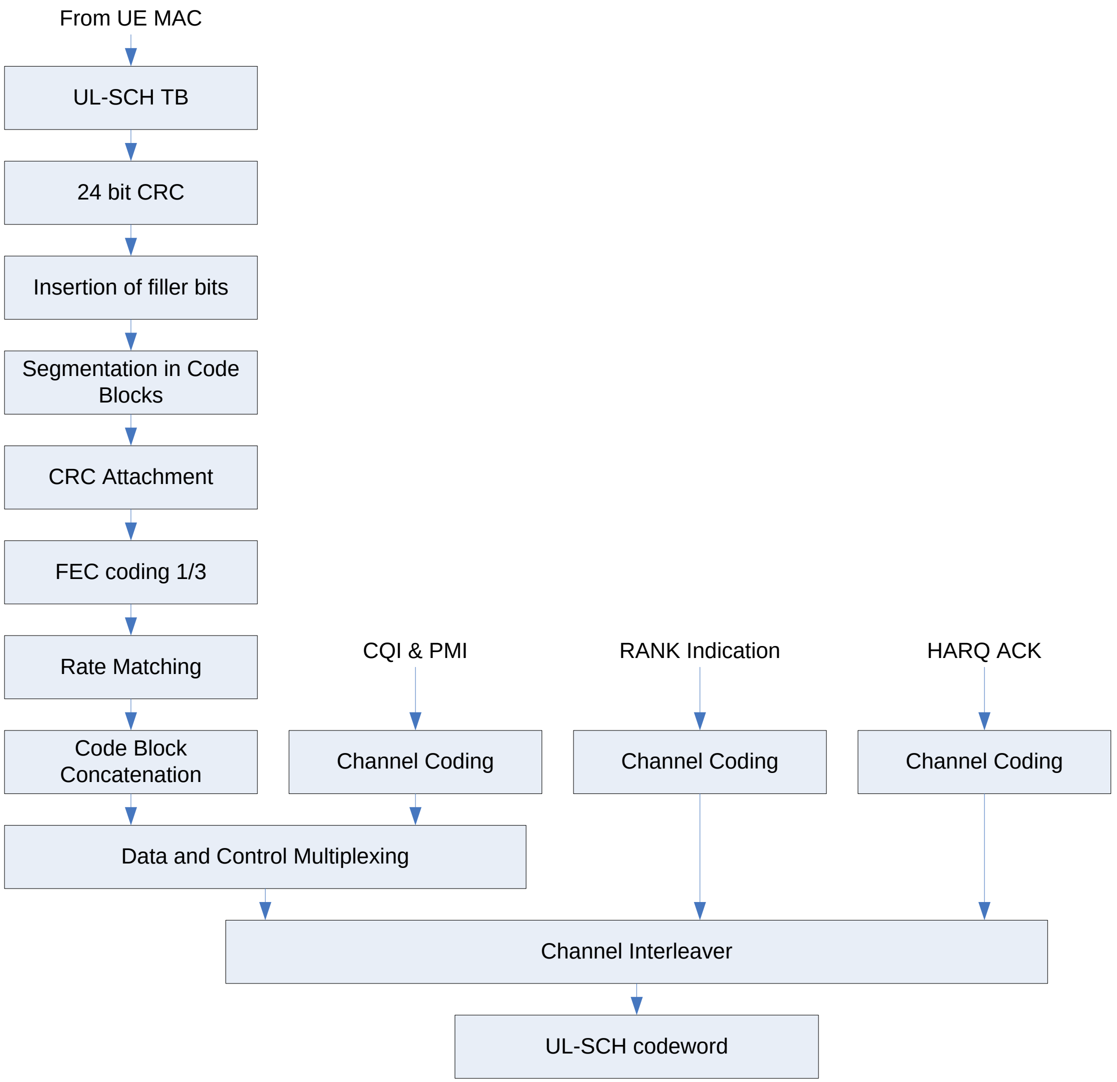
PUCCH signal generation

- PUCCH uses a combination of base sequences, cyclic shifts and orhtogonal codes to differentitate between UEs



Uplink Data Area (PUSCH)

- PUSCH folllows a similar coding procedure as the one done for PUSCH
- Both use the same TBS table
- CSI information and HARQ are coded separately



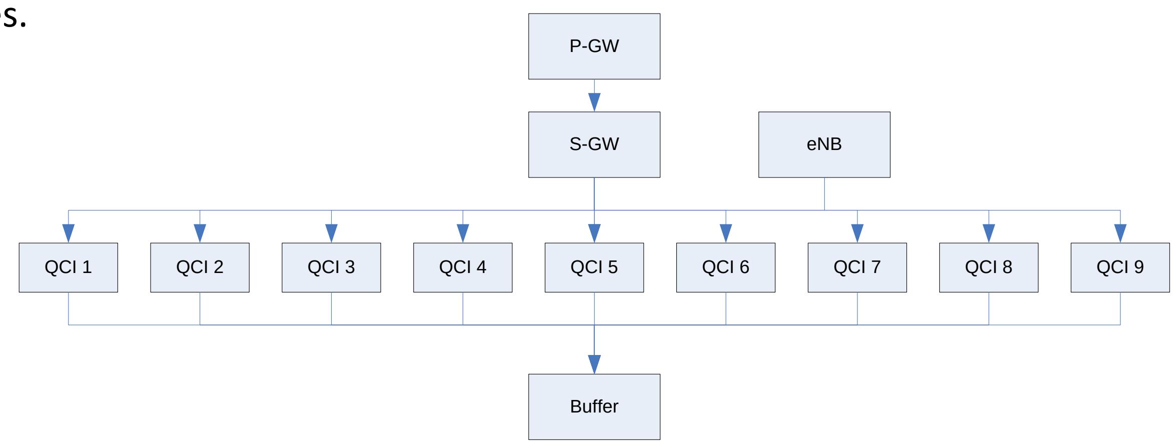
Data Scheduling and Allocation

Data scheduling

- eNB stores data in queues according to its QCI (QoS Class Identifier), which is inferred either from the Internet protocol used or any other established criteria

QCI	Resource type	Priority	Packet Delay (ms)	Packet Error Loss Rate	Service Examples
1	GBR	2	100	10^{-2}	Conversational voice
2		4	150	10^{-3}	Conversational video (live streaming)
3		3	50		Real Time Gaming
4		5	300	10^{-6}	Non-conversational video (buffered streaming)
5	Non GBR	1	100		IMS (IP Multimedia Subsystem) signaling
6		6	300		Video (buffered streaming), TCP (Transmission Control Protocol) applications
7		7	100	10^{-3}	Voice, video (live streaming), Interactive gaming
8		8	300	10^{-6}	Video (buffered streaming), TCP applications
9		9			

- Each QCI has several additional parameters that are specified for GBR (Guaranteed Bit Rate) and Non-GBR bearers
- The scheduler analyses the data in the different queues and applies the criteria it is programmed for. Schedulers are not specified by 3GPP, but the most common types of schedulers are:
- Round Robin   Proportional fairness   Weighted proportional fairness
- Scheduling affects the sequence in which the received packets are sent to the transmission queue (buffer). This is illustrated in the diagram below. The eNB adds broadcast and UE specific messages to respective queues.



Data allocation by PHY

- eNB PHY gets data from scheduler
- eNB PHY allocates data received from its MAC in the DL frame
  - Data location and its transmission characteristics are sent in a DCI message in the control area, in the same TTI
- eNB PHY allocates data for the UE in the UL frame
  - UE does not have a mechanism to request a specific amount of data, it just can indicate that it needs an allocation for data
  - Allocation is done by the eNB based on UE reported buffer size
  - Data location and its transmission characteristics are sent in a DCI message in the control area, to be implemented by the UE 4 subframes later (4 ms)

Data Allocation by PHY

- Transmission Mode (TM) and Modulation and Coding Scheme (MCS) are chosen for DL or UL
  - PHY estimates the SNR requirements in the DL and UL to communicate with UE
  - PHY chooses TM and MCS
    - Broadcast information is always sent using single port or diversity, QPSK modulation and network defined coding rate for cell edge
    - UE specific information is sent based on:
      - UL: PHY receive measurements, HARQ statistics, acknowledge statistics
      - DL: CQI reports from UE, HARQ statistics, acknowledge statistics

How does PHY prepare DCI content?

- Downlink
  - PHY get TB from MAC and adds 24 bit CRC
  - PHY adds address to TB by scrambling CRC with applicable RNTI
    - Bit scrubbing
  - PHY segments TB in code blocks if TB size larger than 6,120 bit
    - PHY adds a 24 bit CRC to each Code Block (CB)
- Uplink
  - PHY estimates the number of resources required by the UE, based on its Buffer Status, reported in uplink MAC if UE transmitted recently or in a Buffer Status , requested previously by the eNB
- PHY chooses the Data Resource Allocation format, based on internal policy
- PHY gets the MCS previously calculated, maps it to a TBI (Transport Block Index) value and consults a pre-defined TBS (Transport Block Size) table
  - TBS table gives the number of Resource Blocks to be used for the different MCS
  - TBS table is standardized for different TBIs assuming an availability of 120 REs per RB pair (PRB)
  - The same TBS table applies to DL and UL
- PHY finds the closest Transport Block size with a stronger MCS than the one required and the number of RBs that correspond to a multiple of the RBG specified for the channel bandwidth
- PHY fills in the original TB to the TBS found in the table with dummy bits

How does PHY prepare DCI content?

- If TB has more than 6,120 bit it segments the TB in Coding Blocks (CB), with a maximum of 6,120 bit
  - The last CB is the one left with the remaining bits
- PHY adds to each CB a 24 bit CRC that uses a different algorithm then the one used for TB
- Each CB is then sent to the turbo encoder with a FEC ratio of 1/3
- PHY maps the PRBs it will use and based on the available REs calculates the number of available bits
- Rate matching (repetition and puncturing) is performed next to match the TB with filler bits and CRC to the available bits

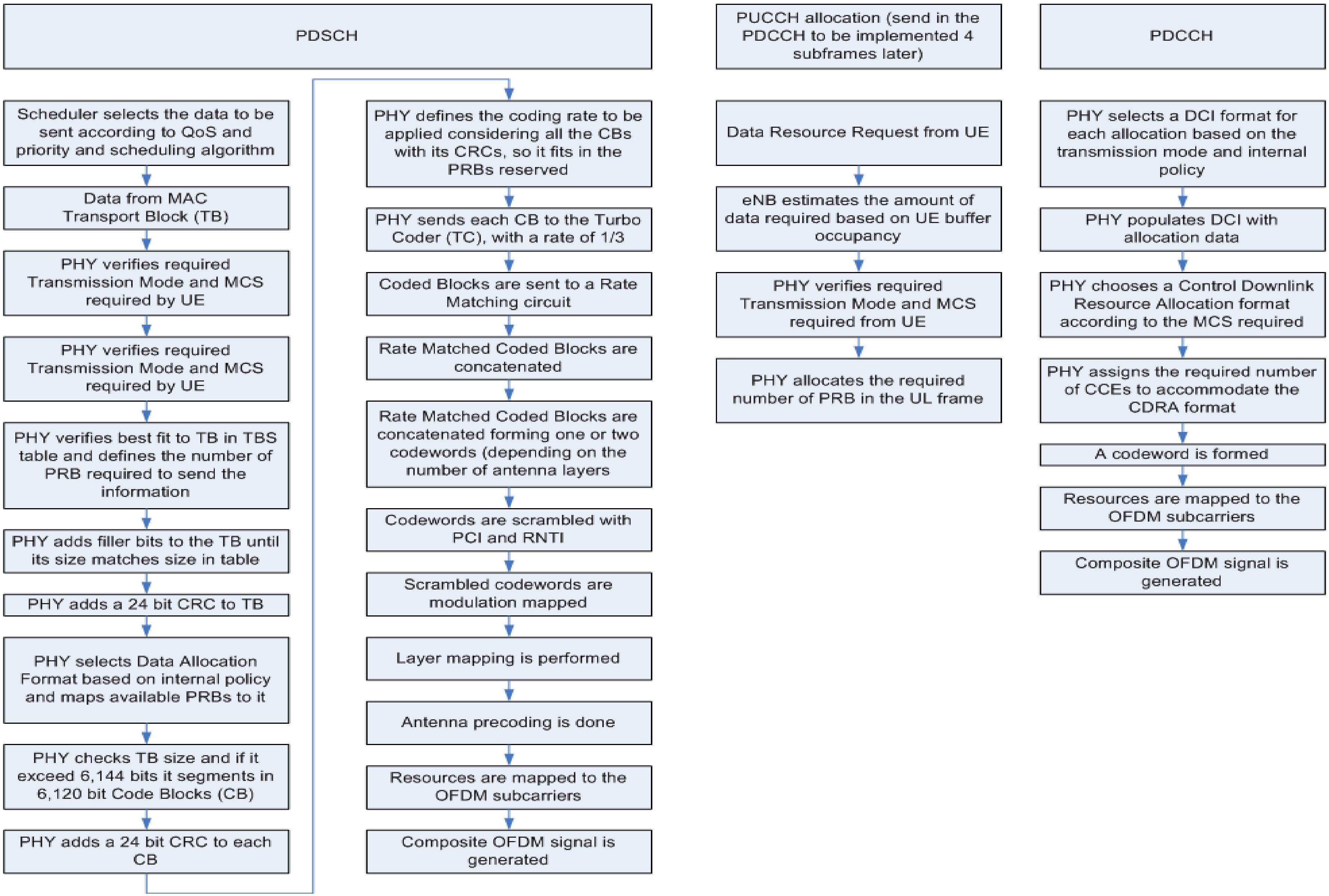
How UE decodes TB?

- The UE gets the MCS and the PRB allocation in the DCI message
- Based on those parameters it finds the size of the TB sent
- UE does then the calculation of the number of CBs (if any) and proceeds to decode the TB with the filler bits and CRC
- It checks the CRC and if it agrees it sends the TB to the MAC
- UE MAC reads the TB subheaders and defines the position and size of its SDU

How does PHY prepare DCI content?

- PHY allocates the number of PRBs and calculates for those PRBS the actual code rate that matches the PRB available resources to the TB size
- This is done the same way for downlink and uplink allocations
- All this information populates then the DCI format chosen
- Each DCI has a 16 bit CRC added
- This CRC is scrambled with the appropriate RNTI, to save addressing bits
- This co

Data Allocation by PHY



Allocation Example

- eNB PHY calculates the PRB average capacity
- After allocation the exact PRB capacity will be calculated

Downlink capacity per PRB		
eNB calculates available bits per PRB downlink (2 antenna, 3 control symbols)		
RE per PRB and TTI	168	RE
Control, CRS	48	RE
RE available for DL-SCH	120	RE
QPSK	240	bit
16QAM	480	bit
64QAM	720	bit

Uplink capacity per PRB		
eNB calculates available bits per PRB (1 antenna)		
RE per TTI	168	RE
DM-RS	24	RE
RE available for UL-SCH	144	RE
QPSK	288	bit
16QAM	576	bit
64QAM	864	bit

Allocation Example (cont.)

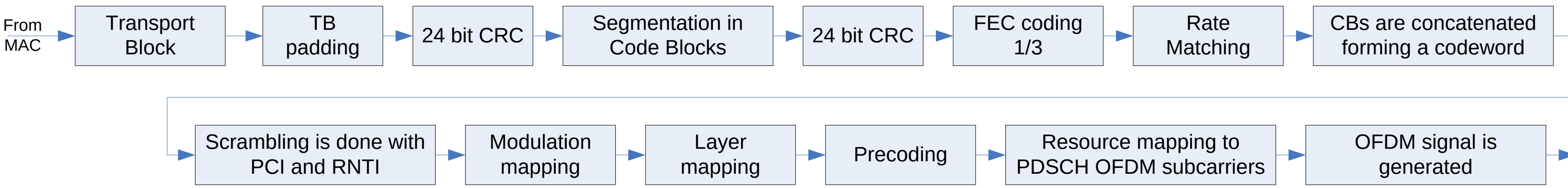
- eNB PHY finds the best fit in the TBS table in terms of TB size and number of RBS that satisfy MCS
  - In the downlink PHY pads the TB to the size in TB table
  - In the uplink PHY allocates the number of RBs found in the TBS table

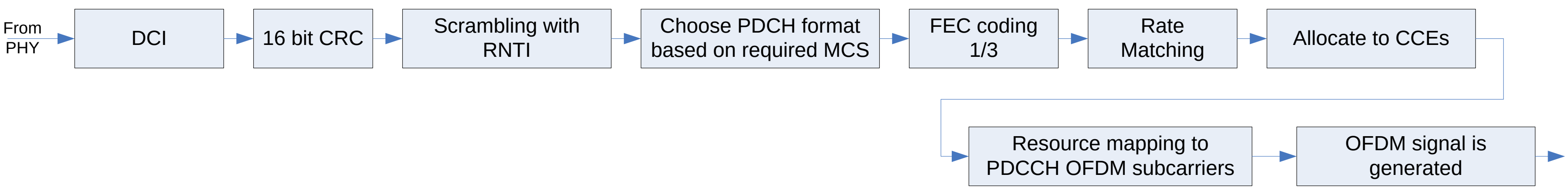
Downlink Allocation		
eNB calculates the MCS for the DL-SCH, based on the UE sent CQI and previous results	15	
MCS corresponds to	16QAM	0.6015625
eNB gets the size of the MAC to be sent to UE	6152	bit
eNB gets the smallest number of RBs that satisfies the MCS and TB size	22	RB
	6200	bit
MCS	15	
eNB adds padding bits to TB that will be transmitted to the UE	48	bit
eNB adds CRC to TB	24	bit
loaded TB size	6224	bit
eNB breaks TB in CBs		
CB 1	6144	
CB2	128	
codeword	6272	
eNB calculates the effective code rate	0.594	
eNB allocates RBs		

Uplink Allocation		
eNB calculates the MCS for the UL-SCH, based on CQI and previous results	8	0.4875
MCS corresponds to	QPSK	
eNB calculates the UE uplink data requirement based on UE buffer size information	8	bits
eNB calculates gets the smallest numbe rof RBs that satisfies the MCS and estimated size	1	RB
	16	bits
MCS	0	
eNB allocates RBs		

Data Allocation by eNB PHY

- Downlink data allocation procedure
  - PDSCH
  - PDCCH



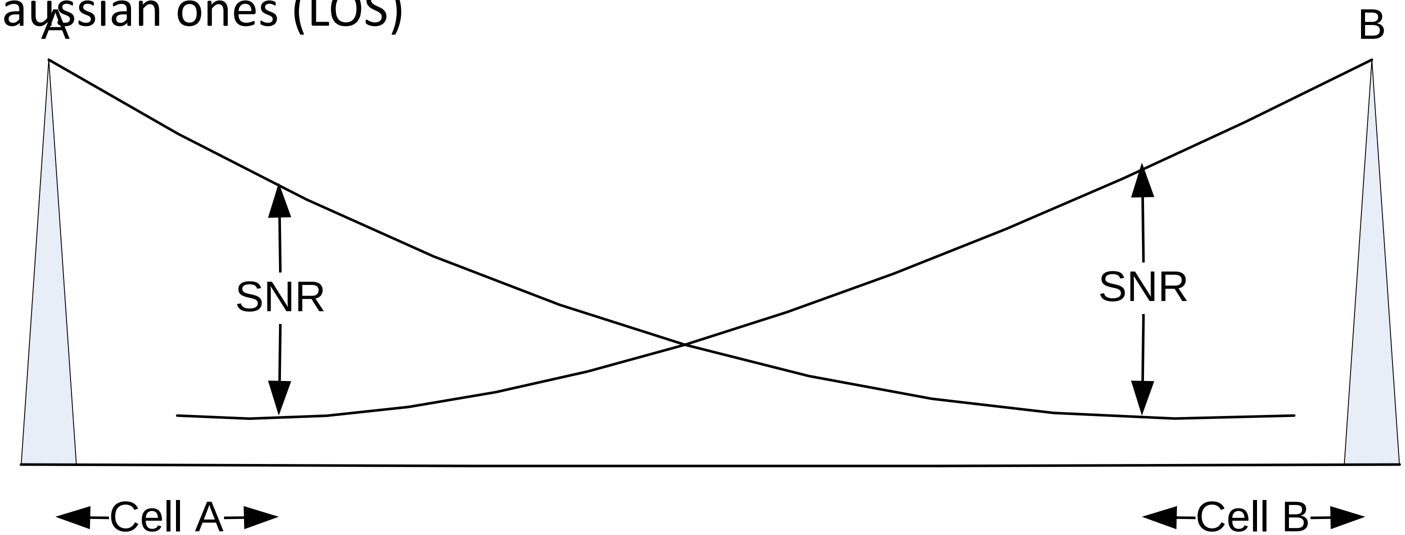


- Uplink data allocation procedure
  - PDCCH
  - Data allocation is done at the UE

Cellular Reuse

Cellular Reuse

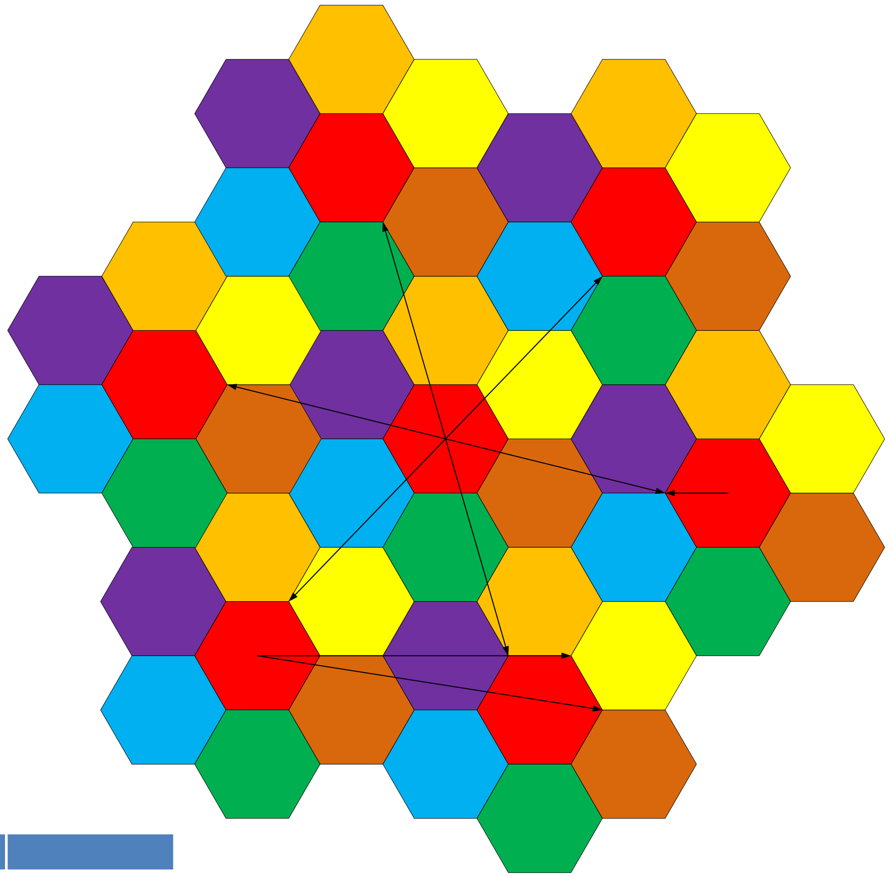
- Cellular technology is based on a physical separation between the usage of the same resources
- Each modulation requires a certain SNR, depending on the environment characteristics
- The separation has to be larger for Rayleigh environments (non LOS) than for Gaussian ones (LOS)



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

Reuse in an omni scenario

- There is one prevalent interference case



Reuse	7	omni	20 db/dec		
	distance		path loss		SNR
	signals	interference	signals	interference	
case 1	1	2.6	0.0	8.5	8.5

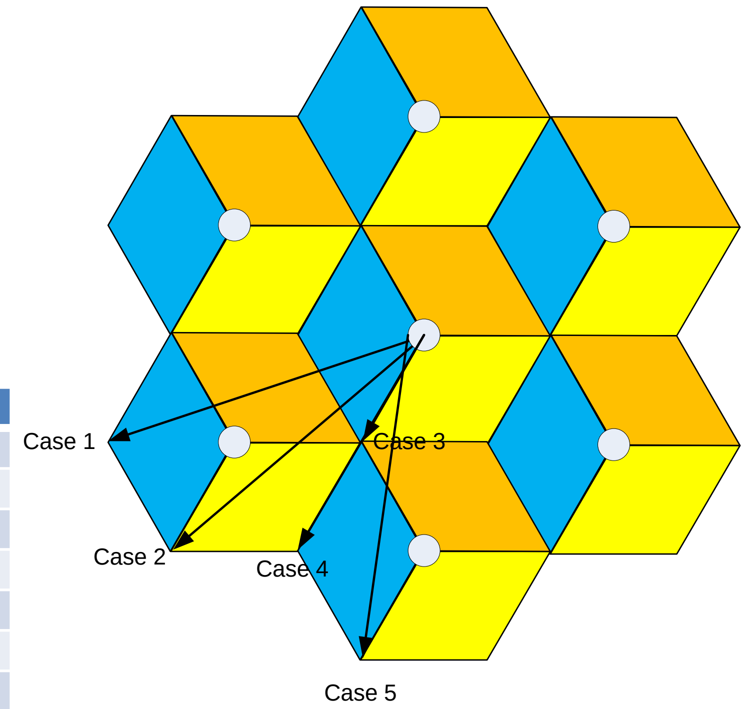
Reuse	7	omni	40 dB/dec		
	distance		path loss		SNR
	signals	interference	signal	interference	
case 1	1	2.6	0.0	16.9	16.9

Sector Scenario with a reuse 3

- There are 5 interference cases

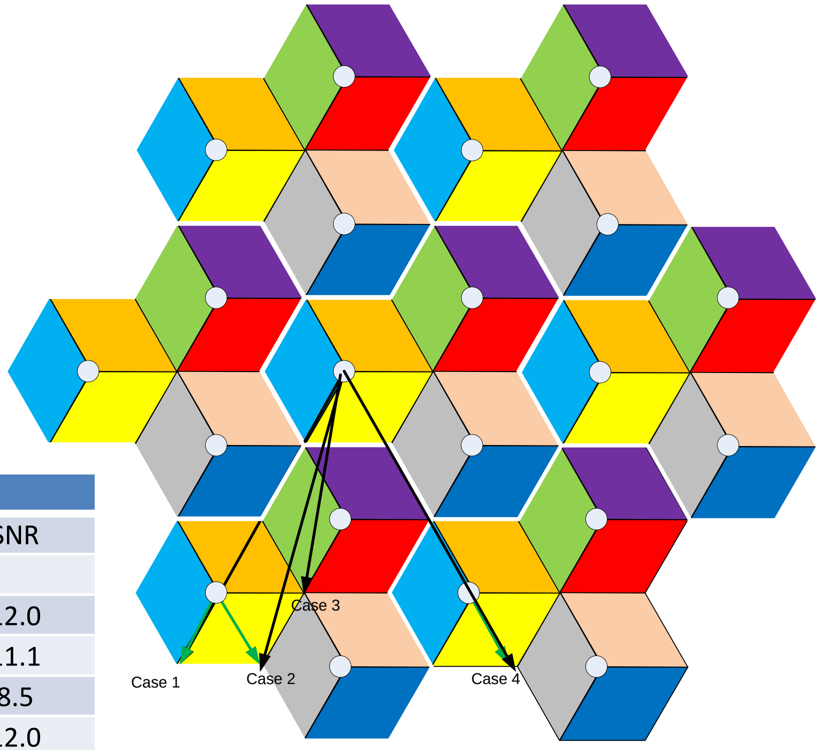
Reuse	3	sector	20 dB/dec		
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	2.6	0.0	8.5	8.5
case 2	1	2.6	0.0	8.5	8.5
case 3	1	1.0	0.0	0.0	0.0
case 4	1	2	0.0	6.0	6.0
case 5	1	2.6	0.0	8.5	8.5
average					7.8

Reuse	3	sector	40 dB/dec		
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	2.6	0.0	16.9	16.9
case 2	1	2.6	0.0	16.9	16.9
case 3	1	1.0	0.0	0.0	0.0
case 4	1	2	0.0	12.0	12.0
case 5	1	2.6	0.0	16.9	16.9
average					15.7



Sector Scenario reuse 9

- There are 4 interference cases

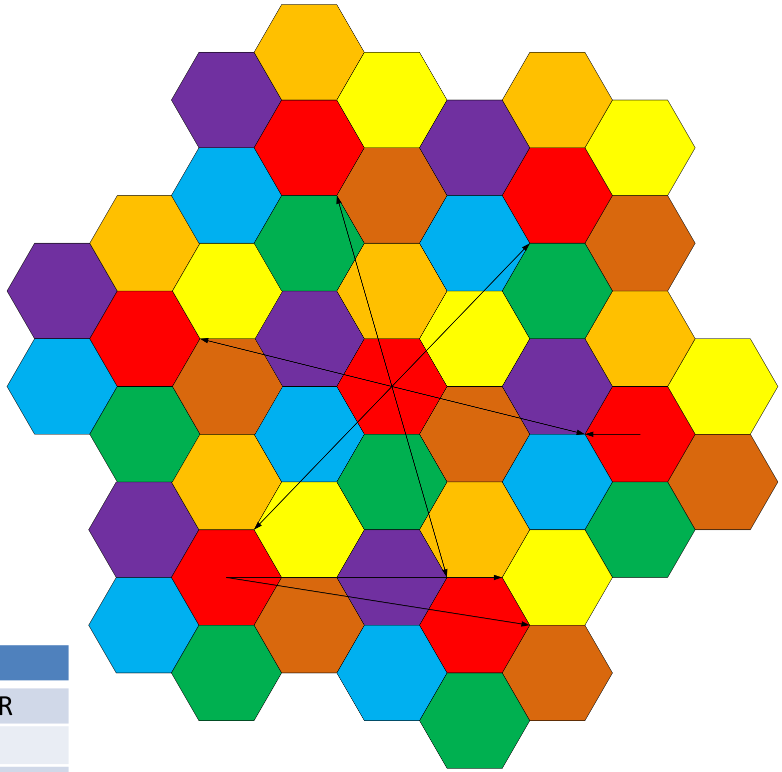


Reuse	9	sector	20 dB/dec		
	distance (cell radius)		path loss		SNR
	signal	interference	signal	interference	
case 1	1	4	0.0	12.0	12.0
case 2	1	3.6	0.0	11.1	11.1
case 3	1	2.6	0.0	8.5	8.5
case 4	1	4.0	0.0	12.0	12.0
average					10.9

Reuse	9	sector	40 dB/dec		
	distance (cell radius)		path loss		SNR
	signal	interference	signal	interference	
case 1	1	4	0.0	24.1	24.1
case 2	1	3.6	0.0	22.3	22.3
case 3	1	2.6	0.0	16.9	16.9
case 4	1	4.0	0.0	24.1	24.1
average					21.8

Sector Scenario reuse 21

- There are 2 prevalent interference cases

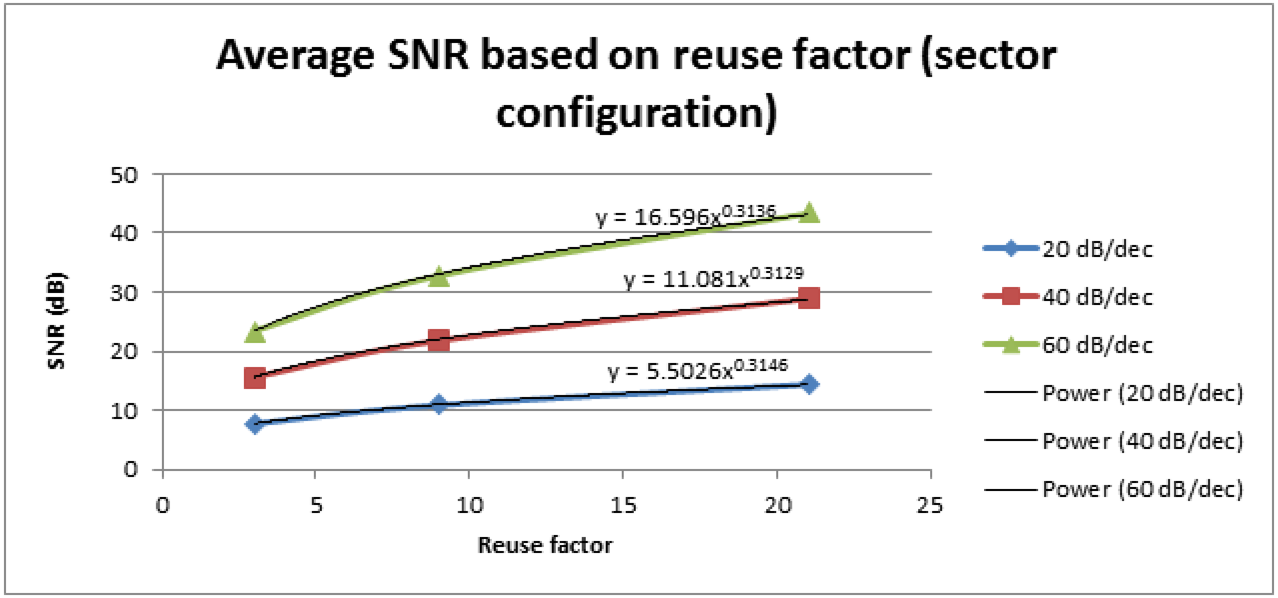


Reuse	21	sector			
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	5.0	0.0	14.0	14.0
case 2	1	5.6	0.0	14.9	14.9
average					14.4

Reuse	21	sector			
	distance		path loss		SNR
	signal	interference	signal	interference	
case 1	1	5.0	0.0	28.0	28.0
case 2	1	5.6	0.0	29.8	29.8
average					28.9

Reuse factor for different environments

- 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: $$x = \left(\frac{SNR}{16.596}\right)^{3.17864}$$



Typical reuse factors

- Typical reuse factor for different density cities

Lubumbashi	Path slope	Coverage	Environment	Target Modulation	SNR (dB)	Reuse
Suburban	20 dB/dec	indoor	Rayleigh	16QAM	21.3	8
Suburban	20 dB/dec	outdoor	Gaussian	64QAM	12.1	12

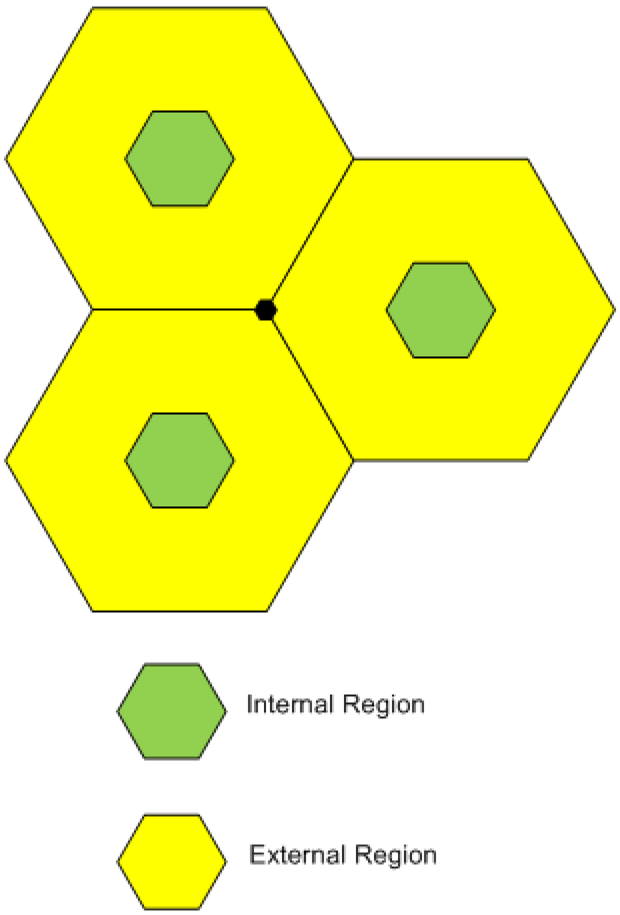
Washington, Rayleigh	Path slope	Coverage	Environment	Target Modulation	SNR (dB)	Reuse
Urban	40 dB/dec	indoor	Rayleigh	16QAM	21.3	8
Urban	40 dB/dec	outdoor	Rice	16QAM	14.75	2.5

Chicago Downtown, São Paulo downtown	Path slope	Coverage	Environment	Target Modulation	SNR (dB)	Reuse
Dense Urban	60dB/dec	indoor	Rayleigh	64QAM	25	3.7
Dense Urban	60dB/dec	outdoor	Rayleigh	64QAM	25	3.7

Reuse in LTE

Reuse in LTE

- LTE was conceived for reuse 1
- A cell was divided in an interior (center) and and an exterior (edge) regions
- The exterior region would use very low coding rates (in the order of 0.07)
- The interior region would use higher coding rates
- No criteria was established to define exterior and interior regions
- Broadcast information has to use low coding rates
- Intercell Cell Interference Coordination (ICIC) was considered to improve the performance, four cases were proposed
  - No ICIC
  - Start-Stop Index (SSI)
  - Start Index (SI)
  - Random Start Index (RSI)
  - Start Index Geometry Weight (SIGW)
  - Random Index Geometry Weight (RIGW)



Bit scrubbing

- 3GPP decision of implementing a reuse of 1 in LTE implied in:
  - High repetition rates for control information
  - This lead to bit scrubbing (bit shaving) and complexity
    - Blind decoding, implicit addressing , multiple options
  - High data spread rates that trade reuse of 1 for low throughputs
  - Complex transmission modes
    - Some transmission modes can be practically used in few locations in the network (if at all)
- 3GPP provided mechanisms to avoid resource reuse conflicts
  - It suggested that interference is concentrated at cell edge and that reuse of 1 can be done in cell center
  - It did not specify how this should be done
    - Several implementation schemes have been suggested, none full proof
    - Traditional segmentation and zoning still being used

Reuse in LTE

- Mechanisms
  - X2 interface
  - Intercell Cell Interference Coordination (ICIC)
  - Self Organizing Network
  - Power control
- Practical approach
  - Segmentation (Resource Block Groups)
  - Zoning (Subframes)

ICIC

- Intercell Cell Interference Coordination (ICIC) was considered to improve the performance, six cases were proposed
  - No ICIC
  - Start-Stop Index (SSI)
  - Start Index (SI)
  - Random Start Index (RSI)
  - Start Index Geometry Weight (SIGW)
  - Random Index Geometry Weight (RIGW)
- The difficulty is to define if a user is in the internal or external region. Criterias are:
  - Distance
  - Signal level
  - SNR
  - Neighbors

CelPlan Patent Applications

- CelPlan proposed a method of regionalizing a cell in several sub-cells according to different criteria
- CelPlan proposed a method of allocating resources to cells from a pool based on owned and shared resource tables

APPLICATION FOR UNITED STATES LETTERS PATENT

Title

APPARATUS TO PERFORM RESOURCE ASSIGNMENT IN A WIRELESS NETWORK

Inventor(s):
Leonhard KOROWAJCZUK

Date Filed:
February , 2013

Attorney Docket No.:
7230-102

APPLICATION FOR UNITED STATES LETTERS PATENT

Title

CHARACTERIZING A BROADBAND WIRELESS CHANNEL

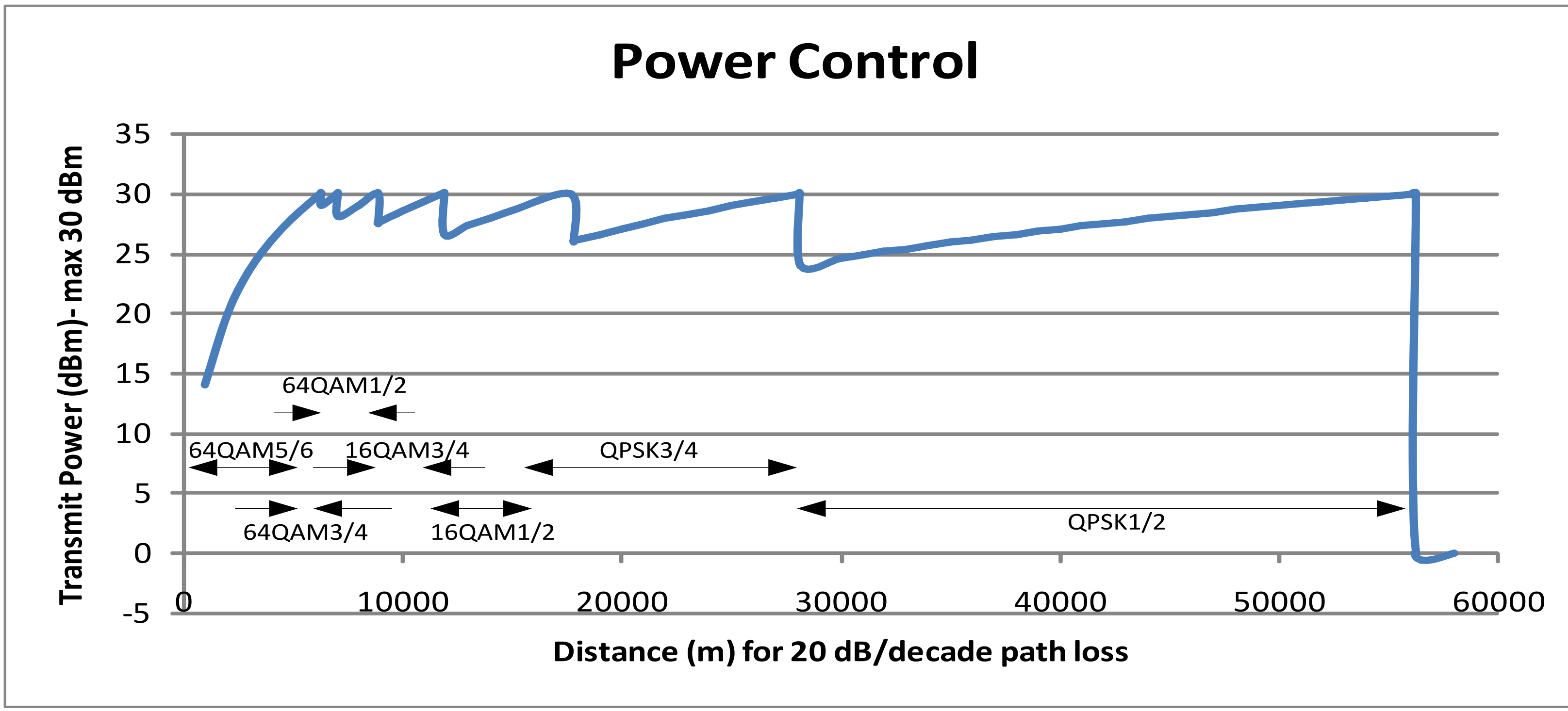
Inventor(s):
Leonhard KOROWAJCZUK

Date Filed:
July 25, 2013

Attorney Docket No.:
7230-101

Power Control

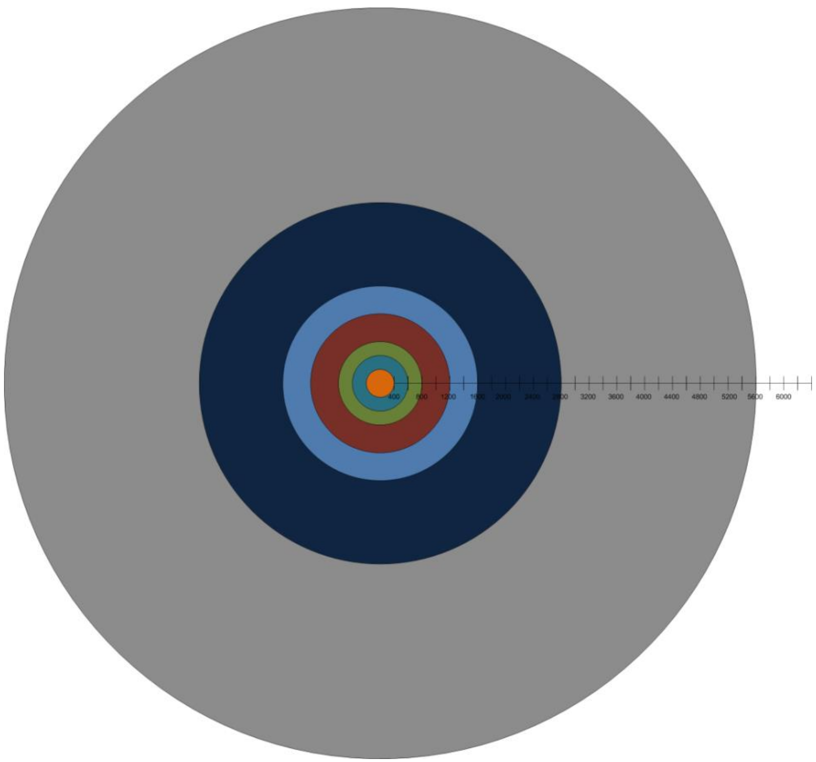
- Power Control is foreseen for the uplink, but its relevance is small considering link adaptation



Adaptive Modulation Relative Areas

CelPlan Wireless Solutions & Consulting

- Unrestricted cell
- Propagation in free space: 20dB/decade
- Percentages will change if cells are closer to each other and lower modulation schemes are not used
- Cell capacity drops with the increase in cell size
- Larger the cell smaller the capacity

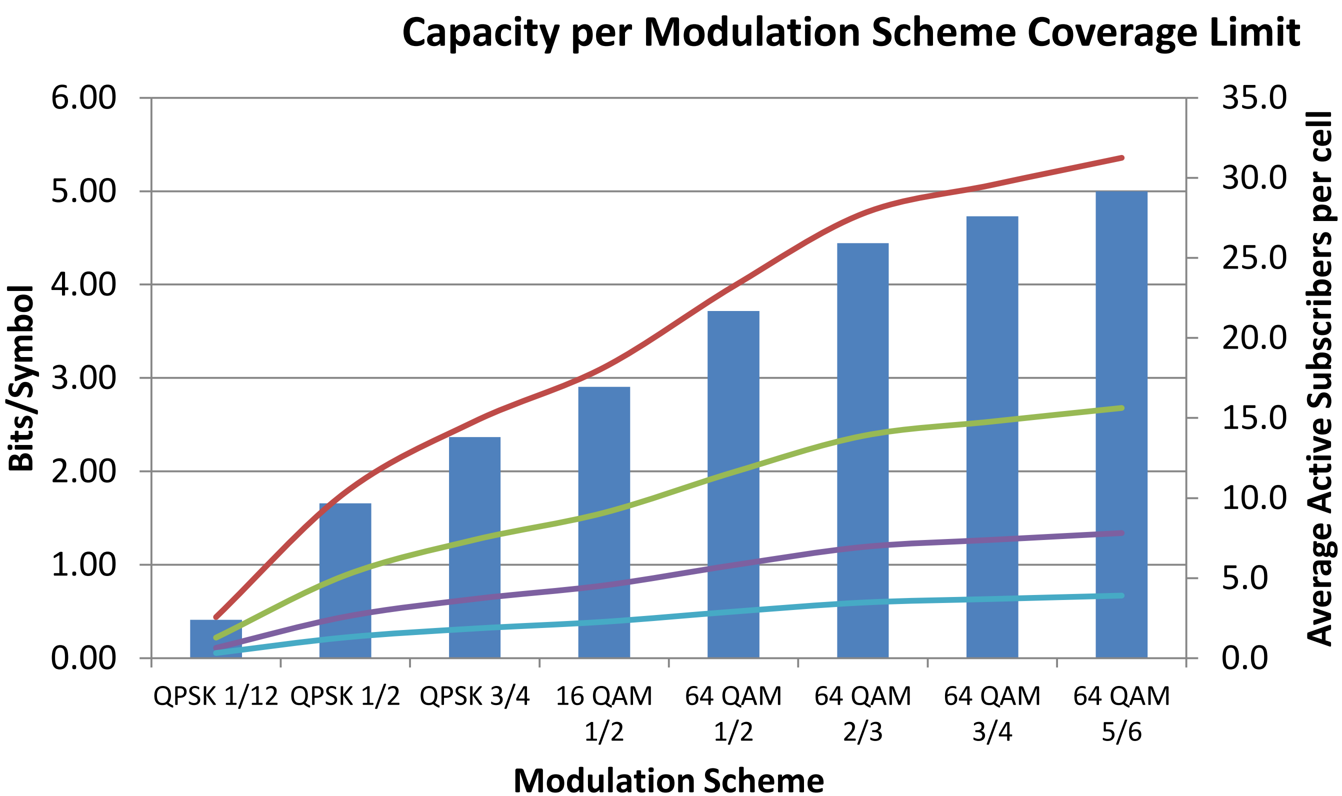


Bits / Symbol	
64QAM 5/6	5
64QAM 3/4	4.5
64QAM 1/2	3
16QAM 3/4	3
16QAM 1/2	2
QPSK 3/4	1.5
QPSK 1/2	1.5

0.5%	64QAM 5/6 (0.4 km^2)
0.6%	64QAM ¾ (0.6 km^2)
0.9%	64QAM ½ (0.8 km^2)
2.6%	16QAM ¾ (1.2 km^2)
3.6%	16QAM ½ (1.6 km^2)
16.8%	QPSK ¾ (2.8 km^2)
75%	QPSK ½ (5.6 km^2)

Adaptive Modulation Capacity

- On the bottom are the modulation schemes
- On the right are the average bits per symbol achieved by each modulation scheme (blue bars)
- On the left are the average active users that can be accommodated by each modulation scheme
  - The curves represent monthly user tonnage plan



Bandwidth: 10 MHz
Frame: 10 ms
Cyclic Prefix: 1/8

Dimensioning and Planning

What are the overheads ?

- Control and Data overheads
  - PDCP, RLC and MAC headers
  - PCFICH and PHICH
  - PDCP IP address compression
  - PHY TB CRC and CB CRC
- DL Frame overheads
  - Reference Signals
  - MBMS
  - Control Area (DCI, ACK/NACK)
  - PHY messages
  - SIB messages
  - RRM messages (CCCH)
- UL Frame overheads
  - Reference Signals
  - Control Area (CSI, ACK/NACK,
  - Random Access
  - RRM messages (CCCH)

- Cell Load
  - Resource interference avoidance
    - Reuse factor
  - Handover
  - Statistical distribution in relation to average

What are the possible bottlenecks?

- Number of available PDCCH limits the number of allocations that can be done in a TTI
- PDSCH area should be enough to allocate data for UE
- PRACH area should be enough for UEs to access it with a minimum amount of conflict
- PUCCH area should be enough for UEs to send CSI and ACK/NACK information
- PUSCH area should be enough to allocate UE data

What has to be dimensioned ?

- Number of DL control symbols (PCFICH)
- PHICH scaling factor (ACK/NACK)
- PRACH iterations capacity
- PUCCH iterations capacity
- Number of users that PDCCH area can handle
- Number of users that PDSCH area can handle
- Number of users that PRACH area can handle
- Number of users that PUCCH area can handle
- Number of users that PUSCH area can handle

What should be planned ?

- Link Budget
- Channel (frequency)
- Cyclic Prefix
- Physical Layer Cell Identity (PCI)
- Cell and BTS Identity Planning
- Tracking Areas
- PRACH
  - Configuration Index (CI)
    - Preamble format, cell range, load, RF
  - Root Sequence Index (RSI)
    - Unique per cell
  - Zero Correlation Zone (ZCZ)
    - Cell range, RF, RSI size
  - High Speed flag
  - Frequency offset
    - PUCCH allocation
- Uplink Reference Signal Sequence
- Neighbors
  - LTE
  - UMTS
  - GSM
  - CDMA
  - WiMAX
- Handover
- Co-siting
- Resource Reuse
  - Cell Planning
    - Segmentation
    - Zoning
  - Fractional Planning
    - Internal/ external
    - ICIC
    - X2 interface

Capacity Calculator

Capacity Calculator

- Interface
  - Aerial
  - GW/Backhaul (layer 4)
  - W/load factor
- Throughput
  - Data Rate or Spectral Efficiency
  - With or without overhead consideration
- MIMO
- UE Information
- DL overhead (RE/Frame)
- UL overhead (RE@PUSCH RBs)
- Resulting Symbol Rate (MSps)

Calculator 1

Calculator 2

Calculator 3

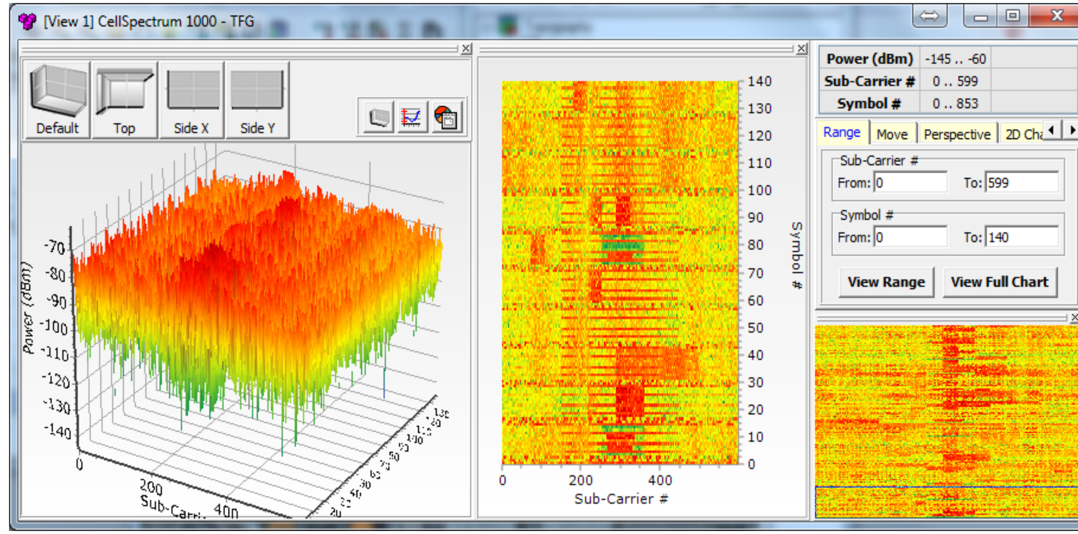
Calculator 4

CelPlan New Products

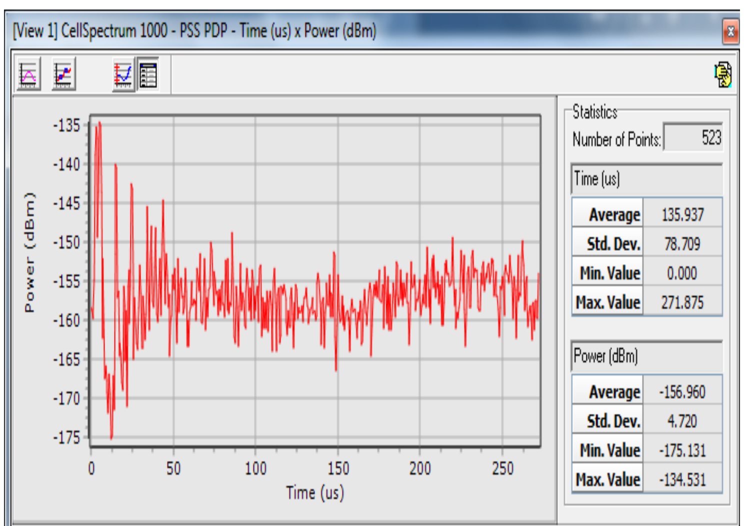
CellSpectrum

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

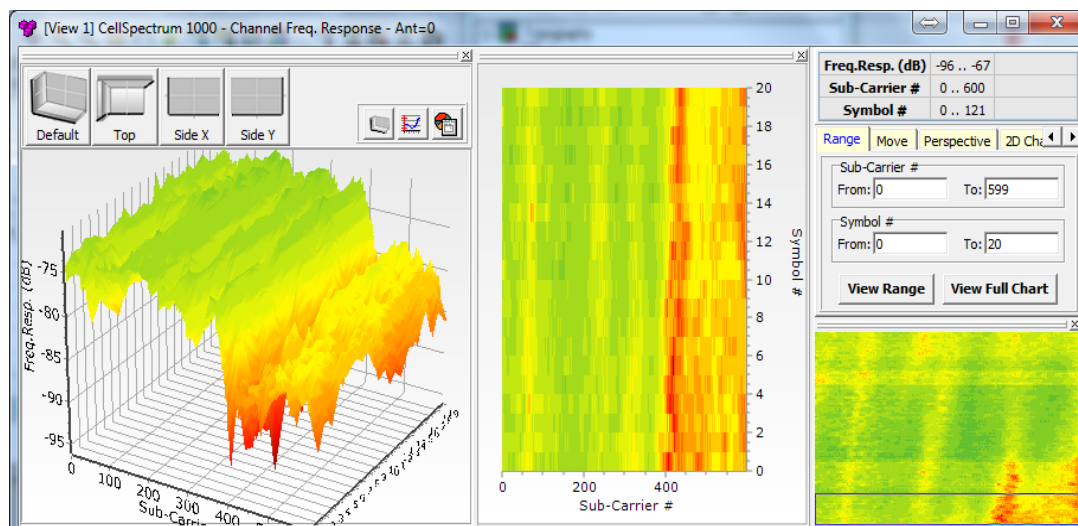
Received Signal level



Multipath



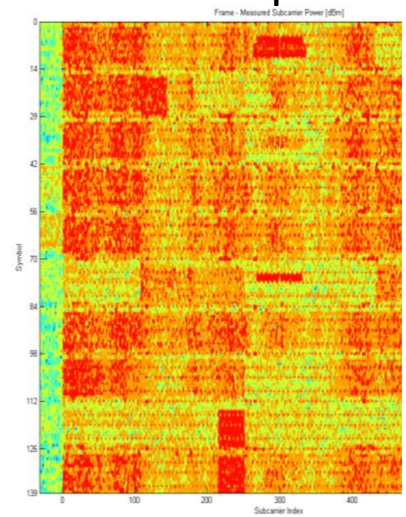
RF Channel Response



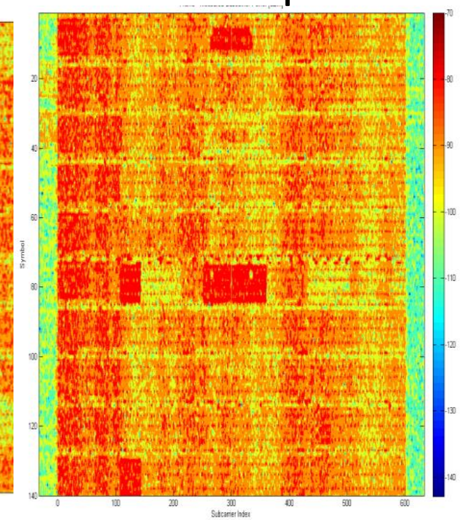
CellSpectrum

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

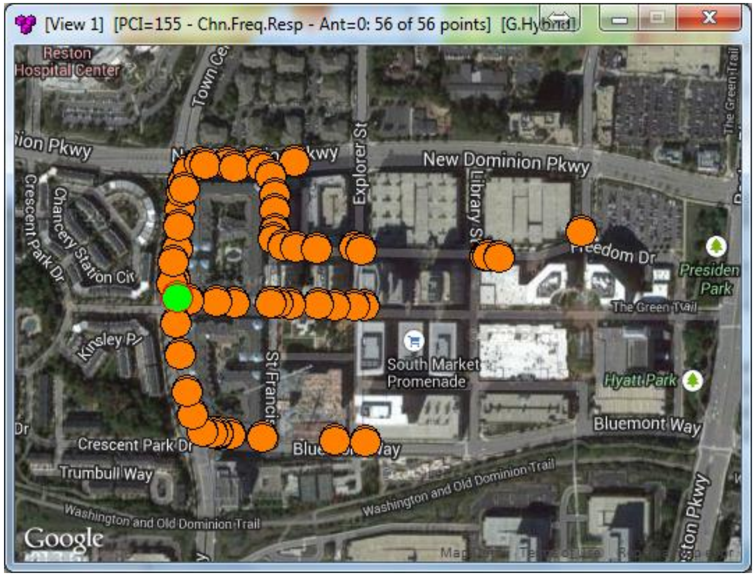
LTE frame port 0



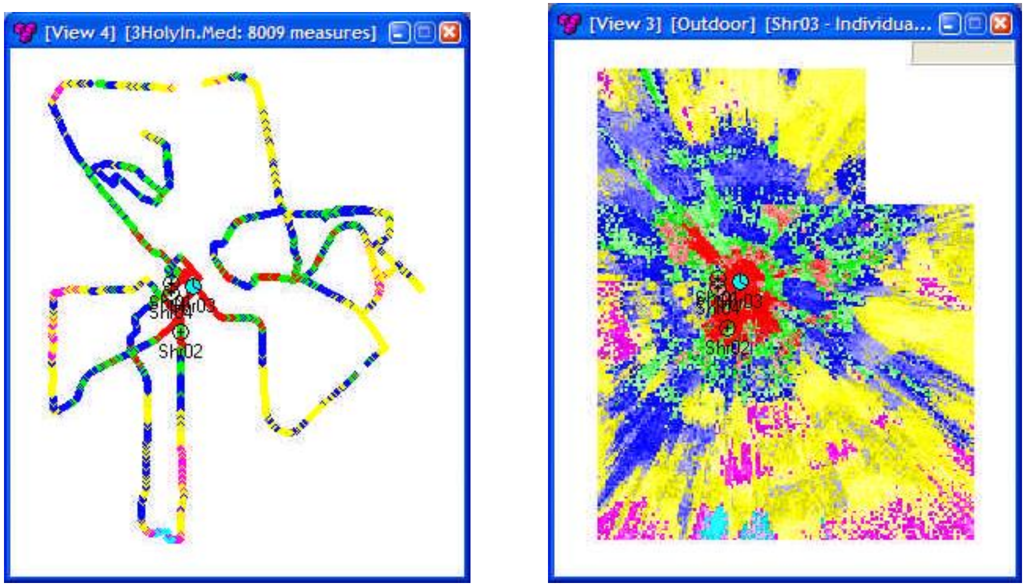
LTE frame port 1



Drive Test



Measurement interpolation



CellDesigner

A new Generation of Planning Tools

A collaborative work with operators

Your input is valuable

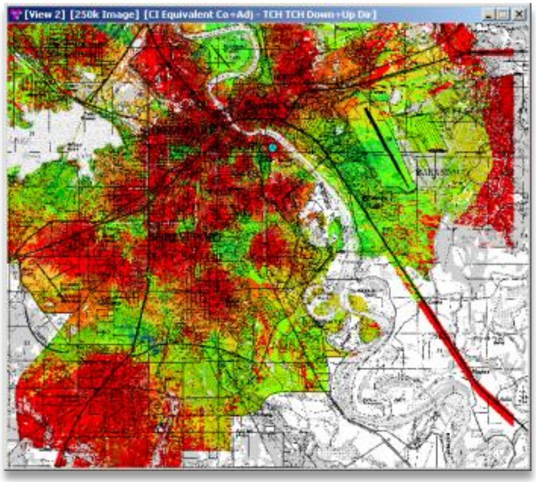
CellDesigner

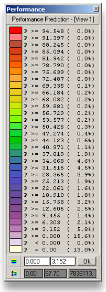
- CellDesigner is the new generation of Planning and Optimization tools
- Wireless networks became so complex that it requires a new generation of tools, capable of:
  - Documenting the physical deployments
  - Documenting network parameters for each technology
  - Flexible data traffic modelling (new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

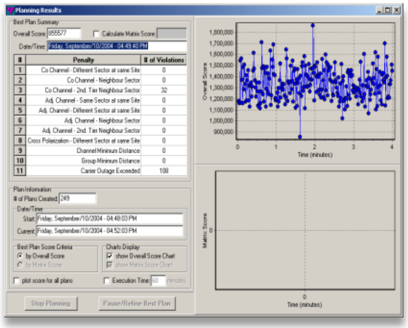
CellDesigner™

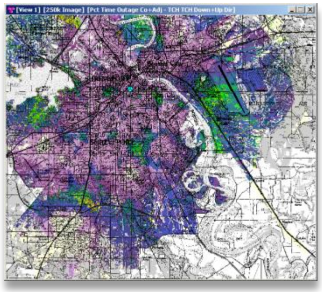
Simultaneous Multi-Technology Support

- 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)

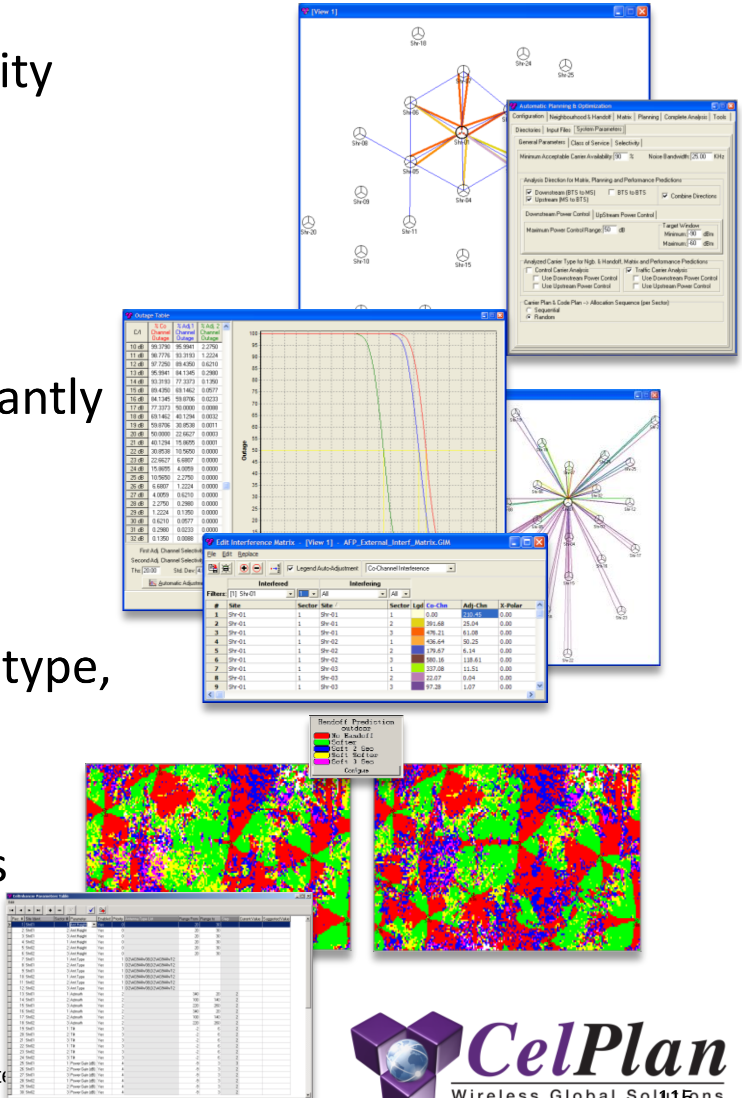
- Enables the dramatic increase of network capacity and performance
- Handover, Frequency and Code Optimization
- Automatically and efficiently optimizes handoff thresholds, neighbor lists, and frequency plans
- Patent-pending methodology capable of significantly increasing cell capacity (SON & ICIC)

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

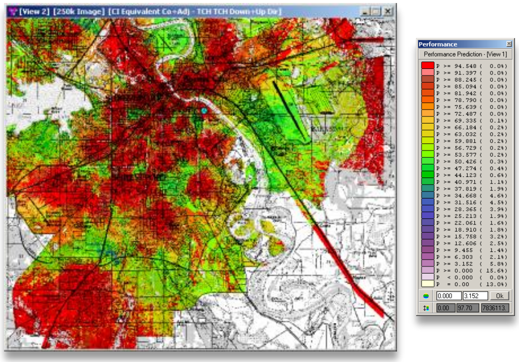
CellDesigner™

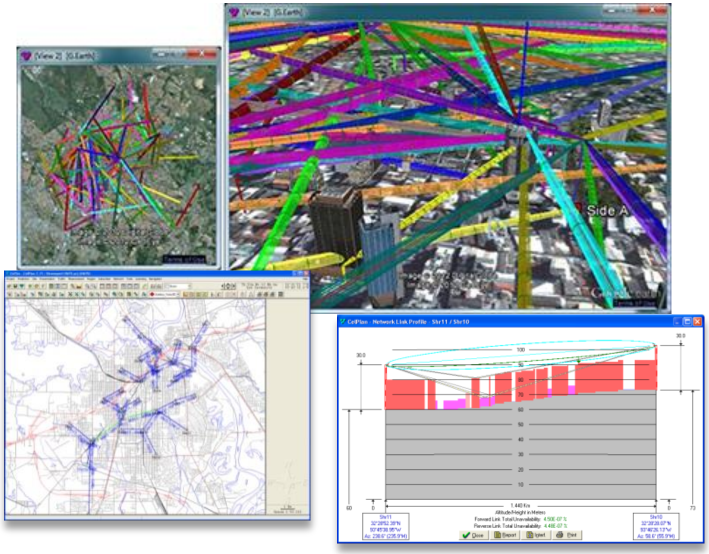
GIS Database Editor

- 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?