How to consider Customer Experience when designing a wireless network

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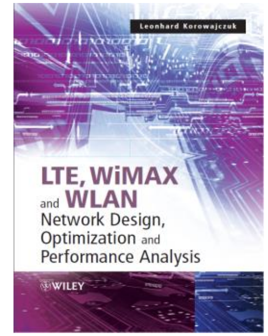
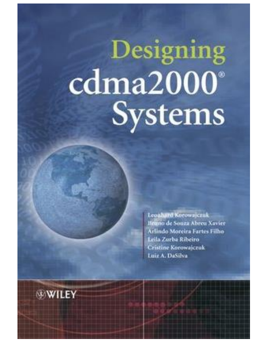
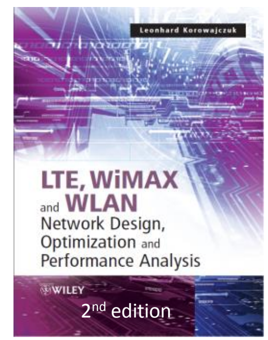
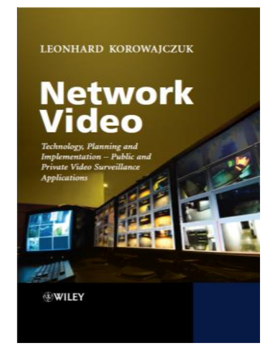
Presenter

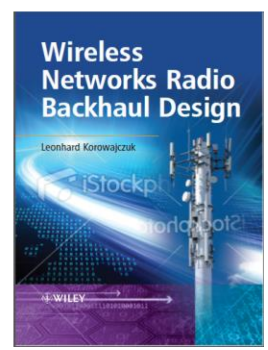
- **Leonhard Korowajczuk**
  - CEO/CTO CelPlan International
  - 45 years of experience in the telecom field (R&D, manufacturing and service areas)
  - Holds13 patents
  - Published books
    - “Designing cdma2000 Systems”
      - published by Wiley in 2006- 963 pages, available in hard cover, e-book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

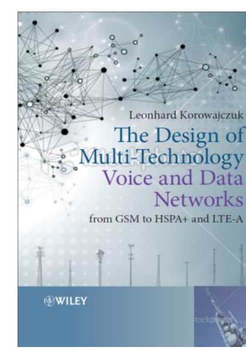












CelPlan International

- 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?**
  - September 3rd 2014
- **Spectrum Analysis for LTE Systems**
  - October 1st 2014
- **MIMO: What is real, what is Wishful Thinking?**
  - November 5th 2014
- **Send suggestions and questions to: webinar@celplan.com**

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

Quiz Challenge

More than 200 participants from 44 countries

Identify the country codes of participants of the last webinar

1	AE	ARE	UNITED ARAB EMIRATES
2	BD	BGD	BANGLADESH
3	BG	BGR	BULGARIA
4	BI	BDI	BURUNDI
5	BR	BRA	BRAZIL
6	BW	BWA	BOTSWANA
7	CA	CAN	CANADA
8	CG	COG	CONGO
9	DE	DEU	GERMANY
10	DK	DNK	DENMARK
11	EG	EGY	EGYPT
12	ES	ESP	SPAIN
13	FR	FRA	FRANCE
14	GB	GBR	UNITED KINGDOM
15	GH	GHA	GHANA
16	GR	GRC	GREECE
17	HU	HUN	HUNGARY
18	IE	IRL	IRELAND
19	IN	IND	INDIA
20	IT	ITA	ITALY
21	JO	JOR	JORDAN
22	KW	KWT	KUWAIT
23	LB	LBN	LEBANON
24	MA	MAR	MOROCCO
25	MV	MDV	MALDIVES
26	NG	NGA	NIGERIA
27	NL	NLD	NETHERLANDS
28	NO	NOR	NORWAY
29	OM	OMN	OMAN
30	PK	PAK	PAKISTAN
31	PT	PRT	PORTUGAL
32	QA	QAT	QATAR
33	SA	SAU	SAUDI ARABIA
34	SE	SWE	SWEDEN
35	SG	SGP	SINGAPORE
36	SI	SVN	SLOVENIA
37	TJ	TJK	TAJIKISTAN
38	TN	TUN	TUNISIA
39	TR	TUR	TURKEY
40	TW	TWN	TAIWAN
41	TZ	TZA	TANZANIA, UNITED REPUBLIC OF
42	UA	UKR	UKRAINE
43	US	USA	UNITED STATES
44	ZA	ZAF	SOUTH AFRICA

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

- 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

How to Dimension User Traffic in 4G Networks 3

- 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

Tonnage Calculator per service

- Unitary Daily Tonnage per terminal

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

How to Dimension User Traffic in 4G Networks

- 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 (Number of UE 500000)			Tablet (Number of UE 100000)			USB (Number of UE 80000)			Modem (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

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

Quiz Challenge

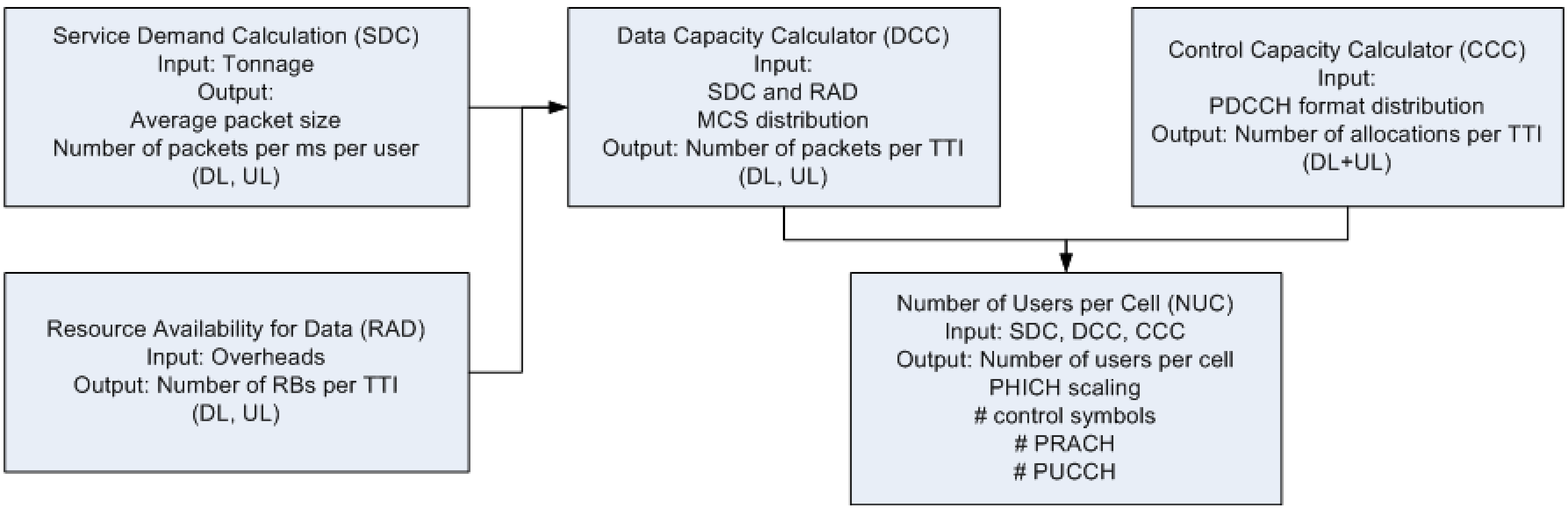
More than 250 participants from 49 countries

1	AE	ARE	UNITED ARAB EMIRATES
2	AN	ANT	NETHERLANDS ANTILLES
3	AR	ARG	ARGENTINA
4	AU	AUS	AUSTRALIA
5	BB	BRB	BARBADOS
6	BH	BHR	BAHRAIN
7	BR	BRA	BRAZIL
8	BZ	BLZ	BELIZE
9	CA	CAN	CANADA
10	CH	CHE	SWITZERLAND
11	CN	CHN	CHINA
12	CO	COL	COLOMBIA
13	DO	DOM	DOMINICAN REPUBLIC
14	EC	ECU	ECUADOR
15	EG	EGY	EGYPT
16	ES	ESP	SPAIN
17	FR	FRA	FRANCE
18	GB	GBR	UNITED KINGDOM
19	GH	GHA	GHANA
20	GN	GIN	GUINEA
21	GR	GRC	GREECE
22	GT	GTM	GUATEMALA
23	HT	HTI	HAITI
24	ID	IDN	INDONESIA
25	IE	IRL	IRELAND

26	IN	IND	INDIA
27	IR	IRN	IRAN (ISLAMIC REPUBLIC OF)
28	IT	ITA	ITALY
29	JO	JOR	JORDAN
30	KW	KWT	KUWAIT
31	MA	MAR	MOROCCO
32	MX	MEX	MEXICO
33	MY	MYS	MALAYSIA
34	NC	NCL	NEW CALEDONIA
35	NG	NGA	NIGERIA
36	NL	NLD	NETHERLANDS
37	NO	NOR	NORWAY
38	OM	OMN	OMAN
39	PA	PAN	PANAMA
40	PE	PER	PERU
41	PK	PAK	PAKISTAN
42	PR	PRI	PUERTO RICO
43	PT	PRT	PORTUGAL
44	SR	SUR	SURINAME
45	TH	THA	THAILAND
46	TT	TTO	TRINIDAD AND TOBAGO
47	TW	TWN	TAIWAN, PROVINCE OF CHINA
48	US	USA	UNITED STATES
49	ZA	ZAF	SOUTH AFRICA

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



LTE Refresher

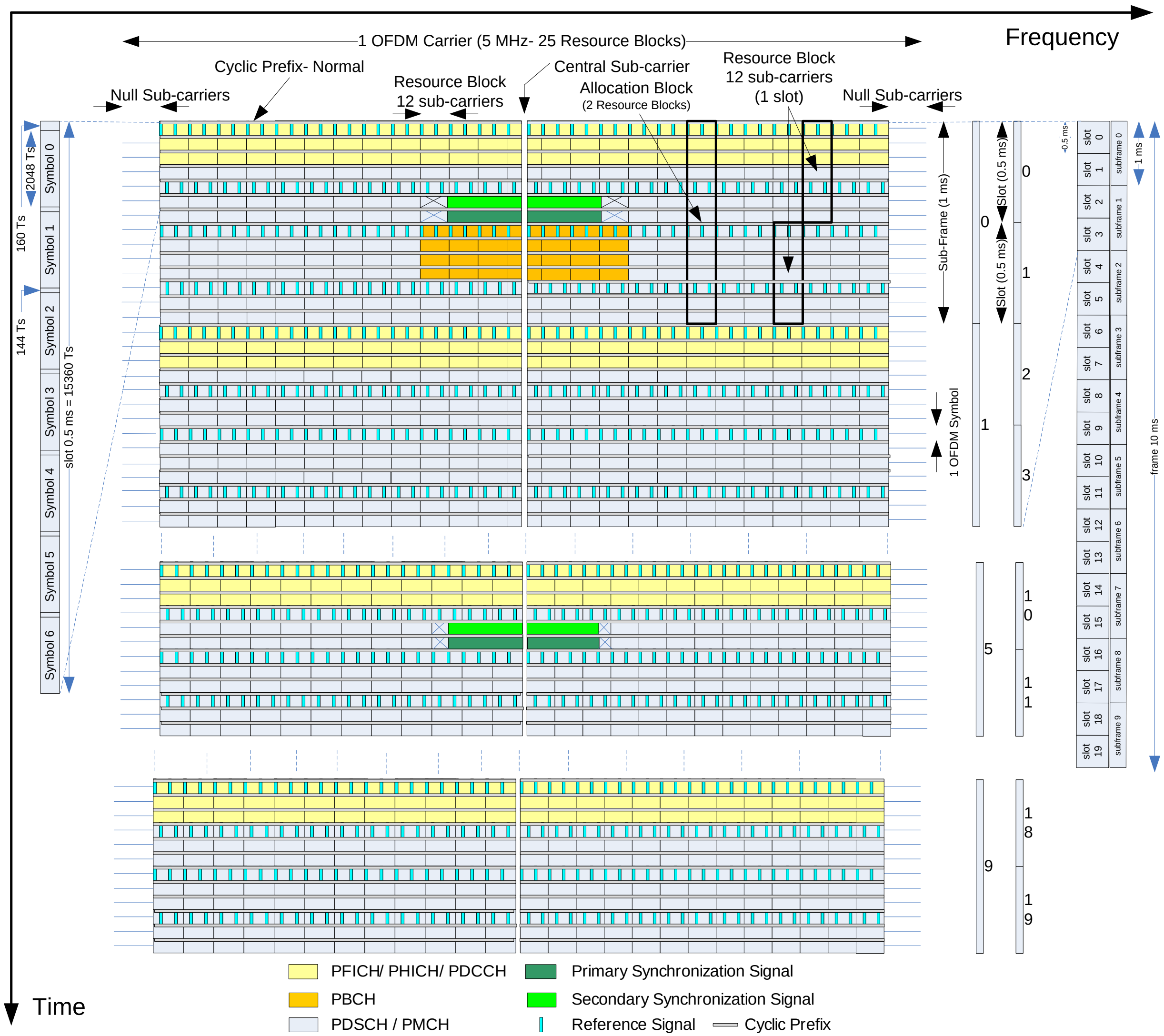
Focused on topics related to capacity and overhead

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)

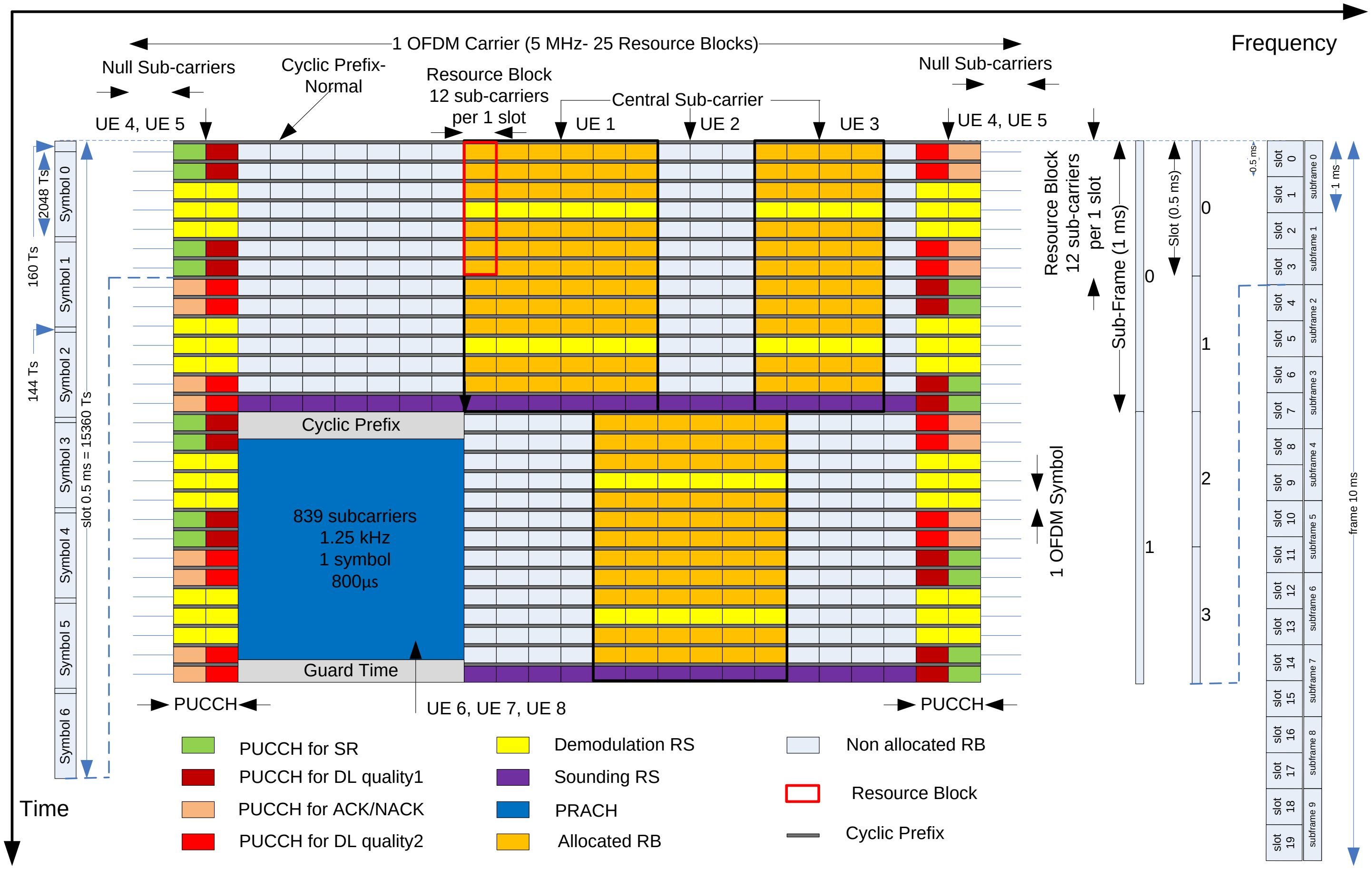
	Ts	µs	km
Cyclic Prefix= Normal	160/144	5.2/4.7	1.4
Cyclic Prefix= Extended	512	16.7	5.0

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



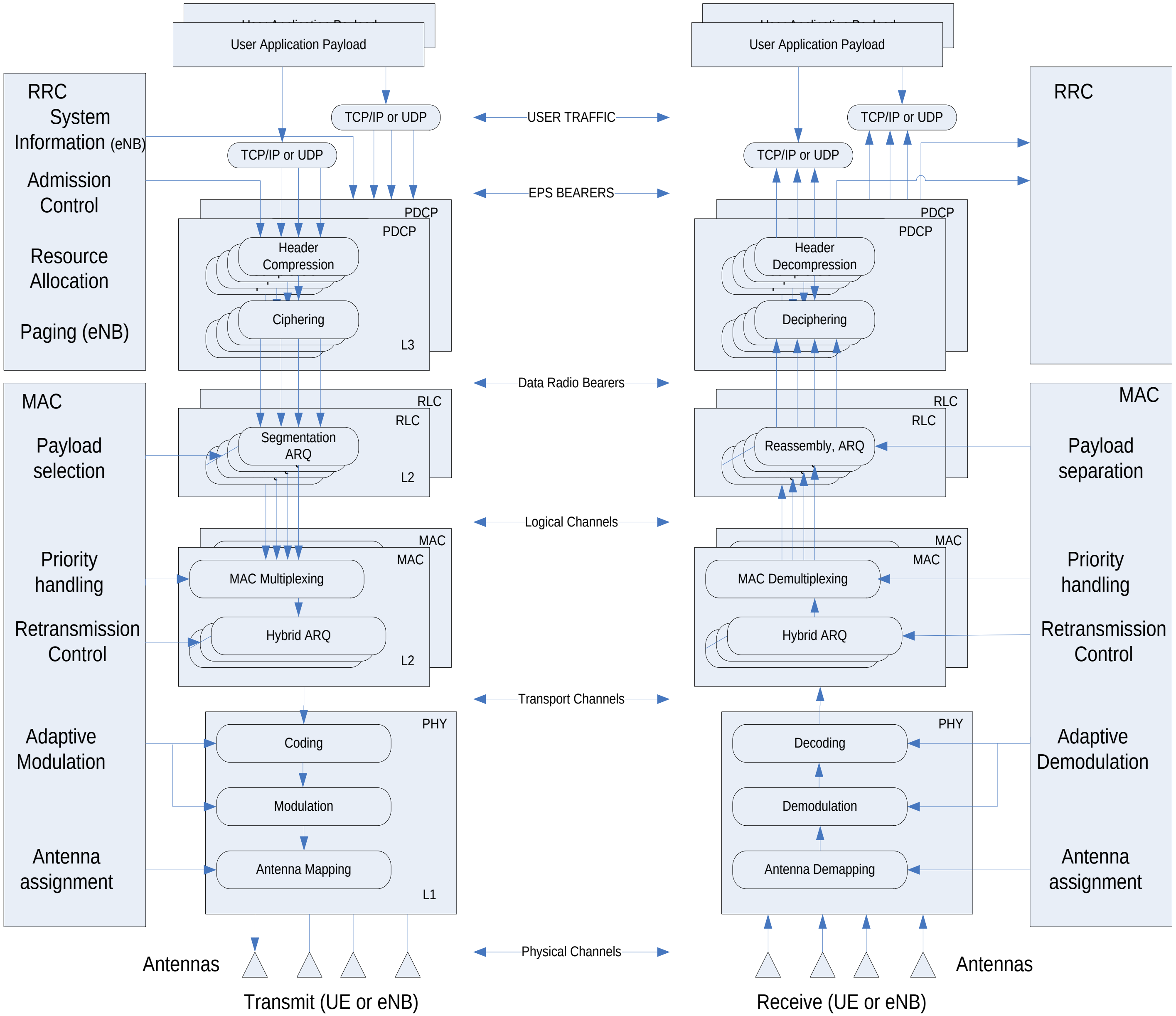
Uplink Frame

- 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



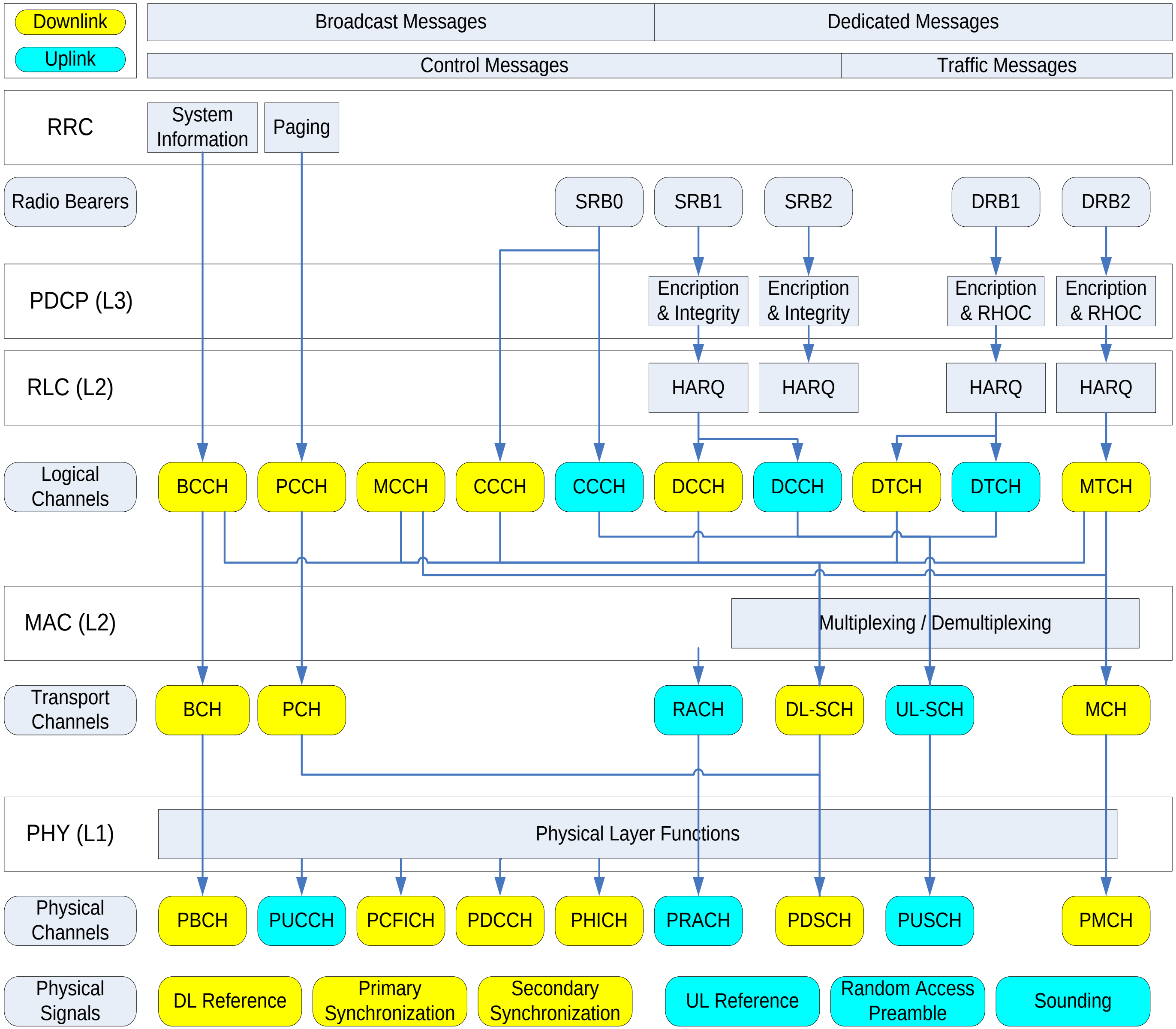
Protocol Layers

- **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)



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



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	

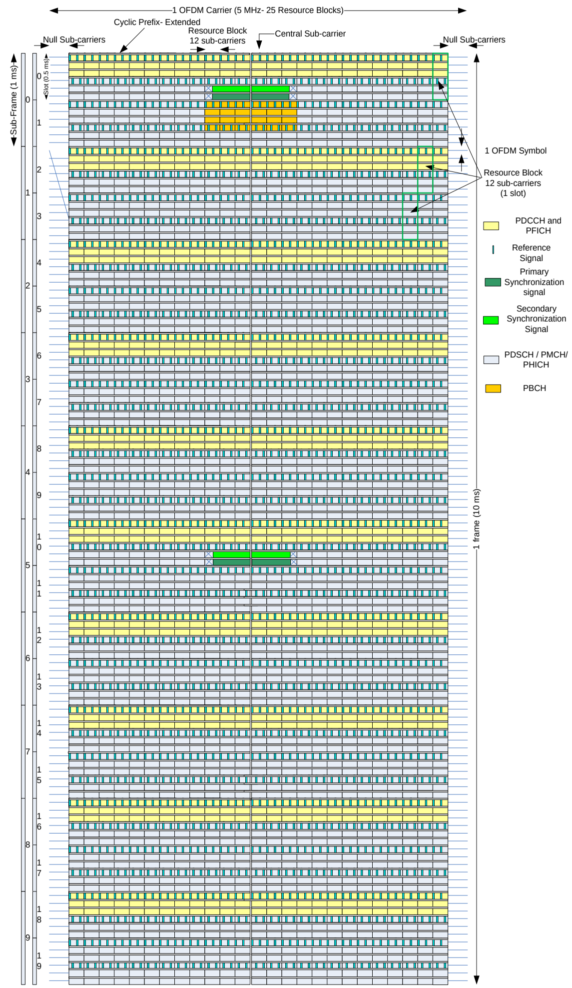
Modulation and Coding Scheme

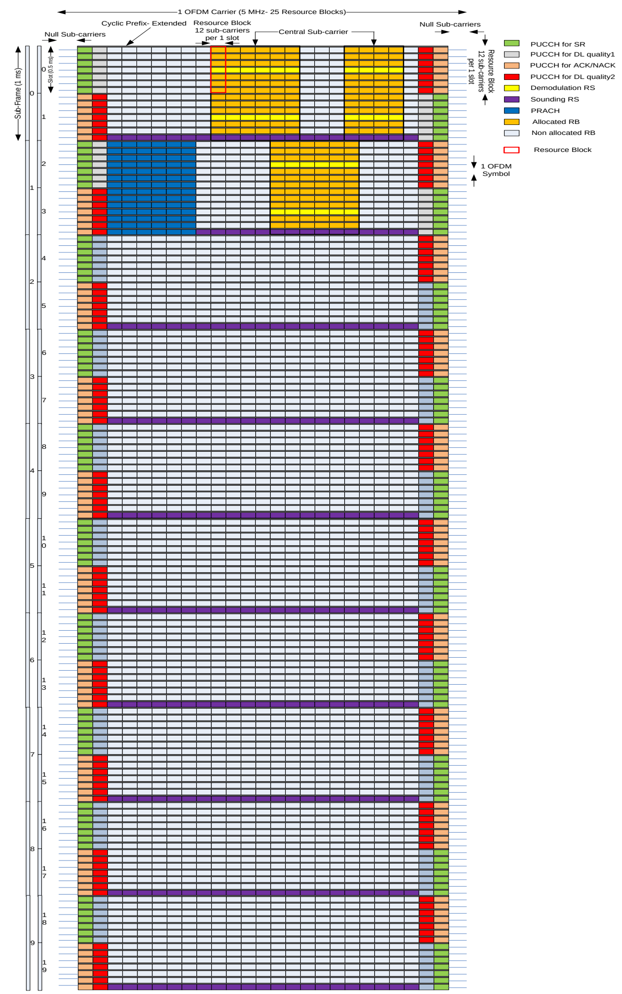
- UE reports one of 15 CQI (Channel Quality Indicator)
- CQI values are mapped to 29 MCS (Modulation and Coding Scheme) indexes
- MCS indexes are mapped to 27 TBS (Transport Block Size) indexes

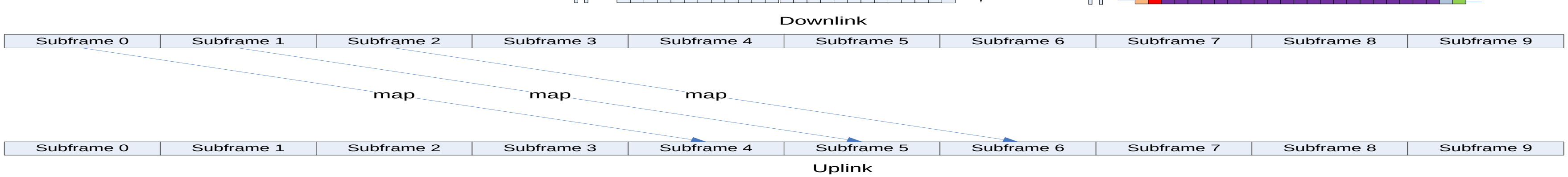
CQI	modulation	coding rate x 1024	Code Rate	efficiency	Adjusted	CR equiv.	MCS Index	modulation	coding rate x 1024	Code Rate	efficiency
2	QPSK	120	0.1172	0.2343750	0.2343750	120.00	0	2	120	0.1172	0.2344
	QPSK				0.3056641	156.50	1	2	157	0.1533	0.3066
3	QPSK	193	0.1885	0.3769531	0.3769531	193.00	2	2	193	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

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

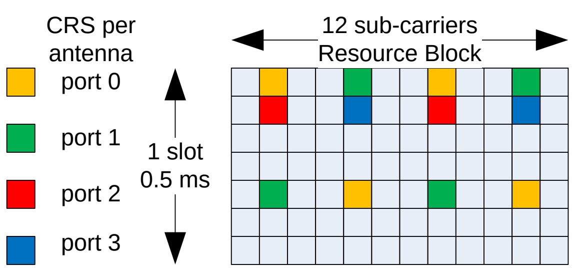


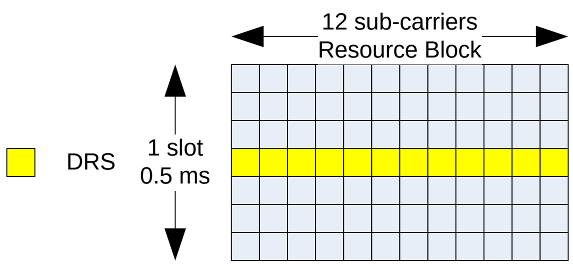




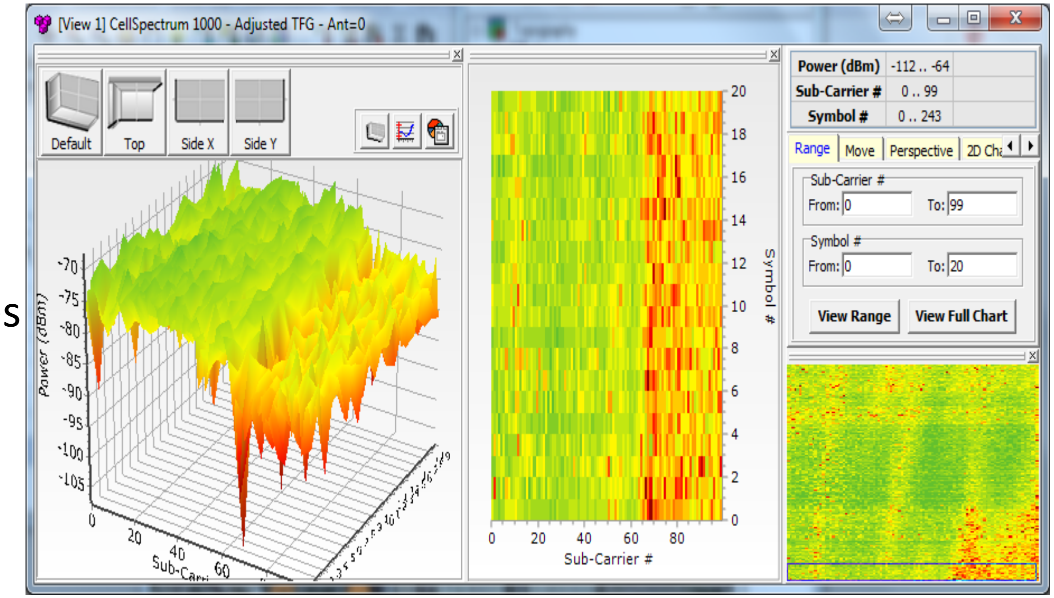
Channel Equalization

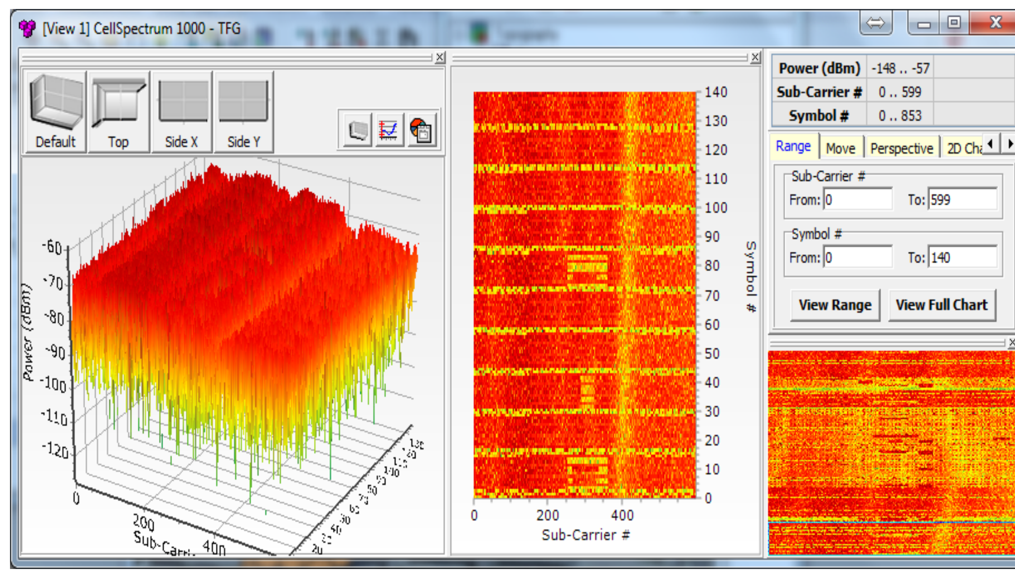
- A broadband channel has significant variations in frequency and time
- This variations have to be corrected before data is extracted
- Reference Signals are used for this purpose
- Reference Signals are known sequences that can be compared to a local reference
- Cell Reference Signals are used in the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





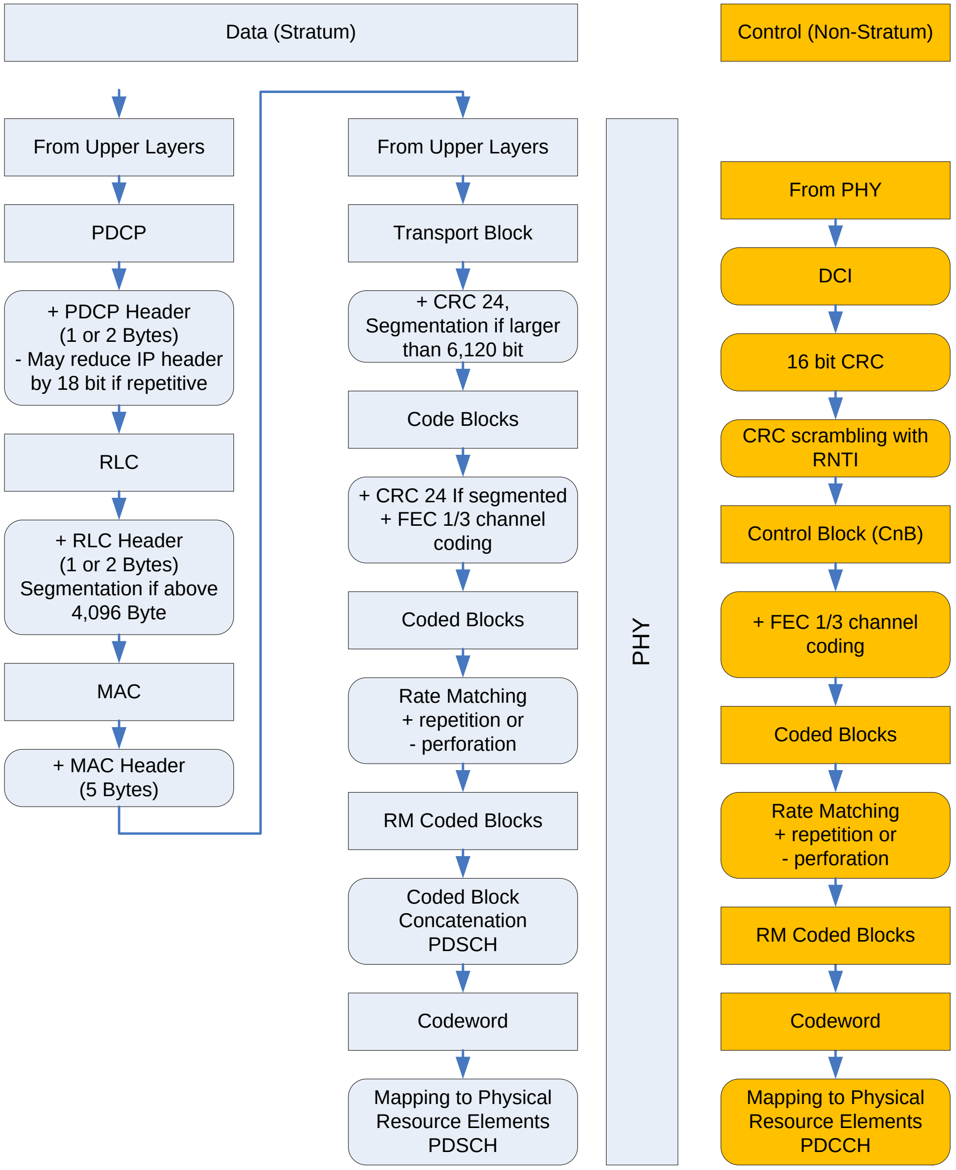
CellSpectrum screen captures





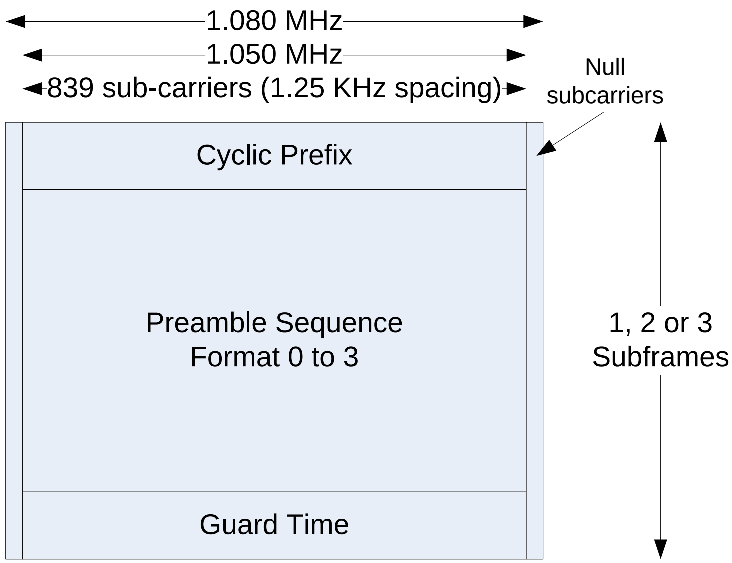
Downlink Control Area

- 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



Uplink RACH Area

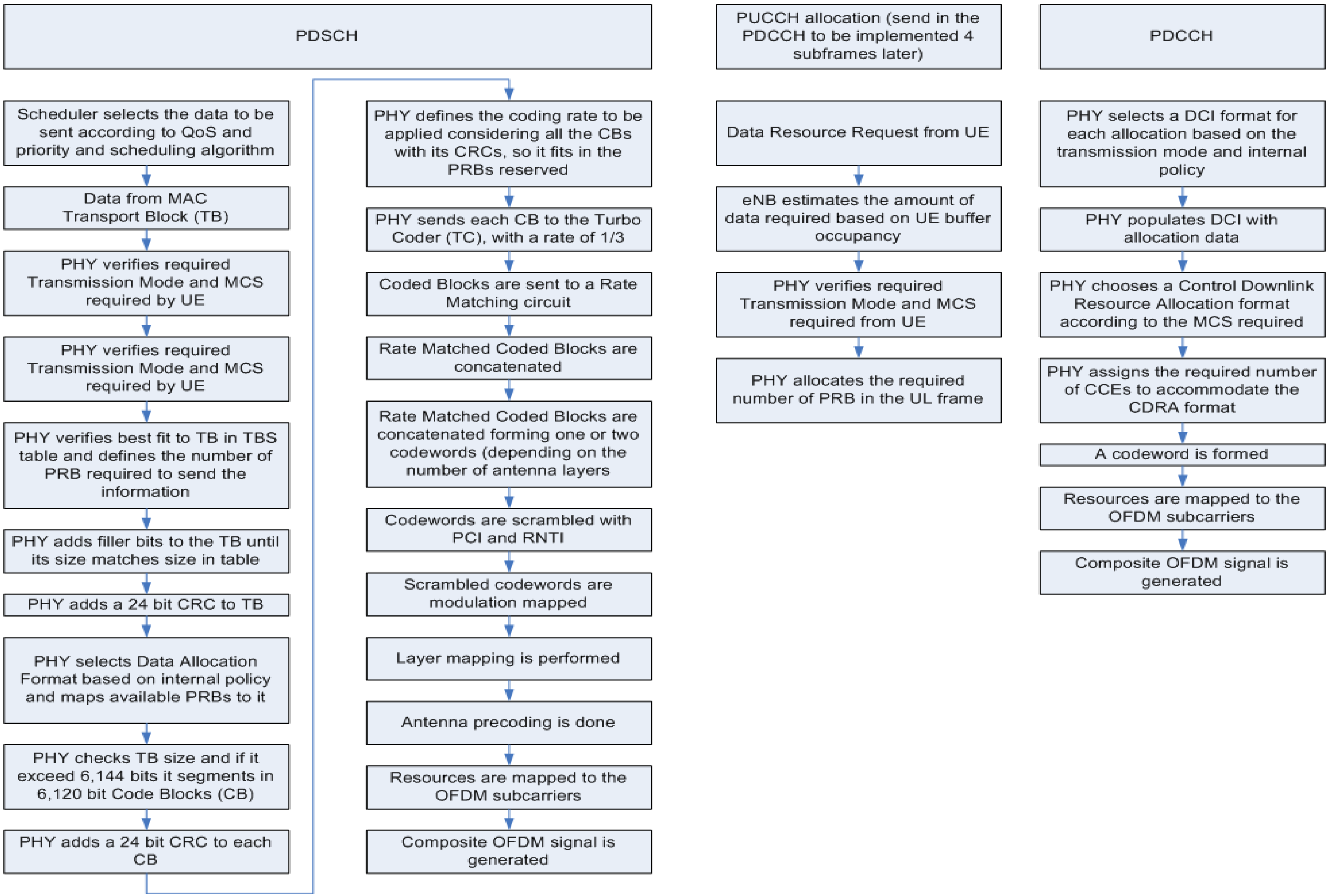
- RACH areas are announced in SIB2
- There are 4 RACH area formats



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

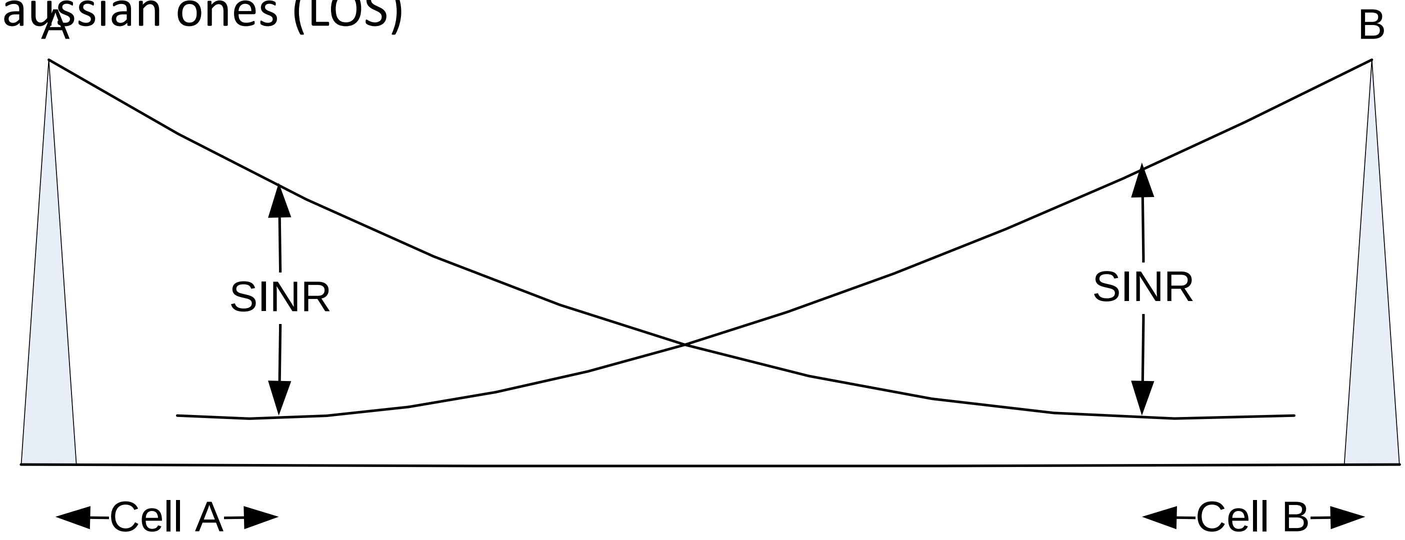
PRACH Format	Duplex	RACH sub-carriers	Sub-carrier width (kHz)	Total width (kHz)	Cell sub-carriers	RBs	PRACH CP (µs)	PRACH Symbols	Sequence (us)	Guard Time (µs)	Total duration (µs)	Sub-frames	Maximum Cell Range (km)	Cell size
0	FDD & TDD	839	1.25	1,049	69.92	6	103.13	1	800	96.88	1000	1	14.5	medium cells
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

Data Allocation by PHY



Cellular Reuse

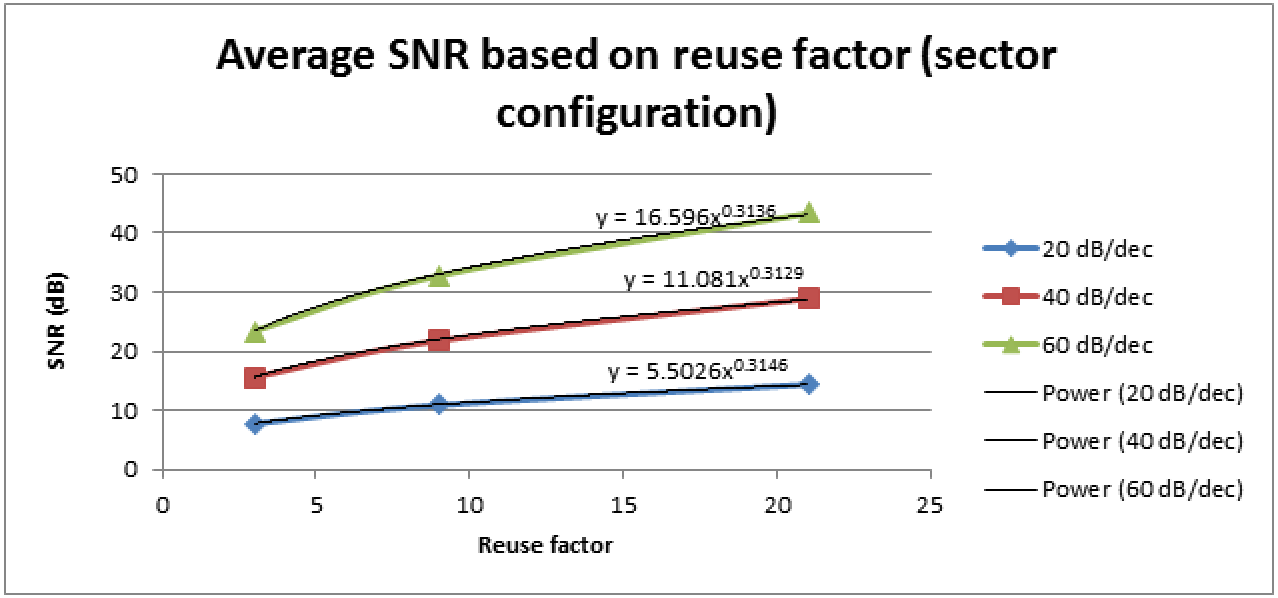
- Cellular technology is based on a physical separation between the usage of the same resources
- Each modulation requires a certain SNR, depending on the environment characteristics
- The separation has to be larger for Rayleigh environments (non LOS) than for Gaussian ones (LOS)



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

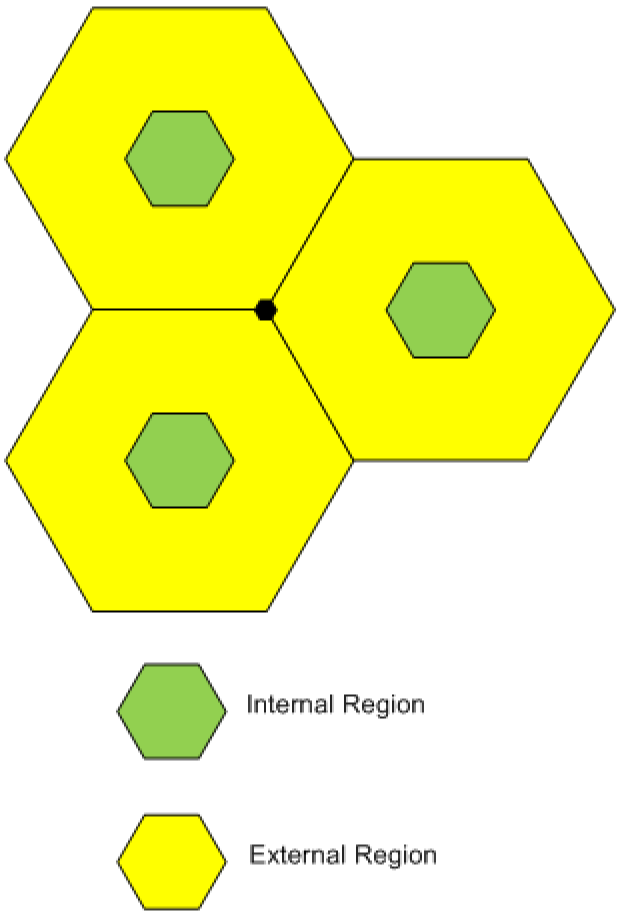
Reuse factor for different environments

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



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

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

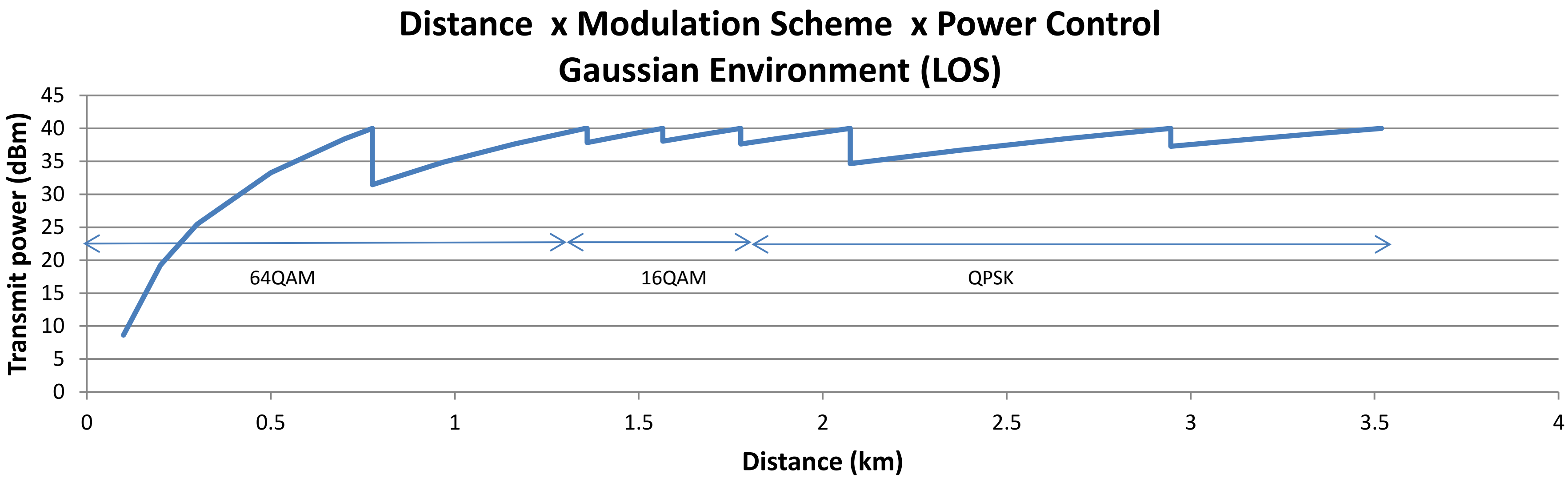
Date Filed:
July 25, 2013

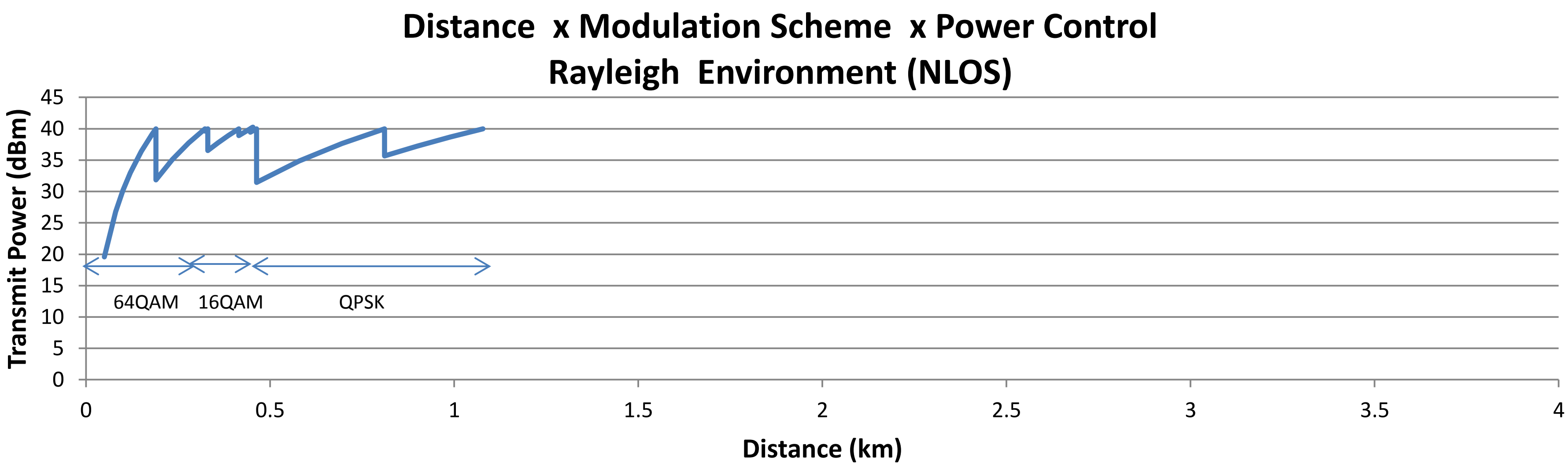
Attorney Docket No.:
7230-101

Adaptive Modulation and Environment

Power Control is used in the uplink, but its relevance is small considering link adaptation

Representation below covers MCS= 0, 4, 9, 10, 16, 17, 28





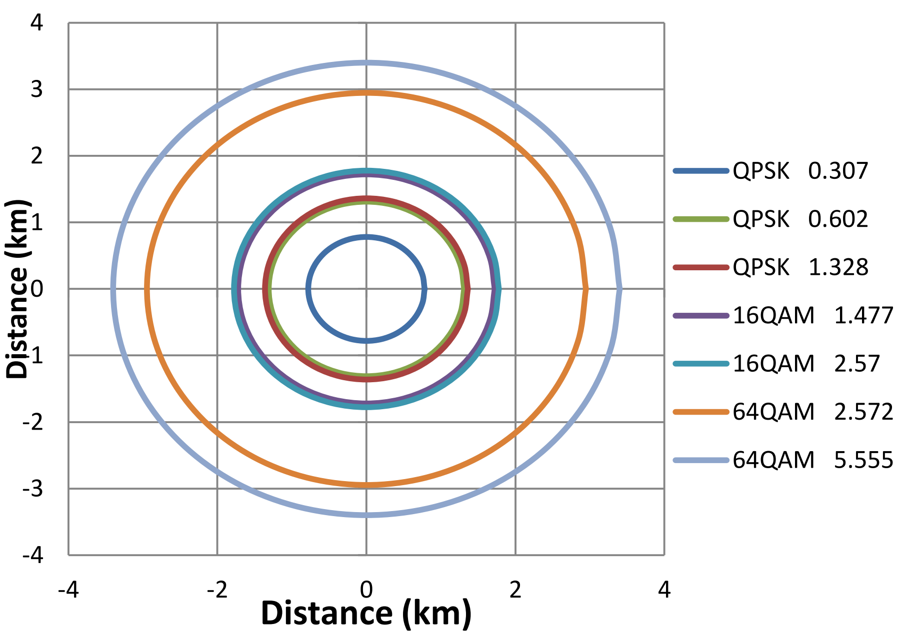
Adaptive Modulation Relative Areas

Frequency: 1 GHz, Bandwidth:10 MHz, TX antenna=12 dB, RX antenna=0 dB, NF= 10 dB
Model Okomura-Hata slope: 35 dB, SNR for AWGN (LOS) and Rayleigh (NLOS)

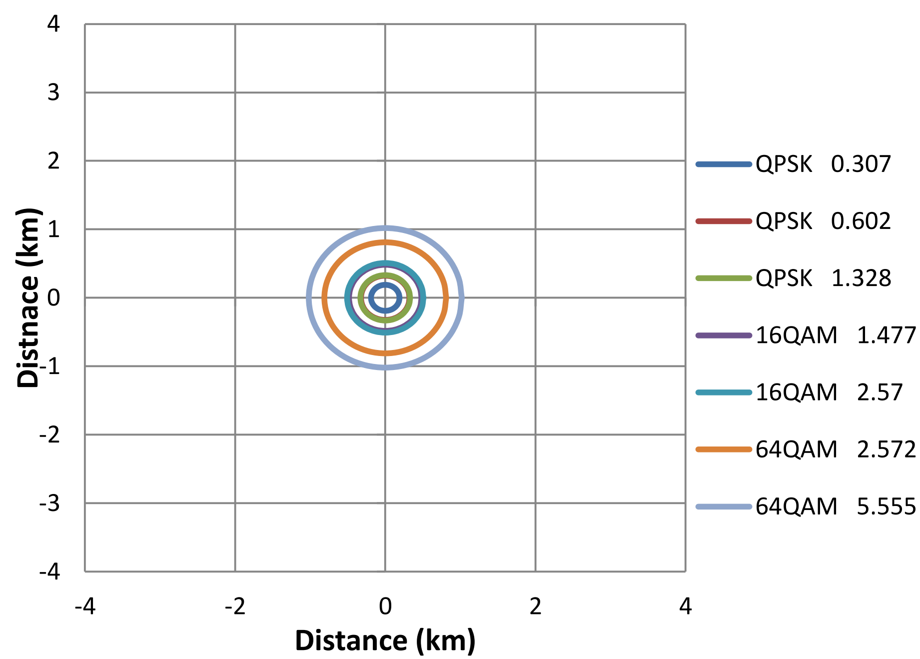
MCS	Modulation	Coding Rate	Spectral Efficiency	Cell Radius (km)	Cell Area (km^2)	Cell Area %	Cell Capacity %
MCS0	QPSK	0.117	0.23	3.5	11.6	29.9%	7%
MCS4	QPSK	0.301	0.602	2.9	13.7	35.3%	20%
MCS9	QPSK	0.663	1.326	2.1	3.6	9.3%	11%
MCS10	16QAM	0.332	1.328	1.8	4.1	10.6%	13%
MCS16	16QAM	0.6425	2.57	1.4	0.0	0.1%	0%
MCS17	64QAM	0.4286	2.572	1.4	3.9	10.0%	24%
MCS28	64QAM	0.9258	5.555	0.8	1.9	4.9%	25%

MCS	Modulation	Coding Rate	Spectral Efficiency	Cell Radius (km)	Cell Area (km^2)	Cell Area %	Cell Capacity %
MCS0	QPSK	0.117	0.23	1.1	1.6	4.1%	13%
MCS4	QPSK	0.301	0.602	0.8	1.4	3.6%	29%
MCS9	QPSK	0.663	1.326	0.5	0.0	0.1%	2%
MCS10	16QAM	0.332	1.328	0.4	0.3	0.7%	13%
MCS16	16QAM	0.6425	2.57	0.3	0.0	0.0%	1%
MCS17	64QAM	0.4287	2.572	0.3	0.2	0.6%	19%
MCS28	64QAM	0.9253	5.555	0.2	0.1	0.3%	22%

Modulation Radius (LOS)

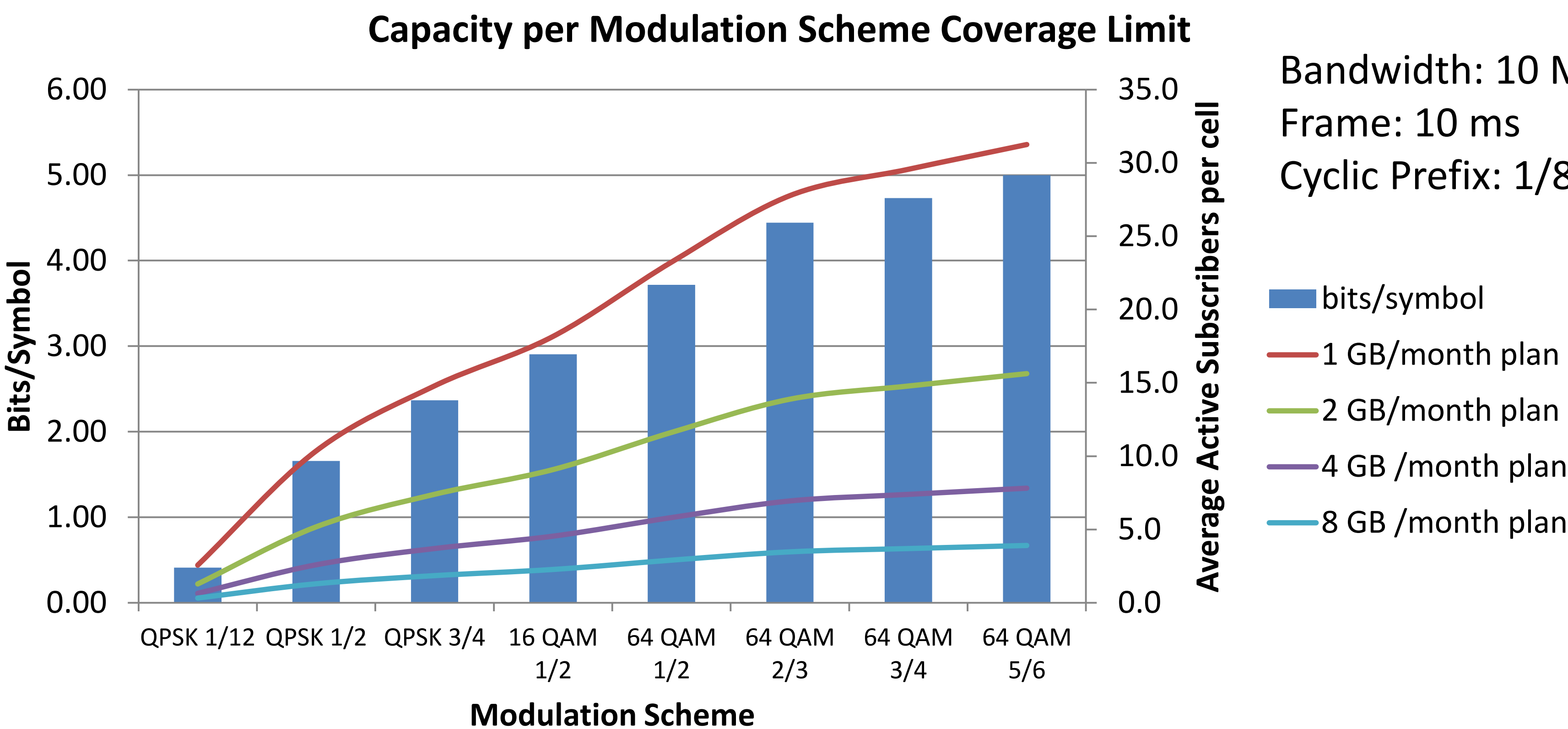


Modulation Radius (NLOS)



Adaptive Modulation Capacity

- On the bottom are the modulation schemes
- On the left are the average bits per symbol achieved by each modulation scheme (blue bars)
- On the right 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
- BTS and Cell Identity
- Tracking Area
- Co-siting
- Resource Reuse
  - Cell Planning
    - Segmentation
    - Zoning
  - Fractional Planning
    - Internal/ external
    - ICIC
    - X2 interface

User Traffic Calculator

User Traffic Calculator

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

Capacity Calculator

Internal tool used for testing code implementation

Capacity Calculator

- Allows user to configure the cell
- Estimates overheads
- Considers design factors
- Provides capacity of UEs considering
  - Downlink
    - Control capacity
    - Data capacity
  - Uplink
    - Control capacity
    - Data capacity
    - Random access capacity

Capacity Calculator

CelPlan
Wireless Solutions & Consulting

Celplan - Resource Calculator

Radio Configuration

- Bandwidth: 10
- Cyclic Prefix: Normal
- HARQ: Chase Combining
- Duplex Mode: FDD
- LTE Release: 10/11
- Frame: 3: DSUUU-DDDDD (6:3)
- Subframe: 0: 3sym-714us-1sym

Factors (%)

DL		UL
80	Load Factor	80
10	Retransm. (BLER)	10
10	Protocol Overhead	10

(%)

- Reuse: 25
- Allocation: 90

Downlink System Information

Control Symbols (PCFICH/PHICH/PDCCH):	3
Positioning (PRS) Bandwidth (MHz):	5
PRS Consecutive Subframes (SF):	1
PRS Periodicity (SF):	1280
Control System Info (CSIRS) Periodicity (SF):	5
MBMS Subframes (SF):	0
MBMS Allocation Period (Frames):	1
Non-MBSFN Region (Symbols):	1
PHICH Scaling Factor:	1
MBSFN Almost Blank Subframe (SF):	0
MBSFN LTE Advanced Subframe (SF):	0

(%)	No MIMO	2x2 MIMO	4x4 MIMO	8x8 MIMO
No BF	84	10	5	1
Beam Form	0	0	0	0

Uplink System Information

PUCCH Resource Blocks per Symbol (RB):	4
PUSCH Resource Blocks per Symbol (RB):	46
PRACH Format Index:	0
PRACH Density per Frame:	2
SRS Resource Elements per Frame (RE):	1000

Interface and Load Factor

- Aerial (PHY)
- GW / Backhaul (Layer 4)
- ☑ Use Load Factor

Downlink Maximum Data Rate Msps	MCS Index	Downlink Available Data Rate Msps	Uplink Available Data Rate Msps
10.625	0	1.549	0.752
13.902	1	2.027	0.984
17.089	2	2.492	1.210
22.225	3	3.240	1.573
27.272	4	3.976	1.930
33.559	5	4.893	2.375
39.757	6	5.797	2.814
46.575	7	6.791	3.297
53.305	8	7.772	3.773
60.123	9	8.766	4.262
60.211	10	8.779	4.738
66.941	11	9.760	4.738
76.858	12	11.206	5.440
86.775	13	12.652	6.142
97.932	14	14.278	6.932
109.088	15	15.905	7.722
116.526	16	16.990	8.261
116.615	17	17.002	8.762
123.787	18	18.048	9.727
137.334	19	20.023	10.667
150.616	20	21.960	11.582
163.633	21	23.858	11.582
176.914	22	25.794	12.523
190.993	23	27.847	13.519
205.072	24	29.899	14.516
218.354	25	31.836	15.456
231.901	26	33.811	16.415
241.730	27	35.244	17.110
251.824	28	36.716	17.825

Output Values

- Spec. Effic. (bps/Hz)
- ◉ Data Rate (Mbps)

DL (Msps)	Overhead Considerations Symbol Rate	UL (Msps)
8.400	Resources without Overhead	8.400
2.235	Control & Signals Overhead	2.049
1.541	Reuse Factor	1.588
1.387	Allococation Efficiency Factor	1.429
1.110	Design Load Factor	1.143
0.999	Retransmissions (BLER)	1.029
0.899	Protocols Overhead	0.926

DL	Capacity per TTI	UL
6,165	Symbols / TTI	6,351
123	Average Symbols / PRB	138
10	PRB / TTI	9

DL Modulation (%) UL

DL		UL
60	QPSK	50
30	16QAM	45
10	64QAM	5

PDCCH Format (%)

	FMT	
10	0 FMT 1	15
30	2 FMT 3	45

DL		UL
1.416	Resulting Spectral Efficiency	1.746
2	CCEs per PDCCH	

Signaling Information

0.5	DL	Signaling Data Rate (kbps)	UL	0.25
200	DL	Signaling Packet Size (bits)	UL	100

DL	Packet Estimation	UL
1680	Capacity (bits / TTI)	2134
92.3	User Demand (bits / TTI)	18.6
18.2	Users according Tonnage @BH	114.5
18.2	Users @ BH limited by PDCCH	18.2
7104	Data Packet Size (bits)	1088
77	Data Packet (ms)	58
0.24	<<<< Data Packets / TTI >>>>	0.31
400	Signaling Packet (ms)	400
0.05	<<< Signaling Packets / TTI >>>	0.05

41	Available	CCEs	Required	1.53
18	Users	FINAL	CCEs	1.53

Today's Topic

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

Content

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

1. How to evaluate Customer Experience?

How to evaluate Customer Experience?

- Existing Network
  - Ask the customer
    - Customer expect the same performance as wired networks
    - Not all customer have the same expectation
    - Customer focuses on symptoms not causes
  - Verify Network Statistics
    - Represent the network as a whole, without identifying specific areas
  - Perform performance tests
    - Covers only the areas under test
  - Compare predicted performance with post deployment evaluation
    - Maps the above issues by location and time
- New Network or Expansion or Improvement
  - Predict performance
    - Only way to anticipate the customer experience
  - Compare predicted performance with post deployment evaluation
    - Calibrates the prediction model

Why KPIs and Measurements do not reflect Customer Experience

- KPIs are not standardized and are implemented by vendors
  - Generally there is not enough documentation to know exactly what is being represented
  - Vendors do not like to present bad statistics, mainly when they design the network
- KPIs provide average results
  - Good performance masks bad performance
  - Clients do not give credits for good performance, KPIs do
- LTE measurements are highly deficient and have a large potential of giving misleading results
  - Generally there is not enough documentation to know exactly what is being measured

Customer Experience Prediction is an essential step in the design and operation of a wireless network

No measurements or statistical KPI analysis can fix a badly designed network

Trying to fix a network after deployment or change is expensive and results in unsatisfied customers

2. What factors affect customer experience?

IP network performance evaluation is different from circuit switched networks

What is the difference between data speed and data tonnage?

- Speed and Tonnage are expressed in data rate (kbit/s)
- A 10 MHz LTE channel, with two TX antennas and 3 control symbols has 5,500 Resource Elements (RE) per TTI available for data
  - Assuming a reuse factor of 7 we get about 800 REs per TTI
- This results in a maximum speed data rate of 800 kbps for QPSK1/2 or 1.6 Mbps for 64QAM1/3
- An over subscription factor of 40 will give result in a tonnage data rate of 20 kbps for QPSK1/2 or 40 kbps for 64QAM1/3

What factors affect customer experience?

- IP communication can be divided in two groups:
  - Interactive (an action requires a reply from the other side to proceed with the communication)
    - Web browsing, e-mail, ftp
    - Uses TCP/IP or similar protocols
    - A communication session is affected by the tonnage available for the user
  - Independent (no action required from the other side to communicate)
    - Voice Conversation
    - Video and voice Streaming
    - Live video
    - Uses UDP/IP or similar protocols
- Customers express their network experience by:
  - Slow network response
    - Tonnage
    - Speed
  - Lost sessions
  - Bad quality (voice, video)
  - Customers like consistent performance

3. Parameters that affect customer experience

Parameters that affect customer experience

- Network Design
  - Customer expectations have to be specified and considered during the network design
  - The main mistake done today is to simply collocate sites with 2G/3G sites, without analyzing the outcome
- Network settings
  - LTE has hundreds of parameters that have to be properly dimensioned
  - Using default values will not result in an optimized network
- Resource Planning
  - LTE has many resources that have to be planned, which are essential to the network operation
  - Vendors have developed proprietary solutions to avoid interference
- Overload
  - Loading a network beyond its capacity will deteriorate its performance and lead to countless corrective actions
- Interference
  - LTE has inherent issues with self-interference, mainly in the control channel
  - Operators should look for vendor solutions for this issue
- Internet connections
  - Internet backhaul needs to be properly dimensioned, otherwise all other efforts will be in vain
- SINR
  - SINR calculation should be done statistically and the network availability calculated

Capacity and Traffic Allocation

Traffic Modeling

- Define traffic per user class
  - Similar service profiles and tonnage
- Define traffic per user equipment model
  - Smartphone
  - Tablet
  - USB
  - Modem
  - Other devices

User Traffic Calculator

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

CellDesigner - Tonnage Calculator

QoS | Unitary | Tonnage | QCI Table

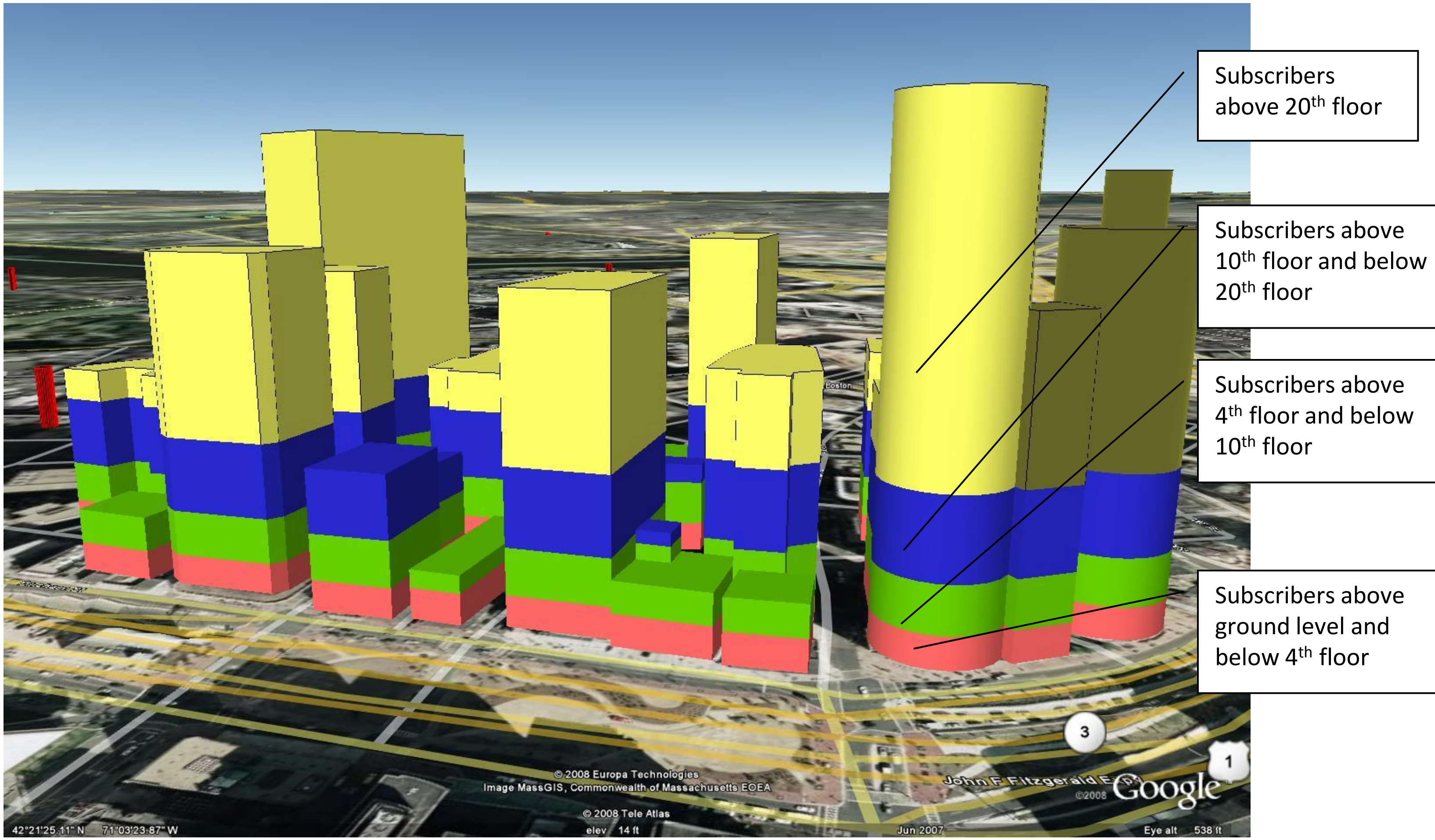
Daily to Busy Hour Factor 0.33333

			Smartphone			Tablet			USB			Modem		
			Number of UE: 500000			Number of UE: 100000			Number of UE: 80000			Number of UE: 40000		
Service Identification			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

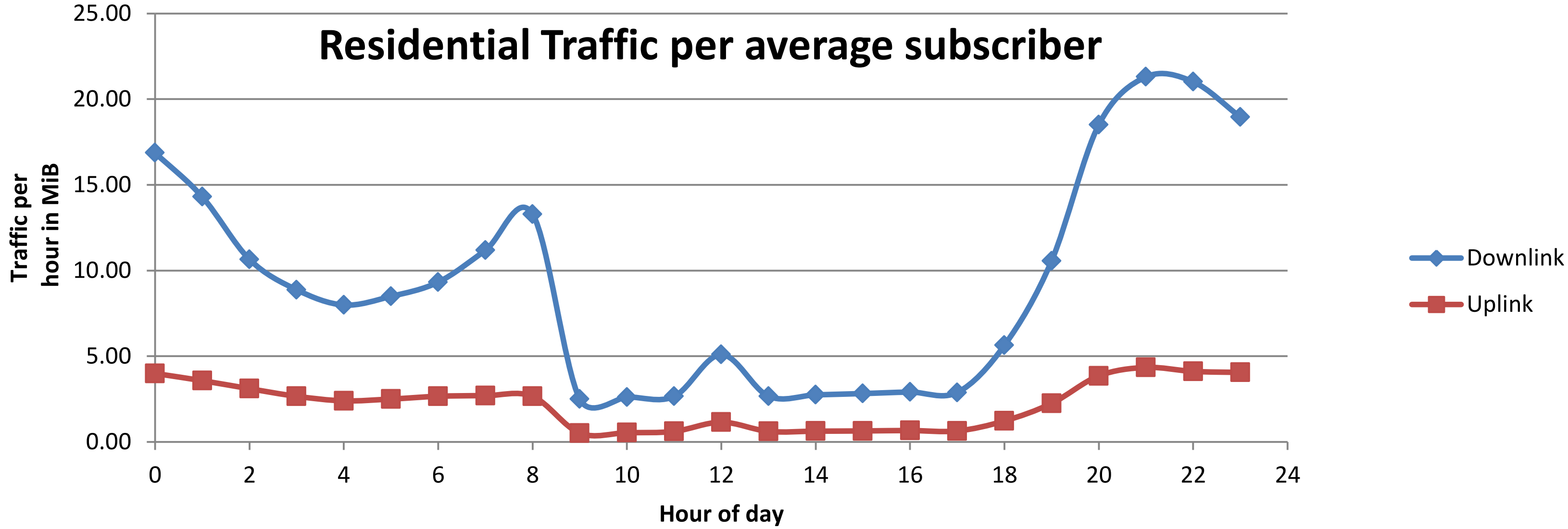
	Smartphone DL	Smartphone UL	Tablet DL	Tablet UL	USB DL	USB UL	Modem DL	Modem UL
UE Total Tonnage (kbps)	70.337	10.561	103.00	30.897	179.00	37.649	157.04	46.252
Backhaul Total Tonnage (Gbps)	35.168	5.2808	10.300	3.0897	14.320	3.0119	6.2819	1.8501
UE Montly Tonnage (GB/Mo)	2.6530	0.3983	3.8852	1.1654	6.7516	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

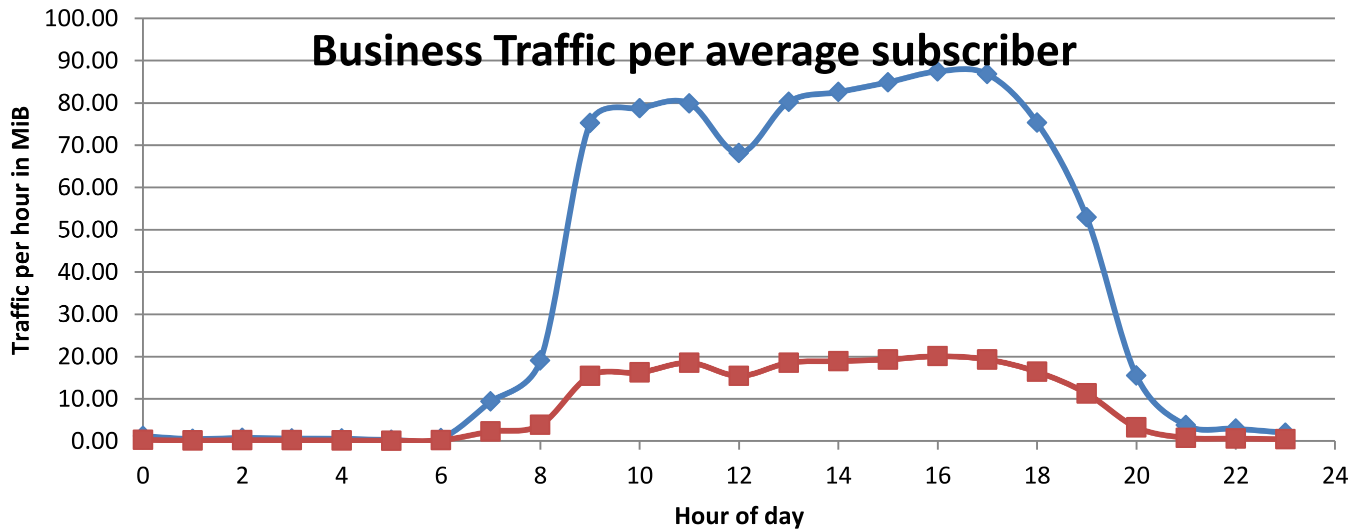
Traffic Modeling In-building



Market Modeling

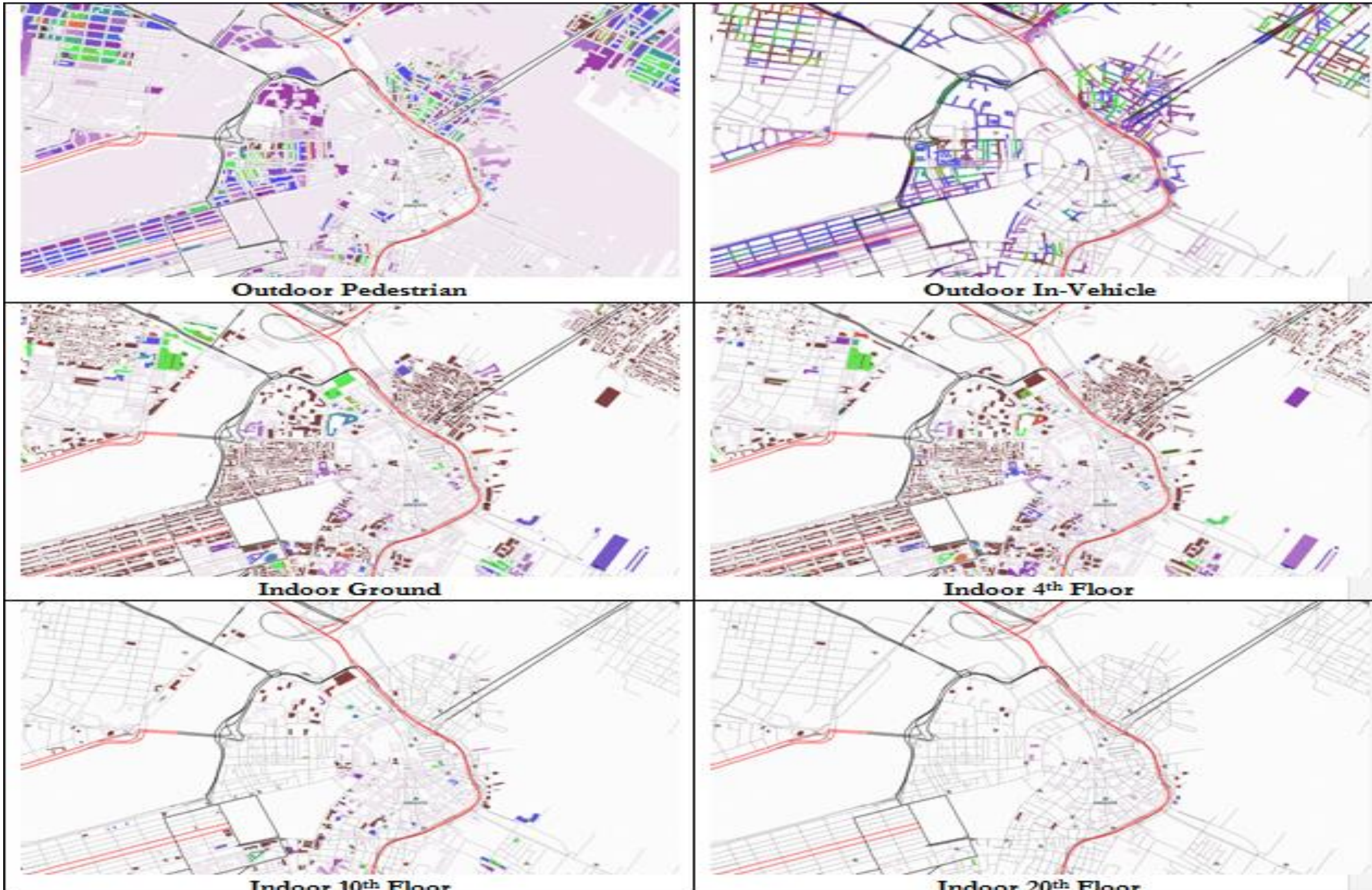
- Traffic varies according to hour of the day





Traffic Distribution Outdoor and Indoor

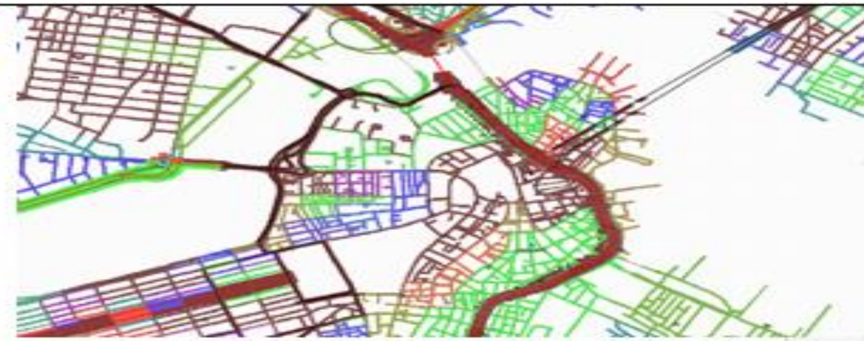
- Residential Layers



Traffic Distribution Outdoor and Indoor

- Business Layers

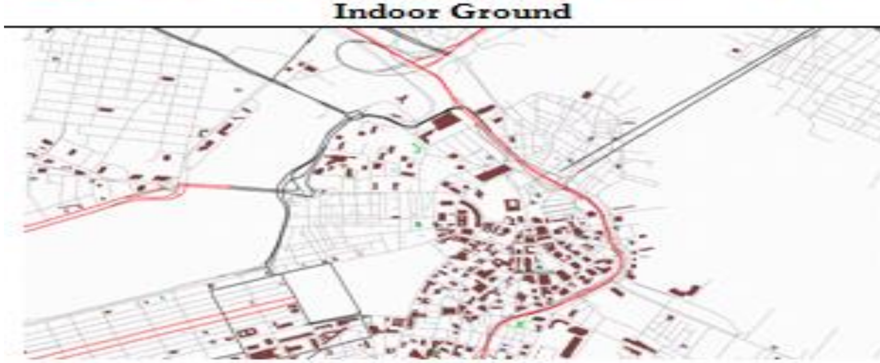
Outdoor Pedestrian



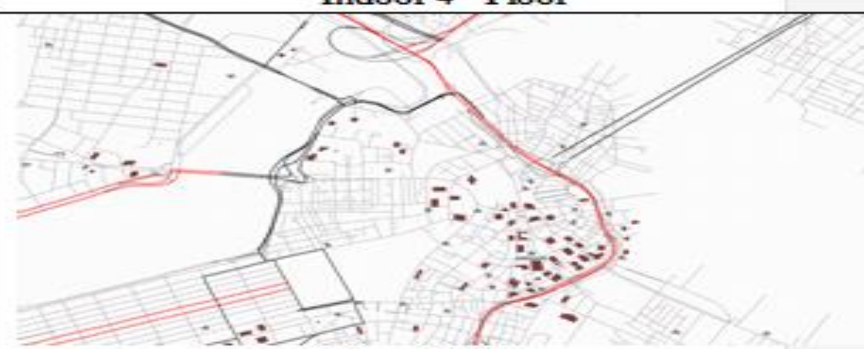
Outdoor In-Vehicle

Indoor Ground

Indoor 4th Floor



Indoor 10th Floor



Indoor 20th Floor

Capacity Calculator

CelPlan Wireless Solutions & Consulting

Celplan - Resource Calculator

Radio Configuration

Bandwidth: 10 | Cyclic Prefix: Normal
HARQ: Chase Combining | Duplex Mode: FDD
LTE Release: 10/11 | Frame: 3: DSUUU-DDDDD (6:3) | Subframe: 0: 3sym-714us-1sym

Factors (%)

DL		UL
80	Load Factor	80
10	Retransm. (BLER)	10
10	Protocol Overhead	10

(%) Reuse: 25 | Allocation: 90

Downlink System Information

Control Symbols (PCFICH/PHICH/PDCCH):	3
Positioning (PRS) Bandwidth (MHz):	5
PRS Consecutive Subframes (SF):	1
PRS Periodicity (SF):	1280
Control System Info (CSIRS) Periodicity (SF):	5
MBMS Subframes (SF):	0
MBMS Allocation Period (Frames):	1
Non-MBSFN Region (Symbols):	1
PHICH Scaling Factor:	1
MBSFN Almost Blank Subframe (SF):	0
MBSFN LTE Advanced Subframe (SF):	0

(%)	No MIMO	2x2 MIMO	4x4 MIMO	8x8 MIMO
No BF	84	10	5	1
Beam Form	0	0	0	0

Uplink System Information

PUCCH Resource Blocks per Symbol (RB):	4
PUSCH Resource Blocks per Symbol (RB):	46
PRACH Format Index:	0
PRACH Density per Frame:	2
SRS Resource Elements per Frame (RE):	1000

Interface and Load Factor

○ Aerial (PHY) ○ GW / Backhaul (Layer 4)
☑ Use Load Factor

Downlink Maximum Data Rate Msps	MCS Index	Downlink Available Data Rate Msps	Uplink Available Data Rate Msps
10.625	0	1.549	0.752
13.902	1	2.027	0.984
17.089	2	2.492	1.210
22.225	3	3.240	1.573
27.272	4	3.976	1.930
33.559	5	4.893	2.375
39.757	6	5.797	2.814
46.575	7	6.791	3.297
53.305	8	7.772	3.773
60.123	9	8.766	4.262
60.211	10	8.779	4.738
66.941	11	9.760	4.738
76.858	12	11.206	5.440
86.775	13	12.652	6.142
97.932	14	14.278	6.932
109.088	15	15.905	7.722
116.526	16	16.990	8.261
116.615	17	17.002	8.762
123.787	18	18.048	9.727
137.334	19	20.023	10.667
150.616	20	21.960	11.582
163.633	21	23.858	11.582
176.914	22	25.794	12.523
190.993	23	27.847	13.519
205.072	24	29.899	14.516
218.354	25	31.836	15.456
231.901	26	33.811	16.415
241.730	27	35.244	17.110
251.824	28	36.716	17.825

Output Values

○ Spec. Effic. (bps/Hz) ◉ Data Rate (Mbps)

DL (Msps)	Overhead Considerations Symbol Rate	UL (Msps)
8.400	Resources without Overhead	8.400
2.235	Control & Signals Overhead	2.049
1.541	Reuse Factor	1.588
1.387	Allococation Efficiency Factor	1.429
1.110	Design Load Factor	1.143
0.999	Retransmissions (BLER)	1.029
0.899	Protocols Overhead	0.926

DL	Capacity per TTI	UL
6,165	Symbols / TTI	6,351
123	Average Symbols / PRB	138
10	PRB / TTI	9

DL Modulation (%) UL

DL		UL
60	QPSK	50
30	16QAM	45
10	64QAM	5

PDCCH Format (%)

10	0 FMT 1	15	
30	2 FMT 3	45	

1.416	Resulting Spectral Efficiency	1.746
2	CCEs per PDCCH	

Signaling Information

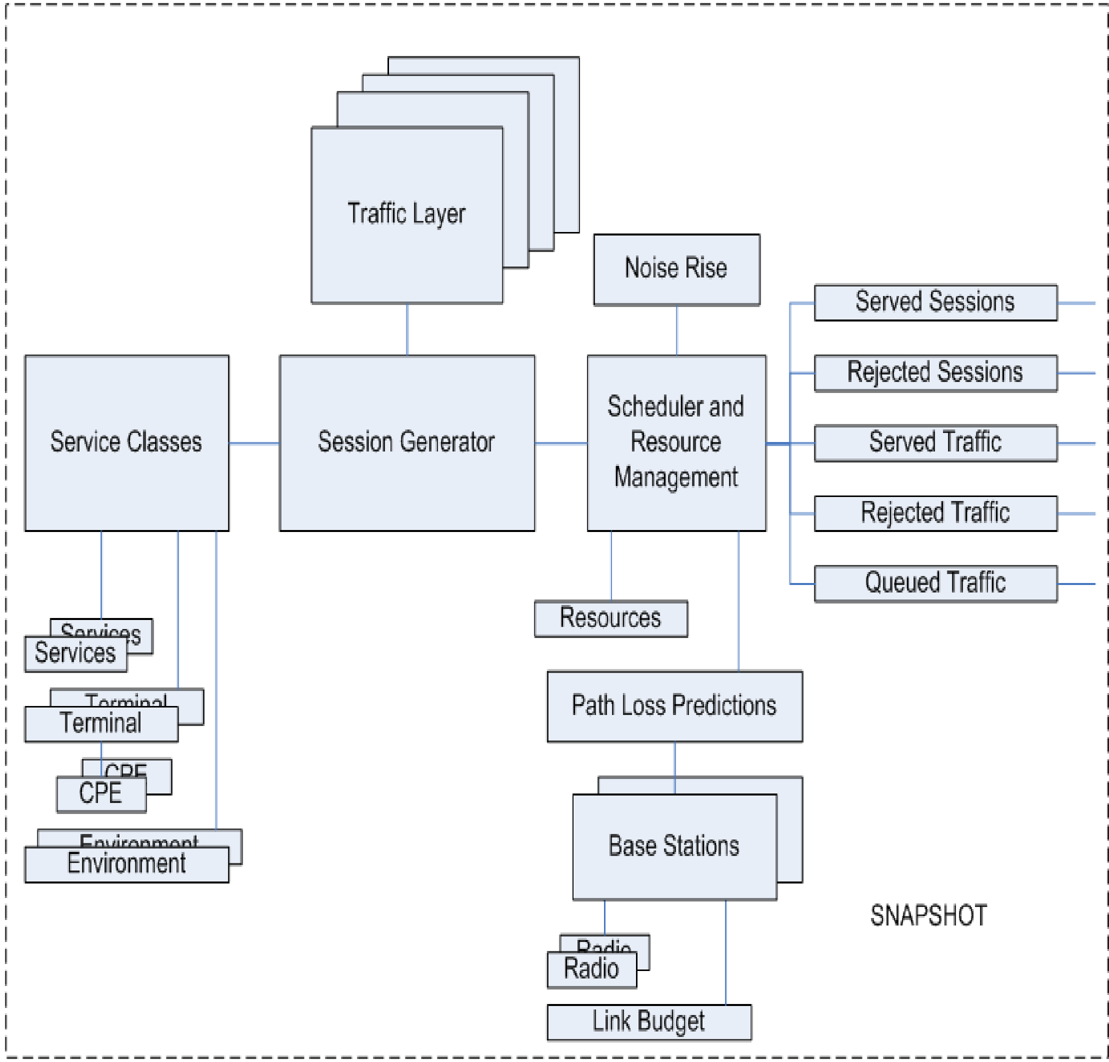
0.5	DL	Signaling Data Rate (kbps)	UL	0.25
200	DL	Signaling Packet Size (bits)	UL	100

DL	Packet Estimation	UL
1680	Capacity (bits / TTI)	2134
92.3	User Demand (bits / TTI)	18.6
18.2	Users according Tonnage @BH	114.5
18.2	Users @ BH limited by PDCCH	18.2
7104	Data Packet Size (bits)	1088
77	Data Packet (ms)	58
0.24	<<<< Data Packets / TTI >>>>	0.31
400	Signaling Packet (ms)	400
0.05	<<< Signaling Packets / TTI >>>	0.05

41	Available	CCEs	Required	1.53
18	Users	FINAL	CCEs	1.53

Traffic Simulation with Noise Rise

- Market is modeled through Service Classes
  - Services
  - Terminals
    - UE radio
  - Environment
- Sessions are randomly generated in proportion to the traffic layers associated with them
  - Snapshot
- Network is modeled by cell and its path loss predictions
  - Cell
    - Radio
    - Link budget
- Scheduler and Resource Management algorithms assign calls, interference is replaced by an average noise rise
- Statistics are recorded for snapshot
  - Served Sessions
  - Rejected Sessions
  - Served Traffic
  - Rejected Traffic
  - Queued traffic



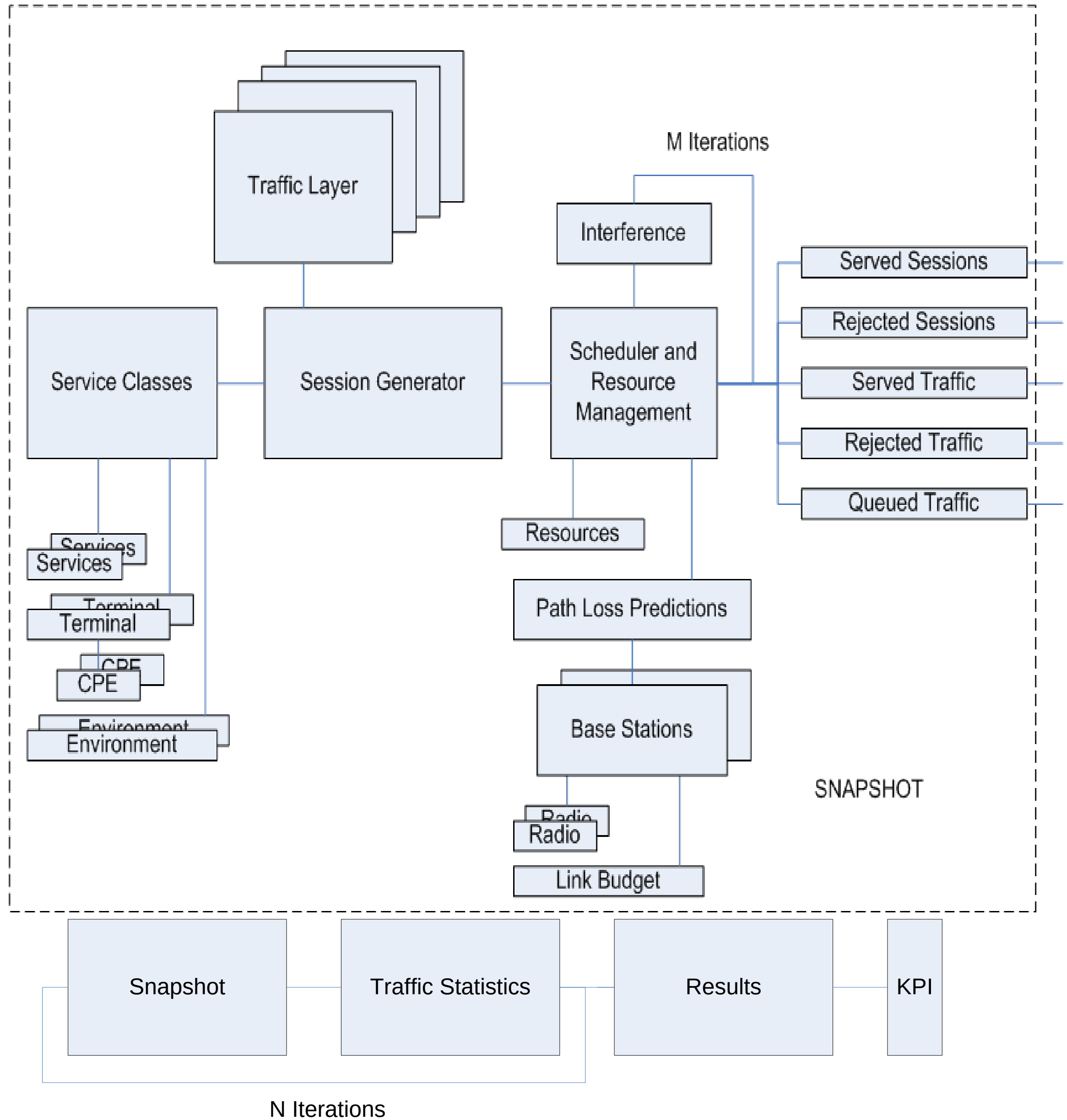
What should be planned ?

- 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
  - IS2000
  - WiMAX
- Handover (Multi-RAT)
- BTS and Cell Identity
- Co-siting
- Resource Reuse
  - Cell Planning
    - Segmentation
    - Zoning
  - Fractional Planning
    - Internal/ external
    - ICIC
    - X2 interface

Resource Planning depends on the correct evaluation of SINR between cells

Traffic Simulation with Interference

- Market is modeled through Service Classes
  - Services
  - Terminals
    - CPE radio
  - Environment
- Sessions are randomly generated in proportion to the traffic layers associated with them
  - Snapshot
- Network is modeled by cell and its path loss predictions
  - Cell
    - Radio
    - Link budget
- Scheduler and Resource Management algorithms assign calls, interference is replaced by an average noise rise
- Statistics are recorded for snapshot
  - Served Sessions
  - Rejected Sessions
  - Served Traffic
  - Rejected Traffic
  - Queued traffic



4. SINR availability and how to calculate it

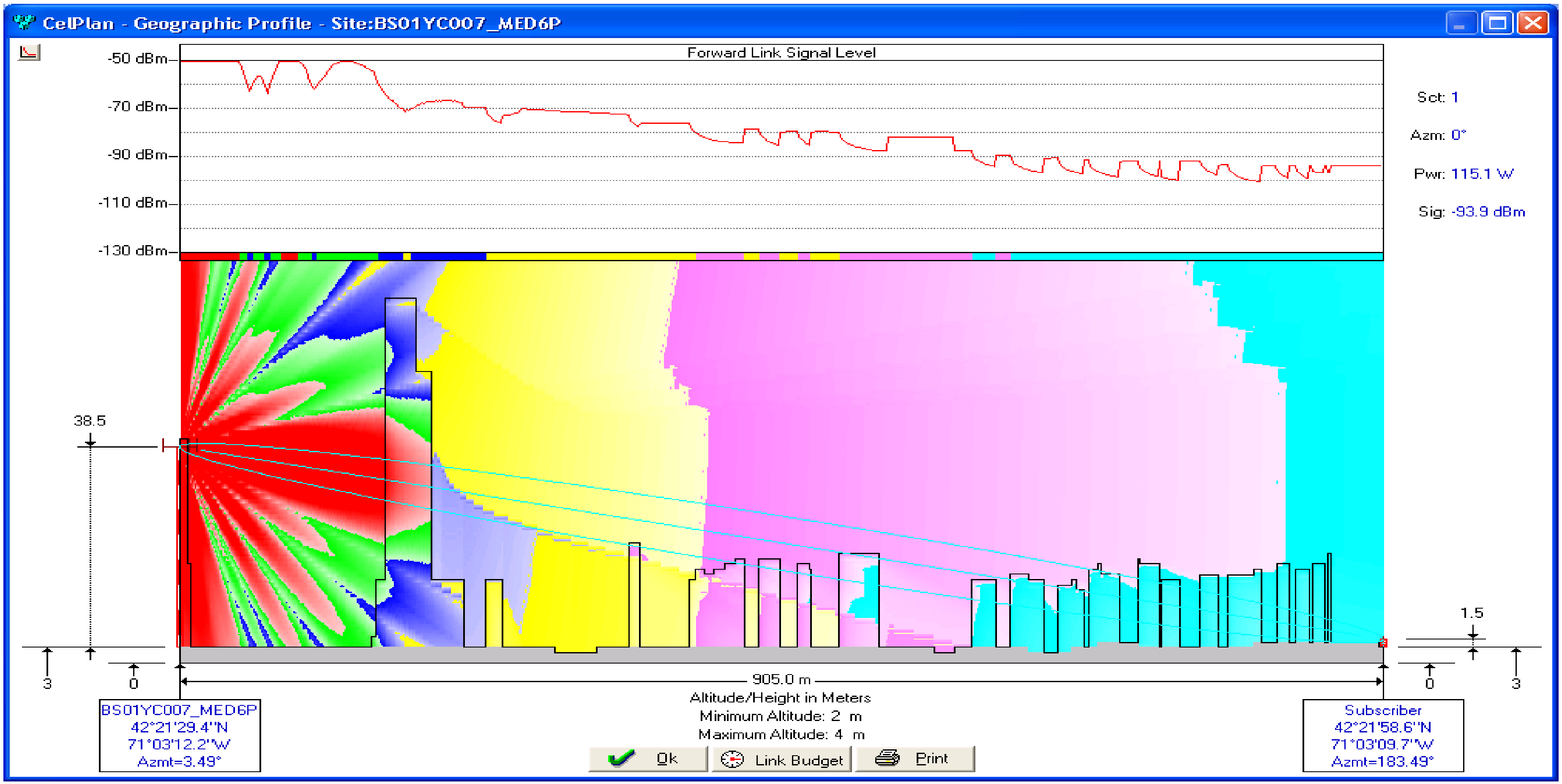
Minimum conditions for a proper SINR analysis

- Use an appropriate propagation model
  - Capable of doing outdoor and indoor simultaneous predictions
  - Capable of considering fractional morphologies
  - Capable of 3D propagation analysis
  - Capable of predicting path loss at different heights
- Use a representative traffic distribution
  - Proper representation of outdoor and indoor traffic
  - Proper representation of traffic at multiple heights
  - Proper representation of different hours of the day
- Statistically valid signal level representation
  - Consider independent fading variations
  - Consider all possible interference sources with their statistical distribution

Korowajczuk 3D Prediction Model

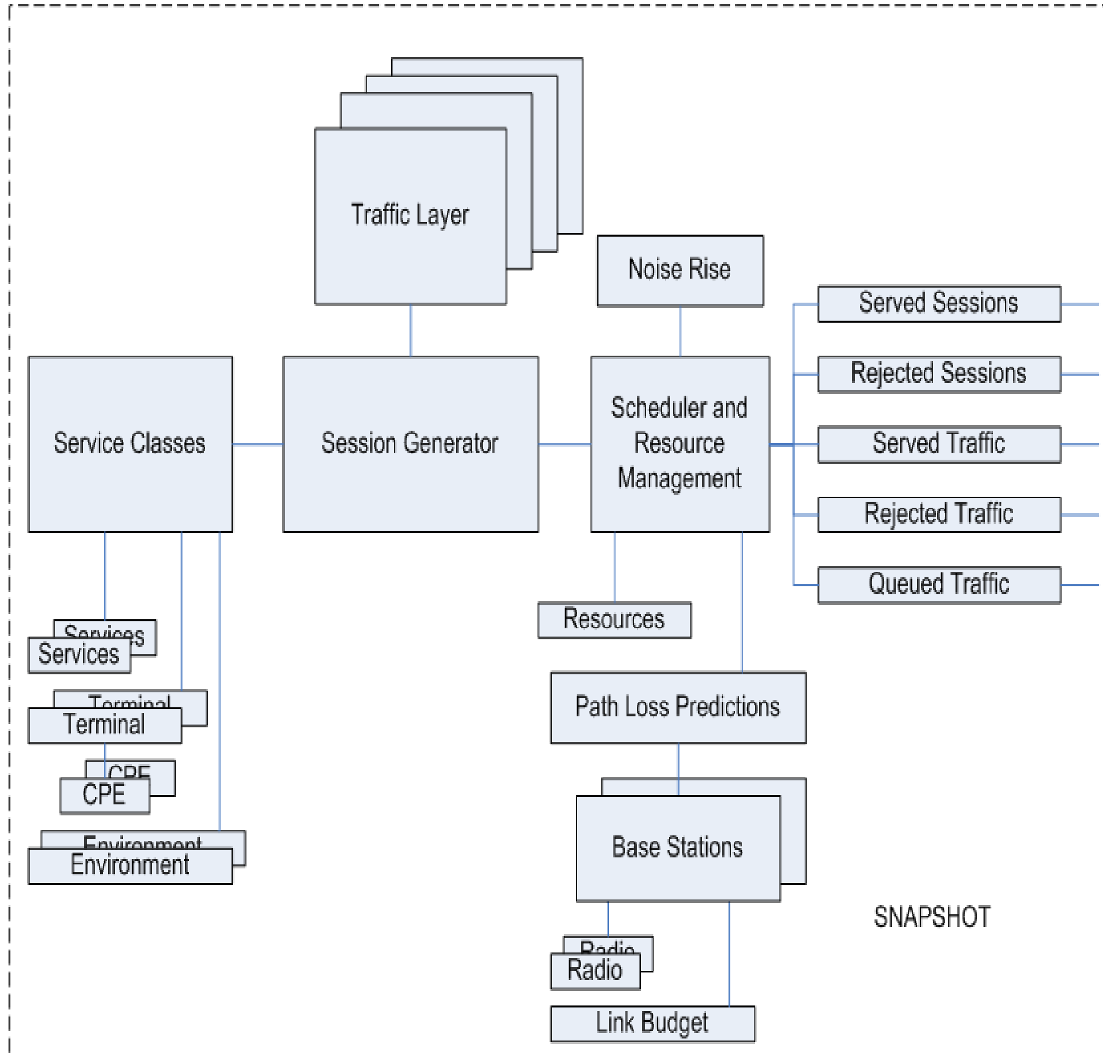
CelPlan Wireless Solutions & Consulting

- Multiple propagation mechanism consideration
- Simultaneous indoor and outdoor prediction
- 3D propagation analysis
- Fractional morphology
- Multiple height analysis



Traffic Simulation with Noise Rise

- Market is modeled through Service Classes
  - Services
  - Terminals
    - CPE radio
  - Environment
- Sessions are randomly generated in proportion to the traffic layers associated with them
  - Snapshot
- Network is modeled by BTS and path loss is predictions
  - BTS
    - Radio
    - Link budget
- Scheduler and Resource Management algorithms assign calls, interference is replaced by an average noise rise
- Statistics are recorded for snapshot
  - Served Sessions
  - Rejected Sessions
  - Served Traffic
  - Rejected Traffic
  - Queued traffic

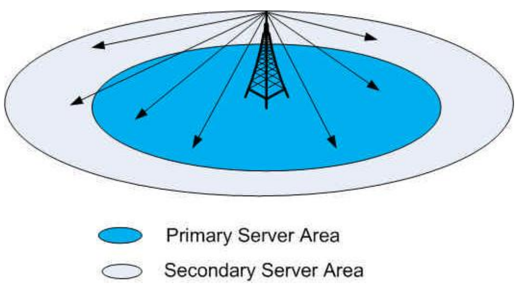


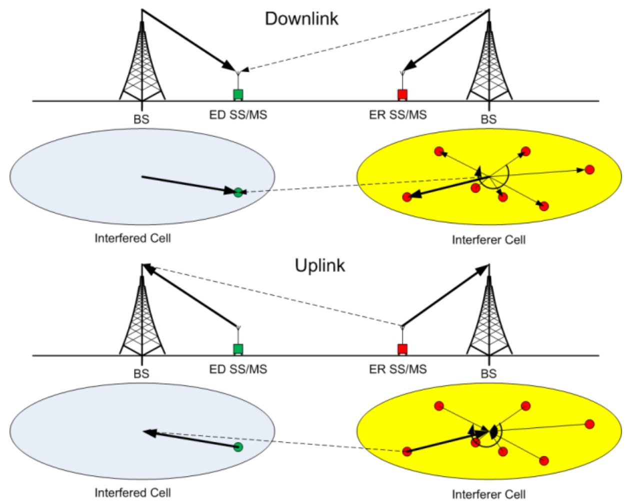
Resource Optimization

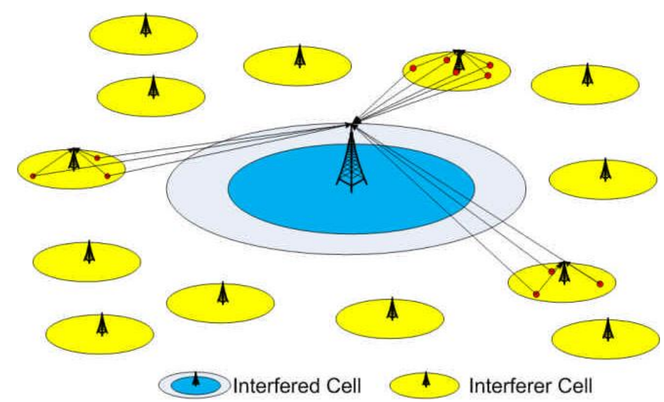
- CelEnhancer
- CelOptima
- Footprint Enhancement
  - Antenna tilt
  - Antenna azimuth
  - Antenna type
  - Antenna height
  - EIRP
- Interference Matrix Calculation
- Neighborhood Determination
  - Topological
- Handover Calculation
- Channel, Permutation and Zone Strategy
- Channel Assignment
- Code Assignment

SINR Analysis

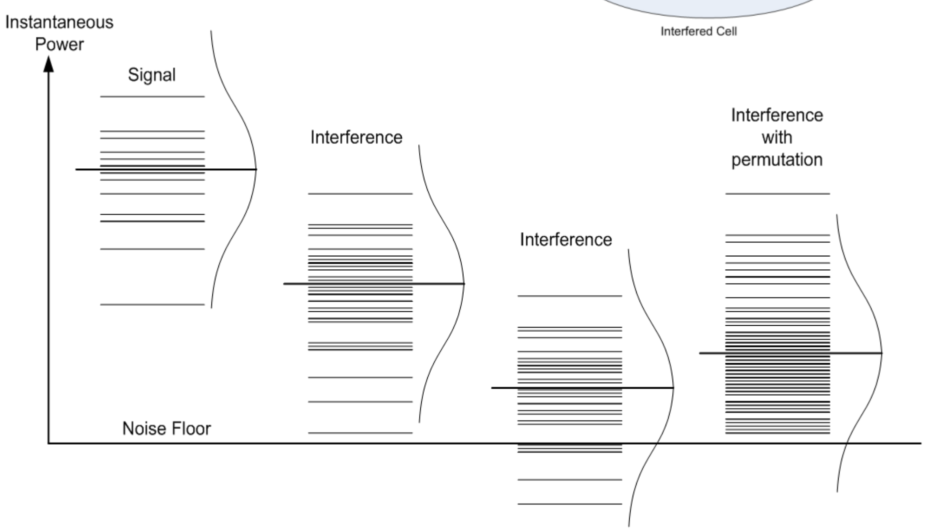
- To perform Resource Optimization Software has to know the interference between any pair of sectors
- The best way to express interference is as an outage against an SINR

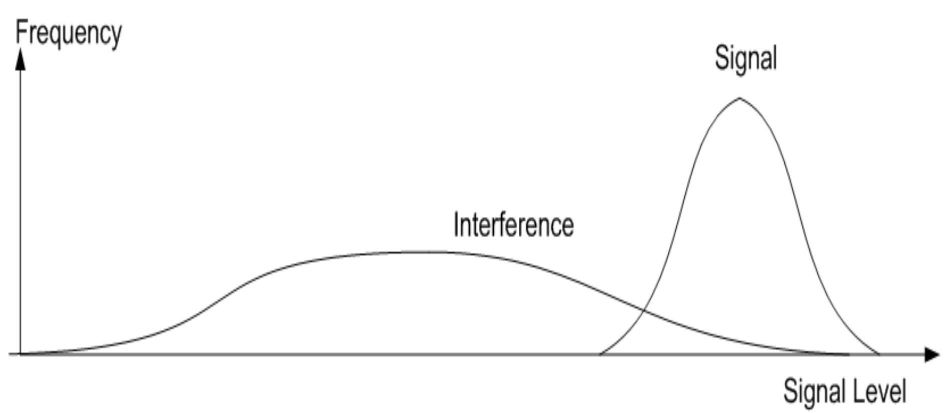






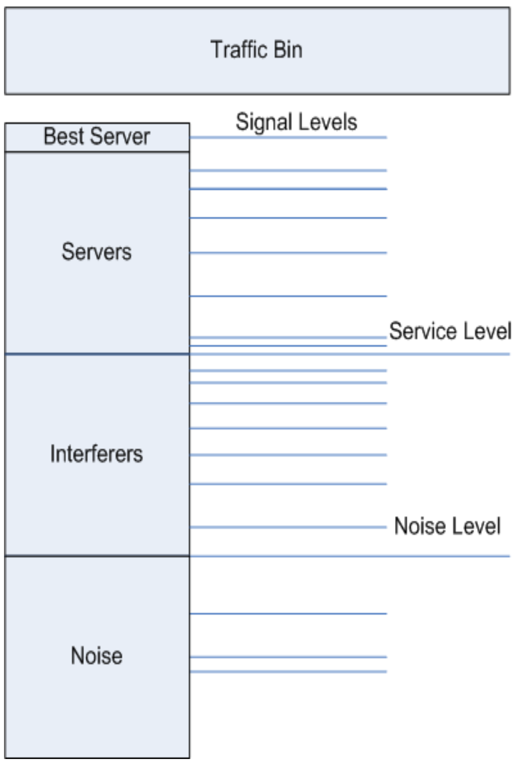
Uplink Interference from multiple cells

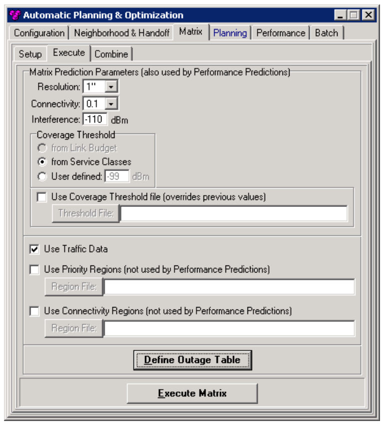


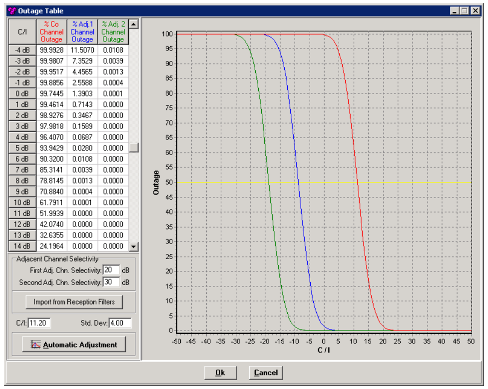


Interference Outage Matrix

- The Outage matrix calculates outages for all sectors pairs
  - Pairs assume that sectors use the same resources, and the outage is multiplied by the affected traffic
- Expressing interference by traffic outage allows us to add interference contributions
  - A special algorithm is used to calculate overlaps





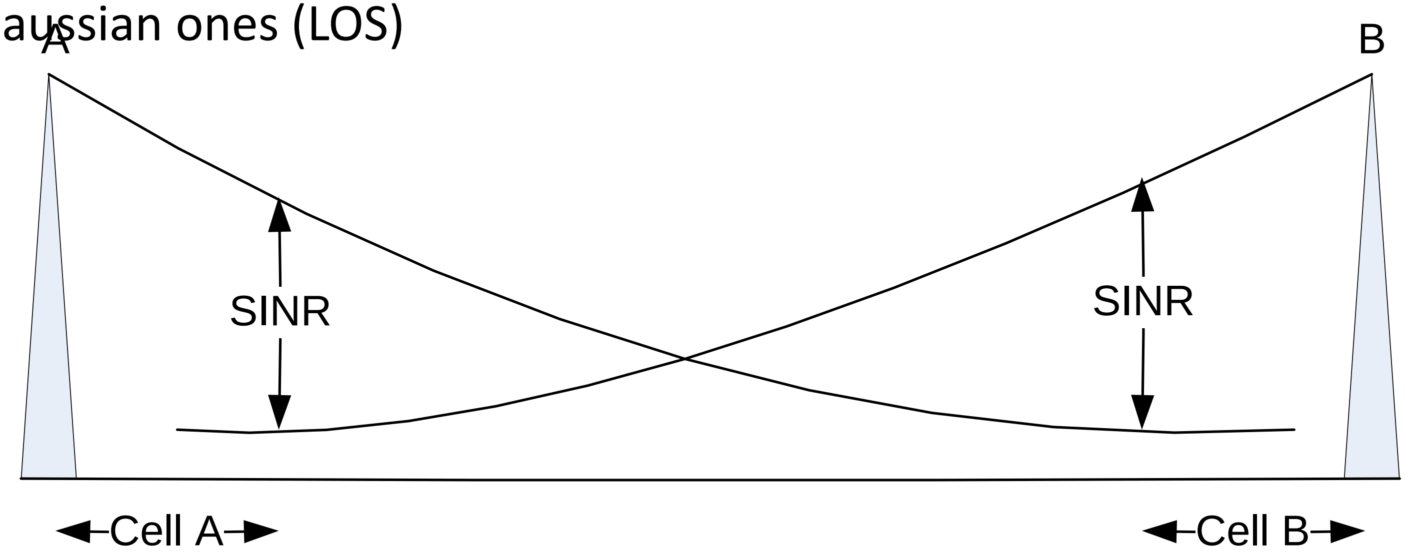


	S1	S2	S3	:	Sn
S1	$O_{1,1}$	$O_{1,2}$	$O_{1,3}$	:	$O_{1,n}$
S2	$O_{2,1}$	$O_{2,2}$	$O_{2,3}$	:	$O_{2,n}$
S3	$O_{3,1}$	$O_{3,2}$	$O_{3,3}$	:	$O_{3,n}$
:	:	:	:	:	:
Sn	$O_{n,1}$	$O_{n,2}$	$O_{n,3}$	:	$O_{n,n}$

Considerations about Interference and 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

Considerations about Interference and Reuse

- LTE uses wide channels and many operators have a single channel, so a channel reuse of 1 is required
- Many people understood that this meant that all cells would use the same channel in its entirety
- Marketers were the main culprits about spreading this concept
- CDMA can reuse the same channel, but pays a spreading penalty and uses orthogonal codes
- In LTE the reuse of 1 concept was coupled with low coding rates (high repetition)
  - Very low coding rates do suggest negative values of SNR (Interference larger than the signal)
  - Very low coding rates reduce significantly network capacity
  - Repetition works well for low level faded signals, but adds very little for strong interfered signals
- Marketers would use high coding rates when the issue was traffic and low coding rates when the issue was interference

Considerations about Interference and Reuse

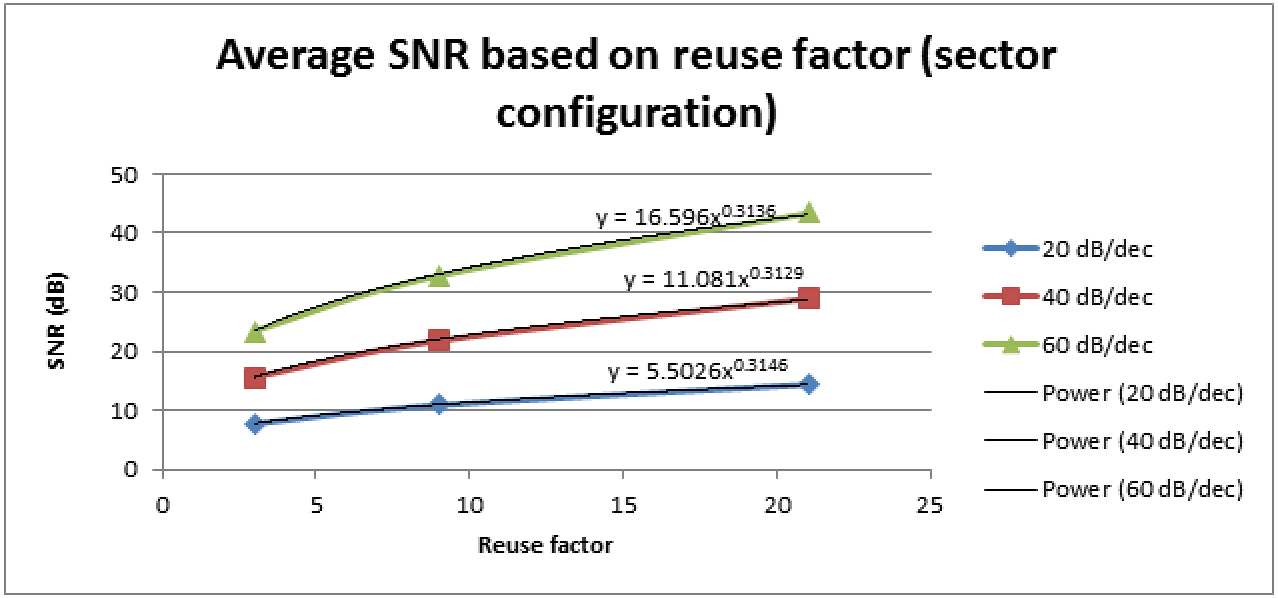
- When a channel reuse of 1 is used, other channel resources had to be partitioned
- 3GPP failed in provide mechanisms to do this in a consistent form, suggesting that if proper mechanism would be used all the channel resources could be used in a cell
- This is partially through and an improvement over the static resource assignment can be achieved, mainly considering beamforming
  - Beamforming is highly successful in Wi-Fi, but only works well when LOS is available
- In a traditional cellular network reuse of 7 is typical
- The new technique can improve this a little, but will not eliminate the need for resource planning
- Reuse in LTE systems will vary between 3 (achieved only in special circumstances) and 9 (applicable to difficult situations)

Considerations about Interference and Reuse

- To avoid interference frequency (segmentation) and time (zoning) resource allocation should be performed
  - Some resources can be allocated to multiple cells, so they can use them on mutually exclusive basis
- Frequency wise the ideal segmentation is a set of RBGs (Resource Block Group)
- Time wise the ideal segmentation is a set of TTIs (Transmission Time Interval), equivalent to a subframe

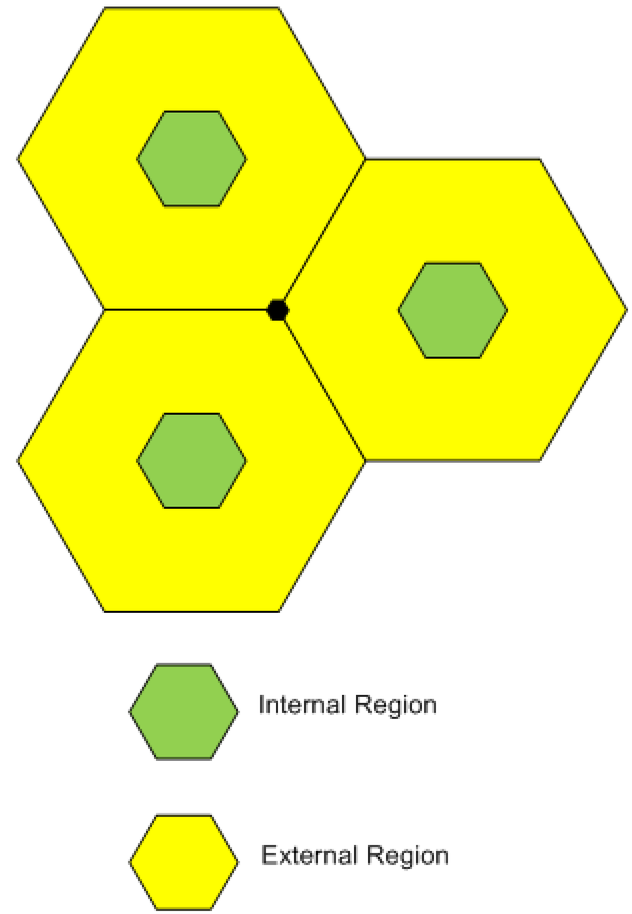
Reuse factor for different environments

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



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)



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

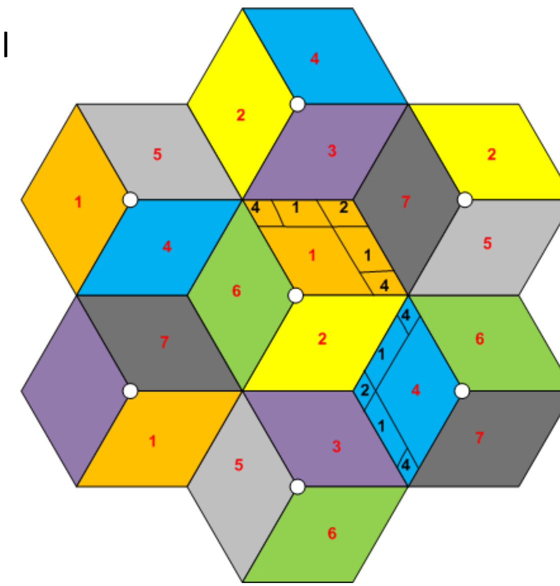
Date Filed:
July 25, 2013

Attorney Docket No.:
7230-101

APPARATUS TO PERFORM RESOURCE ASSIGNMENT IN A WIRELESS NETWORK

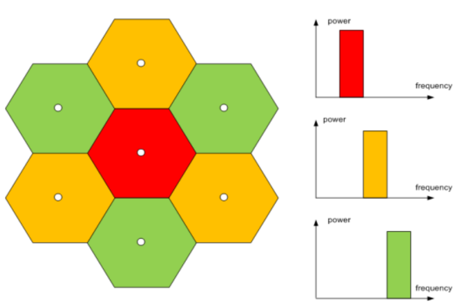
CLAIMS Docket 7230-102

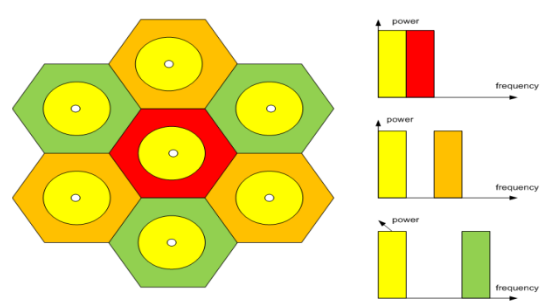
1. An apparatus (or methodology) that maximizes the spectral efficiency by dividing a cell in dynamic regions and allocating resources to each region, instead of the whole cell.
2. Assigning many different resources and parameters, traditionally assigned per cell to cell regions
3. Using fixed or variable number of cell regions for resource optimization purposes

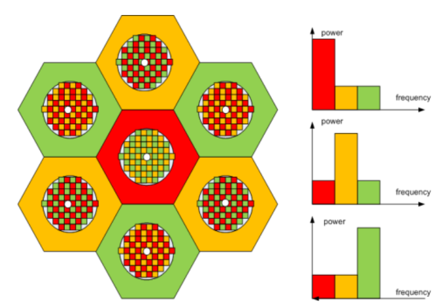


CLAIMS Docket 7230-103

1. A method for resource assignment in a wireless network for maximizing spectral efficiency, comprising:
    1. dividing at least one cell into dynamic regions; and
    2. allocating resources to each region separately, instead of to the cell as a whole
2. The method of claim 1, wherein allocating resources to each region separately comprises assigning many different resources and parameters traditionally assigned per cell to cell regions separately
3. The method of claim 1, wherein the at least one cell comprises a plurality of cells and a number of cell regions the cells are divided into is fixed or variable for resource optimization purposes







5. Conclusion

Conclusions

- Proper network design is essential to achieve a desired customer experience
- There is no amount of field measurement, network statistical data analysis, SON or ICIC procedures that can fix a badly design network
- Advanced tools with statistical analysis capabilities are required for a proper design
- Field measurement, network statistical data analysis are important auxiliary tools to calibrate and adjust design tools
- SON/ICIC capabilities should be considered in the optimization process, but can not solve network issues by themselves

6. CelPlan New Products

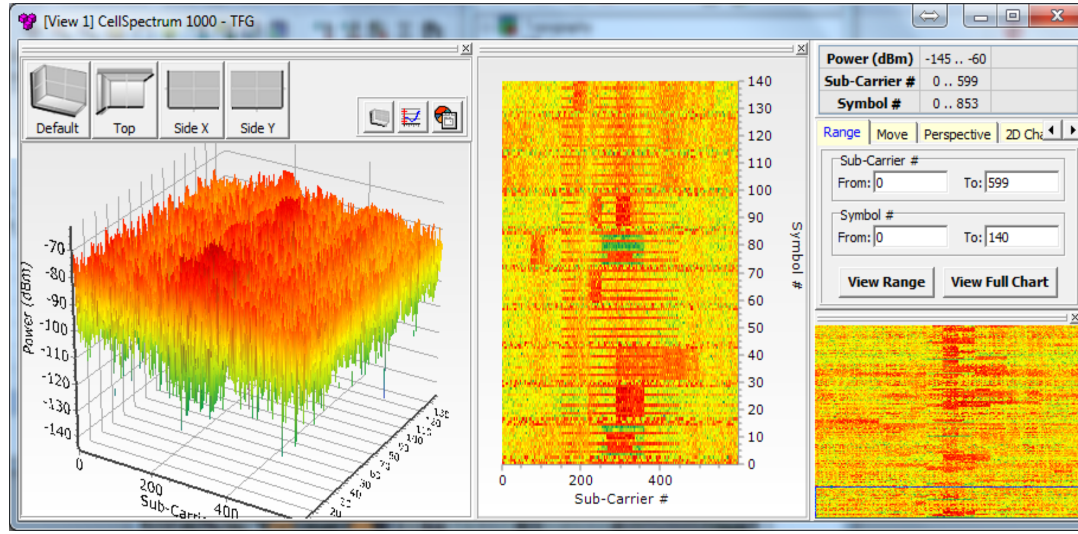
CellSpectrum

CellDesigner

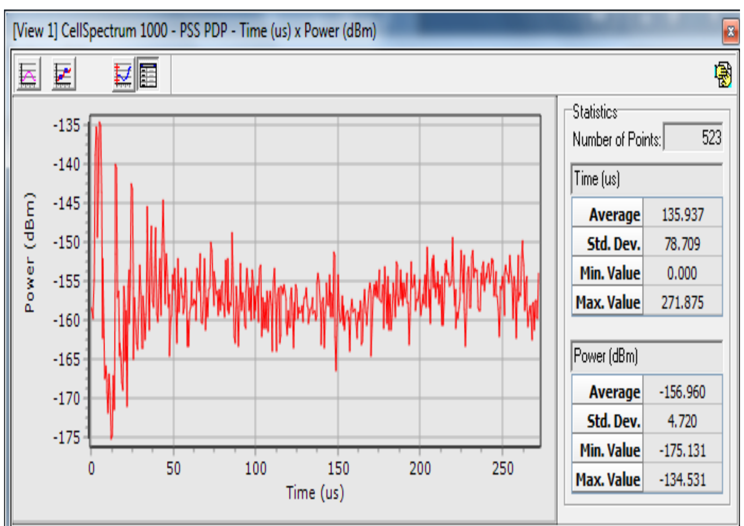
CellSpectrum

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

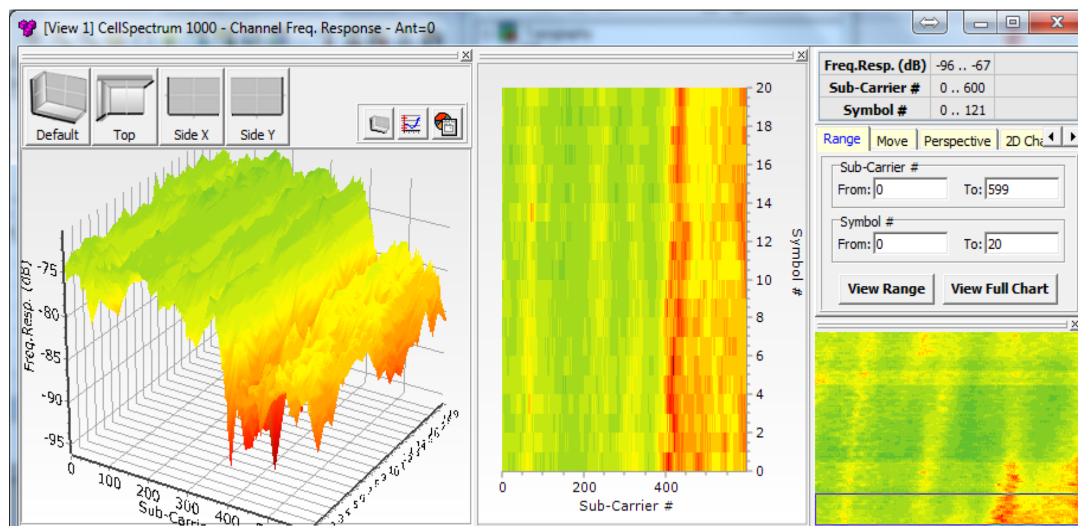
Received Signal level



Multipath



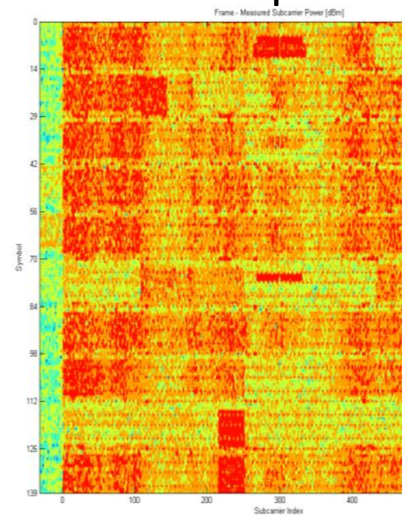
RF Channel Response



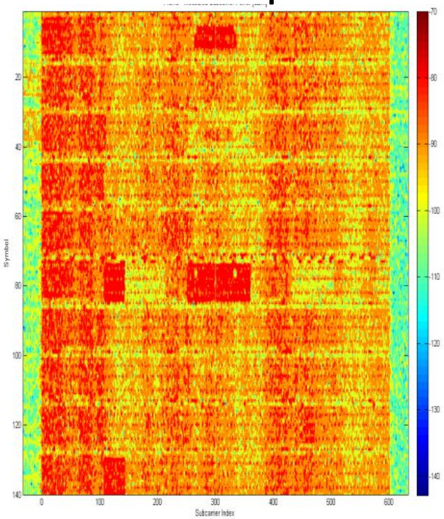
CellSpectrum

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

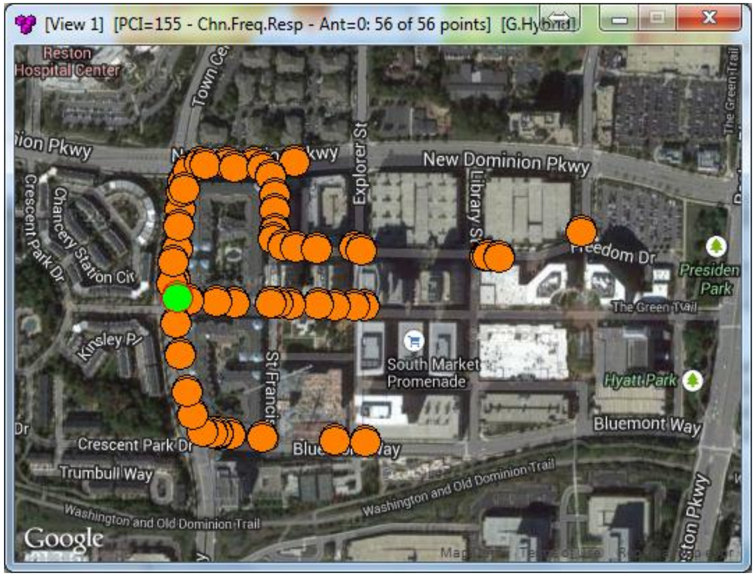
LTE frame port 0



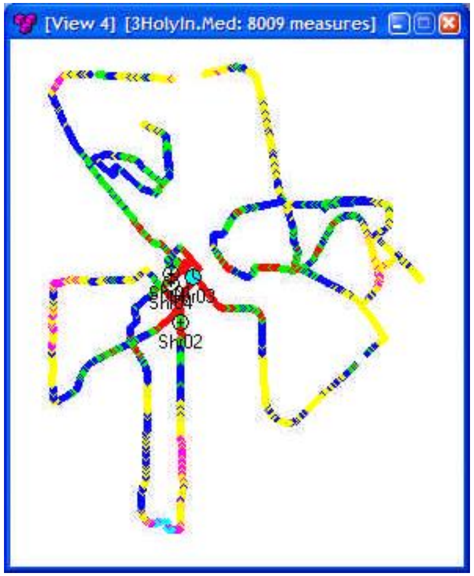
LTE frame port 1

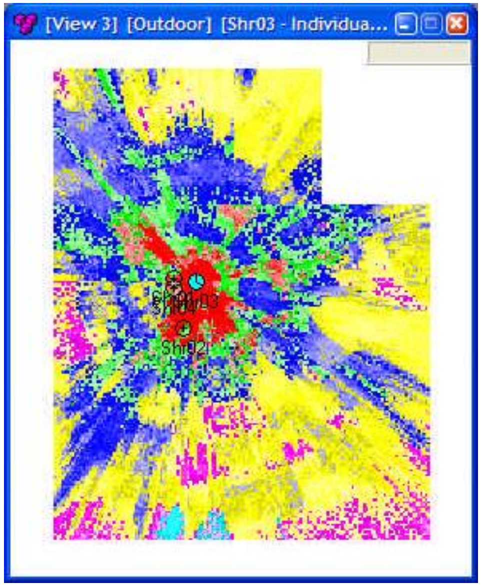


Drive Test



Measurement interpolation





CellDesigner

A new Generation of Planning Tools

A collaborative work with operators

Your input is valuable

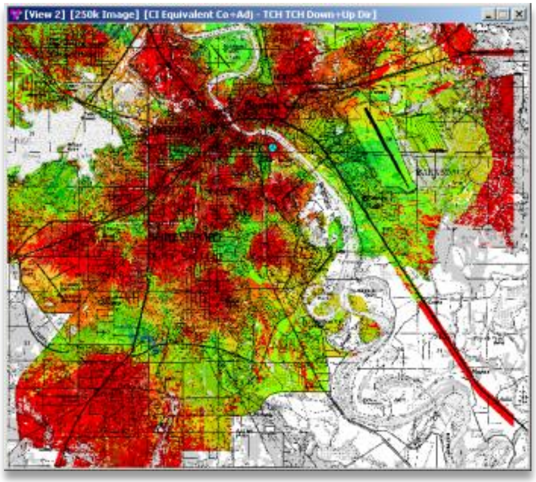
CellDesigner

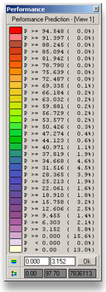
- CellDesigner is the new generation of Planning and Optimization tools
- Wireless networks became so complex that it requires a new generation of tools, capable of:
  - Documenting the physical deployments
  - Documenting network parameters for each technology
  - Flexible data traffic modelling (new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

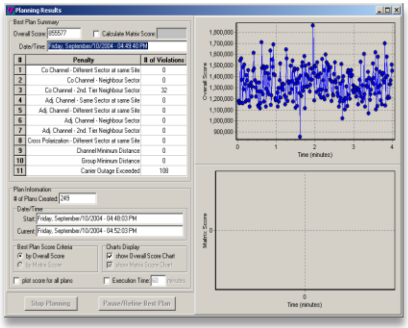
CellDesigner™

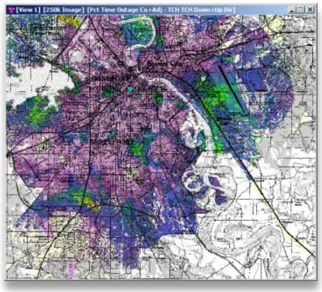
Simultaneous Multi-Technology Support

- 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)

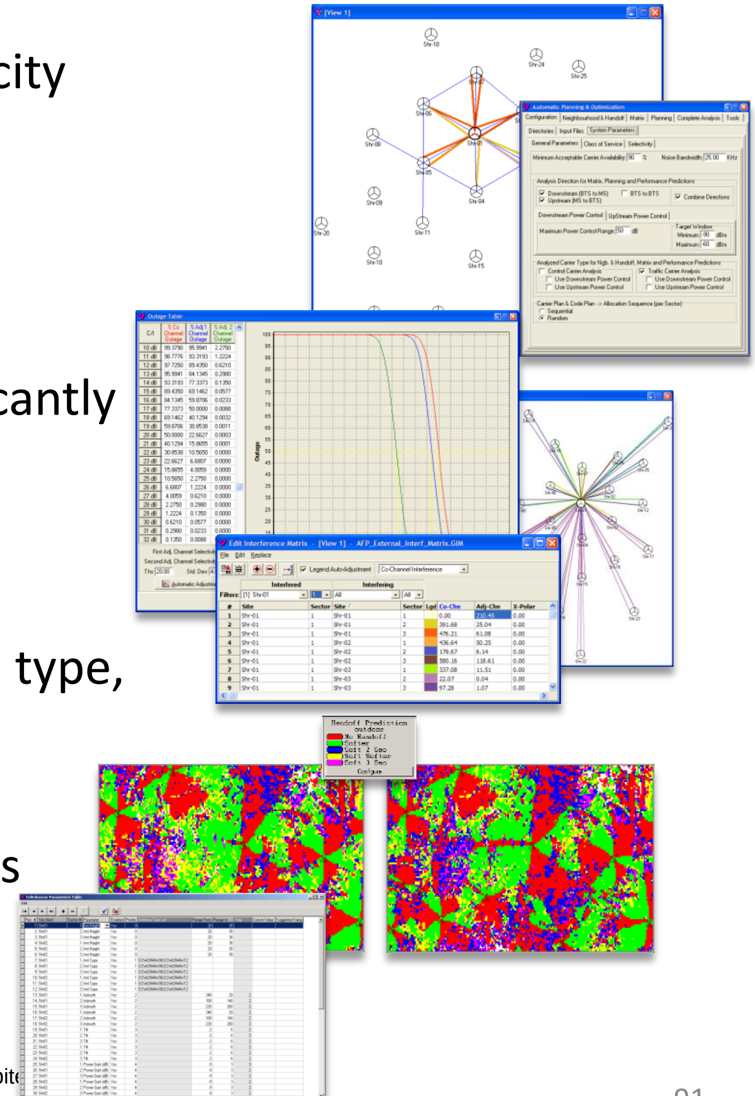
- Enables the dramatic increase of network capacity and performance
- Handover, Frequency and Code Optimization
- Automatically and efficiently optimizes handoff thresholds, neighbor lists, and frequency plans
- Patent-pending methodology capable of significantly increasing cell capacity (SON & ICIC)

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

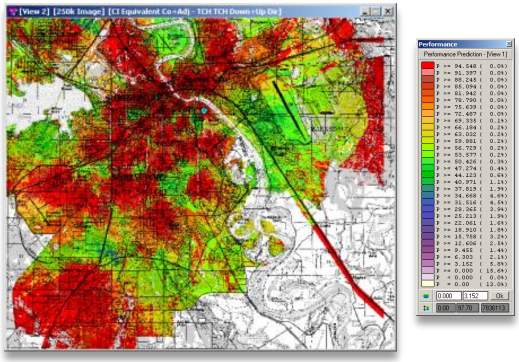
CellDesigner™

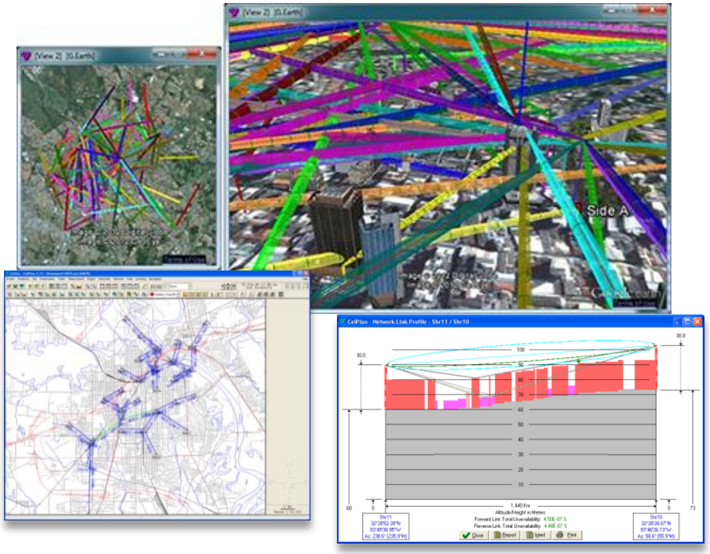
GIS Database Editor

- 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





4G Technologies Boot Camp

Online Edition - EMEA Region

- Designed to give CEOs, CTOs, managers, engineers, and technical staff the practical knowledge on 4G networks (America Region time)
- Modular Course – 2 days per module
  - **Module A: Wireless Communications Fundamentals**
    - July 22nd & 23rd, 2014
  - **Module B: 4G Technologies in-depth Analysis**
    - July 29th & 30th
- 4G Certification (Optional)
- Additional information, Pricing & Registration available at www.celplan.com

Next Webinar

"LTE Measurements, what they mean and how they are used"

August 6, 2014

LTE specifies several measurements to be done at UE and at Network level. Each measurement has precision limitations which need to be understood before taking decision based on the values reported

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

Specialized measurements should be performed to characterize the network RF characteristics

- **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**
- **2D Measurements**
  - **Primary Synchronization Signal Power Delay Profile**
- **3D measurements**
  - **Received Time Frequency Resource Elements**
  - **Channel Frequency response**
  - **Channel Impulse Response**
  - **Transmit Antenna Correlation**
  - **Traffic Load**
- **Measurement based predictions**

Thank You!

Leonhard Korowajczuk

webinar@celplan.com

www.celplan.com

Questions?