The Path to 4G

Interop/Vegas
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225 Cedar Hill Street
Suite 200
Marlborough, MA 01752 USA

Tel: +1.978.376.5841
Fax: 1.866.401.5382
www.octoScope.com

525 East Seaside Way
Suite 705
Long Beach, CA 90802 USA

Agenda

- Fanny Mlinarsky
  - President, octoScope
  - The path to 4G
- Dr. Srini Rao
  - Fellow of the Technical Staff, Motorola Solutions
  - Converged core and services
- Atul Bhatnagar
  - President and CEO, Ixia
  - Testing of converged core and services
- Q&A

Dr. Srini Rao

- Srini Rao is a technology leader in broadband wireless and multimedia communications with more than 17 years of industry experience spanning R&D, standards and strategy.
- He is currently a Fellow of the Technical Staff at Motorola Solutions, working on the evolution of public safety networks to LTE. He previously worked at Motorola as Director of Strategy and Architecture and earlier at Winphoria Networks and IBM T.J. Watson Research Center. He contributed to 3G wireless standards as a working group Vice-Chair and Technical Editor of specifications in 3GPP2 and CDG. He was one of the architects of Advances to IMS (A-IMS) initiative by Verizon Wireless in 2006.
- Dr. Rao received M.S. and Ph.D. degrees in Electrical and Computer Engineering from Rice University, and Bachelor of Technology in from Indian Institute of Technology, Madras. He is a Senior Member of IEEE and a member of Executive Committee and Planning Board of the Boston Chapter of IEEE Communications Society.

Atul Bhatnagar

- Atul Bhatnagar is responsible for Ixia's day-to-day operations and is intimately involved with strategy and long-term business planning. He brings >20 years of experience in the computing and communications industry. Most recently, Atul led product development at a leading mobile to mobile convergence startup, DiVitas Networks, focusing on Wi-Fi and Cellular seamless convergence. Prior to that, Atul served as VP and GM of the Enterprise Data Networks Division of Nortel.
- Atul came to Nortel through its acquisition of Alteon Web Systems in October 2000, where he was vice president of Advanced WebSwitching Products.
- Prior to joining Alteon Web Systems, Atul worked at Hewlett-Packard for almost 15 years where he held several GM assignments in North America and Asia.
- Mr. Bhatnagar holds a MSEE from the University of New Mexico and a BSEE from the Birla Institute of Technology and Science, Pilani, India.

The G's

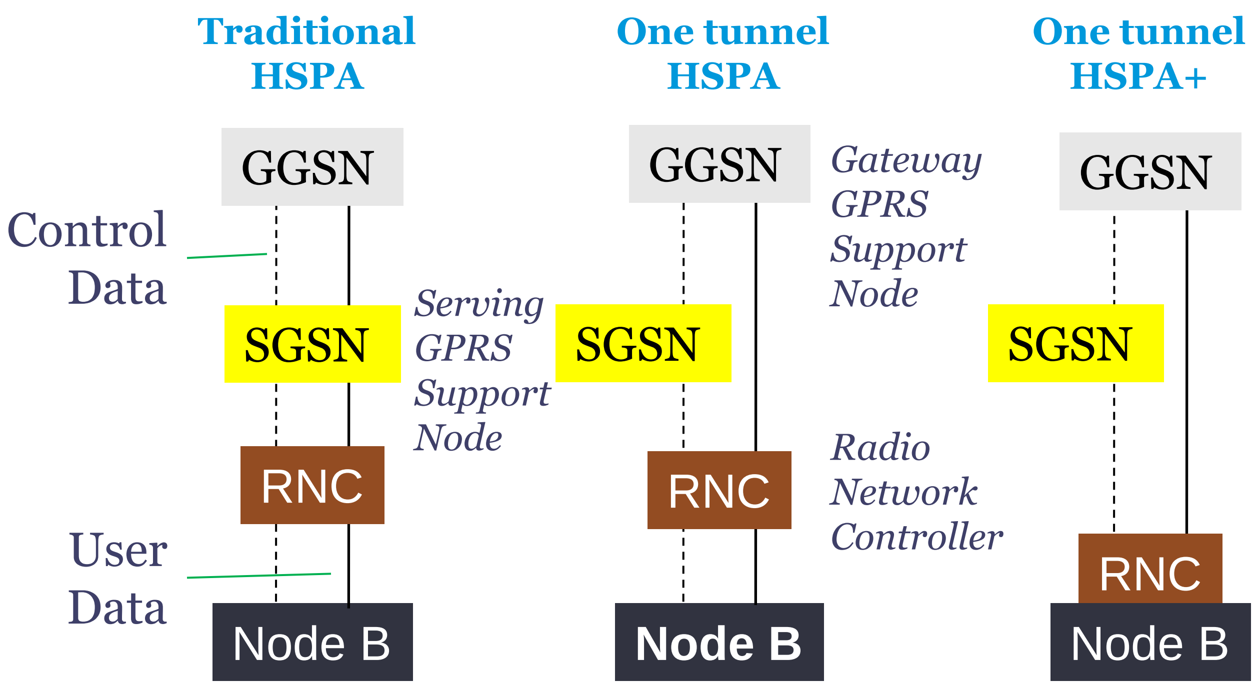
G		Peak Data Rate (Mbps)	
		Downlink	Uplink
1	Analog	19.2 kbps	
2	Digital – TDMA, CDMA	14.4 kbps	
3	Improved CDMA variants (WCDMA, CDMA2000)	144 kbps (1xRTT); 384 kbps (UMTS); 2.4 Mbps (EVDO)	
3.5	HSPA (today)	14 Mbps	2 Mbps
3.75	HSPA (Release 7) DL 64QAM or 2x2 MIMO; UL 16QAM	28 Mbps	11.5 Mbps
	HSPA (Release 8) DL 64QAM and 2x2 MIMO	42 Mbps	11.5 Mbps
3.9	WiMAX Release 1.0 TDD (2:1 UL/DL ratio), 10 MHz channel	40 Mbps	10 Mbps
	LTE, FDD 5 MHz UL/DL, 2 Layers DL	43.2 Mbps	21.6 Mbps
	LTE CAT-3	100 Mbps	50 Mbps

OFDM

Maximum LTE data rates in the 20 MHz channel are 326 Mbps DL (4 streams), 172 Mbps UL (2 streams)

HSPA and HSPA+

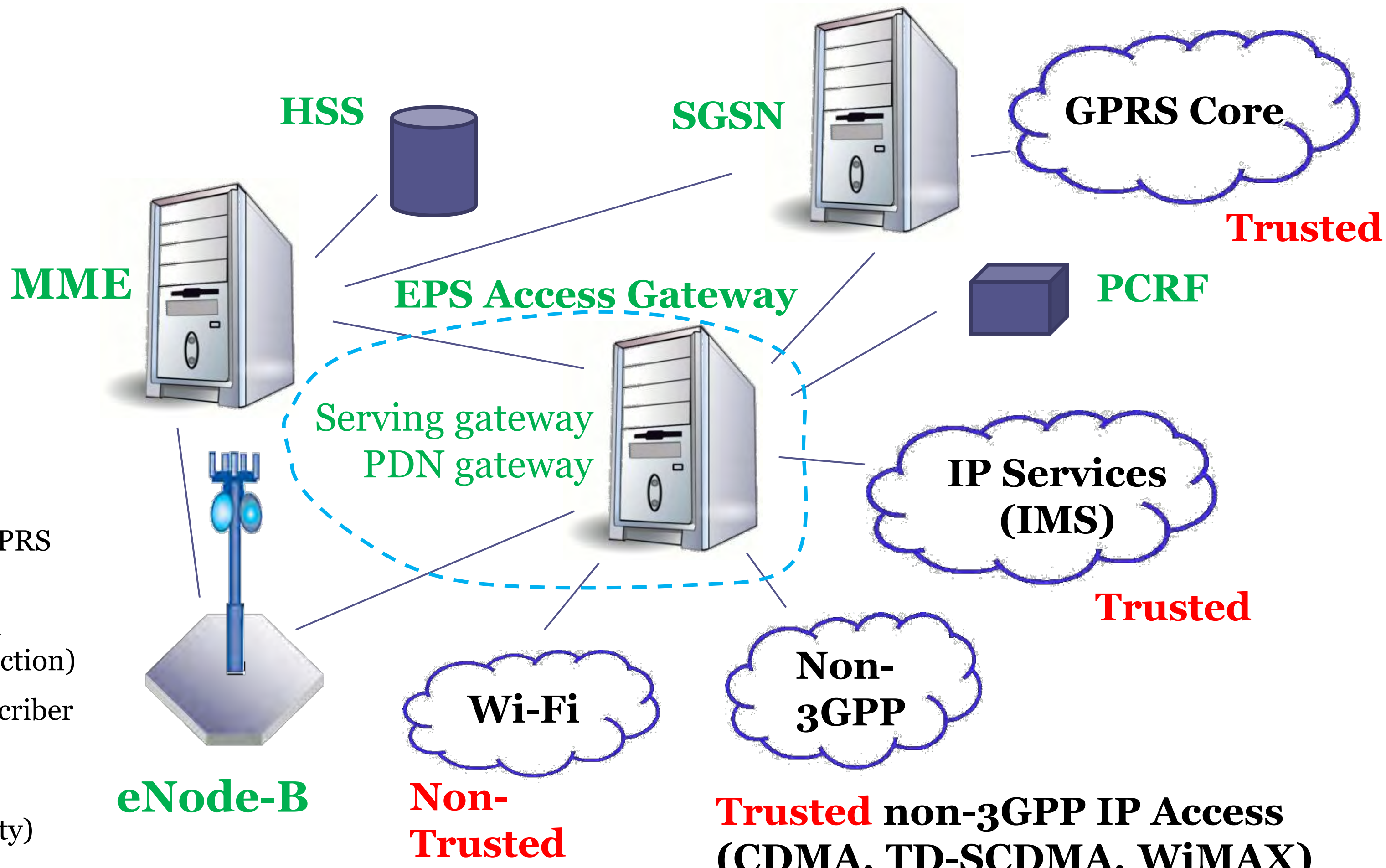
- HSPA+ is aimed at extending operators' investment in HSPA
  - 2x2 MIMO, 64 QAM in the downlink, 16 QAM in the uplink
  - Data rates up to 42 MB in the downlink and 11.5 MB in the uplink.



One-tunnel architecture flattens the network by enabling a direct transport path for user data between RNC and the GGSN, thus minimizing delays and set-up time

HSPA+ is CDMA-based and lacks the efficiency of OFDM

LTE EPS (Evolved Packet System)



SGSN (Serving GPRS Support Node)

PCRF (policy and charging rules function)

HSS (Home Subscriber Server)

MME (Mobility Management Entity)

PDN (Public Data Network)

Flat, low-latency architecture

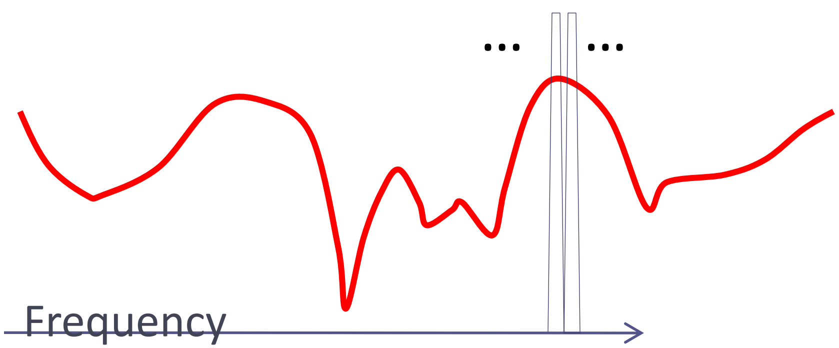
ITU IMT Framework

- ITU IMT framework
  - Defines architecture for worldwide wireless access by linking the diverse systems of terrestrial and satellite based networks.
  - Detailed specifications contributed by 3GPP, IEEE and others
- IMT-2000 (3G)
  - Data rate limit is approximately 30 Mbps
- IMT-Advanced (4G)
  - LTE-Advanced and 802.16m (WiMAX 2)
  - Both are based on MIMO-OFDMA

IMT = International Mobile Telecommunications

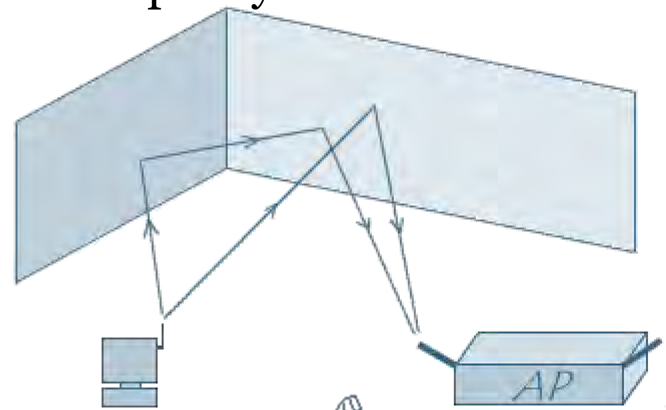
OFDM and MIMO

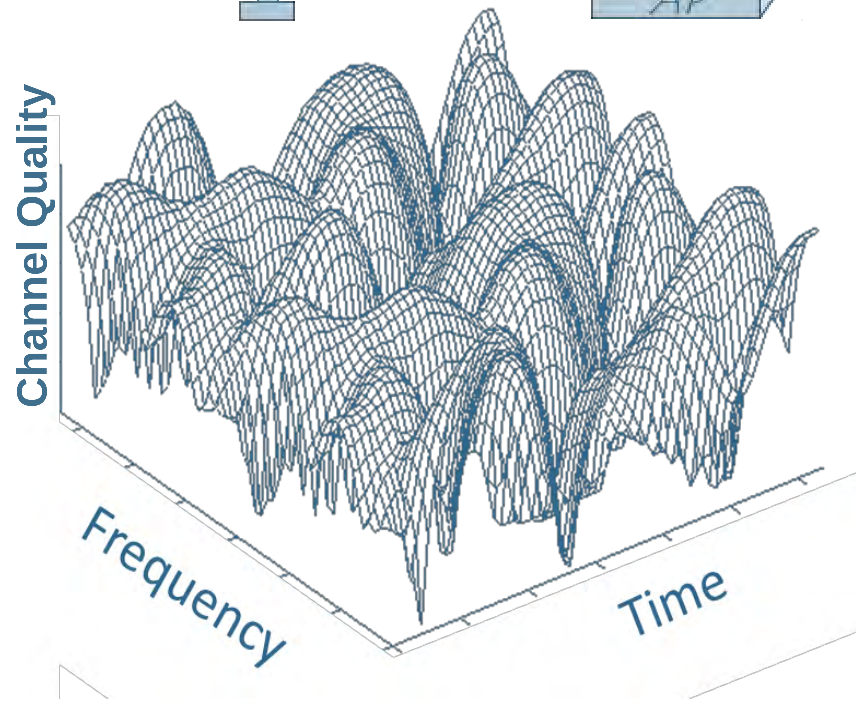
- OFDM transforms a frequency- and time-variable fading channel into parallel correlated flat-fading channels, enabling wide bandwidth operation



Frequency-variable channel appears flat over the narrow band of an OFDM subcarrier.

MIMO uses multipath to increase channel capacity

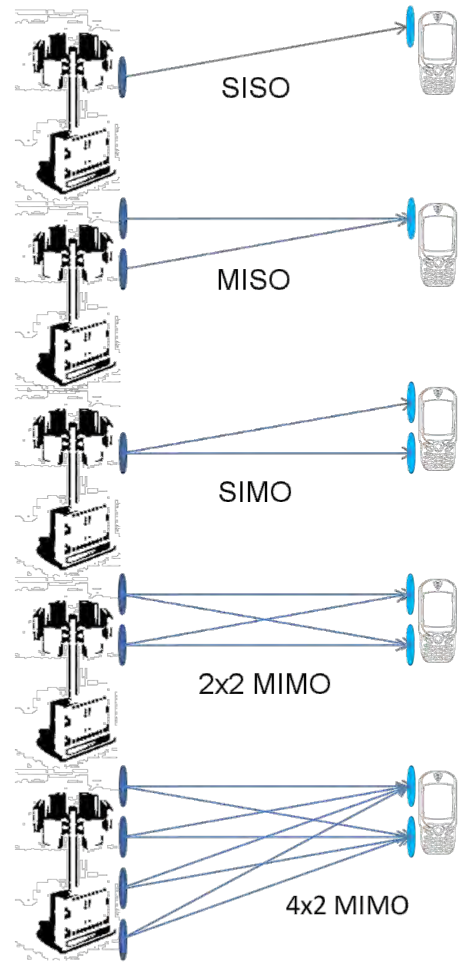




OFDM = orthogonal frequency division multiplexing
MIMO = multiple input multiple output

Multiple Antenna Techniques

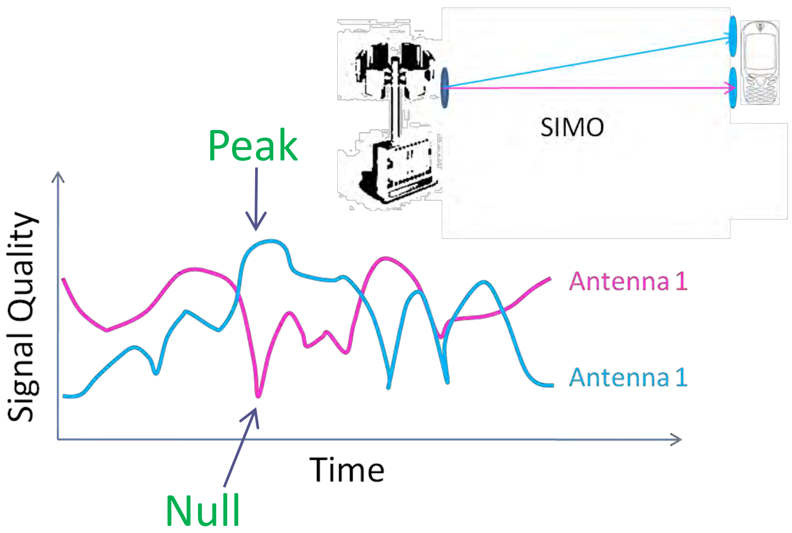
- SISO (Single Input Single Output)
  - Traditional radio
- MISO (Multiple Input Single Output)
  - Transmit diversity (STBC, SFBC, CDD)
- SIMO (Single Input Multiple Output)
  - Receive diversity, MRC
- MIMO (Multiple Input Multiple Output)
  - SM to transmit multiple streams simultaneously; can be used in conjunction with CDD; works best in high SNR environments and channels de-correlated by multipath
  - TX and RX diversity, used independently or together; used to enhance throughput in the presence of adverse channel conditions
- Beamforming



SM = spatial multiplexing
SFBC = space frequency block coding
STBC = space time block coding
CDD = cyclic delay diversity
MRC = maximal ratio combining
SM = Spatial Multiplexing
SNR = signal to noise ratio

MIMO Based RX and TX Diversity

- When 2 receivers are available in a MIMO radio MRC can be used to combine signals from two or more antennas, improving SNR
- MIMO also enables transmit diversity techniques, including CDD, STBC, SFBC
- TX diversity spreads the signal creating artificial multipath to decorrelate signals from different transmitters so as to optimize signal reception



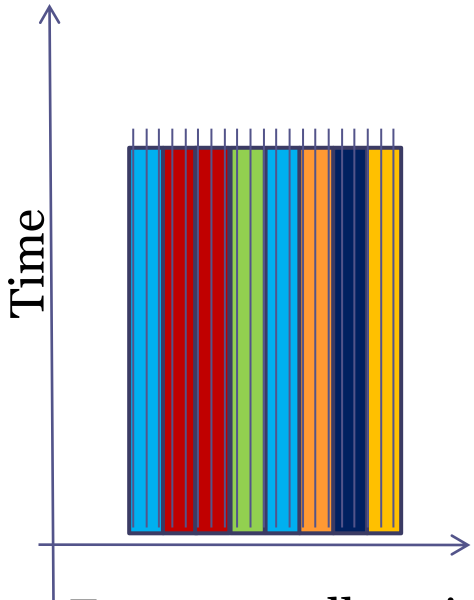
MIMO = multiple input multiple output
SIMO = single input multiple outputs
SM = spatial multiplexing
SFBC = space frequency block coding
STBC = space time block coding
CDD = cyclic delay diversity
MRC = maximal ratio combining
SM = Spatial Multiplexing
SNR = signal to noise ratio

OFDMA

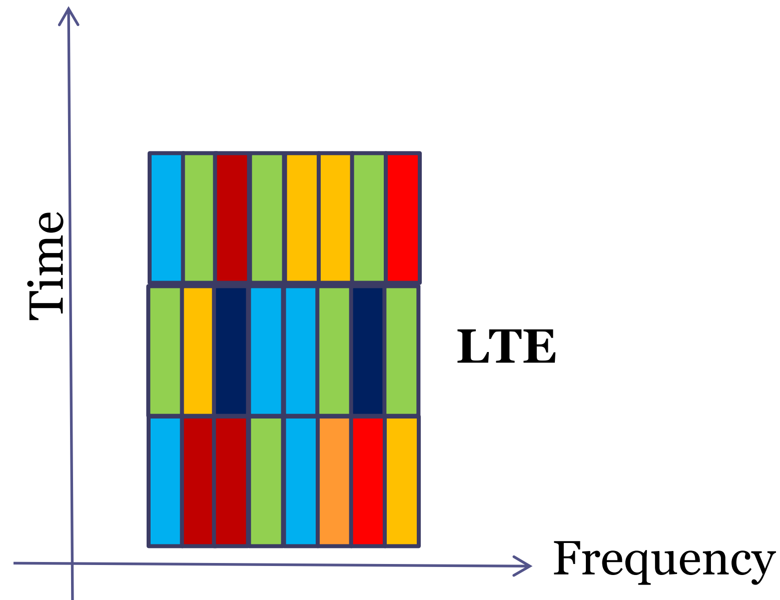
OFDM is a modulation scheme

OFDMA is a modulation and access scheme

Multiple Access



Frequency allocation per user is continuous vs. time

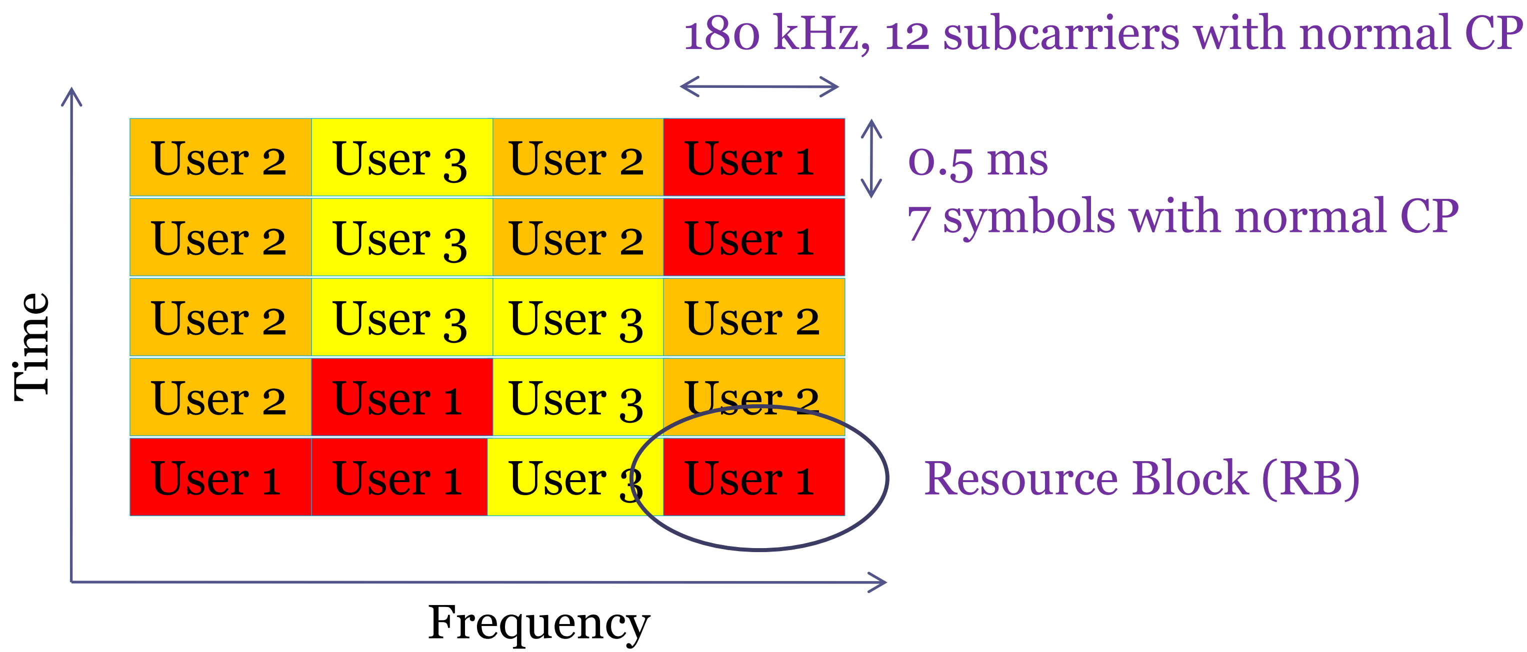


Frequency per user is dynamically allocated vs. time slots

User 1 | User 2 | User 3 | User 4 | User 5

OFDM = orthogonal frequency division multiplexing
OFDMA = orthogonal frequency division multiple access

LTE Resource Allocation

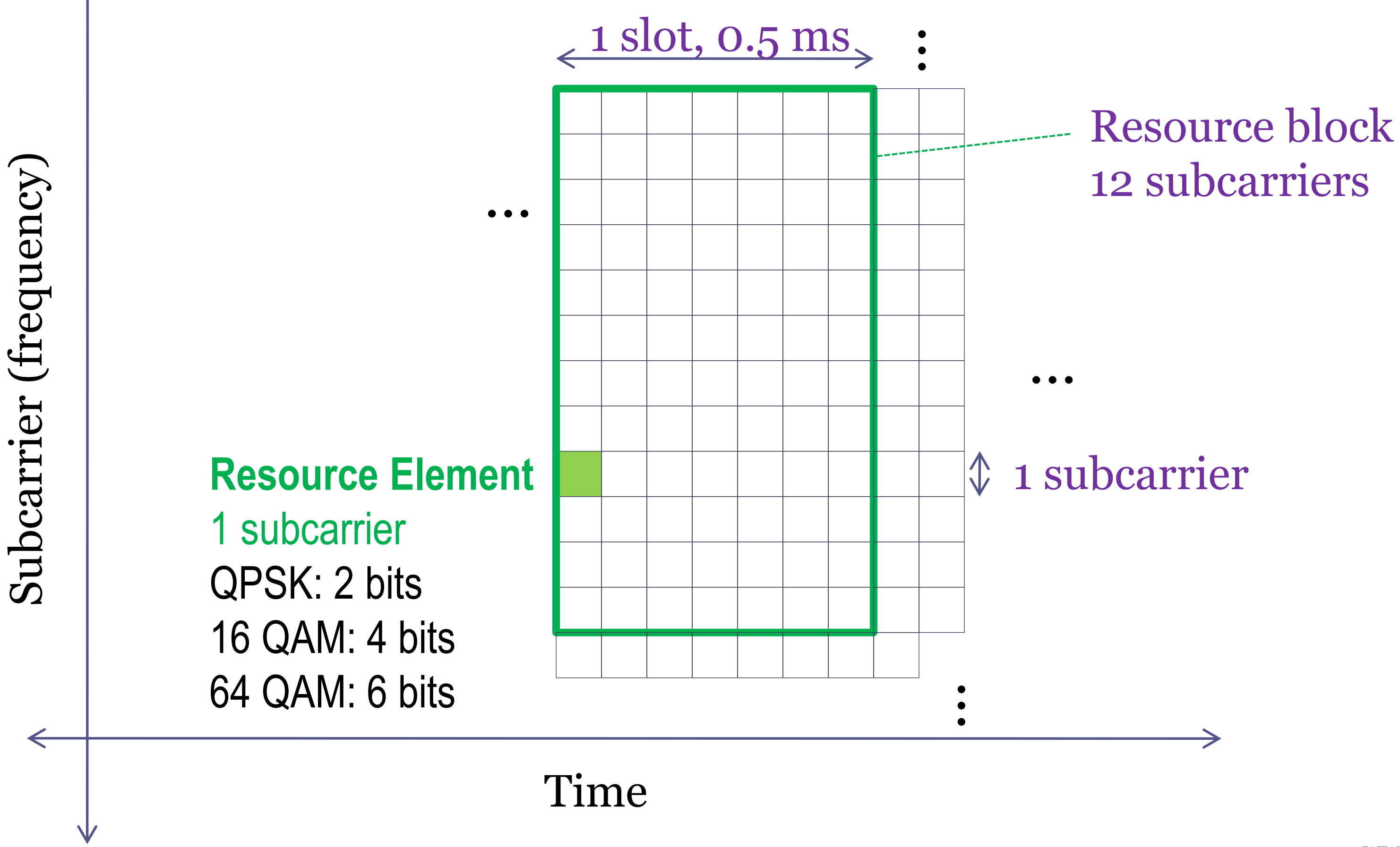


- Resources are allocated per user in time and frequency. RB is the basic unit of allocation.
- RB is 180 kHz by 0.5 ms; typically 12 subcarriers by 7 OFDM symbols, but the number of subcarriers and symbols can vary based on CP

CP = cyclic prefix, explained ahead

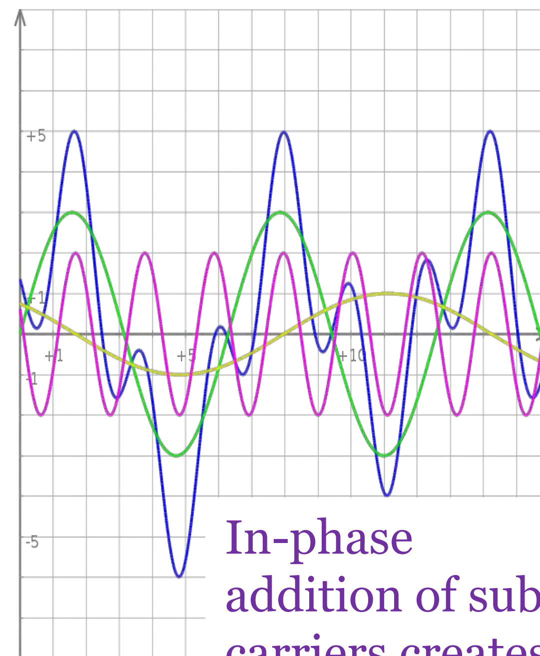
Resource Block

A resource block (RB) is a basic unit of access allocation. RB bandwidth per slot (0.5 ms) is 12 subcarriers times 15 kHz/subcarrier equal to 180 kHz.



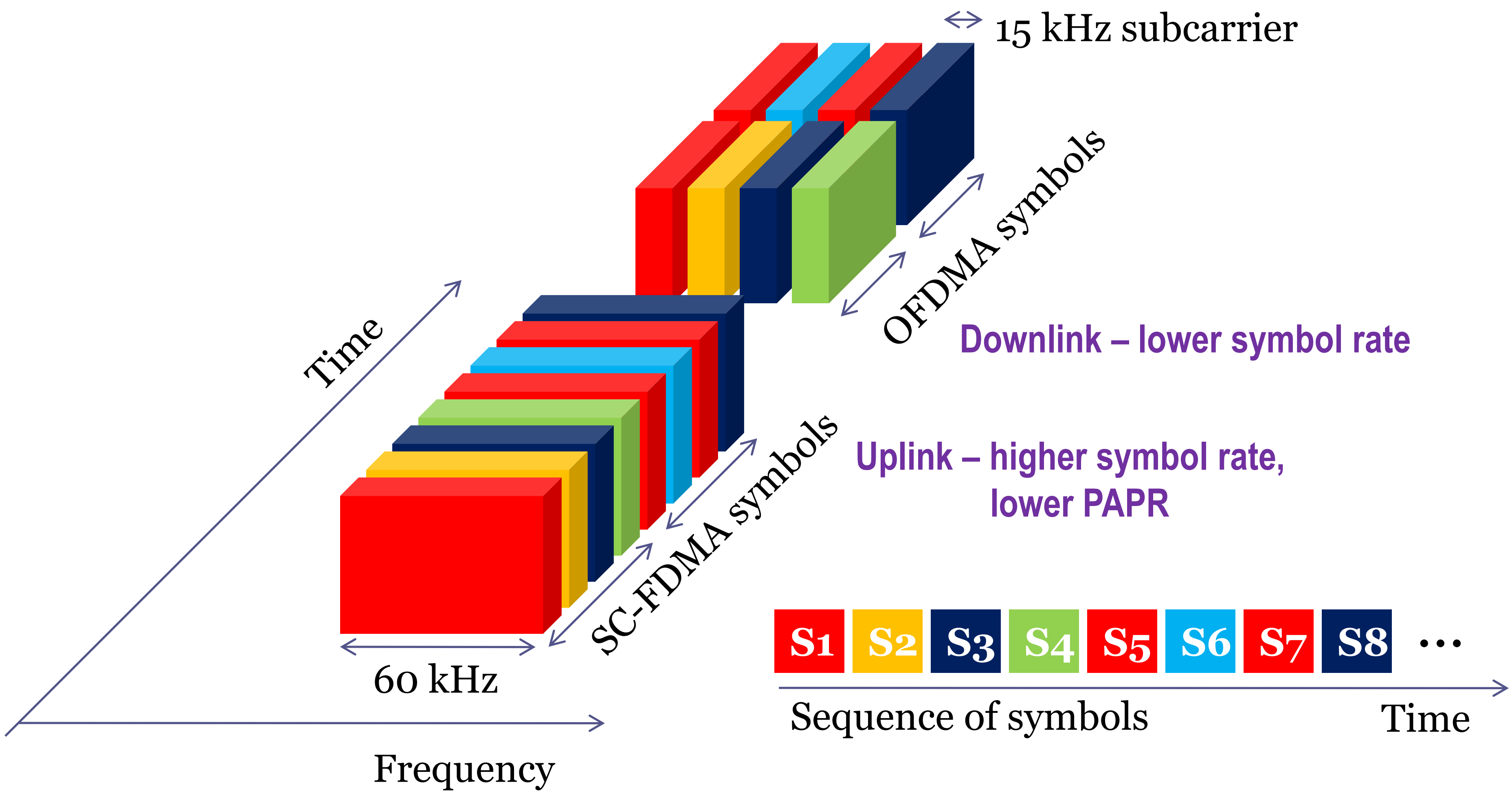
OFDMA vs. SC-FDMA (LTE Uplink)

- Multi-carrier OFDM signal exhibits high PAPR (Peak to Average Power Ratio) due to in-phase addition of subcarriers.
- Power Amplifiers (PAs) must accommodate occasional peaks and this results low efficiency of PAs, typically only 15-20% efficient. Low PA efficiency significantly shortens battery life.
- To minimize PAPR, LTE has adapted SC-FDMA (single carrier OFDM) in the uplink. **SC-FDMA exhibits 3-6 dB less PAPR than OFDMA.**

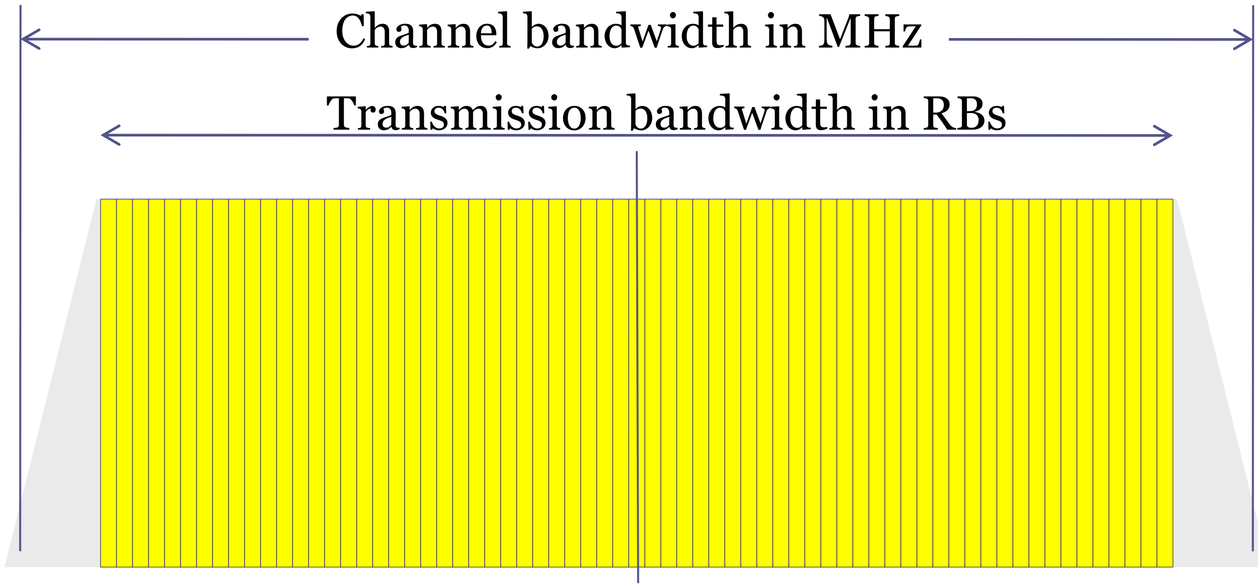


In-phase addition of sub-carriers creates peaks in the OFDM signal

SC-FDMA vs. OFDMA



LTE Scalable Channel Bandwidth

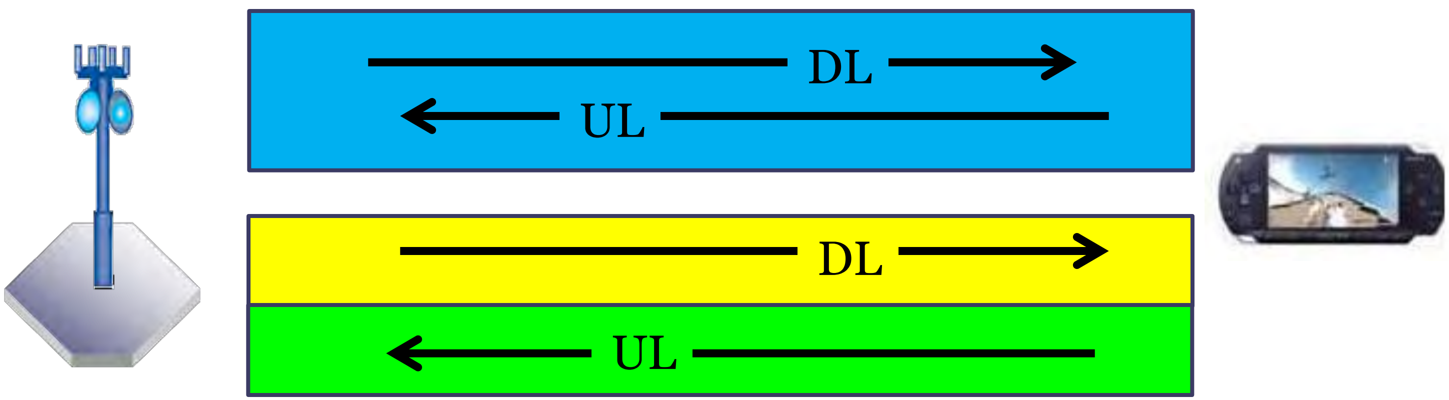


Channel bw	1.4	3	5	10	15	20	MHz
Transmission bw	1.08	2.7	4.5	9	13.5	18	MHz
# RBs per slot	6	15	25	50	75	100	

FDD vs. TDD

- FDD (frequency division duplex)
  - Paired channels
- TDD (time division duplex)
  - Single frequency channel for uplink an downlink
  - Is more flexible than FDD in its proportioning of uplink vs. downlink bandwidth utilization
  - Can ease spectrum allocation issues

TD-LTE

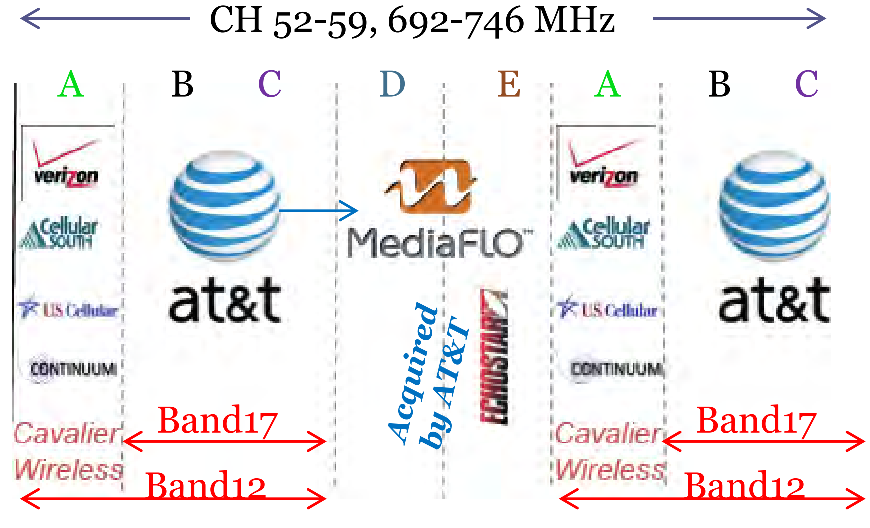


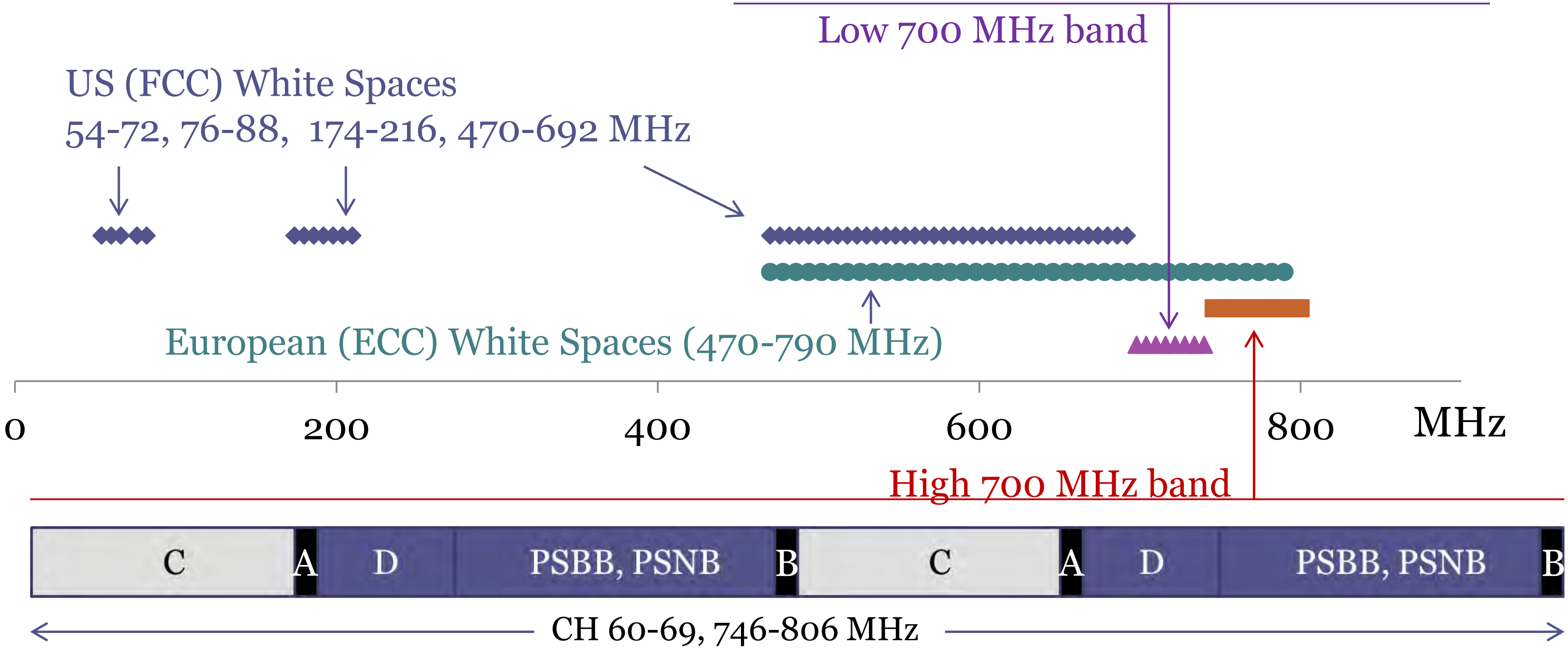
LTE Frequency Bands - FDD

Source: 3GPP TS 36.104; V10.1.0 (2010-12)

Band	Uplink (UL)	Downlink (DL)	Regions
1	1920 -1980 MHz	2110 - 2170 MHz	Europe, Asia
2	1850 -1910 MHz	1930 - 1990 MHz	Americas, Asia
3	1710 -1785 MHz	1805 -1880 MHz	Europe, Asia, Americas
4	1710 -1755 MHz	2110 - 2155 MHz	Americas
5	824-849 MHz	869 - 894 MHz	Americas
6	830 - 840 MHz	875 - 885 MHz	Japan
7	2500 - 2570 MHz	2620 - 2690 MHz	Europe, Asia
8	880 - 915 MHz	925 - 960 MHz	Europe, Asia
9	1749.9 - 1784.9 MHz	1844.9 - 1879.9 MHz	Japan
10	1710 -1770 MHz	2110 - 2170 MHz	Americas
11	1427.9 - 1452.9 MHz	1475.9 - 1500.9 MHz	Japan
12	698 - 716 MHz	728 - 746 MHz	Americas
13	777 - 787 MHz	746 - 756 MHz	Americas (Verizon)
14	788 - 798 MHz	758 - 768 MHz	Americas (D-Block, public safety)
17	704 - 716 MHz	734 - 746 MHz	Americas (AT&T)
18	815 – 830 MHz	860 – 875 MHz	
19	830 – 845 MHz	875 – 890 MHz	
20	832 – 862 MHz	791 – 821 MHz	
21	1447.9 – 1462.9 MHz	1495.9 – 1510.9 MHz	

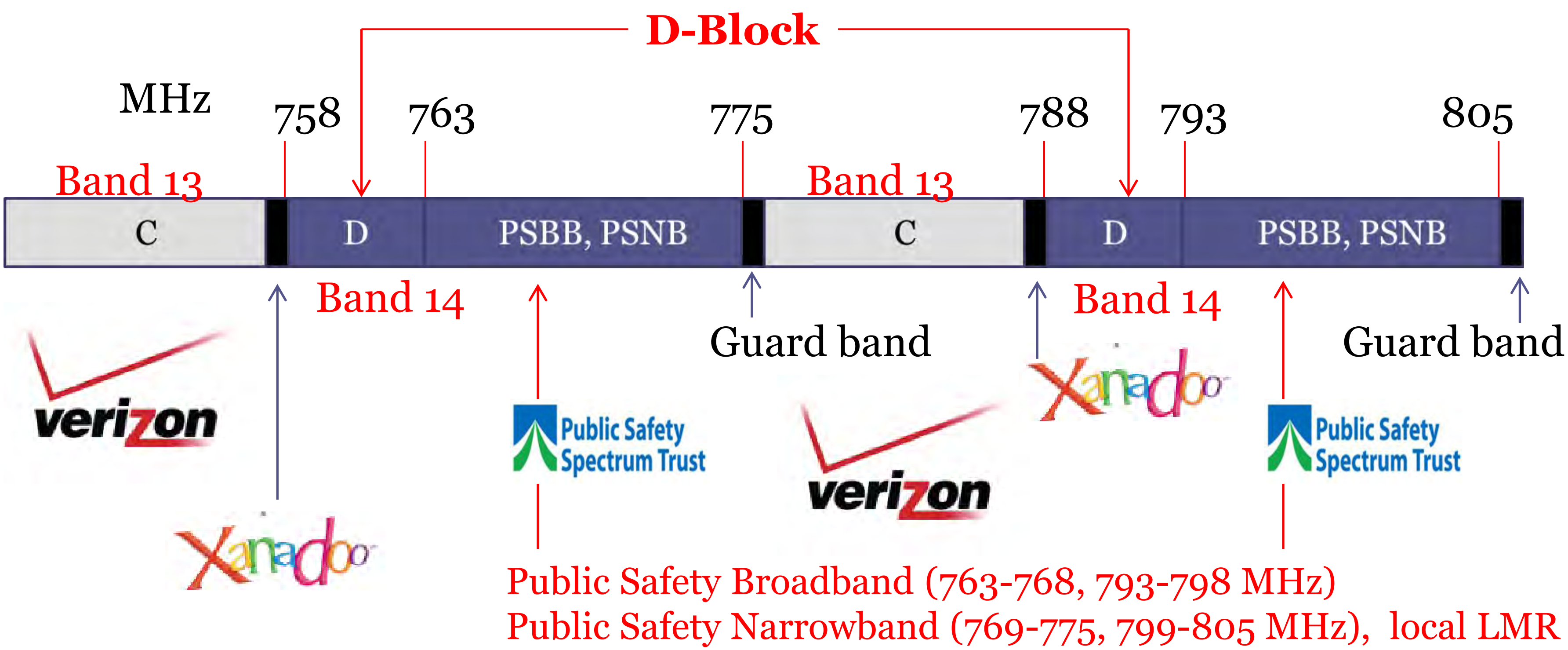
UHF Spectrum, Including White Space Bands





ECC = Electronic Communications Committee

High 700 MHz Band



LMR = land mobile radio

TV Channels and White Space Allocation

US – FCC

Channel #	Frequency Band	
2-4	54-72 MHz	VHF
5-6	76-88 MHz	
7-13	174-216 MHz	
14-20	470-512 MHz**	UHF
21-51*	512-692 MHz	

Fixed TVBDs only (channels 2-20)

White Spaces (channels 2-51)

http://www.fcc.gov/mb/engineering/usallochrt.pdf

*Channel 37 (608-614 MHz) is reserved for radio astronomy
**Shared with public safety

Transition from NTSC to ATSC (analog to digital TV) in June 12, 2009 freed up channels 52-69 (above 692 MHz)

Europe – ECC

Channel #	Frequency Band	
5-12	174-230 MHz	VHF
21-60	470-790 MHz	UHF
61-69	790-862 MHz	

White Spaces (channels 21-60)

LTE Frequency Bands - TDD

TD-LTE

Band	UL and DL	Regions
33	1900 - 1920 MHz	Europe, Asia (not Japan)
34	2010 - 2025 MHz	Europe, Asia
35	1850 - 1910 MHz	
36	1930 - 1990 MHz	
37	1910 - 1930 MHz	
38	2570 - 2620 MHz	Europe
39	1880 - 1920 MHz	China
40	2300 – 2400 MHz	Europe, Asia
41	2496 – 2690 MHz	Americas (Clearwire LTE)
42	3400 – 3600 MHz	
43	3600 – 3800 MHz	

Source: 3GPP TS 36.104; V10.1.0 (2010-12)

WiMAX Frequency Bands - TDD

Band Class	(GHz) BW (MHZ)	Bandwidth Certification Group Code (BCG)
1	**2.3-2.4**	
	8.75	1.A
	5 AND 10	1.B
2	**2.305-2.320, 2.345-2.360**	
	3.5	2.A (Obsolete, replaced by 2.D)
	5	2.B (Obsolete, replaced by 2.D)
	10	2.C (Obsolete, replaced by 2.D)
	3.5 AND 5 AND 10	2.D
3	**2.496-2.69**	
	5 AND 10	3.A
4	**3.3-3.4**	
	5	4.A
	7	4.B
	10	4.C
5	**3.4-3.8**	
	5	5.A
	7	5.B
	10	5.C
7	**0.698-0.862**	
	5 AND 7 AND 10	7.A
	8 MHz	7.F

WiMAX Forum Mobile Certification Profile v1.1.0

A universal frequency step size of 250 KHz is recommended for all band classes, while 200 KHz step size is also recommended for band class 3 in Europe.

WiMAX Frequency Bands - FDD

Band Class	(GHz)BW (MHZ)	Duplexing Mode BS	Duplexing Mode MS	MS Transmit Band (MHz)	BS Transmit Band (MHz)	Bandwidth Certification Group Code (BCG)
2	**2.305-2.320, 2.345-2.360**					
	2x3.5 AND 2x5 AND 2x10	FDD	HFDD	2345-2360	2305-2320	2.E**
	5 UL, 10 DL	FDD	HFDD	2345-2360	2305-2320	2.F**
3	**2.496-2.690**					
	2x5 AND 2x10	FDD	HFDD	2496-2572	2614-2690	3.B
5	**3.4-3.8**					
	2x5 AND 2x7 AND 2x10	FDD	HFDD	3400-3500	3500-3600	5.D
6	**1.710-2.170 FDD**					
	2x5 AND 2x10	FDD	HFDD	1710-1770	2110-2170	6.A
	2x5 AND 2x10 AND Optional 2x20 MHz	FDD	HFDD	1920-1980	2110-2170	6.B
	2x5 AND 2x10 MHz	FDD	HFDD	1710-1785	1805-1880	6.C
7	**0.698-0.960**					
	2x5 AND 2x10	FDD	HFDD	776-787	746-757	7.B
	2x5	FDD	HFDD	788-793 AND 793-798	758-763 AND 763-768	7.C
	2x10	FDD	HFDD	788-798	758-768	7.D
	5 AND 7 AND 10 (TDD), 2x5 AND 2x7 AND 2x10 (H-FDD)	TDD or FDD	Dual Mode TDD/H-FDD	698-862	698-862	7.E*
	2x5 AND 2x10 MHz	FDD	HFDD	880-915	925-960	7.G
8	**1.710-2.170 TDD**					
	5 AND 10	TDD	TDD	1785-1805, 1880-1920, 1910-1930, 2010-2025	1785-1805, 1880-1920, 1910-1930, 2010-2025	8.A

WiMAX Forum Mobile Certification Profile R1 5 v1.3.0

Unlicensed Bands and Services

IEEE 802.11 (Wi-Fi) operates in the ISM-2400 and ISM-5800 bands and in the 5800 UNII band; recently standardized for 3650-3700 contention band

IEEE 802.16 (WiMAX) operates in the UNII/ISM band and in the 3500-3700 MHz contention band

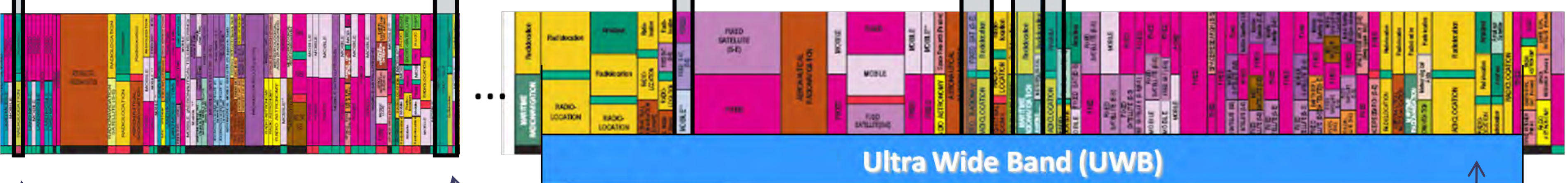
902-928 MHz
ISM band
ZigBee,
proprietary

2400-2500 MHz
ISM band
Wi-Fi, ZigBee,
Bluetooth

3650 - 3700
Contention band
Wi-Fi, WiMAX

5150 – 5350
5470 - 5725
UNII Band
Wi-Fi

5725 - 5825
UNII/ISM Band
Wi-Fi, WiMAX



Most UWB products operate here

3100

4900

10,600

UWB based WiMedia is a short-range network operating in the noise floor of other services

ISM-900 traditionally used for consumer devices such as cordless phones, garage openers and baby monitors, now also used on smart meters

Cordless phones

Standards-based

proprietary

FCC spectrum allocation chart
http://www.ntia.doc.gov/osmhome/allochrt.PDF

For More Information

- Access white papers, presentations and test reports on a variety of wireless topics at
  - www.octoscope.com

Back-up

Smartphones Drive Mobile Broadband

CDMA
GSM
WCDMA/HSxPA
Wi-Fi
Bluetooth
and soon LTE

WEB ACCESS

Email

Skype

VPN

File Sharing

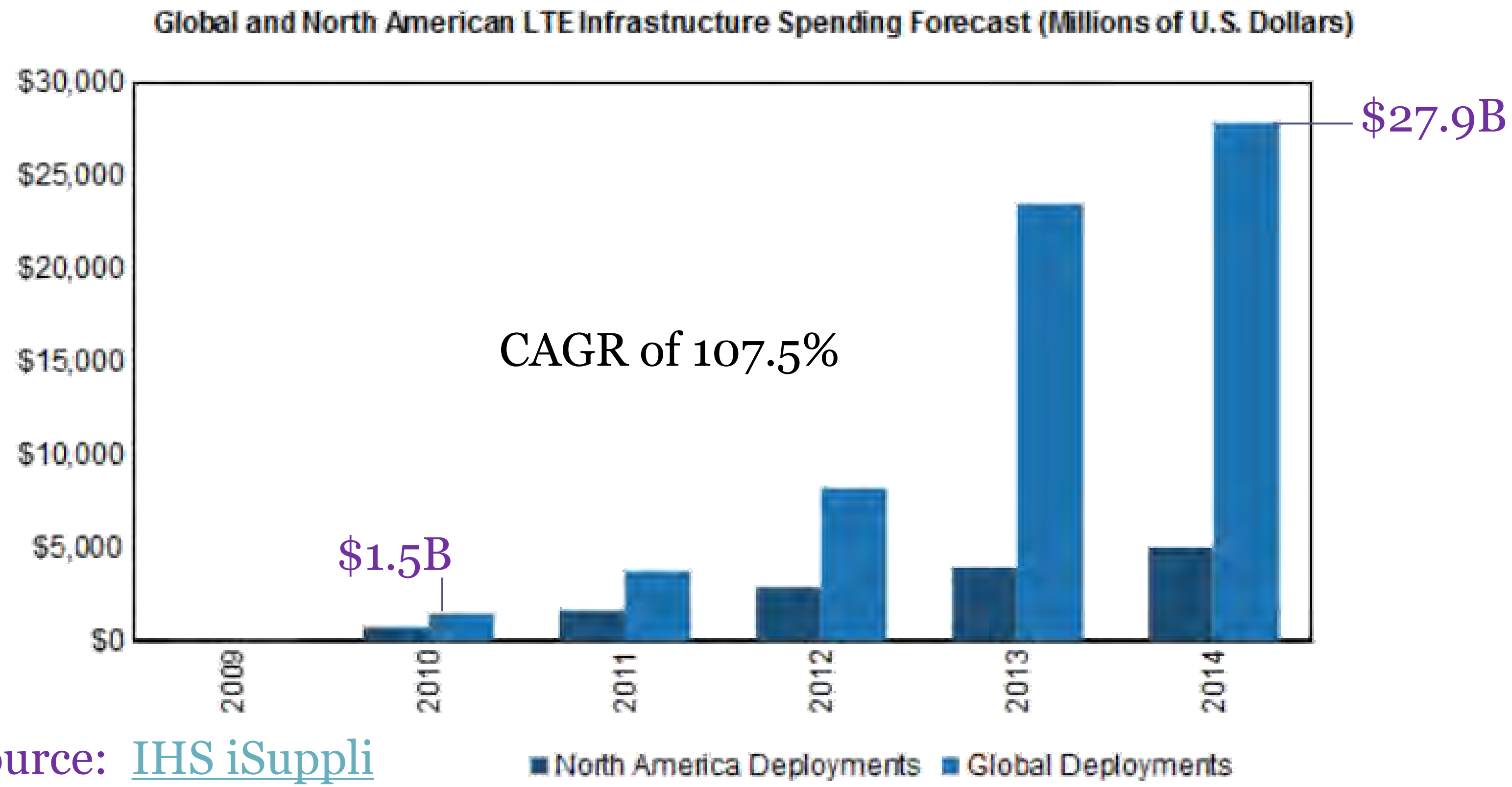
Mobile data revenues in the U.S. approached $25 billion during the 1st half of 2010, up 27% from 1st half of 2009

Source: CTIA

Global LTE infrastructure spending will reach $27.9B by 2014; CAGR of 107.5% from $1.5 billion in 2010.

Source: IHS iSuppli

LTE Infrastructure Spending Forecast



Source: IHS iSuppli

- Global LTE infrastructure spending forecasted at $27.9B by 2014
- CAGR of 107.5% from $1.5B in 2010