SDR'11

Tutorial 4F

700 MHz Nationwide Public Safety Broadband Network

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Tutorial Contents

1. PS wireless communications – background
2. Nationwide PS wireless network – adoption of 3GPP LTE
3. Mission critical PS network requirements
4. LTE technology overview
5. Voice service over LTE
6. Voice service talkaround
7. Interworking to connect disparate legacy PS networks over LTE

PS = public safety
3GPP = 3rd generation partnership project
LTE = long term evolution

Introduction

- Spectrum in the 700 MHz band has recently been licensed by the FCC to carry a nationwide public safety broadband network [2].
- In July of 2009 the 3GPP LTE was selected as the next generation technology for PS communications.
- Initial thrust of LTE has been on data services; voice over LTE is still in its infancy.

PS = public safety
3GPP = 3rd generation partnership project
LTE = long term evolution

Today's Land Mobile Radios (LMR)

- Analog
  - VHF, UHF, 800 MHz bands
- Project 25 (P25) [12]
  - Voice and data
  - Encryption, key management and authentication
  - CAI inter-vendor interoperability [13]
  - VHF, UHF, 700, 800 MHz frequency bands
  - Phase I: FDMA 12.5 KHz channel bandwidth
  - Phase II: TDMA CAI 6.25 kHz in the VHF, UHF and 700 MHz bands; ISSI (bridging)
- ISSI provides interconnectivity but no coast to coast coverage

CAI = Common Air Interface
ISSI = Inter-RF Subsystem Interface

Public-safety Wireless Broadband Worth $22.3B in 2015

- According to research firm MarketsandMarkets, overall market spending is expected to increase from $15.2 billion in 2009 to $22.3 billion in 2015 with CAGR of 6.5% 2010 to 2015 and 9.3% 2015 to 2020.

The Total Addressable Market of Wireless Broadband in Public Safety
By Geography, 2011 – 2020 ($Billion)

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
North America	6.94	7.31	7.73	8.22	8.77	9.37	10.07	10.84	11.69	12.65
EMEA	3.42	3.62	3.87	4.08	4.38	4.73	5.12	5.55	6	6.49
APAC	1.92	2.09	2.25	2.41	2.67	2.98	3.34	3.74	4.22	4.81
Latin America	1.52	1.63	1.76	1.93	2.12	2.4	2.72	3.09	3.51	4.03
Total	**13.8**	**14.65**	**15.61**	**16.64**	**17.94**	**19.48**	**21.25**	**23.22**	**25.42**	**27.98**

Source: MarketsandMarkets, August 2011

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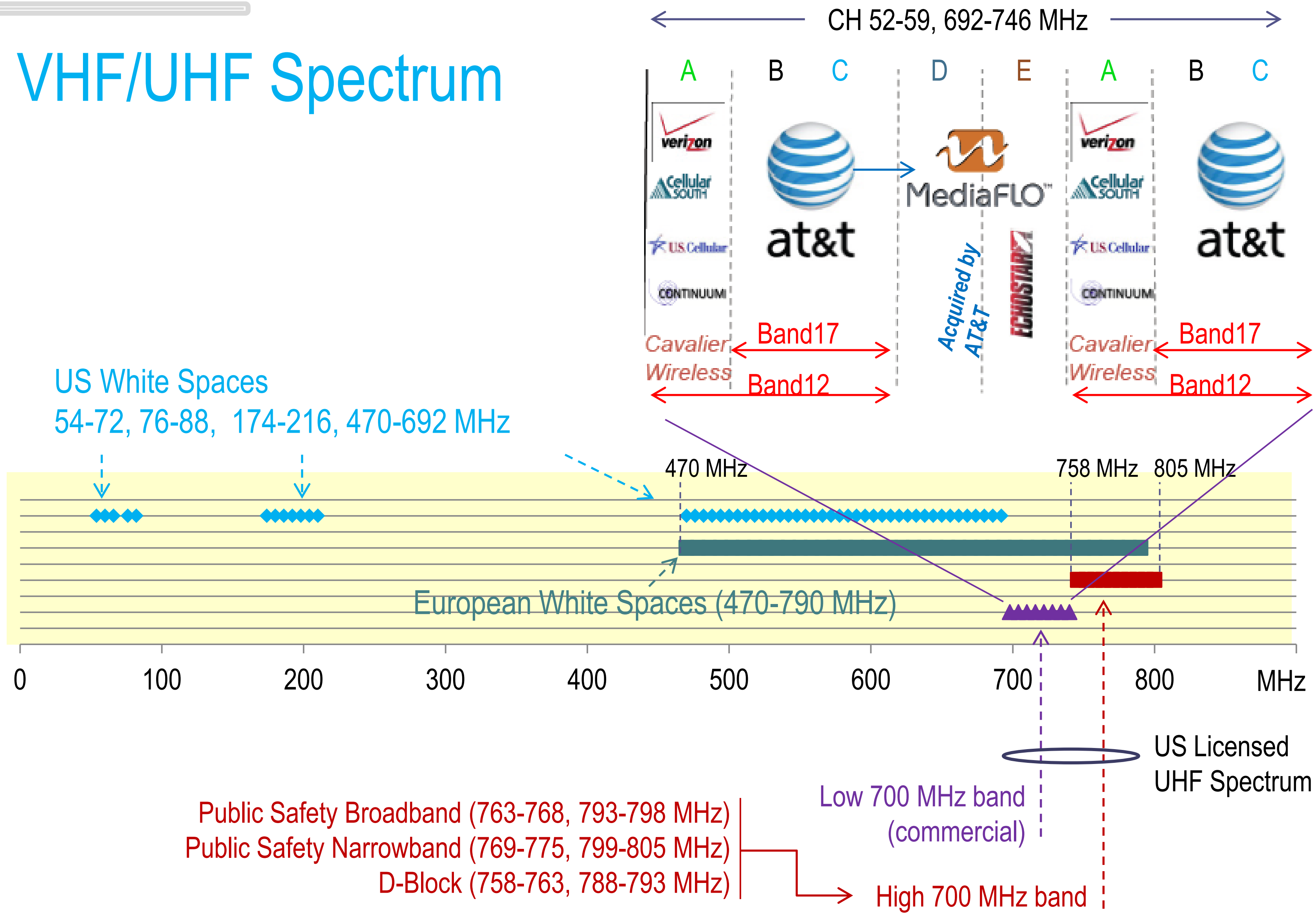
Nationwide PS Wireless Network

- Today, 3GPP technology has outpaced LMR and most PS workers rely on commercial cellular phones for
  - One-to-one calling, voice mail, LBS
  - Coast to coast coverage
- Hundreds of billions of dollars invested every year into commercial open standards based 2G/3G/LTE
  - Commercial solutions will continue to advance faster than purpose-built LMR and P25
- Hence, LTE is a wise choice for PS
- FCC has allocated Band 14 in the 700 MHz range and has mandated the exclusive use of the LTE technology in Band 14 so as to ensure orderly radio access for PS MC Voice, data, video and LBS applications [1].

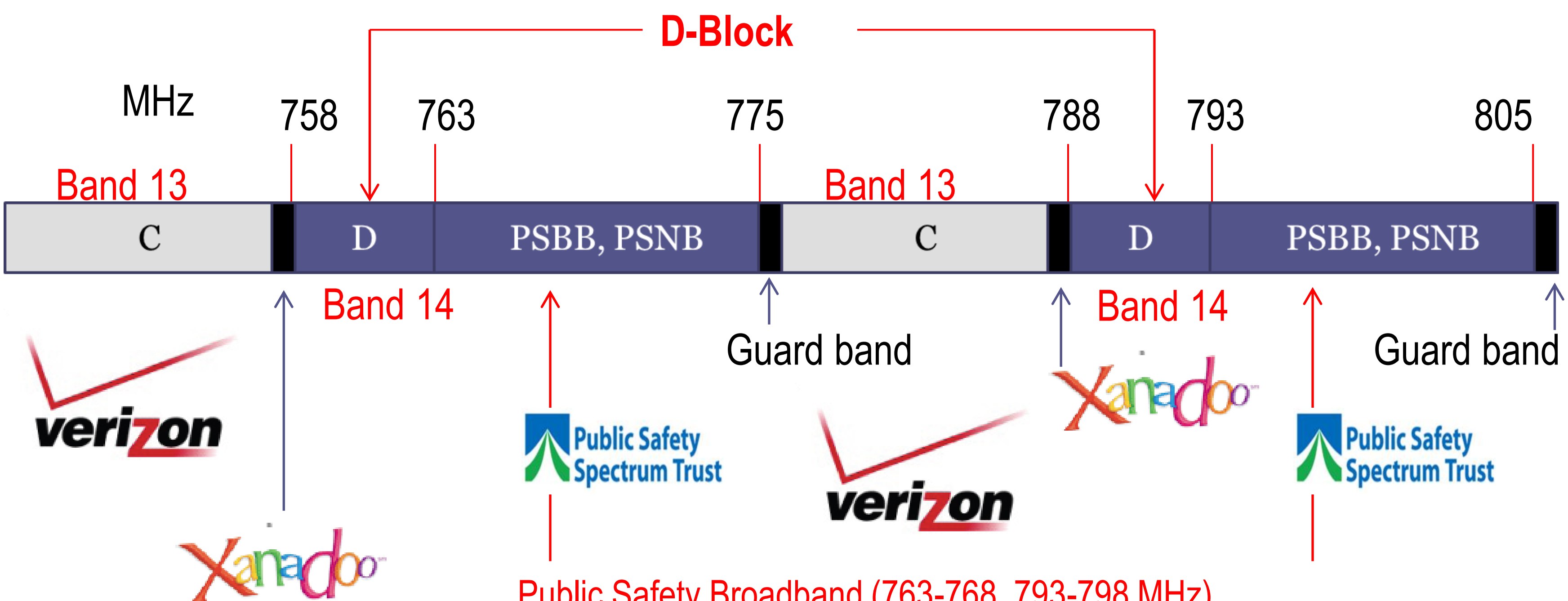
LBS = location based services

VHF/UHF Spectrum



Note: 775-788 MHz inside the High 700 MHz band is Verizon Band 13 and guard-bands

High 700 MHz Band



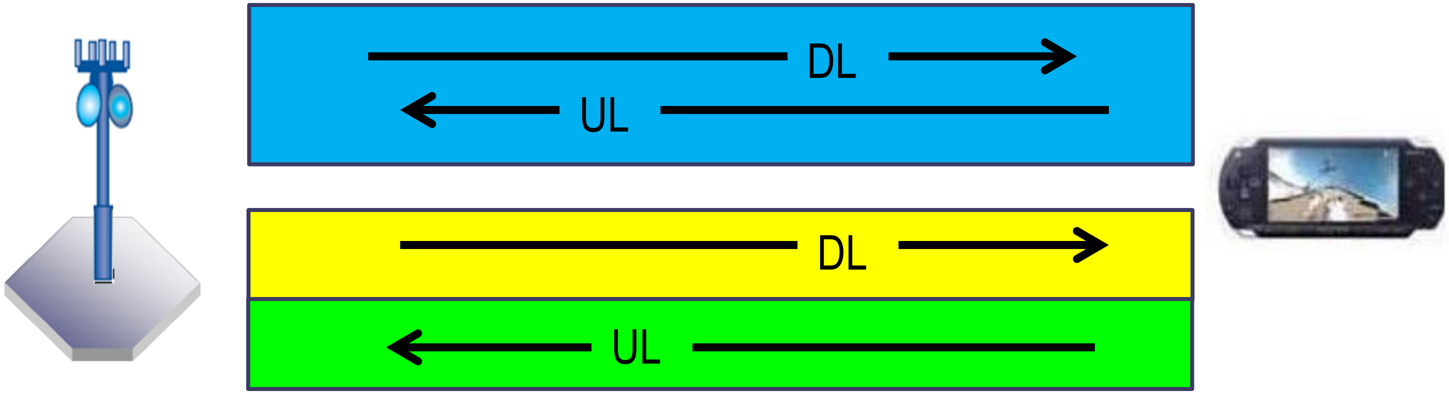
Public Safety Broadband (763-768, 793-798 MHz)
Public Safety Narrowband (769-775, 799-805 MHz), local LMR

LMR = land mobile radio

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	

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

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LTE = long term evolution

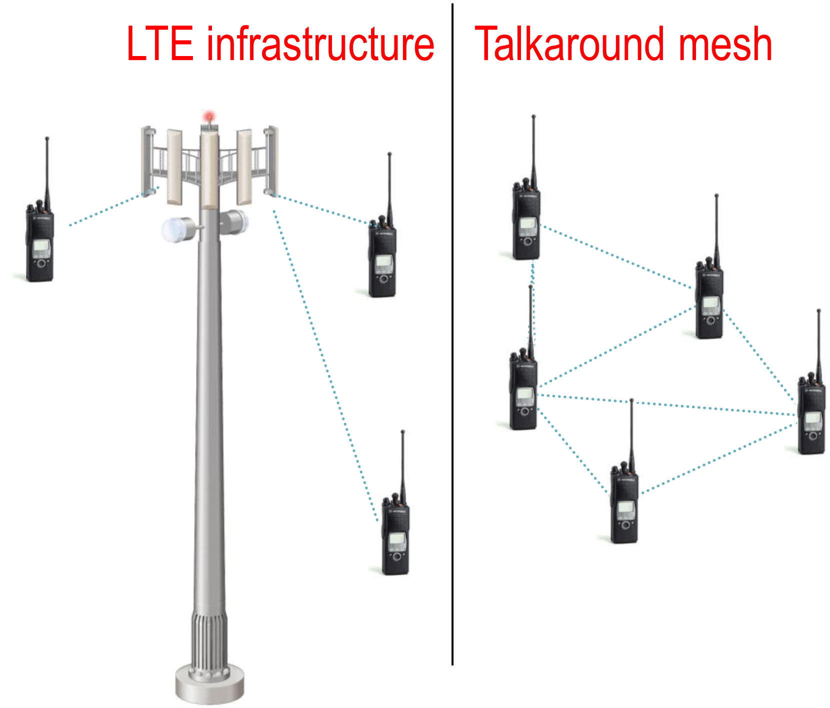
PS Workers – Survey Results

SBIR Contract No. D11PC20137

- The most important features in a life-and-death situation are
  - Fast and reliable access to the communications channel
  - Priority access to the airwaves in emergencies
  - Good coverage through infrastructure or talkaround
  - No dropped calls
- When moving to PS LTE, all the current wireless communication capabilities for first responders should be preserved. New features shouldn't compromise current functionality and simplicity of use.
- Public safety voice-enabled devices need to balance
  - Ease of use, integrated functions, ruggedness and costs
- Combining functions used in multiple devices (e.g. cell phones and police radios) into one integrated device for use in broadband wireless networks is preferred by many (but not all) interviewees.
- The integrated functions include viewing the location of the parties in the talk group while talking; particularly important in a fire situation

PS Mission Critical Voice Requirements

- Push to talk (< 500 ms connection time)
- Low latency voice (< 100 ms)
- Talkaround mode of operation
- Priority access with or without pre-emption
- Guaranteed voice message delivery
- Security with encryption
- Simultaneous voice and data (e.g. seeing location of callers when talking)
- VoIP recording
- Voice service roaming and interworking with private public safety networks and commercial cellular networks



SBIR Contract No. D11PC20137

Open Standards Based Architecture

- IMS based LTE network architecture to support voice, data, video, PTT, QoS
- Interworking function to interconnect legacy handsets, including P25 and analog radios to the LTE network
- Seamless mobility among islands of PS LTE coverage interconnected via commercial 2G/3G and LTE networks
- Talkaround mode of operation using patent-pending ivMesh™ technology (802.11s with layer 2 distributed voice protocol)
- Connection Manager function in the handset to switch operating modes
  - Infrastructure PS LTE
  - Infrastructure 2G/3G and LTE via commercial cellular radio
  - Talkaround

Handset to incorporate LTE, 2G/3G and Wi-Fi radios, based on off-the-shelf hardware

Interoperability with legacy radios ensured by the infrastructure Interworking function

PTT = push to talk
QoS = quality of service
ivMesh = isochronous voice mesh

LTE PS Handset Architecture

SBIR Contract No. D11PC20137

Android platform

Public Safety Voice Application GUI

Integrated PTT Client

Connection Manager

OMA-DM
OTA Provisioning

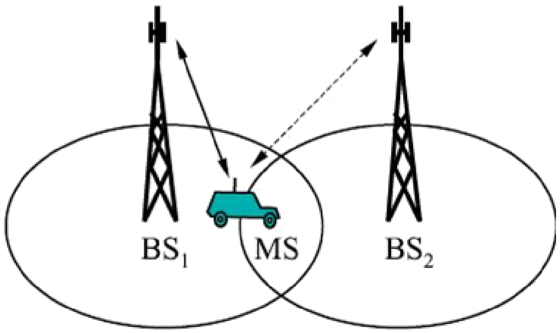
LBS Client	CS POC Agent	SIP/IMS POC Agent / SIP/IMS VoIP Client		ivMesh PTT Agent / ivMesh	P25 PTT Agent
GPS	2G/3G radio		LTE radio	802.11 radio	LMR

Infrastructure mode

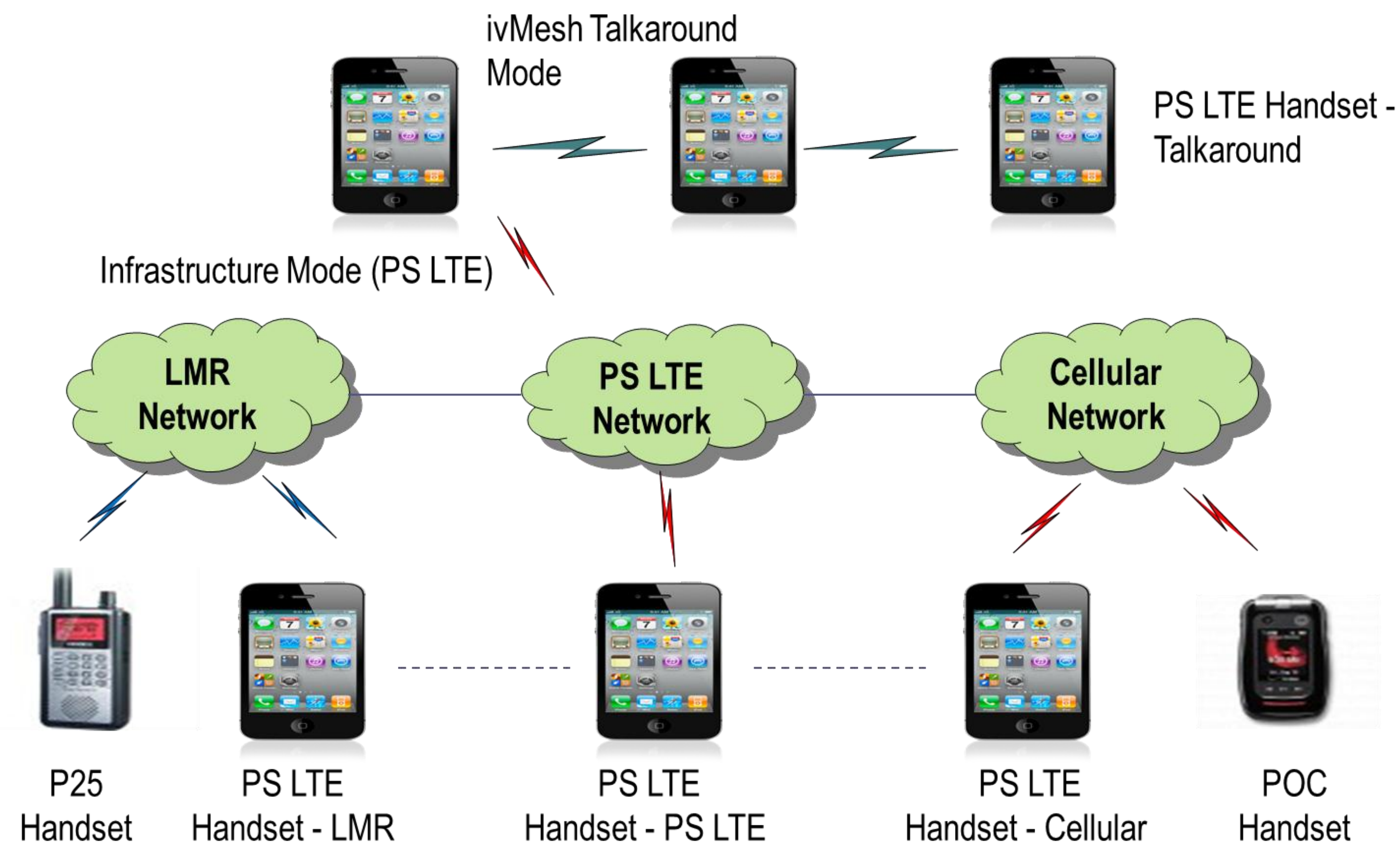
Talkaround mode

Handoff between PS LTE and Commercial Networks

- Need for cooperation with commercial 2G/3G and 4G networks;
  - PS handset to cover bands 12 and 13
  - Handoff without connection loss; voice call continuity
- A voice call shall be able to originate or terminate across any of these networks
  - PS LTE network
  - P25/LMR network
  - Commercial wireless or wireline network
- A PS LTE network shall support voice call continuity for a roaming user from or to
  - Another PS LTE network
  - P25/LMR network
  - Commercial wireless network.



Devices on Disparate Networks Part of the Same Talk Group



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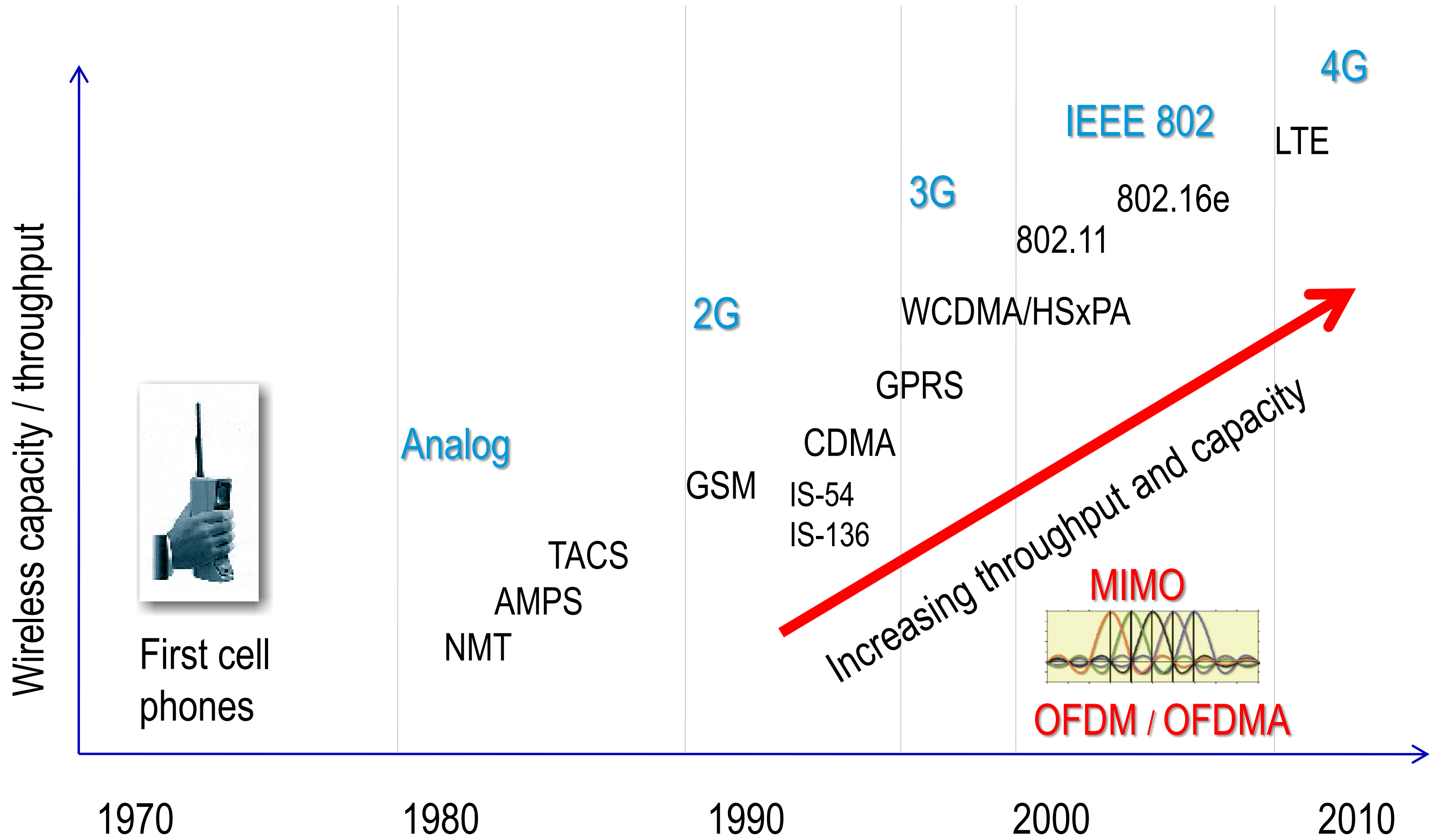
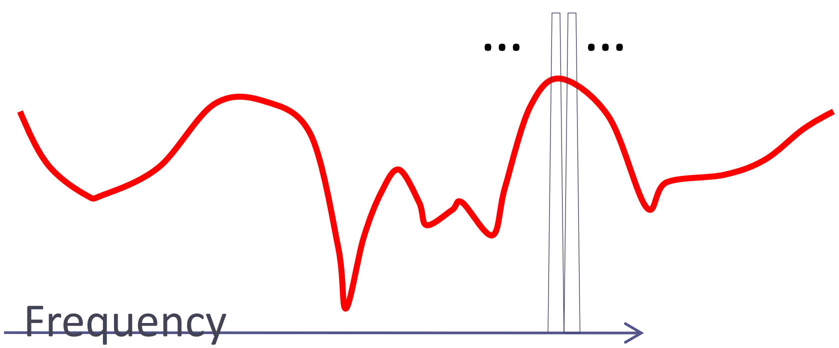
The Evolution of Wireless Broadband



OFDM/OFDMA = orthogonal frequency domain multiplexing / multiple access
MIMO = multiple input multiple output

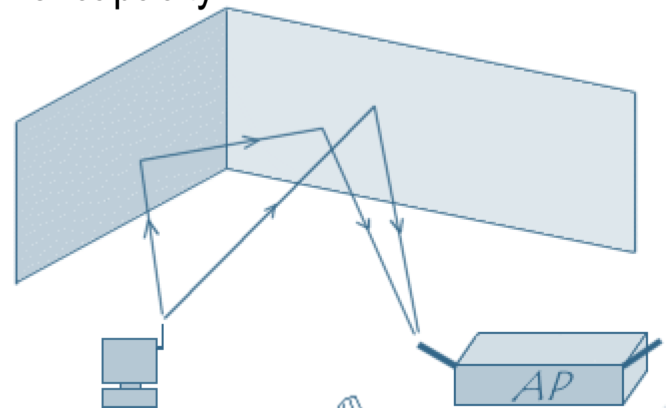
OFDM and MIMO

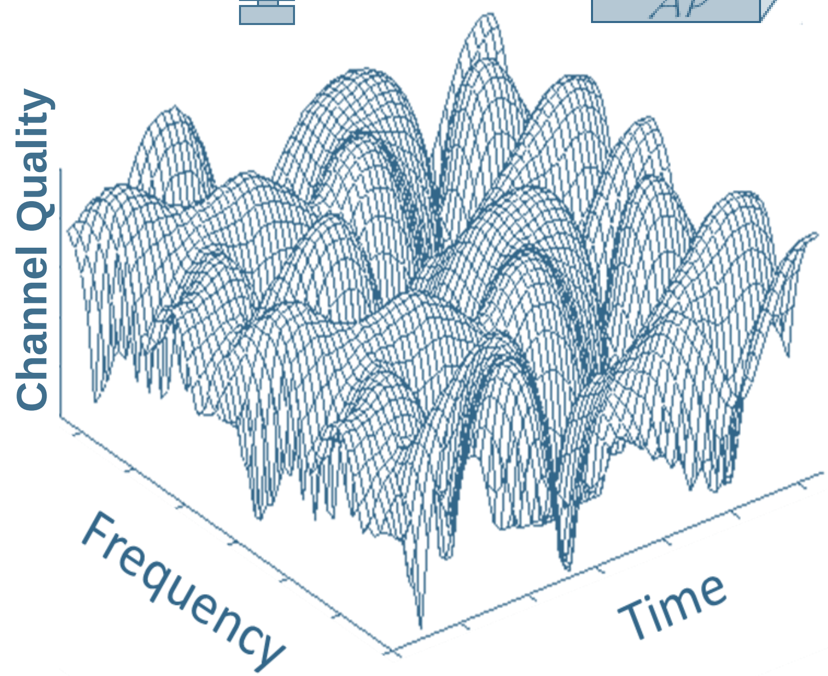
- OFDM transforms a frequency- and time-variable fading channel into parallel correlated flat-fading channels, enabling wide bandwidth operation



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

MIMO uses multipath to increase channel capacity



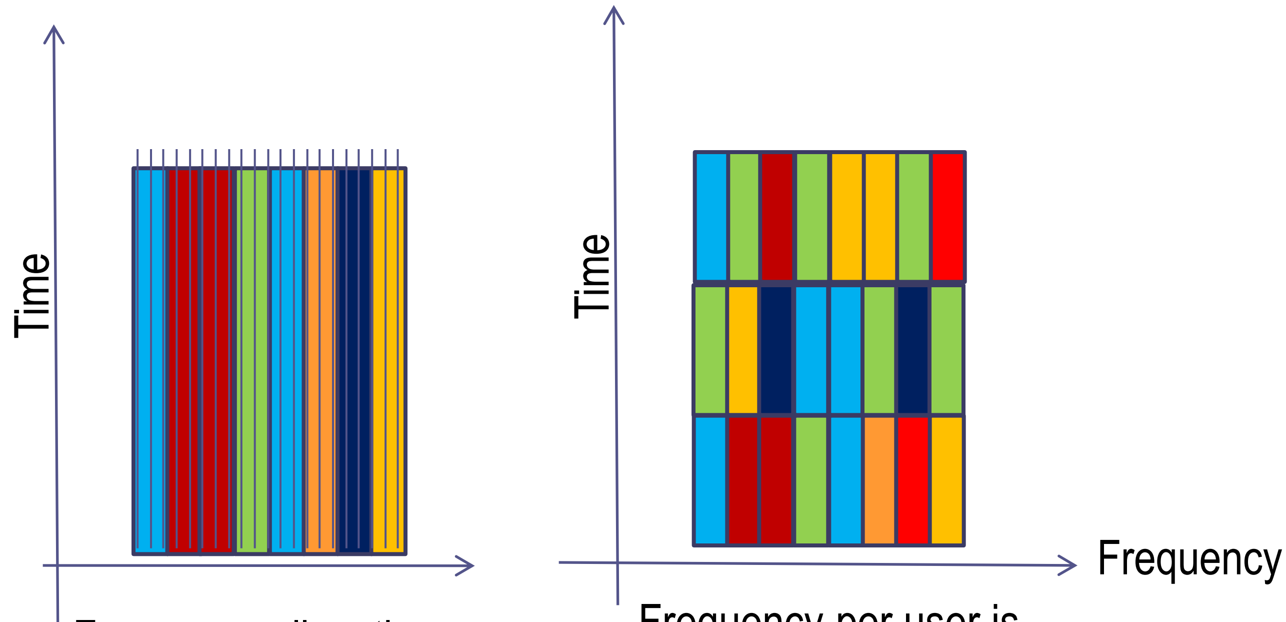


OFDM = orthogonal frequency division multiplexing
MIMO = multiple input multiple output

OFDM vs. OFDMA

OFDM is a modulation scheme

OFDMA is a modulation and access scheme



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

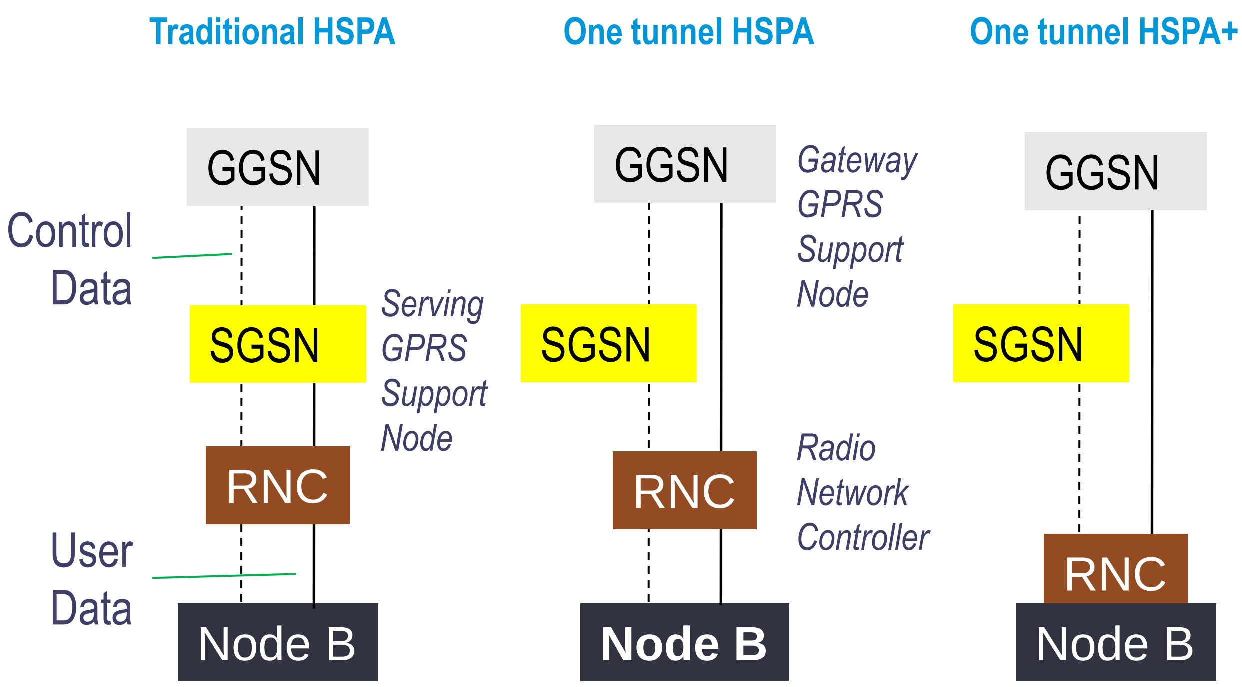
OFDM/OFDMA = orthogonal frequency domain multiplexing / multiple access

- 3GPP = 3rd generation partnership project
- Partnership of 6 regional standards groups that translate 3GPP specifications to regional standards
- LTE = long term evolution

G	The G's	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
4	LTE-Advanced	1000 Mbps	500 Mbps

HSPA and HSPA+

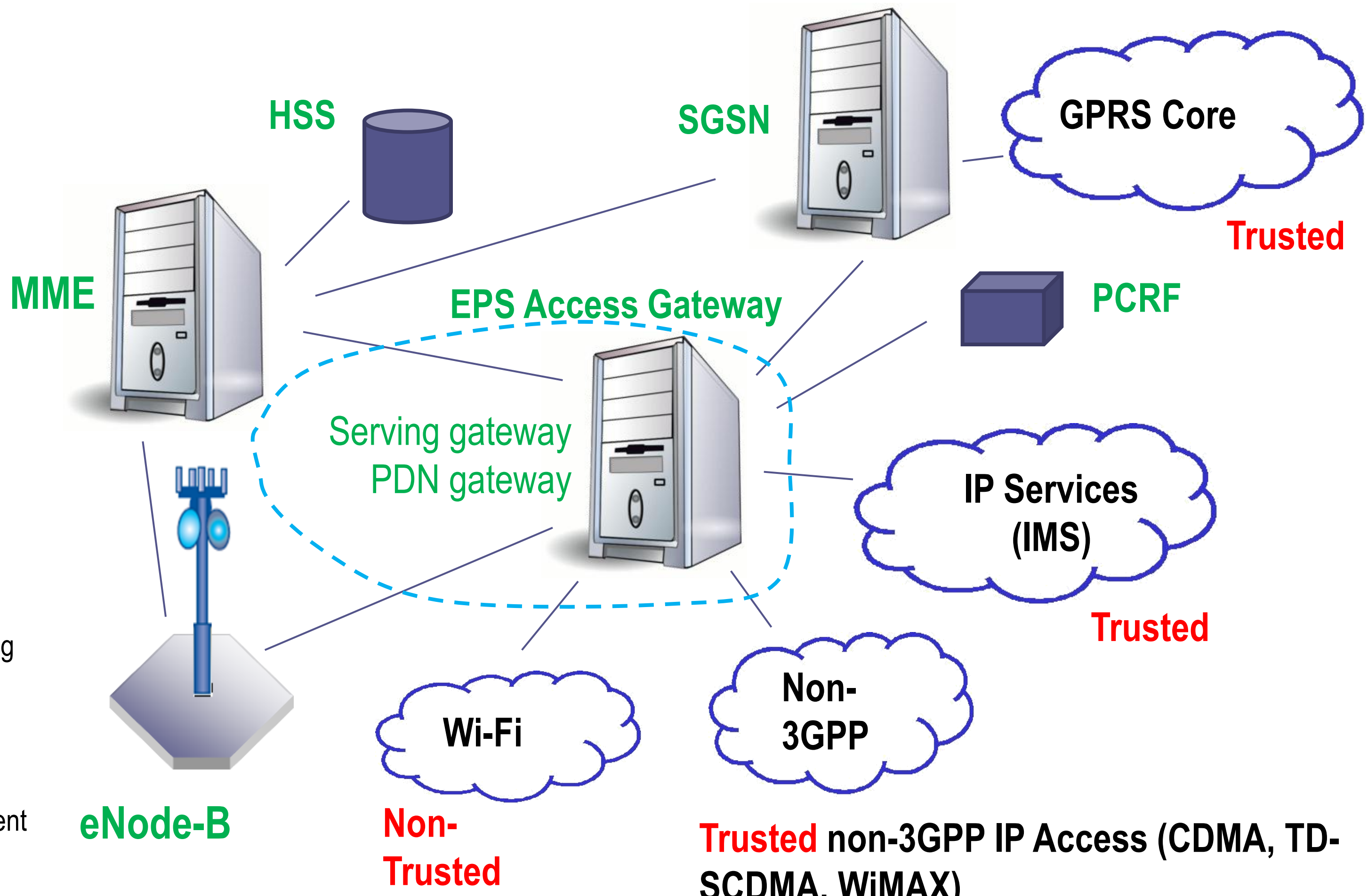
- HSPA+ is aimed at extending operators' investment in HSPA
  - 2x2 MIMO, 64 QAM in the downlink, 16 QAM in the uplink
  - Data rates up to 42 MB in the downlink and 11.5 MB in the uplink.



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)

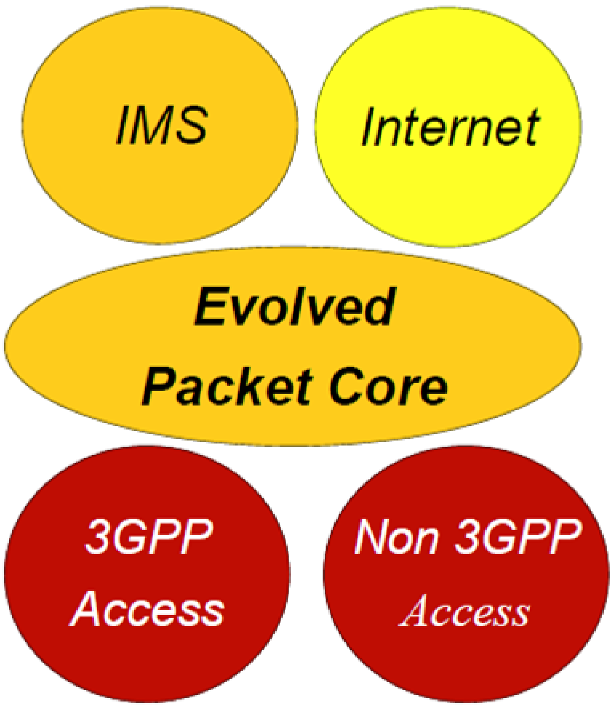
HSS (Home Subscriber Server)

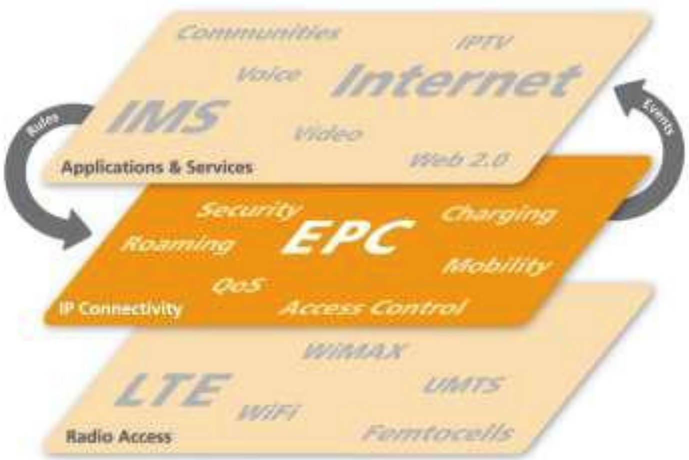
MME (Mobility Management Entity)

PDN (Public Data Network)

Flat, low-latency architecture

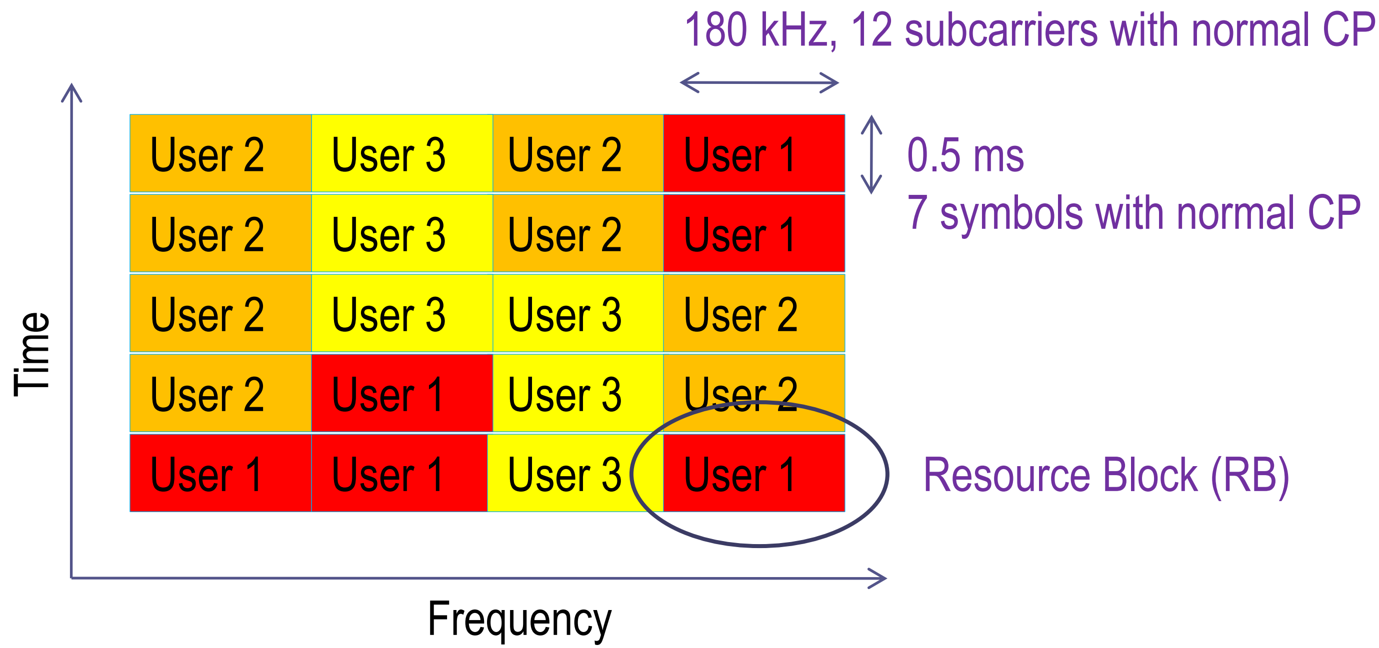
Network Layers





Source: www.OpenEPC.net

LTE Resource Allocation

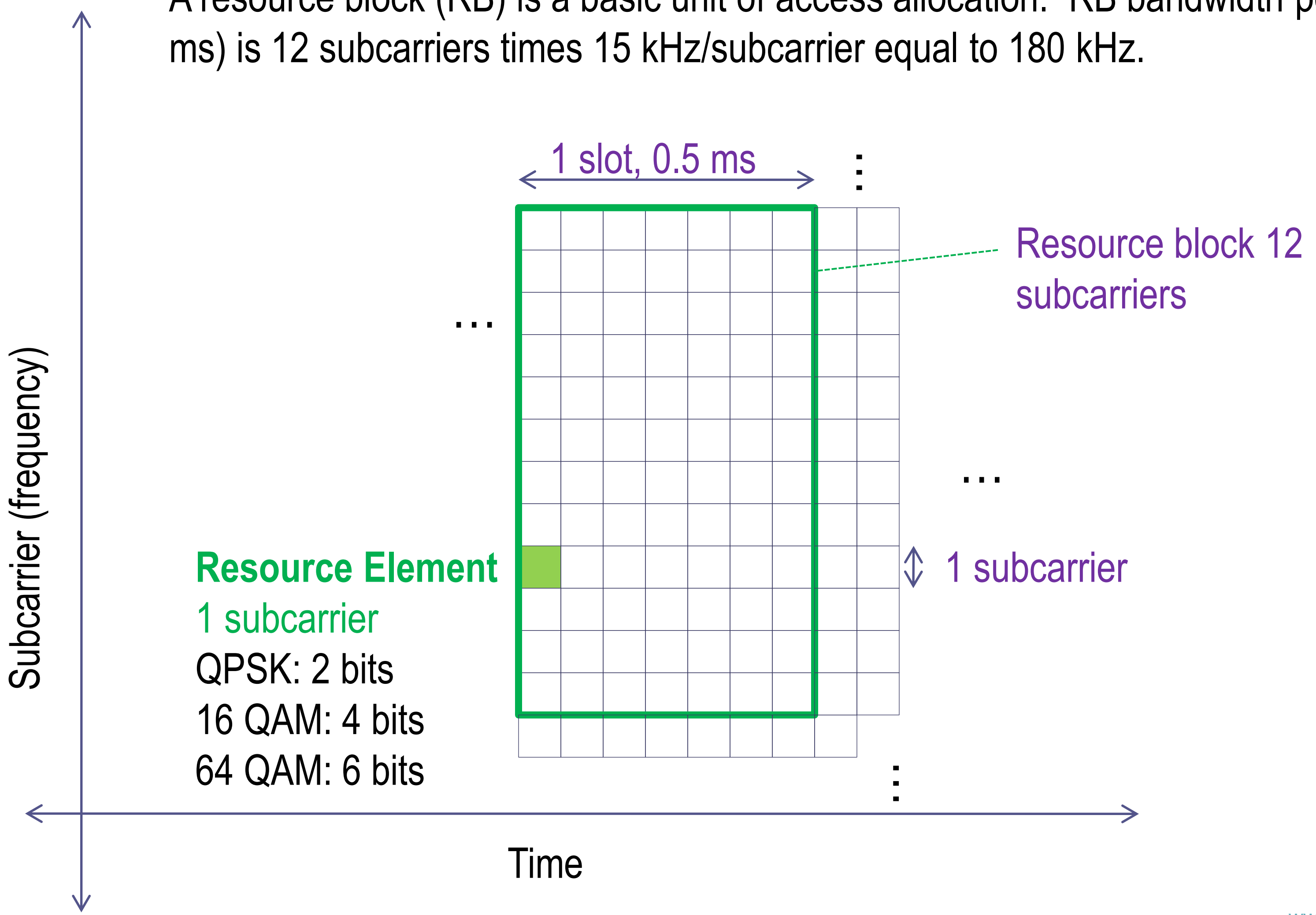


- Resources are allocated per user in time and frequency. RB is the basic unit of allocation.
- RB is 180 kHz by 0.5 ms; typically 12 subcarriers by 7 OFDM symbols, but the number of subcarriers and symbols can vary based on CP

CP = cyclic prefix, explained ahead

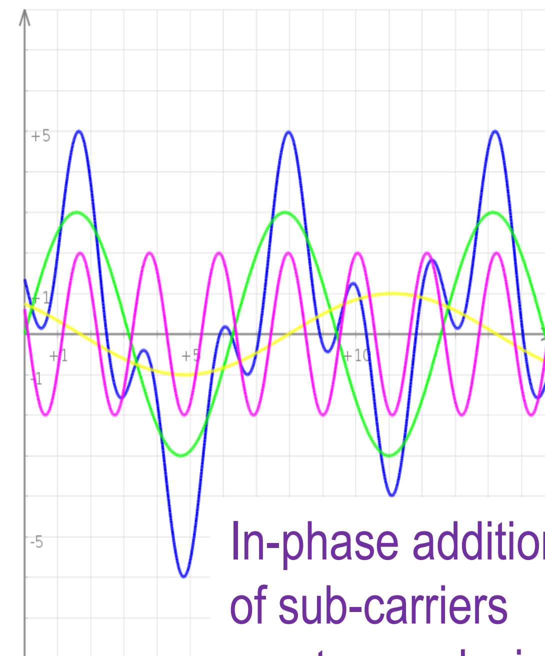
Resource Block

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.



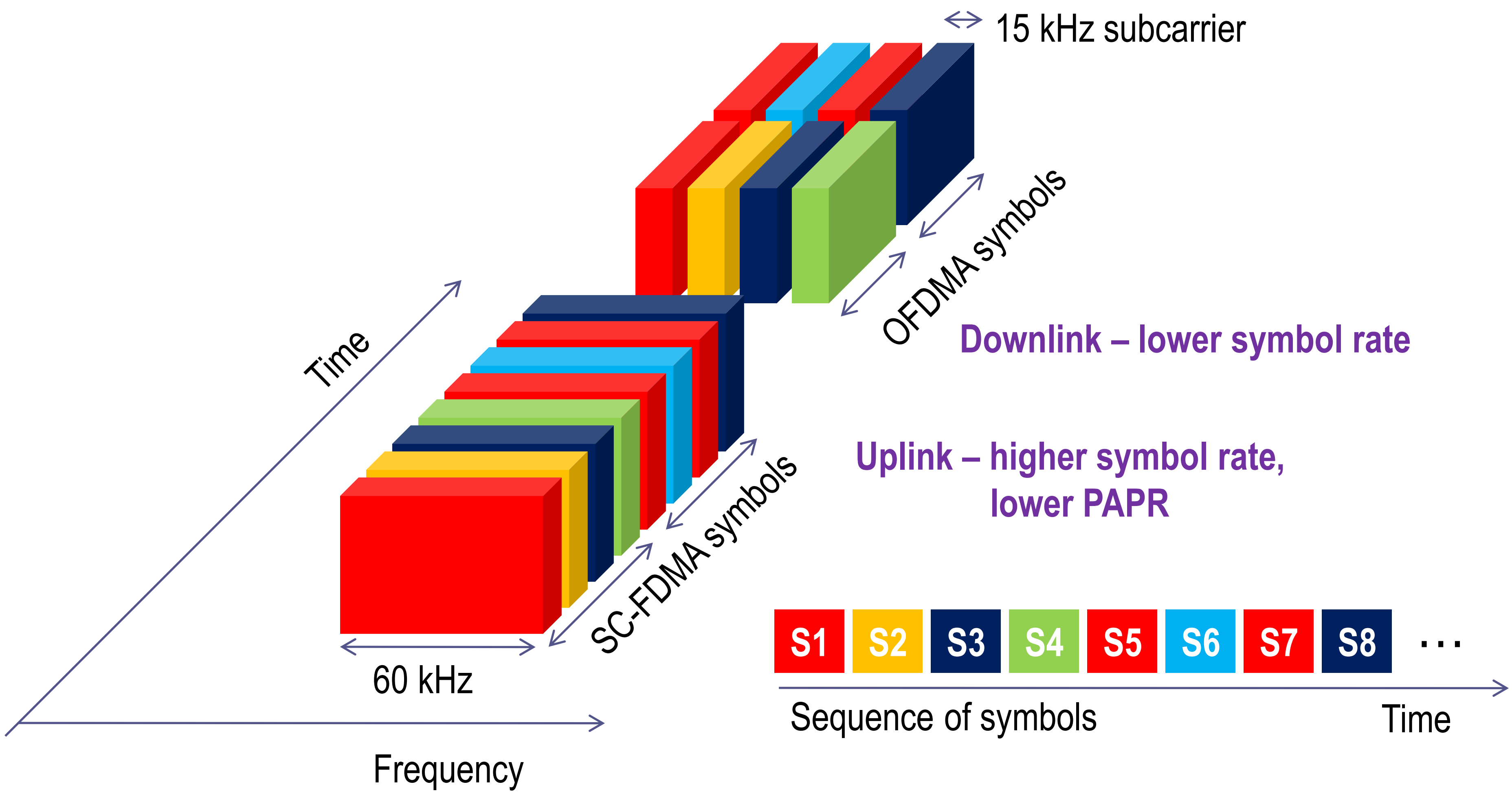
OFDMA vs. SC-FDMA (LTE Uplink)

- 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.

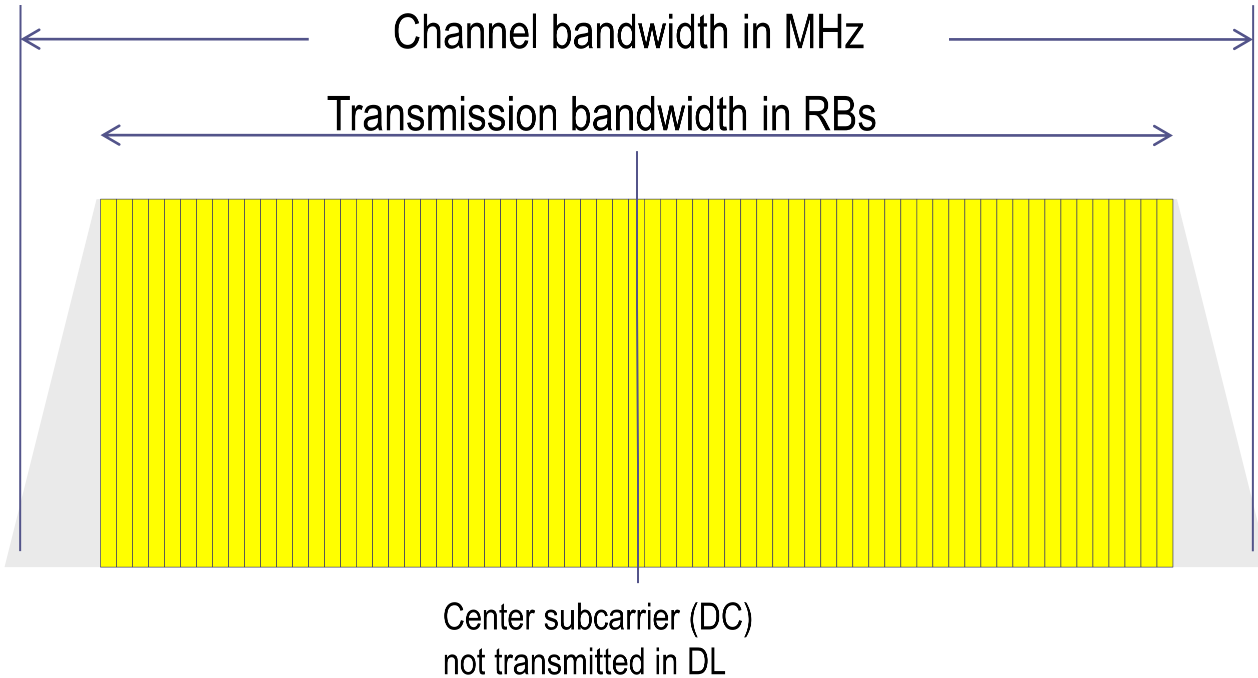


In-phase addition of sub-carriers creates peaks in the OFDM signal

SC-FDMA vs. OFDMA



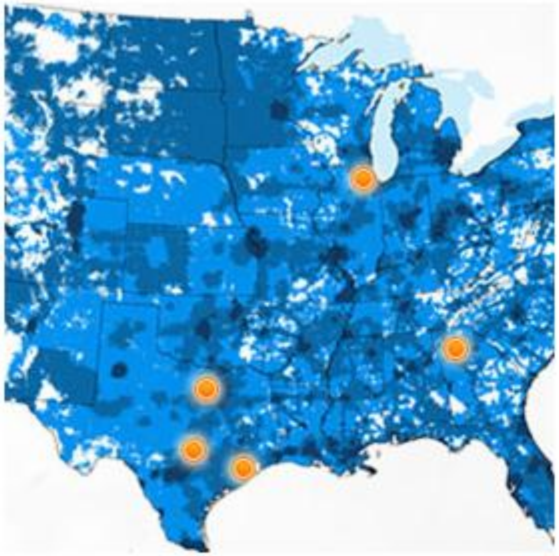
LTE Scalable Channel Bandwidth



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	

AT&T Test

- AT&T launched its LTE network in 5 cities on 9/18/11
- PC Magazine article: AT&T vs. Verizon: LTE, Head-to-Head
  - http://www.pcmag.com/article2/0,2817,2393182,00.asp#fbid=fD0LIOUpHzx
  - Unable to roam between AT&T and Verizon LTE networks
  - AT&T has put coverage maps on its site advocating merger with T-Mobile



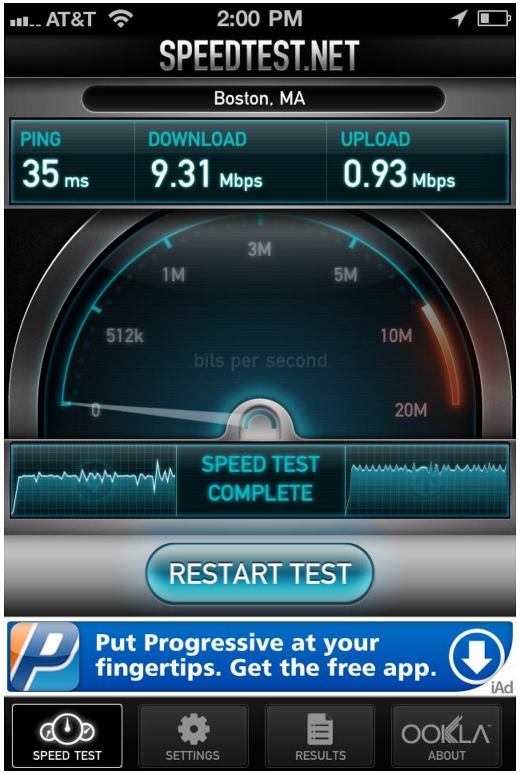
AT&T LTE vs. Verizon Wireless: PCMAG.com results in Houston, TX

Device	Speedtest.net avg download (Mbps)	Speedtest.net max download (Mbps)	Speedtest.net avg upload (Mbps)	Average ping (ms)	Web time to first byte (sec)	Average Web page load speed (Mbps)
AT&T USBConnect Momentum 4G (modem)	24.65	42.85	11.44	45.00	0.30	0.27
AT&T USBConnect Elevate 4G (hotspot)	24.63	39.09	11.53	50.00	0.32	0.24
Pantech UML290 for Verizon Wireless	16.70	23.81	4.01	51.00	0.27	0.25

Dallas-Fort Worth
San Antonio
Houston
Atlanta
Chicago

LTE Throughput Test

- Informal drive-through testing of initial Verizon LTE deployments in the Boston area
- Measure throughput using www.speedtest.net
- Based on our sniffer measurements of the speedtest.net running on the desktop and iPhone:
  - The program uses HTTP protocol to download and upload large images multiple times
- The test runs for about 10 sec in each direction
- Ookla operates speedtest.net using many servers around the world and routing the test traffic to the nearest server
  - http://www.ookla.com/speedtest.php



Verizon Service and Equipment

- Subscribed to Verizon 10 GB plan
- Equipment: Galaxy tablet
  - Android based

WELCOME TO THE LIGHTNING FAST SAMSUNG GALAXY TAB™ 10.1.

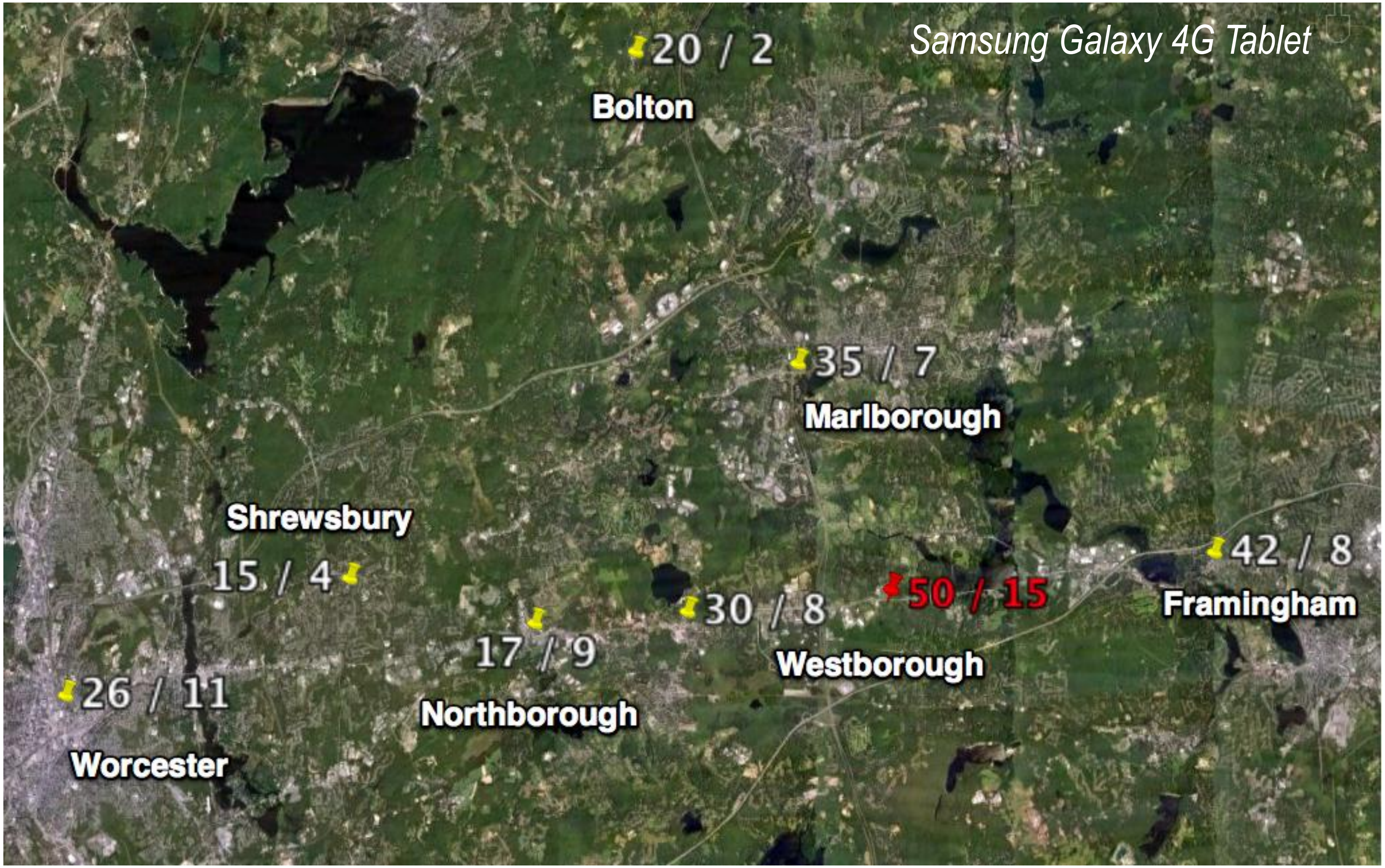
Powered by Verizon 4G LTE, it's a tablet experience like you've never imagined.

	2GB – $30.00/Month	5GB – $50.00/Month	10GB – $80.00/Month
Tablet/Netbook	●	●	●
USB Modem/Notebook /Dedicated Mobile Hotspot		●	●

Overage $10.00/GB (Overage charges occur when you exceed your plan's monthly allowance.)

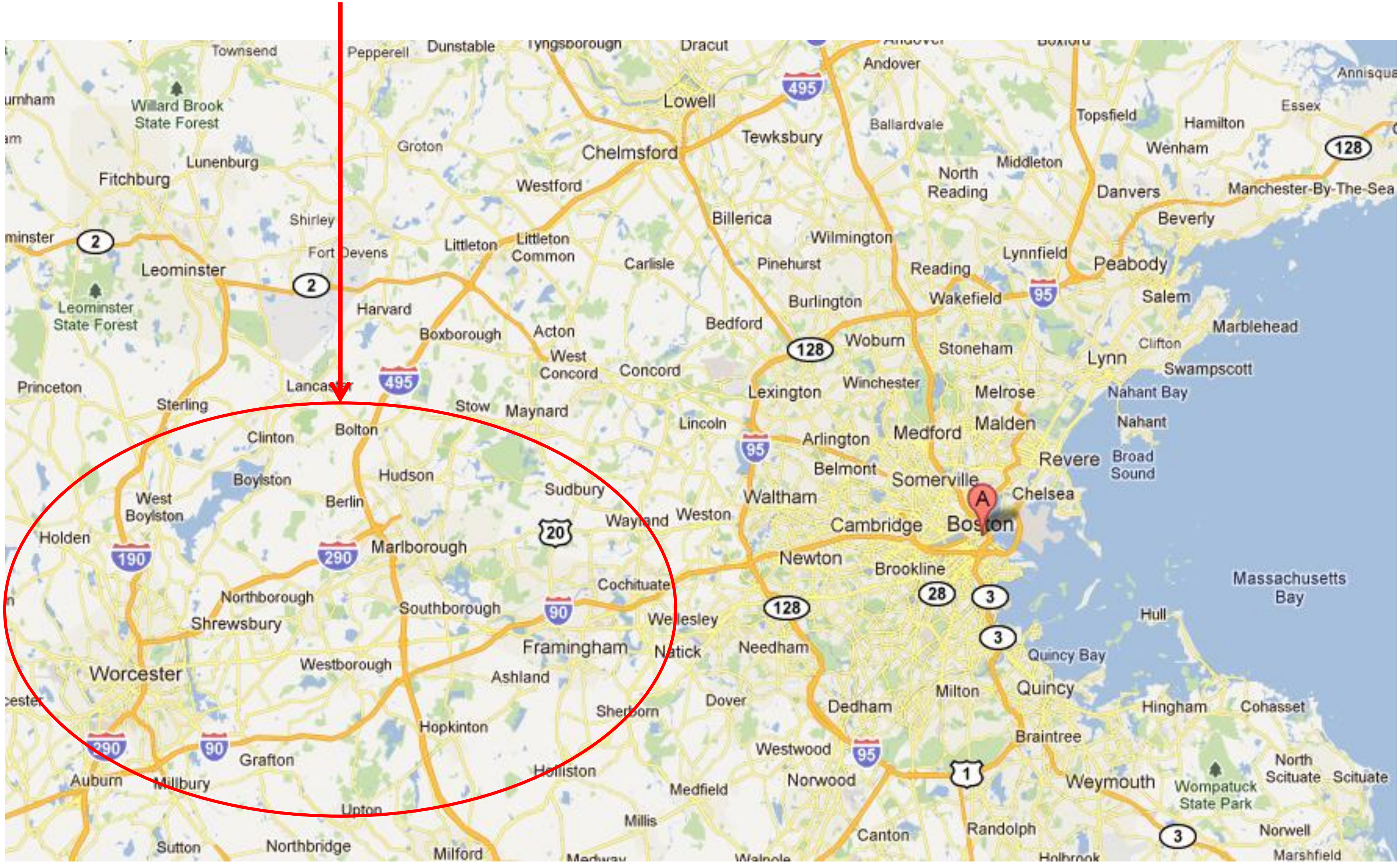
octoScope's LTE Throughput Measurements in MA

DL/UL, Mbps



octoScope

Measurements Performed Here



Output Captured by speedtest.com

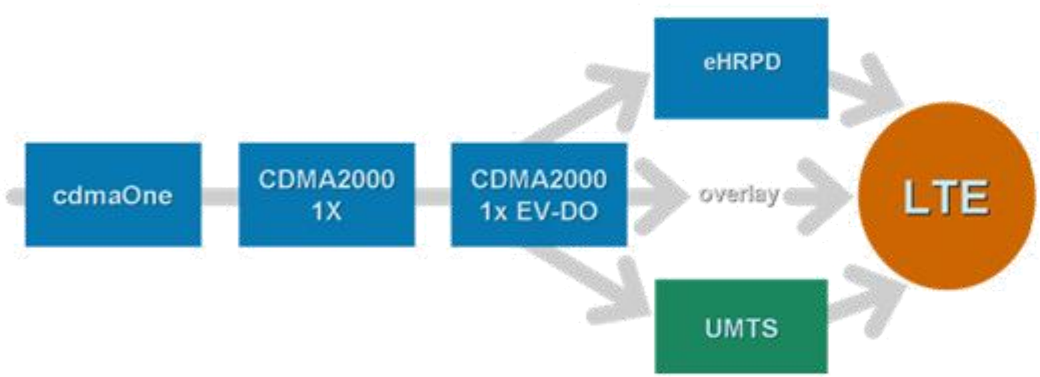
kbps — msec

Date	ConnType	Lat	Lon	Download	Upload	Latency	ServerName	Internal IP	External IP
10/2/2011 11:10	Lte	42.41827	-71.6034	19518	4920	98	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 11:10	Lte	42.41827	-71.6034	19518	3983	106	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 11:09	Lte	42.41827	-71.6034	17300	2772	96	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 11:05	Ehrpd	42.28415	-71.6087	1917	1000	194	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 11:00	Ehrpd	42.28415	-71.6087	742	1000	148	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:57	Ehrpd	42.28415	-71.6087	1373	842	150	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:56	Ehrpd	42.28415	-71.6087	1910	901	180	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:55	Lte	42.28415	-71.6087	11467	309	98	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:55	Lte	42.28415	-71.6087	35694	6542	96	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:54	Lte	42.28415	-71.6087	31827	7324	97	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:53	Lte	42.28415	-71.6087	21281	7423	90	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:53	Lte	42.28415	-71.6087	9455	6937	90	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:52	Lte	42.28415	-71.6087	18291	4633	94	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:39	Ehrpd	42.28415	-71.6087	2341	954	179	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:37	Lte	42.28415	-71.6087	14298	989	94	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:36	Lte	42.28415	-71.6087	41880	7882	92	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:36	Lte	42.28415	-71.6087	34324	7346	92	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:36	Lte	42.28415	-71.6087	42962	8904	90	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:35	Lte	42.28415	-71.6087	44814	7583	94	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:35	Lte	42.28415	-71.6087	22561	9205	100	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:35	Lte	42.28415	-71.6087	14173	3284	104	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:32	Ehrpd	42.28415	-71.6087	1593	830	192	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:29	Lte	42.28415	-71.6087	8507	262	92	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:29	Lte	42.28415	-71.6087	12333	1002	97	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:28	Lte	42.28415	-71.6087	34996	10387	88	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:28	Lte	42.28415	-71.6087	49833	14801	85	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:25	Lte	42.28415	-71.6087	29931	8027	90	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:25	Lte	42.28415	-71.6087	20394	8460	100	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123
10/2/2011 10:25	Lte	42.28415	-71.6087	17250	5815	99	Boston, MA	10.133.86.195, 10.165.70.146	166.248.1.123

Geolocation recorded by speedtest.com is incorrect

What's eHRPD?

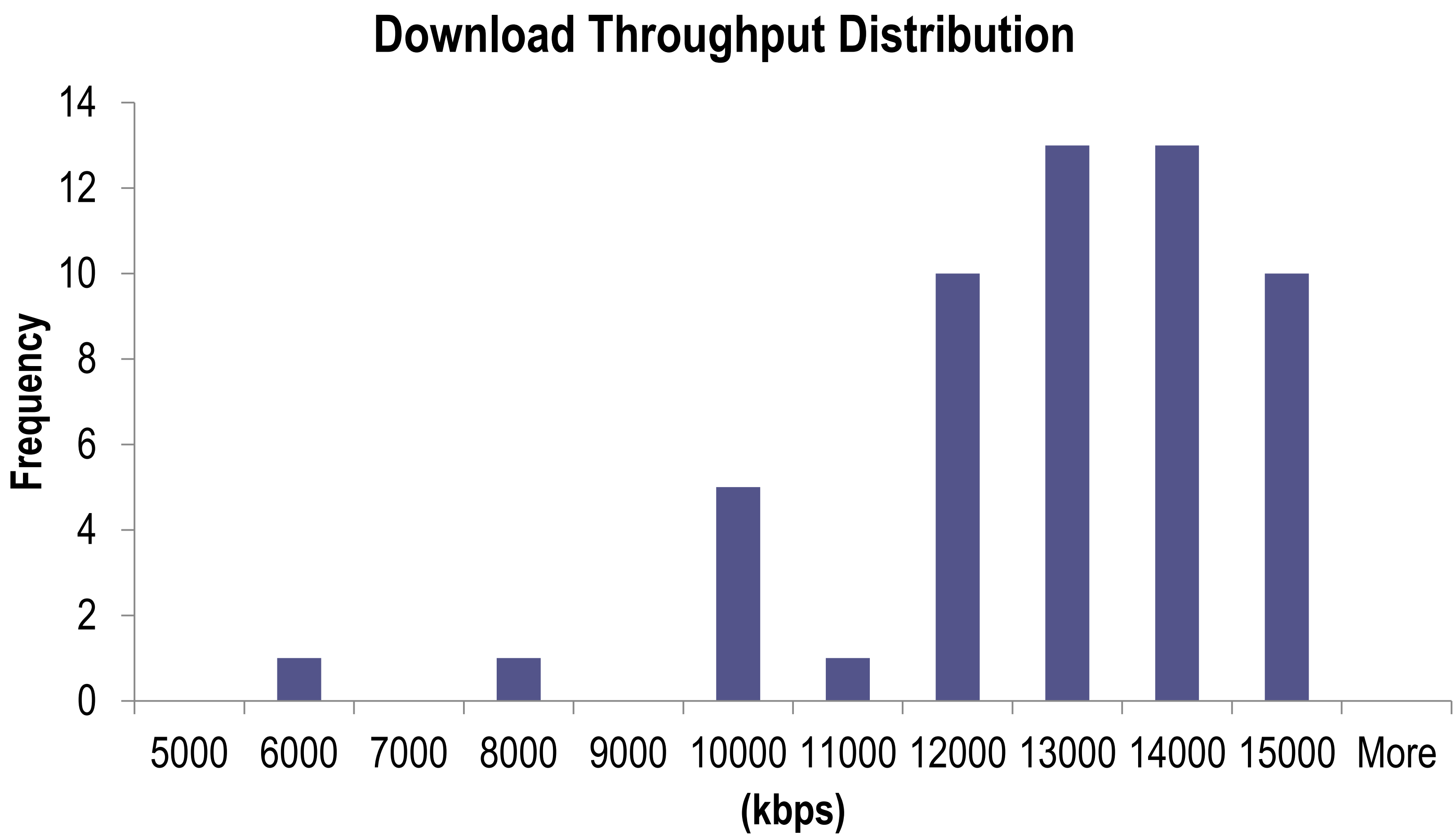
- eHRPD is Verizon's 3G; upgrade path to LTE
  - CDMA based; enhanced HRPD (EVDO)
  - Maintains the same private IP when handset moves from tower to tower
  - Reduces dropped sessions and decreases the handover latency
- eHRPD will be used by Verizon for VOIP calls until 2020



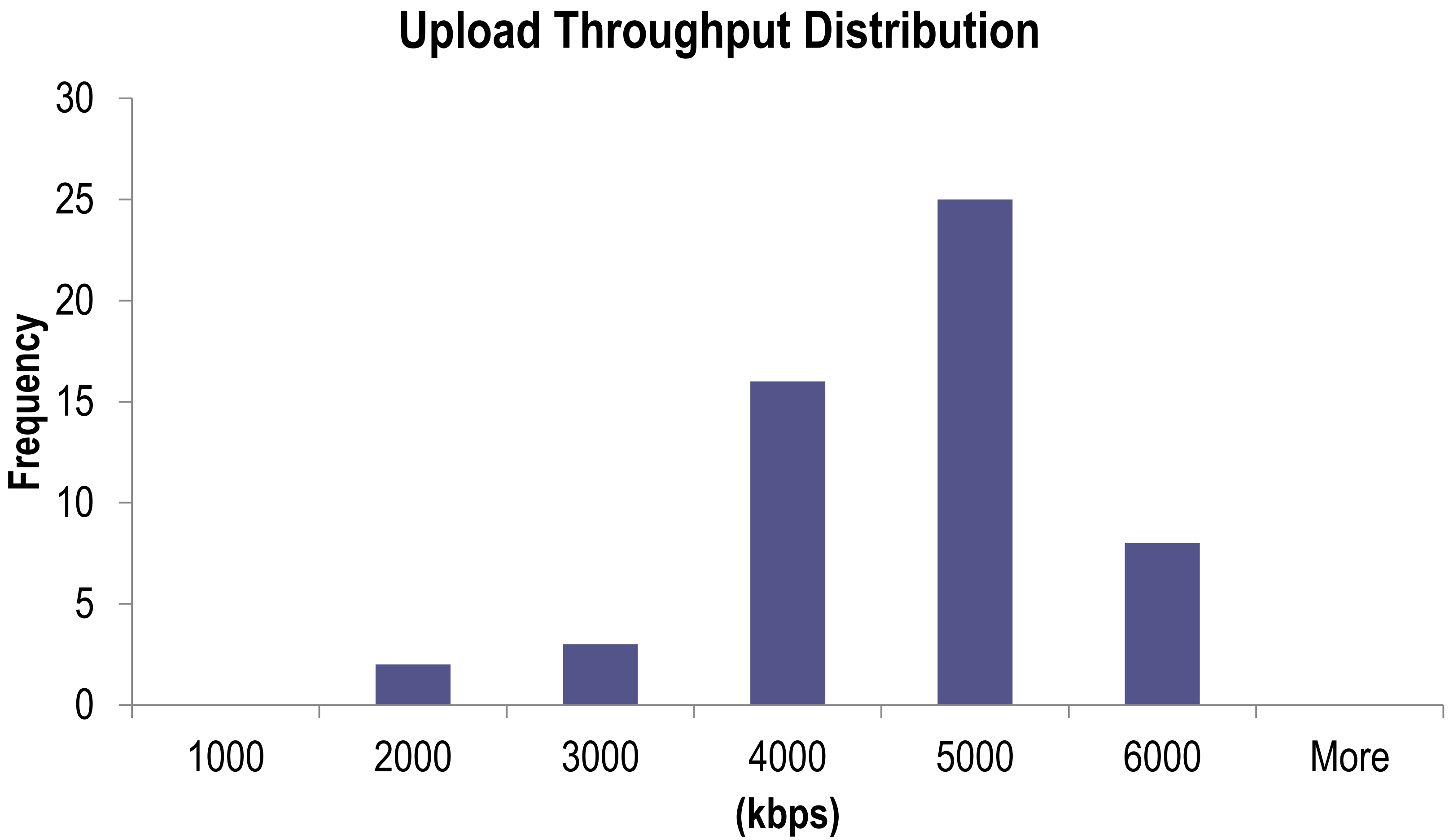
CDMA upgrade paths to LTE

eHRPD = enhanced high rate packet data
EVDO = Evolution-Data Optimized

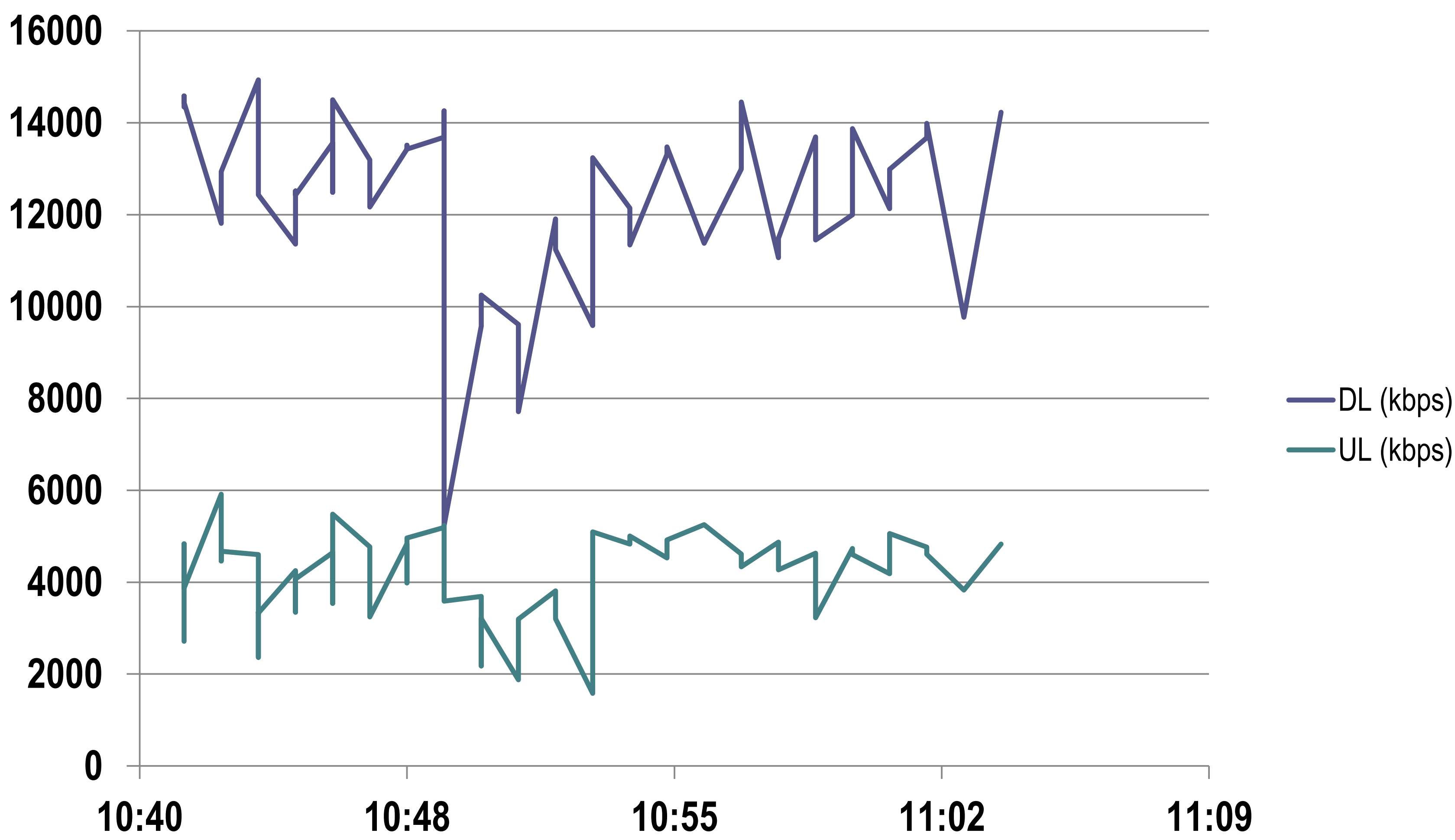
Throughput Distribution - DL



Throughput Distribution - Uplink



Stability of Throughput – vs. Time



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Impact of Speed & Roaming

Date	ConnType	Download(kbps)	Upload(kbps)	Latency(ms)	ServerName	Internal IP	External IP
10/25/2011 13:03	Ehrpd	564	578	183	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 13:03	Ehrpd	783	734	187	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 13:02	Ehrpd	268	330	215	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 13:01	Lte	18209	4430	99	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 13:01	Lte	37263	8048	94	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 13:00	Lte	35722	7566	111	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 13:00	Lte	35596	8374	106	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 13:00	Lte	32816	7150	118	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 13:00	Lte	38081	7598	121	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:59	Lte	36286	7854	106	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:59	Lte	35714	9027	113	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:59	Lte	38519	7755	93	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:59	Lte	18927	8435	112	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:58	Lte	31436	3336	111	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:58	Lte	35918	7699	101	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:58	Lte	34811	7283	114	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:57	Lte	38550	9488	116	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:57	Lte	34797	8880	102	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:57	Lte	25581	7609	117	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:56	Lte	17514	6964	102	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:56	Lte	16636	5468	101	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:56	Lte	31238	5676	118	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:56	Lte	33350	7442	108	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:55	Lte	38943	7735	104	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:55	Lte	35389	7616	109	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:55	Lte	33942	8162	100	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8
10/25/2011 12:54	Lte	33057	7225	116	Boston, MA	10.131.110.240, 10.174.56.202	166.248.3.8

LTE Average		**32012**	**7368**
LTE Median		**34804**	**7612.5**

Connection lost at LTE to eHRPD transition

Certification

Public Safety Communications Research
U.S. Department of Commerce – Boulder Laboratories

- The PS community needs a certification standard for PS handsets similar to GCF and PTCRB
  - GCF is responsible for LTE conformance testing with the focus on European operators; PTCRB provides certification for North American operators
- PS certification has unique certification requirements, for example:
  - PTT-specific certification with the focus on priority and preemption features – infrastructure and talkaround modes
  - Seamless roaming and VCC among islands of PS LTE networks and commercial 2G/3G/LTE networks
  - PS security related certification
  - Call management and VCC between infrastructure and talkaround modes, OTA provisioning and other such operational functionality

www.globalcertificationforum.org

www.ptcrb.com

PTCRB = PCS Type Certification Review Board
PCS = Personal Communications System,
GCF = Global Certification Forum
VCC = voice call continuity
PSCR = public safety communications research
UE = user equipment

Tutorial Contents

PS = public safety
3GPP = 3rd generation partnership project
LTE = long term evolution

Voice over LTE Solutions

- CSFB (3GPP 23.272) whereby voice calls are switched to 2G/3G CS networks
- VoLGA whereby voice calls are encapsulated in data packets traversing LTE networks
- Over-the-Top (OTT) voice, for example Skype operating over LTE networks
- GSMA's selected Voice over LTE (VoLTE) based on IMS

CSFB = circuit switched fallback
CS = circuit switch
VoLGA = voice over LTE with Generic Access
OTT = over-the-top
VoLTE = voice over LTE
IMS = IP multimedia subsystem

GSMA VoLTE

- Our research and analysis [3, 5] led us to select the GSMA VoLTE approach based on IMS.
- IMS is the all-IP layer in the LTE network that ensures
  - Seamless roaming with VCC (voice call continuity)
  - QoS (quality of service)
  - Security
- Seamless voice roaming and connectivity among disparate networks will be a key PS requirement, particularly for the early deployments of PS LTE networks that are expected to emerge as ‘islands’ of localized coverage.

GSMA, VoLTE and IMS

- GSMA advocates VoLTE, which is based on IMS, for voice interoperability in the LTE network.
- Verizon is planning to deploy IMS to implement VoLTE. And PS LTE handsets will almost certainly need to use Verizon's network in areas where PS LTE coverage is unavailable.
- OMA specifies PTT over IMS for PTT interoperability across different radio access technologies (RATs). Such an open standard will facilitate PS LTE interworking with other public cellular networks and with LMR/P25 private networks.
- IMS is the ideal protocol to unify session control for existing and future public safety voice related applications, such as PTT, cellular voice, E911.

OMA = open mobile alliance

Tutorial Contents

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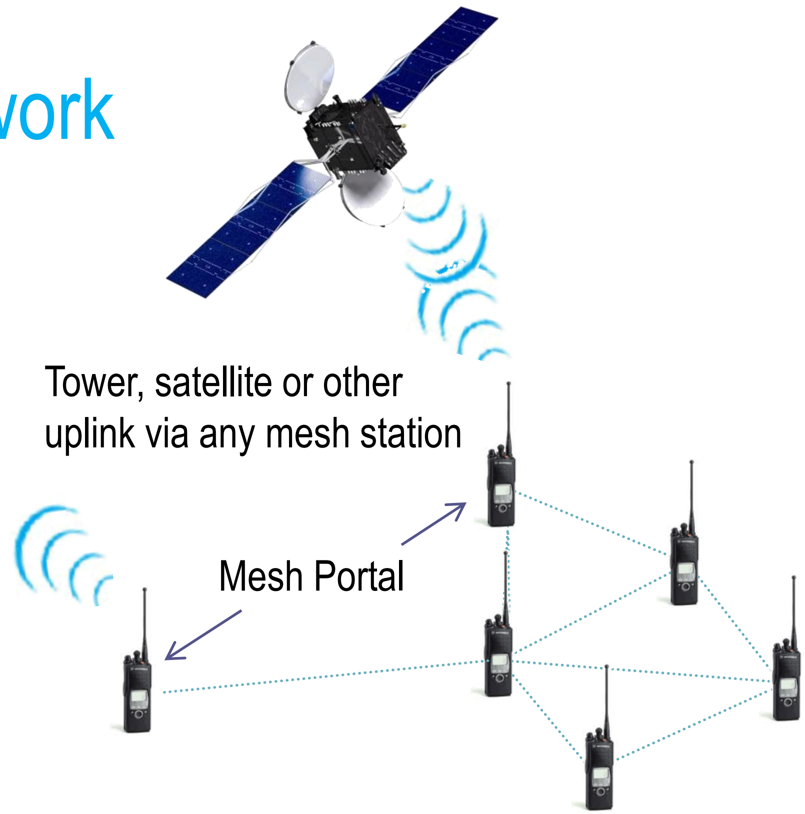
Mesh-Based Talkaround Network

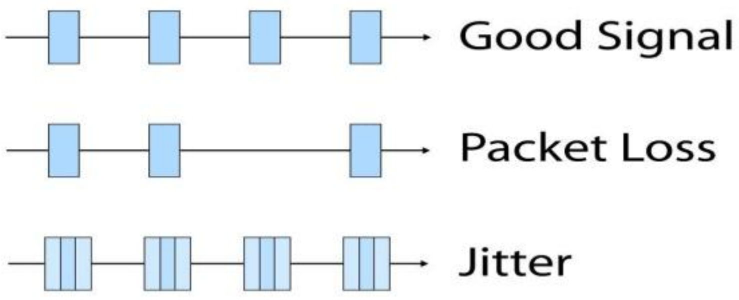
- IEEE 802.11s [9] supports
  - Self-forming
  - Self-healing
  - Peer-to-peer
    - Security
    - QoS
    - Powersave
    - PTT?
  - Mesh portals for uplink to the internet or to a central control network



Approximately 32 nodes per mesh result in manageable routing

Voice Quality Considerations

- Voice packet stream is a series of short packets (100-200 usec, depending on the CODEC) separated by gaps on the order of 20 msec. To optimize voice quality, packets need to be recovered at the receiver at regular intervals (i.e. isochronously).
- ITU has defined voice quality standards with R-Factor being commonly used as a VoIP metric



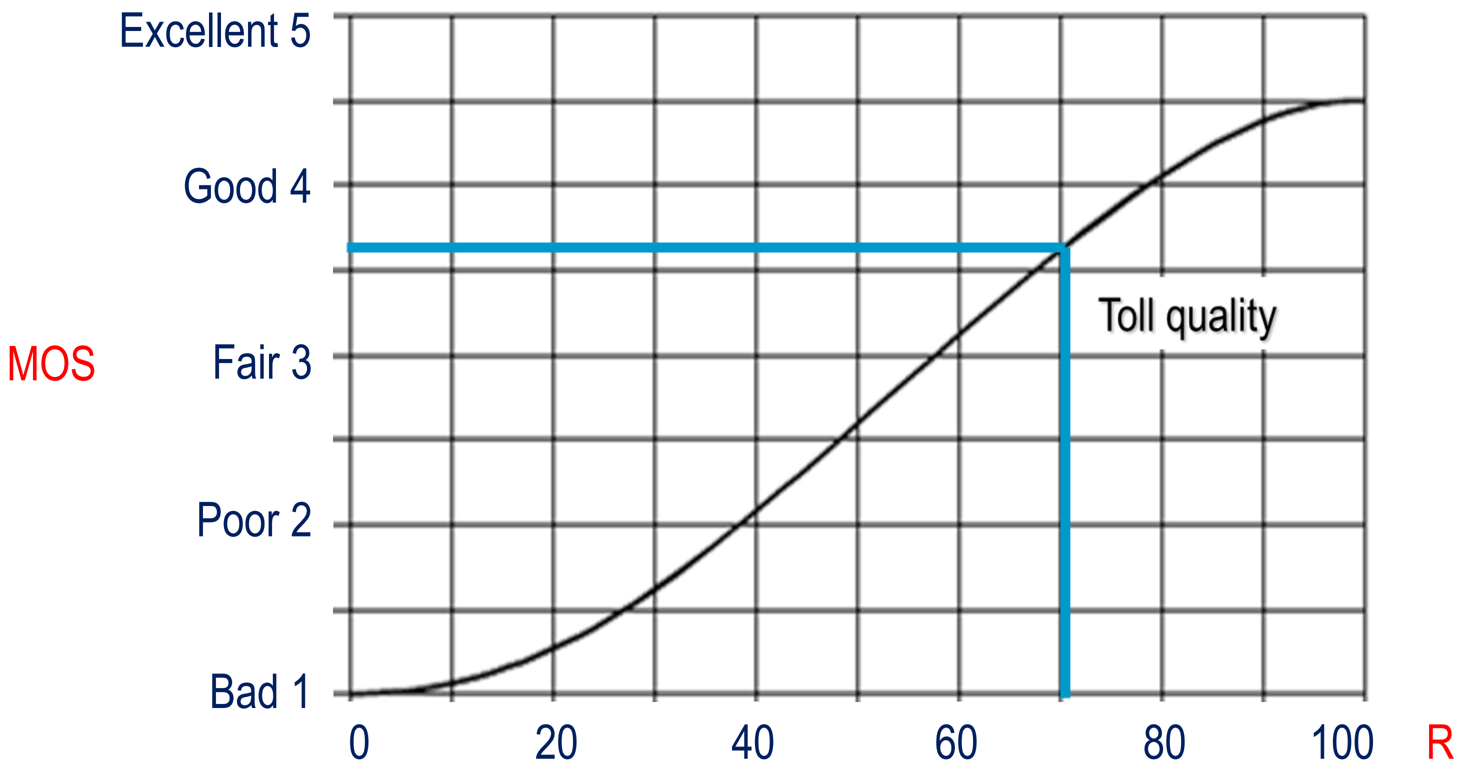
Delay, jitter (packet to packet delay variation through the network) and packet loss result in degraded voice quality.

ITU E-Model Parameters to Compute R-Factor

Parameter	Abbr.	Unit	Default Value	Permitted Range
Send Loudness Rating	SLR	dB	+8	0 … +18
Receive Loudness Rating	RLR	dB	+2	-5 … +14
Sidetone Masking Rating	STMR	dB	15	10 … 20
Listener Sidetone Rating	LSTR	dB	18	13 … 23
D-Value of Telephone, Send Side	Ds	-	3	-3 … +3
D-Value of Telephone Receive Side	Dr	-	3	-3 … +3
Talker Echo Loudness Rating	TELR	dB	65	5 …65
Weighted Echo Path Loss	WEPL	dB	110	5 ... 110
Mean one-way Delay of the Echo Path	T	ms	0	0 … 500
Round-Trip Delay in a 4-wire Loop	Tr	ms	0	0 … 1000
Absolute Delay in echo-free Connections	Ta	ms	0	0 … 500
Number of Quantization Distortion Units	qdu	-	1	1 … 14
Equipment Impairment Factor	Ie	-	0	0 … 40
Packet-loss Robustness Factor	Bpl	-	1	1 … 40
Random Packet-loss Probability	Ppl	%	0	0 … 20
Circuit Noise referred to 0 dBr-point	Nc	dBmOp	-70	-80 … -40
Noise Floor at the Receive Side	Nfor	dBmp	-64	-
Room Noise at the Send Side	Ps	dB(A)	35	35 … 85
Room Noise at the Receive Side	Pr	dB(A)	35	35 … 85
Advantage Factor	A	-	0	0 … 20

R-Factor to MOS Conversion

- MOS (mean opinion score) uses a wide range of human subjects to provide a subjective quality score (ITU-T P.800); E-Model computes Rating Factor or R-Factor as a function of delay, packet loss and other variables (ITU-T G.107)

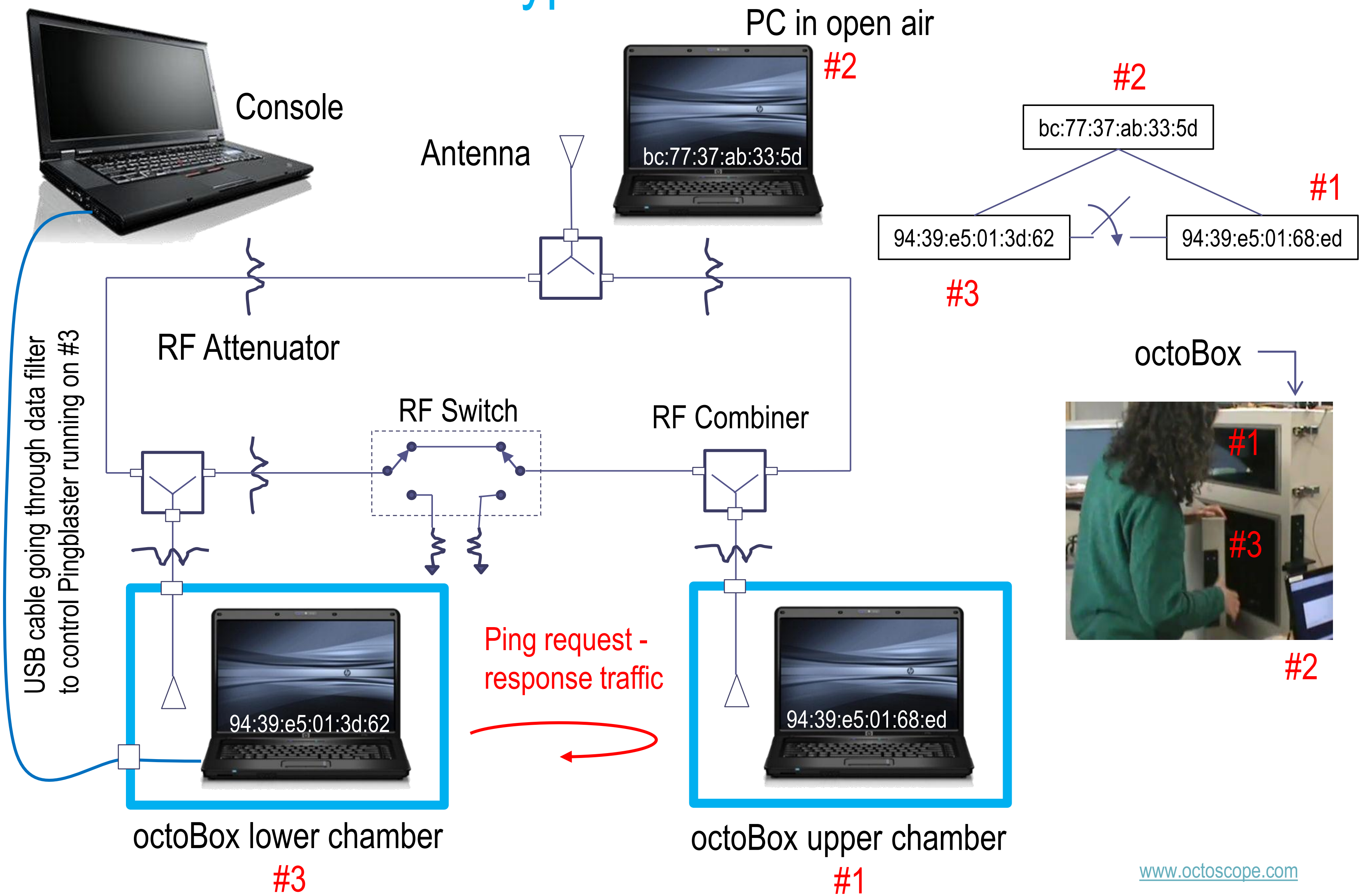


Challenges of Mobile Mesh for PTT

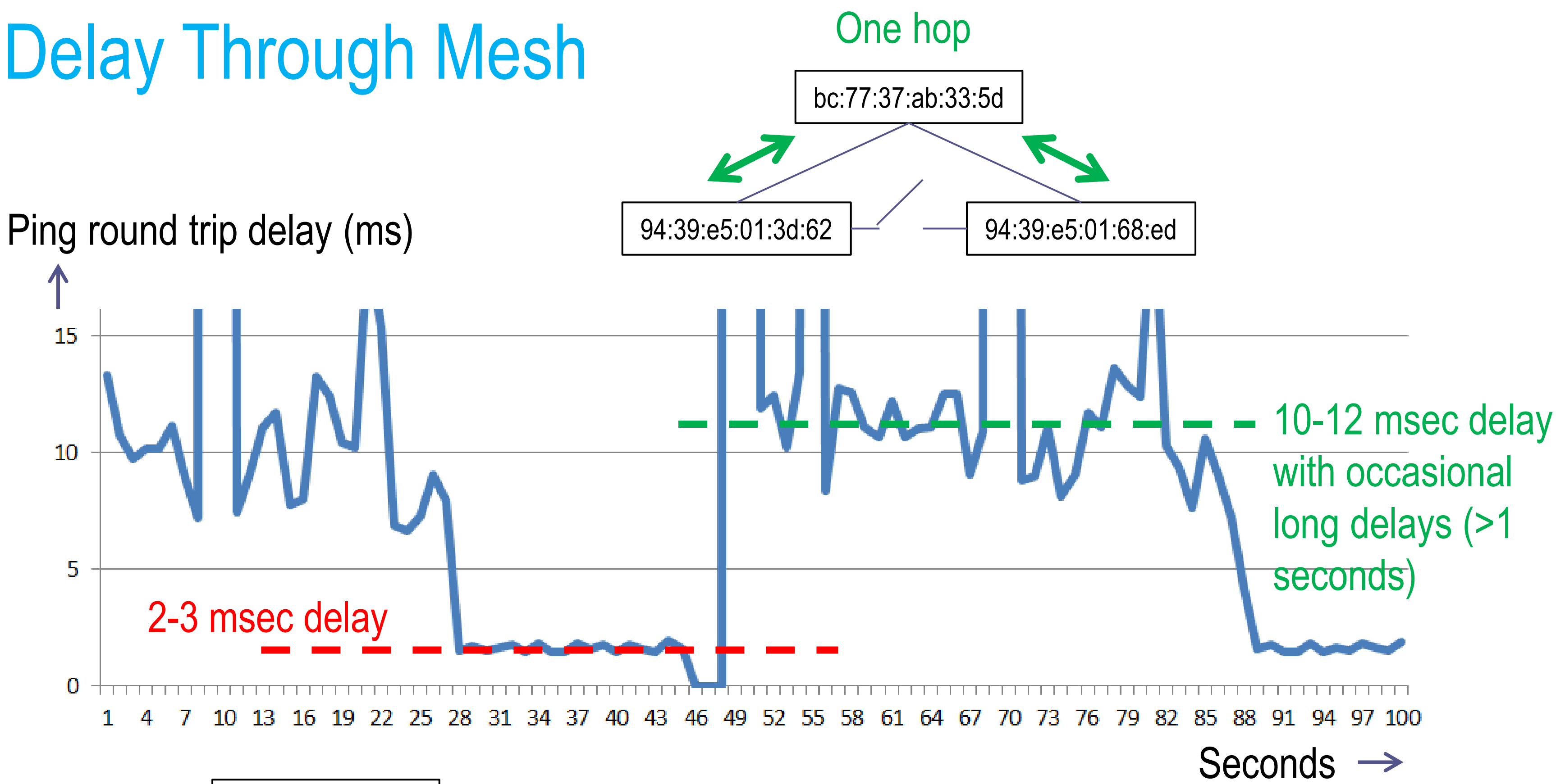
- Bursty packet loss due to handsets moving around
  - Loosing neighbor connections and associating with new neighbors
- … snowballs into excessive routing and rout discovery traffic from conventional VoIP/SIP
- Irregular delays due to traffic traveling through variable number of hops
- Inefficient routing
  - Hysteresis

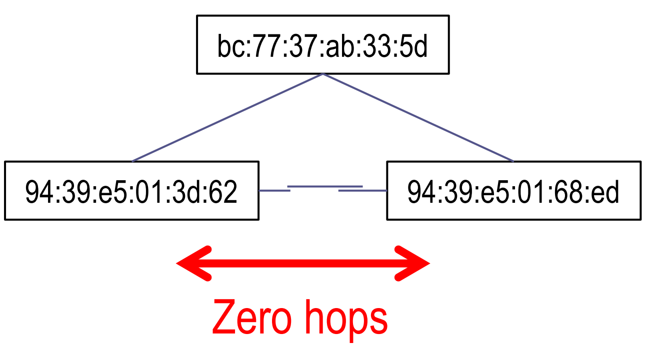
Video of test is available
at www.octoscope.com/testbed

Mesh Testbed Prototype



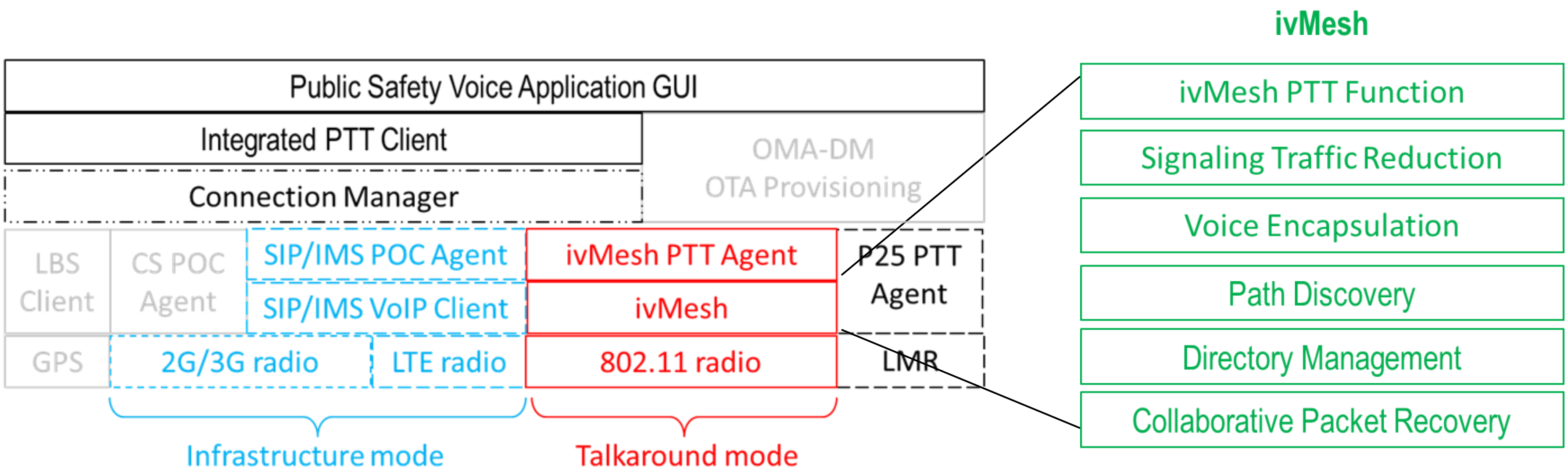
Delay Through Mesh





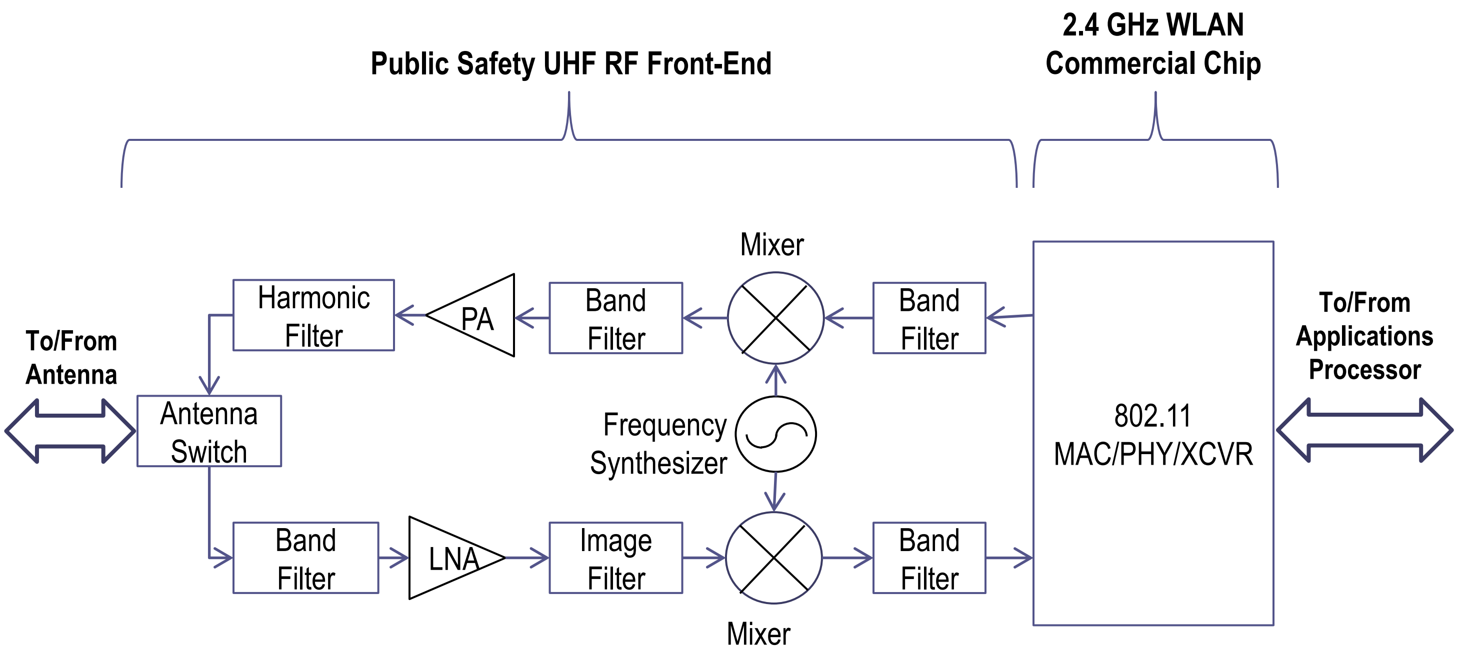
Pingblaster application	BATMAN control app
BATMAN 2011.3.0 driver	
Linux kernel 2.6.38	
Linux Mint distribution v11	

ivMesh™ Architecture



- Patent-pending ivMesh architecture incorporates algorithms to enable mission-critical voice to operate over mesh [4]

VHF/UHF Front End for 802.11



- Increase the operating range of 802.11 radio by translating operating frequencies down to the VHF/UHF region into the White Spaces [10, 11] or 900 MHz band
  - We would prefer to use the PS 700 MHz band but FCC disallows transmissions other than LTE Release 8 in this band [1]

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PS = public safety
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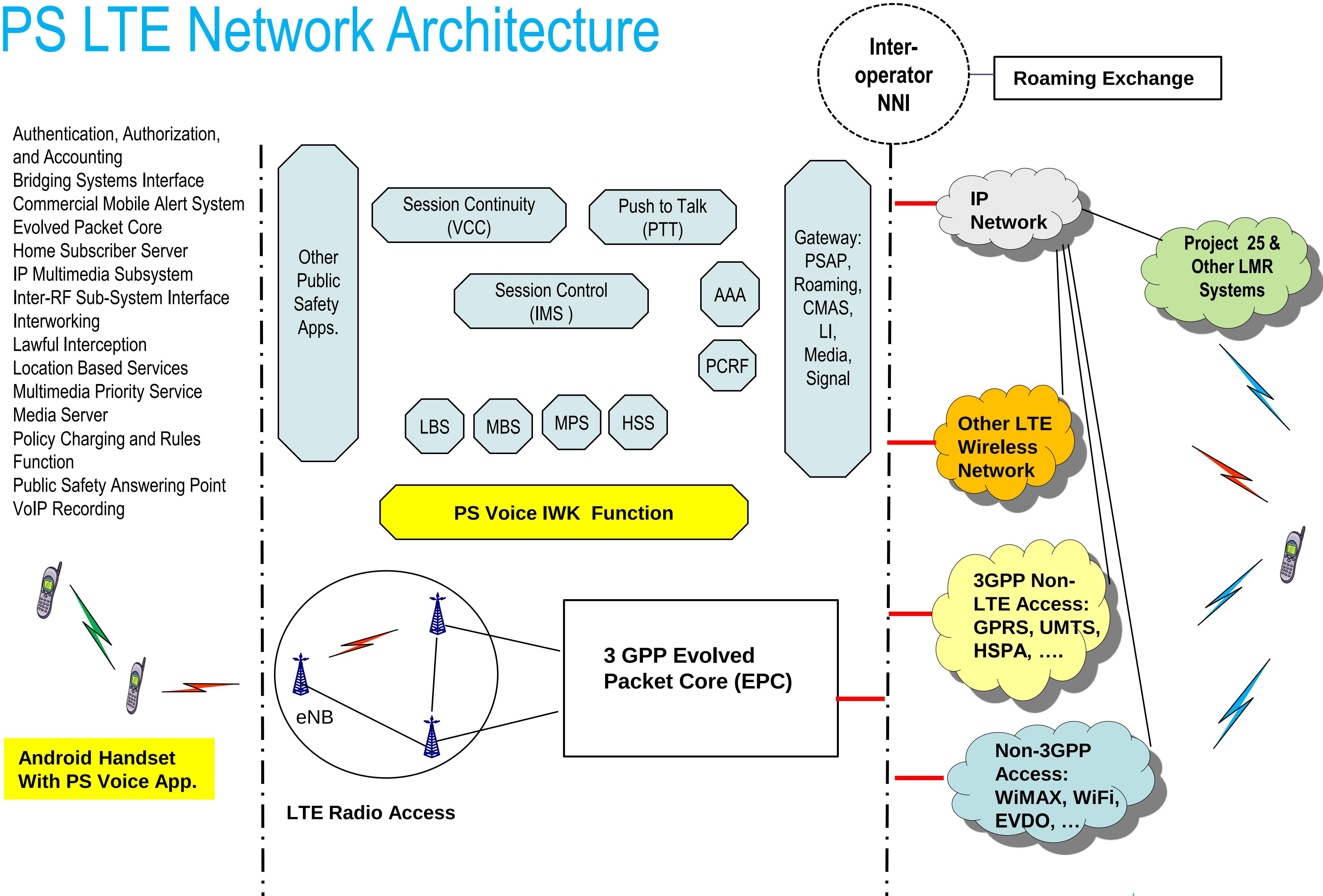
LTE = long term evolution

PS LTE Network Architecture

AAA	Authentication, Authorization, and Accounting
BSI	Bridging Systems Interface
CMAS	Commercial Mobile Alert System
EPC	Evolved Packet Core
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
ISSI	Inter-RF Sub-System Interface
IWK	Interworking
LI	Lawful Interception
LBS	Location Based Services
MPS	Multimedia Priority Service
MS	Media Server
PCRF	Policy Charging and Rules Function
PSAP	Public Safety Answering Point
VR	VoIP Recording



EPC Interworking Function for PS LTE

- The PS Voice IWK Function

PS Voice IWK Function

  - Maps QoS and priorities between IMS based PS LTE network, legacy P25/LMR and other networks
  - Handles security protocols in the network
  - Ensures seamless voice roaming
  - Ensures inter-RAT voice communications , providing PTT or VoIP service across disparate networks
- The IWK function must interconnect disparate PS services with sufficient speed to keep the network delays low

Small Cells – More Challenging Handoff

- With emergence of 3G and 4G
  - Cells are getting smaller
  - Lower range smaller basestations, Metrocells, are displacing traditional tower-based Macrocells
  - FCC is working to free up more bandwidth and to remove burdensome regulations for microwave backhaul
- This means roaming across small Metrocells on the road will be more challenging as we now have more frequent roaming for any given road trip

Conclusion

- PS LTE
  - May take 5 years to become usable
  - Will initially be deployed in islands of coverage and will need to leverage commercial 2G/3G/LTE networks
- PTT currently not interoperable across different operator's network
- The market needs standards based products to lower cost
  - 3GPP LTE
  - OMA PTT
  - IEEE 802.11s talkaround

For More Information

- White papers, presentations, articles and test reports on a variety of wireless topics

www.octoscope.com

References

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2. octoScope-Telcordia architecture document
3. octoScope ivMesh white paper
4. octoScope-Telcordia, “Considerations for Public Safety Voice Solution – Infrastructure Mode and Interworking”
5. Functional and Interface Standards for NG9-1-1 (i3), version 1.0, Dec. 2007
6. Lynnette Luna, “Research: Public-safety wireless broadband worth $22.3B in 2015”; http://www.fiercebroadbandwireless.com/story/research-public-safety-wireless-broadband-worth-223b-2015/2011-08-12?utm_medium=nl&utm_source=internal
7. Fraunhofer Institute FOKUS, Germany; www.FOKUS.fraunhofer.de/go/ngni; www.FUSECO-Playground.org; www.OpenEPC.net
8. IEEE Draft P802.11-REVmb™/D11, October 2011, “IEEE for Information Technology — Telecommunications and information exchange between systems— Local and metropolitan area networks— Specific requirement. Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications”, incorporating the IEEE Std 802.11s™-2011 Amendment, based on the latest draft of IEEE P802.11s™/D12.0 document dated May 2011

References (Continued)

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10. IEEE P802.11af™/D1.04, October 2011, "Amendment 4: TV White Spaces Operation"
11. TIA-102 (PN-3-3591-UGRV1) TIA TR8 DRAFT 10-08-100-R1; PROJECT 25 SYSTEM AND STANDARDS DEFINITION
12. DHS Compliance Assessment Program http://www.safecomprogram.gov/SAFECOM/currentprojects/project25cap/

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Acronyms

AAA	Authentication, Authorization, and Accounting
BSI	Bridging Systems Interface
CMAS	Commercial Mobile Alert System
EPC	Evolved Packet Core
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
ISSI	Inter-RF Sub-System Interface
IWK	Interworking
LI	Lawful Interception
LTE	Long Term Evolution
MAC	Medium Access Control
MC	Mission Critical
MPS	Multimedia Priority Service
MS	Media Server
OMA-DM	Open Mobile Alliance – Device Management
PCRF	Policy Charging and Rules Function
POC	Push to talk Over Cellular
PS	Presence Server
PSAP	Public Safety Answering Point
PTT	Push To Talk
VR	VoIP Recording
XDMS	XML Document Management Server

Technology Background

White Spaces – Brief History

- NPRM in May 2004
  - http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-04-113A1.pdf
- November 4, 2008 FCC approved Report & Order 08-260, allowing unlicensed use of TV band spectrum
  - http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-01-260A1.pdf
- February 17, 2009, the FCC released the final rules for "Unlicensed Operation in the TV Broadcast Bands"
  - http://edocket.access.gpo.gov/2009/pdf/E9-3279.pdf
- Sep 23, 2010 The FCC reaffirmed a 2008 decision to open the broadcast airwaves

THE WALL STREET JOURNAL.
WSJ.com
SEPTEMBER 24, 2010
FCC to Open Unused TV Airwaves, Extending Wi-Fi's Possibilities

NPRM = Notice of Proposed Rule Making

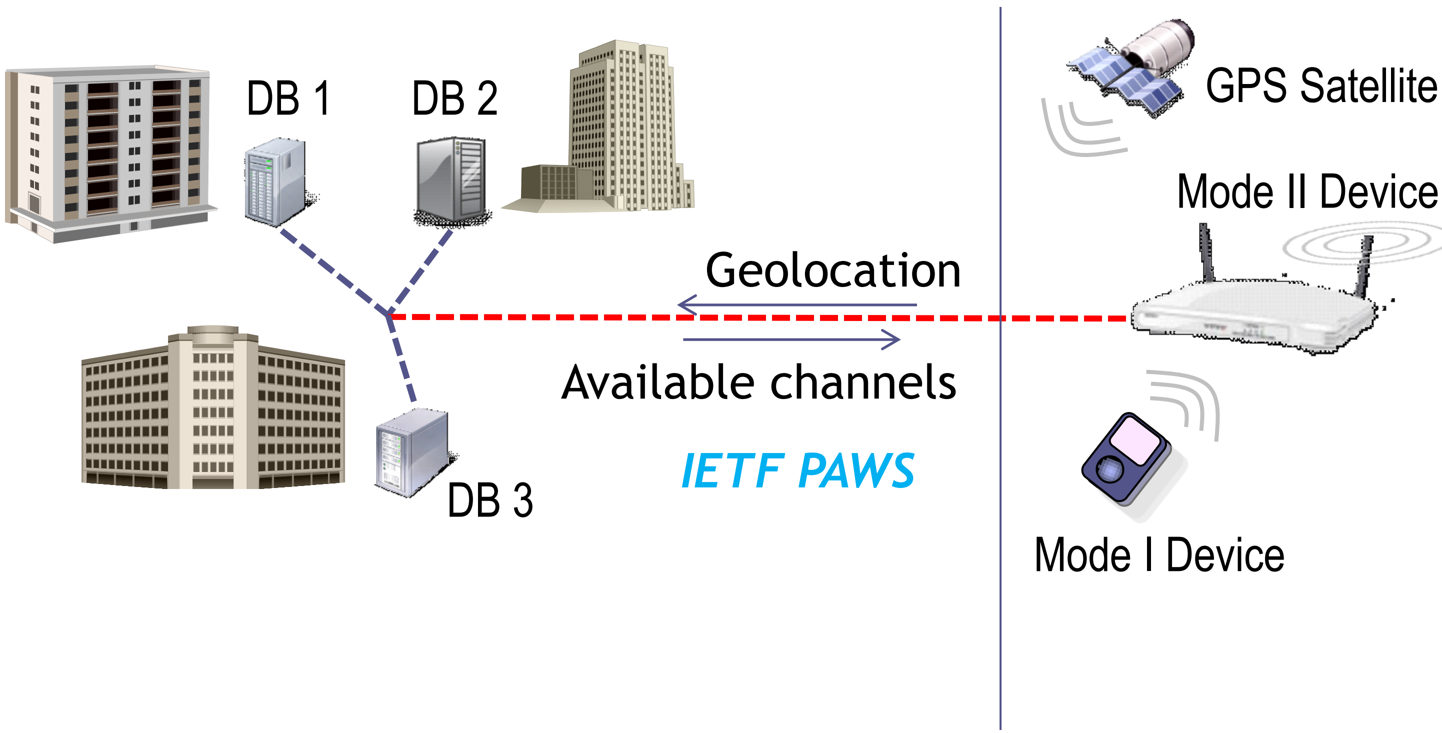
European White Space Regulation

- Ofcom (UK) is in the process of making this Digital Dividend band available
  - https://mentor.ieee.org/802.18/dcn/09/18-09-0059-00-0000-ofcom-update-on-the-digital-dividend.ppt
  - http://stakeholders.ofcom.org.uk/consultations/geolocation/summary
- ECC of CEPT in Europe has published a report on White Spaces in Jan 2011
  - http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP159.PDF
- China TV band regulations expected in 2015

ECC = Electronic Communications Committee
CEPT = European Conference on Postal and Telecommunications

White Space Spectrum Access

Spectrum access is database-driven. Database is designed to protect licensed TV transmitters from interference by unlicensed White Spaces devices.



Source: Neal Mellen, TDK

IETF = internet engineering task force
PAWS = protocol to access white space

TV Channels and White Space

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 2-4 through 14-20

White Spaces: channels 2-4 through 21-51*

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

Transition from NTSC to ATSC (analog to digital TV) 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

octoScope

Unlicensed Bands and Services

Frequency range	Bandwidth	Band	Notes
433.05 – 434.79 MHz	1.74 MHz	ISM	Europe
420–450 MHz	30 MHz	Amateur	US
868-870 MHz	2 MHz	ISM	Europe
902–928 MHz	26 MHz	ISM-900	Region 2
2.4–2.5 GHz	100 MHz	ISM-2400	International allocations (see slides 7, 8 for details)
5.15–5.35 GHz	200 MHz	UNII-1,2	
5.47–5.725 GHz	255 MHz	UNII-2 ext.	
5.725–5.875 GHz	150 MHz	ISM-5800 UNII-3	
24–24.25 GHz	250 MHz	ISM	US, Europe
57-64 GHz 59-66 GHz	7 GHz	ISM	US Europe

Medical devices
Remote control

RFID and other unlicensed services

Smart meters, remote control, baby monitors, cordless phones

802.11b/g/n, Bluetooth
802.15.4 (Bluetooth, ZigBee), cordless phones

802.11a/n, cordless phones

Emerging 802.11ad
802.15.3c, ECMA-387
WirelessHD

Americas, including US and Canada; Australia, Israel

European analog of the ISM-900 band

ISM = industrial, scientific and medical
UNII = unlicensed national information infrastructure