Wireless Technologies for the Enterprise

Interop/NYC

October 2010

Fanny Mlinarsky, octoScope

Agenda

- How smartphones are changing the network
- Wireless technologies
- Wi-Fi update
- White spaces
- Concluding thoughts

Smartphones Need Wireless Bandwidth

- Smartphone market is set for fast growth
  - Converging on 2 platforms: Apple iPhone and Google Android
- Operators, accustomed to having tight reigns over traffic on their networks, have now lost control over hundreds of thousands of mobile applications consuming wireless bandwidth.

By the end of 2010, smartphone sales will pass 250 million units worldwide - a rise of over 35% and representing 1 in 5 of all handsets sold.

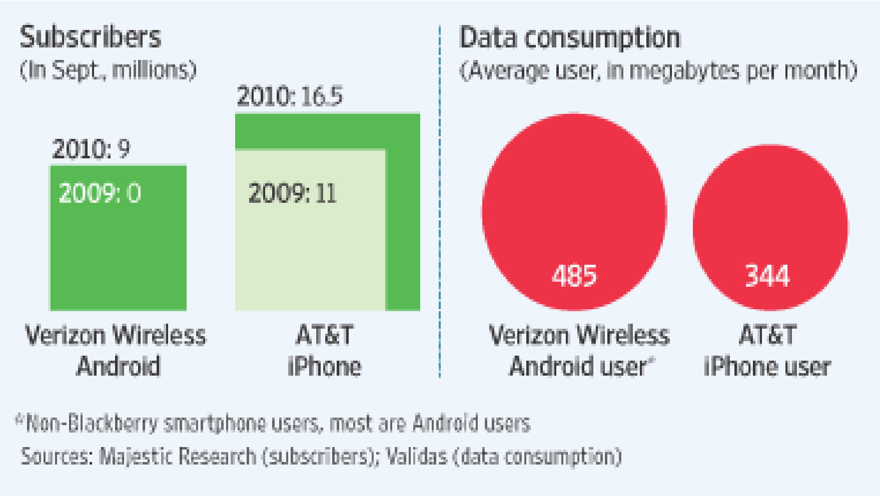
20% market share smartphones consume over 80% of mobile bandwidth.

Source: Informa Telecoms & Media

Smartphones Load Mobile Nets

- Priority for carriers like Verizon and AT&T is to optimize smartphone user experience
  - Ensure adequate bandwidth on their networks
  - Verify application behavior in the presence of network impairments (delay, jitter, packet loss), roaming and physical layer conditions
  - Optimize range and throughput on the physical layer (radio and antenna)
- Verizon's ODI and other certification programs are a vehicle to optimize smartphone user experience.

Verizon "has been meeting with Apple, adding capacity and testing its networks to prepare for the heavy data load from iPhone users. The carrier is seeking to avoid the kind of public-relations hit AT&T Inc. took when iPhone users overtaxed its network", WSJ.



Smartphones Drive Mobile Broadband

- Traditionally voice-centric mobile industry is bracing for the flood of smartphones that are...
  - Running data-centric apps
  - Equipped with multiple radios

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

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

WEB ACCESS

Email

Skype

VPN

File Sharing

Motorola's Droid Pro features corporate email, a unified calendar with additional work tools and Quickoffice Mobile Suite

Source: FireceWireless

Complex Smartphone Technology

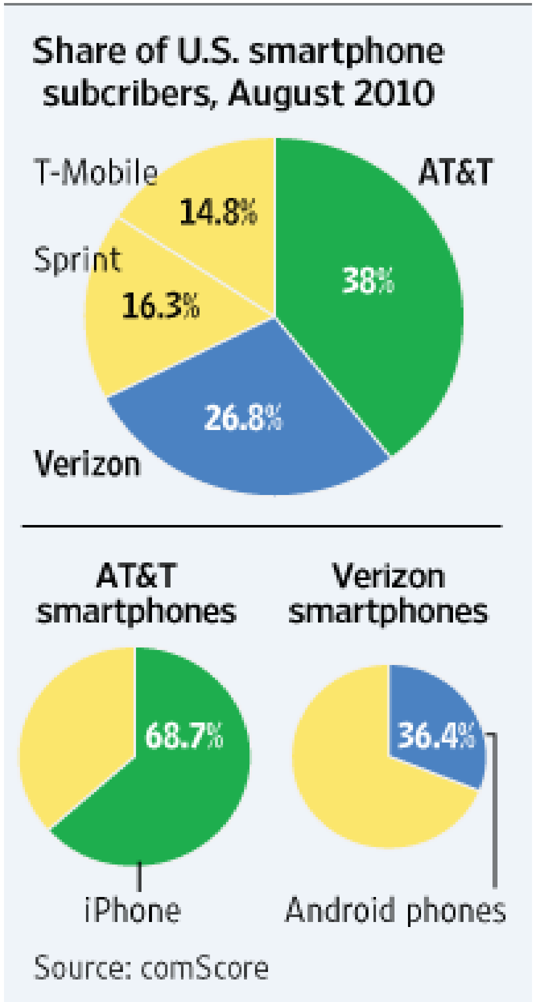
- New smartphone challenges include
  - Performance and responsiveness of apps
  - Roaming functionality and speed
  - Simultaneous operation of multiple radios
  - Battery life

Applications	Radio interfaces
Circuit calls	Bluetooth
Web access	Wi-Fi
Email	CDMA
VPN	WCDMA/HSxPA
File sharing	GSM
Handovers	LTE

Exponential # of Use Cases

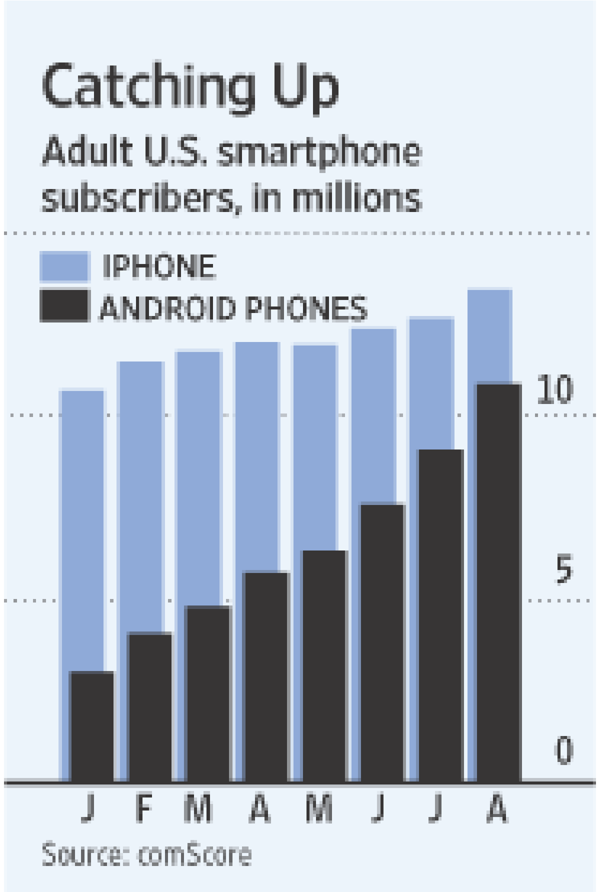
Operators Focusing on the Enterprise

- Smartphones are computers connected over the operator network to enterprise IT services
  - Email, file sharing, VPN, collaborative apps
- Due to explosive growth of smartphones, pads and mobile applications, mobility is now part of the Enterprise IT's budget.
- Operators can use this budget to optimize IT user experience.



iPhone vs. Android

- In the last 6 months, Android has been the most popular OS; BlackBerry and Apple are equal contenders for 2nd place.
- 100,000 Android applications are available to download.
- Major adopters of Android
  - Motorola, Samsung, HTC
- Next version of iPhone will support Verizon's CDMA network; iPhone 4 supports AT&T's GSM and UMTS



Transition to LTE

- By the end of 2010 Verizon plans to have LTE networks in 38 cities, including New York, San Francisco, Los Angeles and Boston.
- LTE, being the first all-IP mobile network, will present operators with new challenges
  - Ensuring end-to-end network QoS
  - High-quality service delivery
  - IMS for the delivery of multimedia services

Applications need to work during handovers among 2G/3G/4G RANs.

More than a dozen LTE networks will go live by the end of this year and more than 60 operators have committed to LTE deployments.

Source: Infonetics Research

101 LTE network deployments are in progress in 41 countries around the world.

Source: GSA

The G's

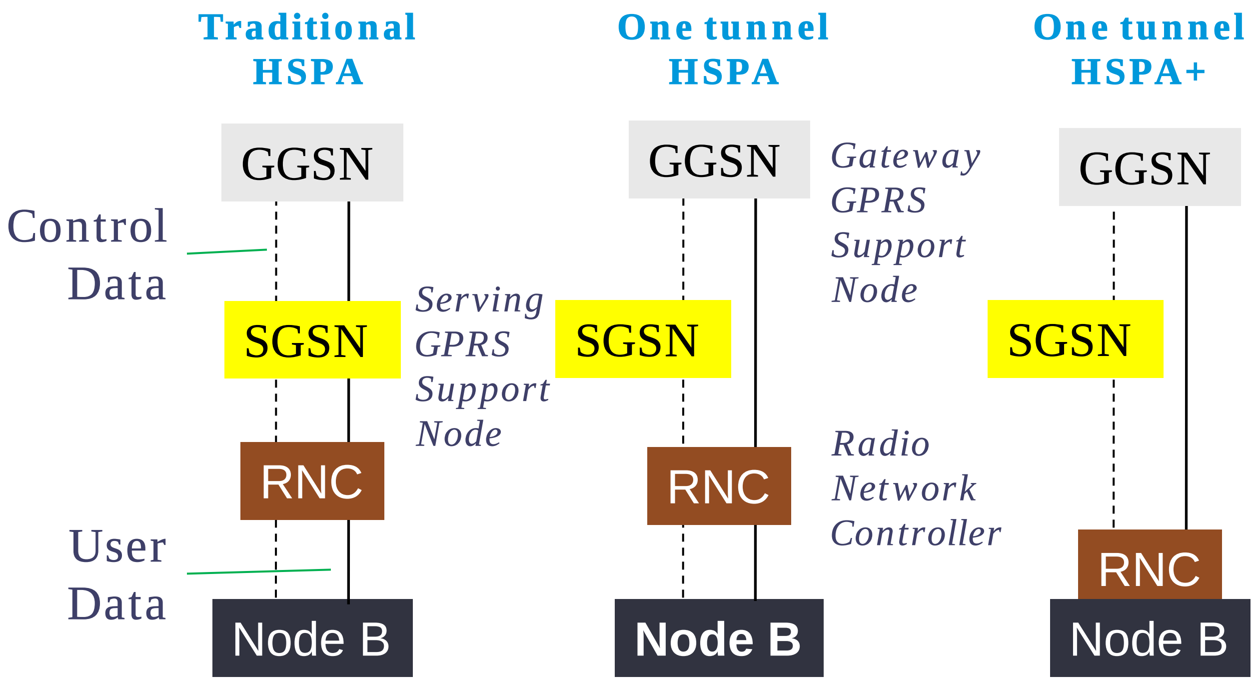
G		Peak Data Rate (Mbps)	
		Downlink	Uplink
1	Analog	19.2 kbps	
2	Digital – TDMA, CDMA	14.4 kbps	
3	Improved CDMA variants (WCDMA, CDMA2000)	144 kbps (1xRTT); 384 kbps (UMTS); 2.4 Mbps (EVDO)	
3.5	HSPA (today)	14 Mbps	2 Mbps
3.75	HSPA (Release 7) DL 64QAM or 2x2 MIMO; UL 16QAM	28 Mbps	11.5 Mbps
	HSPA (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)

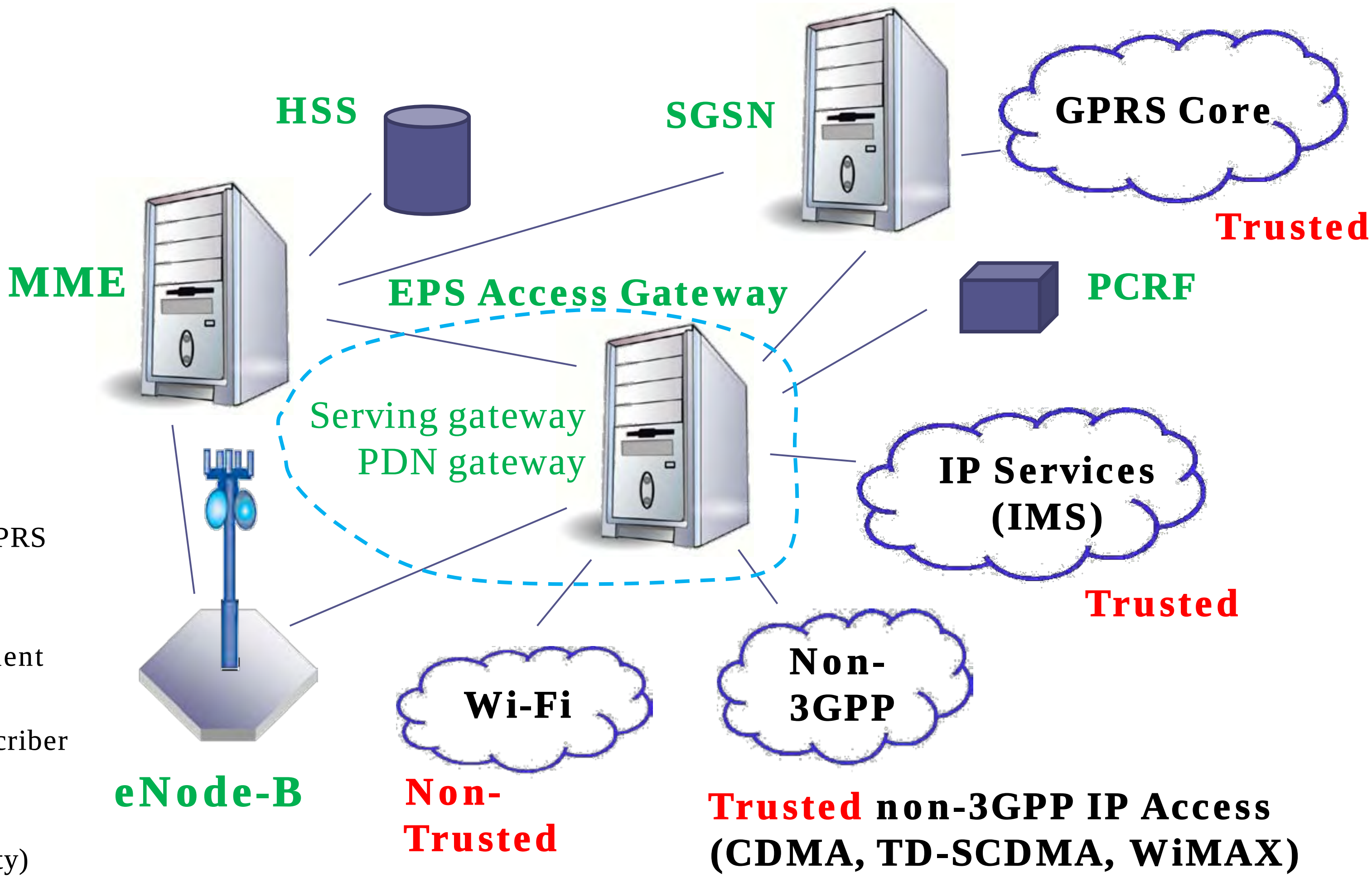
HSPA and HSPA+

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



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

LTE EPS (Evolved Packet System)



SGSN (Serving GPRS Support Node)

PCRF (policy and charging enforcement function)

HSS (Home Subscriber Server)

MME (Mobility Management Entity)

PDN (Public Data Network)

Flat, low-latency architecture

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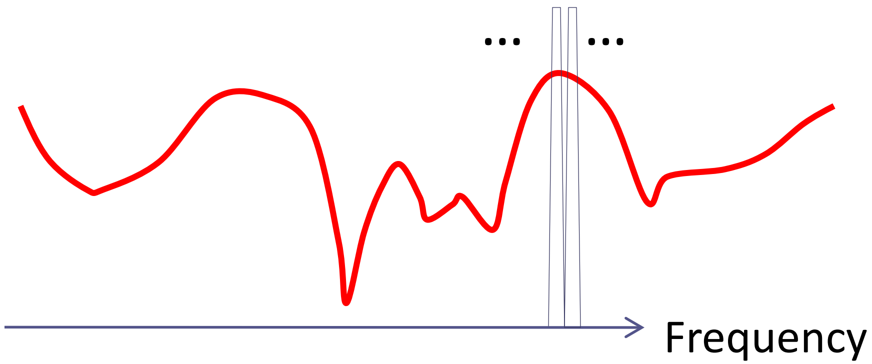
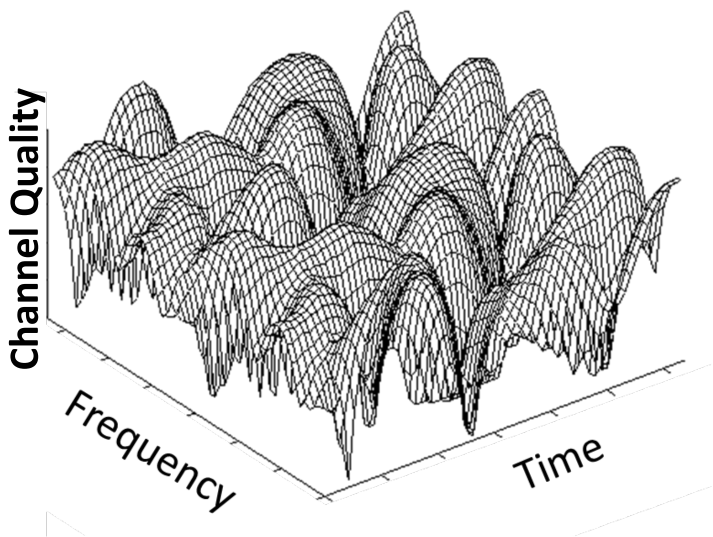
OFDM

- OFDM transforms a frequency- and time-variable fading channel into parallel correlated flat-fading channels, eliminating the need for complex equalization



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



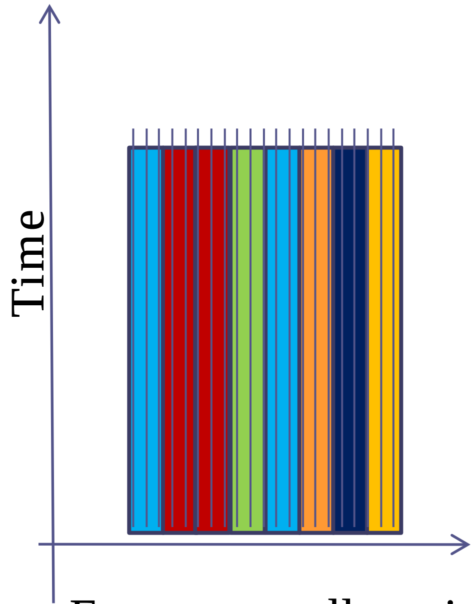
OFDM combined with MIMO combats time- and frequency-variability of the wireless channel

OFDMA

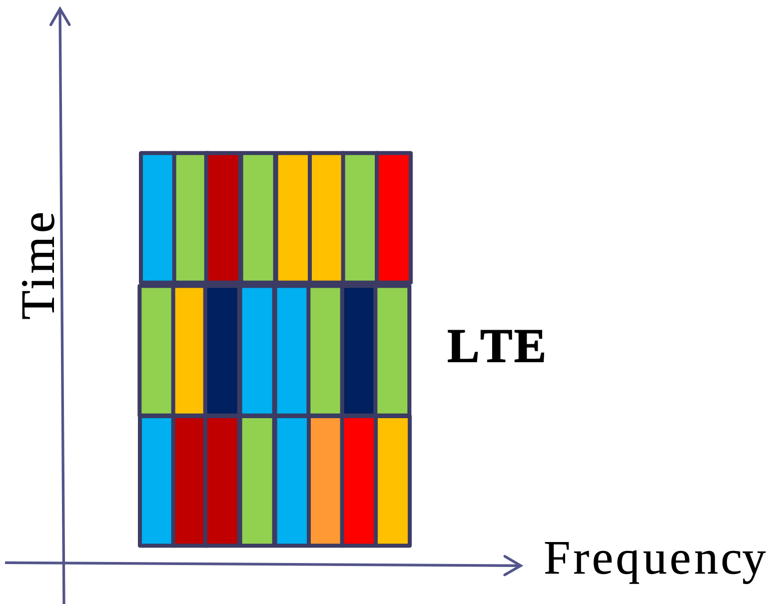
OFDM is a modulation scheme

OFDMA is a modulation and access scheme

Multiple Access



Frequency allocation per user is continuous vs. time

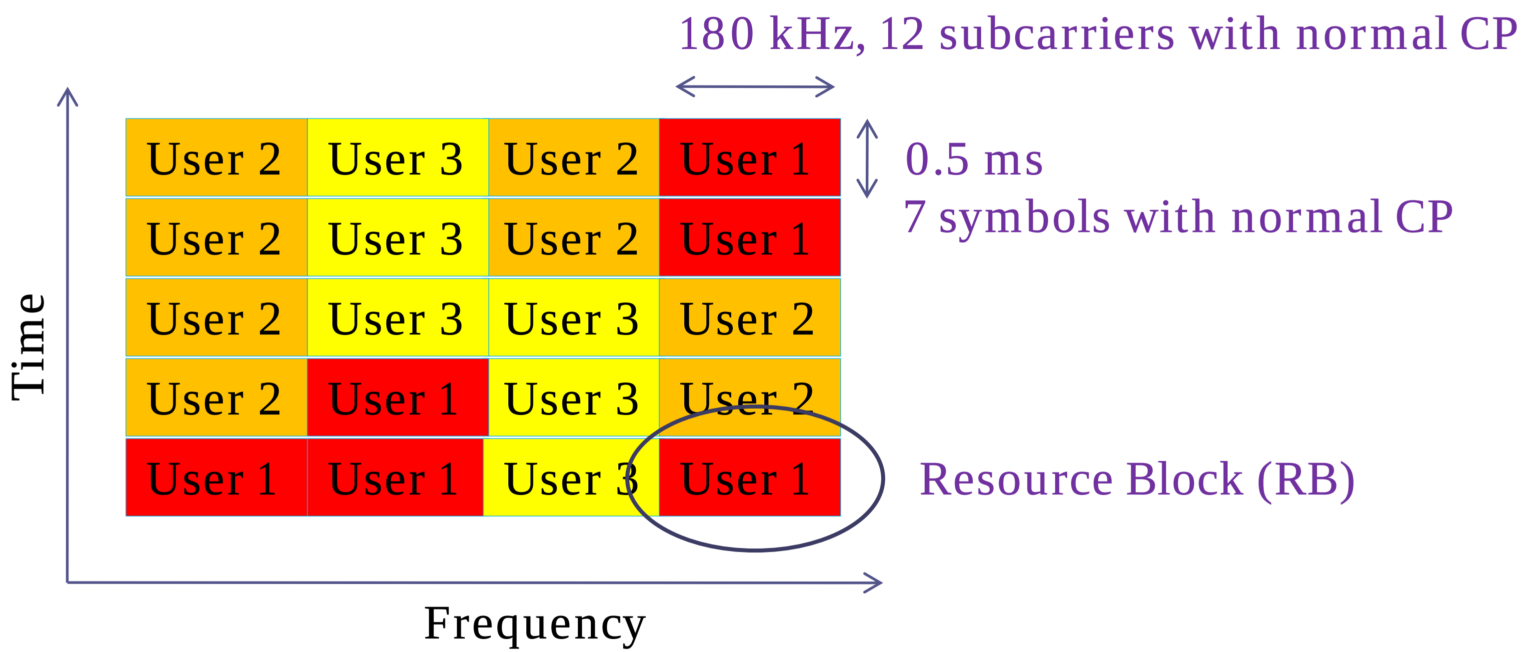


Frequency per user is dynamically allocated vs. time slots

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

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

LTE Resource Allocation

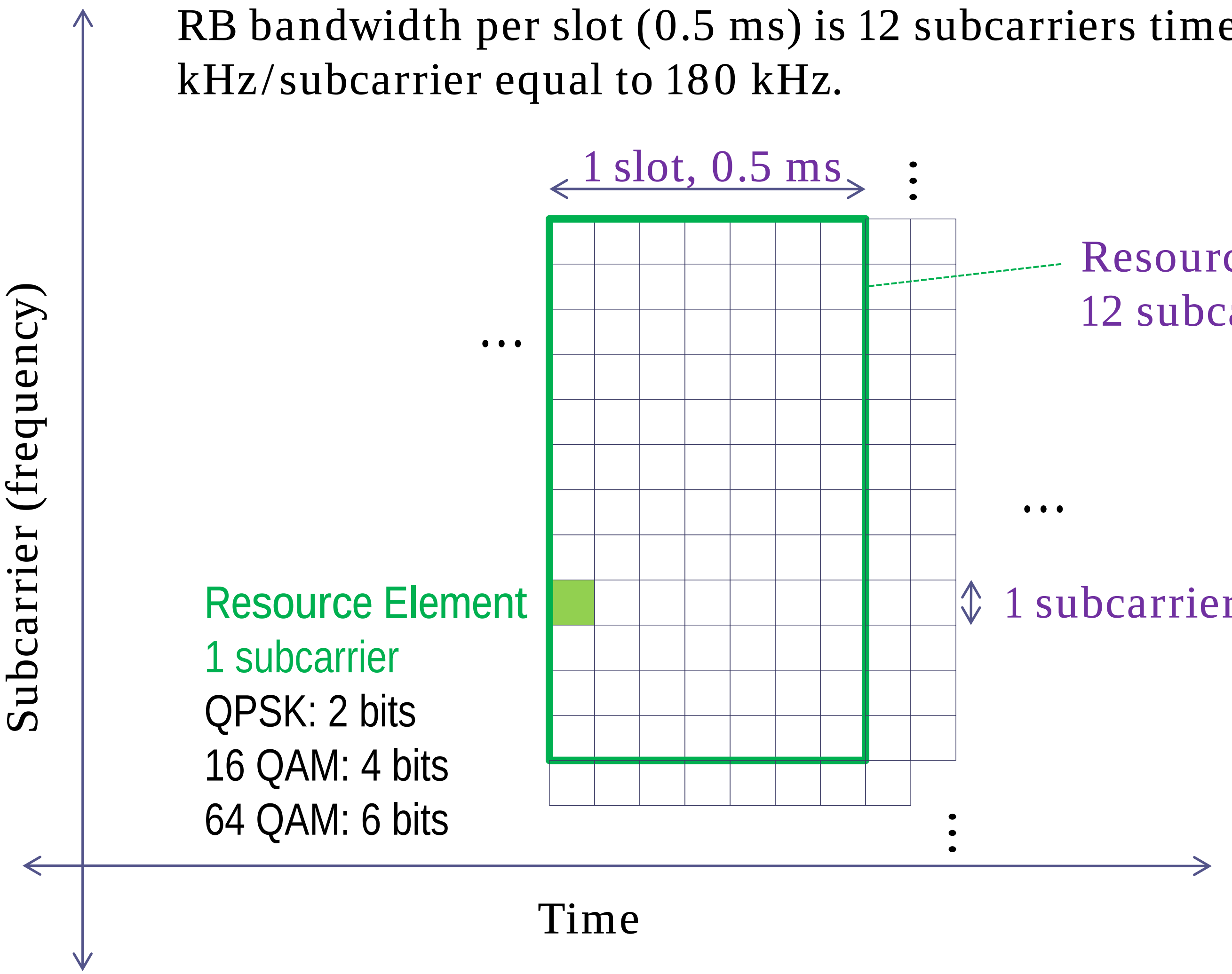


- Resources are allocated per user in time and frequency. RB is the basic unit of allocation.
- RB is 180 kHz by 0.5 ms; typically 12 subcarriers by 7 OFDM symbols, but the number of subcarriers and symbols can vary based on CP

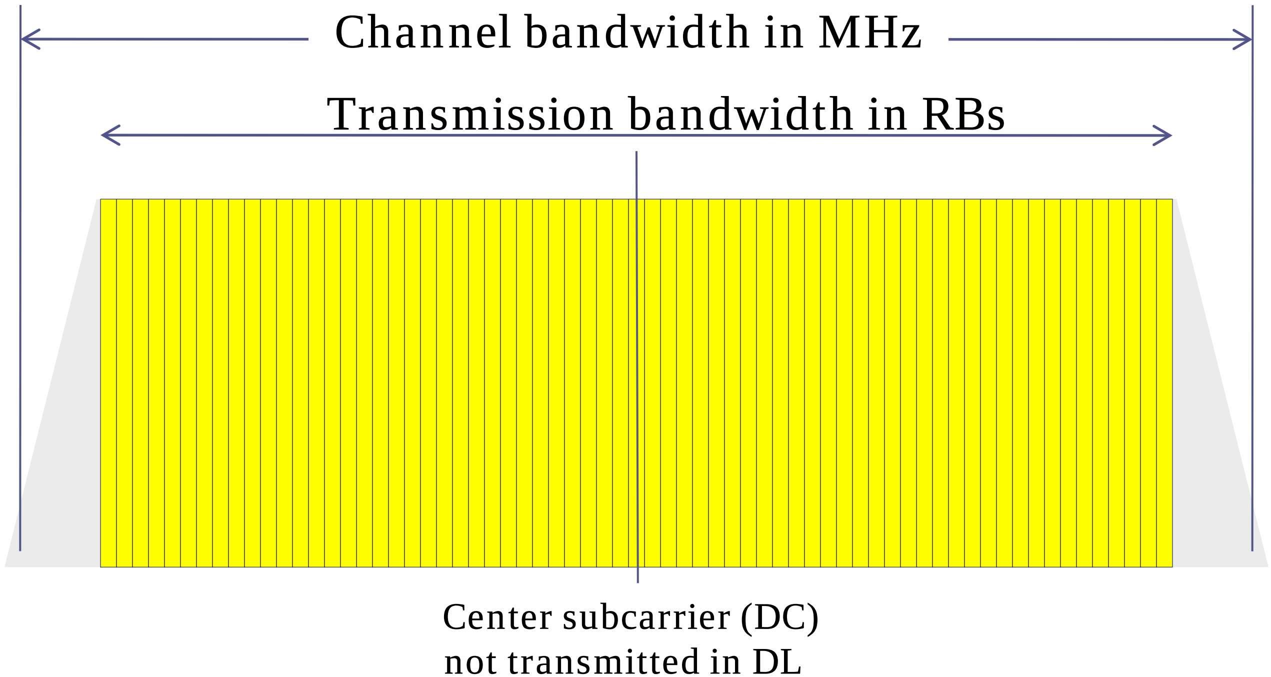
CP = cyclic prefix, explained ahead

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.



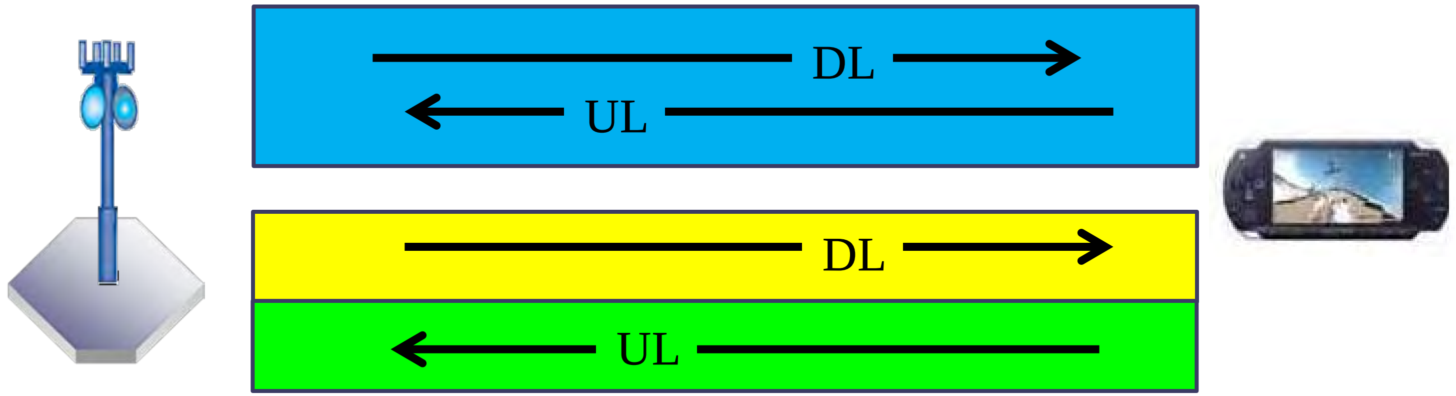
LTE Scalable Channel Bandwidth



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	

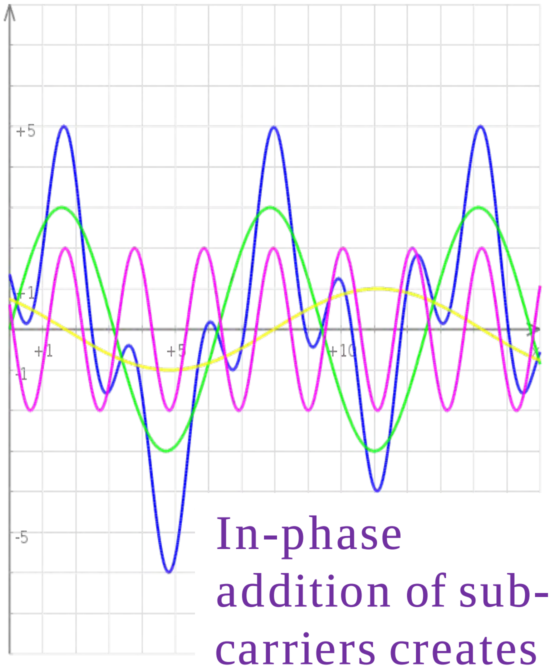
FDD vs. TDD

- 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



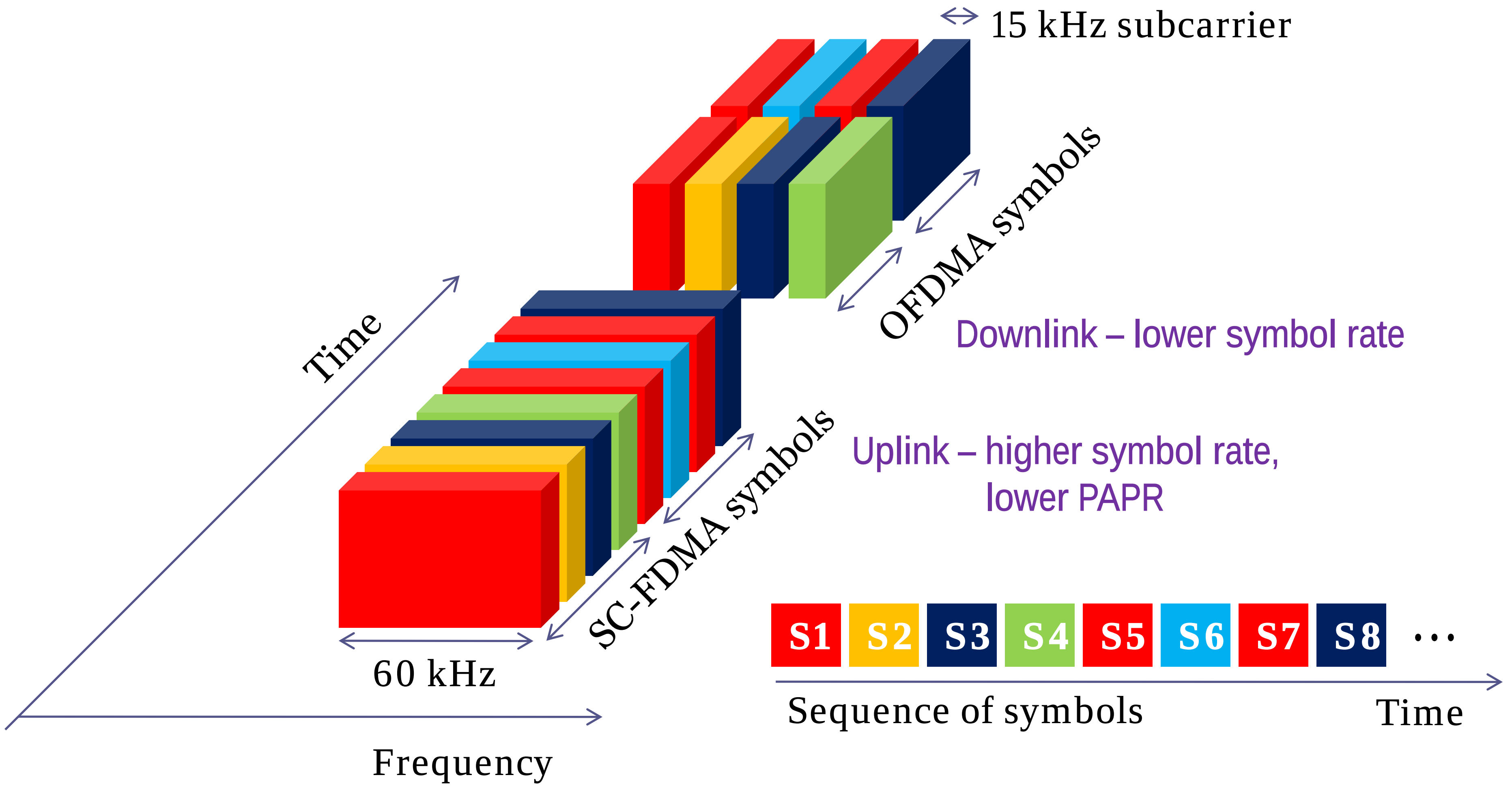
OFDMA vs. SC-FDMA (LTE Uplink)

- 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



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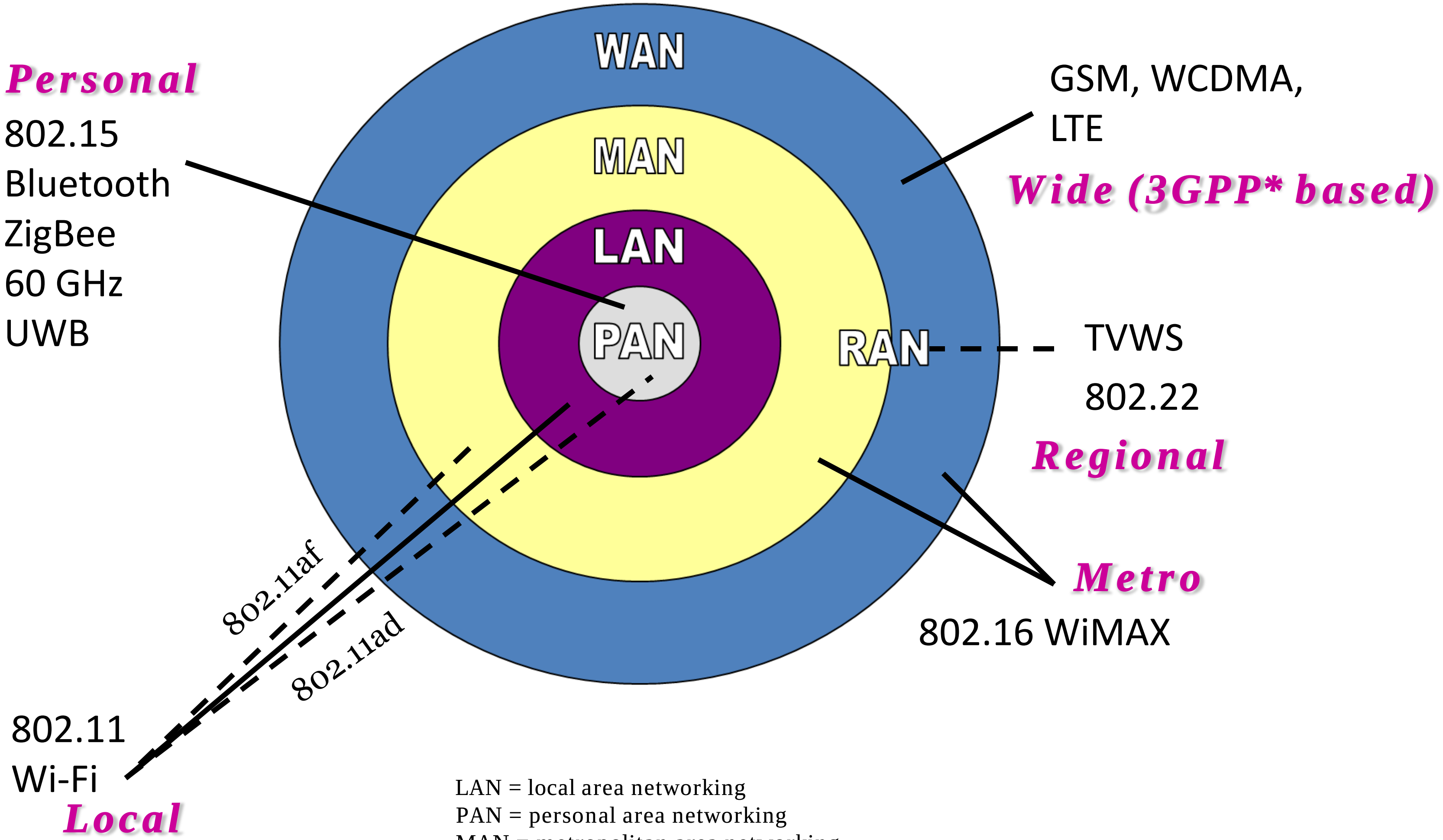
IEEE 802 Wireless



LAN = local area networking
PAN = personal area networking
MAN = metropolitan area networking
WAN = wide area networking
RAN = regional area networking
TVWS = television white spaces
3GPP = 3rd generation partnership project

IEEE 802.11 Active Task Groups

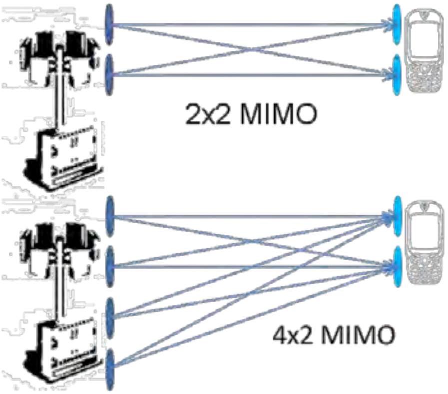
- **TGp** – Wireless Access Vehicular Environment (WAVE)
- **TGs** – ESS Mesh Networking
- **TGu** – InterWorking with External Networks
- **TGv** – Wireless Network Management
- **TGz** – Direct Link Setup
- **TGaa** – Robust streaming of AV Transport Streams
- **TGac** – VHTL6 (very high throughput < 6 GHz)
- **TGad** – VHT 60 GHz
- **TGae** – Prioritization of Management Frames
- **TGaf** – TV Band Operation

http://grouper.ieee.org/groups/802/11

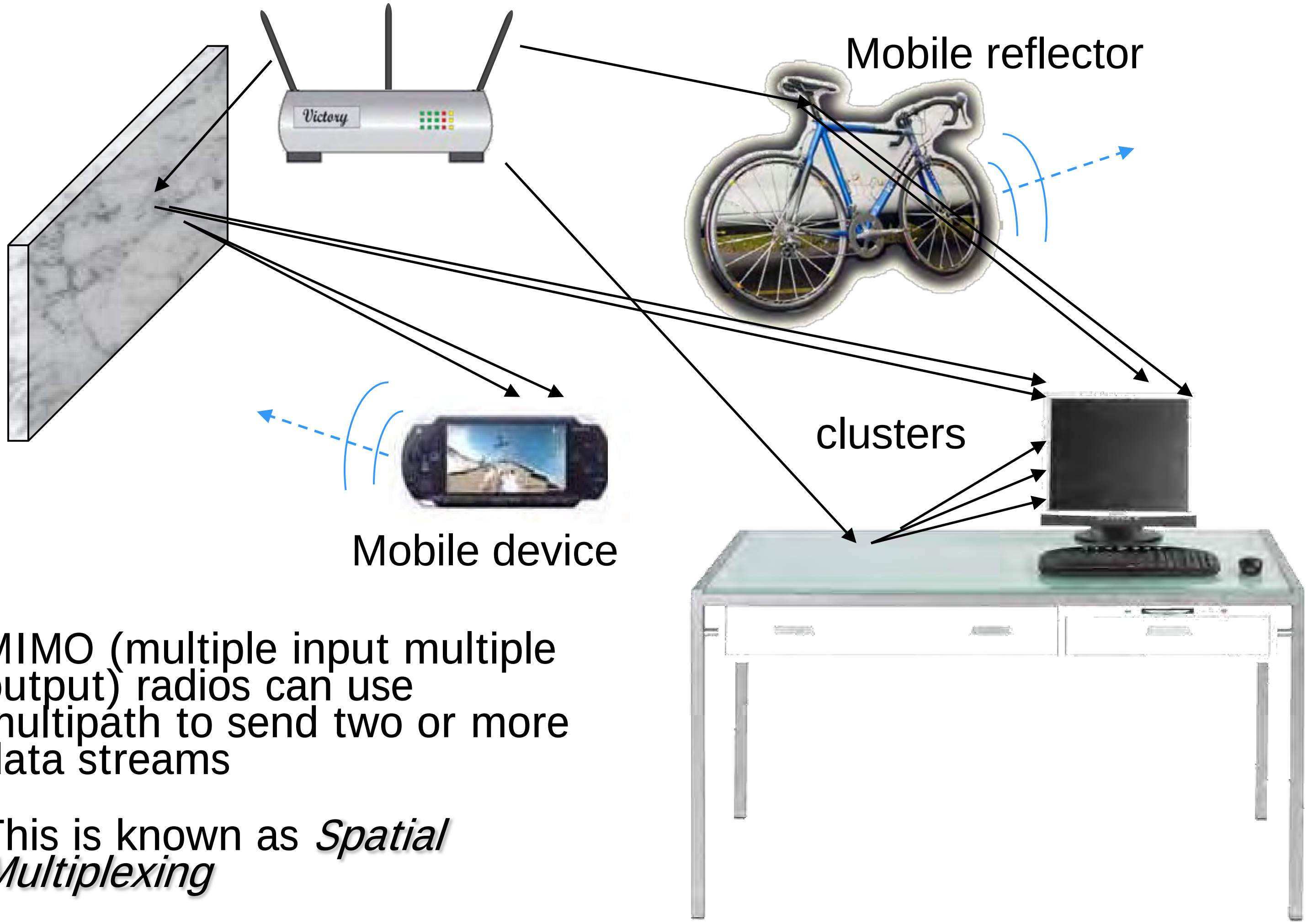
TG = task group

802.11n MIMO Technology

- Goal: 100 Mbps of real throughput; data rate up to 600 Mbps with 4 spatial streams in a 40 MHz channel
- PHY improvements
  - MIMO – Spatial Multiplexing, Beamforming, up to 4x4 MIMO, 40 MHz channels
- MAC improvements
  - Frame aggregation, block acknowledgements
- Battery life improvements for handsets
  - Sleep mode with scheduled packet delivery



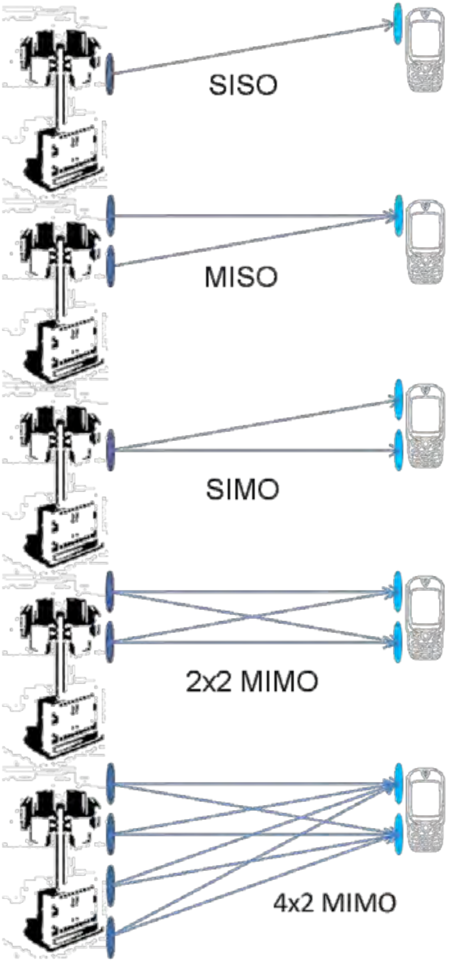
Multipath and Spatial Multiplexing



- MIMO (multiple input multiple output) radios can use multipath to send two or more data streams
- This is known as *Spatial Multiplexing*

Multiple Antenna Techniques

- **SISO (Single Input Single Output)**
  - Traditional radio
- **MISO (Multiple Input Single Output)**
  - Transmit diversity
  - Space Time Block Coding (STBC) or Cyclic Delay Diversity (CDD)
- **SIMO (Single Input Multiple Output)**
  - Receive diversity
  - Maximal Ratio Combining (MRC)
- **MIMO (Multiple Input Multiple Output)**
  - Spatial Multiplexing (SM) to transmit multiple streams simultaneously; can be used in conjunction with Cyclic Delay Diversity (CDD); works best in high SNR environments and channels de-correlated by multipath
  - TX and RX diversity can be used independently or together to enhance throughput in the presence of adverse channel conditions



STBC = Space Time Block Coding
CDD = Cyclic Delay Diversity
MRC = Maximal Ratio Combining
SM = Spatial Multiplexing

SISO = Single Input Single Output
MISO = Multiple Input Single Output
SIMO = Single Input Multiple Output
MIMO = Multiple Input Multiple Output

802.11n Throughput Enhancements

802.11n throughput enhancement	Description	Throughput enhancement over legacy
Spatial multiplexing	With 2 spatial streams throughput can be double that of a single stream.	100%
40 MHz channel width	Doubling the channel width over the legacy 20 MHz channel can double the throughput.	100%
More efficient OFDM	With 52 data sub-carriers vs. 48 for the legacy networks, the highest data rate per stream is 65 Mbps vs. the 802.11a/g 54 Mbps	20%
Shorter GI (guard interval)	The short GI of 400 ns allowed by 802.11n reduces the symbol time from 4 microseconds to 3.6 microseconds increasing the symbol rate by 10%.	10%
Frame aggregation and Block ACK	64k bytes A-MPDU; 8k bytes A-MSDU	Up to 100%

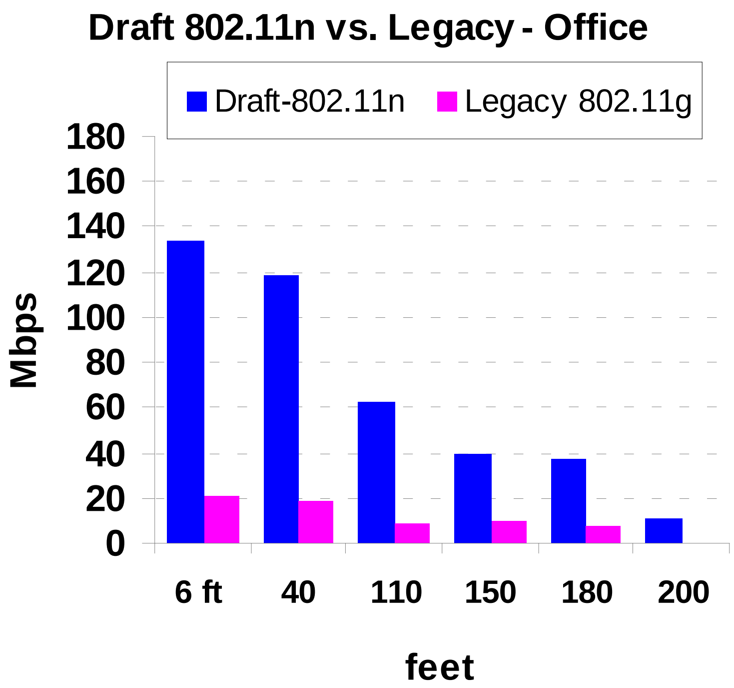
A-MPDU = Aggregated Mac Protocol Data Unit
A-MSDU = Aggregated Mac Service Data Unit

IEEE 802.11a,b,g,n Data Rates

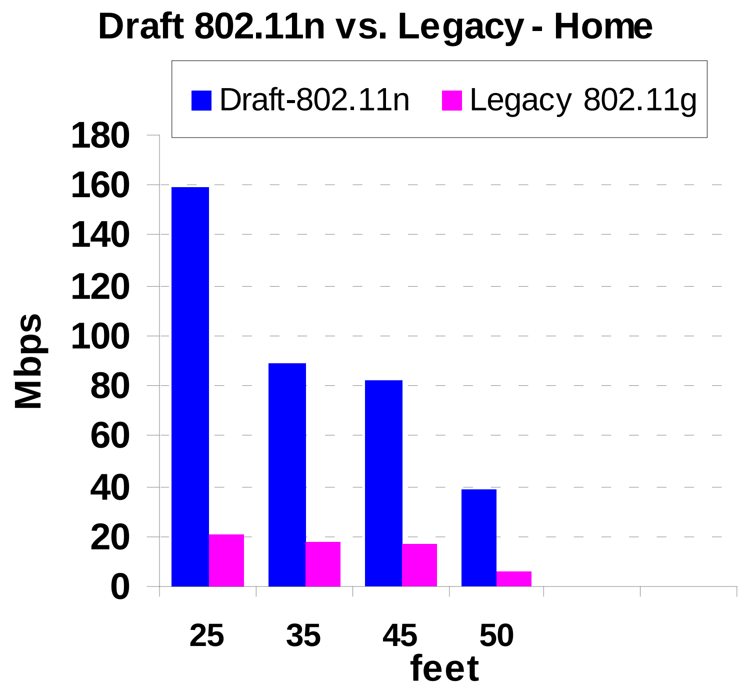
	20 MHz Channel				40 MHz Channel			
	1 stream	2 streams	3 streams	4 streams	1 stream	2 streams	3 streams	4 streams
	Data Rate, in Mbps							
802.11b 2.4 GHz	1, 2, 5.5, 11							
802.11a 5 GHz	6, 9, 12, 18, 24, 36, 48, 54							
802.11g 2.4 GHz	1, 2, 6, 9, 12, 18, 24, 36, 48, 54							
802.11n 2.4 and 5 GHz	6.5, 13, 19.5, 26, 39, 52, 58.5, 65	13, 26, 39, 52, 78, 104, 117, 130	19.5, 39, 58.5, 78, 117, 156, 175.5, 195	26, 52, 78, 104, 156, 208, 234, 260	13.5, 27, 40.5, 54, 81, 108, 121.5, 135	27, 54, 81, 108, 162, 216, 243, 270	40.5, 81, 121.5, 162, 243, 324, 364.5, 405	54, 108, 162, 216, 324, 432, 486, 540
802.11n, SGI enabled 2.4 and 5 GHz	7.2, 14.4, 21.7, 28.9, 43.3, 57.8, 65, 72.2	14.4, 28.9, 43.3, 57.8, 86.7, 115.6, 130, 144.4	21.7, 43.3, 65, 86.7, 130, 173.3, 195, 216.7	28.9, 57.8, 86.7, 115.6, 173.3, 231.1, 260, 288.9	15, 30, 45, 60, 90, 120, 135, 150	30, 60, 90, 120, 180, 240, 270, 300	45, 90, 135, 180, 270, 360, 405, **450**	60, 120, 180, 240, 360, 480, 540, **600**

Top rate commercially available today

MIMO vs. SISO Throughput Performance



Vendor 1



Vendor 2

MIMO = multiple input multiple output
SISO = single input single output

IEEE 802.11 – Very High Throughput

- The goal of the 802.11 VHT effort is to achieve 1 Gbps throughput at nomadic (walking speeds) to support HD video transmission and high speed data applications and to satisfy the IMT-Advanced requirements
- The work is ongoing at TGac and TGad
- TGac
  - under 6 GHz; same channels as 802.11 in the 5 and 2.4 GHz bands
  - Considering more efficient OFDM and 80 MHz channels
- TGad
  - 60 GHz band
  - May capitalize on work already done by 802.15.3c in the 60 GHz band

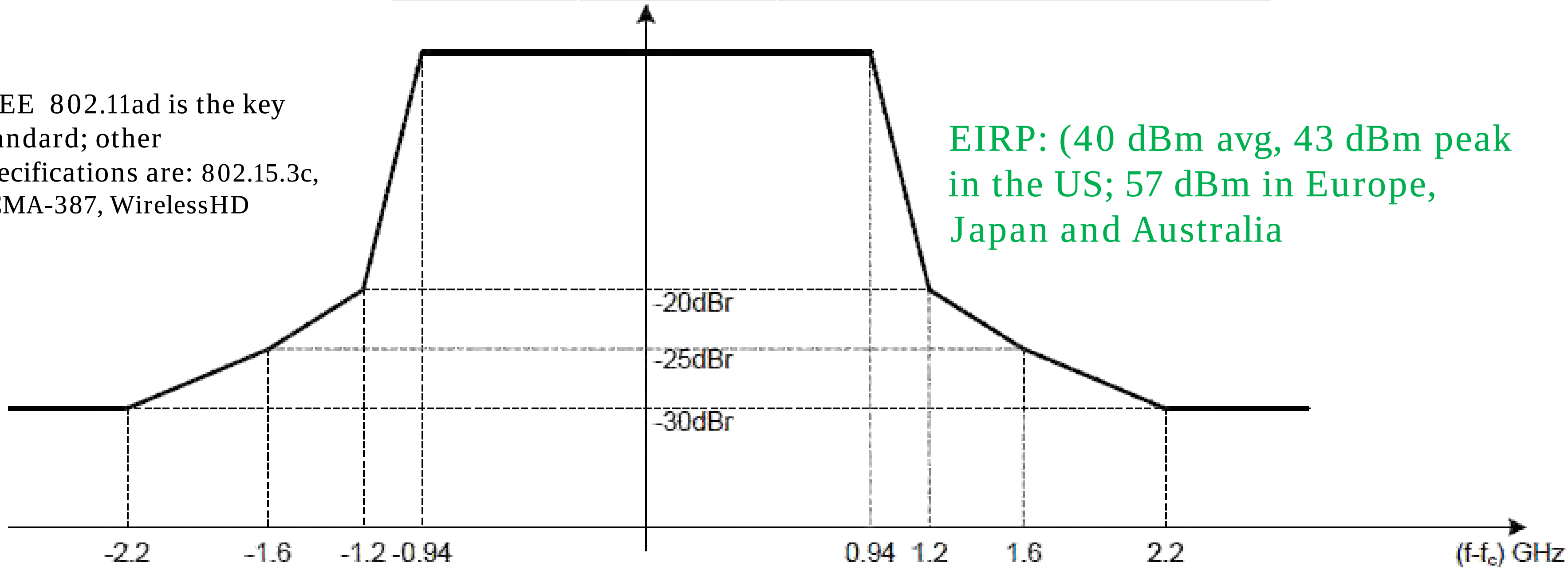
VHT = very high throughput

802.11ad 60 GHz Frequency Bands

Channel 2 must be supported

Channel	f_c (GHz)	Country
1	58.32	US
2	60.48	US, Japan, EU, Australia
3	62.64	US, Japan, EU
4	64.80	Japan, EU

IEEE 802.11ad is the key standard; other specifications are: 802.15.3c, ECMA-387, WirelessHD

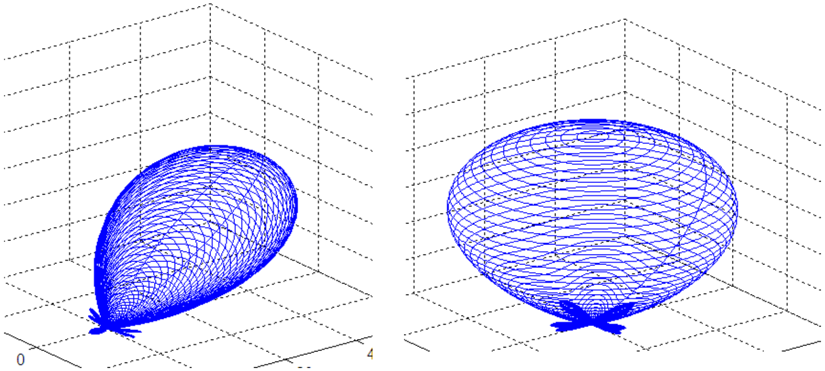


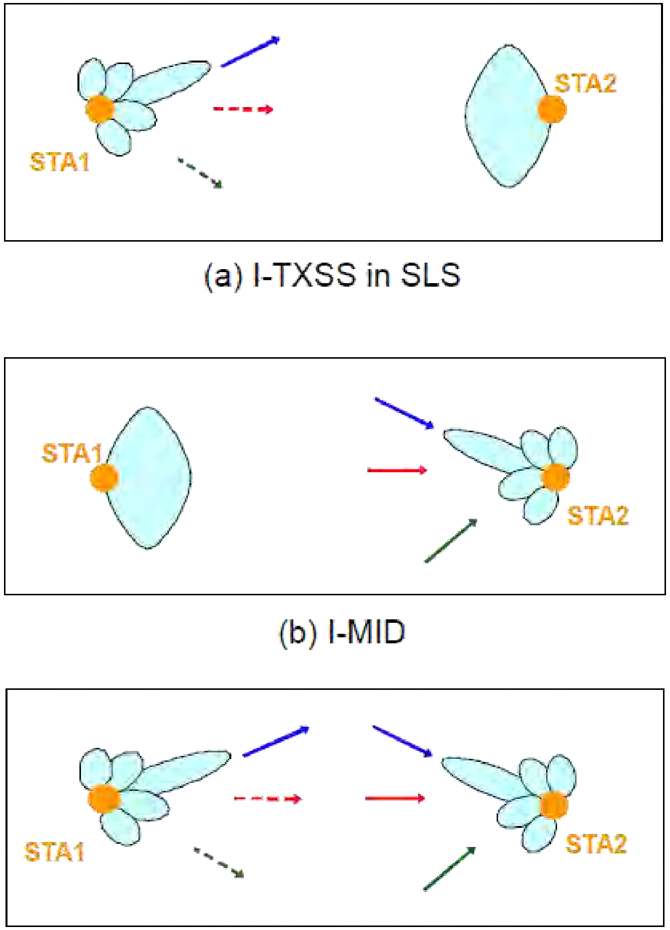
EIRP: (40 dBm avg, 43 dBm peak in the US; 57 dBm in Europe, Japan and Australia

Channel spacing = 2160MHz

Beam Steering

- Beam steering, central to 802.11ad, optimizes the range by focusing the energy between transmitting and receiving nodes
  - Involves two-way channel sounding, sector sweeping and beamforming to make optimum use of a lossy 60 GHz channel





(a) I-TXSS in SLS

(b) I-MID

(c) I-BC (Beam Combining)

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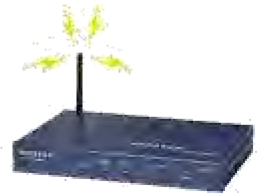
THE WALL STREET JOURNAL.
WSJ.com
SEPTEMBER 24, 2010

FCC to Open Unused TV Airwaves, Extending Wi-Fi's Possibilities

- Sep 23, 2010 The FCC reaffirmed a 2008 decision to open the broadcast airwaves
- Enables Wi-Fi networks with longer range
  - Microsoft reports achieving a mile of operating range on their Redmond, Wash., campus
- Broadcasters and wireless microphone operators expected to resume the law suit filed against the FCC in 2009 to stop new uses of the TV spectrum

Introducing TV White Spaces

- Spectrum under 3 GHz has significant unused capacity
  - Average occupancy over various locations studied is 5.2% and the maximum occupancy is 13.1% (in New York City)
  - Shared Spectrum Company, NSF funded measurements, http://www.sharedspectrum.com/measurements
- Only 10% of Americans receive broadcast TV
  - J. H. Snider and Max Vilimpoc, "Reclaiming the vast wasteland" http://vilimpoc.org/research/policy/Issue-Brief-12-Unlicensed-Sharing-of-Broadcast-Spectrum.pdf
- The economic potential for the TV white spaces was estimated at $100 billion
  - R. Thanki, "The economic value generated by current and future allocations of unlicensed spectrum," http://www.ingeniousmedia.co.uk/websitefiles/Value_of_unlicensed_-_website_-_FINAL.pdf
- Modern technology allows effective sharing of sparsely used TV broadcast spectrum
- In 2004, the FCC started investigating the potential of allowing operation of unlicensed 2-way data communications in the TV broadcast VHF and UHF bands



TVBD
TV Band Device

History and Regulatory Landscape

- 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
- 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
- ECC of CEPT in Europe is conducting consultation on the band
  - http://www.ero.dk/D9634A59-1F13-40D1-91E9-DAE6468ED66C?frames=no&
  - Requirements for operation of cognitive radio systems in the "white spaces" of the frequency band 470-790 MHz
  - Consultation closes 11/30/10
- China TV band regulations expected in 2015

ECC = Electronic Communications Committee
CEPT = European Conference on Postal and Telecommunications
NPRM = Notice of Proposed Rule Making

Frequency Allocation of TV Channels

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)

*Channel 37 (608-614 MHz) is reserved for radio astronomy
**Shared with public safety
http://www.fcc.gov/mb/engineering/usallochrt.pdf

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

NTSC = National Television System Committee
ATSC = Advanced Television Systems Committee

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

TVB

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

Operation in TV Bands – Latest Rules

Access based on *geo-location & database* or *spectrum sensing*

Fixed

Personal /portable

For fixed TVBDs max output power < 4 Watts EIRP

Must access a TV bands database over the Internet to determine channel availability

For PP TVBDs max output power < 100 mW EIRP on non-adjacent channels and < 40 mW EIRP on adjacent channels

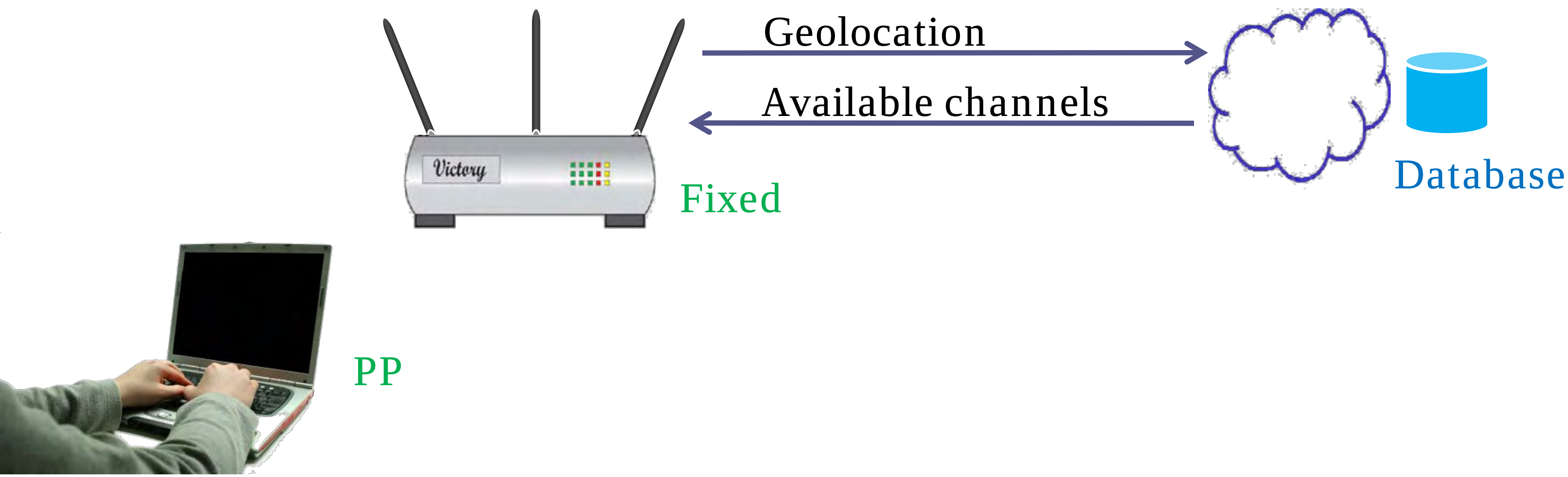
Mode I: obtain a list of available channels from a master device

Mode II: incorporate geo-location capability

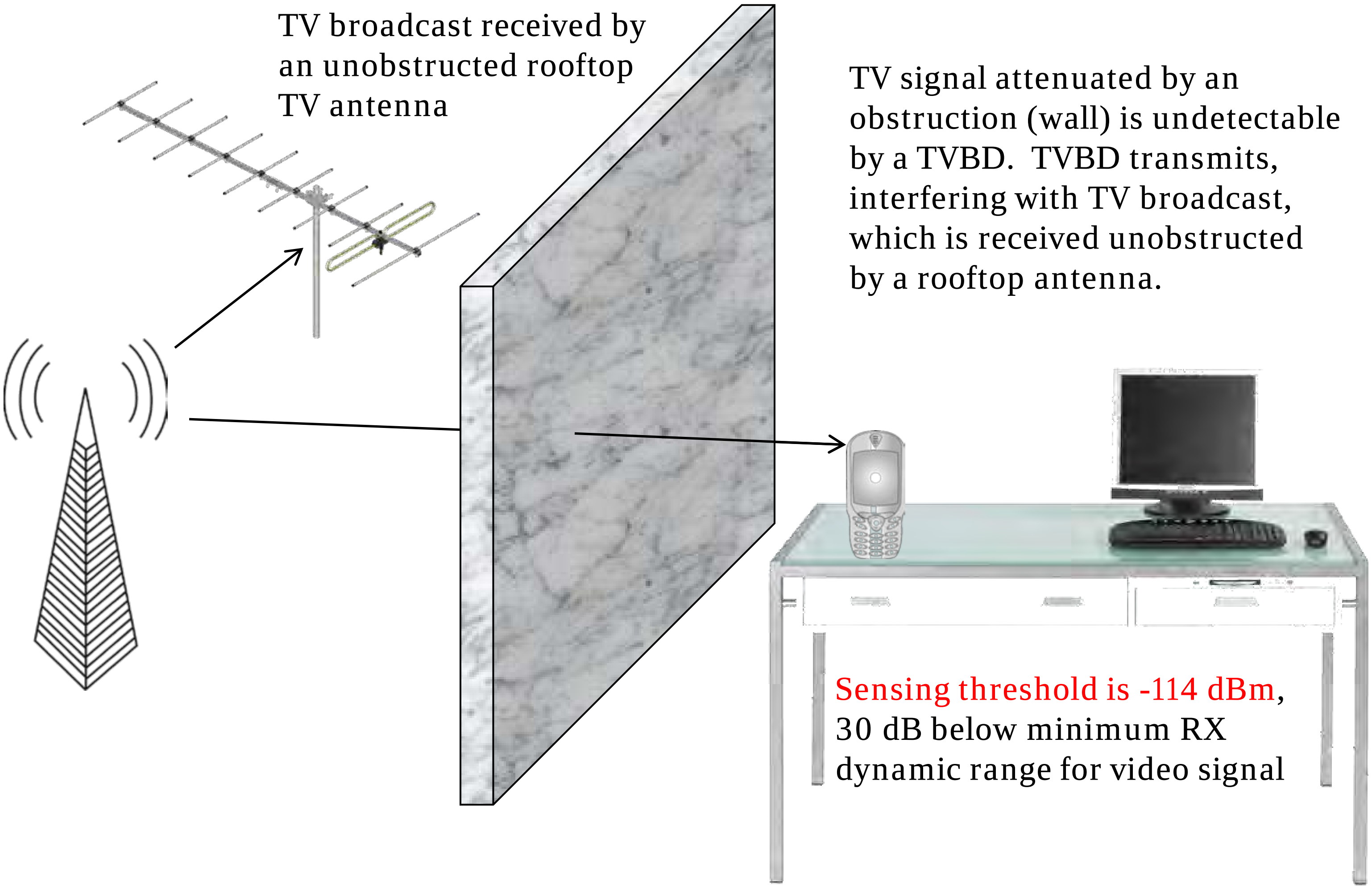
PP = personal/portable

Database

- Fixed TVBDs require geolocation capability and Internet access to a database of protected radio services.
- *White Spaces Database Group* was started by Google and other companies to create and standardize the database.

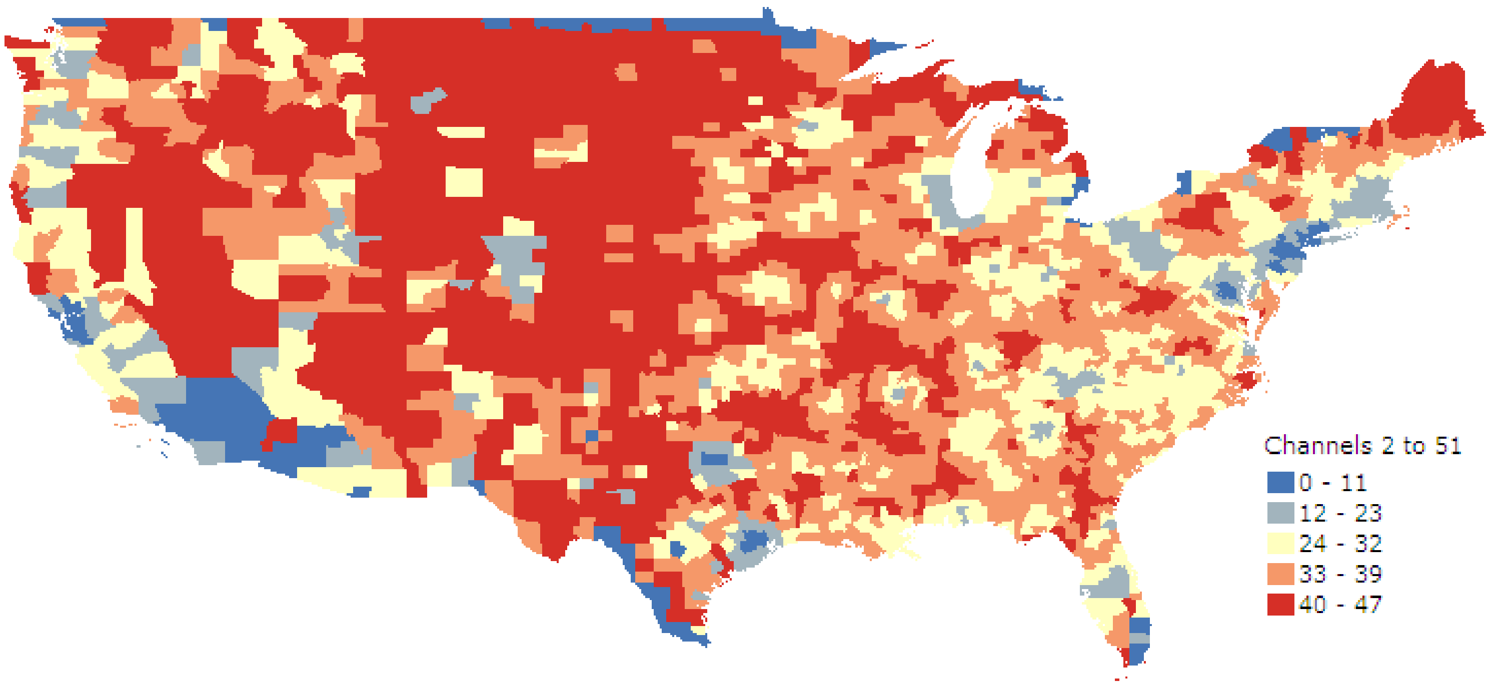


Spectrum Sensing



Taking Advantage of TV White Spaces

- Channel availability based on the geolocation query of TV band internet database



Source: Rick Tornado, Spectrum Bridge

IEEE TV Band Related Standards

- **802.11af** – formed in January 2010 to adapt 802.11 to TV band operation
- **802.16h** – originally organized to adapt 802.16 to the 3650-3700 MHz contention band now working on TV band operation of 802.16
- **802.22** – cognitive radio approach
  - Regional Area Networks group that guided the FCC in the recent TV band regulations
  - Uses spectrum sensing and location information to determine whether given transmit frequencies and power levels will cause harmful interference to licensed services.
- **802.19** TAG – defines coexistence among dissimilar networks that will operate in the TV band
- **SCC 41** – defines layers above the MAC and PHY for dynamic spectrum access networks

TAG = technical advisory group

Contention Band

- March 2005 FCC offered 50 MHz 3650 to 3700 MHz for *contention-based protocol*
- 802.11y and 802.16h are expected to share this band
- 21st century regulation geared for digital communications
  - multiple services to share the band in an orderly way

- **300 Million licenses one for every person or company**
- **$300 per license for 10 years**
- **Registered stations (base stations): 1 W/MHz, ~15 km**
- **Unregistered stations (handsets, laptops): 40 mW/MHz, 1-1.5 km**

802.11af

IEEE P802.11af™/D0.05, August 2010
(Draft Amendment to IEEE P802.11mb/D5.0)

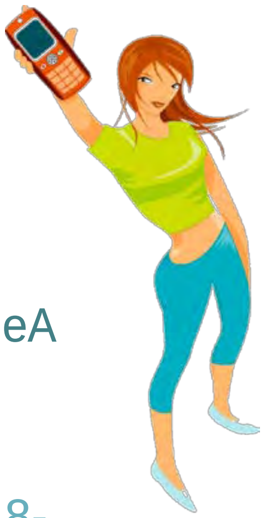
IEEE P802.11af™/D0.05

Draft Standard for Information Technology—

- Re-band the popular 802.11 systems; capitalize on work already done for 802.11y
  - Use 5, 10, 20 and 40 MHz wide channels
  - FCC EIRP: 4 W, 100 mW, 50 mW
- Possible deployment scenarios
  - Indoor (< 100 m): like present WLAN
  - Outdoor (< 5 km): comparable to the range of typical urban model
- Database is considered out of scope of 802.11af

Ecma and CogNeA TV Band Standard

- Ecma International TC48-TG1 is developing PHY-MAC and coexistence protocols for wireless networks in the TV band http://www.ecma-international.org/memento/TC48-TG1.htm
- Sponsor Organization: Ecma International (http://www.ecma-international.org) and CogNeA (http://www.cognea.org)
- CogNeA and Ecma TC48-TG1 standard
  - CogNeA is an industry alliance formed in 2008 to develop a specification for white spaces.
  - In March 2009 the draft/early specification developed by CogNeA was transferred to the Technical Committee 48 – Task Group 1 (TC48-TG1) within Ecma-International
  - http://www.ecma-international.org/publications/files/drafts/tc48-tg1-2009-132.pdf



CogNeA = Cognitive Networking Alliance

Future of TV Band Use

- Dynamic spectrum market with the database access capability
  - Buy spectrum for a slice of time/space/band
- Protocol? Contention-based Wi-Fi?
- Technology must evolve to make flexible use of available channels up to 6 GHz
  - RF front end technology still not ready for this

Agenda

- How smartphones are changing the network
- Wireless technologies
- Standards
- White spaces
- Concluding thoughts

Pervasive Connectivity

- Smartphones and pads will continue to drive mobile broadband
  - Billions of dollars in Enterprise IT budgets are now shifting from wired to wireless networks
- The war between LTE and WiMAX is over; WiMAX will remain a niche
- Wi-Fi will continue to dominate in-doors with a stable, reliable and high-performing 802.11n
- White spaces – a frontier for now
  - Wi-Fi (802.11af) is emerging as the dominant signaling scheme, but contention access is not FCC mandated in this band

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