Making Sense of Mobile Broadband

Interop/NYC
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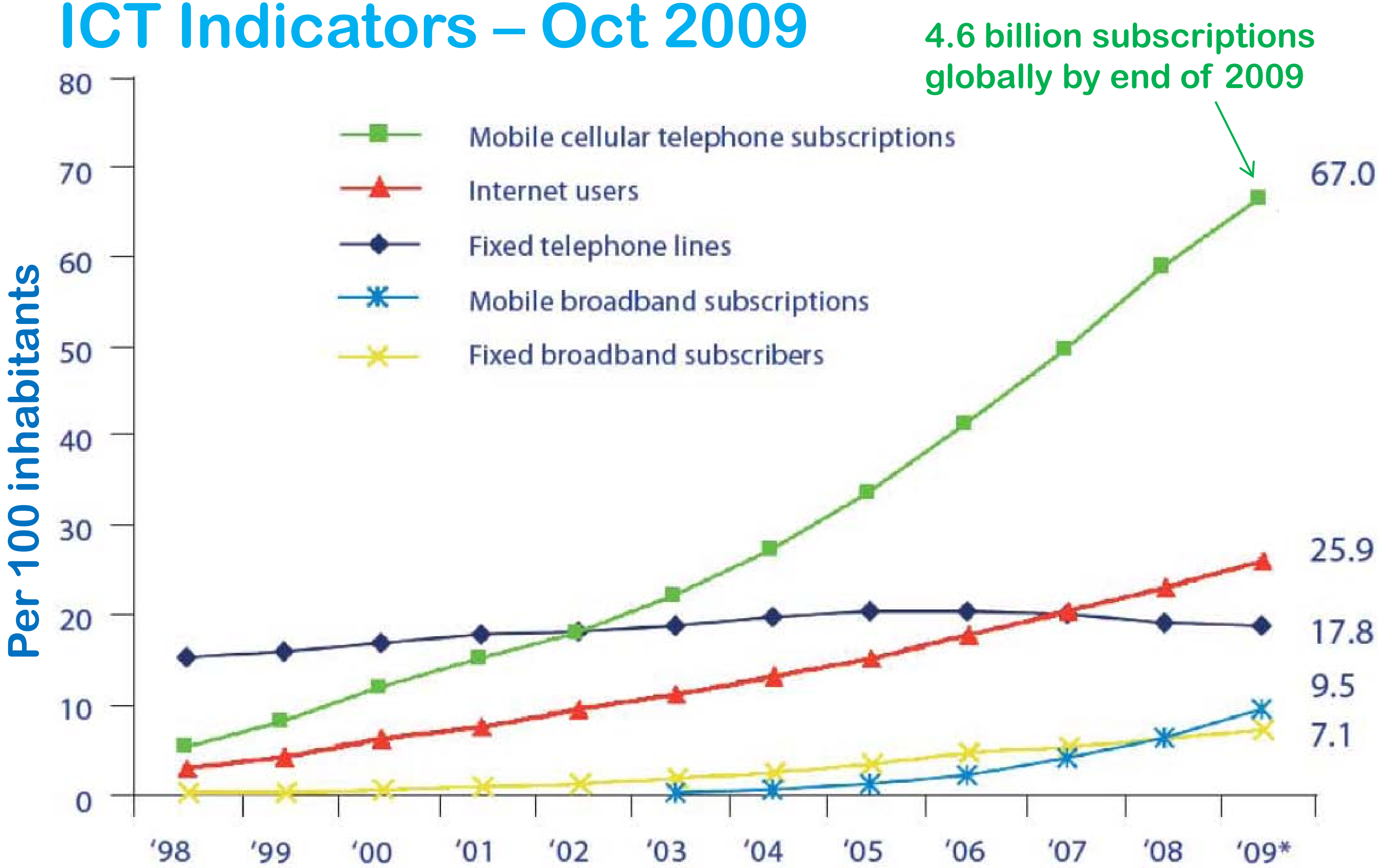
ITU World Telecommunications ICT Indicators – Oct 2009

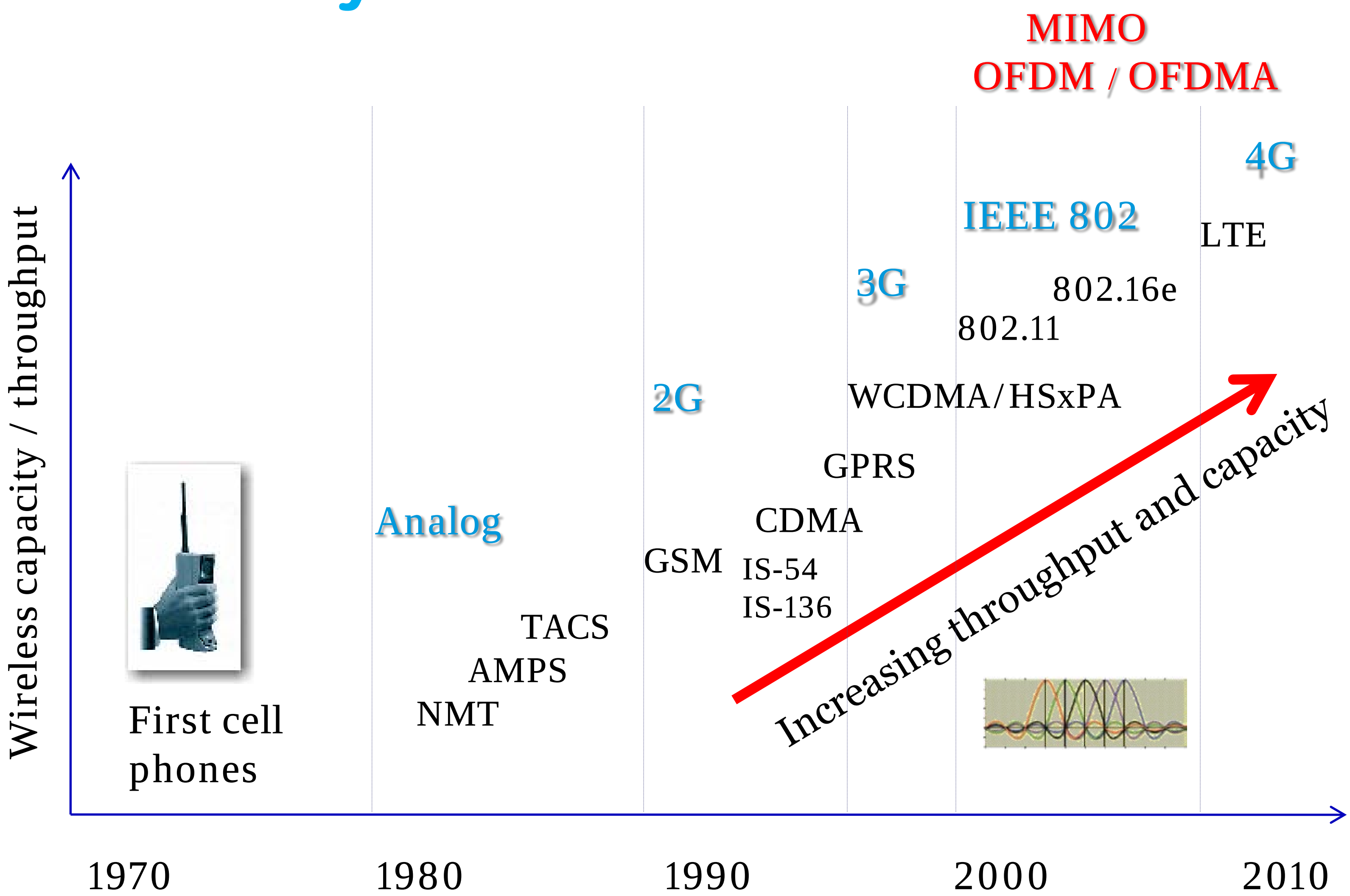


* = estimated
ICT = information and communications technology

Agenda

- The G's – historical perspective
- OFDM, OFDMA and multiple antenna techniques
- Standards – 3GPP, IEEE 802 wireless
- White Spaces
- Concluding thoughts

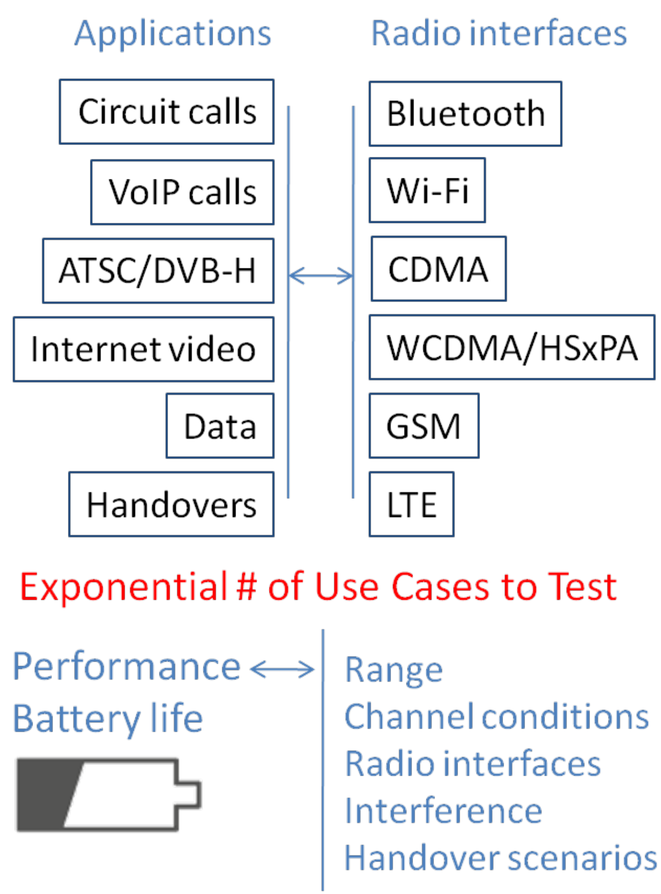
Brief History

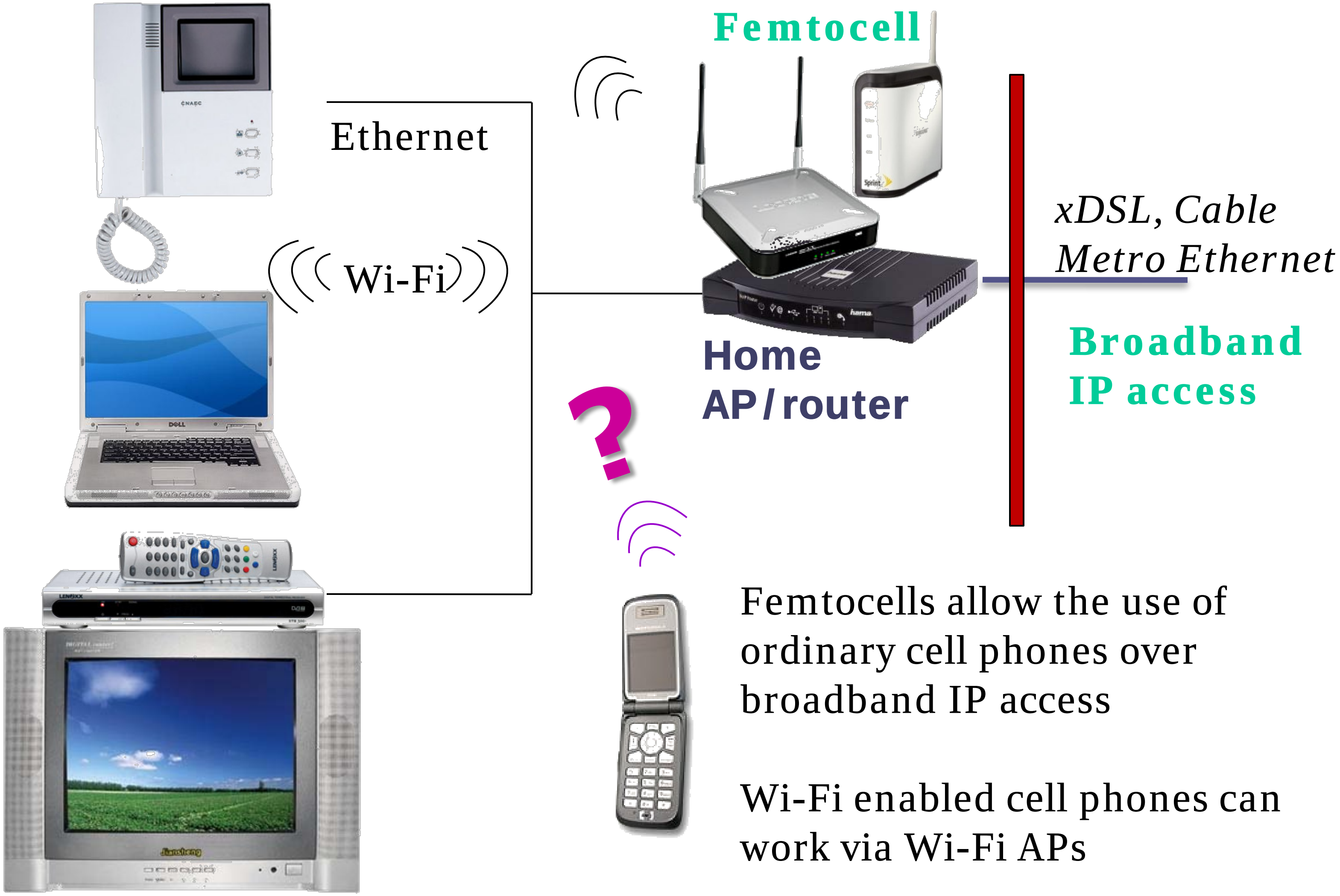


OFDM/OFDMA = orthogonal frequency domain multiplexing / multiple access
MIMO = multiple input multiple output

Handset Evolution

- Handsets are evolving to run mobile applications, such as video, Internet access, VoIP, location and other services...
- ... enabled by new generation radios, such as 3G/WCDMA and emerging 3.9G/LTE
- Performance and roaming behavior are currently measured primarily for circuit voice services
- Performance of emerging mobile applications is little understood
- Battery life of 3G and 4G radios need to be carefully qualified as a function of use cases and handover scenarios
- The number of use cases and test cases is growing exponentially

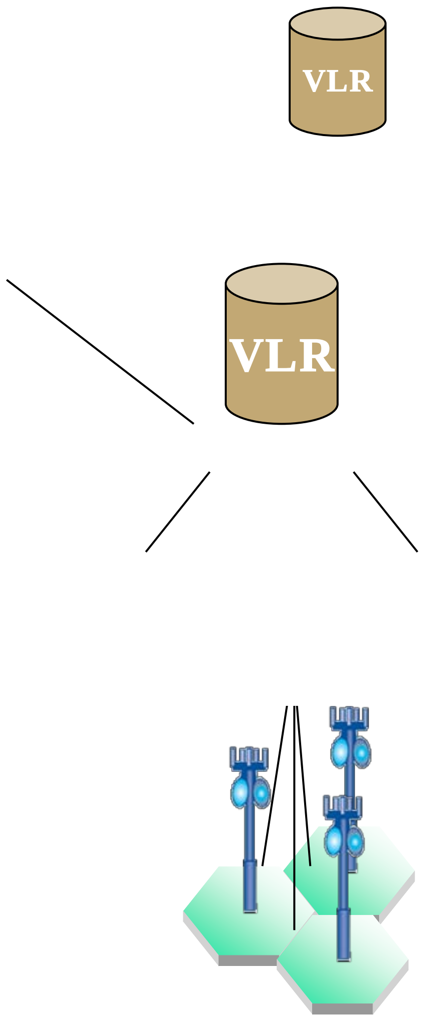




Femtocells allow the use of ordinary cell phones over broadband IP access

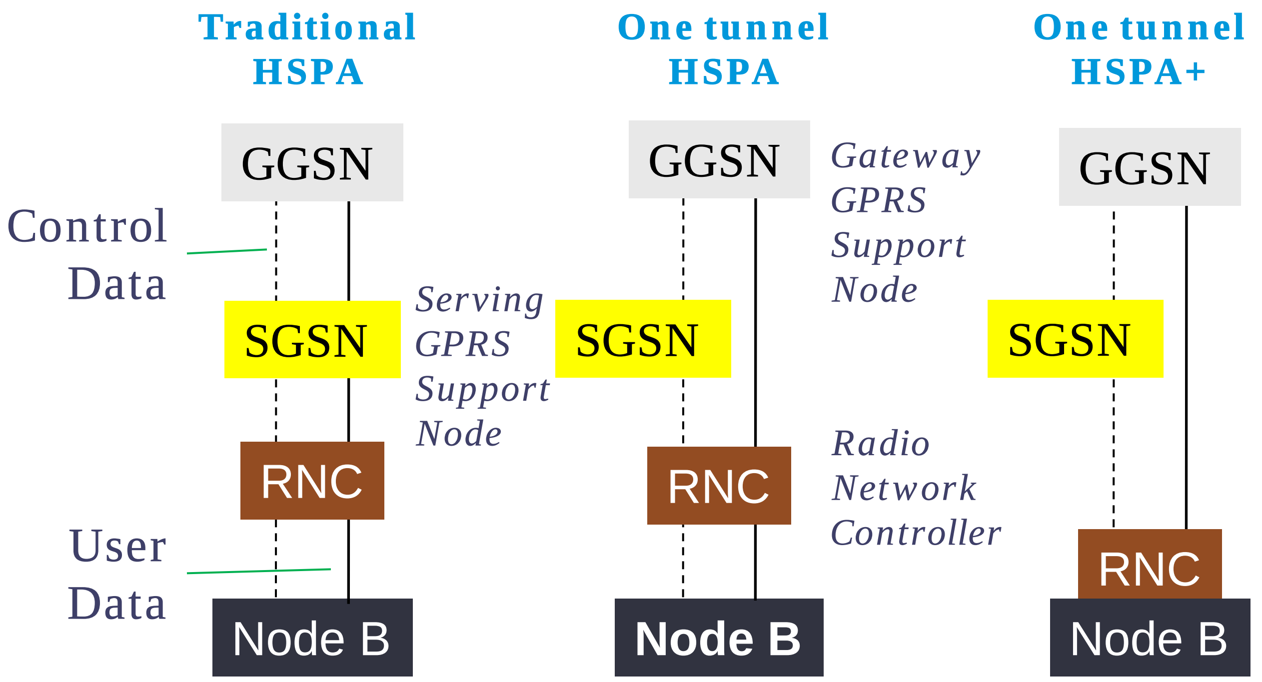
Wi-Fi enabled cell phones can work via Wi-Fi APs

Data Networks vs. Traditional Cellular Networks



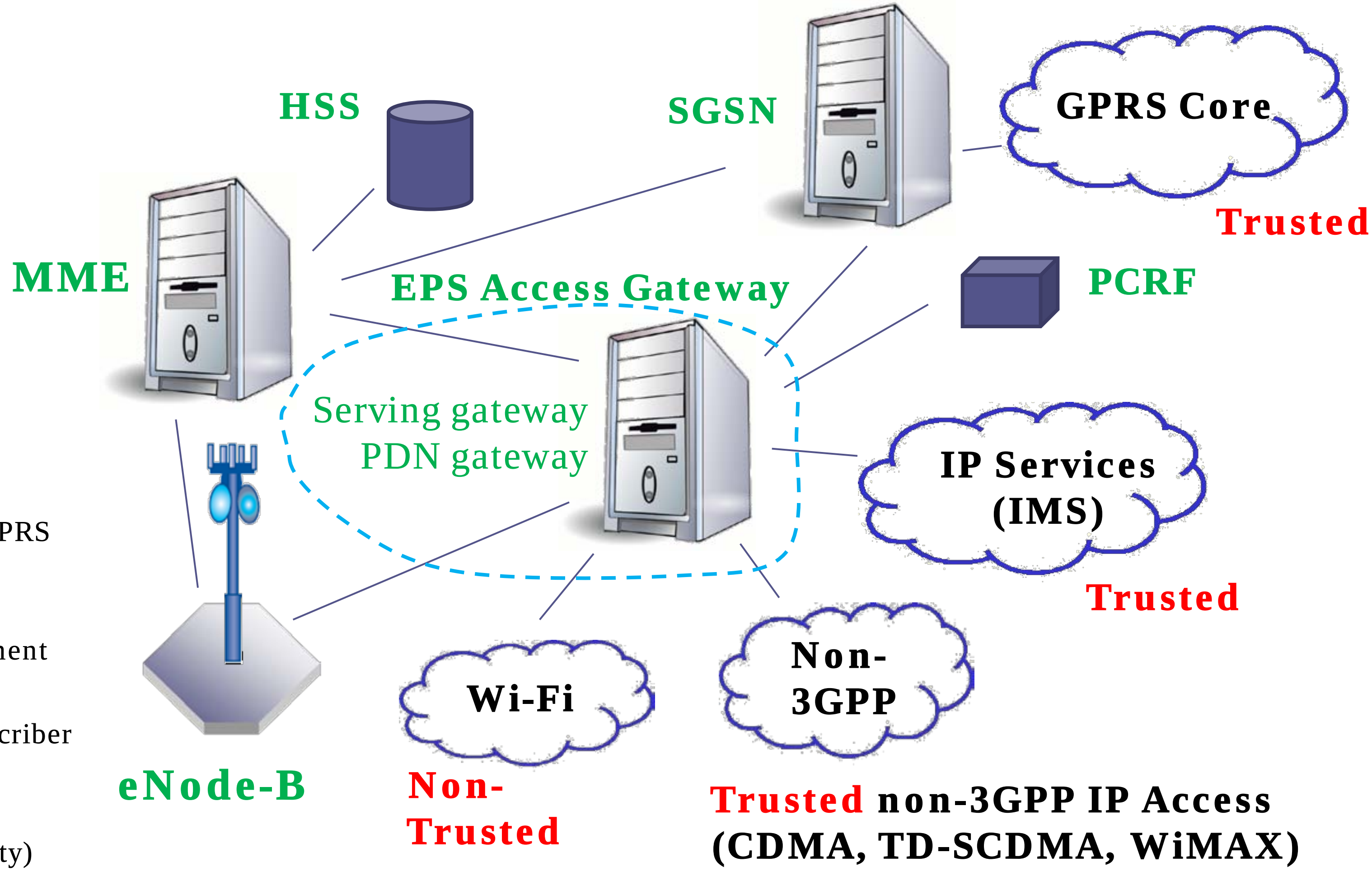
HSPA and HSPA+

- 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)

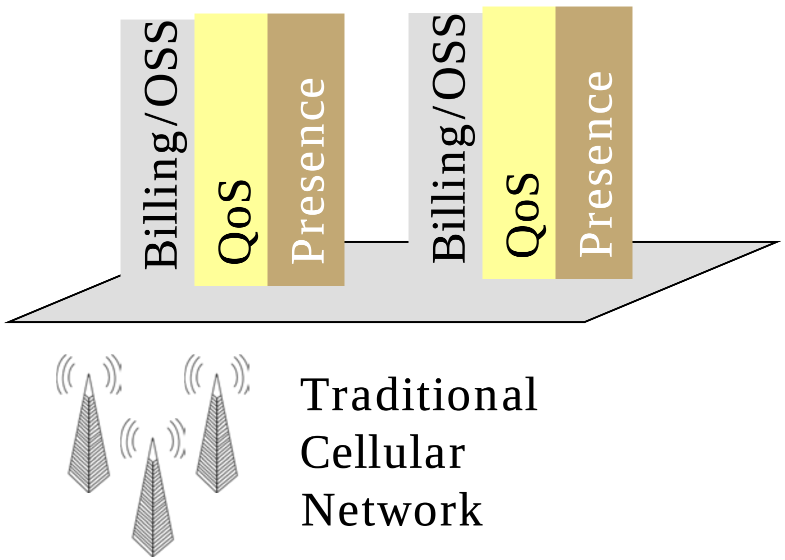
PCRF (policy and charging enforcement function)

HSS (Home Subscriber Server)

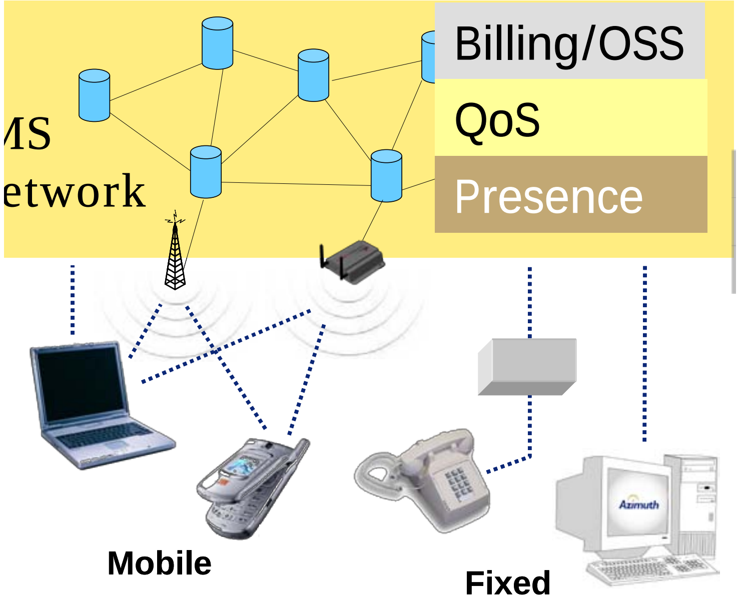
MME (Mobility Management Entity)

PDN (Public Data Network)

Flat, low-latency architecture



Billing/OSS
QoS
Presence
Billing/OSS
QoS
Presence
Traditional
Cellular
Network



MS
etwork
Billing/OSS
QoS
Presence
Mobile
Fixed

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)

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- OFDM, OFDMA and multiple antenna techniques
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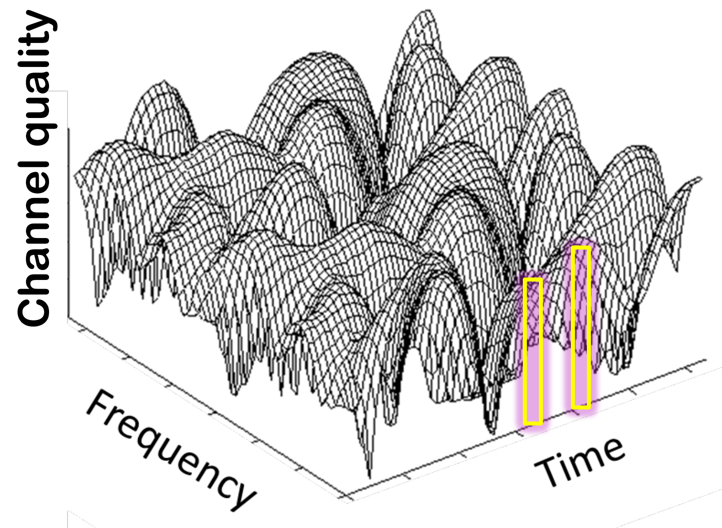
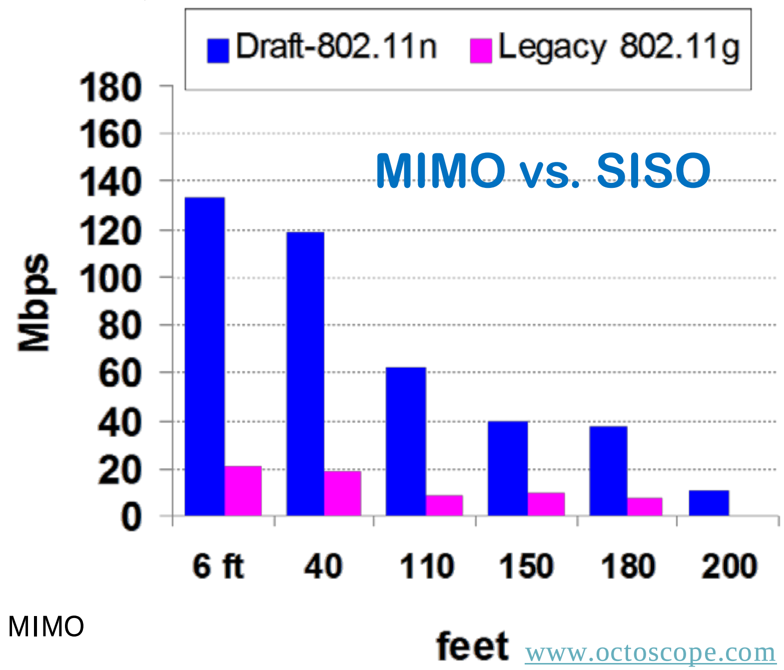
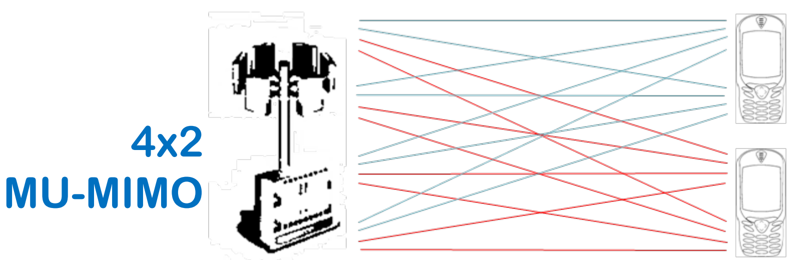
- Concluding thoughts

OFDM and MIMO

- OFDM is the most robust signaling scheme for wideband wireless, adapted by modern standards:
  - 802.11a, g and draft 802.11ac, ad
  - 802.16d,e; 802.22
  - DVB-T, DVB-H, DAB
- MIMO signaling, pioneered by 802.11n and adapted by WiMAX and LTE, exhibits vast improvements in throughput and range



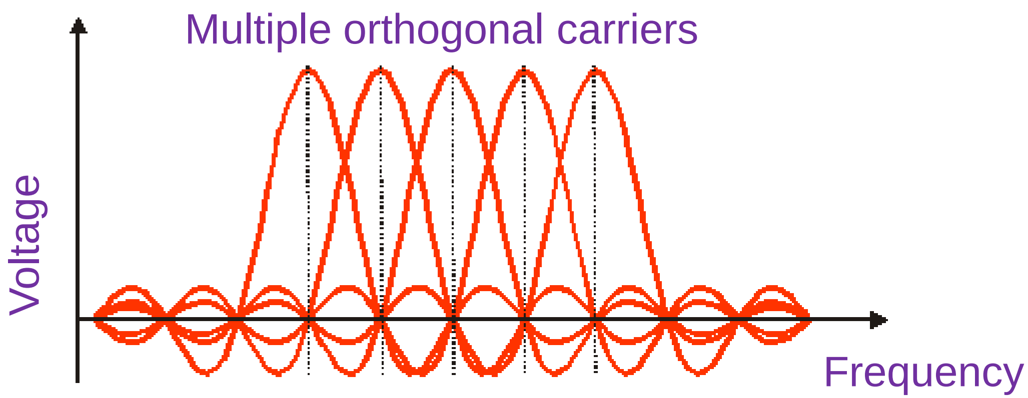




MIMO = multiple input multiple output; MU-MIMO = multi user MIMO
SISO = single input single output

OFDM (Orthogonal Frequency Division Multiplexing)

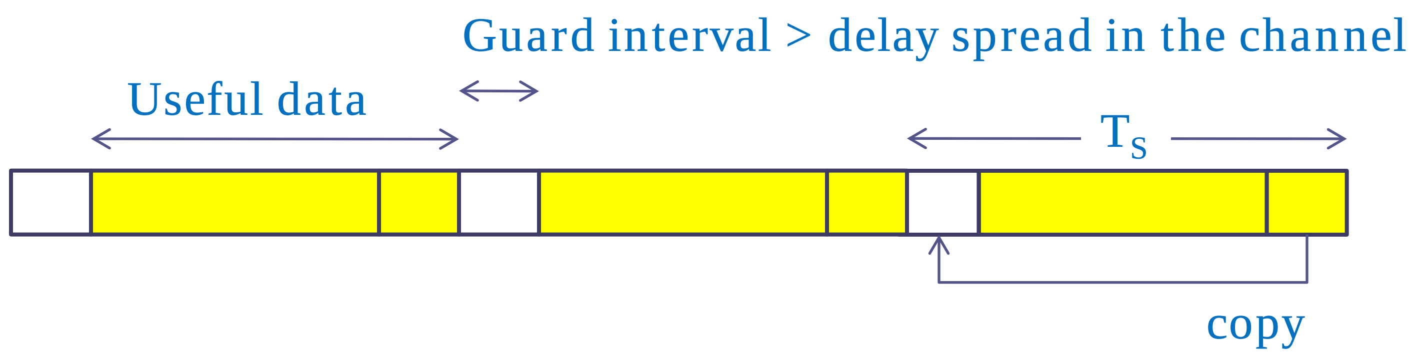
ADSL, VDSL
DVB, DAB
MediaFLO
Wi-Fi
WiMAX
LTE



- OFDM is the most robust signaling scheme for a hostile wireless channel
  - Works well in the presence of multipath thanks to multi-tone signaling and cyclic prefix (aka guard interval)
- OFDM is used in all new wireless standards, including
  - 802.11a, g and draft 802.11ac, ad
  - 802.16d,e; 802.22
  - DVB-T, DVB-H, DAD
- LTE is the first 3GPP standard to adopt OFDM

MediaFLO = Media Forward Link Only

Cyclic Prefix

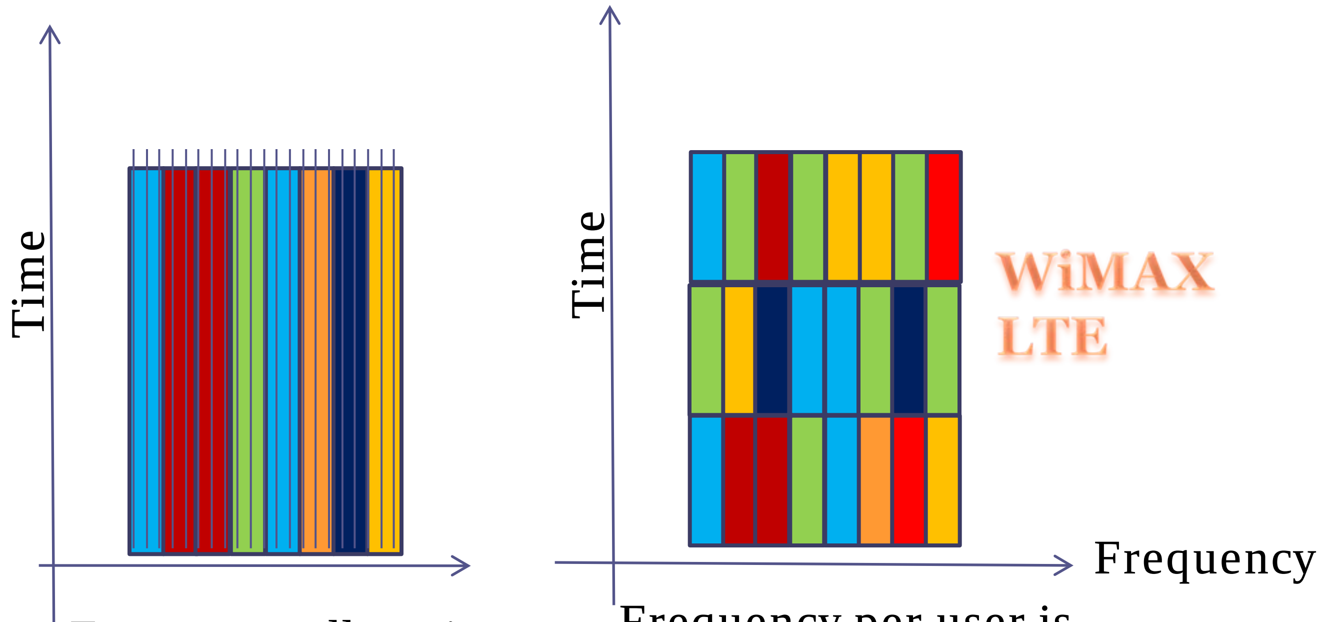


- The OFDM symbol is extended by repeating the end of the symbol in the beginning. This extension is called the Cyclic Prefix (CP).
- CP is a guard interval that allows multipath reflections from the previous symbol to settle prior to receiving the current symbol. CP has to be greater than the delay spread in the channel.
- CP eliminates Intersymbol Interference (ISI) and makes the symbol easier to recover.

OFDMA (Orthogonal Frequency Division Multiple Access)

OFDM is a modulation scheme

OFDMA is a modulation and access scheme

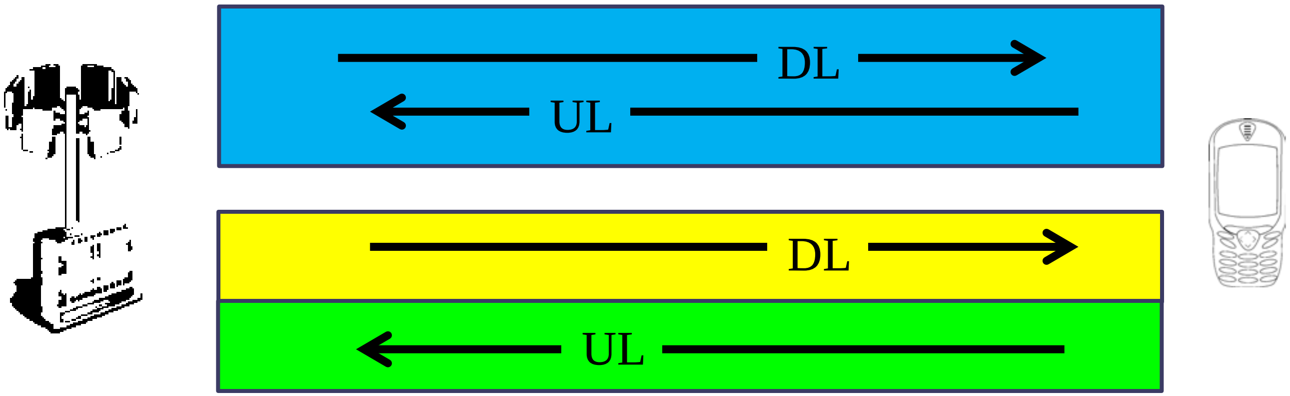


Frequency allocation per user is continuous vs. time

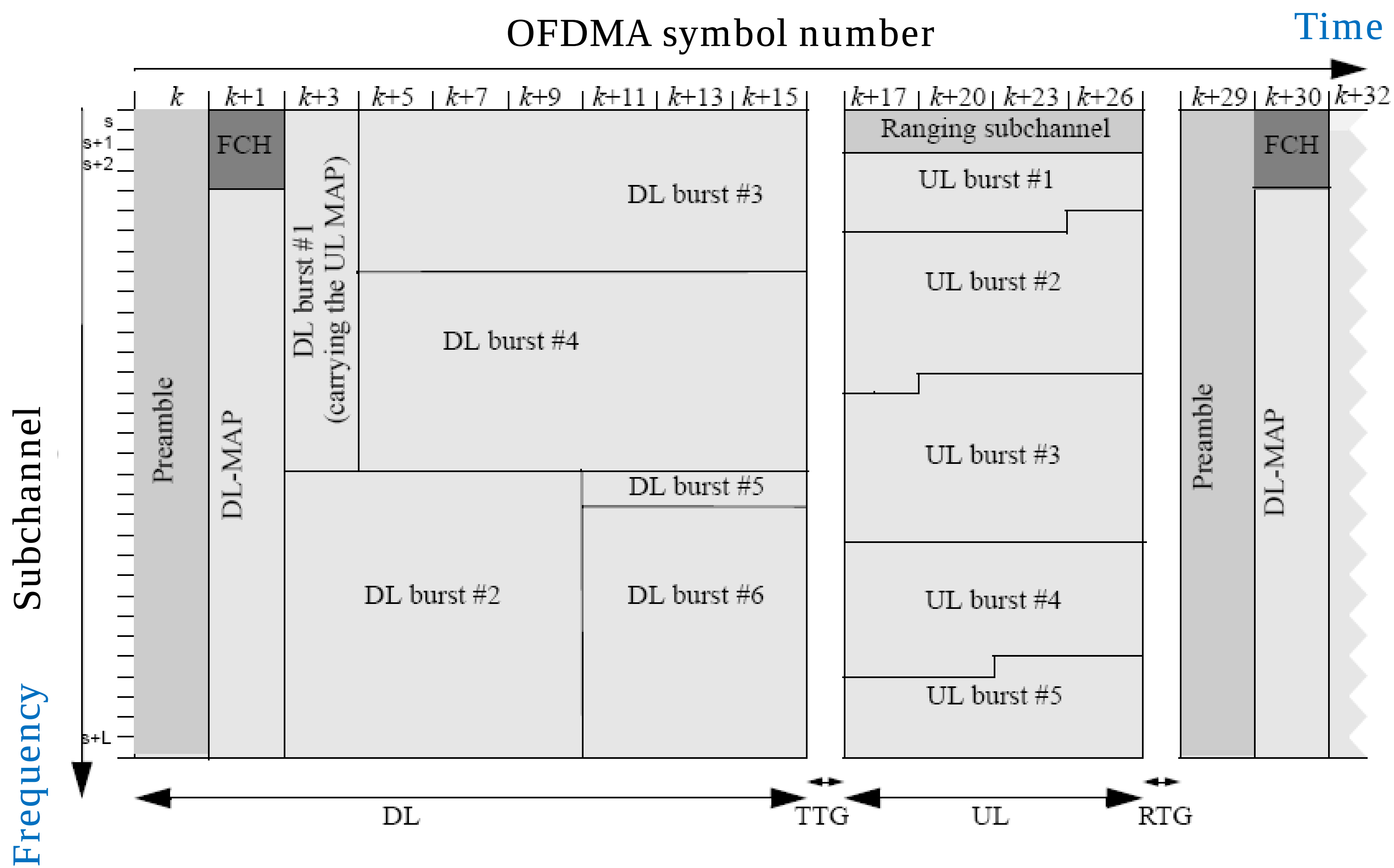
Frequency per user is dynamically allocated vs. time slots

FDD and TDD Support

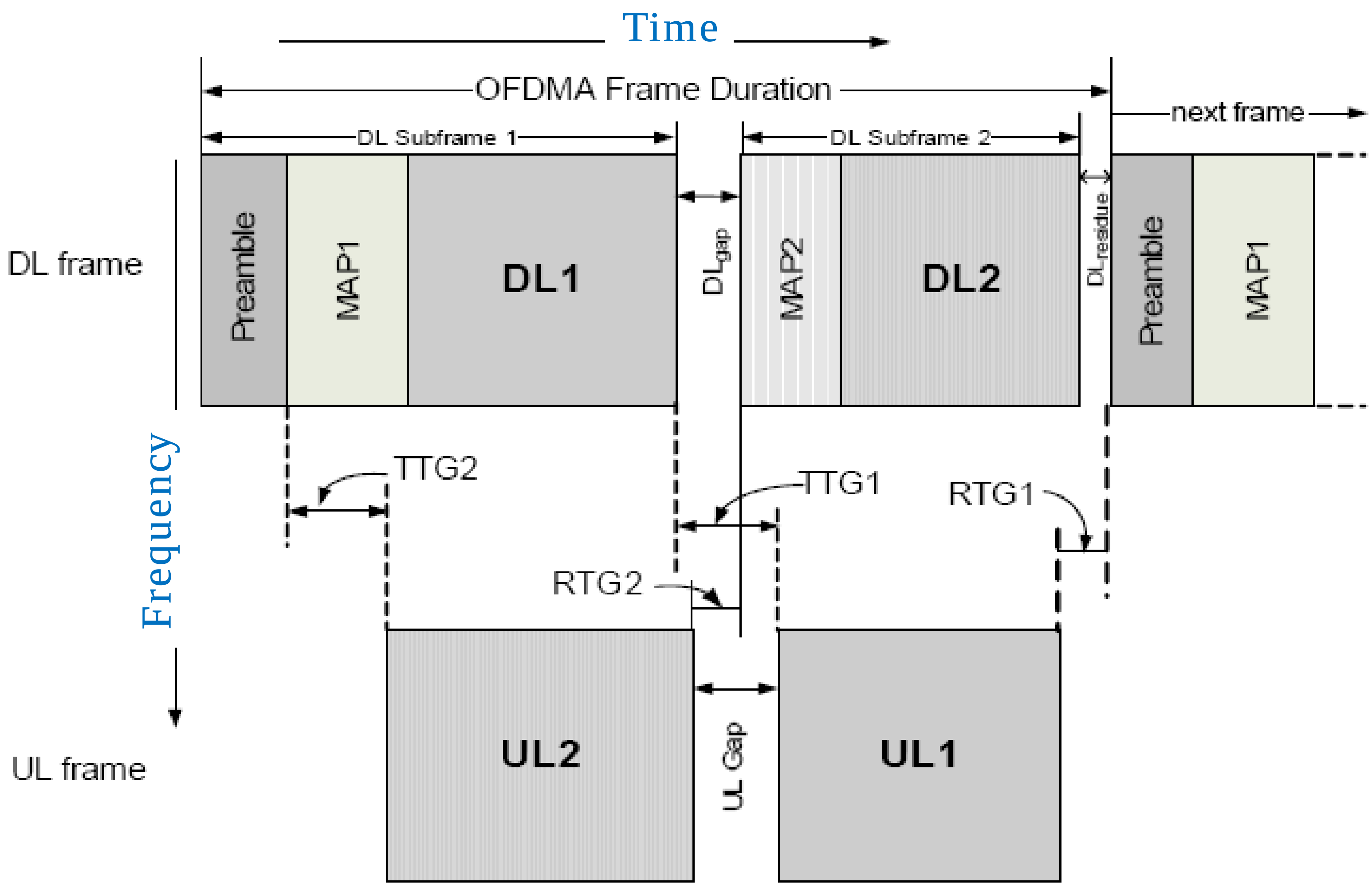
- FDD (frequency division duplex)
  - Paired channels
- TDD (time division duplex)
  - Single frequency channel for uplink an downlink
  - Is more flexible than FDD in its proportioning of uplink vs. downlink bandwidth utilization
  - Can ease spectrum allocation issues



WiMAX TDD Transmission



WiMAX H-FDD Transmission



H-FDD (half-duplex FDD)

TDD Configurations in LTE

Subframe

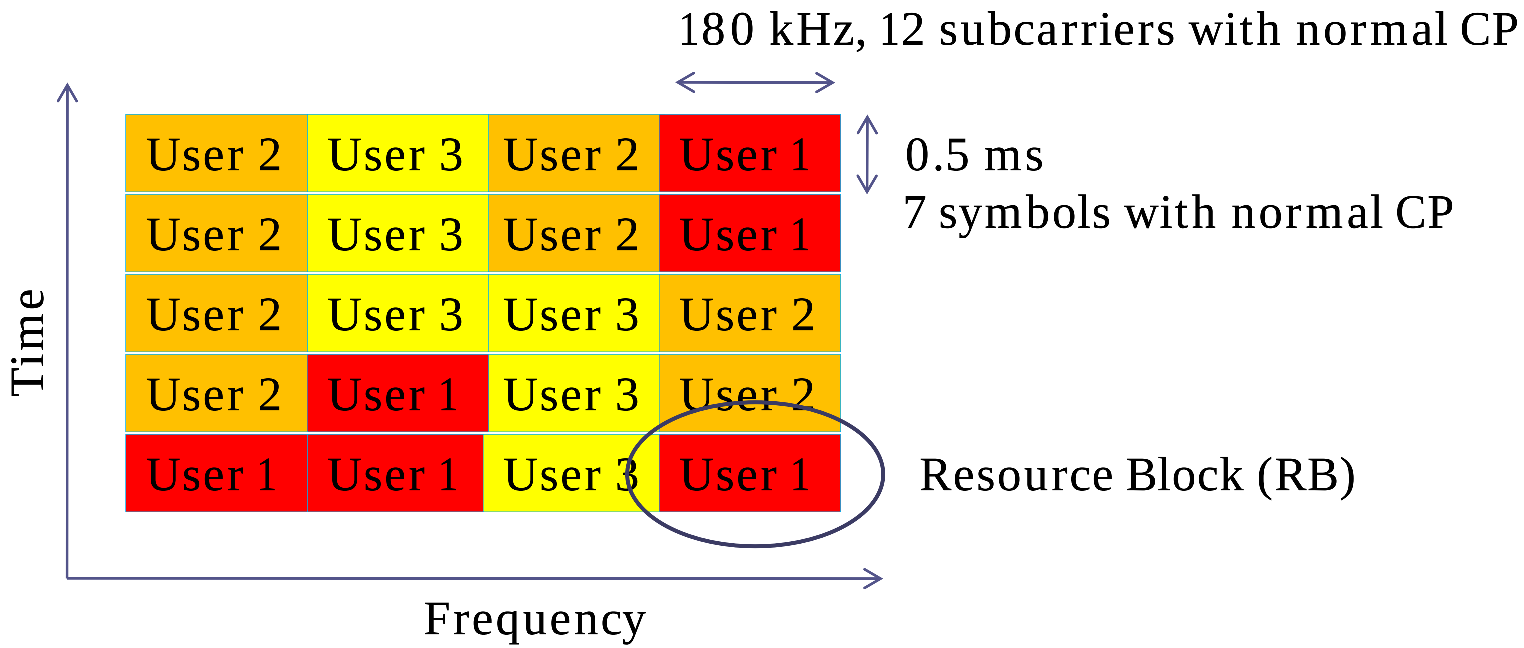
TDD Frame, Type 2

0 2 3 4 5 7 8 9

Config #	Subframe number									
	0	1	2	3	4	5	6	7	8	9
0	DL		UL	UL	UL	DL		UL	UL	UL
1	DL		UL	UL	DL	DL		UL	UL	DL
2	DL		UL	DL	DL	DL		UL	DL	DL
3	DL		UL	UL	UL	DL		DL	DL	DL
4	DL		UL	UL	DL	DL		DL	DL	DL
5	DL		UL	DL	DL	DL		DL	DL	DL
6	DL		UL	UL	UL	DL		UL	UL	DL

5 ms

LTE Resource Allocation

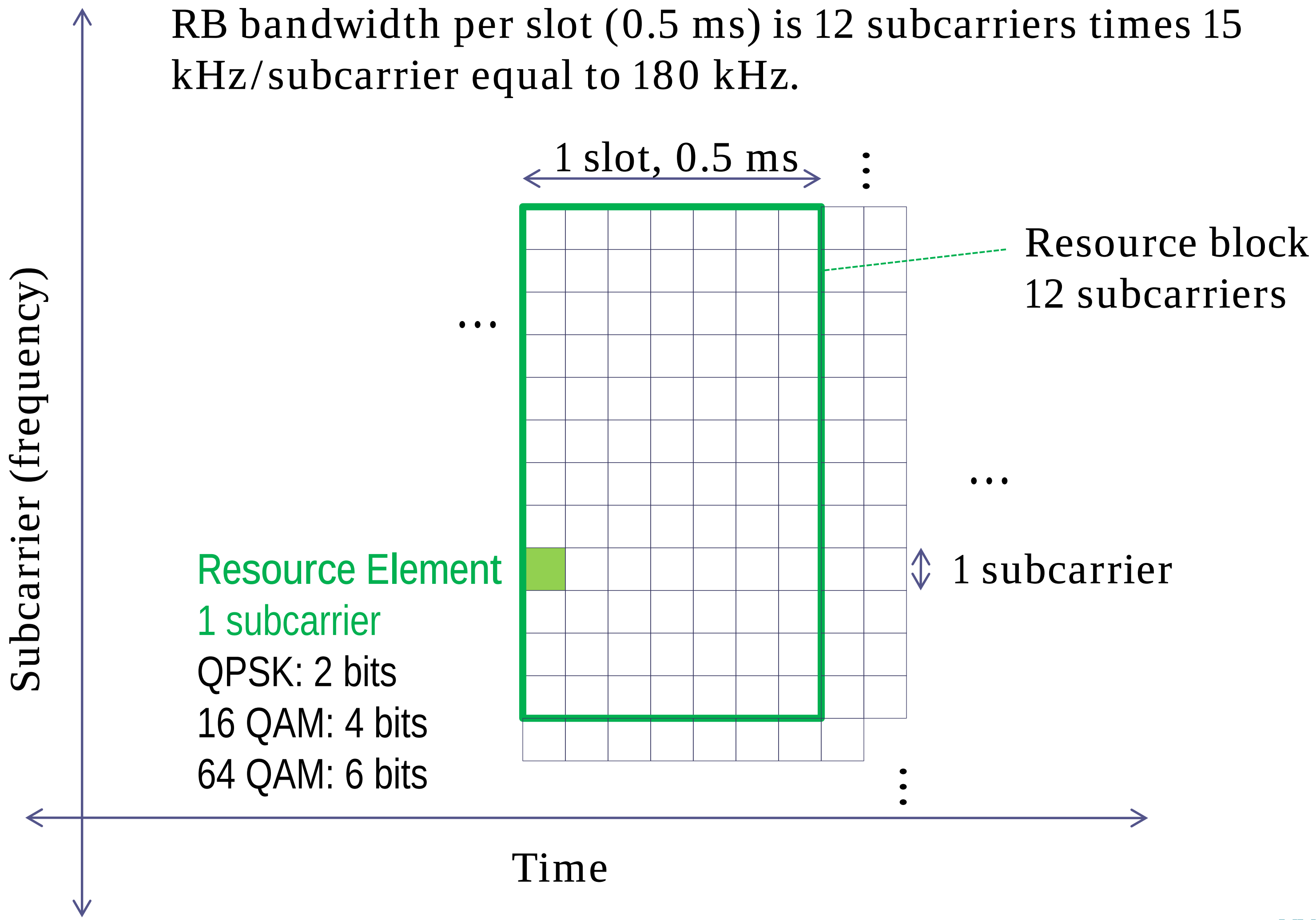


- Resources are allocated per user in time and frequency. RB is the basic unit of allocation.
- RB is 180 kHz by 0.5 ms; typically 12 subcarriers by 7 OFDM symbols, but the number of subcarriers and symbols can vary based on CP

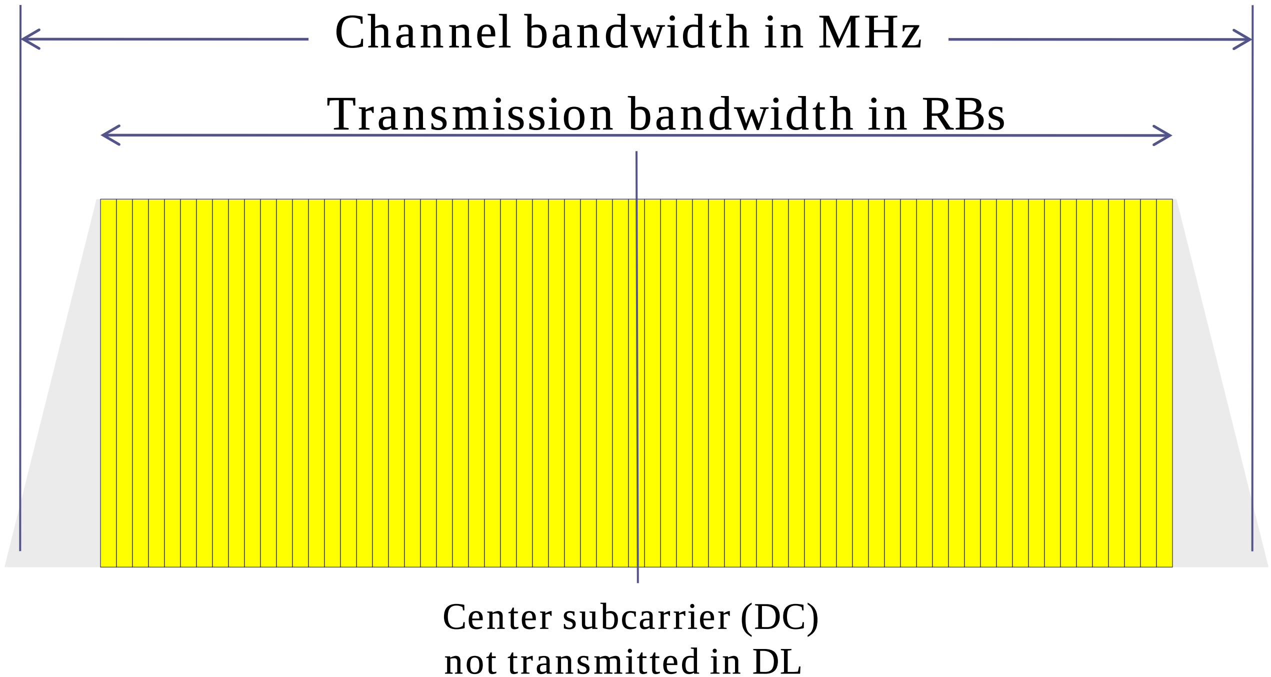
CP = cyclic prefix, explained ahead

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	

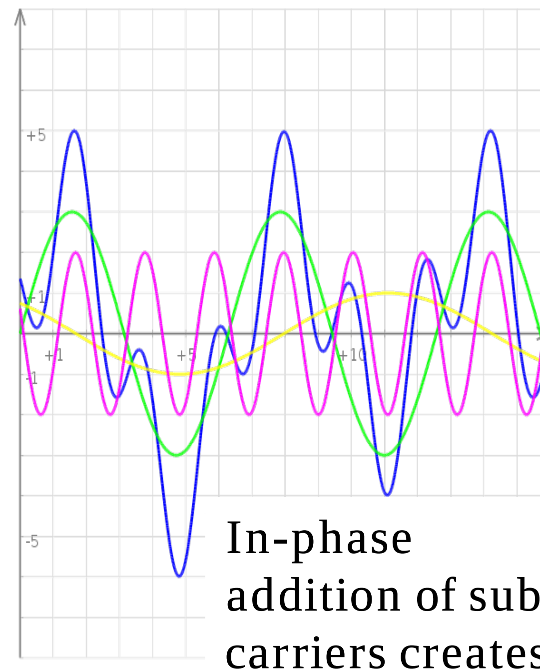
Channel Scalability

	WiMAX						
Channel bandwidth (MHz)	1.25	5	10	20	3.5	7	8.75
Sample time (ns)	714.3	178.6	89.3	44.6	250	125	100
FFT size	128	512	1024	2048	512	1024	1024
Subcarrier spacing (kHz)	10.9				7.8		9.8
Symbol time (usec)	91.4				128		102.4

	LTE					
Channel bandwidth (MHz)	1.4	3	5	10	15	20
FFT size	128	258	512	1024	1536	2048
Subcarrier spacing	15 kHz					
Symbol time (usec)	71.4 (with normal CP)					

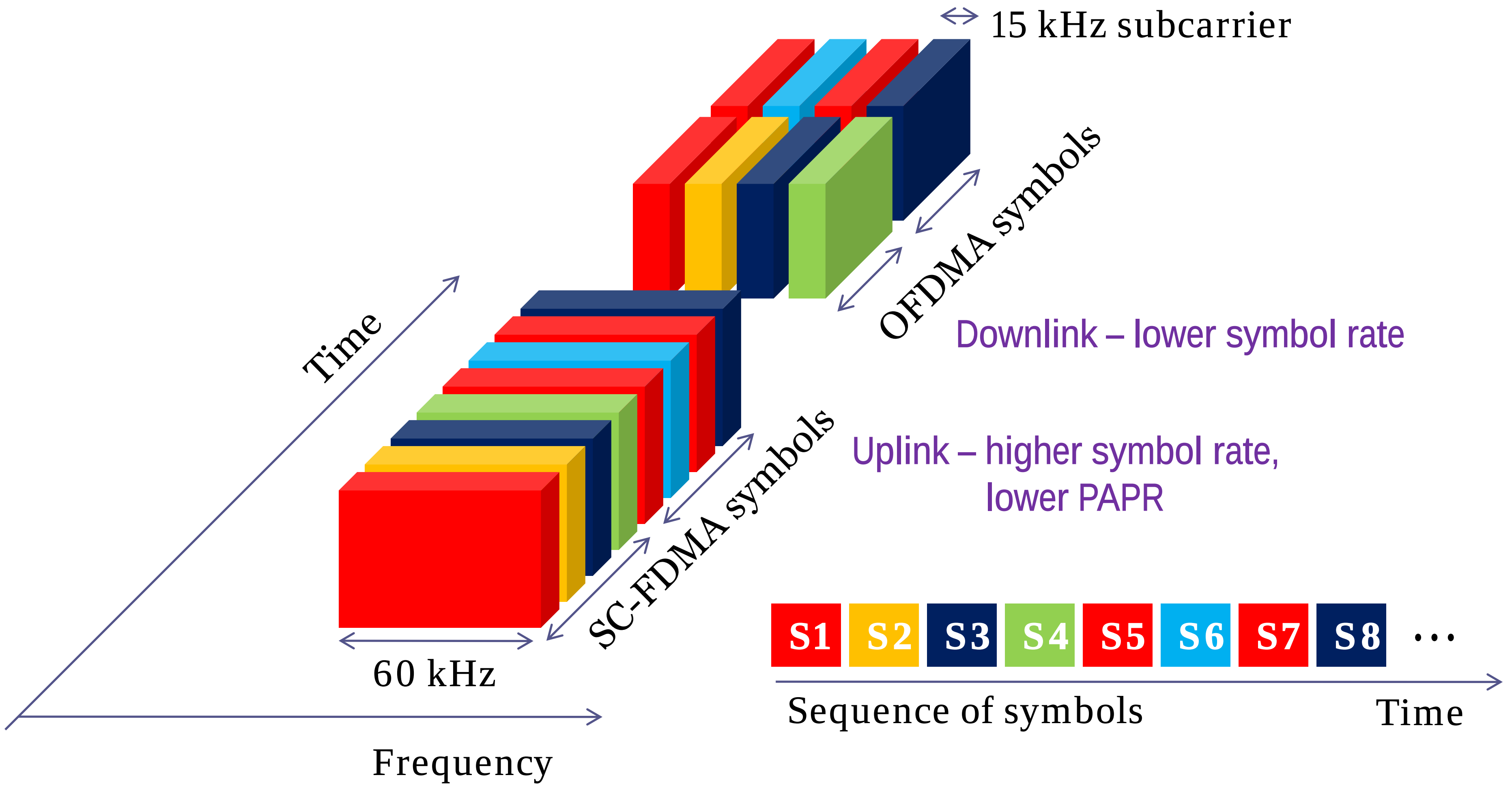
OFDMA vs. SC-FDMA (LTE Uplink)

- 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.**



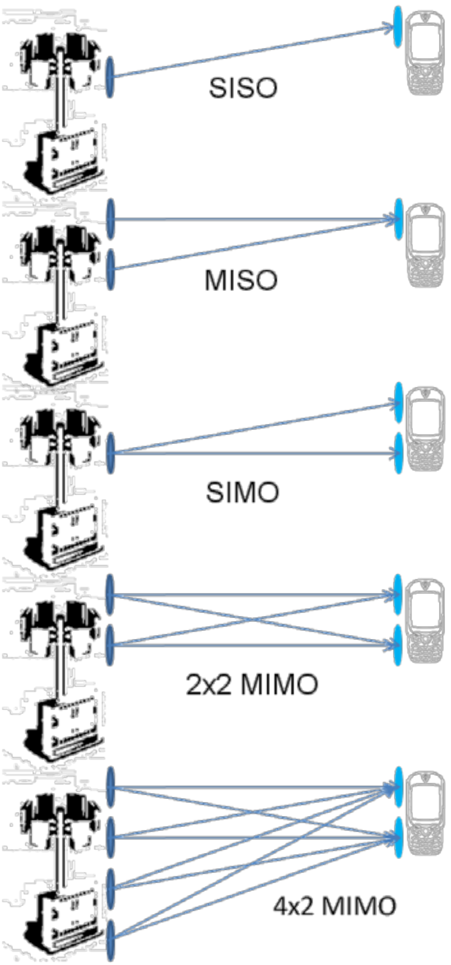
In-phase addition of sub-carriers creates peaks in the OFDM signal

SC-FDMA vs. OFDMA



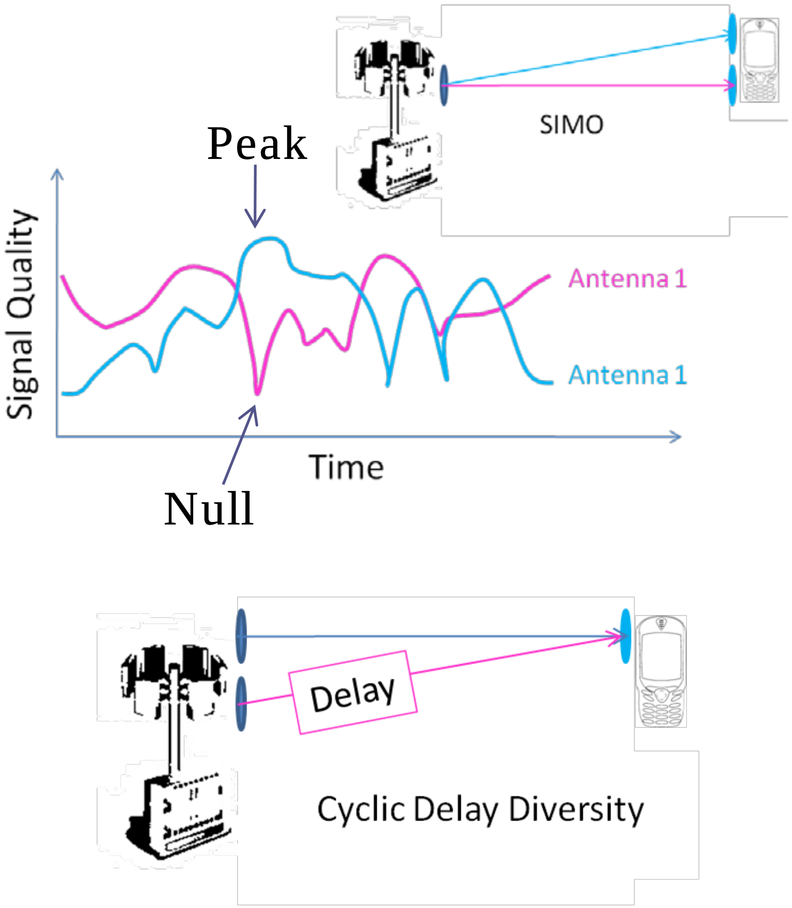
Multiple Antenna Techniques

- **SISO (Single Input Single Output)**
  - Traditional radio
- **MISO (Multiple Input Single Output)**
  - Transmit diversity
  - Space Time Block Coding (STBC), Space Frequency Block Coding (SFBC), 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
    - Works best in high SINR environments and channels de-correlated by multipath
  - Transmit/Receive diversity
    - Used in low SNR conditions



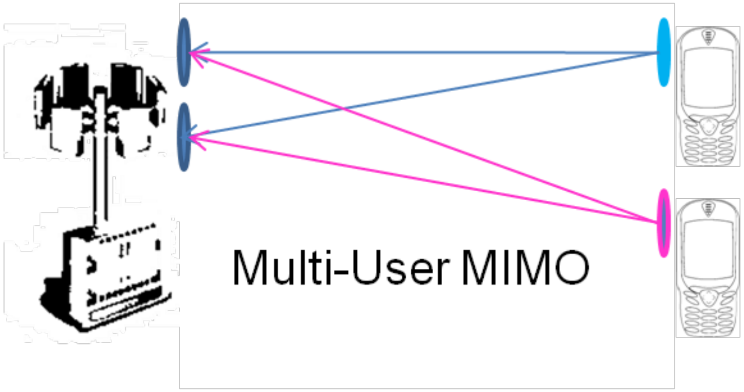
Receive and Transmit Diversity

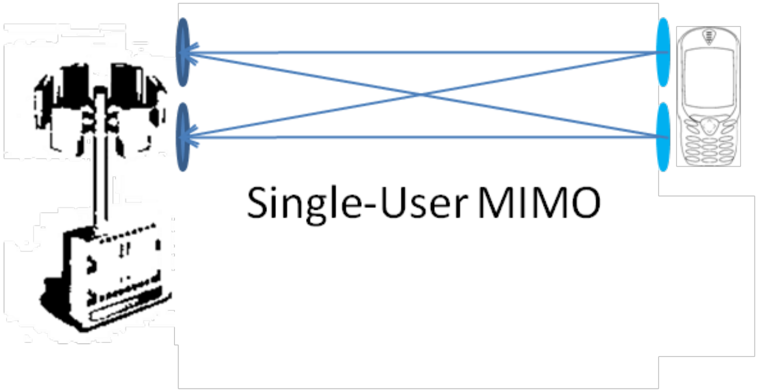
- Receive diversity, MRC, makes use of the highest signal quality, combining signals from both antennas
- Transmit diversity techniques, STBC, SFBC or CDD, spread the signal so as to create artificial multipath to decorrelate signals from different antennas.



Single-, Multi-User MIMO

- MU-MIMO allows two mobile stations to share subcarriers provided their channels to the base station are sufficiently decorrelated.
- MU-MIMO increases uplink capacity.
- SU-MIMO requires a mobile station to have two transmitters, which shortens battery life and costs more





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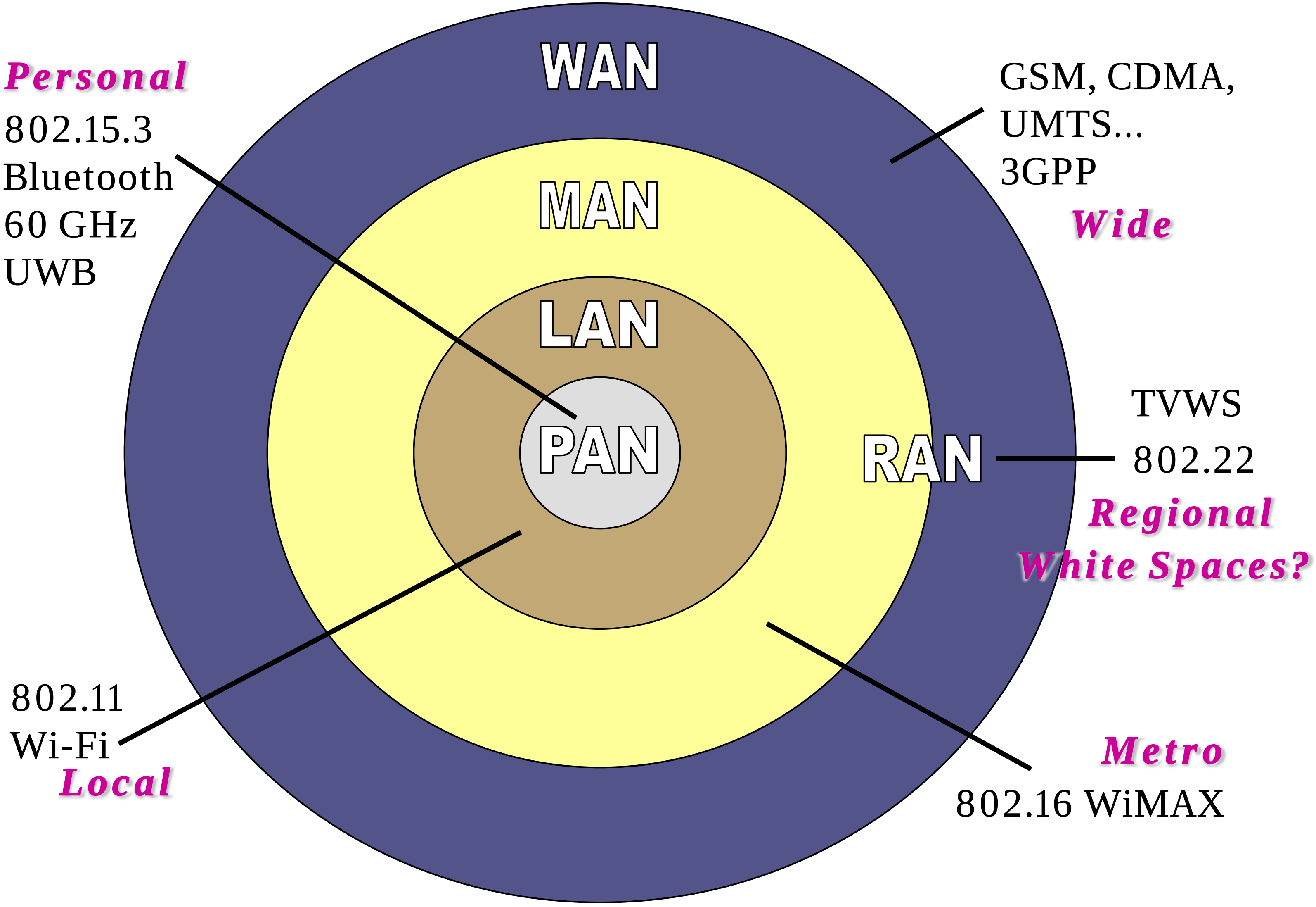
ITU International Mobile Telecommunications

- **IMT-2000**
  - Global standard for third generation (3G) wireless communications
  - Provides a framework for worldwide wireless access by linking the diverse systems of terrestrial and satellite based networks.
  - Data rate limit is approximately 30 Mbps
  - Detailed specifications contributed by 3GPP, 3GPP2, ETSI and others
- **IMT-Advanced**
  - New generation framework for mobile communication systems beyond IMT-2000 with deployment around 2010 to 2015
  - Data rates to reach around 100 Mbps for high mobility and 1 Gbps for nomadic networks (i.e. WLANs)
  - IEEE 802.11ac and 802.11ad VHT (very high throughput) working to define the nomadic interface
  - 3GPP working to define LTE and LTE-Advanced high mobility interface and so is IEEE 802.16m

3GPP (3rd Generation Partnership Project)

- Partnership of 6 regional standards groups that translate 3GPP specifications to regional standards
- Defines standards for mobile broadband, including UMTS and LTE

The IEEE 802 Wireless Technologies



IEEE 802 LAN/MAN Standards Committee (LMSC)

Wireless standards dominate the work of IEEE 802

- **802.1** Higher Layer LAN Protocols
- **802.3** Ethernet
- ➡ **802.11** Wireless LAN
- ➡ **802.15** Wireless Personal Area Network
- ➡ **802.16** Broadband Wireless Access
- ➡ **802.17** Resilient Packet Ring
- ➡ **802.18** Radio Regulatory TAG
- ➡ **802.19** Coexistence TAG
- ➡ **802.21** Media Independent Handoff
- ➡ **802.22** Wireless Regional Area Networks

Work on TV White Spaces (802.11, 802.19, 802.22)

TAG = technical advisory group

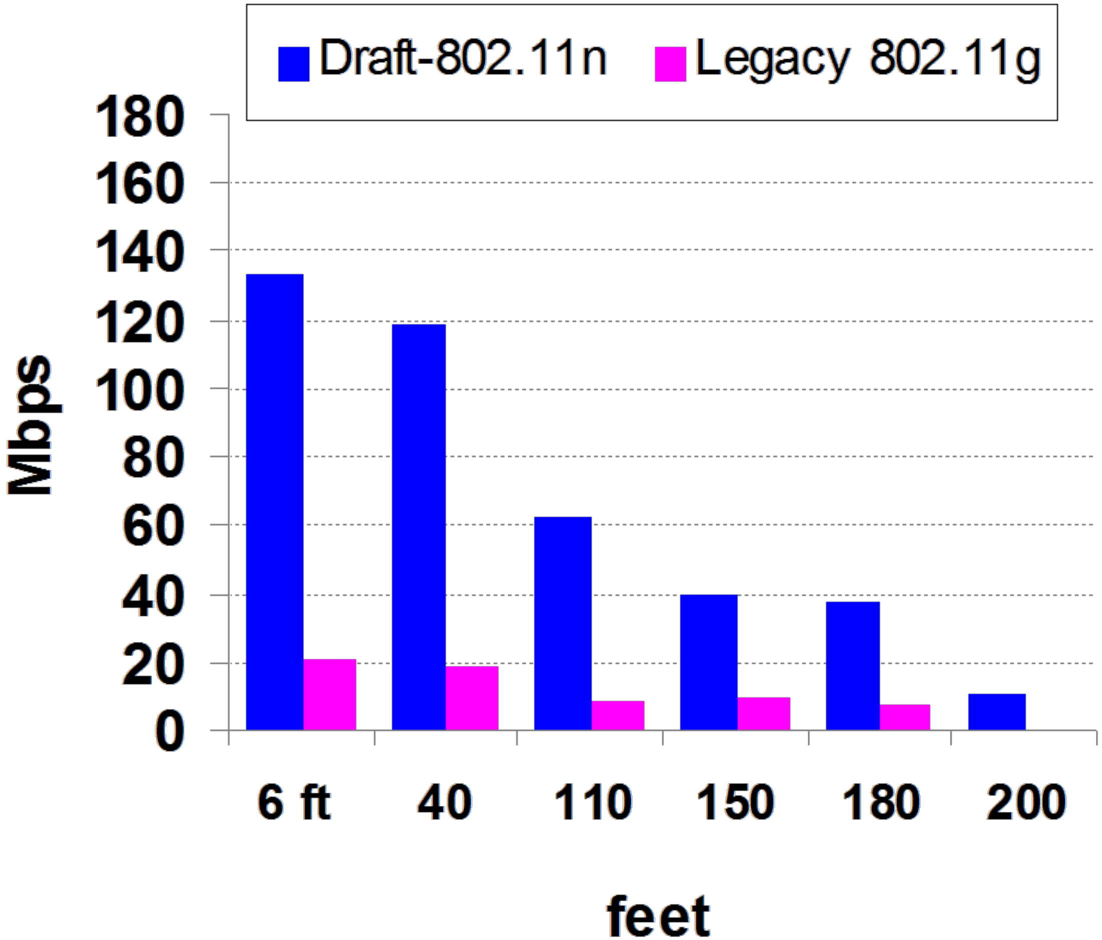
History of IEEE 802.11

- **1989**: FCC authorizes ISM bands (Industrial, Scientific and Medical)
  - 900 MHz, 2.4 GHz, 5 GHz
- **1990**: IEEE begins work on 802.11
- **1994**: 2.4 GHz products begin shipping
- **1997**: 802.11 standard approved
- **1998**: FCC authorizes the UNII (Unlicensed National Information Infrastructure) Band - 5 GHz
- **1999**: 802.11a, b ratified
- **2003:** 802.11g ratified
- **2006:** 802.11n draft 2 certification by the Wi-Fi Alliance begins
- **2009:** 802.11n certification

20??: 802.11 ac/ad: 1 Gbps Wi-Fi

802.11 has pioneered commercial deployment of OFDM and MIMO – key wireless signaling technologies

Draft 802.11n vs. Legacy Throughput Performance



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**

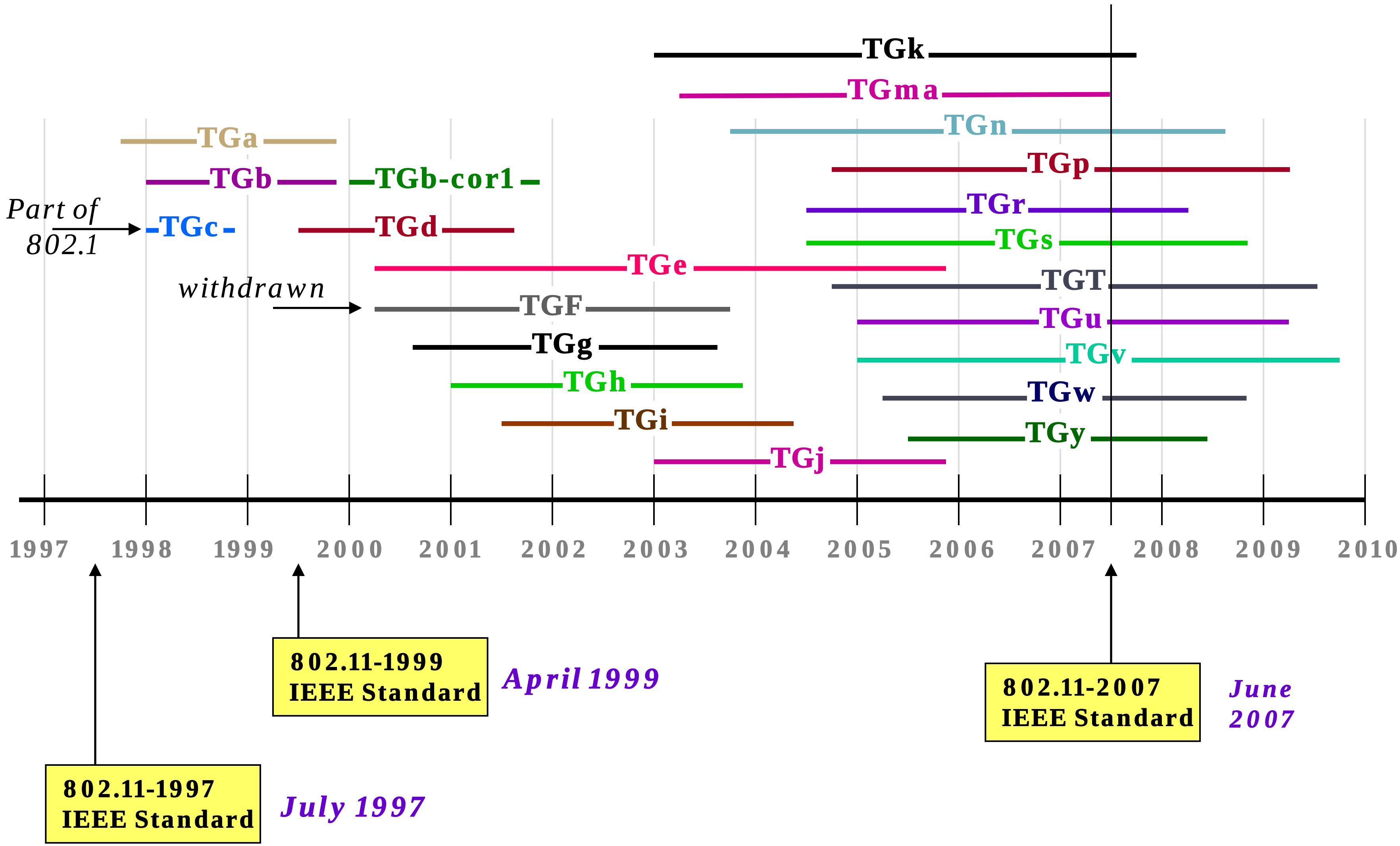
Top rate commercially available today

IEEE 802.11 Active Task Groups

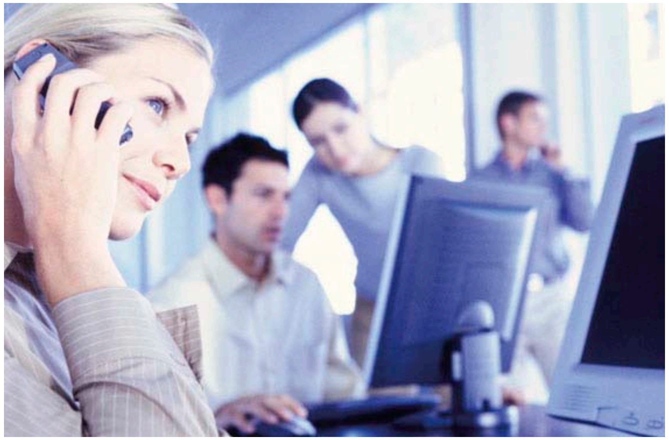
- **TGp** – Wireless Access Vehicular Environment (WAVE/DSRC)
- **TGs** – ESS Mesh Networking
- **TGu** – InterWorking with External Networks
- **TGv** – Wireless Network Management
- **TGz** – Direct Link Setup
- **TGaa** – Robust streaming of AV Transport Streams
- **TGac** – VHTL6 (very high throughput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

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

IEEE 802.11 Timeline



Making 802.11 Enterprise-grade



- 802.11r
  - Fast Roaming
  - √ released
- 802.11k
  - Radio Resource Measurement
  - √ released
- 802.11v
  - Wireless Network Management

802.11r Fast Transition (Roaming)

- Needed by voice applications
- Basic methodology involves propagating authentication information for connected stations through the ‘mobility domain’ to eliminate the need for re-authentication upon station transition from one AP to another
- The station preparing the roam can setup the target AP to minimize the actual transition time

802.11k Radio Resource Measurement

- Impetus for 802.11k came from the Enterprises that needed to manage their WLANs from a central point
- 802.11k makes a centralized network management system by providing layer 2 mechanisms for
  - Discovering network topology
  - Monitoring WLAN devices, their receive power levels, PHY configuration and network activity
- Can be used to assists 802.11r Fast Transition (roaming) protocol with handoff decisions based on the loading of the infrastructure, but 802.11v is more focused on load balancing

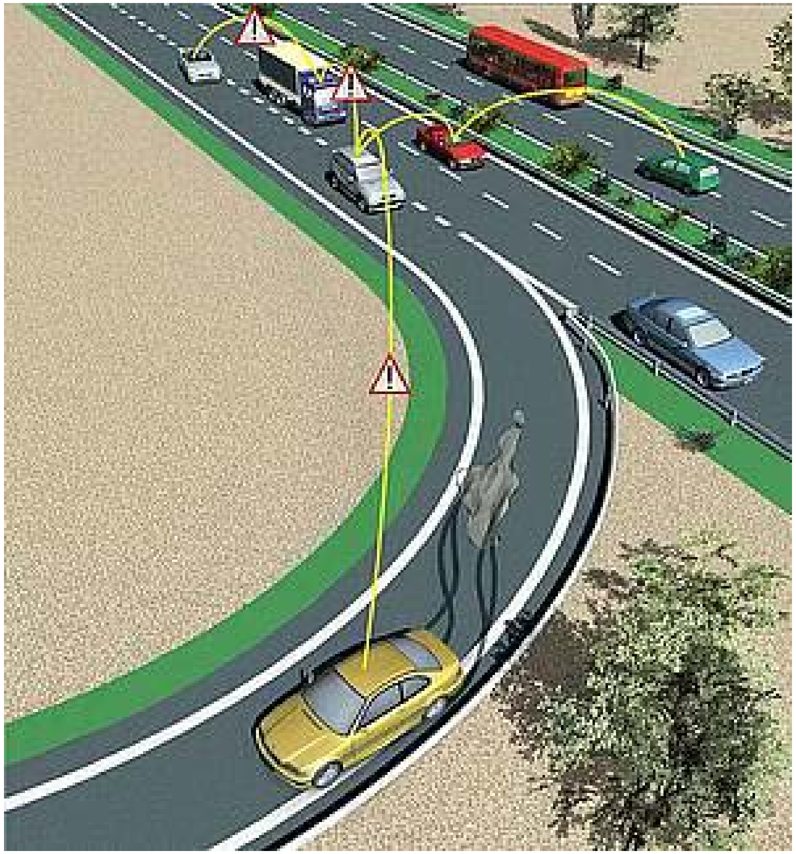
802.11v Wireless Network Management

- TGv's charter is to build on the network *measurement* mechanisms defined by TGk and introduce network *management* functions to provide Enterprises with centralized network management and load balancing capabilities.
- Major goals: **manageability, improved power efficiency** and **interference avoidance**
- Defines a protocol for requesting and reporting location capability
  - Location information may be CIVIC (street address) or GEO (longitude, latitude coordinates)
- For the handset, TGv may enable awareness of AP e911 capabilities while the handset is in sleep mode; this work has common ground with TGu

Making Wi-Fi Carrier-grade

- 802.11u - InterWorking with External Networks
  - Main goal is to enable Interworking with external networks, including other 802 based networks such as 802.16 and 802.3 and 3GPP based IMS networks
  - Manage network discovery, emergency call support (e911), roaming, location and availability
  - The network discovery capabilities give a station looking to connect information about networks in range, service providers, subscription status with service providers
- 802.11u makes 802.11 networks more like cellular networks where such information is provided by the infrastructure

802.11p WAVE/DSRC

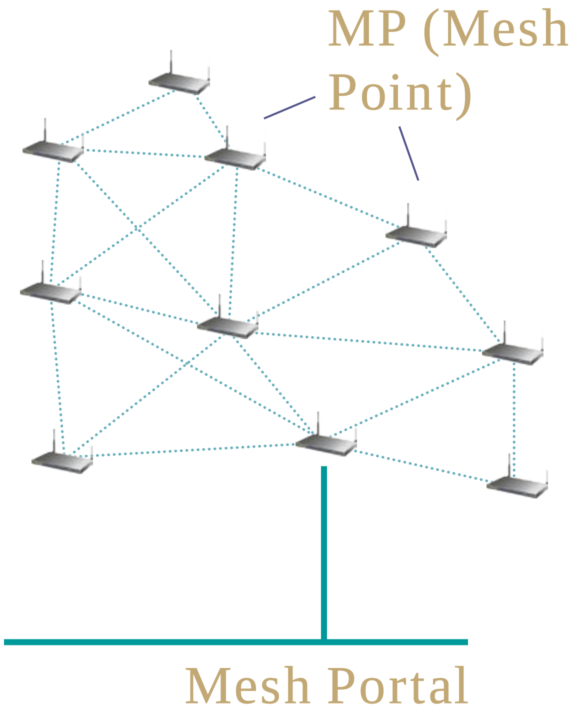


- 802.11p is the PHY in the Intelligent Transportation Systems (ITS)
- WAVE/DSRC is the method for vehicle to vehicle and vehicle to road-side unit communications to support…
  - Public safety, collision avoidance, traffic awareness and management, traveler information, toll booth payments
- Operates in the 5.9 GHz frequency band dedicated by the FCC for WAVE/DSRC
- This band falls right above the 802.11a band, making it supportable by the commercial 802.11a chipsets

DSRC = Dedicated Short Range Communications
WAVE = Wireless Access Vehicular Environment

IEEE 802.11s Mesh

- Wireless Distribution System with automatic topology learning and wireless path configuration
- Self-forming, self-healing, dynamic routing
- ~32 nodes to make routing algorithms computationally manageable
- Extension of 802.11i security and 802.11e QoS protocol to operate in a distributed rather than centralized topology



History of IEEE 802.16

From OFDM to OFDMA

orthogonal frequency division multiplexing
orthogonal frequency division multiple access

- **1998**: IEEE formed 802.16 WG
  - Started with 10–66 GHz band; later modified to work in 2–11GHz to enable NLOS (non-line of site)
- **2004:** IEEE 802.16-2004d
  - Fixed operation standard ratified
- **2005:** 802.16-2005e
  - Mobility and scalability in 2–6 GHz
- **Latest:** P802.16-2009 (Rev2)
- **Future:** 802.16m – next generation

IEEE 802.16 Active Task Groups

- 802.16h, License-Exempt Task Group
  - Working with 802.11 TGy and 802.19 Coexistence TAG
- 802.16m, IMT Advanced Air Interface
- Maintenance
  - Completed 802.16 Rev2
  - Working with the WiMAX Forum

http://grouper.ieee.org/groups/802/16

WiMAX Forum

- IEEE 802.16 contains too many options
- The WiMAX Forum defines *certification profiles* on parts of the standard selected for deployment; promotes interoperability of products through testing and certification
- The WiMAX Forum works closely with the IEEE 802.16 *Maintenance group* to refine the standard as the industry learns from certification testing

WiMAX Forum™ Mobile System Profile
Release 1.0 Approved Specification
(Revision 1.6.1: 2008-04-01)

	Release 1.0	802.16e/TDD
	Release 1.5	802.16e/TDD and FDD
Future	Release 2.0	802.16m (IMT Advanced)

Agenda

- The G's – historical perspective
- OFDM, OFDMA and multiple antenna techniques
- Standards – 3GPP, IEEE 802 wireless
- White Spaces
- Concluding thoughts

TV White Spaces

- 6 MHz TV channels 2-69
  - VHF: 54-72, 76-88, 174-216 MHz
  - UHF: 470-806 MHz
- *November 4, 2008* FCC allowed unlicensed use of TV white spaces
- *June 12, 2009* transition from analog to digital TV freed up channels 52-69 (above 692 MHz) due to higher spectral efficiency of digital TV
- TVBD = TV Band Device

White Spaces Radio Technology

- FCC Docket 04-186 requires the use of *cognitive radio* technology to determine whether a channel is available prior to transmitting.
- Methods for detecting licensed transmissions:
  - An internal GPS could be used in conjunction with a database to determine whether the TVBD is located far enough away from licensed stations.
  - TVBD could incorporate sensing capabilities to detect whether licensed transmitters are in its range. If licensed devices are detected, the TVBD would have to search for another channel.

FCC Rules

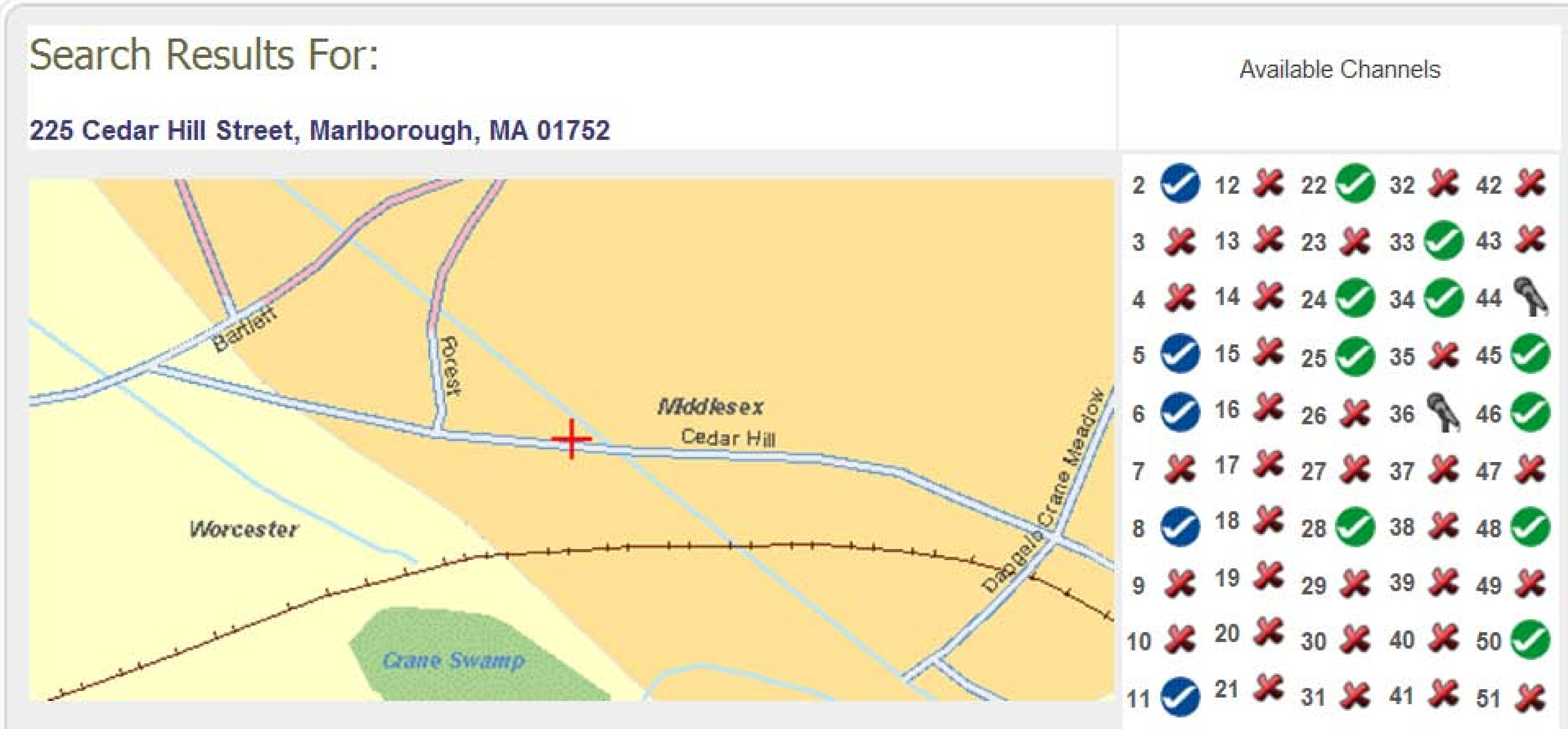
- TVBDs require geolocation capability and Internet access to a database of protected radio services. The TVBDs must first access the database before operating.
- Fixed devices can operate on any channel between 2 and 51, except 3, 4 and 37
  - Up to 4 Watts EIRP (Effective Isotropic Radiated Power)
- Channels 2 – 20 are restricted for use by fixed devices to protect wireless microphones
- Fixed and personal portable devices must sense TV broadcasting and wireless microphone signals

Frequency Allocation of TV Channels by the FCC

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

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

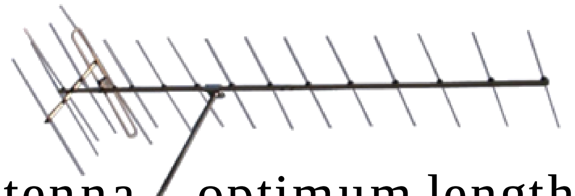
www.showmywhitespace.com



Maintained by Spectrum Bridge

Beach-front Property?

- Lower frequencies experience lower attenuation in free space and through obstructions, e.g. buildings
- However, when propagating through metal frames in modern buildings, Fresnel zone gets constricted and attenuation is introduced

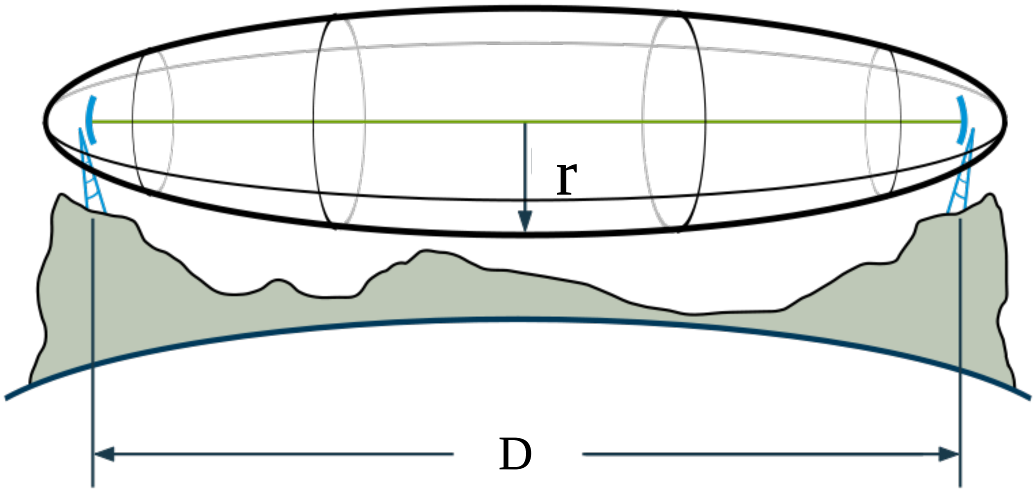


Antenna – optimum length is a multiple of ¼ wavelength

3.3 feet for 70 MHz
4” for 700 MHz
1” for 2.4 GHz

Longer antennas required for UHF may be problematic for handheld devices

Antenna Fresnel Zone



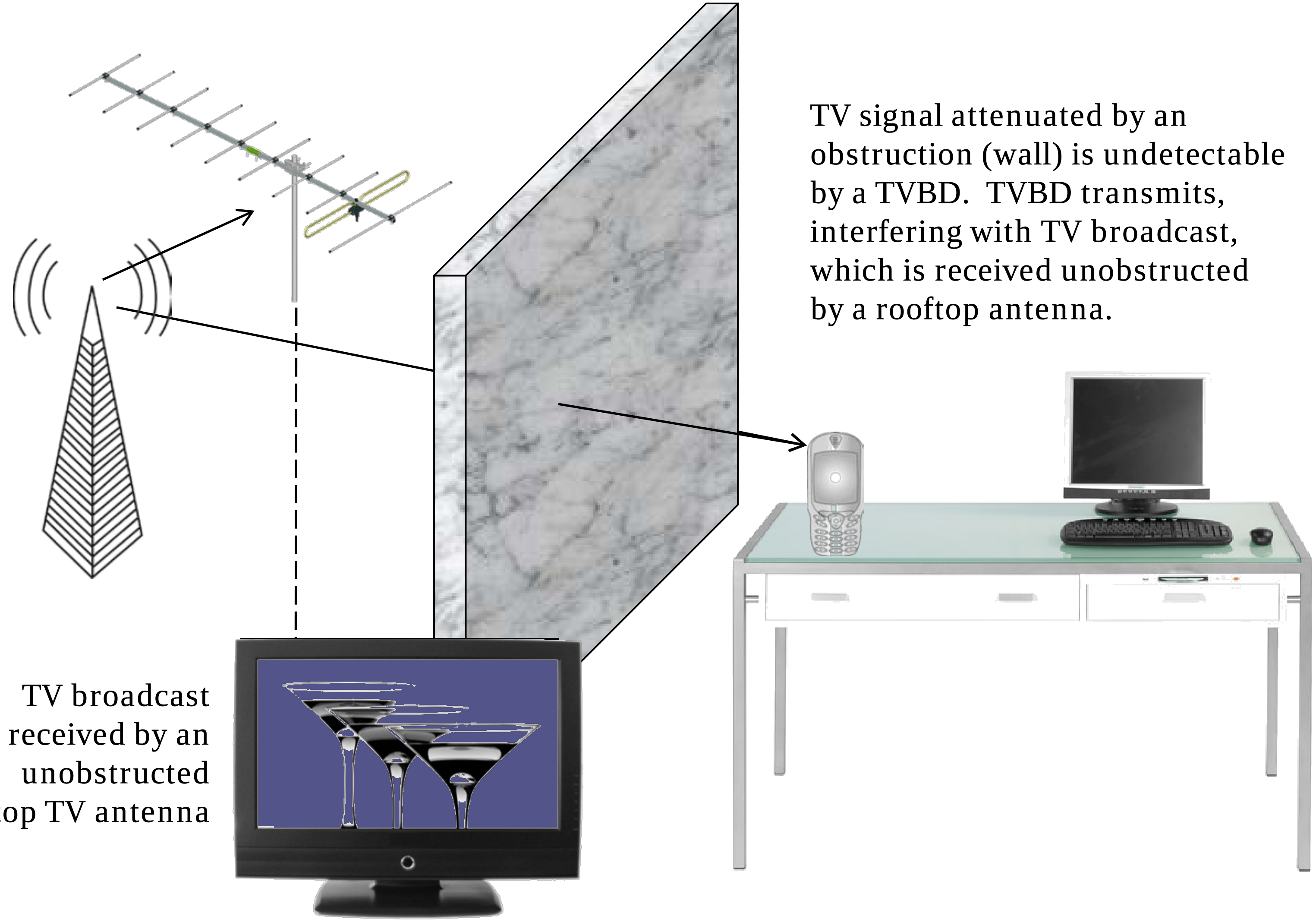
- *Fresnel zone* is the shape of electromagnetic signal and is a function of frequency
- Constricting the Fresnel zone introduces attenuation and signal distortion

$$r = 72.05\sqrt{\frac{D}{4f}}$$

r = radius in feet
D = distance in miles
f = frequency in GHz

Example: D = 0.5 mile
r = 30 feet for 700 MHz
r = 16 feet for 2.4 GHz
r = 10 feet for 5.8 GHz

Hidden Node Scenario



TV signal attenuated by an obstruction (wall) is undetectable by a TVBD. TVBD transmits, interfering with TV broadcast, which is received unobstructed by a rooftop antenna.

TV broadcast received by an unobstructed rooftop TV antenna

White Spaces Communications Standards

- IEEE 802.22
  - Based on 802.16d
  - Ongoing effort for almost 5 years
  - Worked with the FCC on White Spaces regulations
- IEEE 802.19
  - Coexistence standards
- IEEE 802.11 TVWS Study Group

Agenda

- The wireless G's – historical perspective
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- Standards – 3GPP, IEEE 802 wireless
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Challenges on the Horizon

- Wireless infrastructure
  - Support millions of small cells (femto, pico)
  - Manage interference among base stations
  - Manage coexistence among diverse standards, including White Spaces
- Mobile terminals
  - Support multiple radio standards
  - Roaming and handoff
  - Application and network performance
  - Cost, size, weight and battery life

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