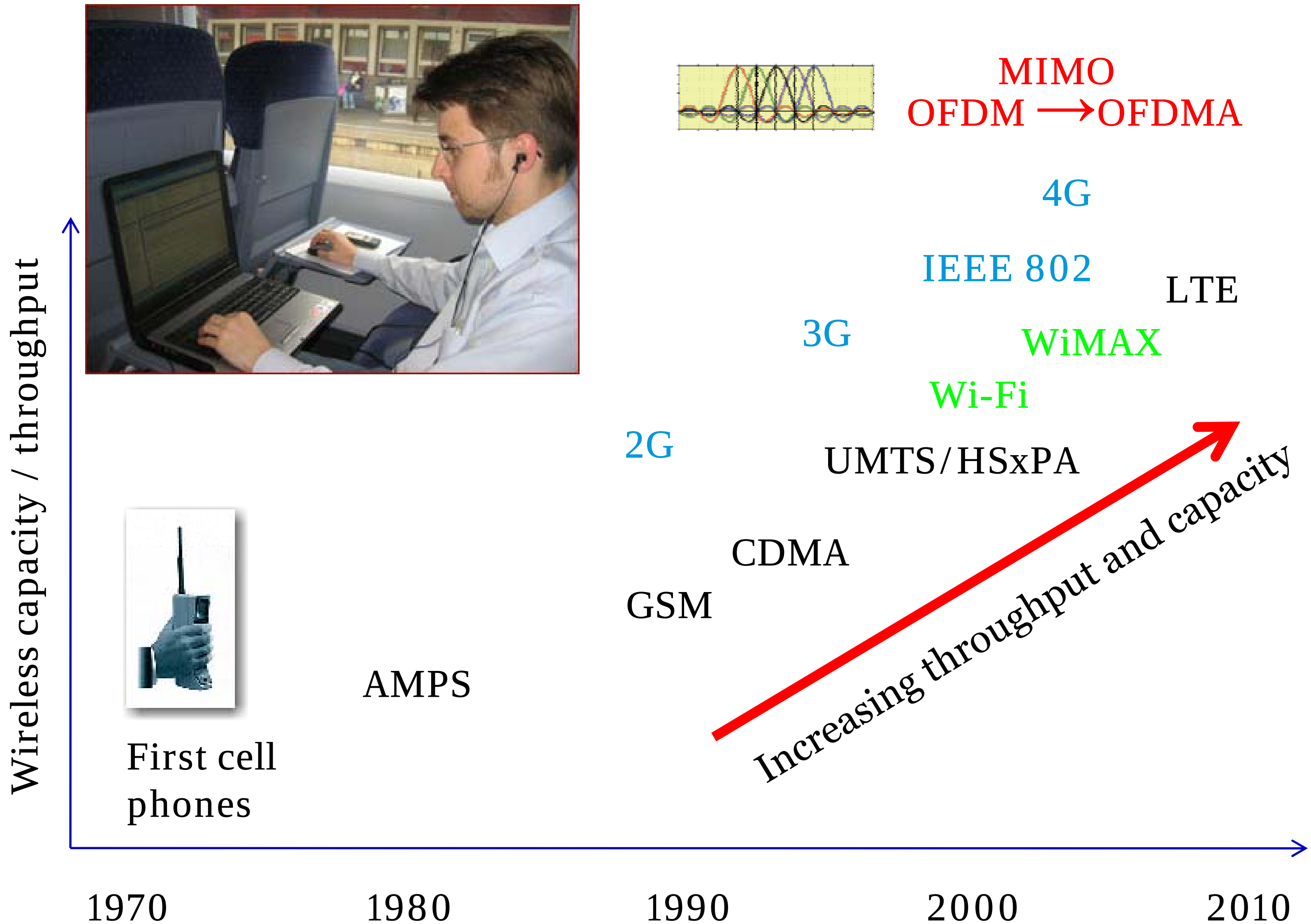
Wireless Tutorial

Wi-Fi, 3G, 4G, White Spaces
and Beyond

Agenda

10:30 – 12:00 noon	Our G-enealogy – History and Evolution of Mobile Radio
	Lunch
1:00 – 2:00	**The IEEE's Wireless Ethernet Keeps Going and Growing**
2:00 – 2:45	4G Tutorial: Vive la Différence?
	Break
3:00 – 3:45	Mobile Broadband - New Applications and New Business Models
	Break
4:00 – 4:45	Tutorial: White Spaces and Beyond


MIMO
OFDM → OFDMA
4G
IEEE 802
LTE
3G
WiMAX
Wi-Fi
2G
UMTS/HSxPA
CDMA
GSM
AMPS
First cell phones
Increasing throughput and capacity
Wireless capacity / throughput
1970
1980
1990
2000
2010

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

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

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

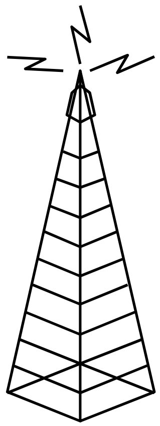
History of 802.16

- **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:** P802.16Rev2/D8 draft
- **Future:** 802.16m – next generation
  - SDD (system definition document)
  - SRD (system requirements document)

From OFDM to OFDMA

orthogonal frequency division multiplexing
orthogonal frequency division multiple access

ITU-T Framework



Pervasive connectivity
WLAN - WMAN - WWAN

ITU-T – United Nations telecommunications standards organization

Accepts detailed standards contributions from 3GPP, IEEE and other groups

IEEE 802.11 – WLAN (wireless local area network)

IEEE 802.16 – WMAN (wireless metropolitan area network)

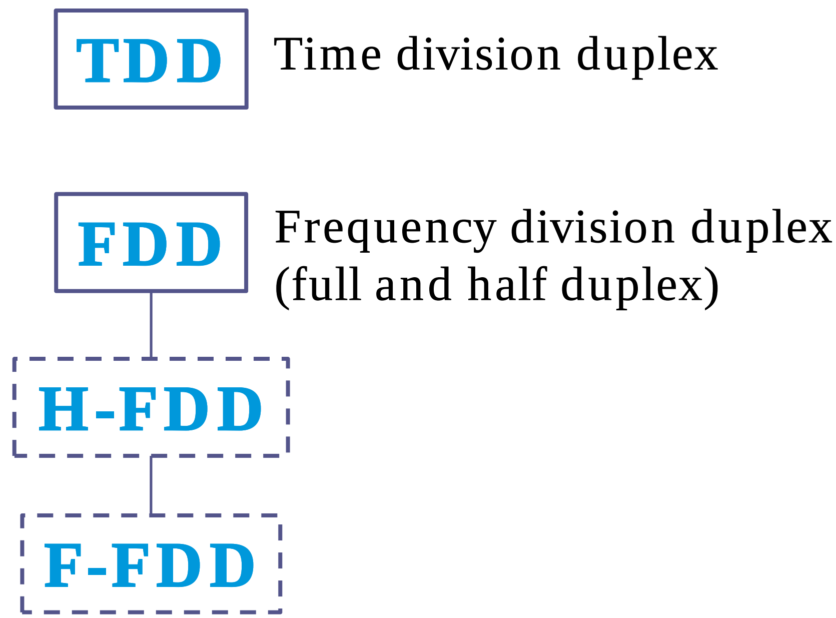
3GPP – WBA (wireless broadband access)

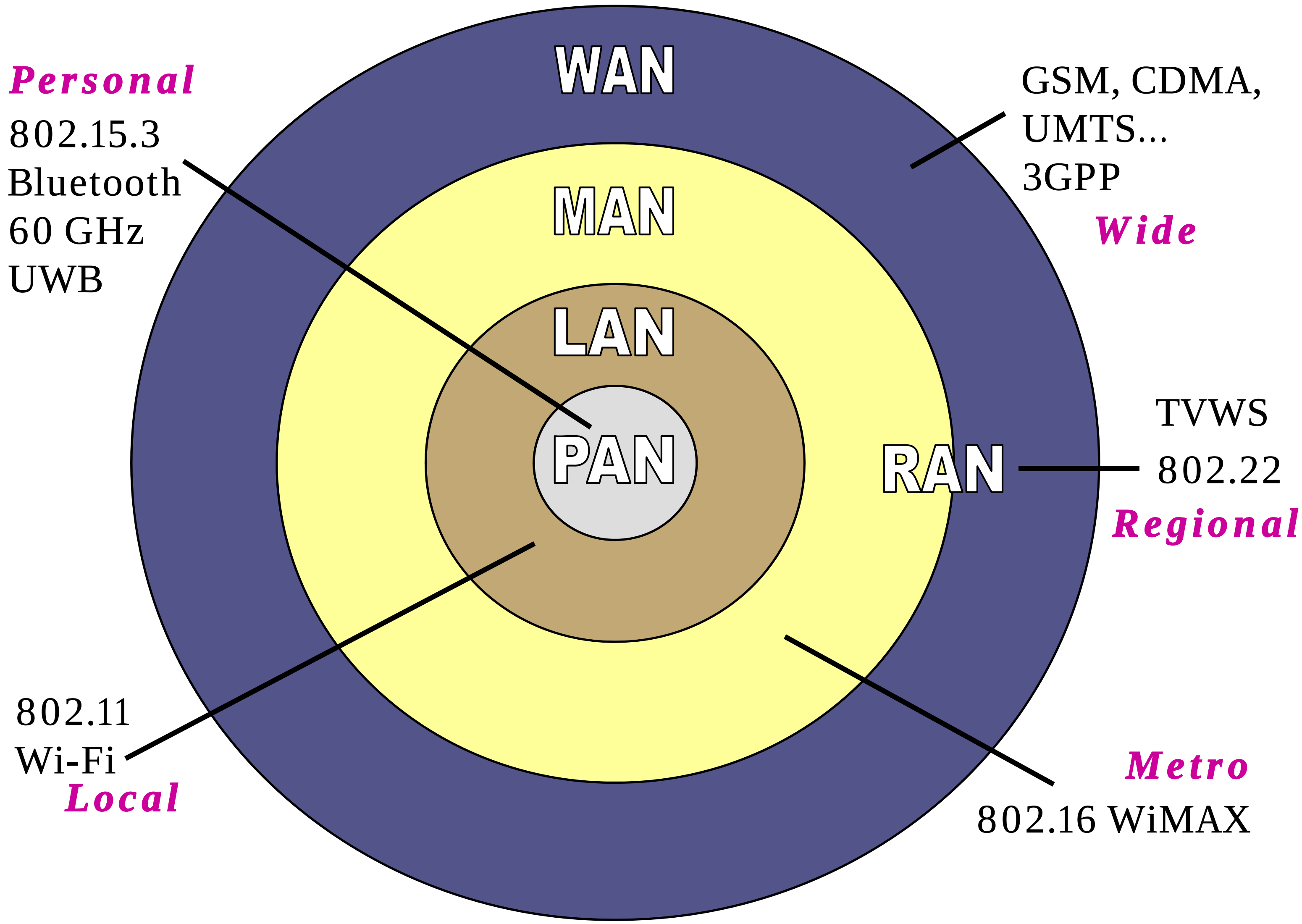
ITU International Mobile Telecommunications

- **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 802.16m working to define the high mobility interface
  - IEEE 802.11ac and 802.11ad VHT (very high throughput) working to define the nomadic interface

ITU Frequency Bands for IMT Advanced

- 450-470 MHz
- 698-960 MHz
- 1710-2025 MHz
- 2110-2200 MHz
- 2300-2400 MHz
- 2500-2690 MHz
- 3400-3600 MHz




WAN
MAN
LAN
PAN
RAN
Personal
802.15.3
Bluetooth
60 GHz
UWB
GSM, CDMA,
UMTS…
3GPP
Wide
TVWS
802.22
Regional
802.11
Wi-Fi
Local
Metro
802.16 WiMAX

Wireless standards dominate the work of IEEE 802

IEEE 802 LAN/MAN Standards Committee (LMSC)

- **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 (technical advisory group)
- ➡ **802.19** Coexistence TAG
- ➡ **802.21** Media Independent Handoff
- ➡ **802.22** Wireless Regional Area Networks
- ➡ **802** TV White Spaces Study Group

IEEE

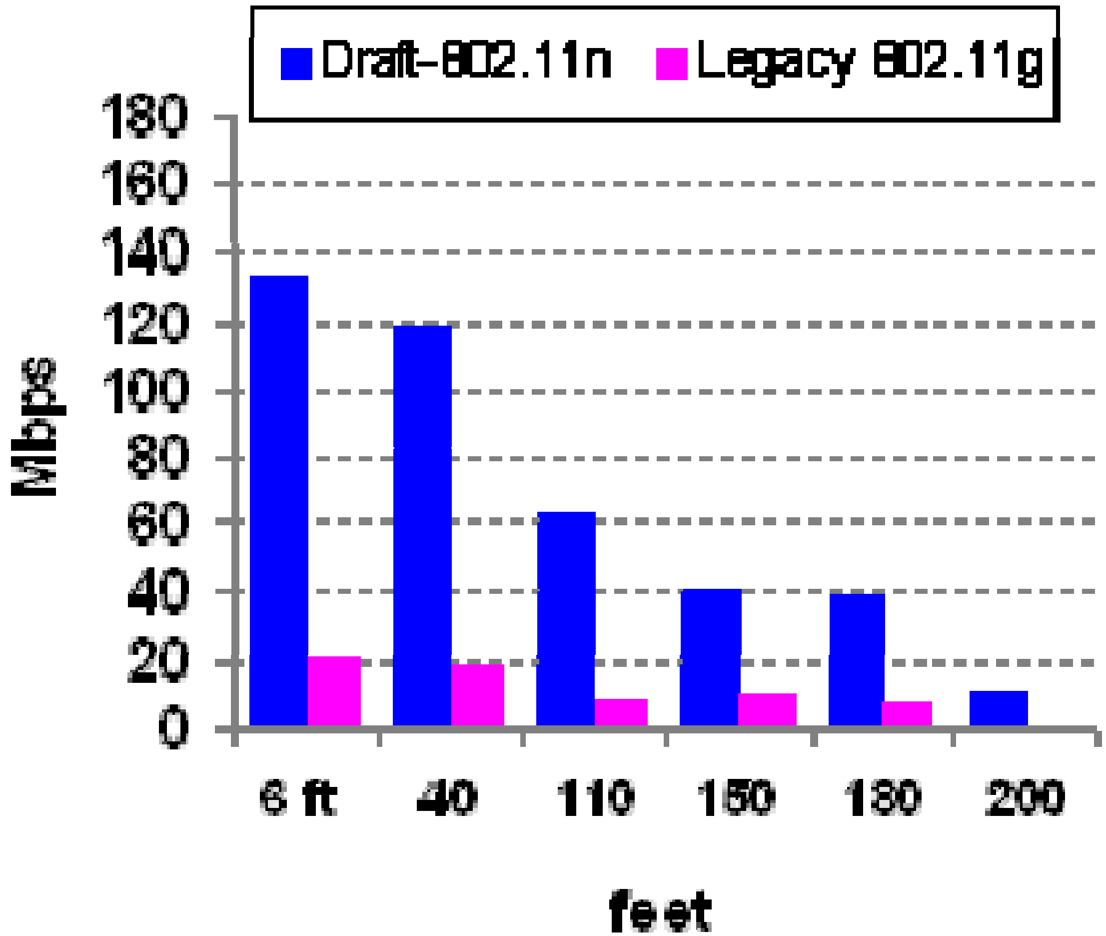
IEEE 802

IEEE 802.11 Active Task Groups

- **TGn** – High Throughput
- **TGp** – Wireless Access Vehicular Environment (WAVE/DSRC)
- **TGs** – ESS Mesh Networking
- **TGT** – IEEE 802 Performance
- **TGu** – InterWorking with External Networks
- **TGv** – Wireless Network Management
- **TGw** – Protected Management Frames
- **TGy** – 3650-3700 MHz Operation in USA
- **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

Draft 802.11n vs. Legacy Throughput Performance



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	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%

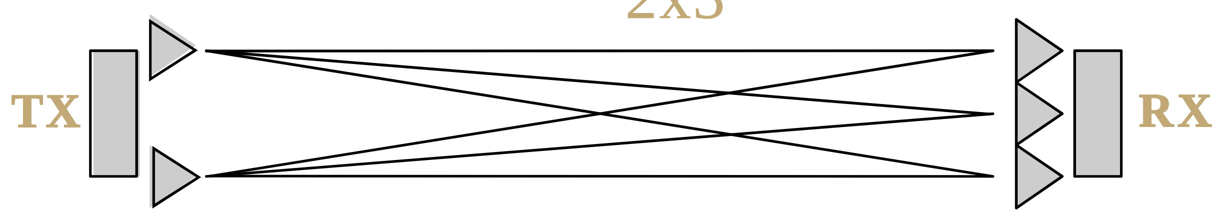
IEEE 802.11a,b,g,n

	20 MHz Channel		40 MHz Channel	
	1 stream	2 streams	1 stream	2 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 GI[1]=800ns 2.4 GHz	6.5, 13, 19.5, 26, 39, 52, 58.5, 65	13, 26, 39, 52, 78, 104, 117, 130		
802.11n GI[1]=800ns 5 GHz	6.5, 13, 19.5, 26, 39, 52, 58.5, 65	13, 26, 39, 52, 78, 104, 117, 130	13.5, 27, 40.5, 54, 81, 108, 121.5, 135	27, 54, 81, 108, 162, 216, 243, 270
802.11n, GI=400ns 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	15, 30, 45, 60, 90, 120, 135, 150	30, 60, 90, 120, 180, 240, 270, **300**

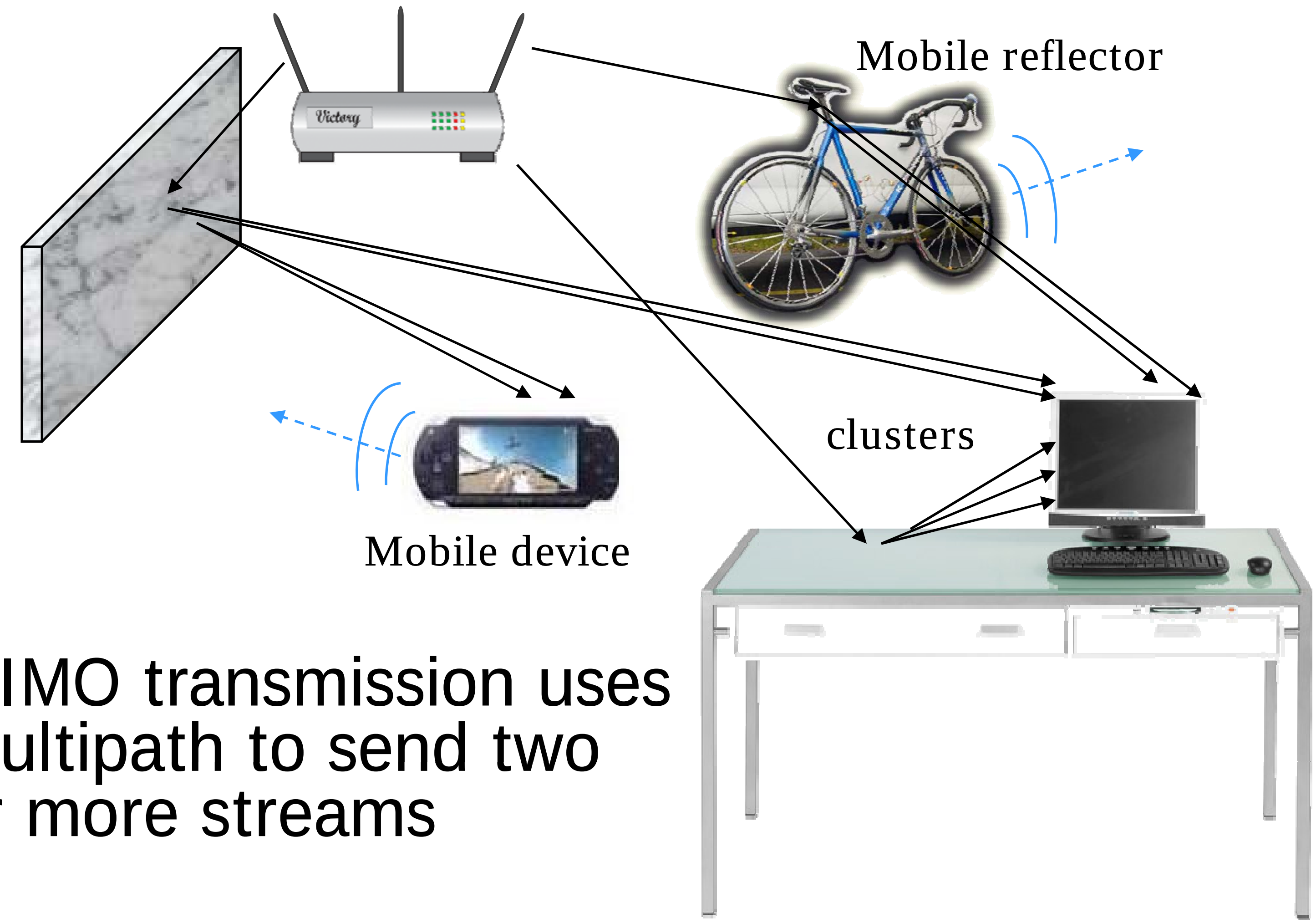
[1,] GI = Guard Interval, period within an OFDM symbol allocated to letting the signal settle prior to transmitting the next symbol. Legacy 802.11a/b/g devices use 800ns GI. GI of 400ns is optional for 802.11n.

MIMO Radio Systems

2x3



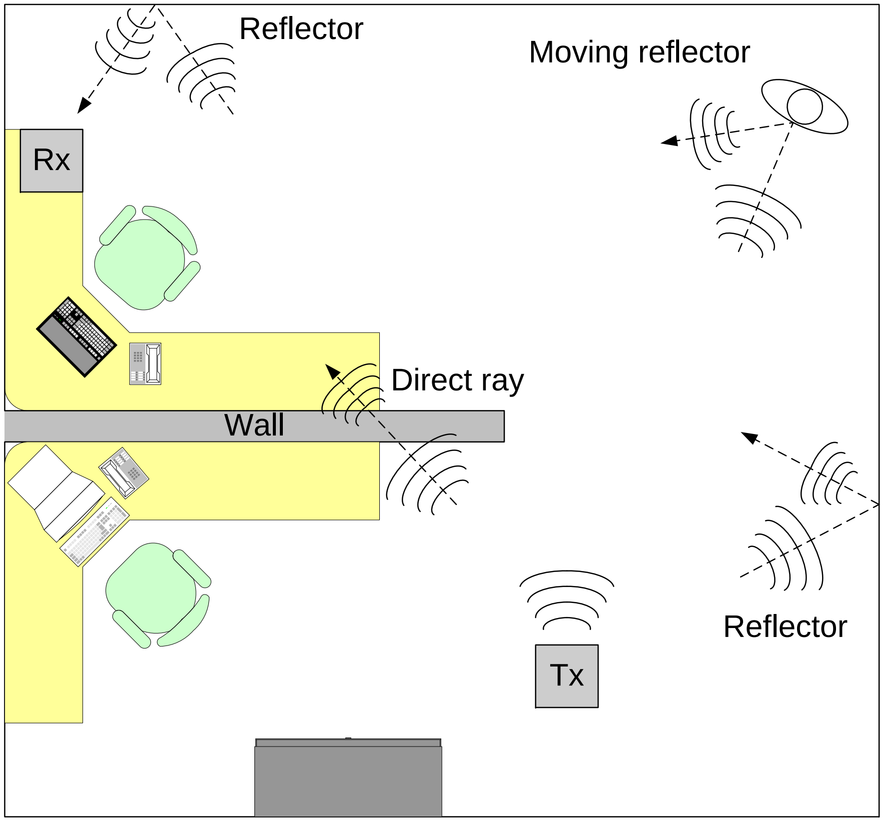
- Data is organized into spatial streams that are transmitted simultaneously - This is known as *Spatial Multiplexing*
- **SISO**: Single-Input/Single-Output; **MIMO**: Multi-Input/Multi-Output; **SIMO**: Single-Input/Multi-Output; **MISO**
- There's a propagation path between each transmit and receive antenna (a "MIMO path")
- N x M MIMO (e.g. "4x4", "2x2", "2x3")
  - *N* transmit antennas
  - *M* receive antennas
  - Total of *N* x *M* paths



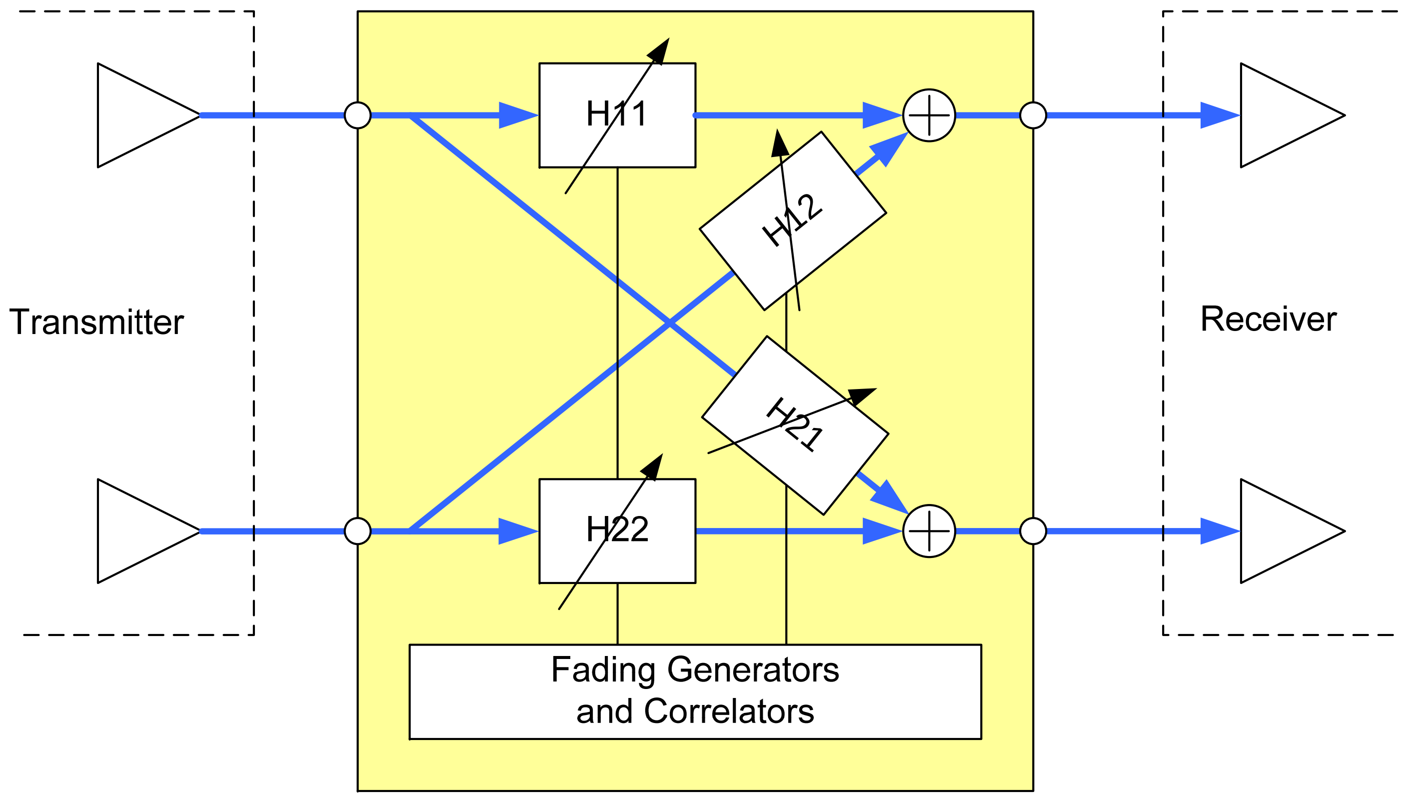
MIMO transmission uses multipath to send two or more streams

Indoor MIMO Multipath Channel

- Multipath reflections come in "clusters"
- Reflections in a cluster arrive at a receiver all from the same general direction
- Statistics of clusters are key to MIMO system operation
- 802.11n developed 6 models: A through F

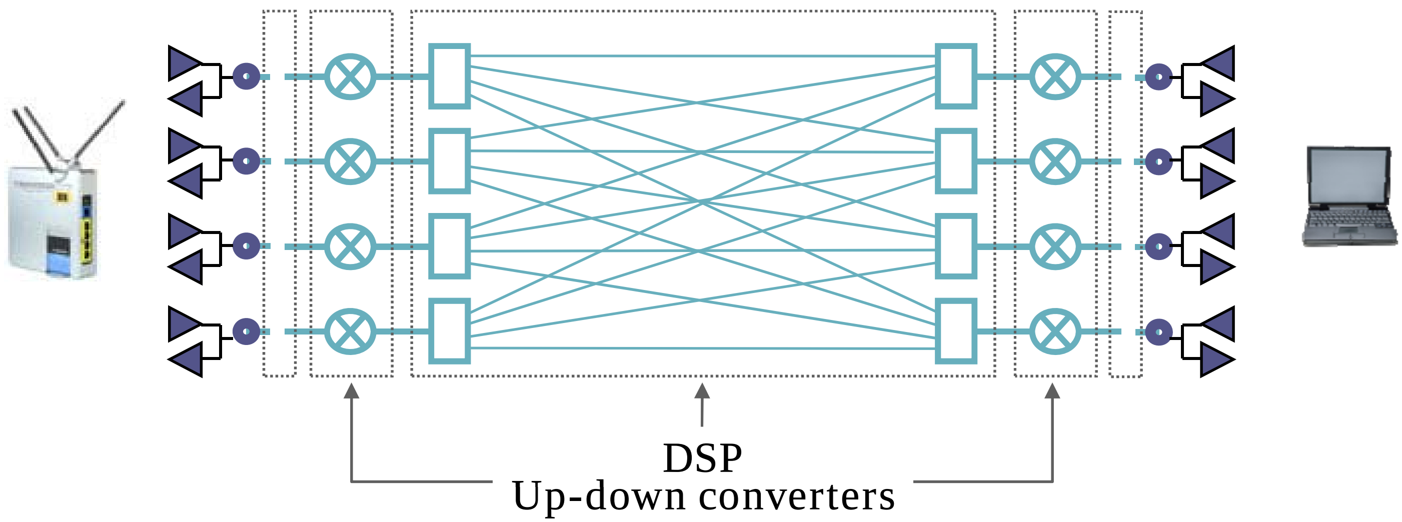


Example 2x2 MIMO Channel Model



- Time-varying FIR filter weights
  - Spatially correlated: H_{11} correlated with H_{12}, etc., according to antenna spacing and cluster statistics
  - Time correlated according to the Doppler model

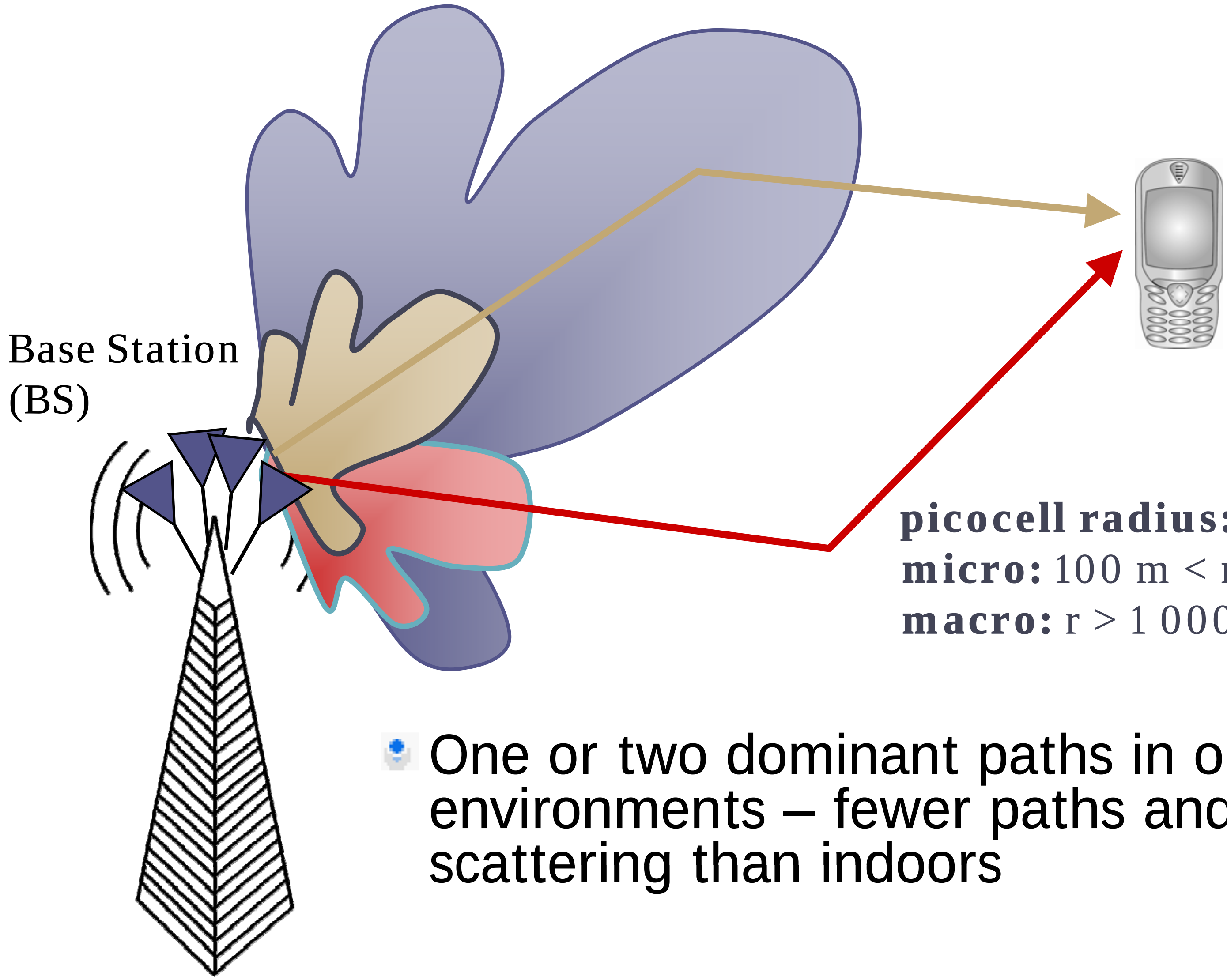
MIMO Channel Emulation



- 4 x 4 MIMO paths to support 802.11n
- WiMAX requires 2 x 2
- 802.11n and ITU M.1225 channel models
- Bidirectionality required to support beamforming

Municipal Multipath Environment

Outdoor Multipath Environment



picocell radius: r < 100 m
micro: 100 m < r < 1 000 m
macro: r > 1 000 m

- One or two dominant paths in outdoor environments – fewer paths and less scattering than indoors

802.11n Channel Models

Parameters	Models					
	A	B	C	D	E	F
Avg 1st Wall Distance (m)	5	5	5	10	20	30
RMS Delay Spread (ns)	0	15	30	50	100	150
Maximum Delay (ns)	0	80	200	390	730	1050
Number of Taps	1	9	14	18	18	18
Number of Clusters	N/A	2	2	3	4	6

- Delay spread is a function of the size of the modeled environment
- Number of clusters represents number of independent propagation paths modeled
- Doppler spectrum assumes reflectors moving in environment at 1.2 km/h, which corresponds to about 6 Hz in 5 GHz band, 3 Hz in 2.4 GHz band

ITU MIMO Channel Models – For BWA

WiMAX system performance simulations are based on ITU models

Channel Model	Path 1	Path 2	Path 3	Path 4	Path 5	Path 6
ITU Pedestrian B (relative figures)	0 dB 0 ns	-0.9 dB 200 ns	-4.9 dB 800 ns	-8.0 dB 1200 ns	-7.8 dB 2300 ns	-23.9 dB 3700 ns
ITU Vehicular A (relative figures)	0 dB 0 ns	-1.0 dB 310 ns	-9.0 dB 710 ns	-10.0 dB 1090 ns	-15.0 dB 1730 ns	-20.0 dB 2510 ns

Channel Model	Speed	Probability
ITU Pedestrian B	3 km/hr	60%
ITU Vehicular A	30 km/hr	30%
	120 km/hr	10%

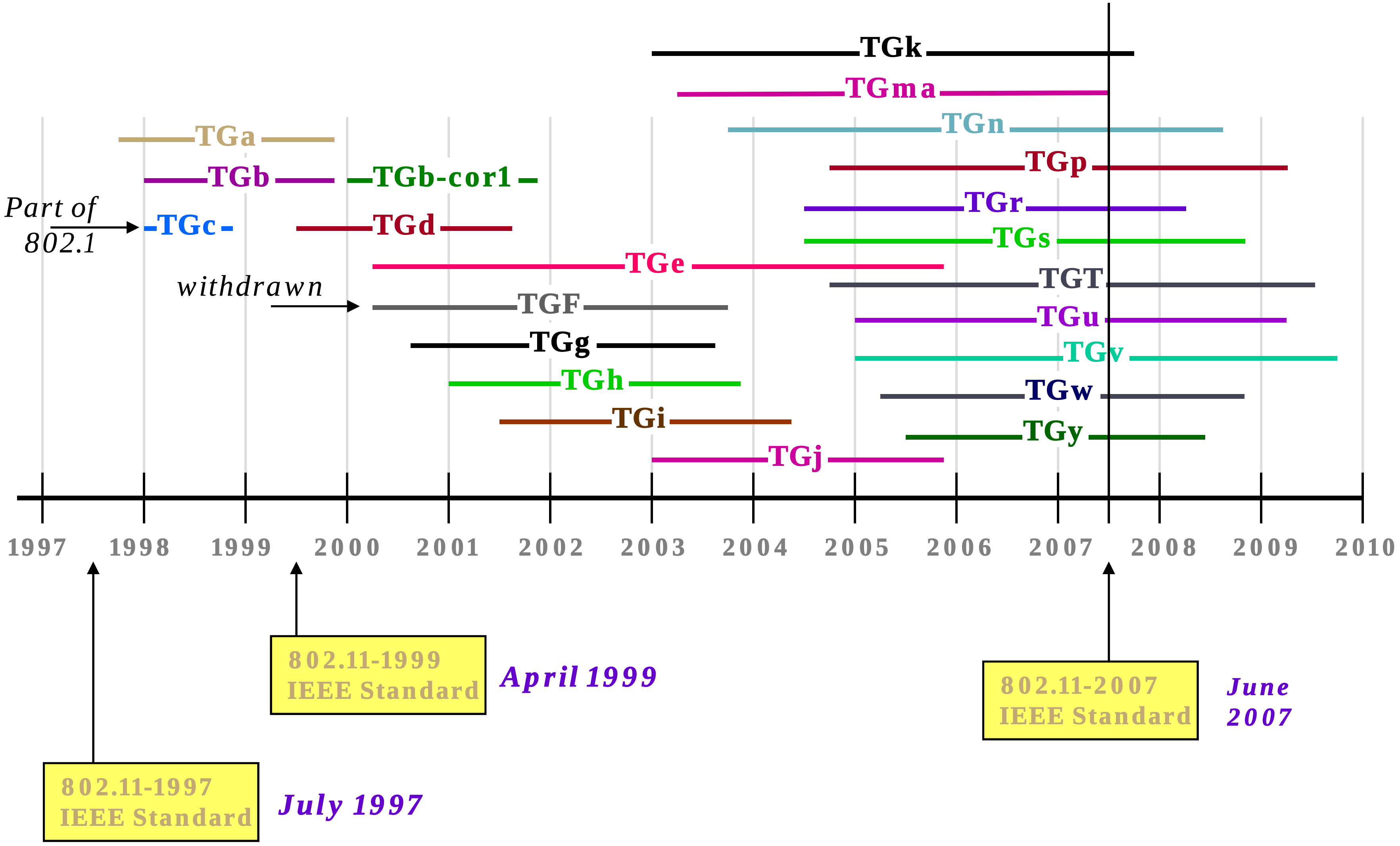
BWA = Broadband Wireless Access

Lightly Regulated Band for 802.11, 802.16

- March 2005 FCC offered 50 MHz 3650 to 3700 MHz for *contention-based protocol*
- 802.11y meets FCC requirement; 802.16h is working to comply
- 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**

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

802.11v Improves Power Efficiency

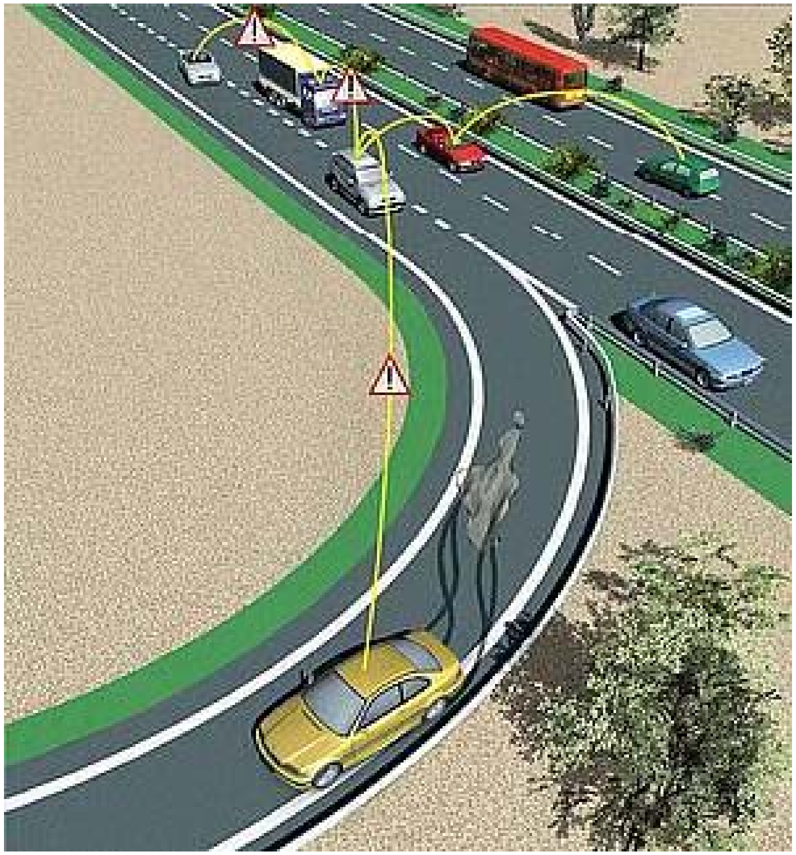
- TGv defines FBMS (flexible broadcast multicast service) – the mechanism to let devices extend their sleep period
- Devices can specifying the wake up interval to be longer than a single DTIM (delivery traffic indication message). This consolidates traffic receive/transmit intervals and extends battery life of handsets.

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

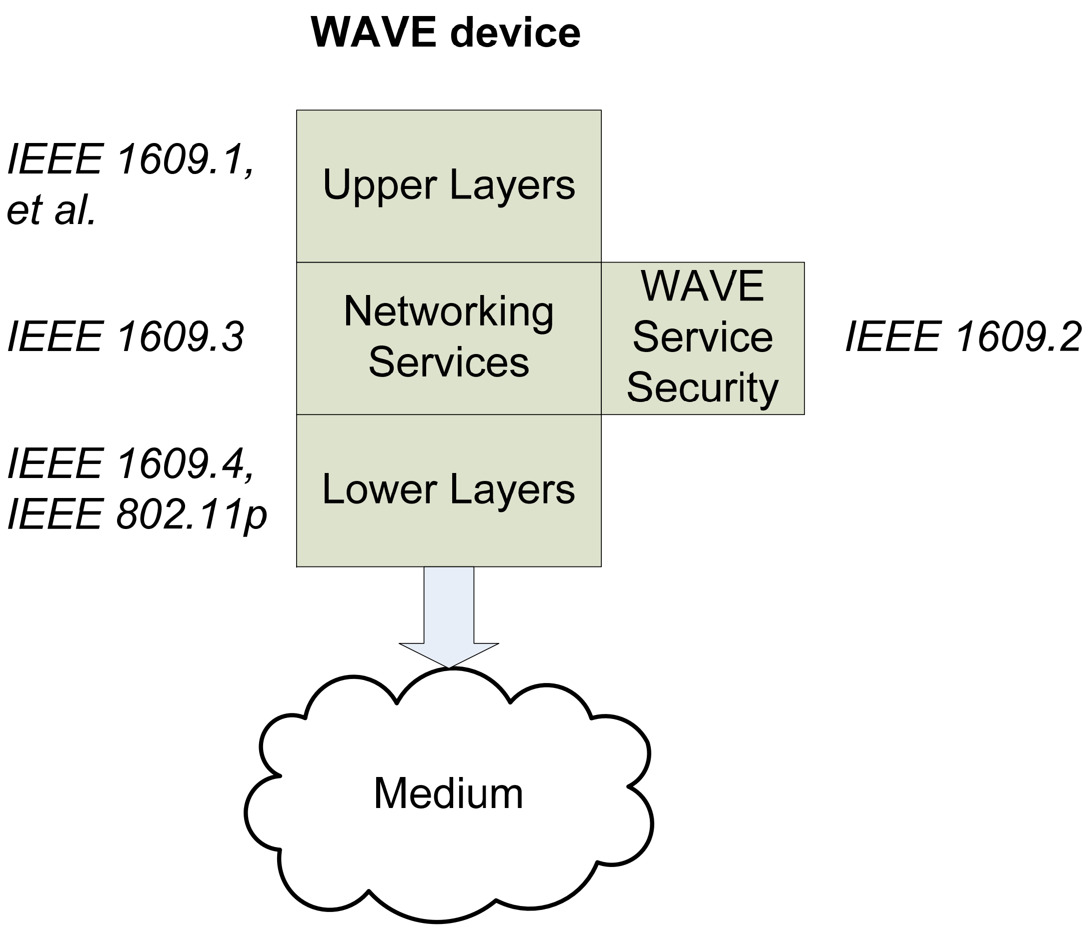
802.11p Wireless Access Vehicular Environment (WAVE)

- Transportation communications systems under development by Department of Transportation (DoT)
- 802.11p is the PHY in the Intelligent Transportation Systems (ITS)
- WAVE is also called DSRC (Dedicated Short Range Communications)
- 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



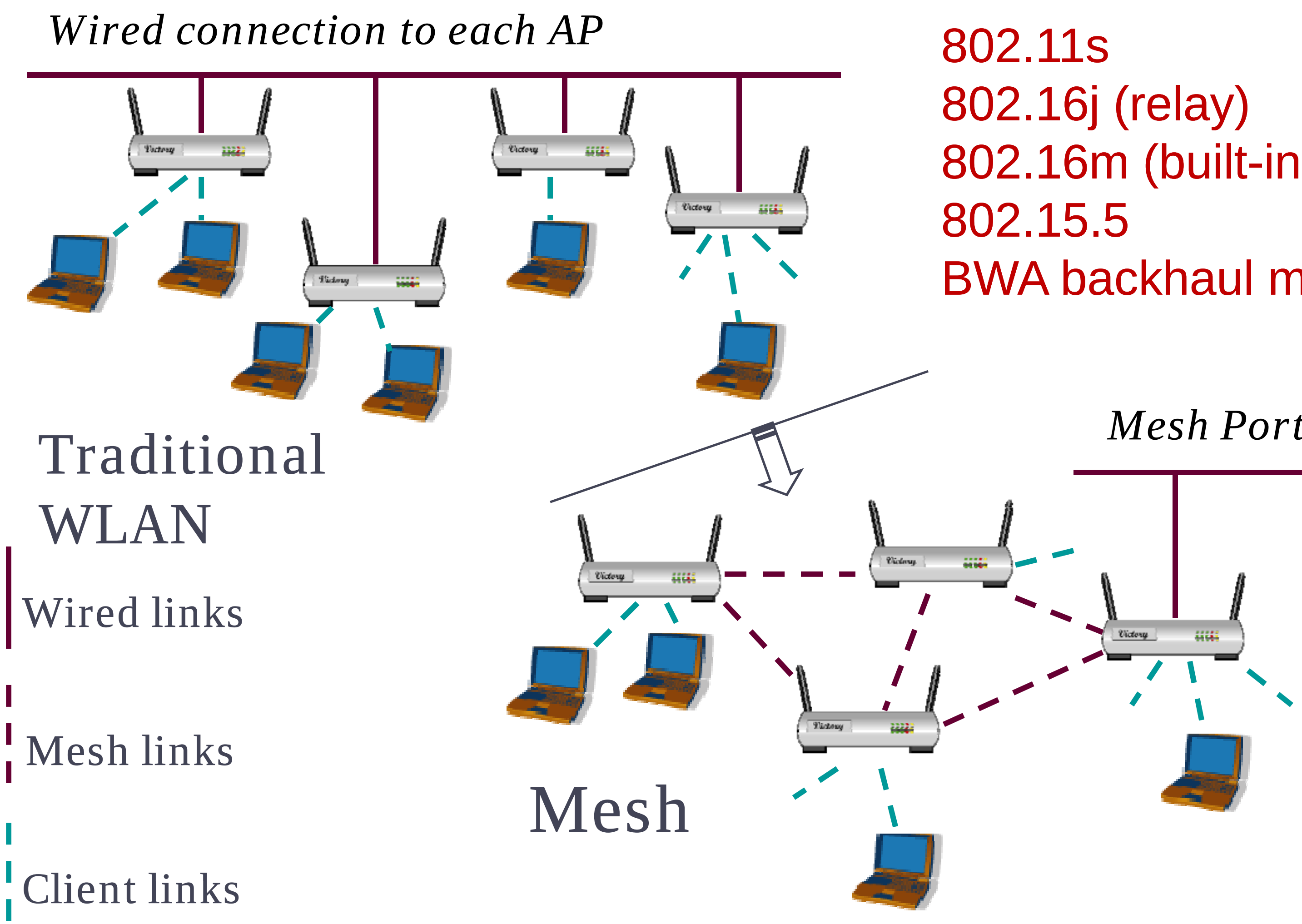
802.11p Wireless Access Vehicular Environment (WAVE)

- 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



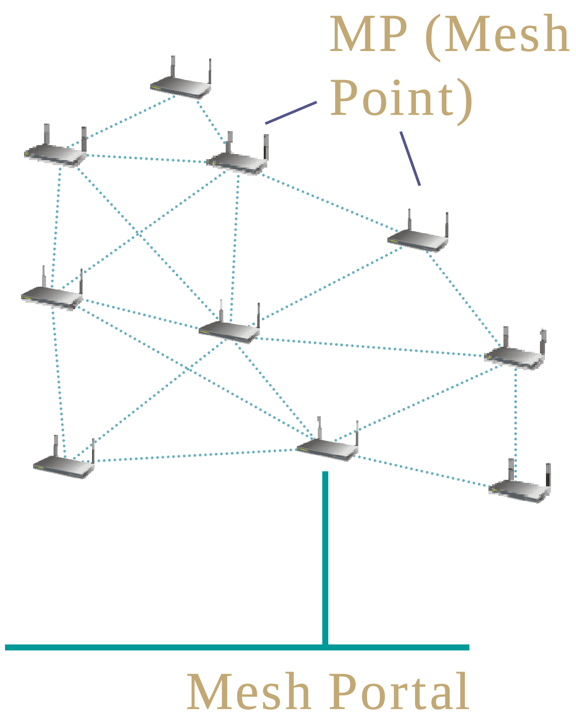
Wireless Mesh

802.11s
802.16j (relay)
802.16m (built-in meshing)
802.15.5
BWA backhaul mesh



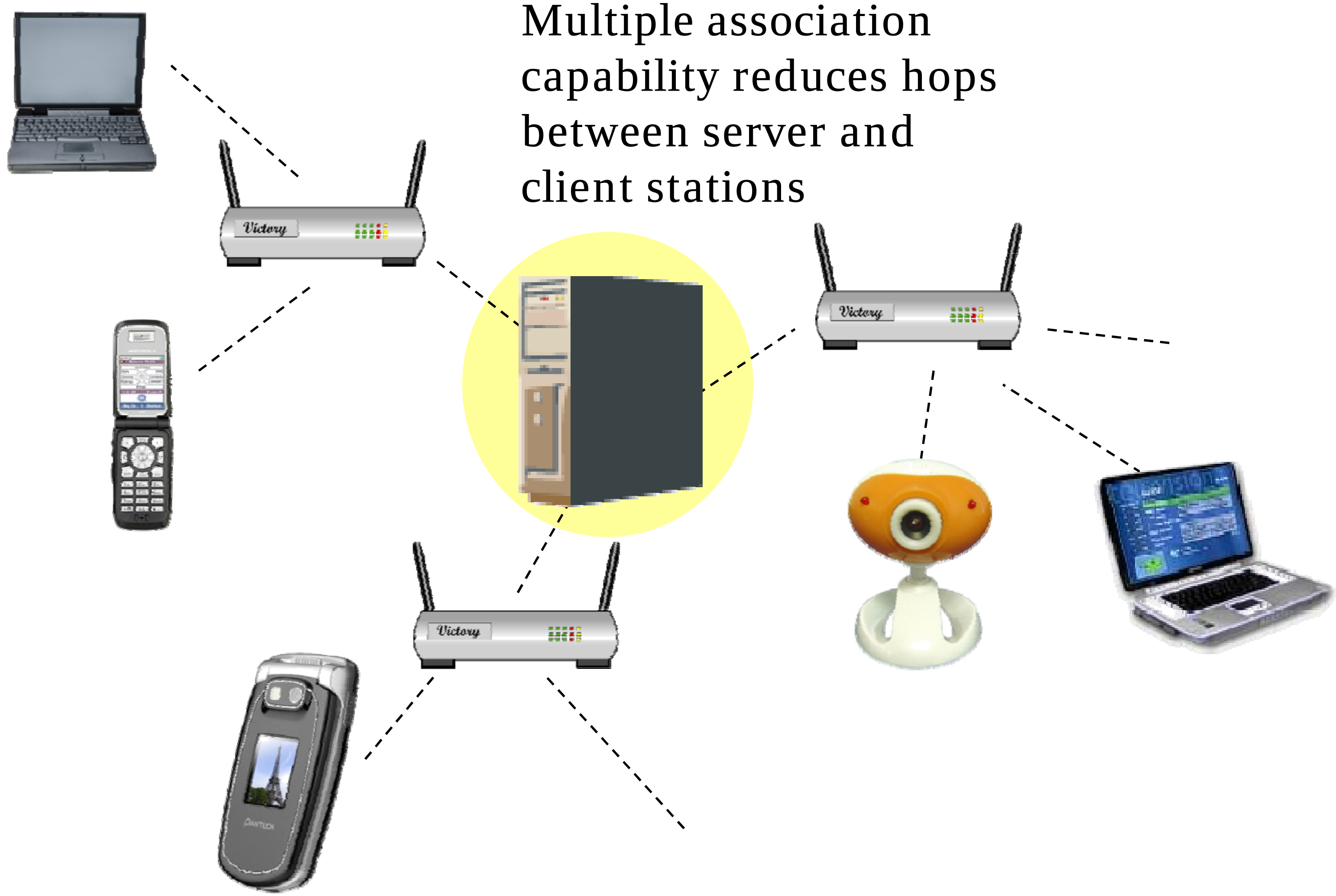
IEEE 802.11s Mesh

- 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



802.11s Mesh Enhanced Stations

Multiple association capability reduces hops between server and client stations

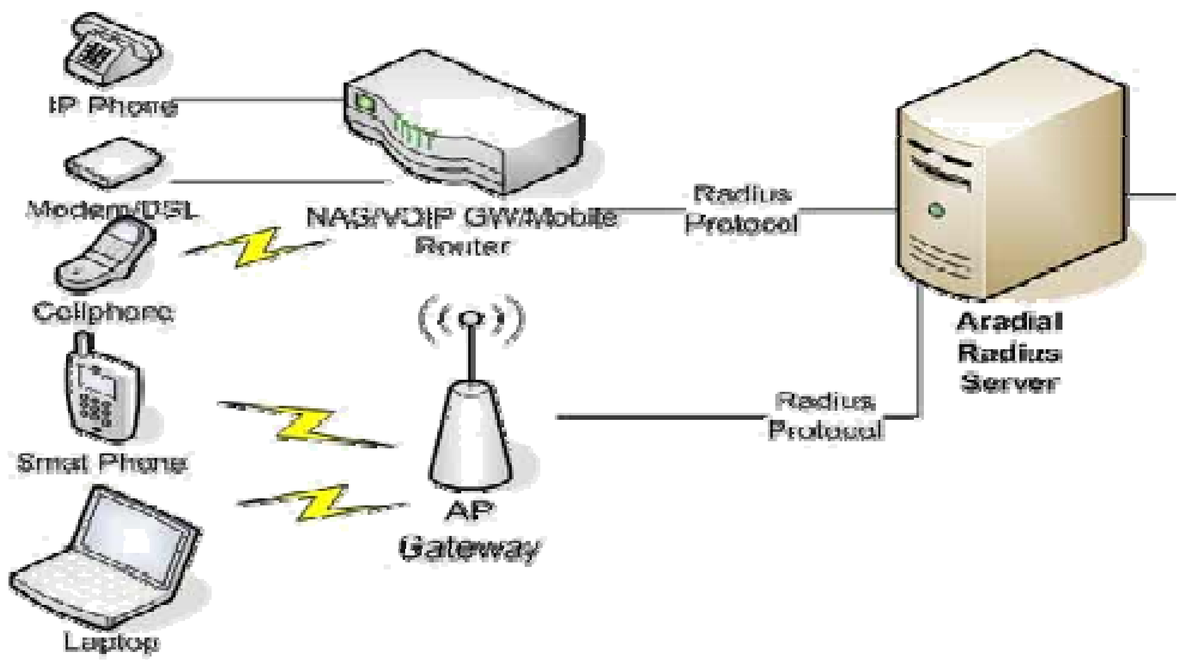


Fast Handoff in Dynamic Meshes

- To support VoIP, 802.11s needs to incorporate the fast handoff mechanisms defined in 802.11r.
  - Enable stations to roam from one mesh AP to another within approximately 50 ms without noticeable degradation in the quality of a voice call
  - In a dynamic mesh (e.g. in vehicles) MPs may be roaming with respect to other MPs and the 802.11s standard requires fast roaming of MPs with respect to one another.

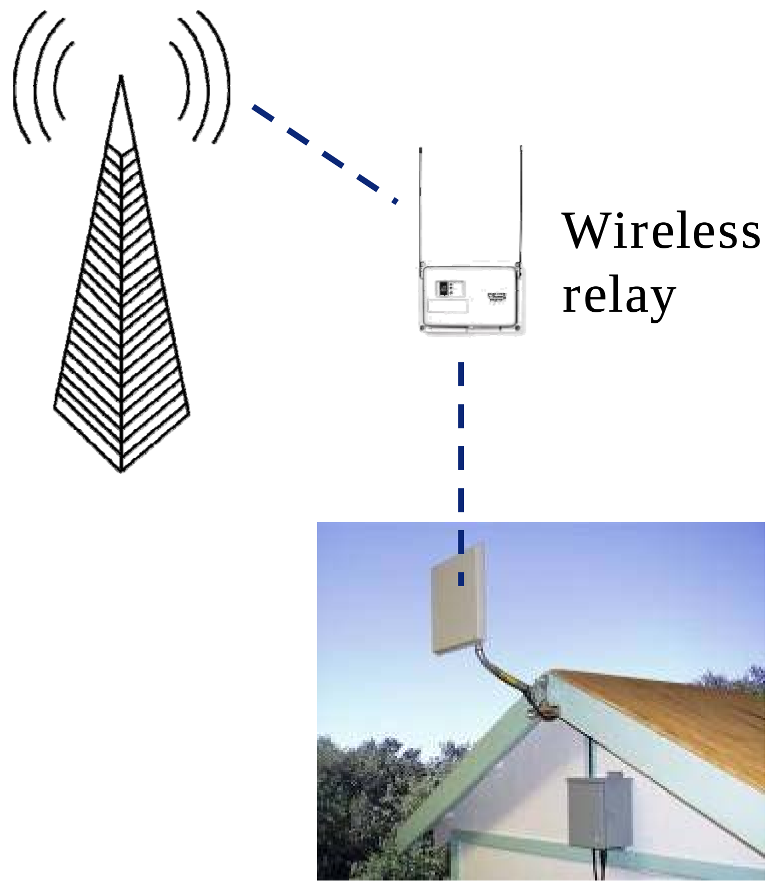
802.11s Security

- 802.11s has to make special provisions for security. In the traditional fixed infrastructure stations authenticate through APs with a centralized AAA server.
- In a mesh network MPs have to mutually authenticate with one another. 802.11s security features extend 802.11i to peer-to-peer environment.

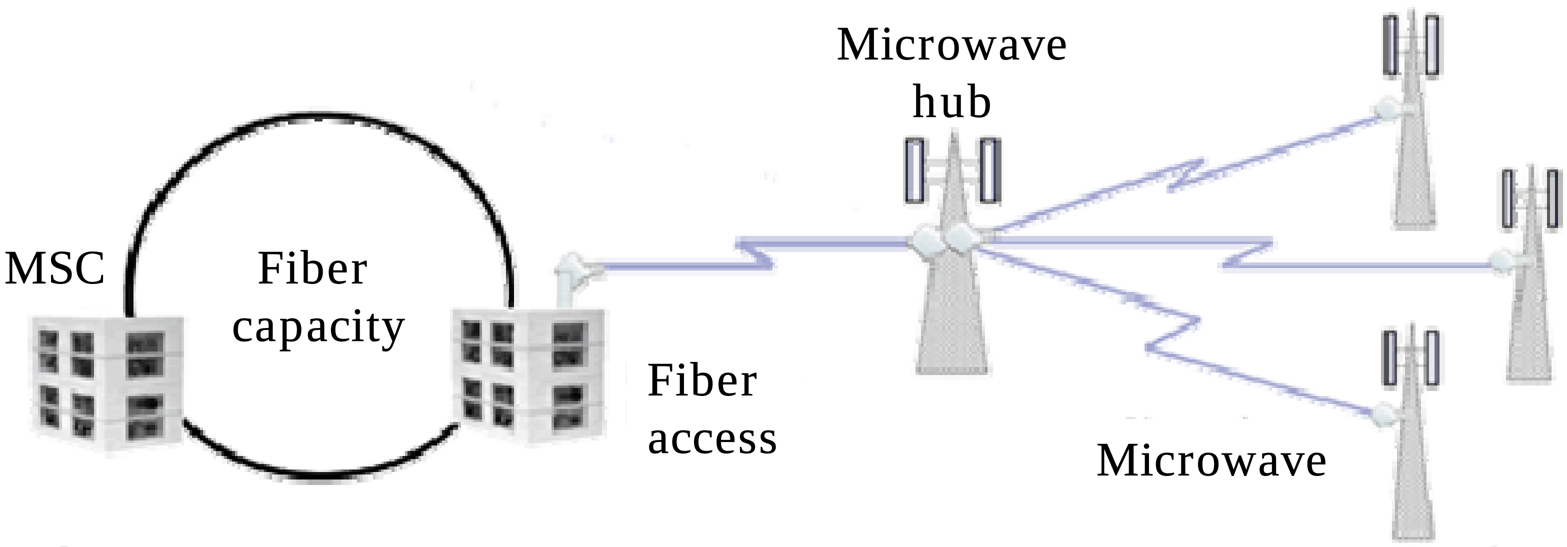


IEEE 802.16 and 802.15 Mesh Standards

- 802.16j and 802.15.5 are also standardizing mesh topologies
- 802.16j is not an ad-hoc mesh, but a relay to extend the range between a CPE and a base station
- 802.16m has meshing protocol built in



Cellular Microwave Backhaul Mesh



- Microwave backhaul for base stations can be configured in PTP, PTMP, mesh, and ring topologies.
- NGMN* (www.ngmn.org) and 3GPP are considering the mesh architecture due to its high resiliency and redundancy.

* NGMN is an organization of major operators that defines high level requirements for 3GPP.

IEEE 802.16 Active Task Groups

- 802.16h, License-Exempt Task Group
  - Working with 802.11 TGy and 802.19 Coexistence TAG
- 802.16j, Mobile Multihop Relay
  - Extended reach between BS (base station) and CPE (customer premises equipment)
- 802.16m, IMT Advanced Air Interface
- Maintenance
  - Developing 802.16Rev2
  - 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)

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

Mobility and Handoff

- Two basic requirements for mobility
  - **Location management**: tracking where a mobile station (MS) is at any time
  - **Handoff management**: ensuring a seamless transition for the current session as the MS moves out of the coverage range of one base station and into the range of another

Location Management

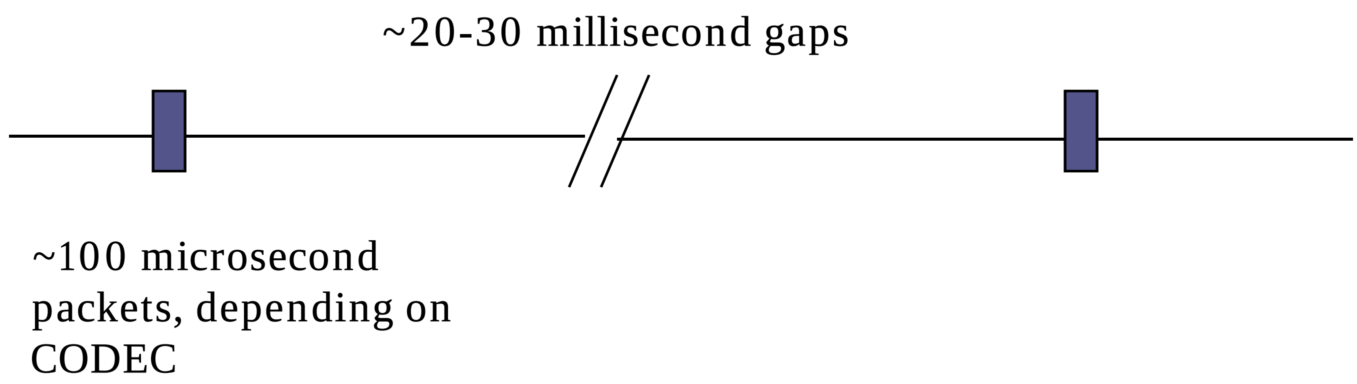
- The MS periodically informs the network of its current location: *location registration*
- Location area usually includes one or more base stations
- Needs to be done frequently to ensure accurate information is recorded about the location of each MS
- When an incoming call arrives at the network, the *paging process is initiated*
- The recipient's current location is retrieved from a database and the base stations in that area page the subscriber

Handoff

- WiMAX requires handoff latency be less than 50ms with an associated packet loss of less than 1 percent for speeds up to 120kmph
- The MS makes the decisions while the BS makes recommendations on target BS's for the handoff
- Either the SINR (Signal to Interference plus Noise Ratio) or RSS (receive signal strength) can be used as criteria

Voice Requirements

- Packet loss, especially bursty packet loss, causes poor signal quality
- Delay and jitter (variation in delay) can also cause loss of quality
- 200 ms events (signal loss or delay) are audible to the ear
- In wireless networks, bursty packet loss can be due to
  - Congestion in the infrastructure
  - Client roaming from one AP to another

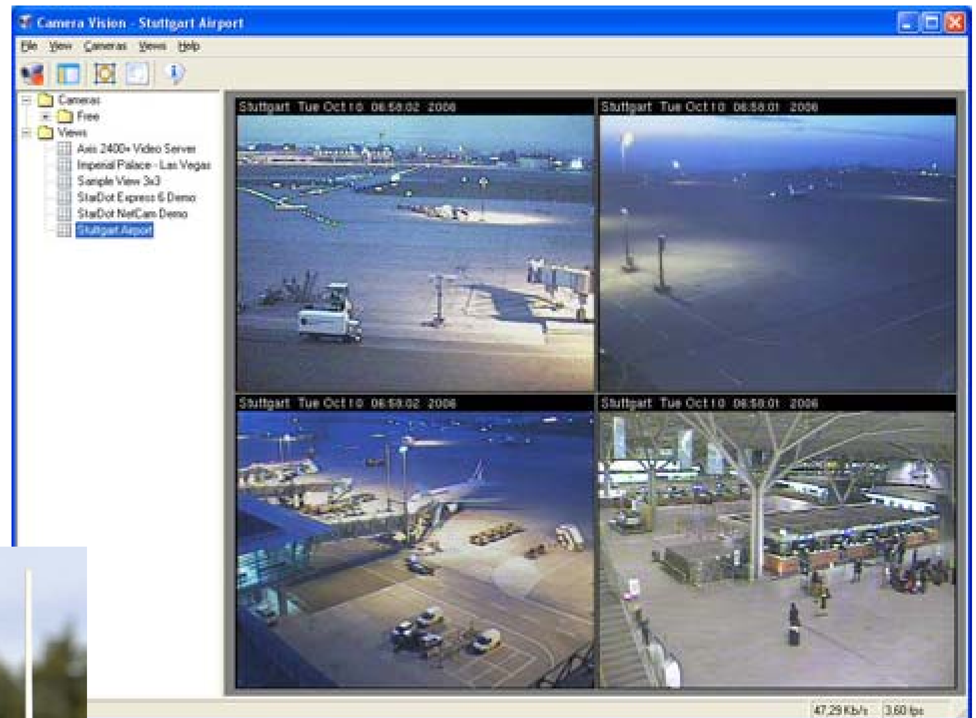


Video Requirements

Format		Average throughput required for high quality video	
		480i60	**1080p30**
Broadcast Cable TV	MPEG-2	8 Mbps	20 Mbps
Windows Media Video DivX XviD QuickTime	MPEG-4 Part 2	5 Mbps	12 Mbps

Video Surveillance

- Required throughput is a function of video frame rate, resolution and color
- Approximately 2 Mbps needed for full VGA, 7 frames/sec



802 Wireless

- 802.11
  - Faster (802.11n, ac/ad)
  - More power efficient (sleep modes 802.11n, u, v)
  - Location aware (802.11u, v)
  - VoIP and Video capable
  - Manageable
- 802.16
  - Scalable, supports mobility
  - 802.16m has built in meshing and femtocell support
- White spaces
  - Major new disruptive market
  - Currently no industry standard other than FCC

Agenda

10:30 – 12:00 noon	Our G-enealogy – History and Evolution of Mobile Radio
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2:00 – 2:45	**4G Tutorial: Vive la Différence?**
	Break
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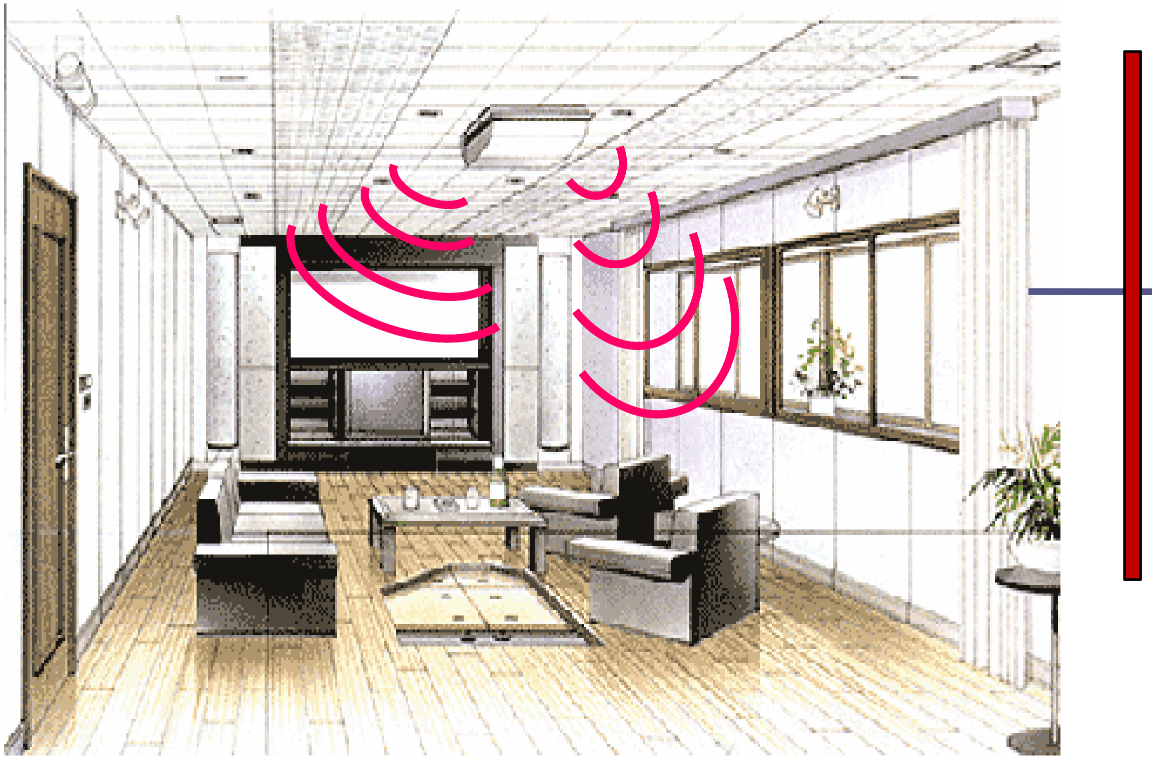
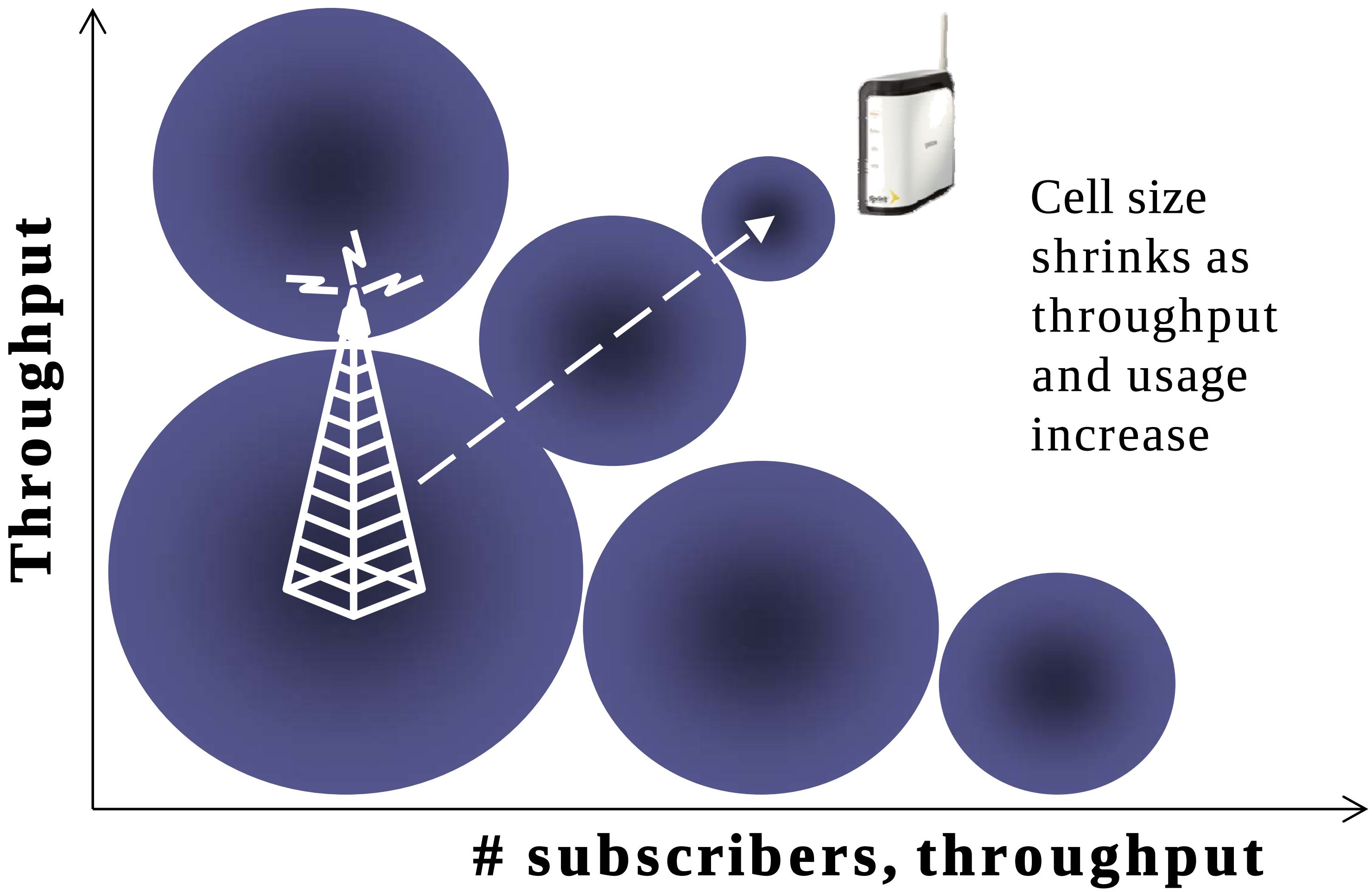
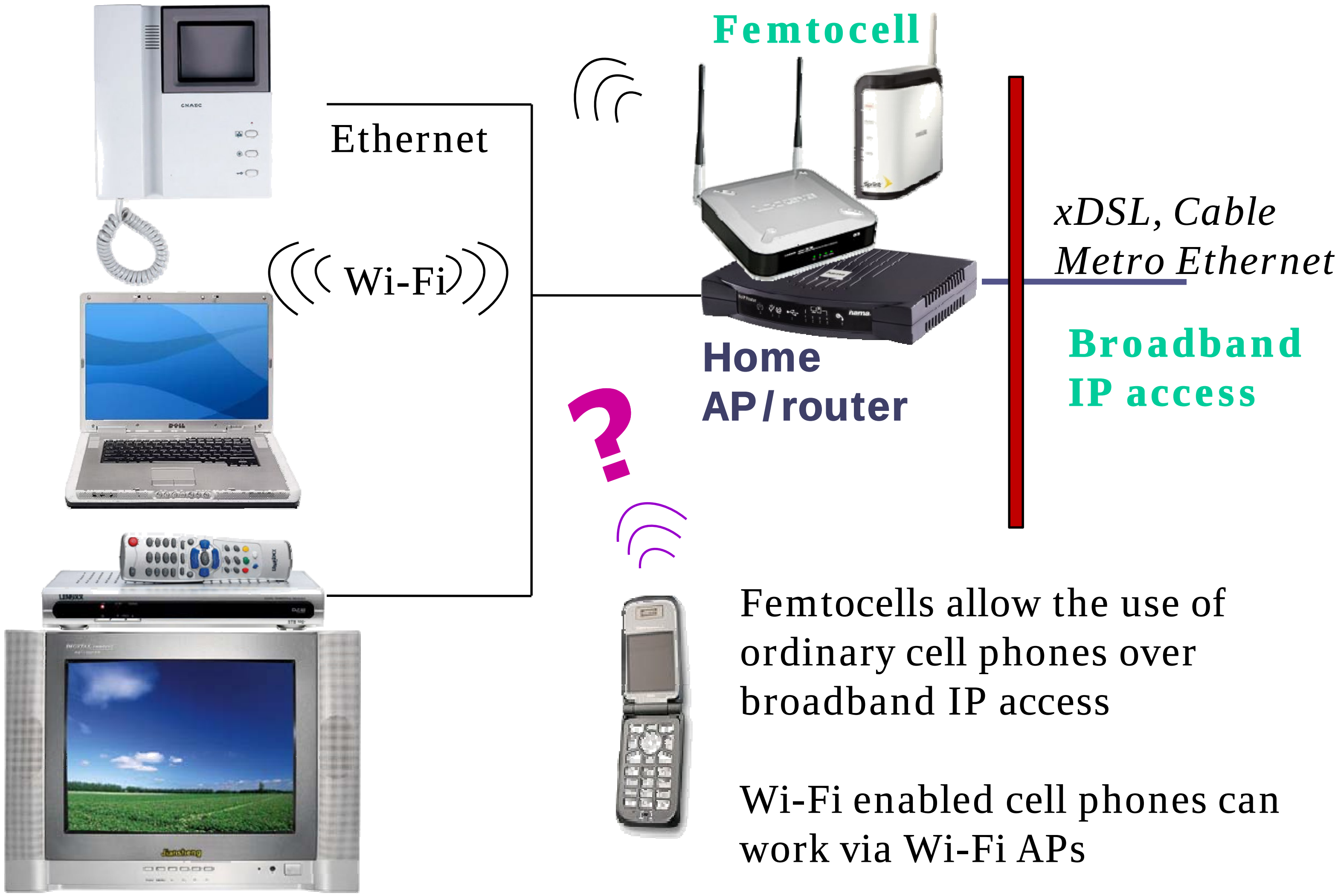
4:00 – 4:45	Tutorial: White Spaces and Beyond

4G Starts in the Home

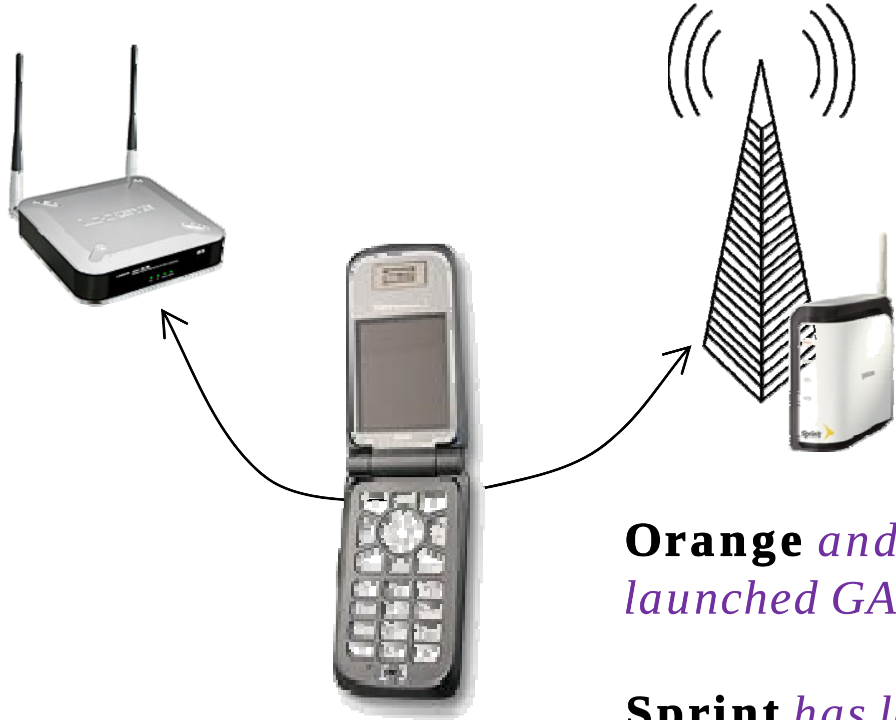



Throughput
Cell size shrinks as throughput and usage increase
subscribers, throughput



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

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



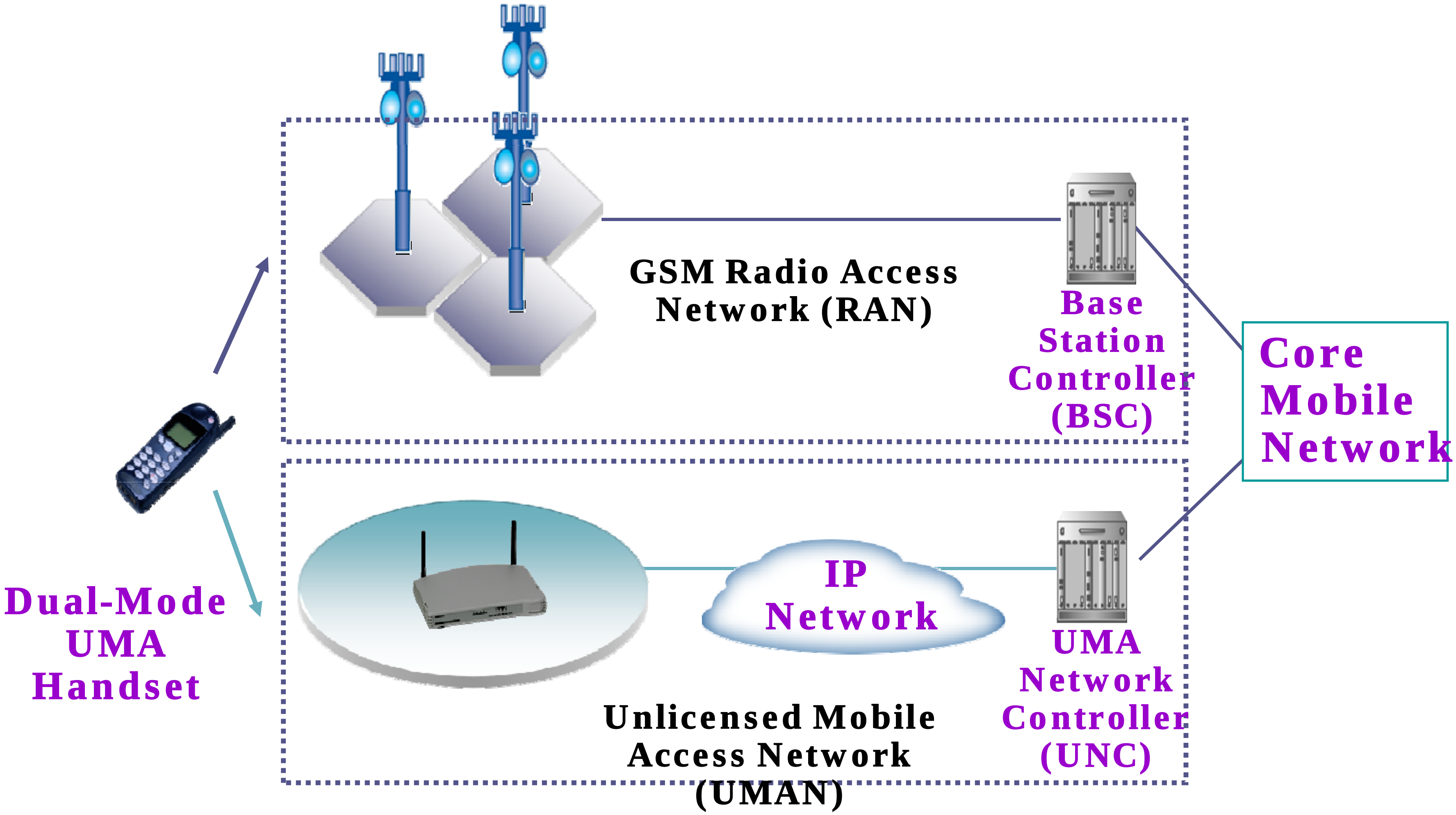
Orange *and* **T-Mobile** *have launched GAN/UMA services*

Sprint *has launched Femtocell service,* **at&t** *and* **Verizon** *have made Femtocell announcements*

Wi-Fi cell phone transitions between cellular and Wi-Fi networks (3GPP GAN, VCC or proprietary SIP)

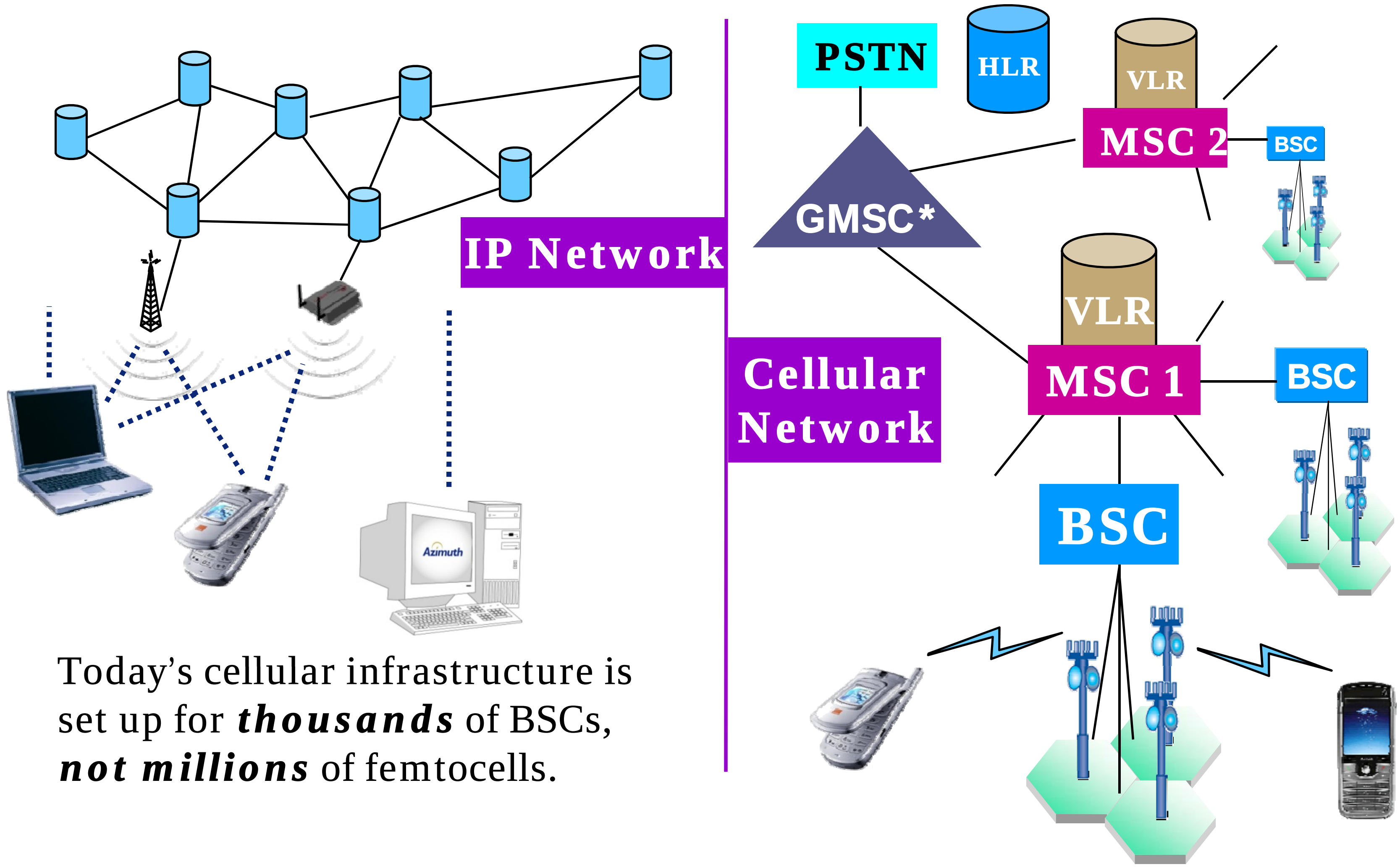
Femtocells support traditional phones

GAN (Generic Access Network) / UMA (Unlicensed Mobile Access)



Operators and vendors agreed to develop UMA in December 2003

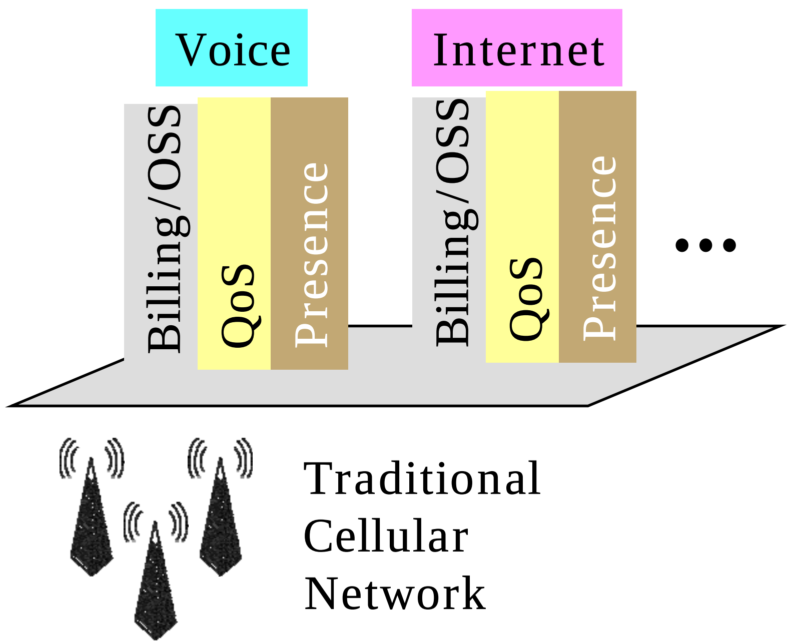
Data Networks vs. Traditional Cellular Networks



Today's cellular infrastructure is set up for ***thousands*** of BSCs, ***not millions*** of femtocells.

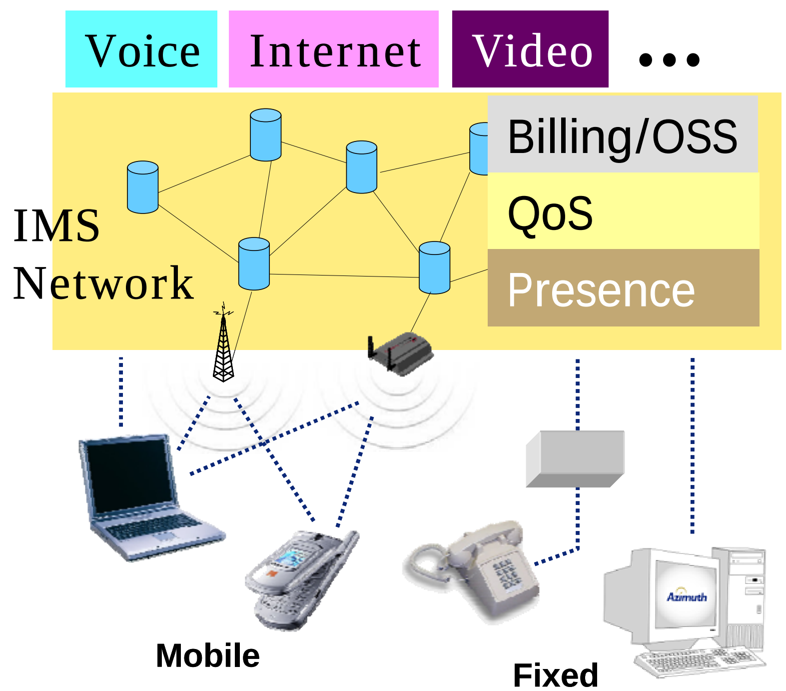
*Gateway Mobile Switching Center

Traditional "Stovepipe"



Stovepipe model – replicates functionality

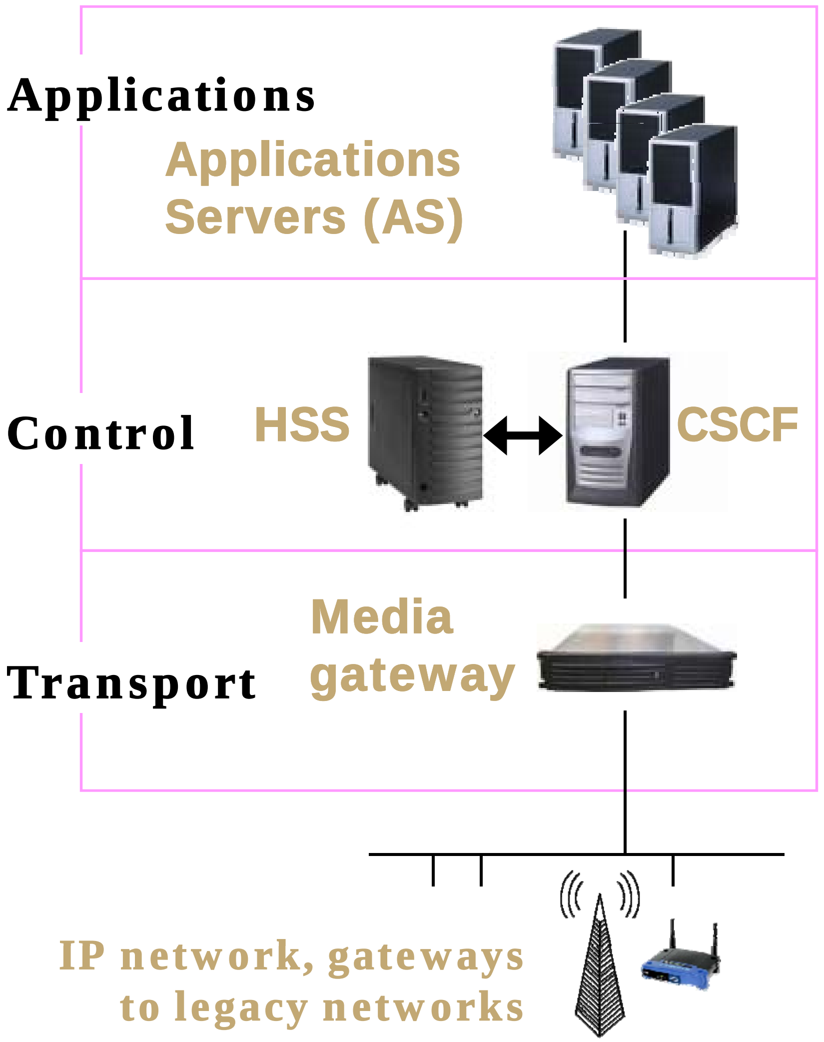
IMS



IMS – common layers facilitate adding services

Key Components of the IMS Architecture

- **CSCF (call session control function)**
  - Heart of IMS architecture
  - Handles multiple real-time IP based services (voice, IMM, streaming video, etc.)
  - Responsible for registering user devices and for ensuring QoS
- **HSS (home subscriber server)**
  - Central repository for customer data
  - Interfaces with operators HLRs (home location registers), which keep subscriber profiles
  - Enables roaming across distinct access networks
- **AS (application server)**
  - Delivers services, such as gaming, video telephony, etc.
  - Types of AS: SIP, Parlay X, customized legacy AS



LTE Architecture – IMS Based

- LTE specifies IP multimedia subsystem (IMS), optimizing the architecture for services .
- IMS is being used in wired infrastructure to enable VoIP and other applications; LTE expands on this capability to deliver seamless services.
- Hotspot-like initial deployments, primarily in urban areas will leverage HSPA for full coverage
- Most LTE devices will be multi-mode, supporting HSPA and other interfaces
- LTE femtocells will be integrated in the architecture from the onset to increase capacity and indoor coverage.

3GPP (3rd Generation Partnership Project)

- Partnership of 6 regional standards groups, which translate 3GPP specifications to regional standards
- ITU references the regional standards

Operator Influence on LTE

- LTE was built around the features and capabilities defined by Next Generation Mobile Networks (NGMN) Alliance (www.ngmn.org)
  - Operator buy-in from ground-up
- LTE/SAE (Service Architecture Evolution) Trial Initiative (LSTI) formed through the cooperation of vendors and operators to begin testing LTE early in the development process (www.lstiforum.org)
- NGMN defines the requirements
- LSTI conducts testing to ensure conformance.

formed 9/2006 by major operators:

- Sprint Nextel
- China Mobile
- Vodafone
- Orange
- T-Mobile
- KPN Mobile
- NTT DoCoMo

LTE Frequency Bands - FDD

Band	Uplink (UL)	Downlink (DL)
1	1920 -1980 MHz	2110 - 2170 MHz
2	1850 -1910 MHz	1930 - 1990 MHz
3	1710 -1785 MHz	1805 -1880 MHz
4	1710 -1755 MHz	2110 - 2155 MHz
5	824-849 MHz	869 - 894 MHz
6	830 - 840 MHz	875 - 885 MHz
7	2500 - 2570 MHz	2620 - 2690 MHz
8	880 - 915 MHz	925 - 960 MHz
9	1749.9 - 1784.9 MHz	1844.9 - 1879.9 MHz
10	1710 -1770 MHz	2110 - 2170 MHz
11	1427.9 - 1452.9 MHz	1475.9 - 1500.9 MHz
12	698 - 716 MHz	728 - 746 MHz
13	777 - 787 MHz	746 - 756 MHz
14	788 - 798 MHz	758 - 768 MHz
17	704 - 716 MHz	734 - 746 MHz

Source: 3GPP TS 36.104 V8.4.0 (2008-12)

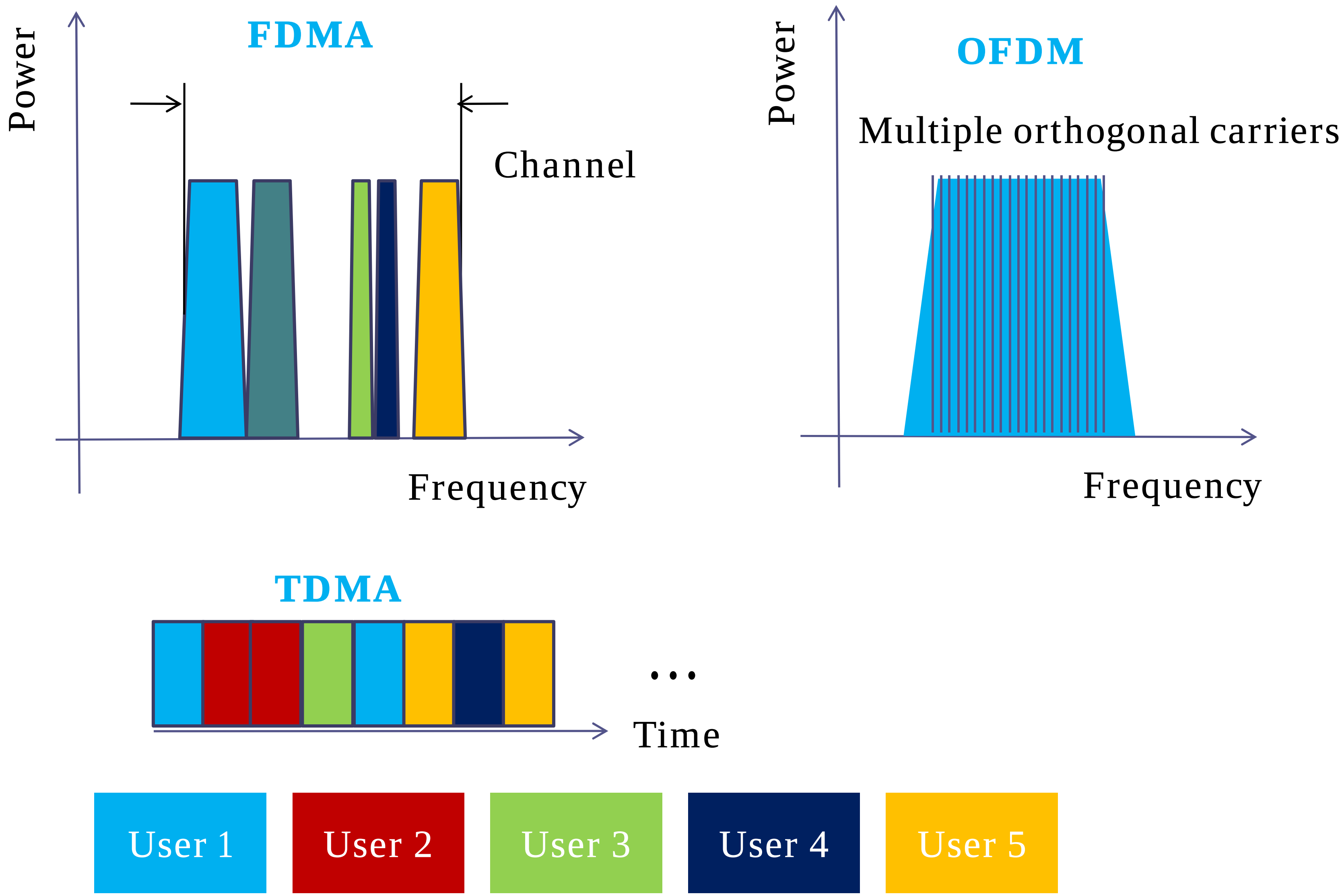
LTE Frequency Bands - TDD

Band	Uplink (UL) /Downlink (DL)
33	1900 - 1920 MHz
34	2010 - 2025 MHz
35	1850 - 1910 MHz
36	1930 - 1990 MHz
37	1910 - 1930 MHz
38	2570 - 2620 MHz
39	1880 - 1920 MHz
40	2300 – 2400 MHz

Source: 3GPP TS 36.104 V8.4.0 (2008-12)

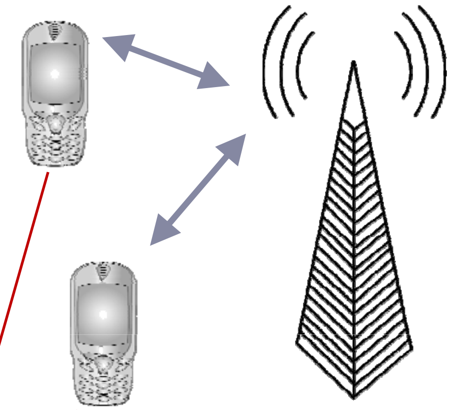
LTE and WiMAX Modulation and Access

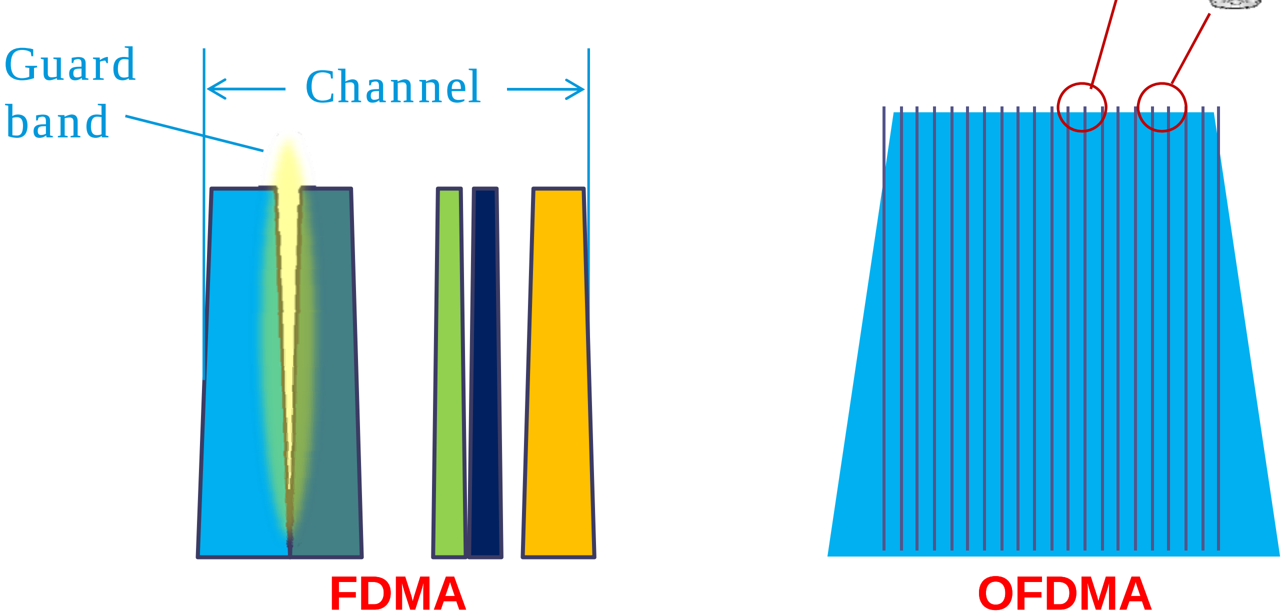
- **CDMA** (code division multiple access) is a coding and access scheme
  - CDMA, W-CDMA, CDMA-2000
- **SDMA** (space division multiple access) is an access scheme
  - MIMO, beamforming, sectorized antennas
- **TDMA** (time division multiple access) is an access scheme
  - AMPS, GSM
- **FDMA** (frequency division multiple access) is an access scheme
- **OFDM** (orthogonal frequency division multiplexing) is a modulation scheme
- **OFDMA** (orthogonal frequency division multiple access) is a modulation and access scheme

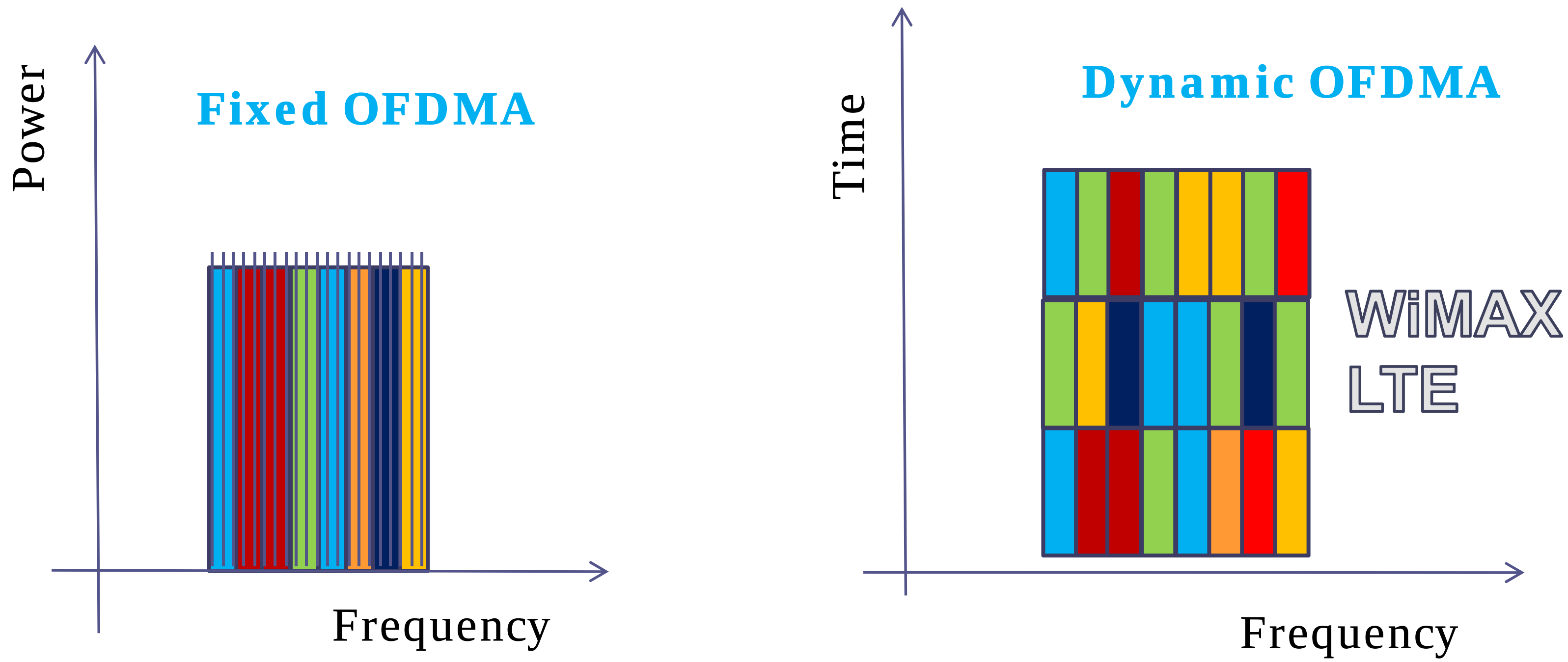

FDMA
Power
Channel
Frequency
OFDM
Power
Multiple orthogonal carriers
Frequency
TDMA
…
Time
User 1
User 2
User 3
User 4
User 5

FDMA vs. OFDMA

- OFDMA is more frequency efficient than FDMA
  - Each station is assigned a set of subcarriers, eliminating frequency guard bands between users







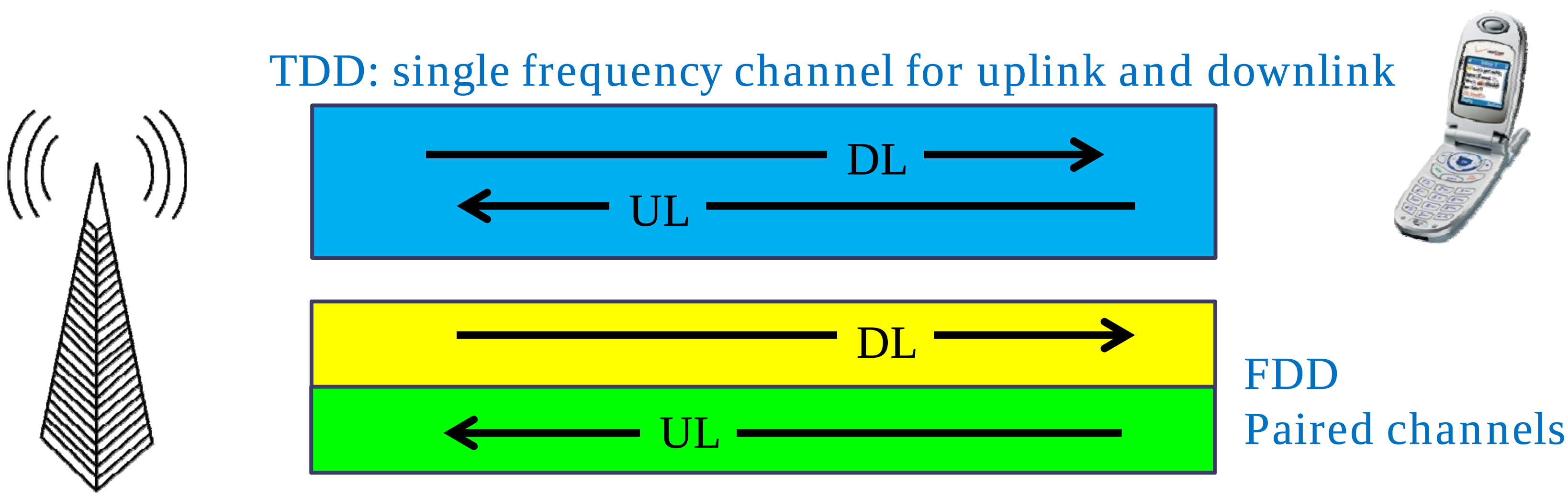
Frequency allocation per user is continuous vs. time

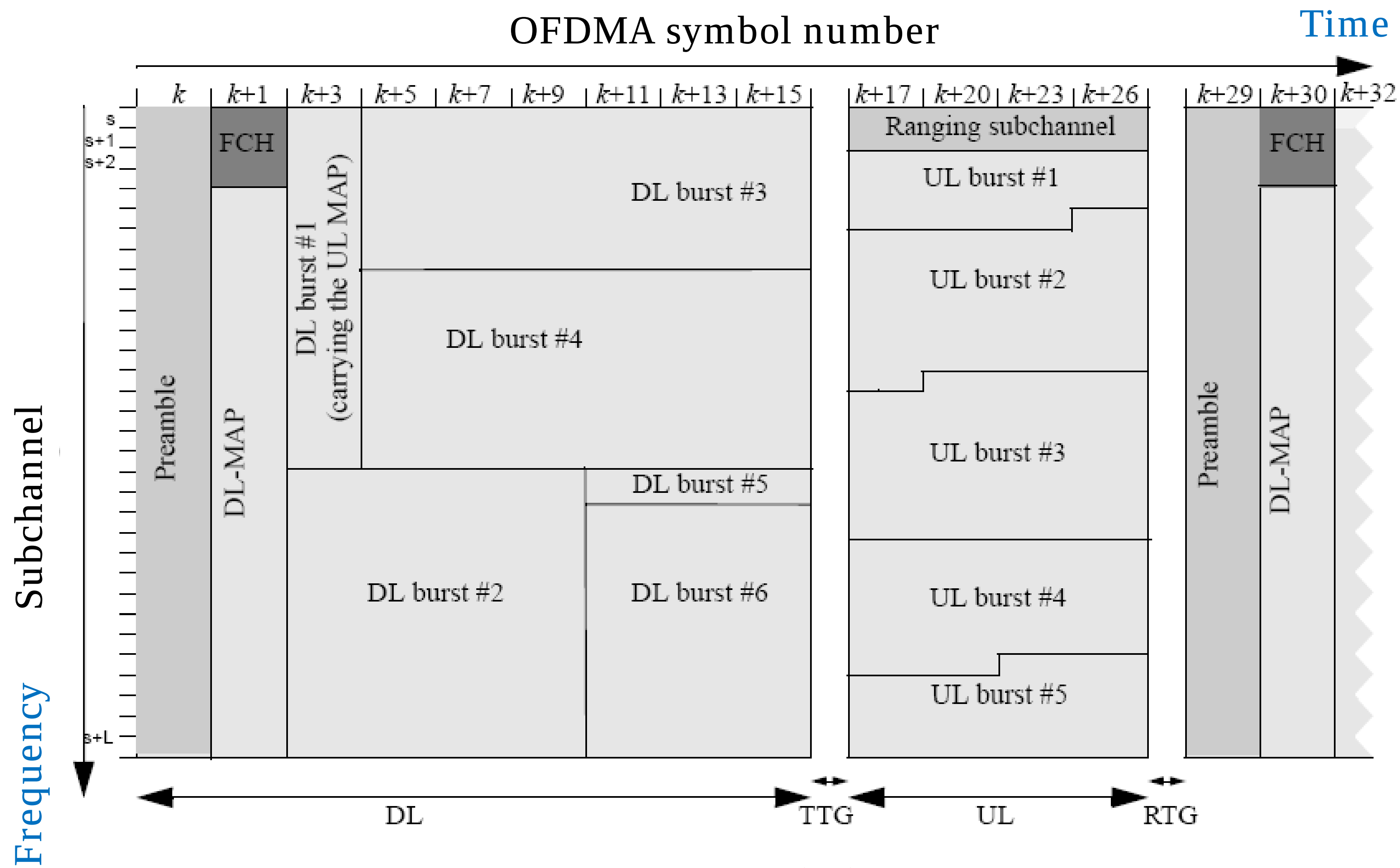
Frequency allocation per user is dynamically allocated vs. time slots

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

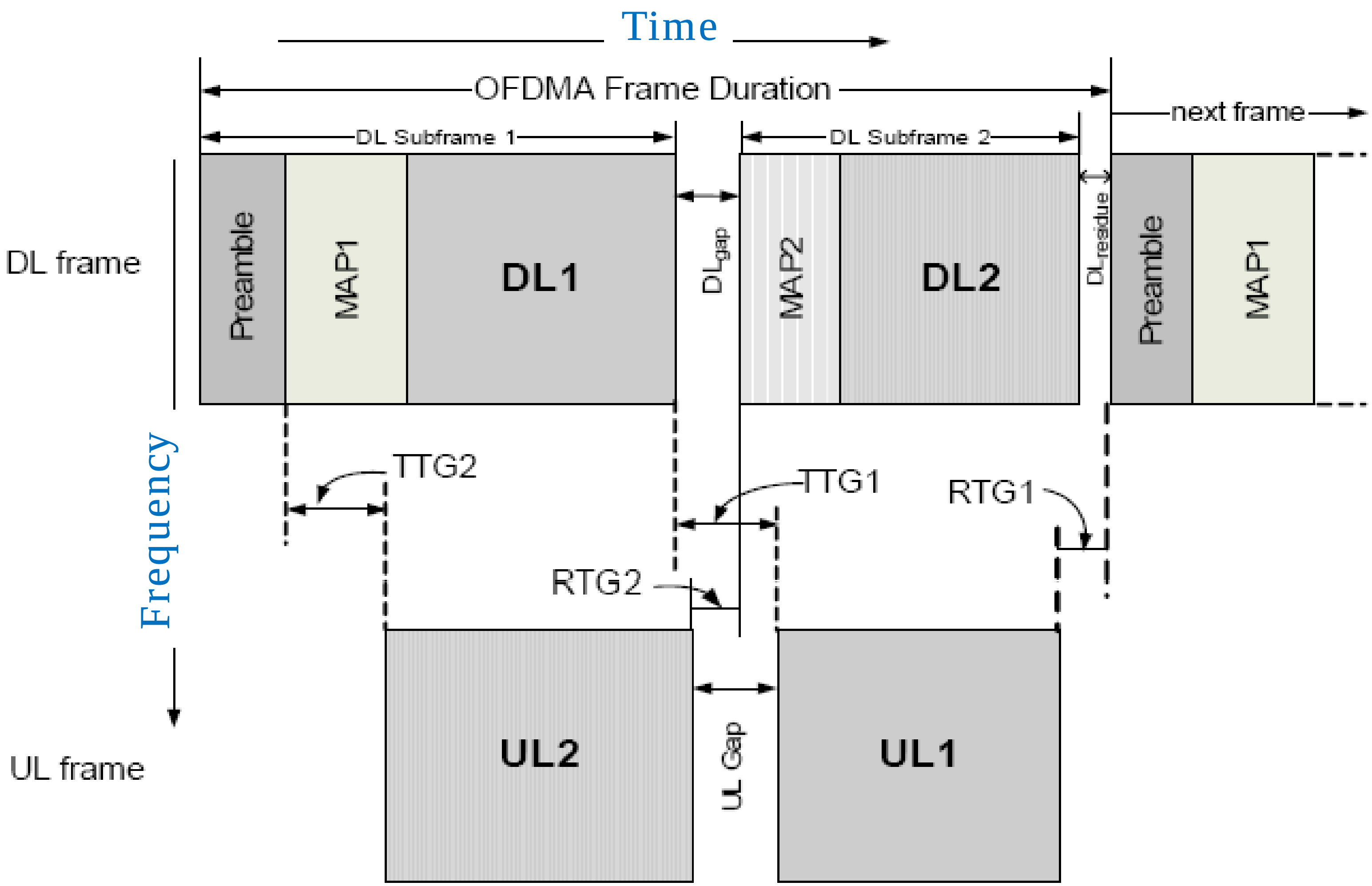
Key Features of WiMAX and LTE

- OFDMA (Orthogonal Frequency Division Multiple Access)
- Users are allocated a slice in time and frequency
- Flexible, dynamic per user resource allocation
- Base station scheduler for uplink and downlink resource allocation
  - Resource allocation information conveyed on a frame-by frame basis
- Support for TDD (time division duplex) and FDD (frequency division duplex)





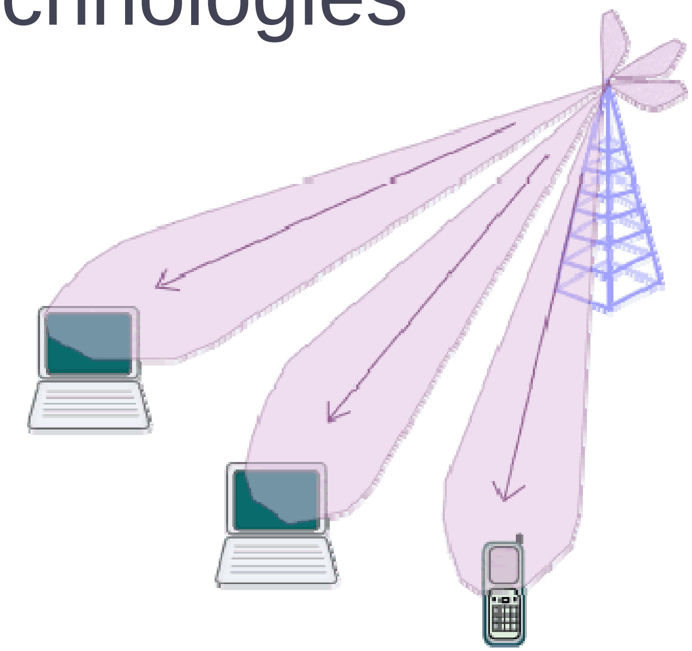
TDD Transmission



H-FDD (half-duplex FDD) Transmission

SDMA = Smart Antenna Technologies

- **Beamforming**
  - Use multiple-antennas to spatially shape the beam to improve coverage and capacity
- **Spatial Multiplexing (SM) or Collaborative MIMO**
  - Multiple streams are transmitted over multiple antennas
  - Multi-antenna receivers separate the streams to achieve higher throughput
  - In uplink single-antenna stations can transmit simultaneously
- **Space-Time Code (STC)**
  - Transmit diversity such as Alamouti code [1,2] reduces fading



2x2 Collaborative MIMO increases the peak data rate two-fold by transmitting two data streams.

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
Sampling factor (ch bw/sampling freq)	28/25				8/7		
Subcarrier spacing (kHz)	10.9375				7.8125		9.766
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

3G/4G Comparison

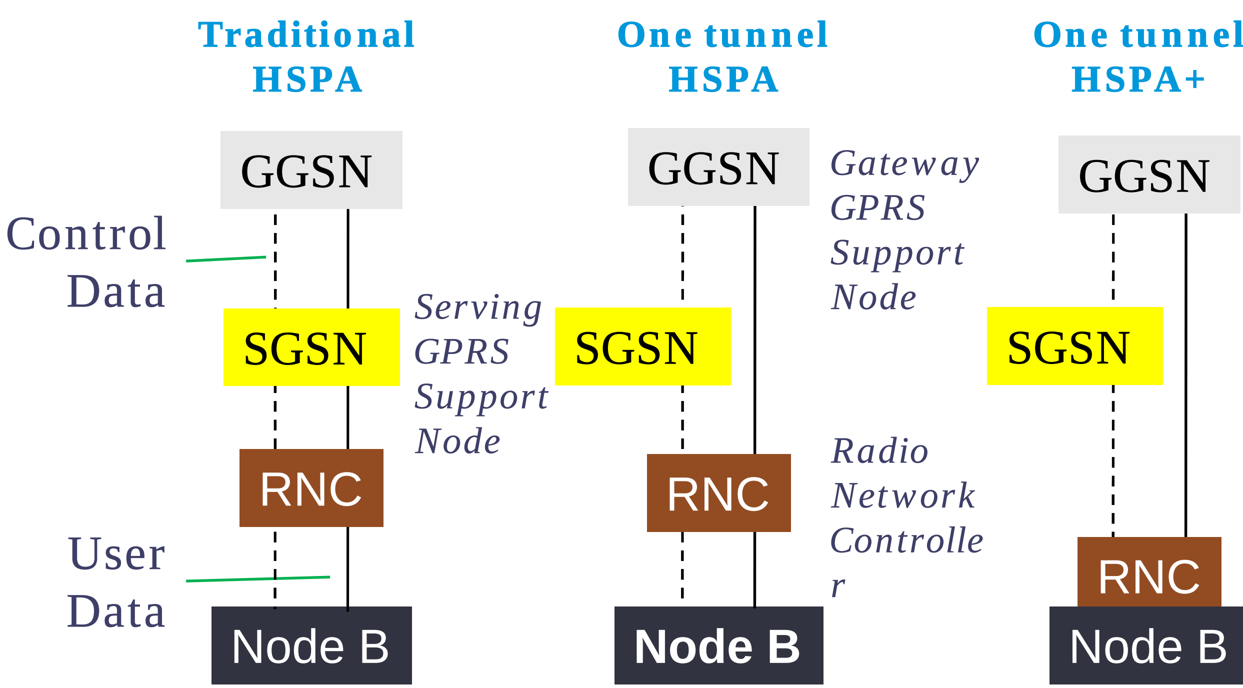
	Peak Data Rate (Mbps)		Access time (msec)
	Downlink	Uplink	
HSPA (today)	14 Mbps	2 Mbps	50-250 msec
HSPA (Release 7) MIMO 2x2	28 Mbps	11.6 Mbps	50-250 msec
HSPA + (MIMO, 64QAM Downlink)	42 Mbps	11.6 Mbps	50-250 msec
WiMAX Release 1.0 TDD (2:1 UL/DL ratio), 10 MHz channel	40 Mbps	10 Mbps	40 msec
LTE (Release 8), 5+5 MHz channel	43.2 Mbps	21.6 Mbps	30 msec

Release 8 – LTE
Release 9 – enhancements to LTE, 2009
Release 10 - LTE Advanced (1Gbps DL and 500 Mbps UL, 100 MHz bw) 2010

HSPA and HSPA+

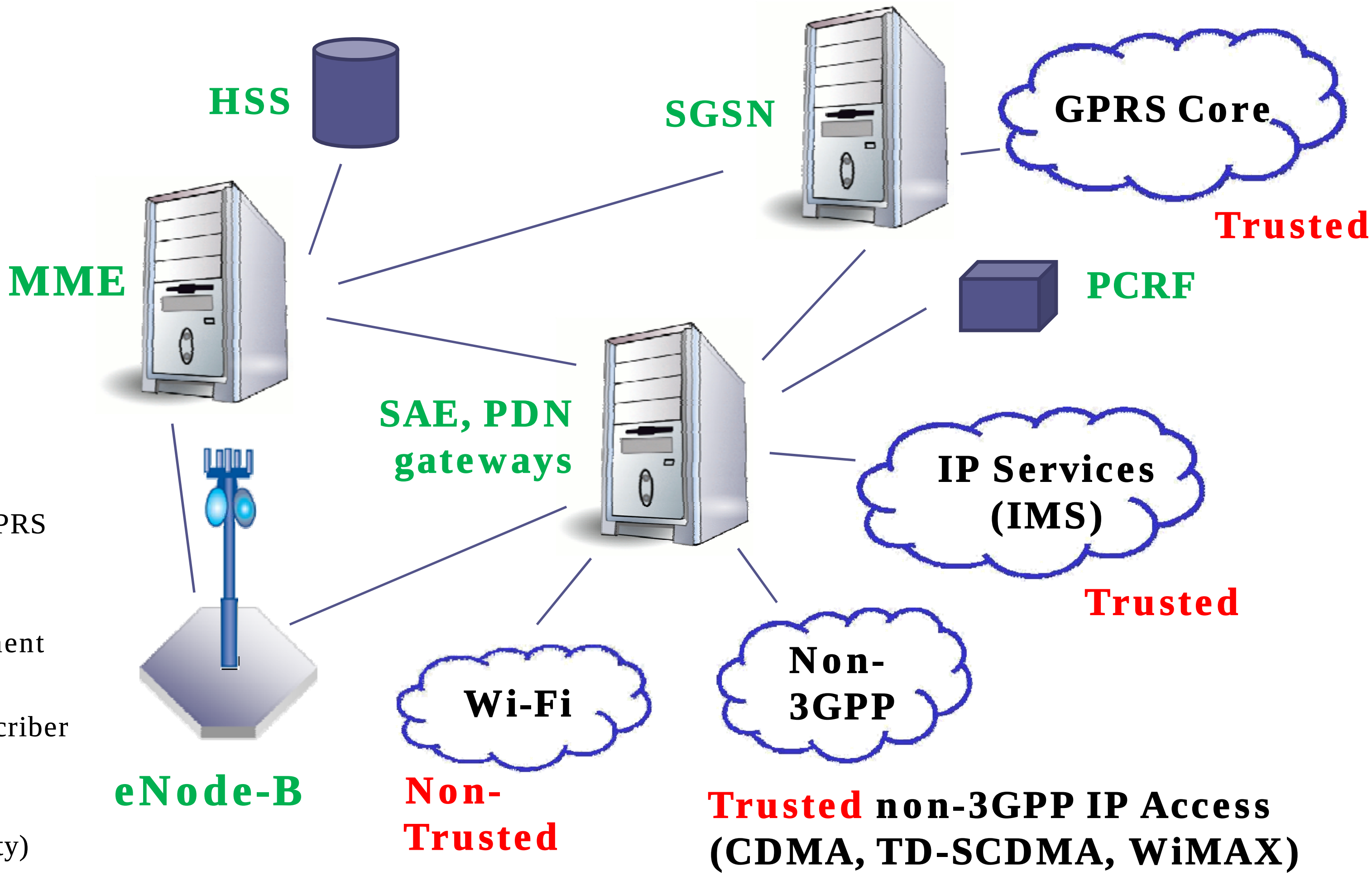
- HSPA+ is aimed at extending operators' investment in HSPA
  - 2x2 MIMO, 64 QAM in the downlink, 16 QAM in the uplink
  - Data rates up to 42 MB in the downlink and 11.5 MB in the uplink.

- 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 SAE (System Architecture Evolution)



SGSN (Serving GPRS Support Node)

PCRF (policy and charging enforcement function)

HSS (Home Subscriber Server)

MME (Mobility Management Entity)

SAE (System Architecture Evolution)

PDN (Public Data Network)

SAE includes RAN and EPS

EPS (Evolved Packet System)

Not hierarchical as GSM EDGE HSPA

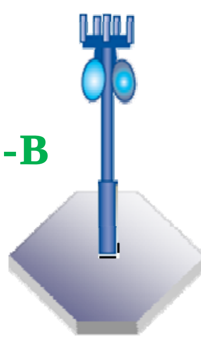
- EPS is the core network for LTE and other advanced RAN technologies
  - Flat IP architecture minimizes round trip time (RTT) to <10 ms and setup time to <100 ms
  - Higher data rates, seamless interworking between 3GPP and non-3GPP networks and IMS
  - Primary elements are eNodeB, MME (Mobility Management Entity) and the SAE gateway
- MME provides connectivity between the eNodeB and the legacy GSM and UMTS networks via SGSN*. The MME also supports the following: user equipment context and identity, authorization, and authentication.
- The SAE gateway, or EPS access gateway, provides the PDN (packet data network) gateway and serving gateway functions.

SAE GW
PDN GW

MME

SGSN

eNode-B

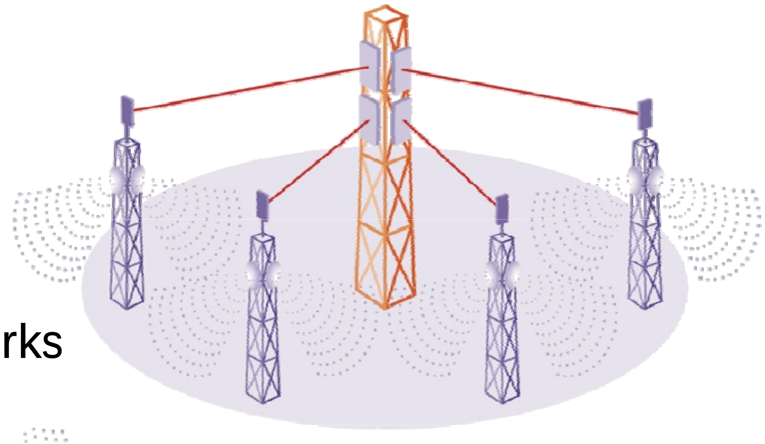


*GPRS Gateway Support Node
Serving GPRS Support Node

Backhaul

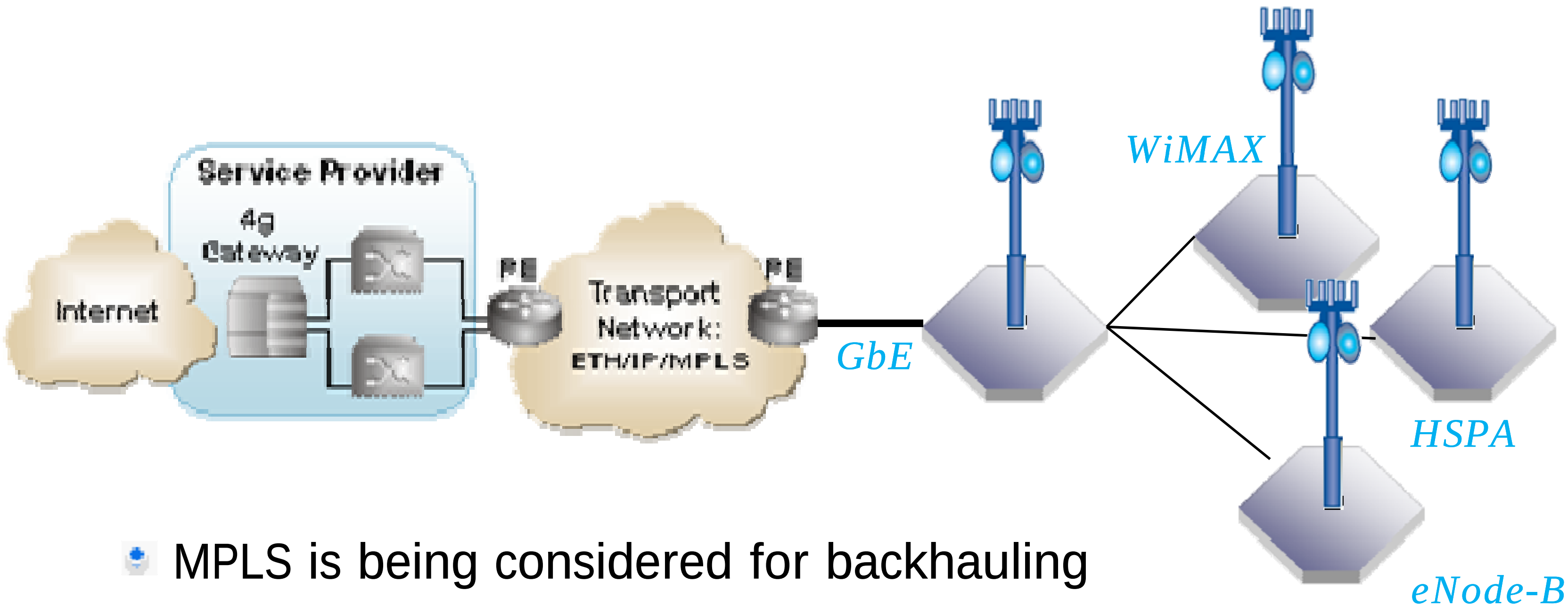
- LTE requires high-capacity links between eNodeB and the core. The options are:
  - Existing fiber deployments
  - Microwave in locations where fiber is unavailable
  - Ethernet
- Co-location of LTE with legacy networks means the backhaul has to support
  - GSM/UMTS/HSPA/LTE or LTE/CDMA
  - Time division multiplexing (TDM), asynchronous transfer mode (ATM) and Ethernet traffic
- NGMN wants to standardize backhaul in order to reduce cost while meeting stringent synchronization requirements.

Backhaul is the key to reducing TCO for operators.



Non-TDM backhaul solutions may be unable to maintain the strict timing required for cellular backhaul.

Multi-Protocol Label Switching (MPLS) Backhaul



- MPLS is being considered for backhauling
  - Supports TDM, ATM, and Ethernet simultaneously
  - Incorporates RSVP-TE (Resource Reservation Protocol-Traffic Engineering) for end-to-end QoS
  - Enables RAN sharing via the use of VPNs
- BS (base stations) could act as edge MPLS routers, facilitating migration to pure IP.

WiMAX vs. LTE

- Commonalities
  - IP-based
  - OFDMA and MIMO
  - Similar data rates and channel widths
- Differences
  - Carriers are able to set requirements for LTE through organizations like NGMN and LSTI, but cannot do this as easily at the IEEE based 802.16
  - LTE backhaul is designed to support legacy services while WiMAX is better suited to greenfield deployments

Commercial Issues

LTE

- Deployments likely slower than projected

But

- Eventual migration path for GSM/3GSM, i.e. for > 80% share
- Will be lowest cost & dominant in 2020

WiMAX

- 2-3 year lead, likely maintained for years
- Dedicated spectrum in many countries
- *But*
  - Likely < 15% share by 2020 & thus more costly

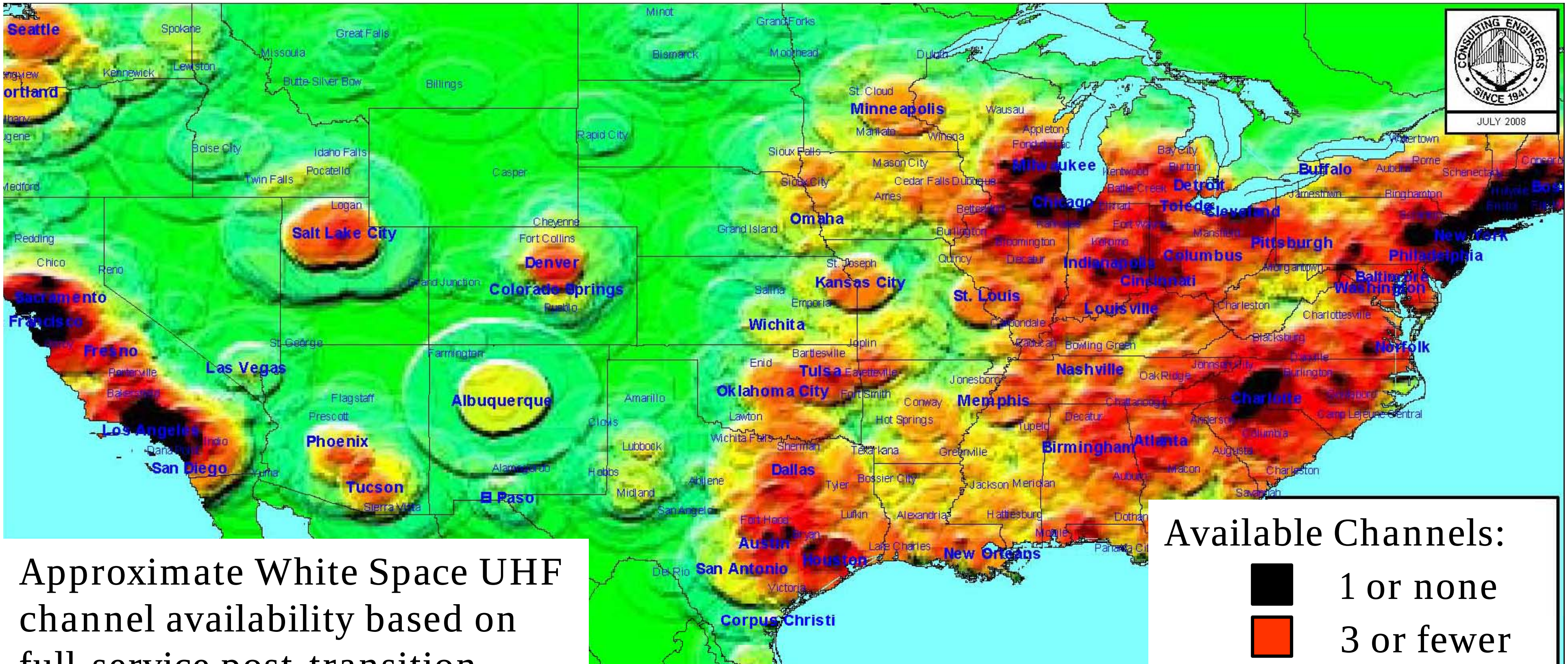
Agenda

10:30 – 12:00 noon	Our G-enealogy – History and Evolution of Mobile Radio
	Lunch
1:00 – 2:00	The IEEE's Wireless Ethernet Keeps Going and Growing
2:00 – 2:45	4G Tutorial: Vive la Différence?
	➔ Break←
3:00 – 3:45	Mobile Broadband - New Applications and New Business Models
	Break
4:00 – 4:45	Tutorial: White Spaces and Beyond

TV Spectrum Availability

- 6 MHz TV channels 2-69
  - VHF: 54-72, 76-88, 174-216 MHz
  - UHF: 470-806 MHz
- 2009 transition from analog to digital TV frees up channels 52-69 due to higher spectral efficiency of digital TV
- FCC is updating its regulations and has recently allowed the use of cognitive radio for White Spaces, unused TV spectrum
- WSD = white spaces device

White Space Channel Availability



Approximate White Space UHF channel availability based on full-service post-transition broadcast station allocation

duTreil, Lundin & Rackley, Inc.
Sarasota, Florida

Available Channels:

- 1 or none
- 3 or fewer
- 10 or fewer
- 20 or more
- 30 or more

White Spaces Radio Technology

- The new regulations (FCC Dockets 04-186, 02-380) require the use of cognitive radios to determine whether a channel is available prior to transmitting.
- Two types of services are targeting TV spectrum:
  - Fixed services: WRAN (wireless rural area networks), being standardized by IEEE802.22
  - Mobile services: White Spaces, being advocated by the WIA (www.wirelessinnovationalliance.org)
  - IEEE 802 LAN/MAN committee formed new study group in November, 2008 to investigate white spaces standardization

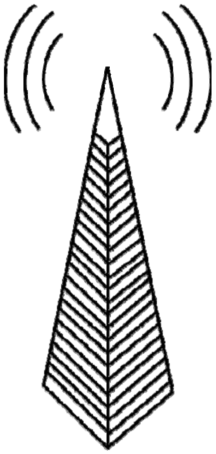
Detailed standard needed

taking initiative

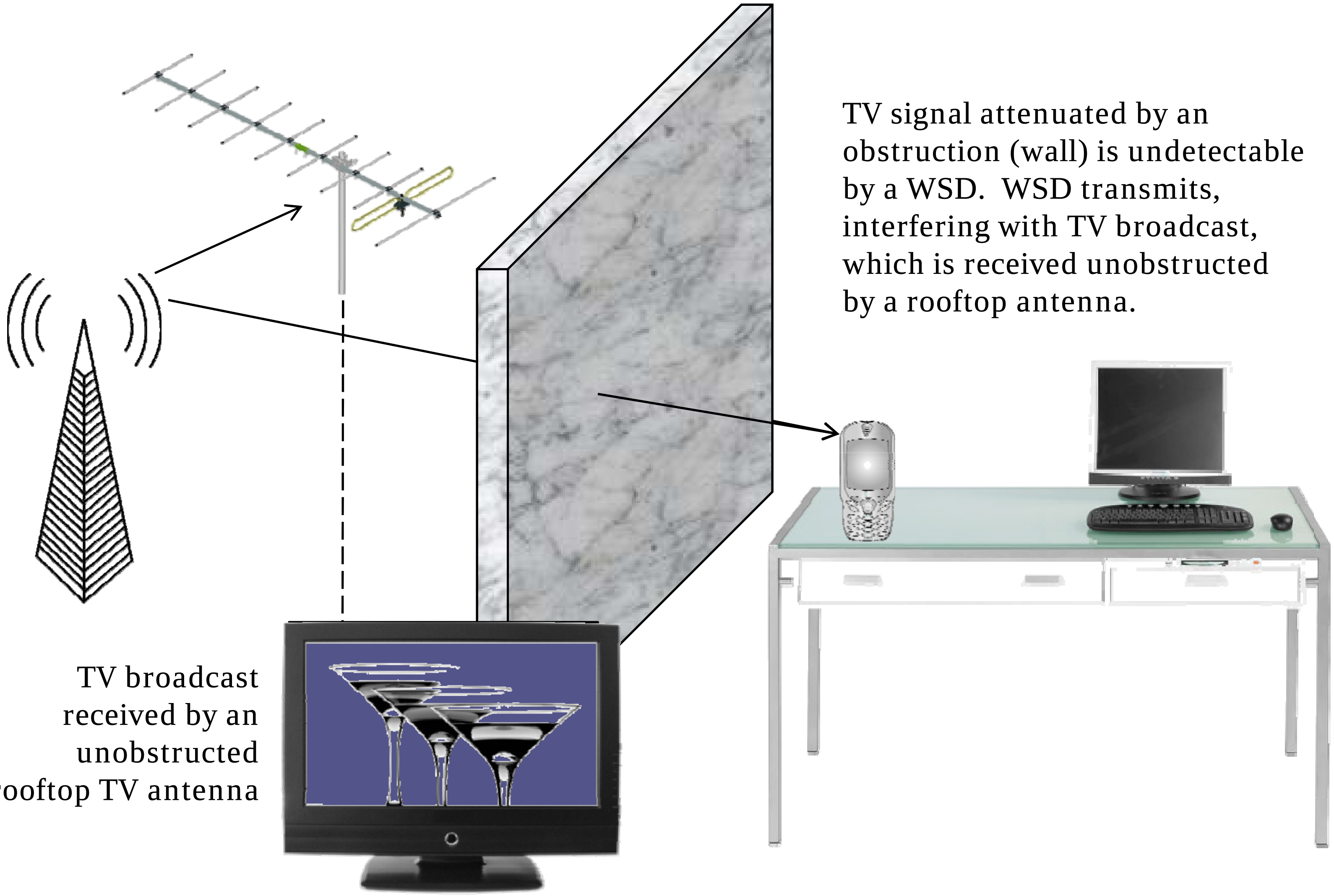
Detecting Licensed Transmissions

- Methods for detecting licensed transmissions:
  - An internal GPS could be used in conjunction with a database to determine whether the WSD is located far enough away from licensed stations.
  - WSD could receive information from a broadcast station indicating which channels are available.
  - WSD could incorporate sensing capabilities to detect whether licensed transmitters are in its range. If no signals are detected, the device could transmit. If signals are detected, the device would have to search for another channel.
- FCC sensing thresholds :
  - -116 dBm for ATSC (Advanced Television Systems Committee, digital TV)
  - -94 dBm for NTSC (National Television System Committee, analog TV)
  - -107 dBm for wireless microphones

Protected devices: TV stations, wireless microphones



Hidden Node Scenario



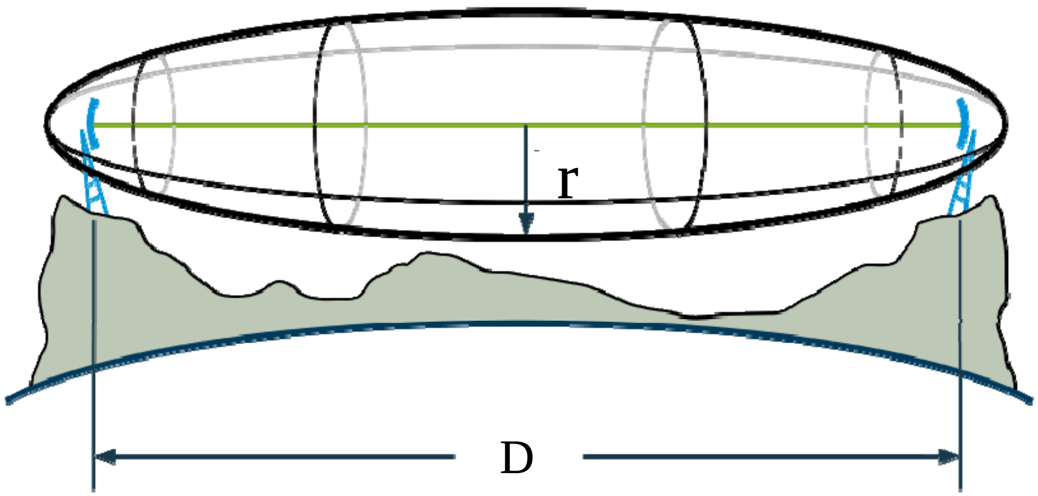
TV signal attenuated by an obstruction (wall) is undetectable by a WSD. WSD transmits, interfering with TV broadcast, which is received unobstructed by a rooftop antenna.

TV broadcast received by an unobstructed rooftop TV antenna

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 size also matters – 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



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

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

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

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 – an Issue?

- Analysis and field testing done by ITU-R, FCC and other organizations demonstrate that even when a WSD is deep inside a building, the signal reaching it is likely to be at most 30 dB lower than the signal at a rooftop antenna.
- The 802.22 draft sets the detection threshold 30 dB below a tuner's lowest receive level and states that an unlicensed device must detect a broadcast within 2 seconds and with probability of >=90%.

Turf Battles to Continue…

- Broadcasters and traditional wireless operators will continue to oppose TV White Spaces developments
- The battle lines are drawn and the stakes are high

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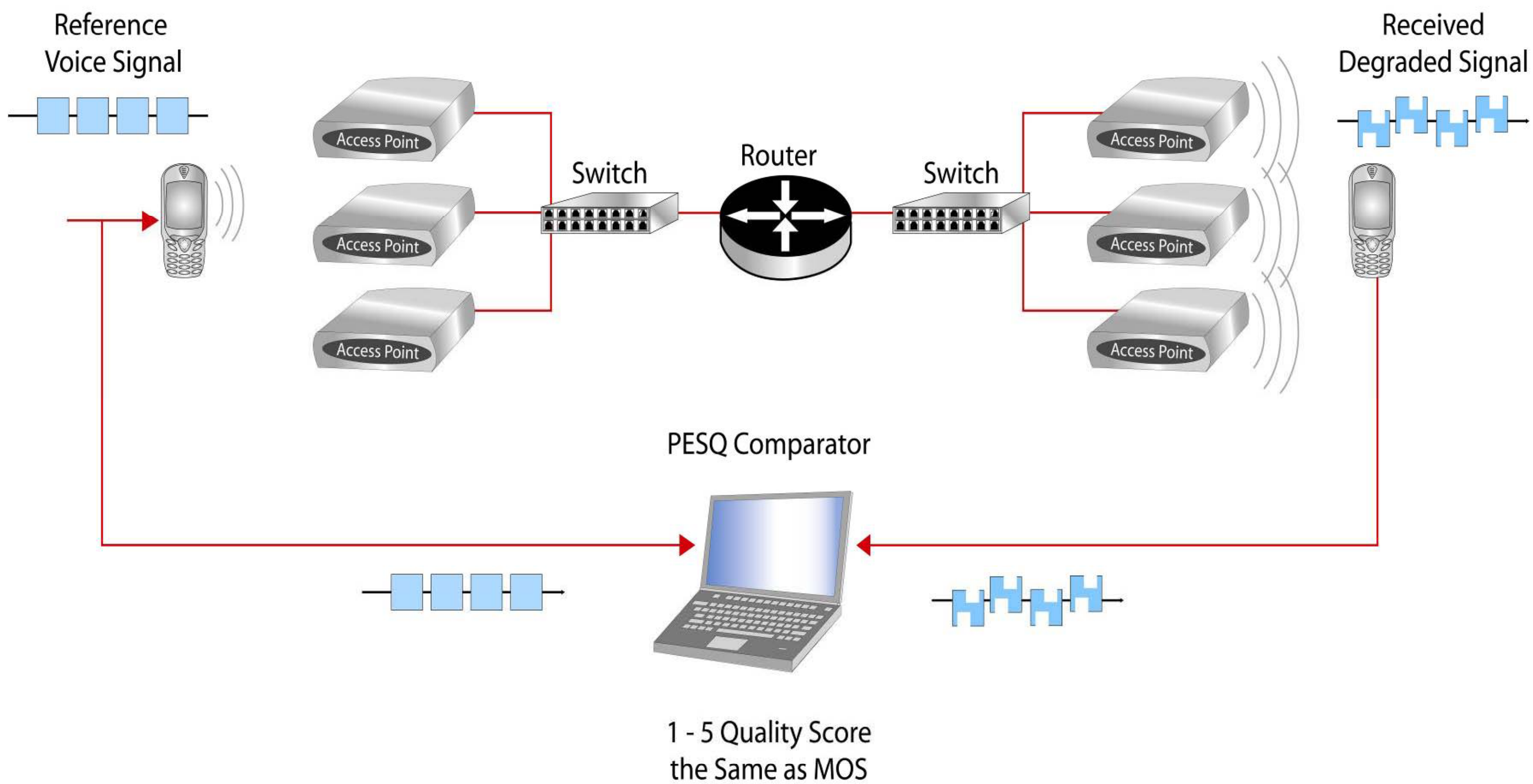
Additional Content

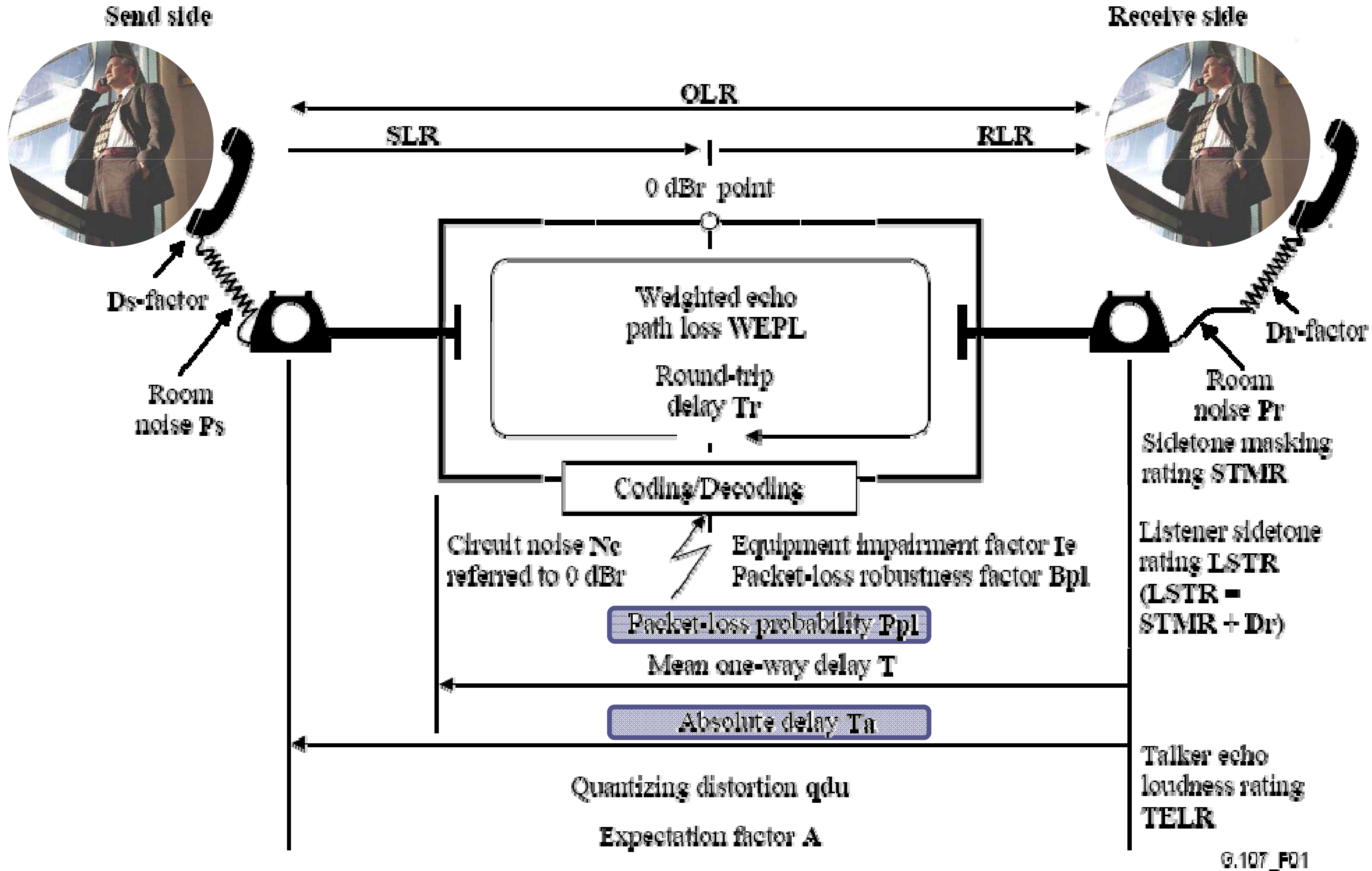
ITU-T Voice Quality Standards

- **MOS (mean opinion score)** uses a wide range of human subjects to provide a subjective quality score (ITU-T P.800)
- **PESQ (perceptual speech quality measure)** sends a voice pattern across a network and then compares received pattern to the original pattern and computes the quality rating (ITU-T P.862)
- **R-Factor (Rating factor)** computed based on delay packet loss and other network performance parameters; R-Factor directly translates into MOS (ITU-T G.107)

ITU-T PESQ Model



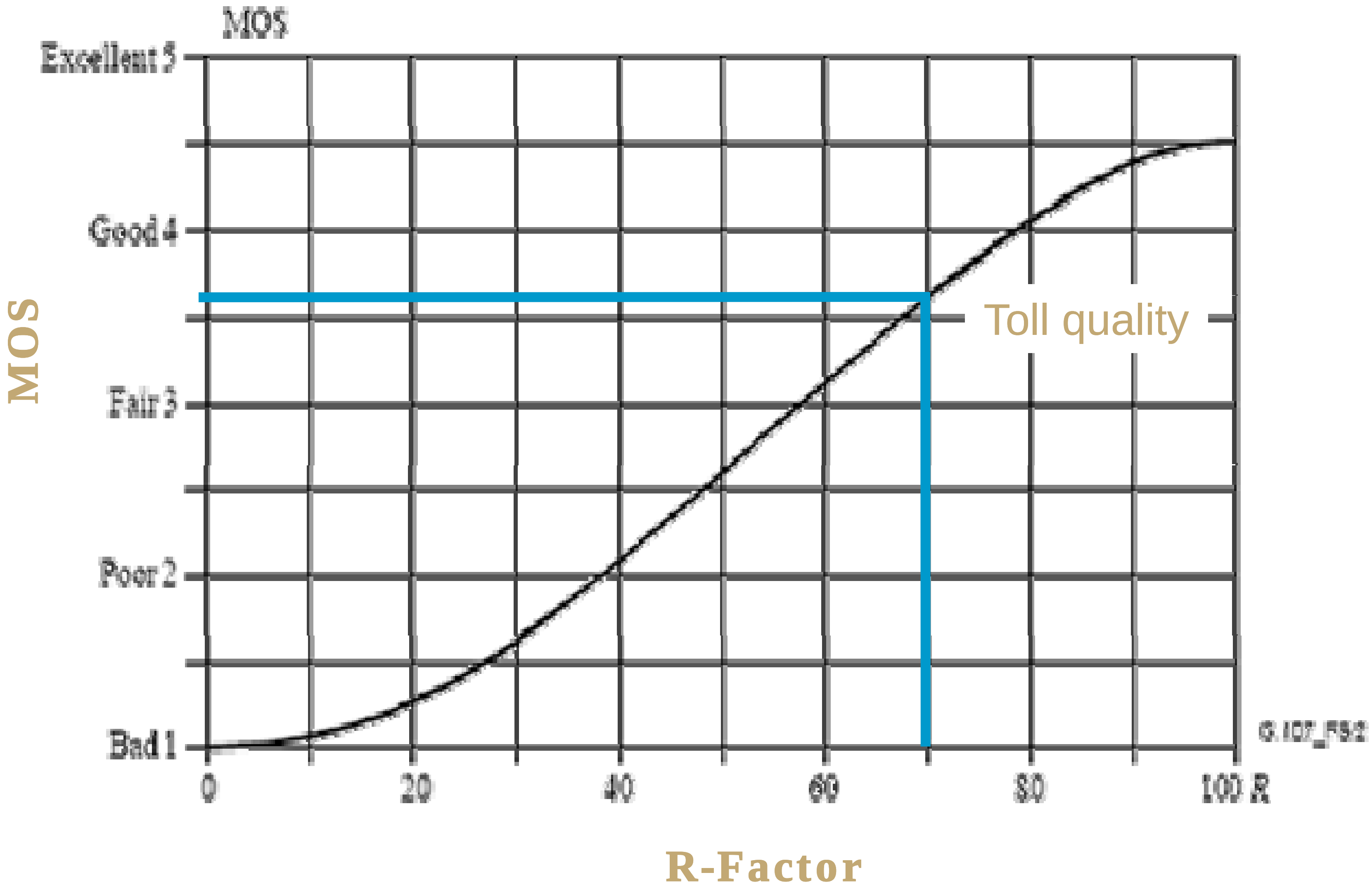
ITU-T E-Model (G.107) for Computing R-Factor



G.107 – Default values and permitted ranges for the E-model parameters

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



Video Metrics

- Media Delivery Index (MDI) defined in RFC 4445 describes media capacity of a network composed of the Media Loss Rate (MLR) and Delay Factor (DF)
  - MLR is a media-weighted metric that expresses the number of expected IEEE Std 802.11 packets dropped from a video stream
  - DF represents the amount of time required to drain the endstation buffer at the bit rate of the media stream
- MLR = (Packets Expected - Packets Received) / Interval in Seconds
- DF is calculated as follows:
  - VB = |Bytes Received - Bytes Drained|
  - DF = (max(VB) – min(VB)) / Video Bit rate in Bytes
  - Where VB = video buffer