

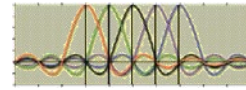


Wireless Tutorial

The IEEE's Wireless Ethernet Keeps Going and Growing

September 1-3, 2009 • Los Angeles, CA • www.4GWE.com





MIMO
 OFDM → OFDMA

Wireless capacity / throughput



First cell phones

AMPS

2G

GSM

CDMA

UMTS/HSxPA

3G

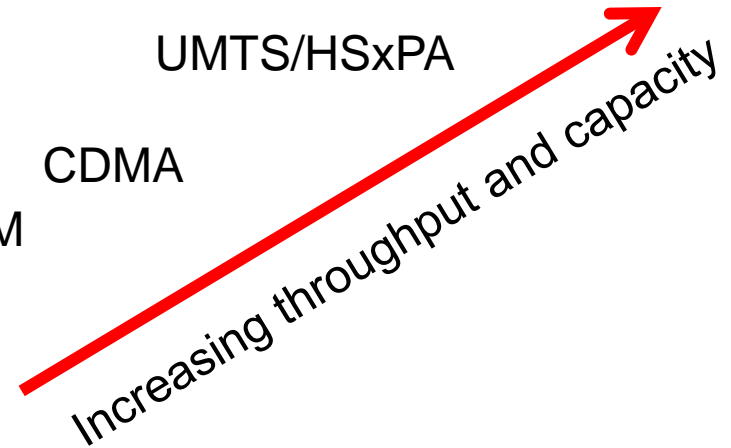
Wi-Fi

WiMAX

IEEE 802

4G

LTE



1970

1980

1990

2000

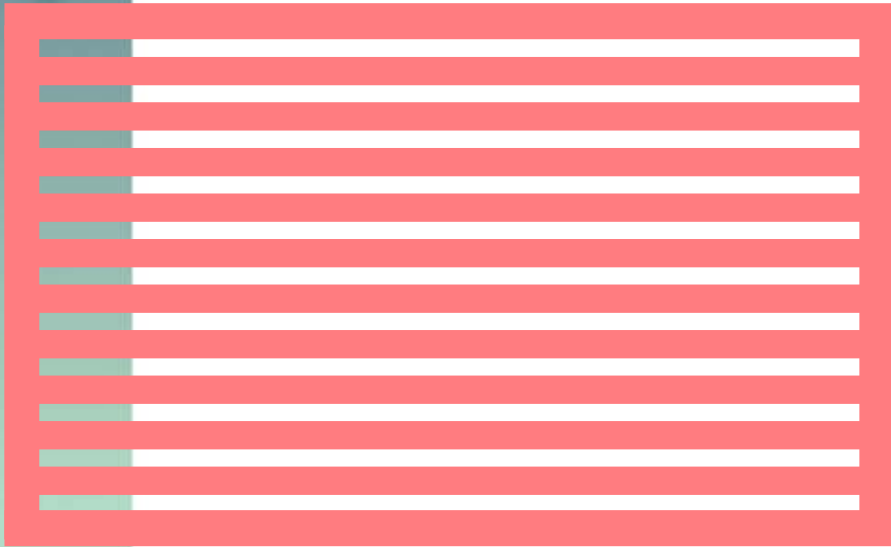
2010

Modulation and Access

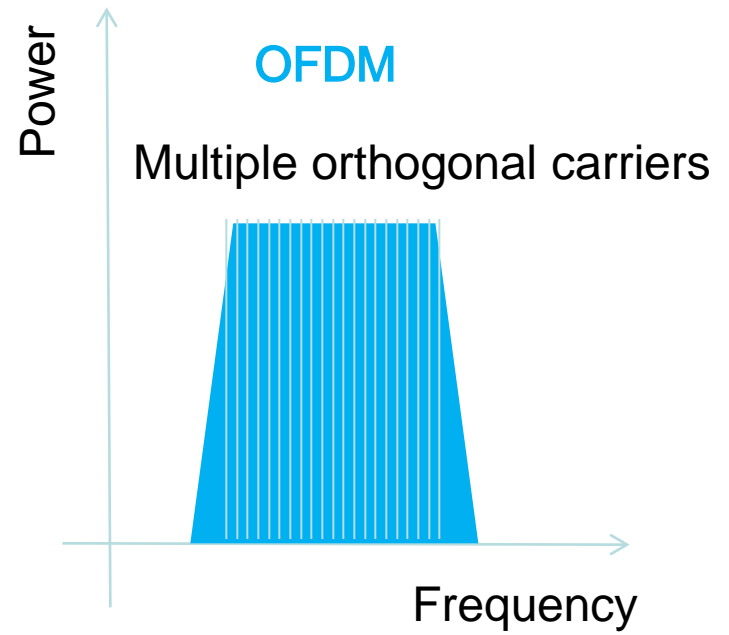
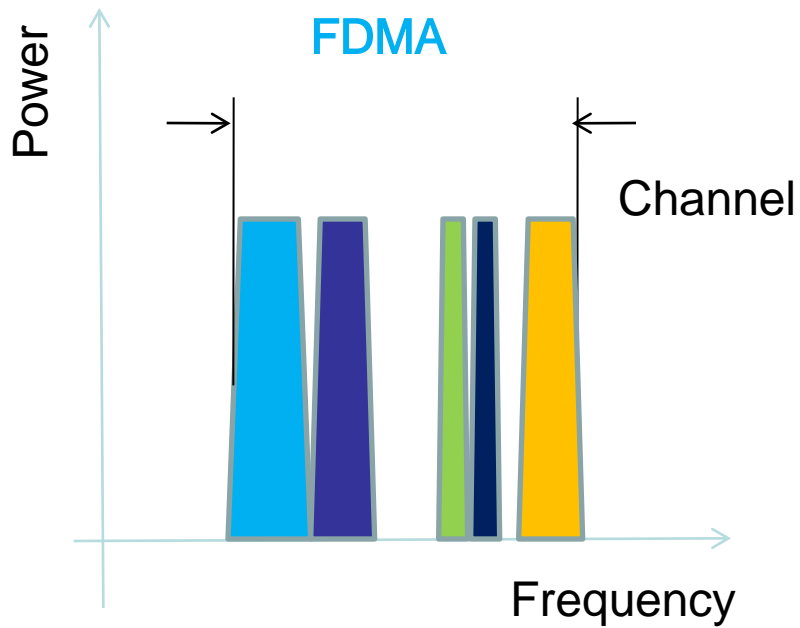
- **TDMA** (time division multiple access) is an access scheme
 - AMPS, GSM
- **CDMA** (code division multiple access) is a coding and access scheme
 - CDMA, W-CDMA, CDMA-2000
- **SDMA** (space division multiple access) is an access scheme
 - MIMO, beamforming, sectorized antennas
- **FDMA** (frequency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



CDMA



Courtesy of Suresh Goyal & Rich Howard
Via Brough Turner



User 1

User 2

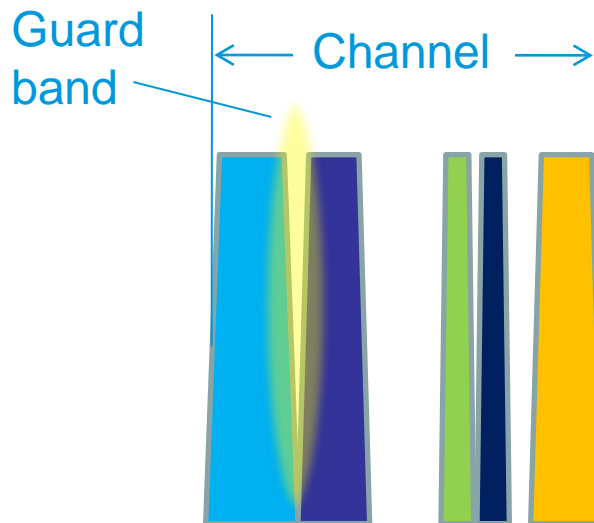
User 3

User 4

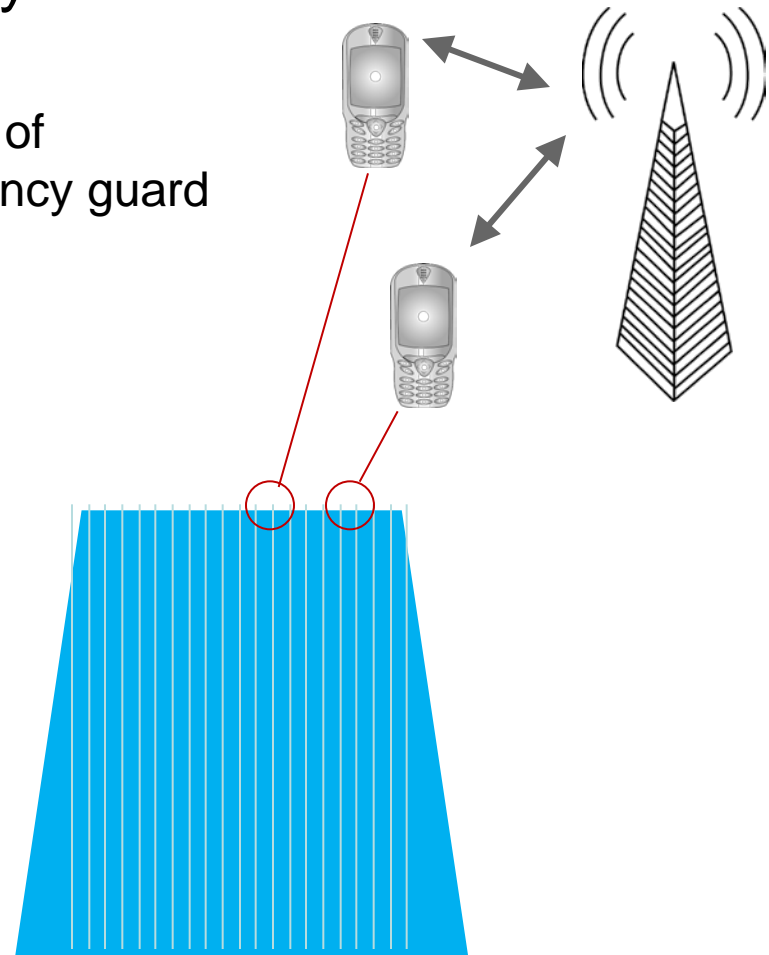
User 5

FDMA vs . OFDMA

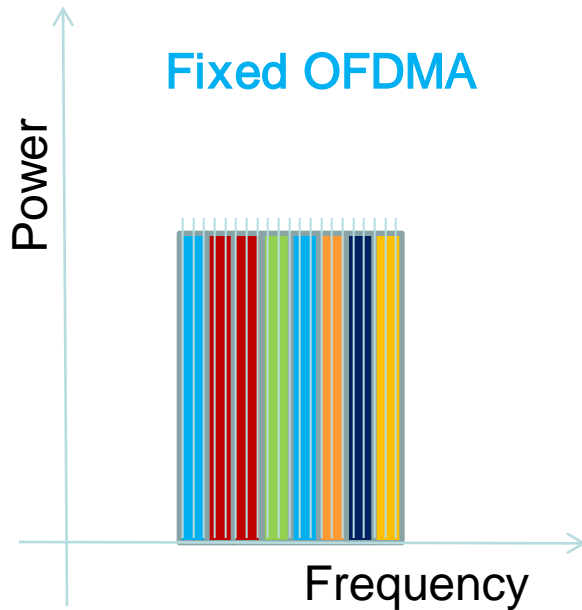
- OFDMA is more frequency efficient than FDMA
 - Each station is assigned a set of subcarriers, eliminating frequency guard bands between users



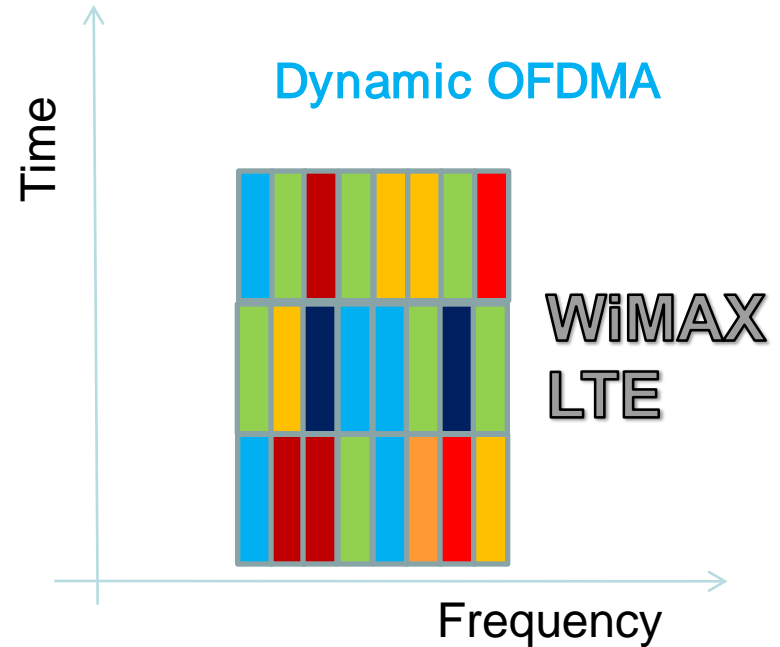
FDMA



OFDMA



Frequency allocation per user is continuous vs. time



Frequency allocation per user is dynamically allocated vs. time slots

User 1

User 2

User 3

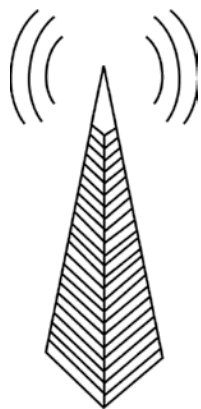
User 4

User 5

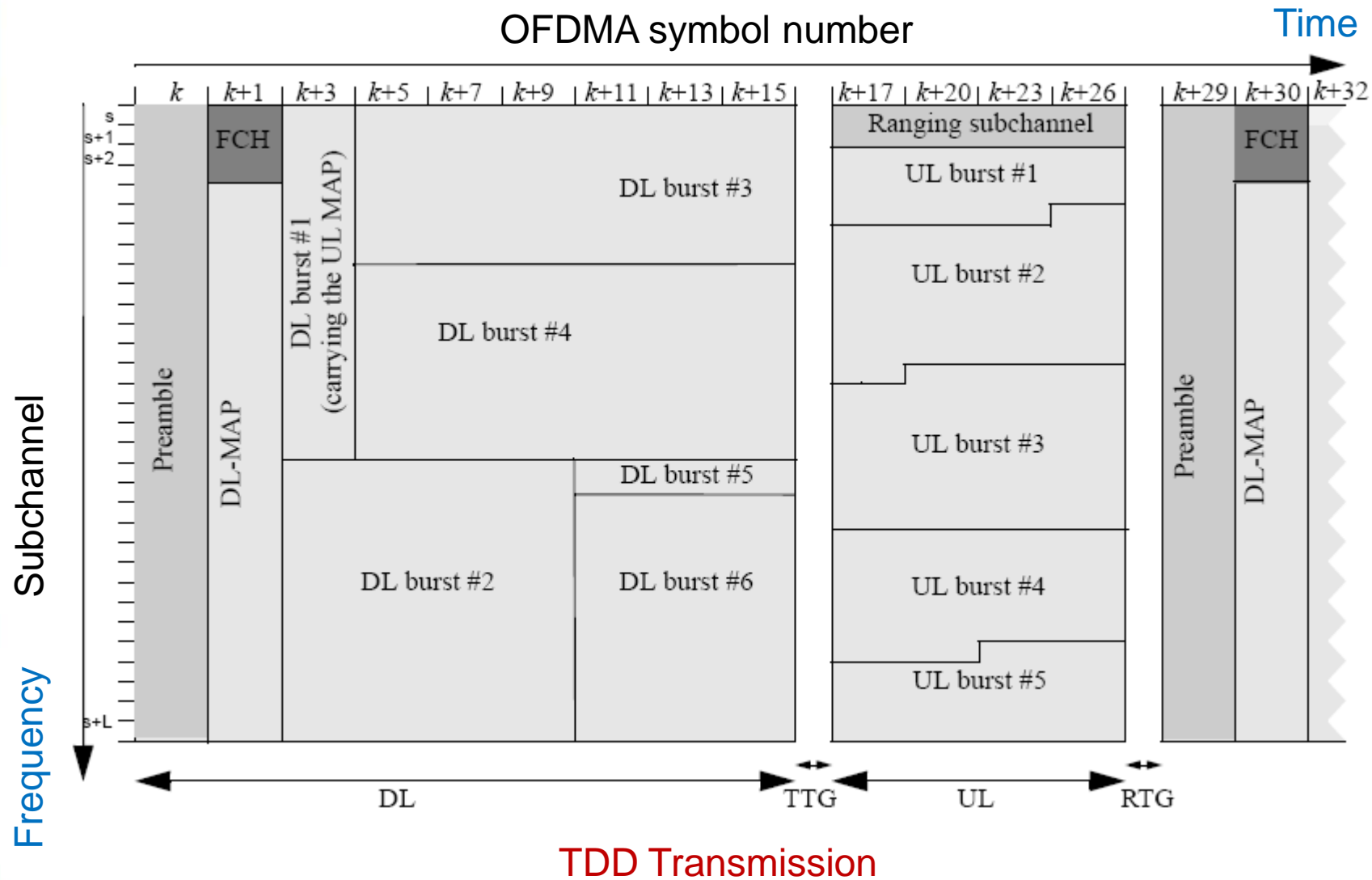
FDD and TDD

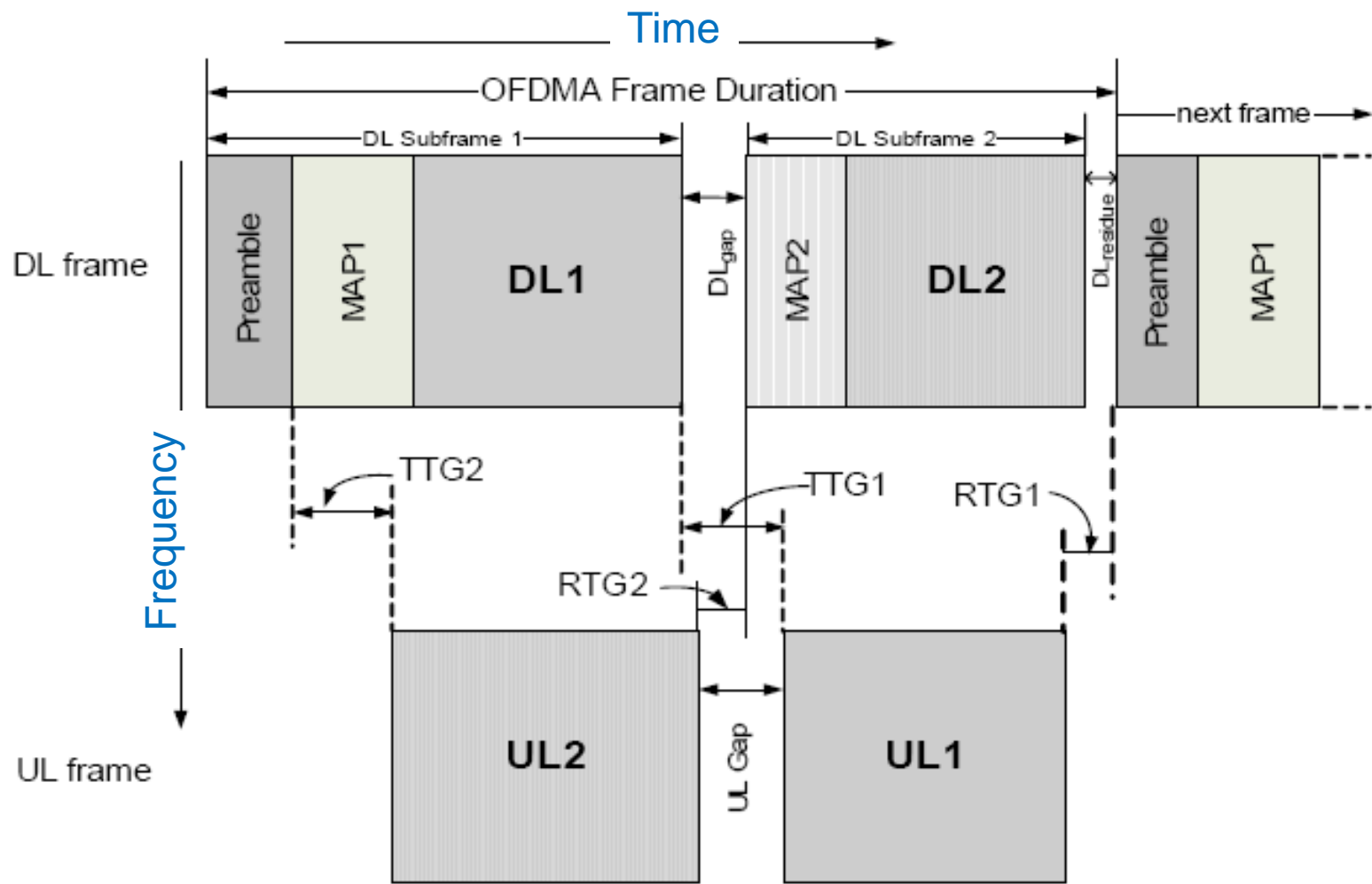
- TDD (time division duplex) and FDD (frequency division duplex) are both supported by WiMAX and LTE

TDD: single frequency channel for uplink and downlink



FDD
Paired channels





H-FDD (half-duplex FDD) Transmission

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

TDD

Time division duplex

FDD

Frequency division duplex
(full and half duplex)

H-FDD

F-FDD

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-T Framework



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)

3GPP (3rd Generation Partnership Project)



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

Operator Organizations

Working with 3GPP



- 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:

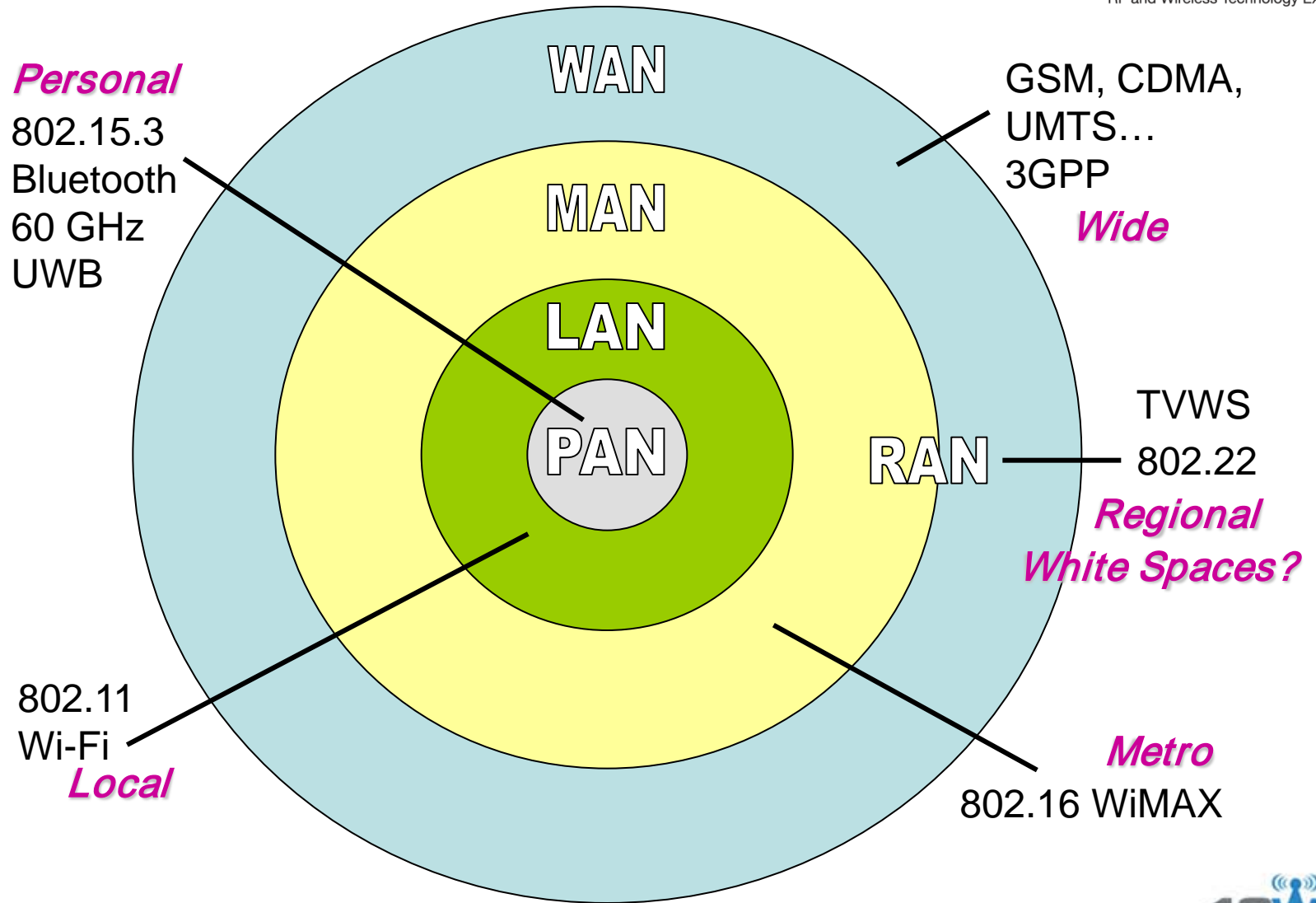
- Sprint Nextel
- China Mobile
- Vodafone
- Orange
- T-Mobile
- KPN Mobile
- NTT DoCoMo



The 'G's

G		Peak Data Rate (Mbps)	
		Downlink	Uplink
1	Analog	22 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) MIMO 2x2	28 Mbps	11.6 Mbps
	HSPA + (MIMO, 64QAM Downlink)	42 Mbps	11.6 Mbps
4	WiMAX Release 1.0 TDD (2:1 UL/DL ratio), 10 MHz channel	40 Mbps	10 Mbps
	LTE, 5+5 MHz channel	43.2 Mbps	21.6 Mbps
	LTE CAT-3	100 Mbps	50 Mbps

The IEEE Technologies



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 today

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 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 802.11 Active Task Groups

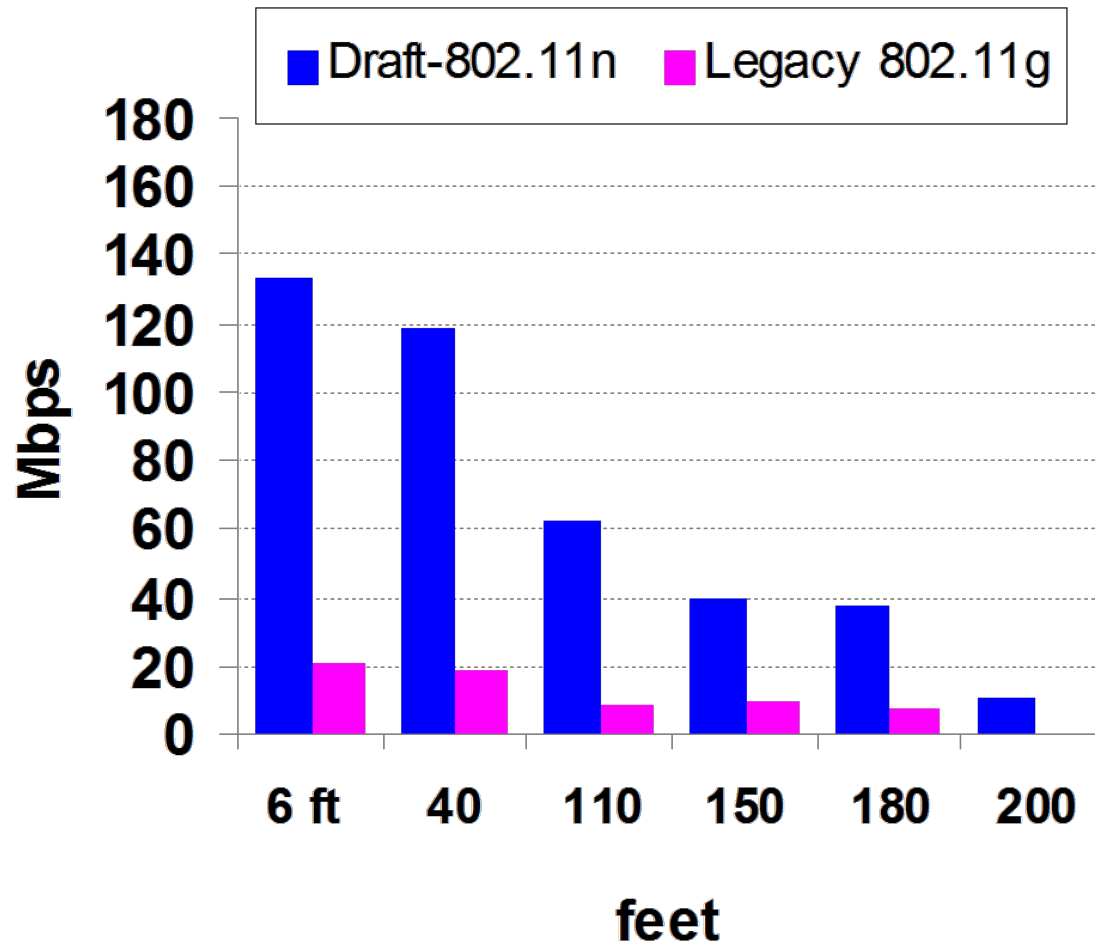
- **TGn** – High Throughput
- **TGp** – Wireless Access Vehicular Environment (WAVE/DSRC)
- **TGs** – ESS Mesh Networking
- **TGT** – IEEE 802 Performance
- **TGu** – InterWorking with External Networks
- **TGv** – Wireless Network Management
- **TGw** – Protected Management Frames
- **TGy** – 3650-3700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

IEEE
802.11™

Draft 802.11n vs. Legacy Throughput Performance

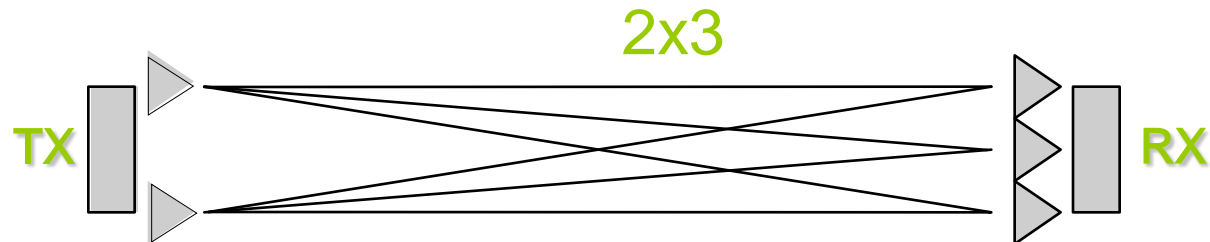


IEEE 802.11a,b,g,n Data Rates

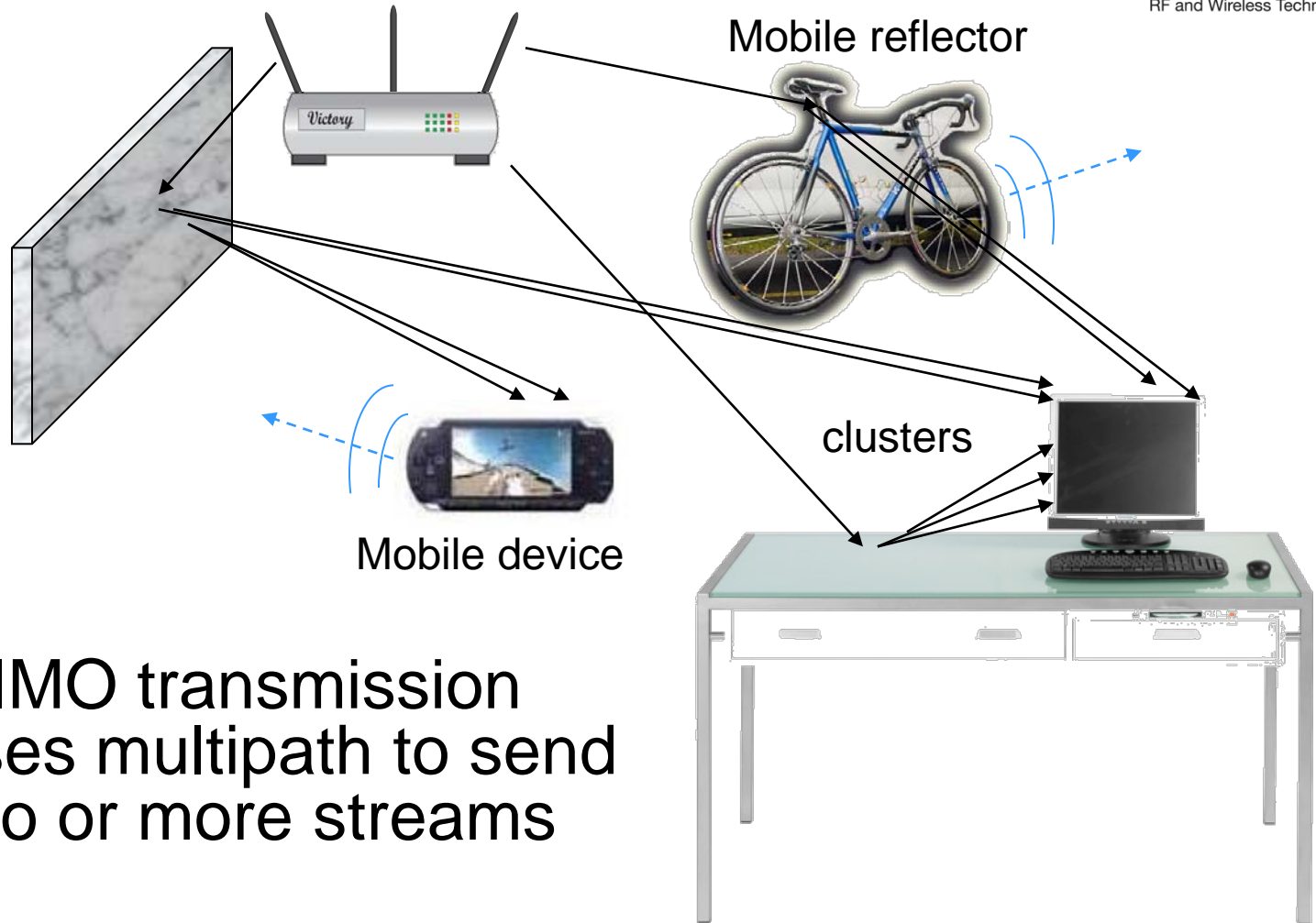
	20 MHz Channel				40 MHz Channel			
	1 stream	2 streams	3 streams	4 streams	1 stream	2 streams	3 streams	4 streams
	Data Rate, in Mbps							
802.11b 2.4 GHz	1, 2, 5.5, 11							
802.11a 5 GHz	6, 9, 12, 18, 24, 36, 48, 54							
802.11g 2.4 GHz	1, 2, 6, 9, 12, 18, 24, 36, 48, 54							
802.11n 2.4 and 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

MIMO Radio Systems



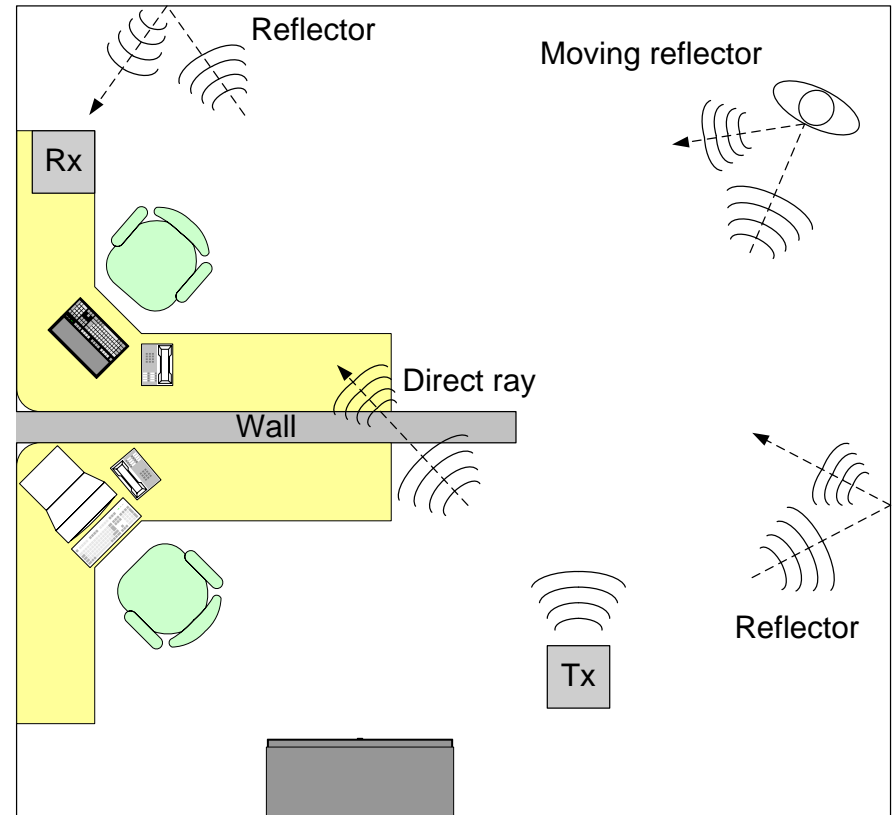
- Data is organized into spatial streams that are transmitted simultaneously - This is known as *Spatial Multiplexing*
- **SISO**: Single-Input/Single-Output; **MIMO**: Multi-Input/Multi-Output; **SIMO**: Single-Input/Multi-Output; **MISO**
- There's a propagation path between each transmit and receive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



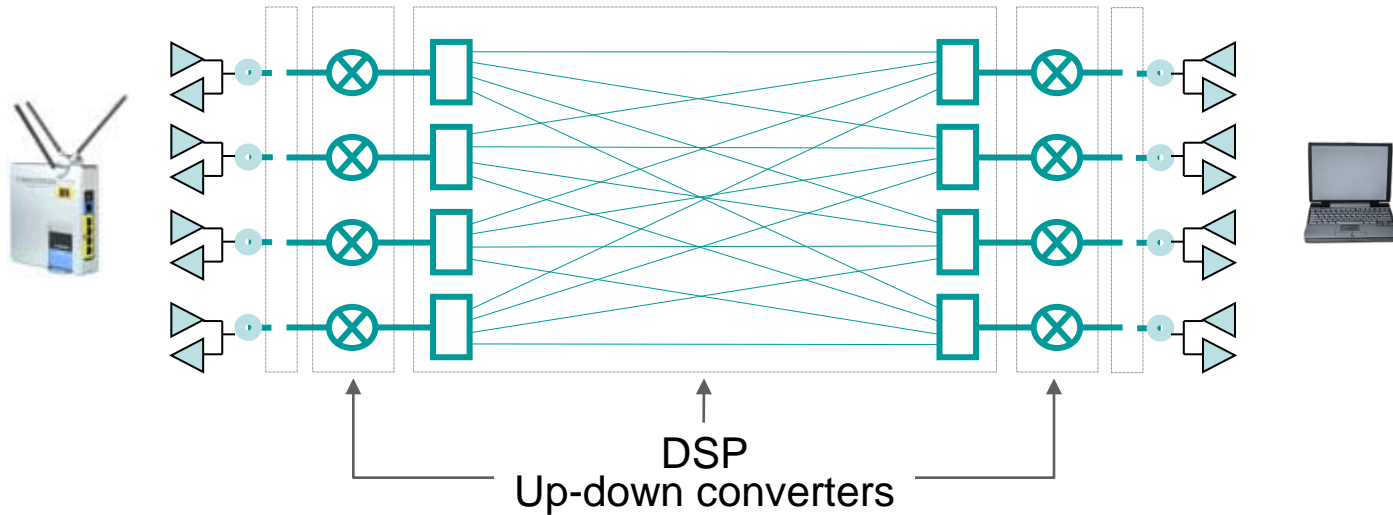
MIMO transmission
uses multipath to send
two or more streams

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



MIMO Channel Emulation

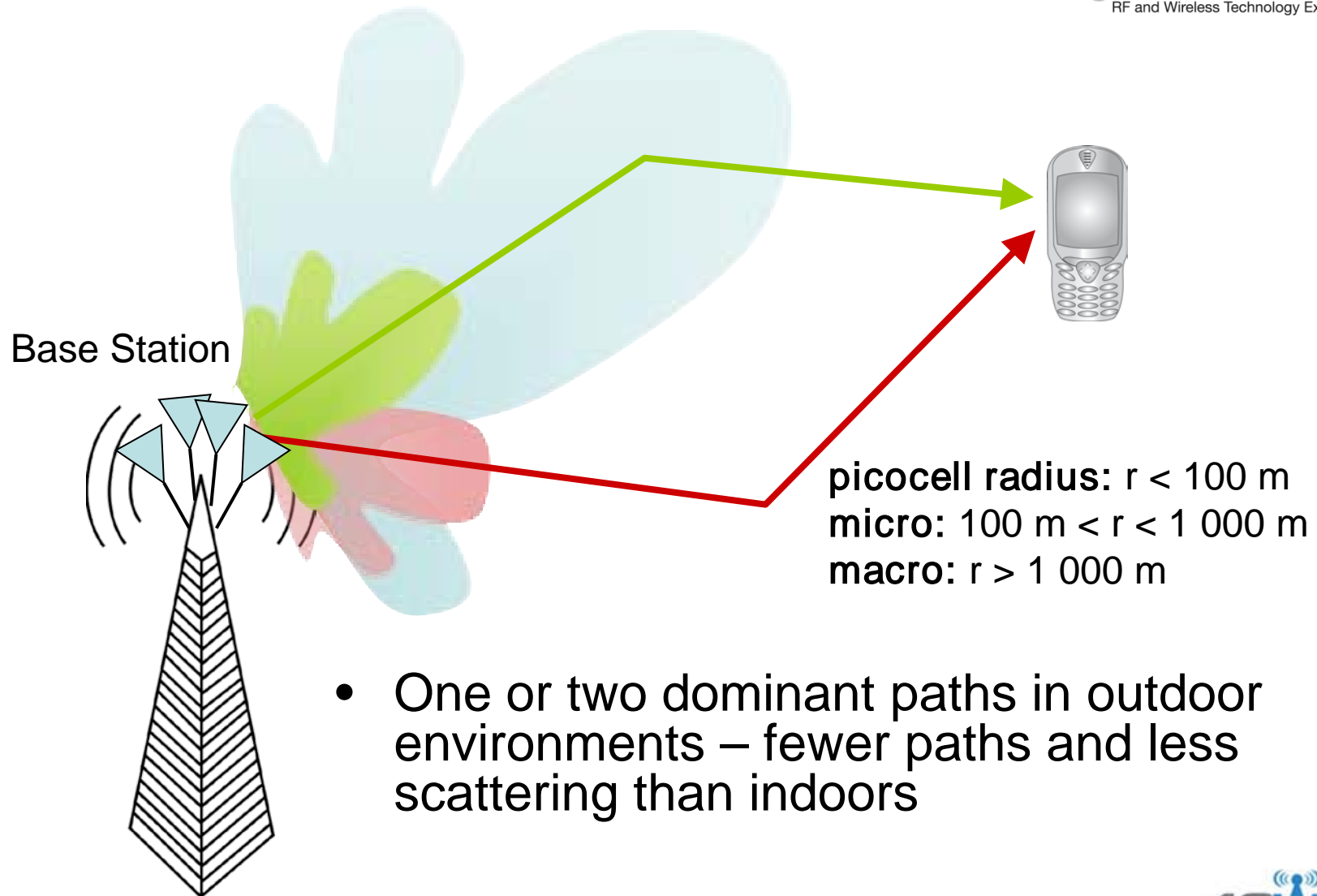


- 4 x 4 MIMO paths to support 802.11n
- WiMAX requires 2 x 2
- 802.11n and ITU M.1225 channel models
- Bidirectionality required to support beamforming

Municipal Multipath Environment

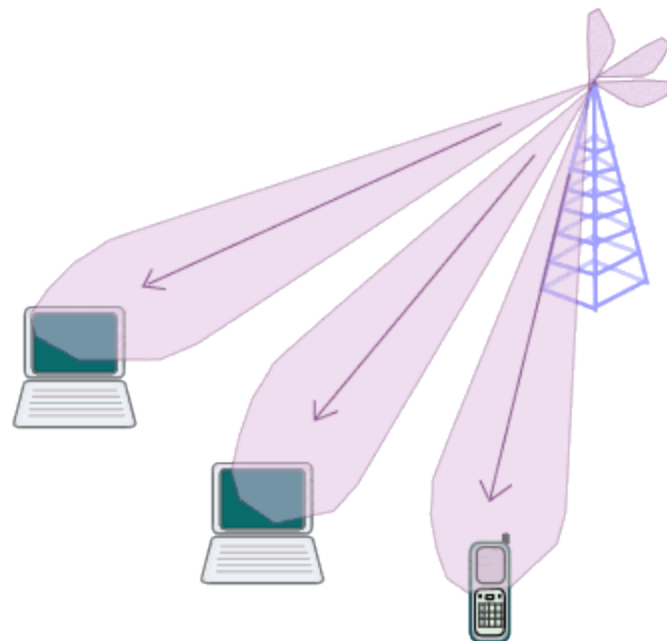


Outdoor Multipath Environment



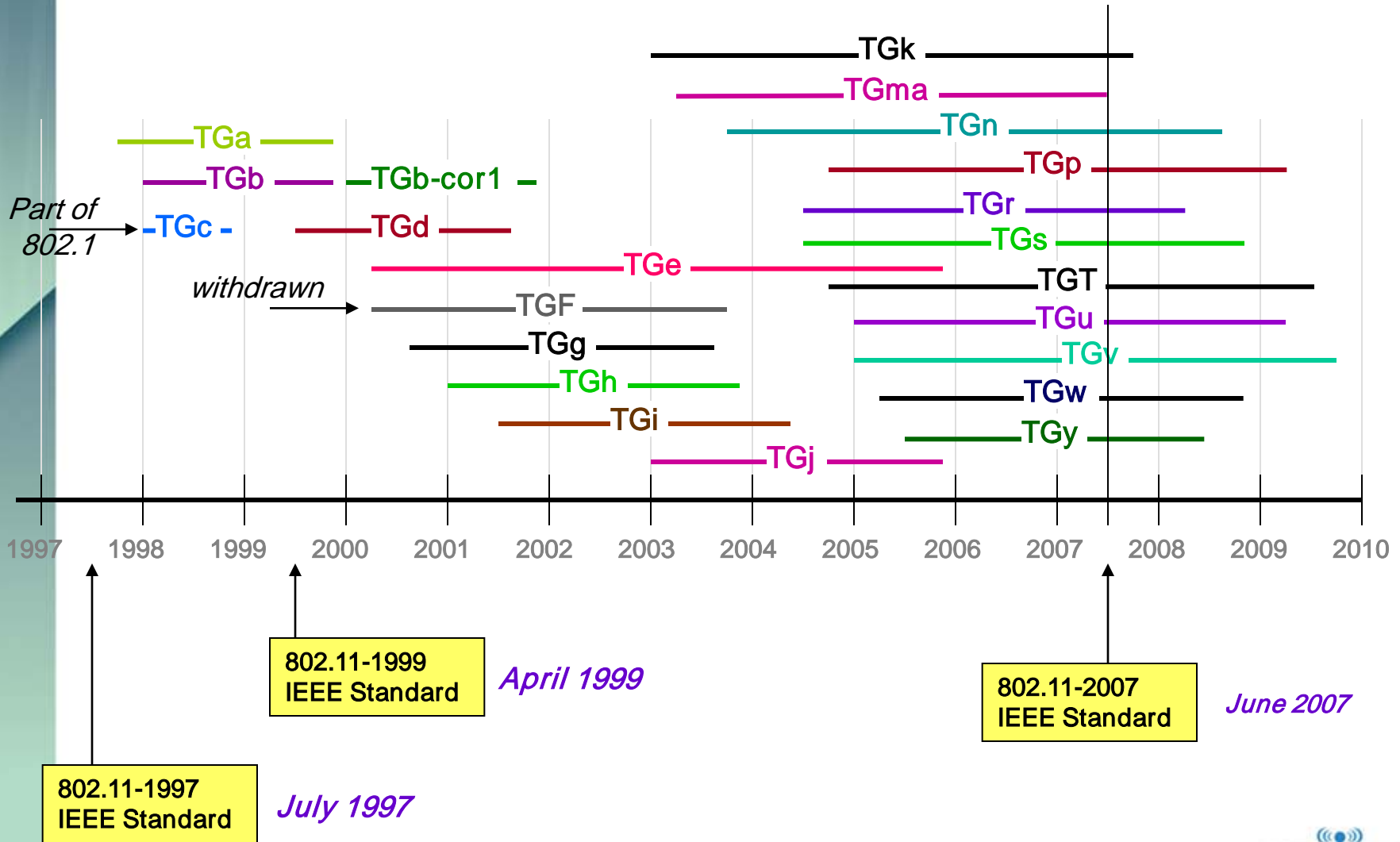
SDMA = Smart Antenna Technologies

- **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 reduces fading



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

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 assist 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 specify 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



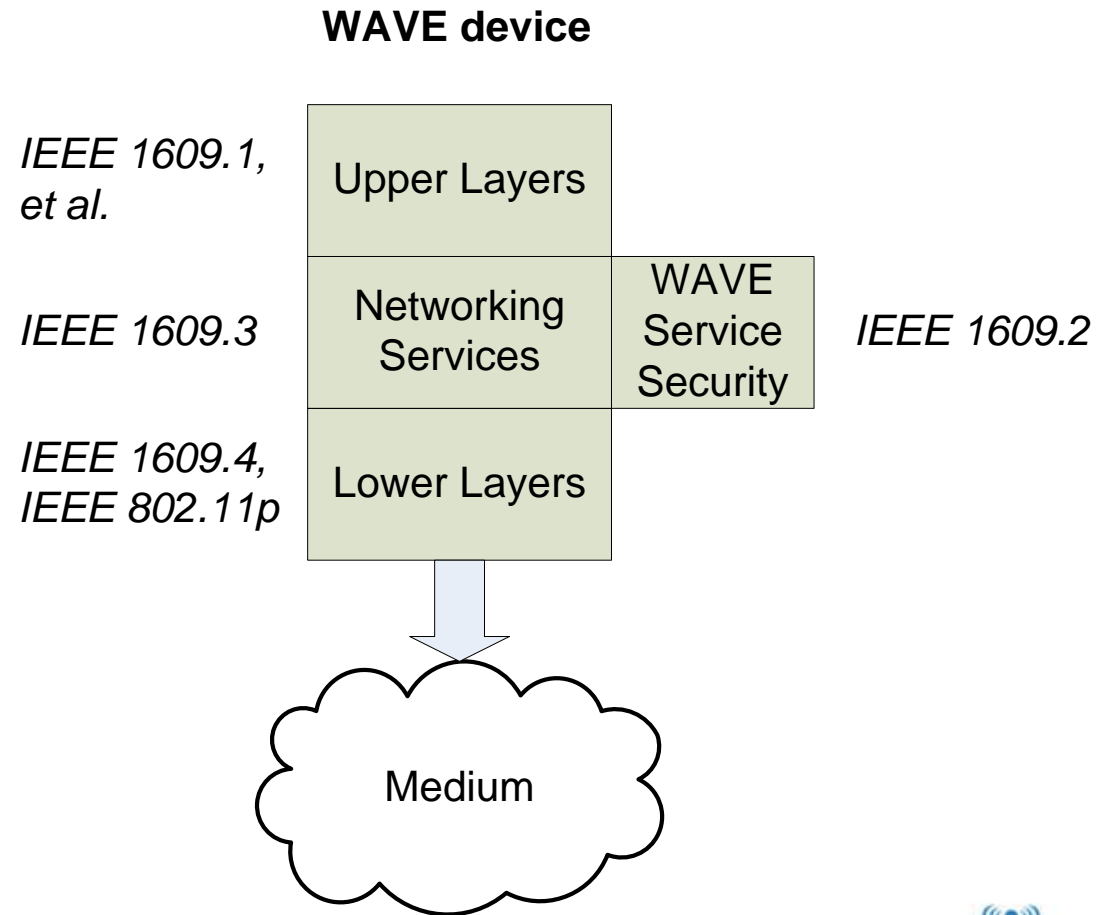
802.11p Wireless Access Vehicular Environment (WAVE)



- 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

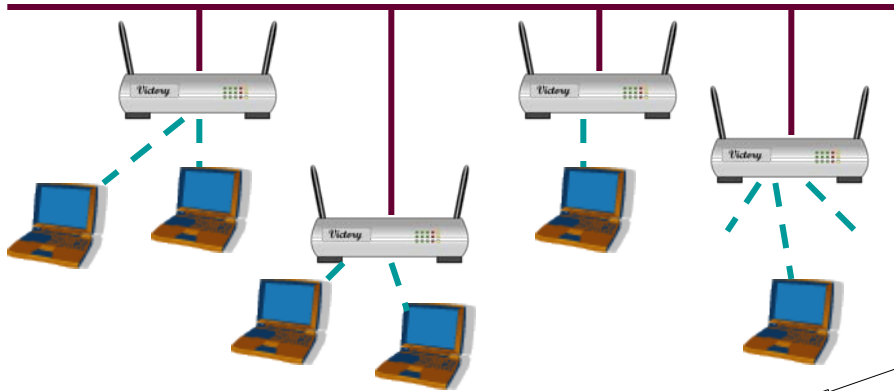
802.11p Wireless Access Vehicular Environment (WAVE)

- 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

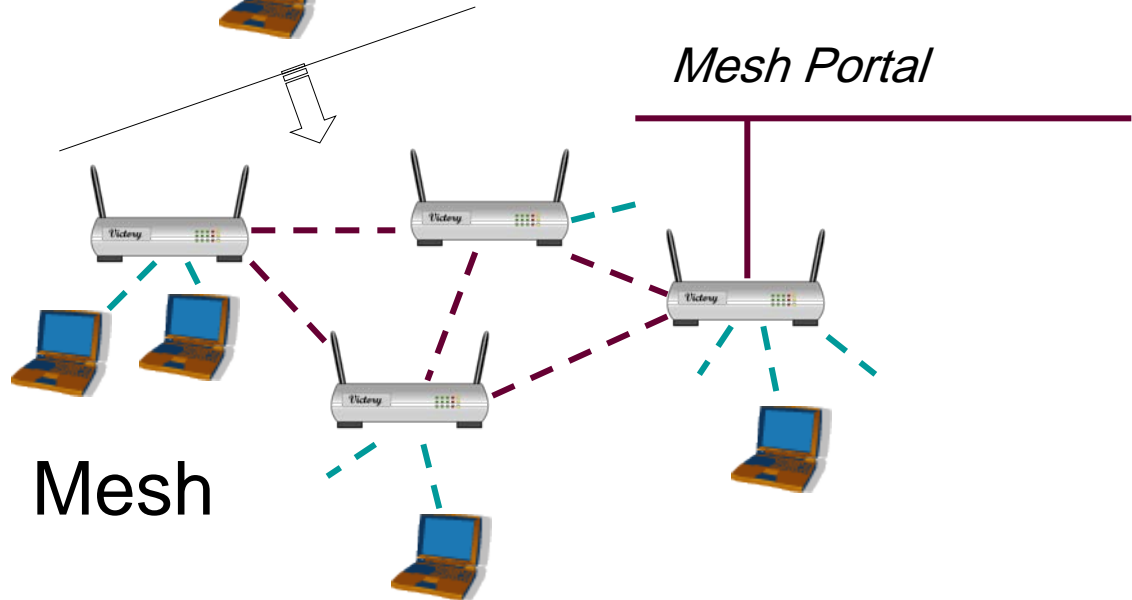
Wired connection to each AP



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

Traditional WLAN

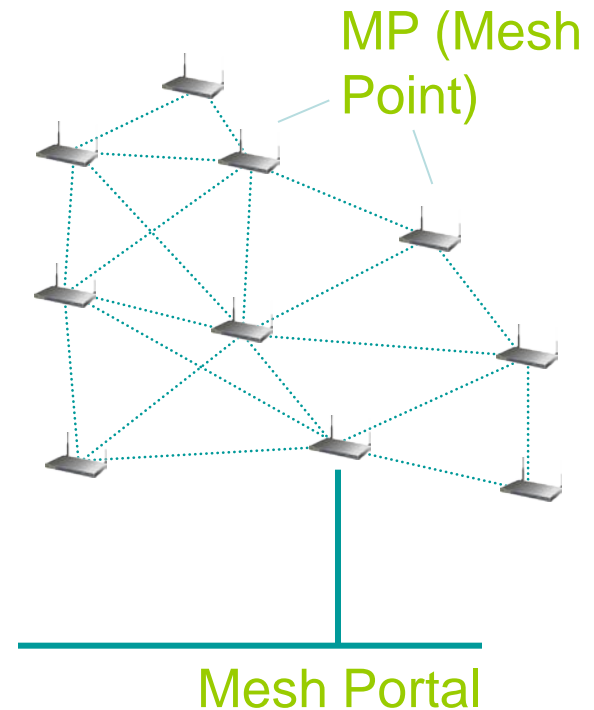
- Wired links
- - Mesh links
- - - Client links



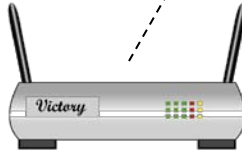
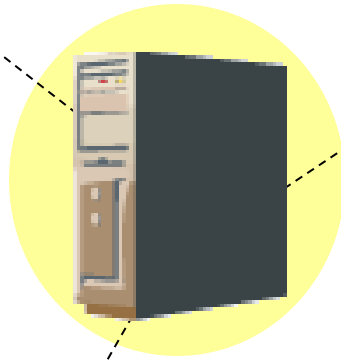
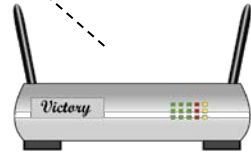
Mesh

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

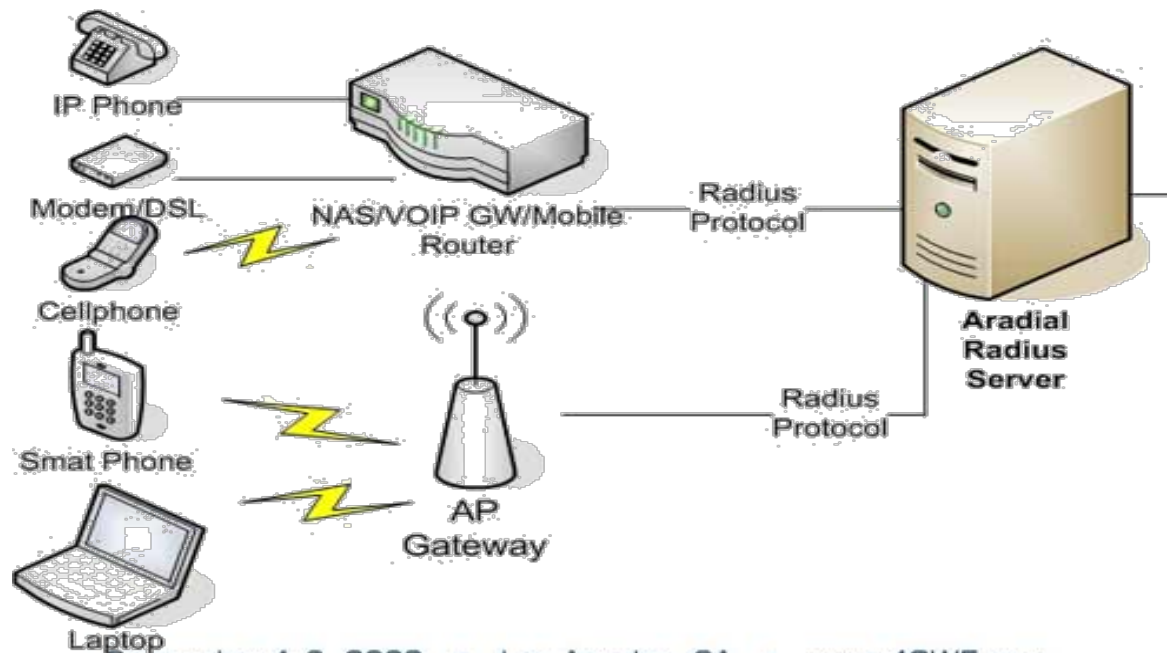
Fast Handoff in Dynamic Meshes

- 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



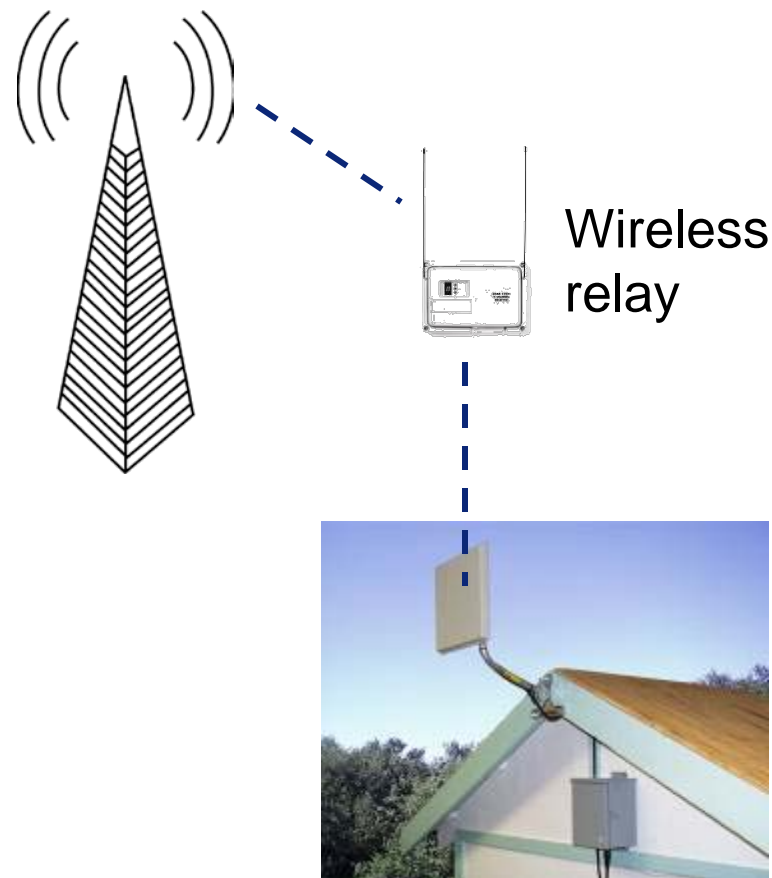
802.11s Security

- 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.

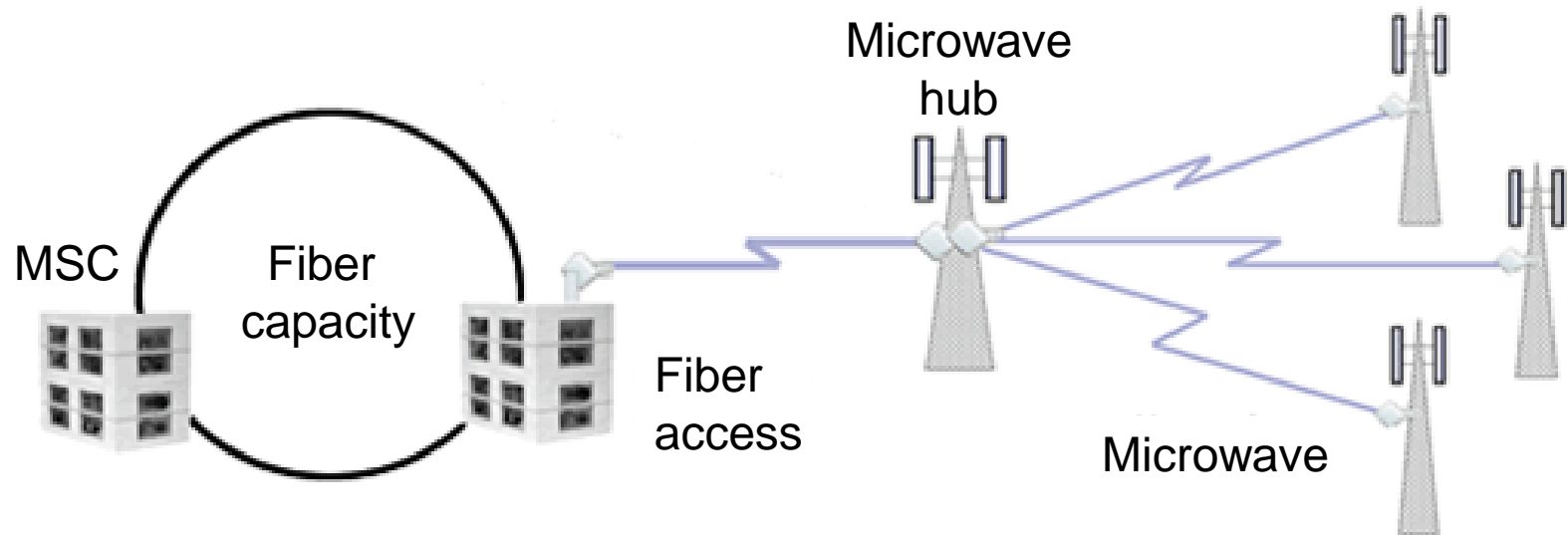


IEEE 802.16 and 802.15 Mesh Standards

- 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
- 802.16m, 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)

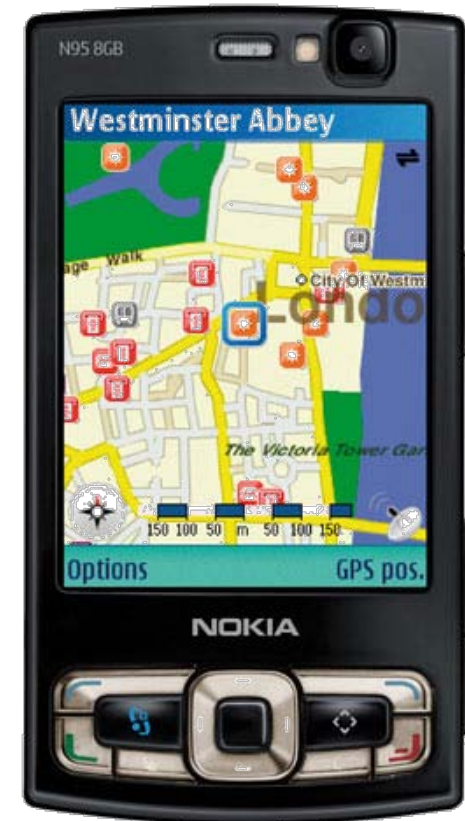
Mobility and Handoff

- 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



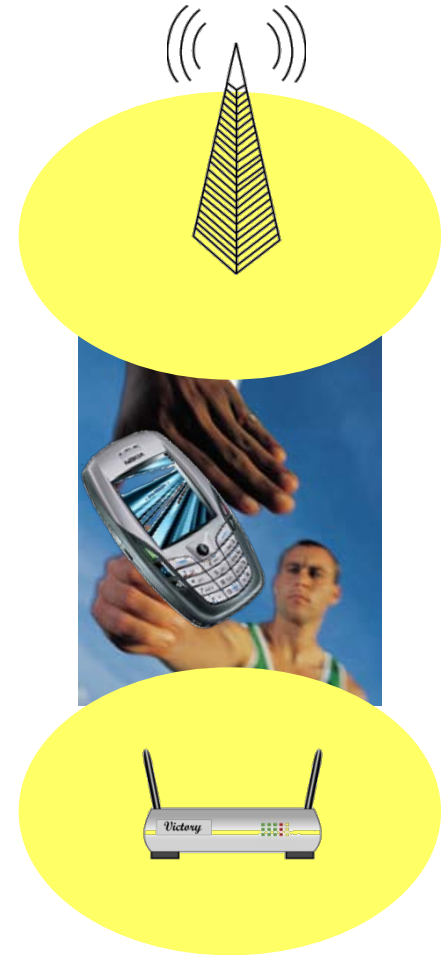
Location Management

- 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



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 market
 - Currently no industry standard other than FCC
 - IEEE 802.22, 802.19, 802.11 may be developing communications standards

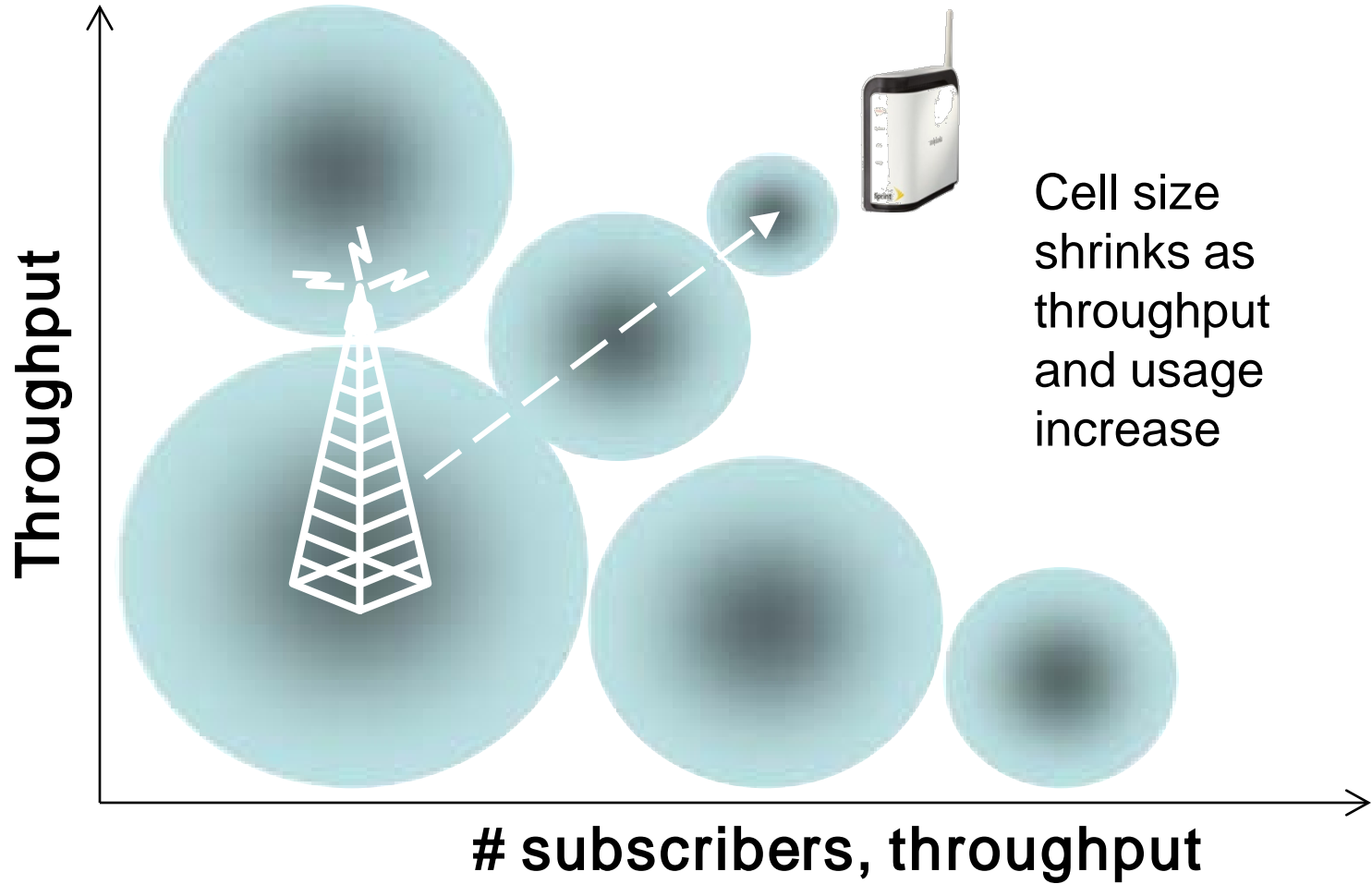
Wireless Broadband

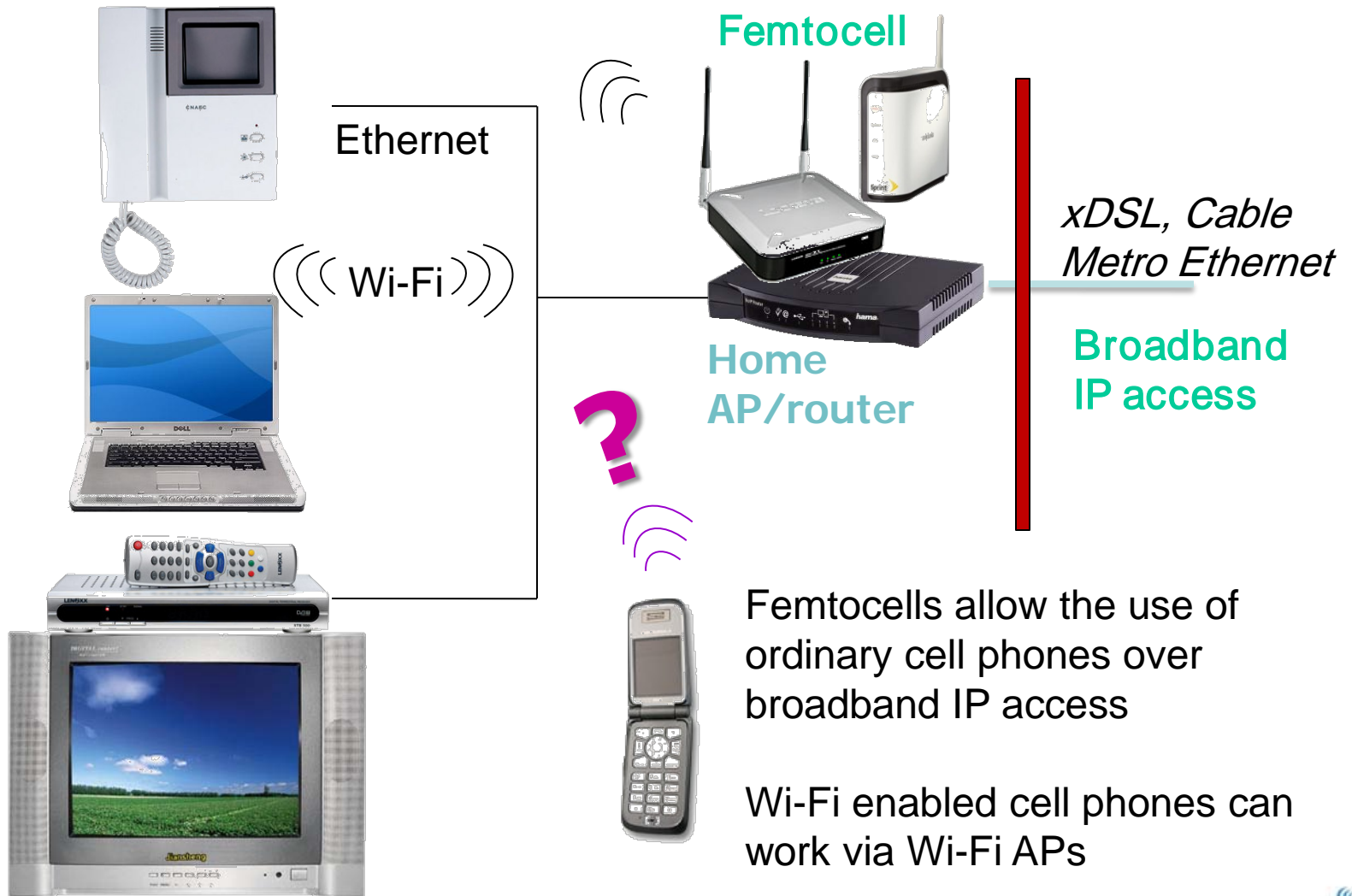
4G Starts in the Home



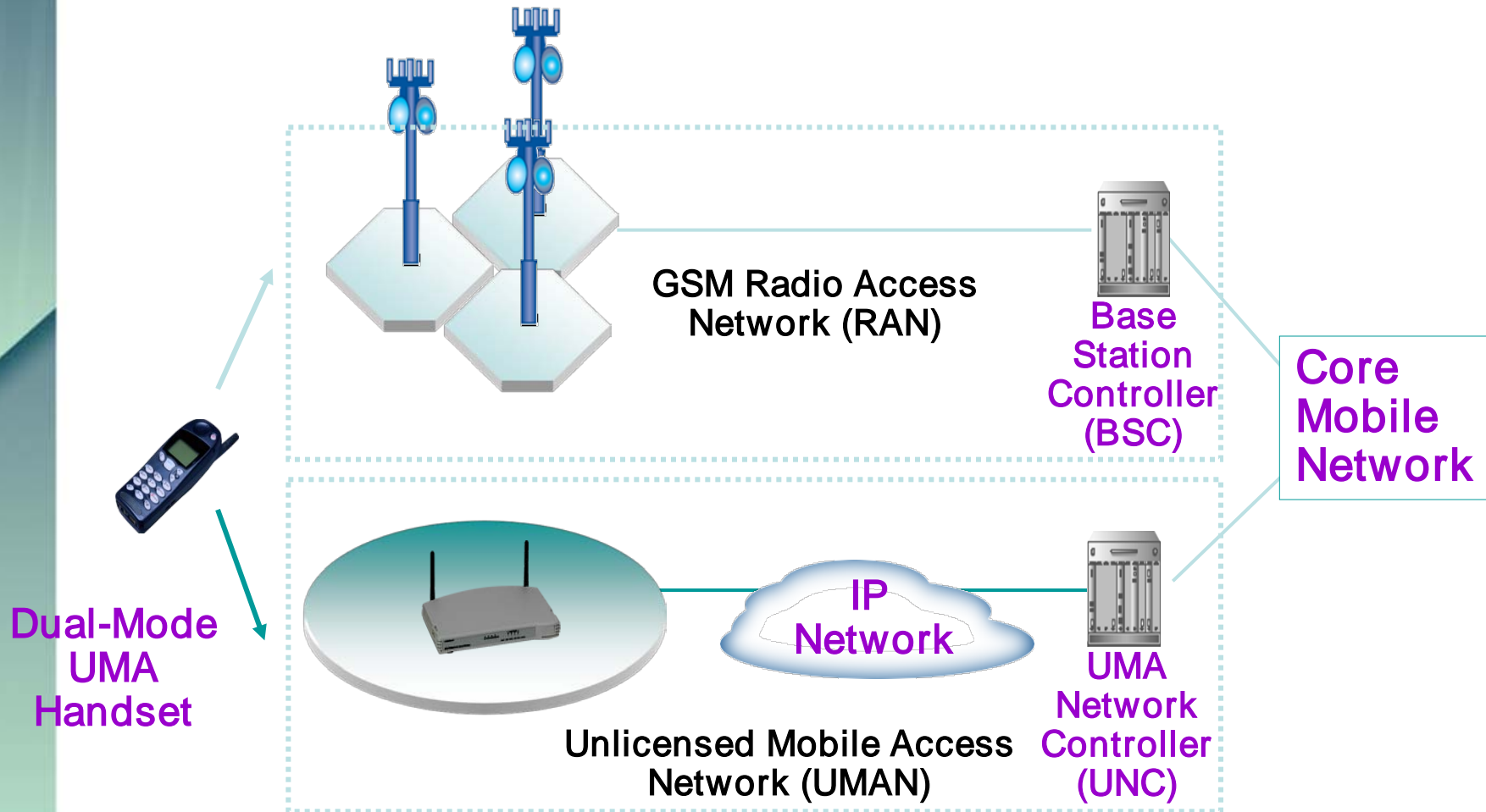
*xDSL, Cable
Metro Ethernet*

**Broadband
IP access**



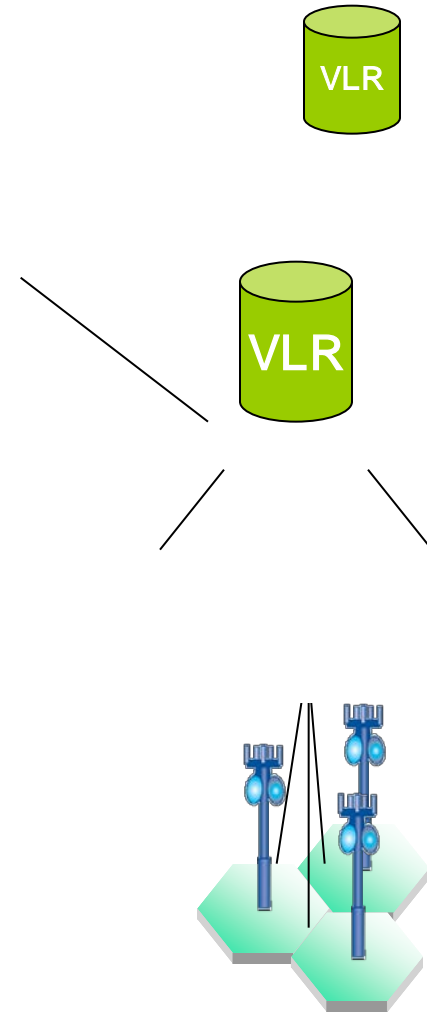


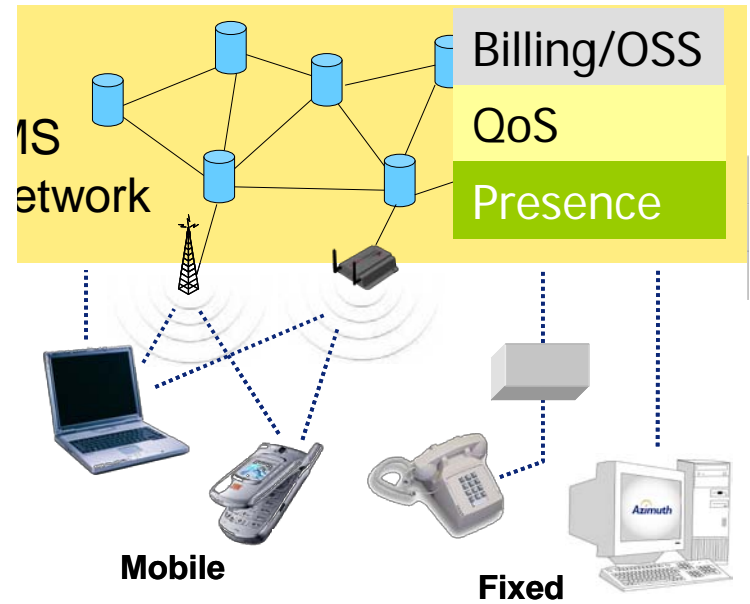
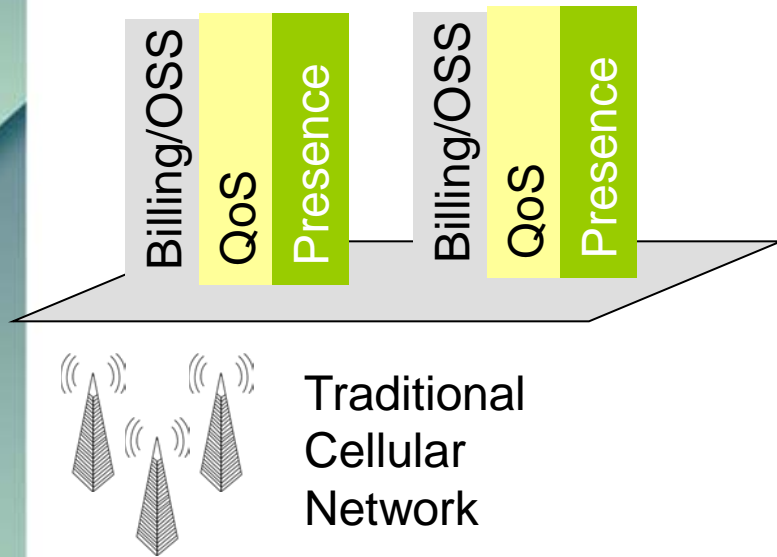
GAN (Generic Access Network) / UMA (Unlicensed Mobile Access)



Operators and vendors agreed to develop UMA in December 2003

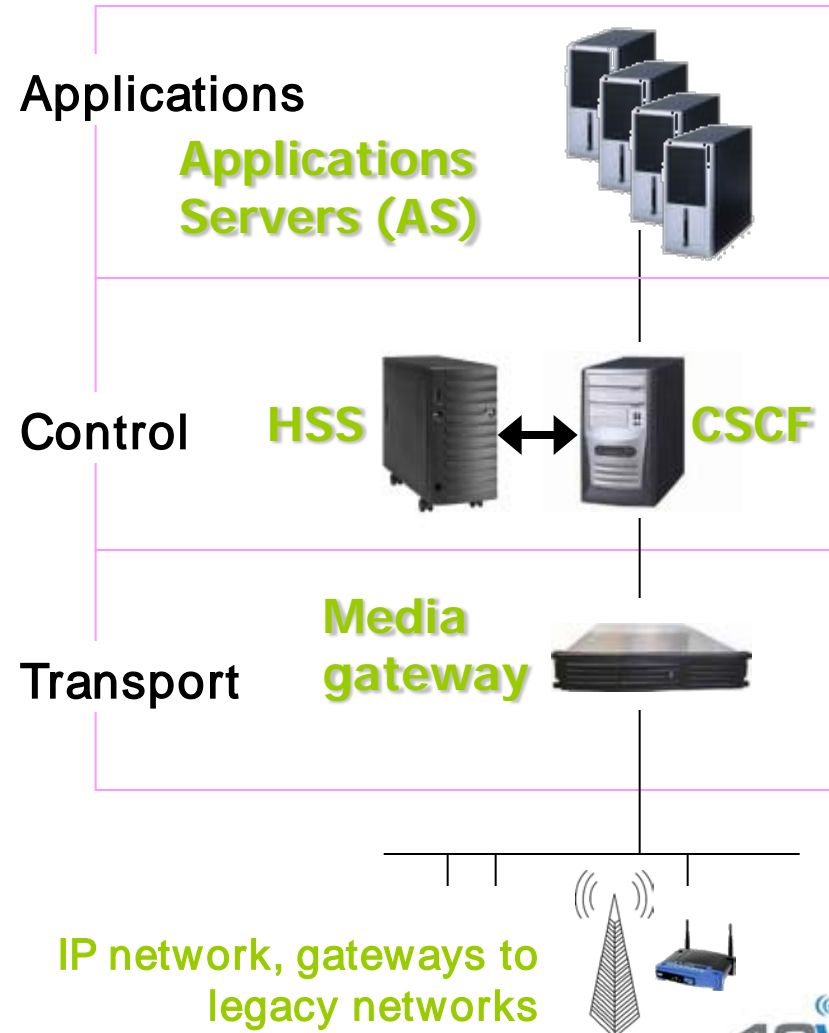
Data Networks vs. Traditional Cellular Networks





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.

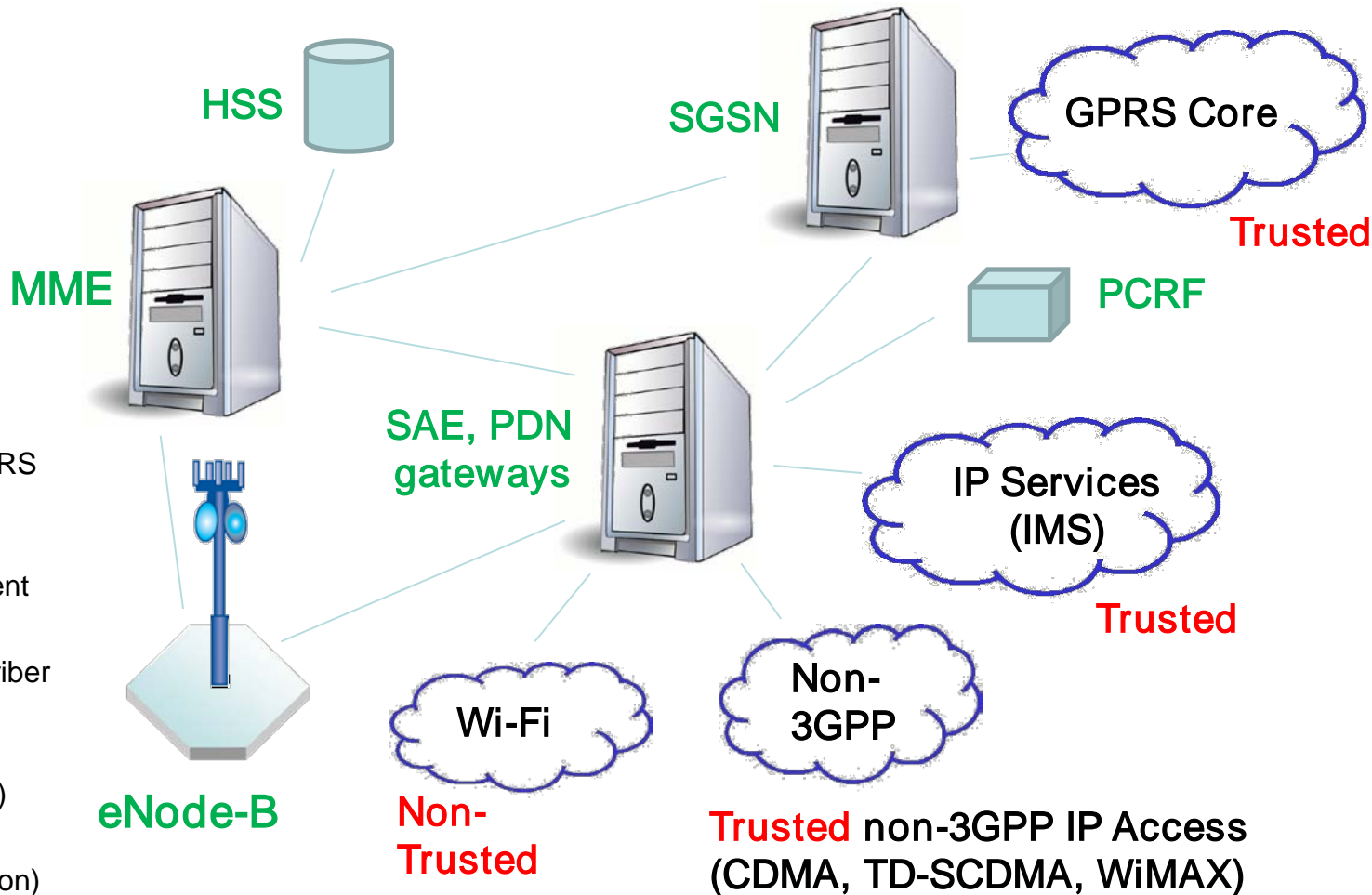


Scalability

	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

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.

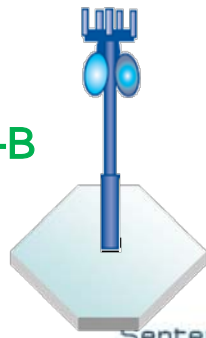
SAE GW
PDN GW



MME



eNode-B



SGSN

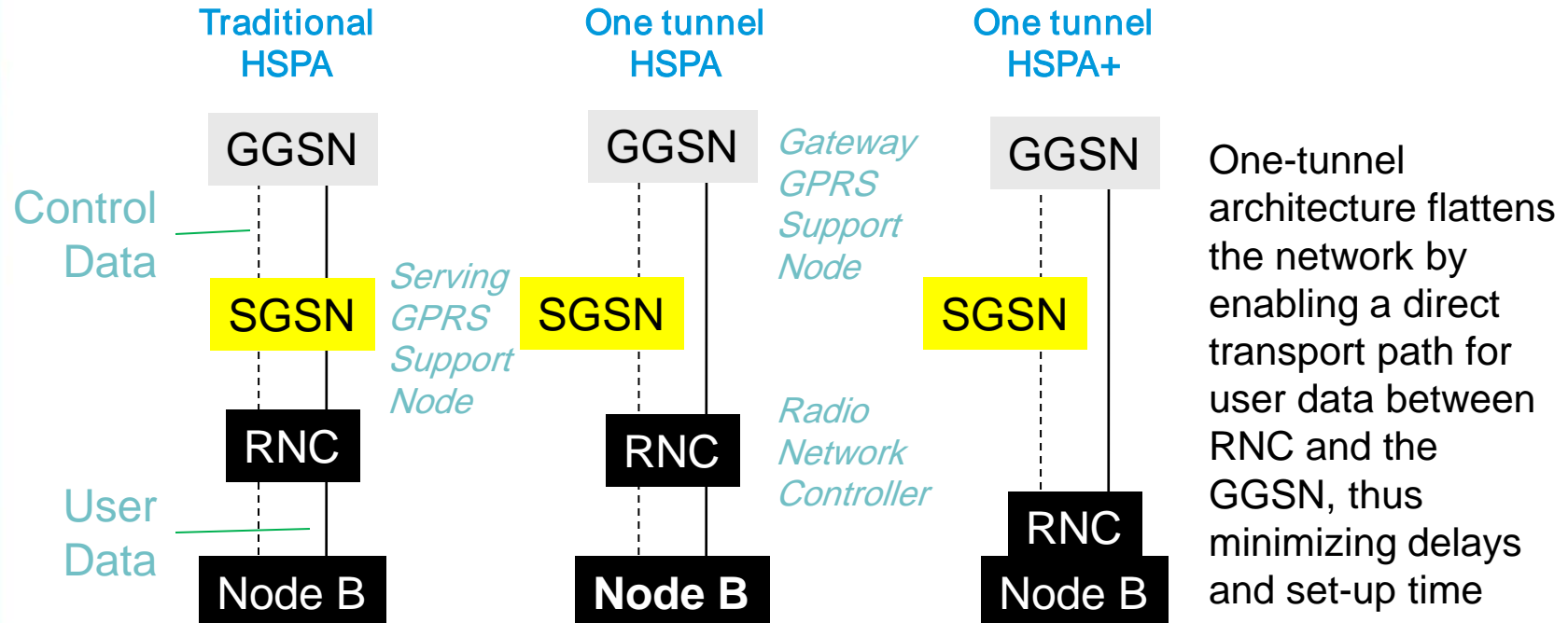


*GPRS Gateway Support Node

Serving GPRS Support Node

HSPA and HSPA+

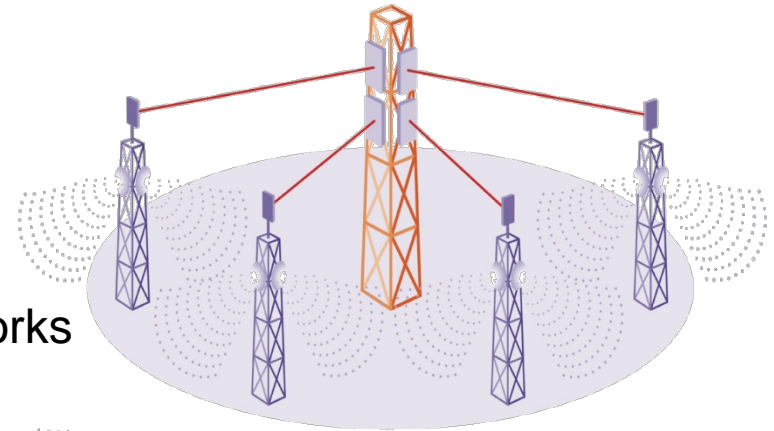
- HSPA+ is aimed at extending operators' investment in HSPA
 - 2x2 MIMO, 64 QAM in the downlink, 16 QAM in the uplink
 - Data rates up to 42 MB in the downlink and 11.5 MB in the uplink.
- HSPA+ is CDMA-based and lacks the efficiency of OFDM



Backhaul

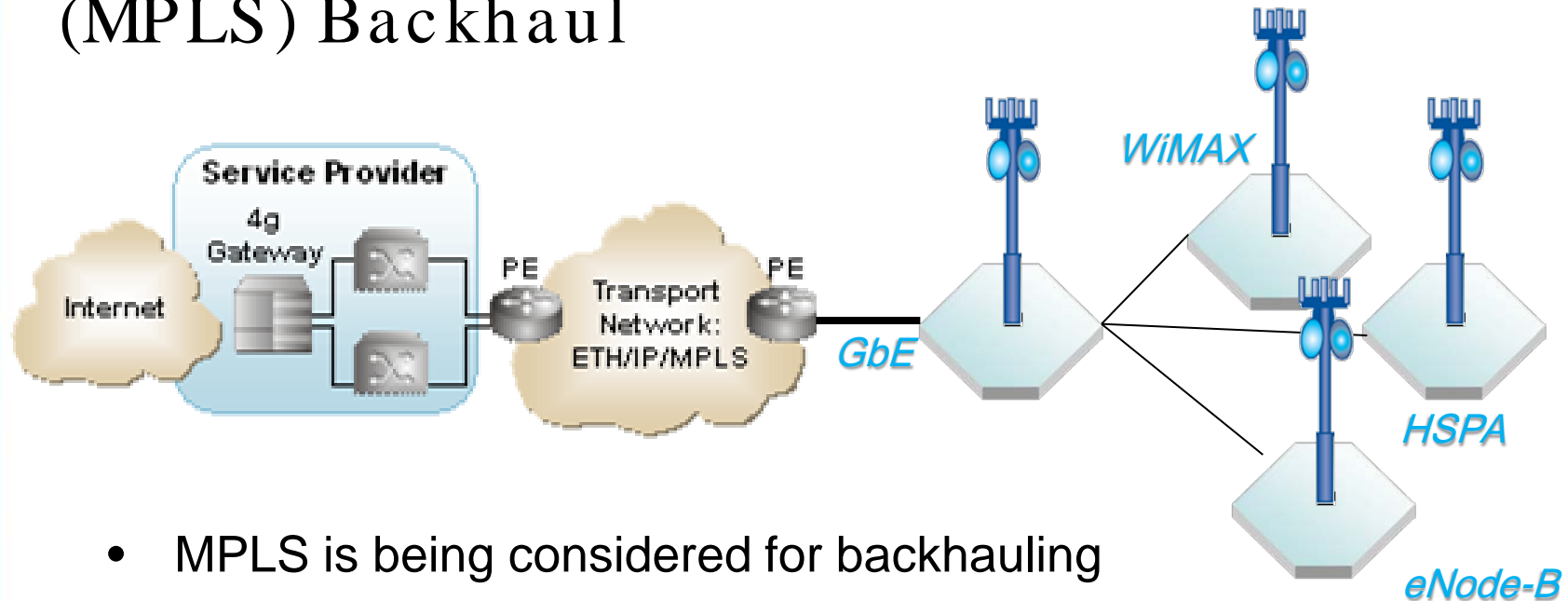
- LTE requires high-capacity links between eNodeB and the core. The options are:
 - Existing fiber deployments
 - Microwave in locations where fiber is unavailable
 - Ethernet
- Co-location of LTE with legacy networks means the backhaul has to support
 - GSM/UMTS/HSPA/LTE or LTE/CDMA
 - Time division 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
 - Users are allocated a slice in time and frequency
 - Flexible, dynamic per user resource allocation conveyed on a frame-by-frame basis
- Differences
 - LTE introduced 'Single Carrier' FDMA on the uplink to reduce PAPR (peak to average power ratio) and save battery
 - Traditional carriers closer to LTE than to WiMAX (via NGMN and LSTI)
 - LTE backhaul is designed to support legacy services while WiMAX is better suited to Greenfield deployments



Lightly Regulated Band

- 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

White Spaces

- 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
- At the end of 2008 has opened up the use of cognitive radio for White Spaces, unused TV spectrum
- IEEE 802.22, 802.19 and 802.11 are working on communications standards in the White Spaces bands



Turf Battles to Continue...

- Broadcasters are resistant TV White Spaces
- Open spectrum, both in the 3650 MHz band and in the UHF band, is certainly a disruptor to business as usual



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