Femtocell Tutorial

VON, Boston

29 October 2007

Fanny Mlinarsky

President, octoScope

Agenda

- 9:00 – 11:00 am **FMC and Femtocell history, architecture and standards**
  - Fanny Mlinarsky, President, octoScope
  - Asa Kalavade, Founder and CTO, Tatara Systems
- 11:00 – 11:15 am **Break**
- 11:15 – 12:00 noon **Femtocell regulatory issues**
  - Barlow Keener, Keener Law Group
- 12:00 – 1:00 pm **Lunch**
- 1:00 – 3:00 pm **Focus on the physical layer**
  - Vicki Griffiths, Product Manager, Cellular Applications, picoChip Designs
  - David Donovan, Analog Devices
  - Tim Counihan, Director of Product Marketing, BitWave Semiconductor
- 3:00 – 3:15 pm **Break**
- 3:15 – 5:00 pm **The Bridge from FMC to FMS**
  - Michael Blanchard, Sr. Product Manager, Femtocell Products, Airvana
  - Scott Poretsky, Director, Carrier Network Engineering, ReefPoint

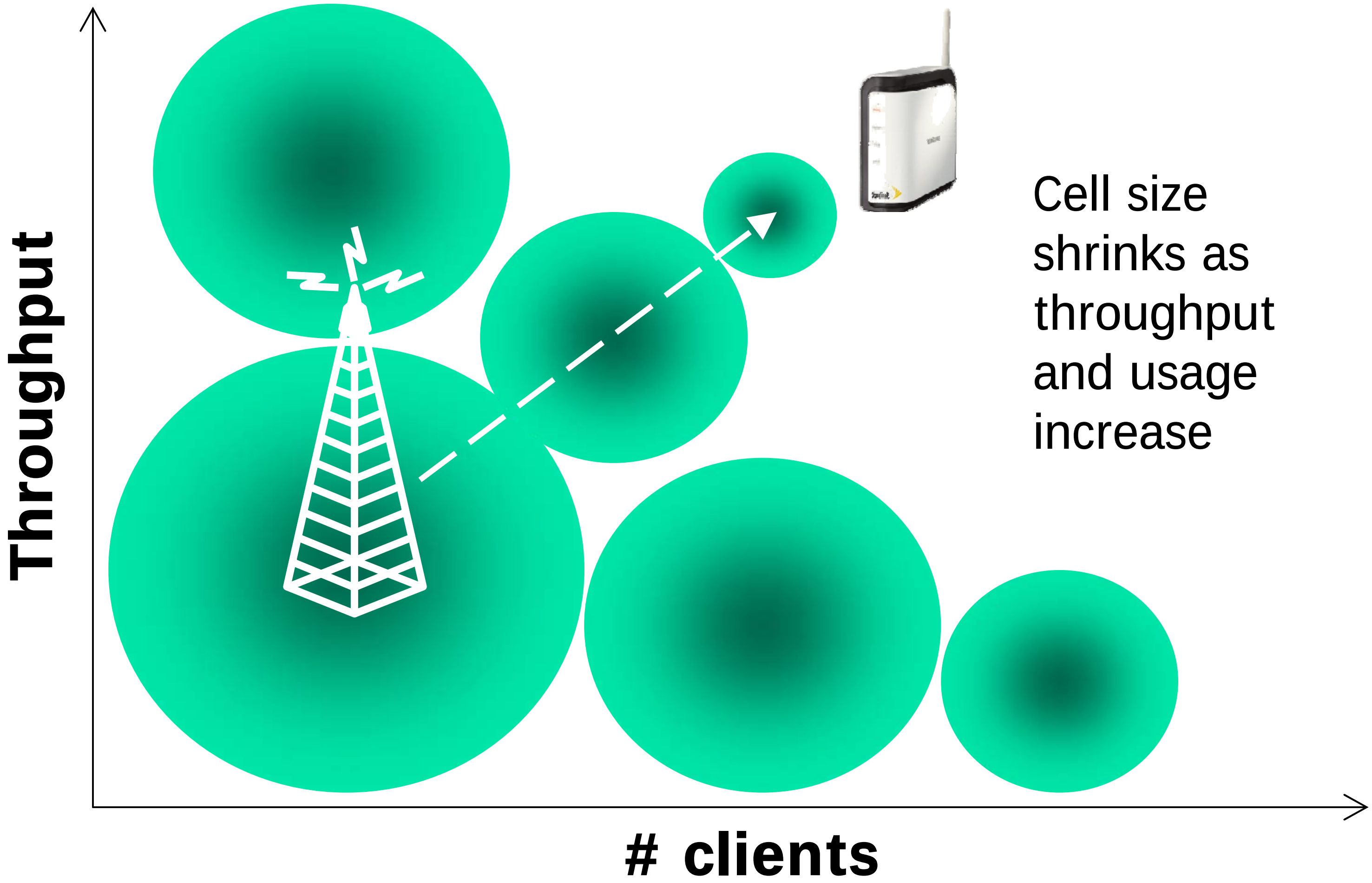
Fanny Mlinarsky

- President of octoScope, consulting company focusing on
  - RF and wireless design
  - Network or device architecture
  - Performance verification
  - Product advocacy
- Founder and Chief Technology Officer, Azimuth Systems, leading wireless test platform for Wi-Fi and WiMAX test (10/01 – 10/06)
- R&D Manager, General Manager, Agilent Technologies for the WireScope handheld network certification and monitoring products (10/98 – 10/01)
- BS/EE, BA/CS Columbia University, graduate EE work at MIT

Azimuth Test Platform

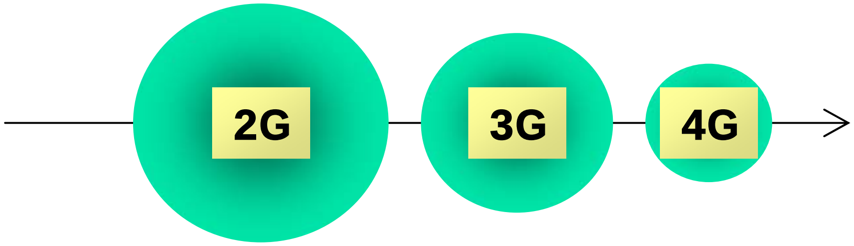
Agilent WireScope

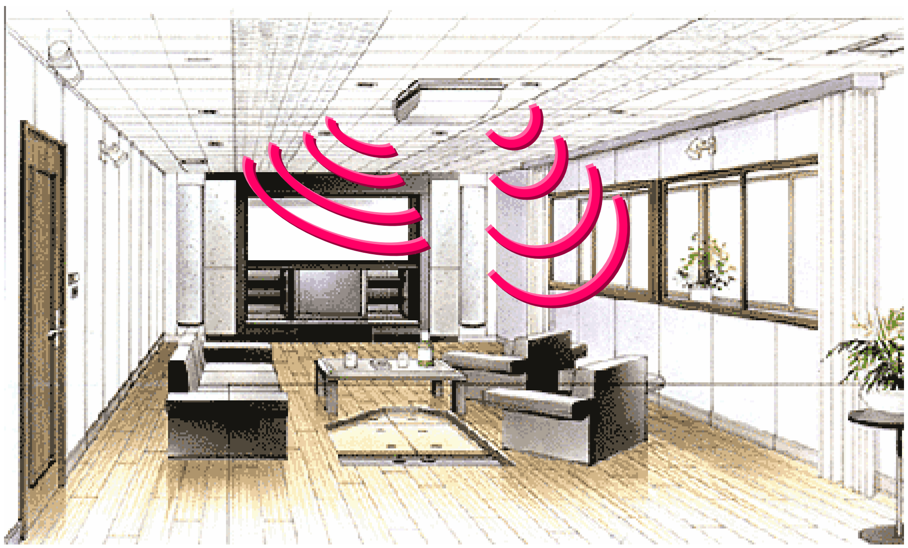
Cell Size and Load Distribution



Cell size shrinks as throughput and usage increase

Progression to Pervasive Connectivity



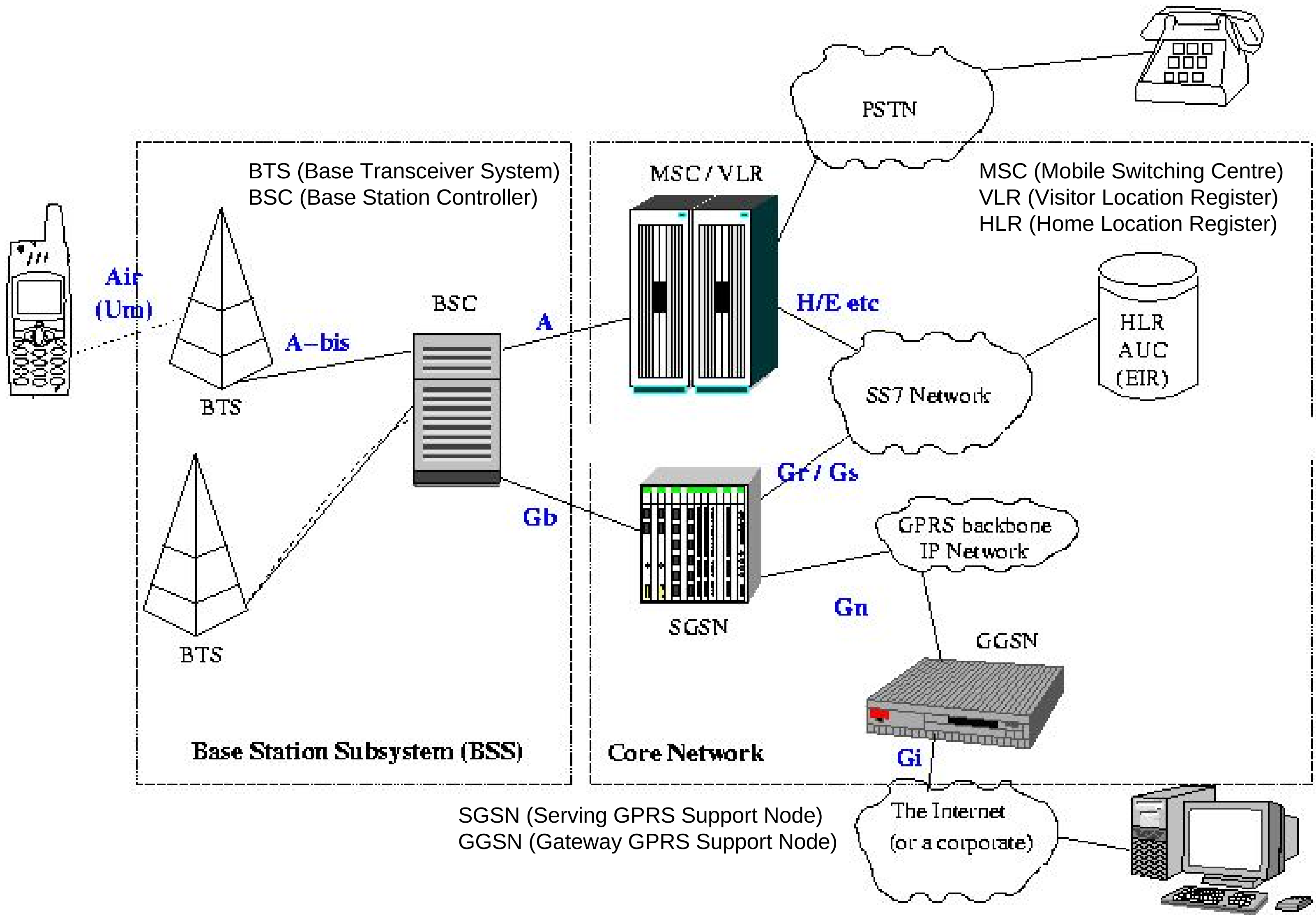


- Cells Shrink
- Wireless coverage expands indoors

3G Coverage Issues

- 3G cells are smaller by virtue of supporting higher data rates
- 3G infrastructure needs to proliferate
- Femtocells are a vehicle for expanding 3G coverage and improving indoor coverage
- Infrastructure must evolve to support millions of small cells

Traditional Infrastructure - GSM



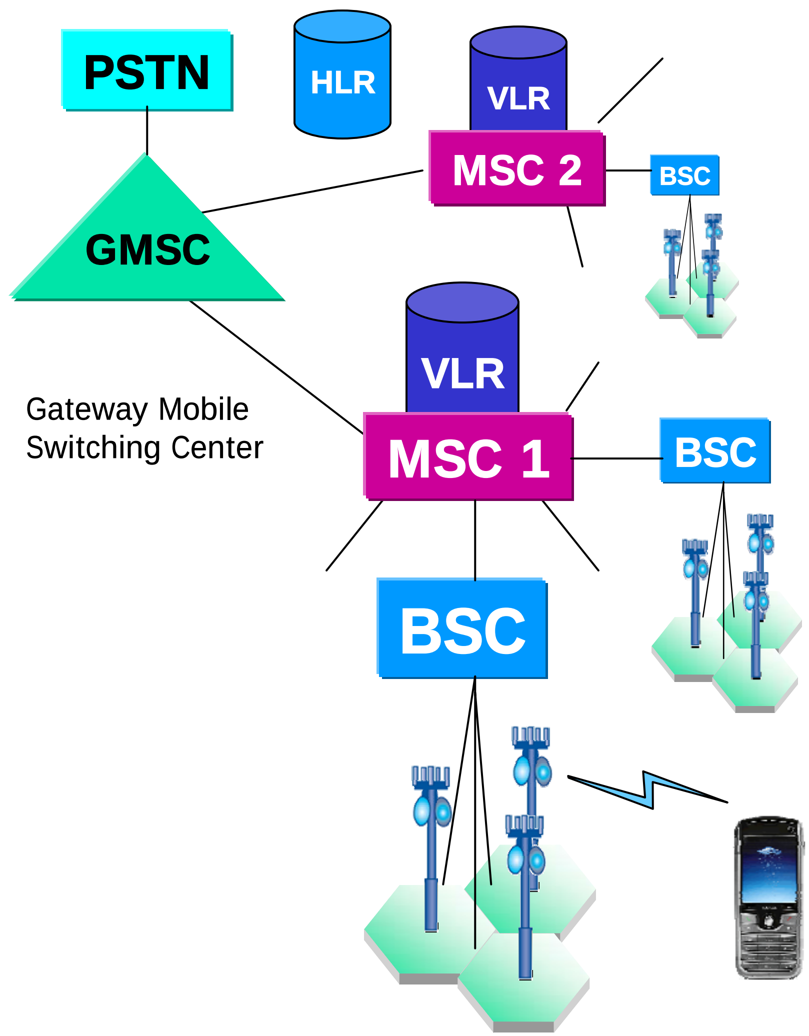
BTS (Base Transceiver System)
BSC (Base Station Controller)

MSC (Mobile Switching Centre)
VLR (Visitor Location Register)
HLR (Home Location Register)

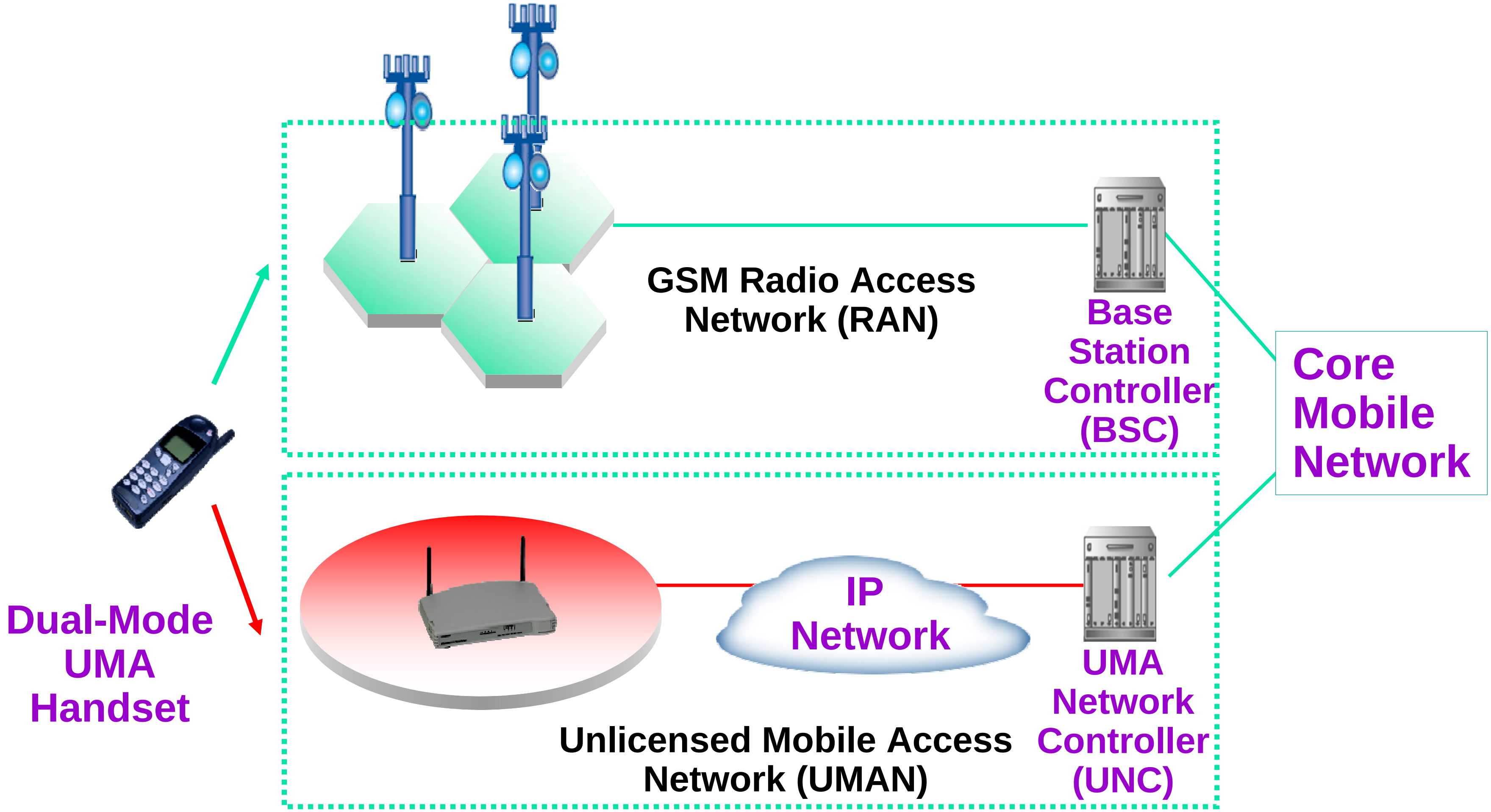
SGSN (Serving GPRS Support Node)
GGSN (Gateway GPRS Support Node)

Traditional Infrastructure

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

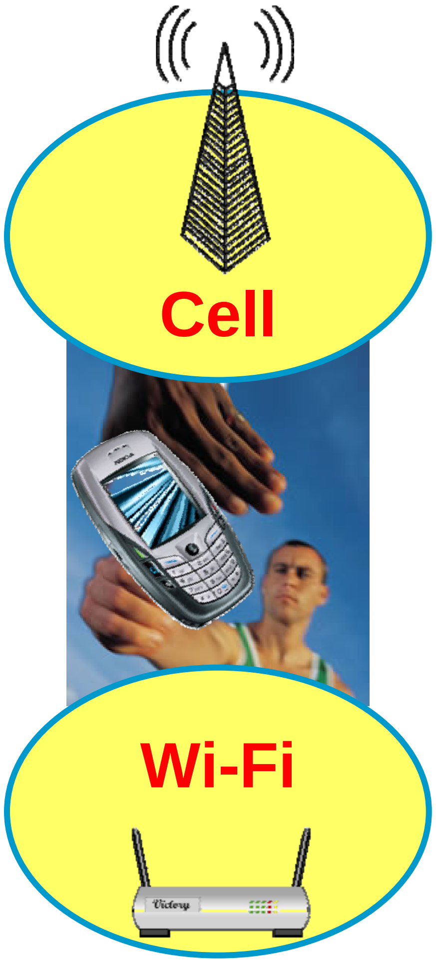


GAN (Generic Access Network) / UMA (Unlicensed Mobile Access)

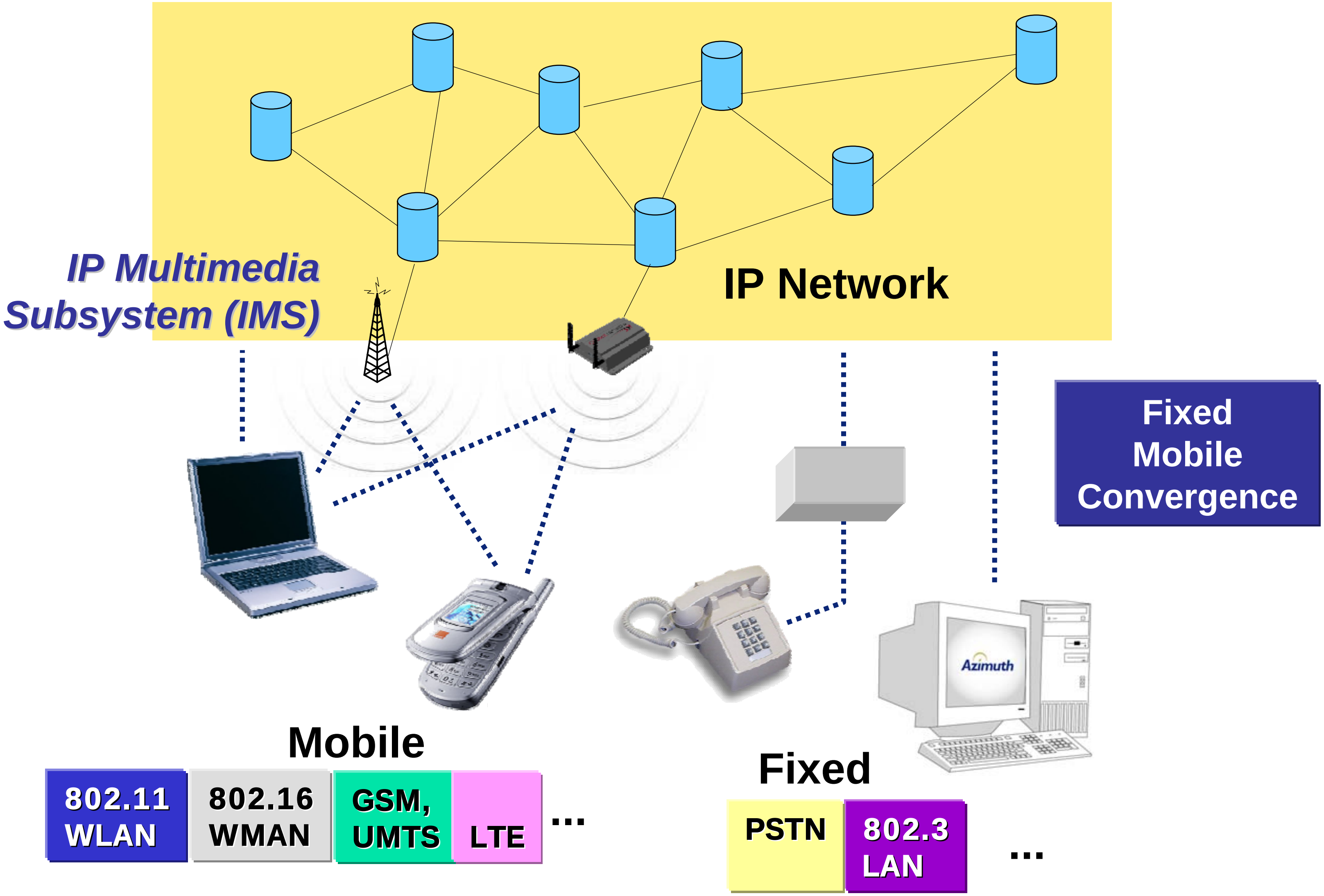


3GPP GAN vs. VCC

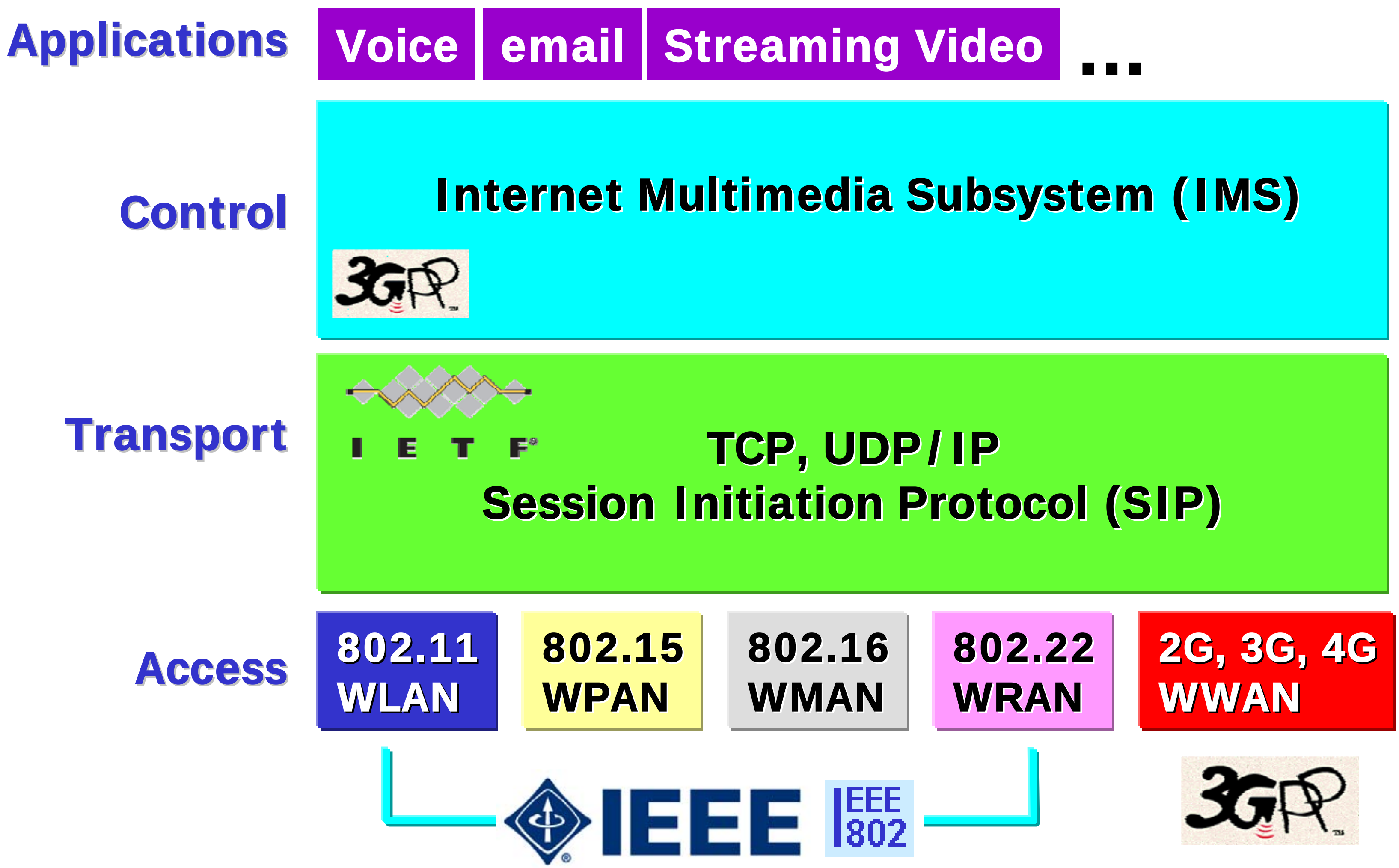
- **GAN (generic access network)** is a simple protocol for GSM networks only
  - Uses GSM call setup
  - Gives GSM users access to high speed data via Wi-Fi hotspots
  - Call continuity across Wi-Fi and GSM domains
  - Does not offer benefits of IMS
- **VCC (voice call continuity)** is an IMS protocol for seamless call handoff between any 3GPP networks
  - SIP (session initiation protocol) based connection management
  - GSM, UMTS, W-CDMA, Wi-Fi, etc.
  - WiMAX not officially accommodated by VCC with LTE (Long Term Evolution) technology emerging instead



IMS Infrastructure for FMC

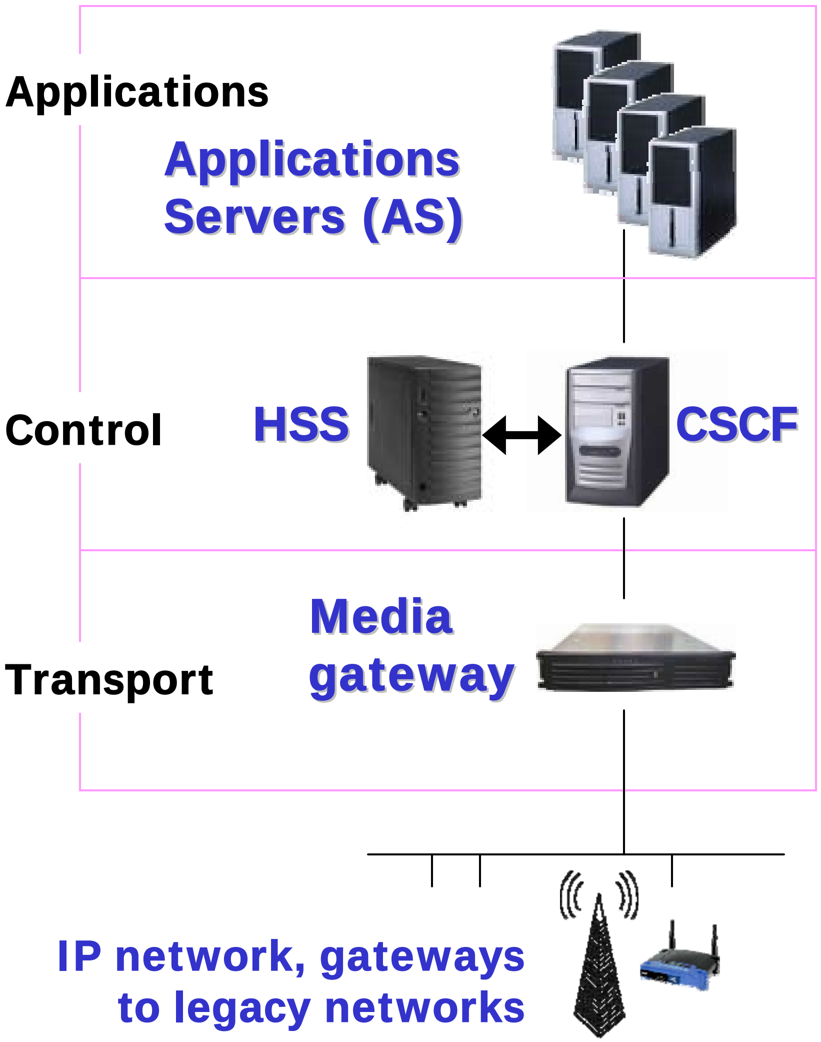


Standards Jigsaw Puzzle

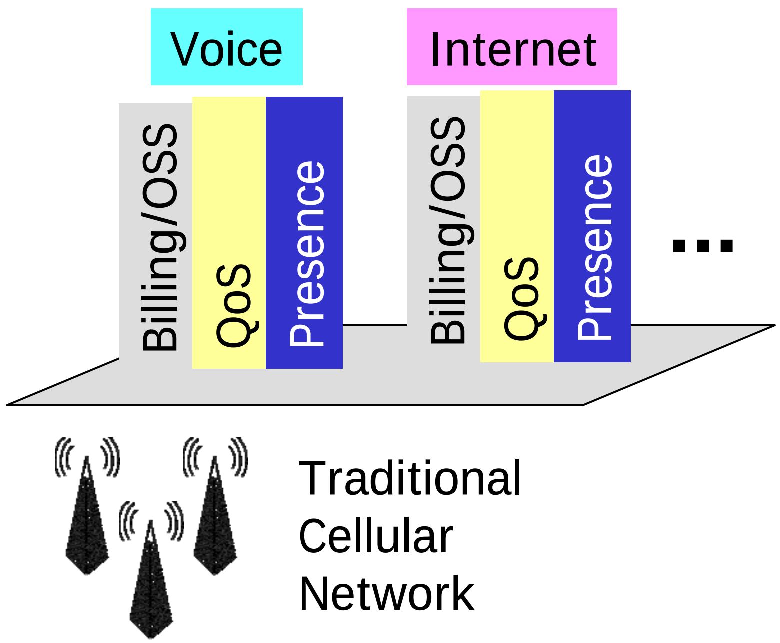


Key Components of the IMS Architecture

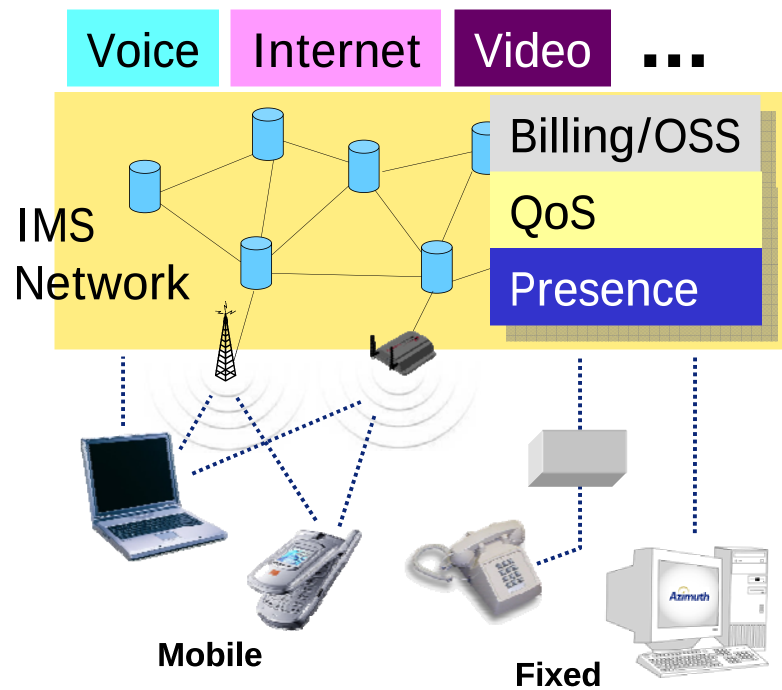
- **CSCF (call session control function)**
  - Heart of IMS architecture
  - Handles multiple real-time IP based services (voice, IMM, streaming video, etc.)
  - Responsible for registering user devices and for ensuring QoS
- **HSS (home subscriber server)**
  - Central repository for customer data
  - 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



IMS vs. Traditional "Stovepipe"



Stovepipe model – replicates functionality



IMS – common layers facilitate adding services

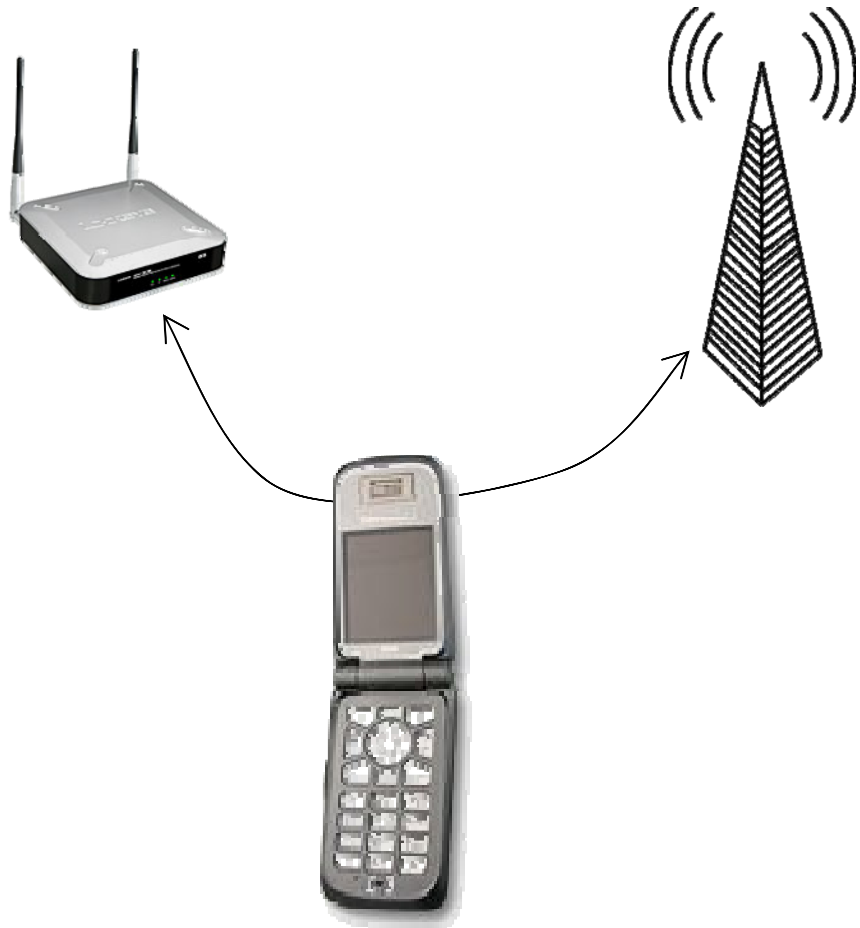
Standards for FMC

- **3GPP- IMS**
  - **GAN/UMA *2G***
  - **VCC *3G/4G***
  - **I-WLAN (no handoff)**
- **IEEE**
  - **802.11n, k, u, v, y, s**
  - **802.16e, g, m**
  - **802.21**

GAN / UMA
GSM-WiFi phones

GAN = generic access network
UMA = unlicensed mobile access
VCC = Voice Call Continuity
I-WLAN = Interworking-WLAN
IMS = internet multimedia subsystem

Multimode Phone vs. Femtocell



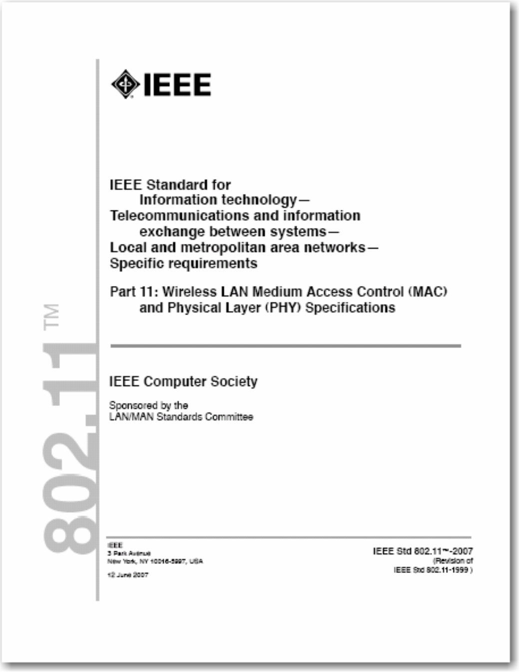
Cell / Wi-Fi Phone must have the capability to roam

Femtocells support traditional simple phones

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

Wireless standards dominate the work of IEEE 802


802.11™

IEEE

IEEE Standard for
Information technology—
Telecommunications and information exchange between systems—
Local and metropolitan area networks—
Specific requirements

Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

12 June 2007

IEEE Std 802.11™-2007
(Revision of
IEEE Std 802.11-1999)

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)

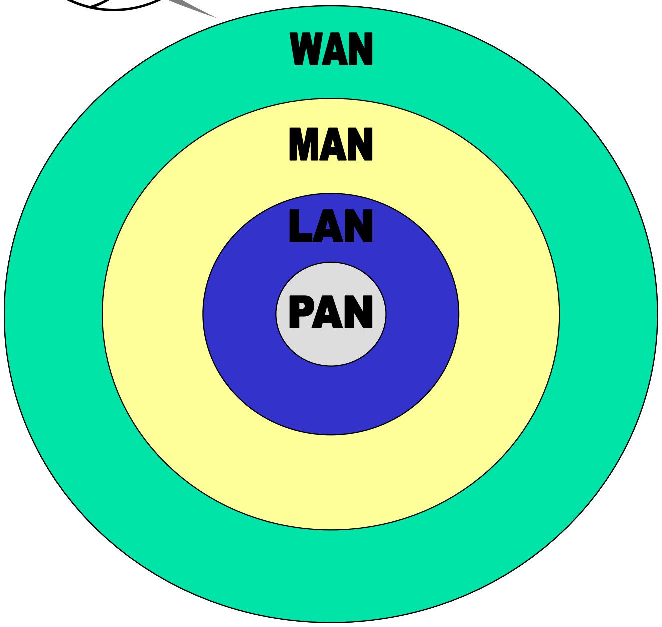
3GPP – WWAN (wireless wide area network, cellular)

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 802.11 VHT SG (very high throughput study group) working to define the nomadic interface

ITU-T and ITU-R

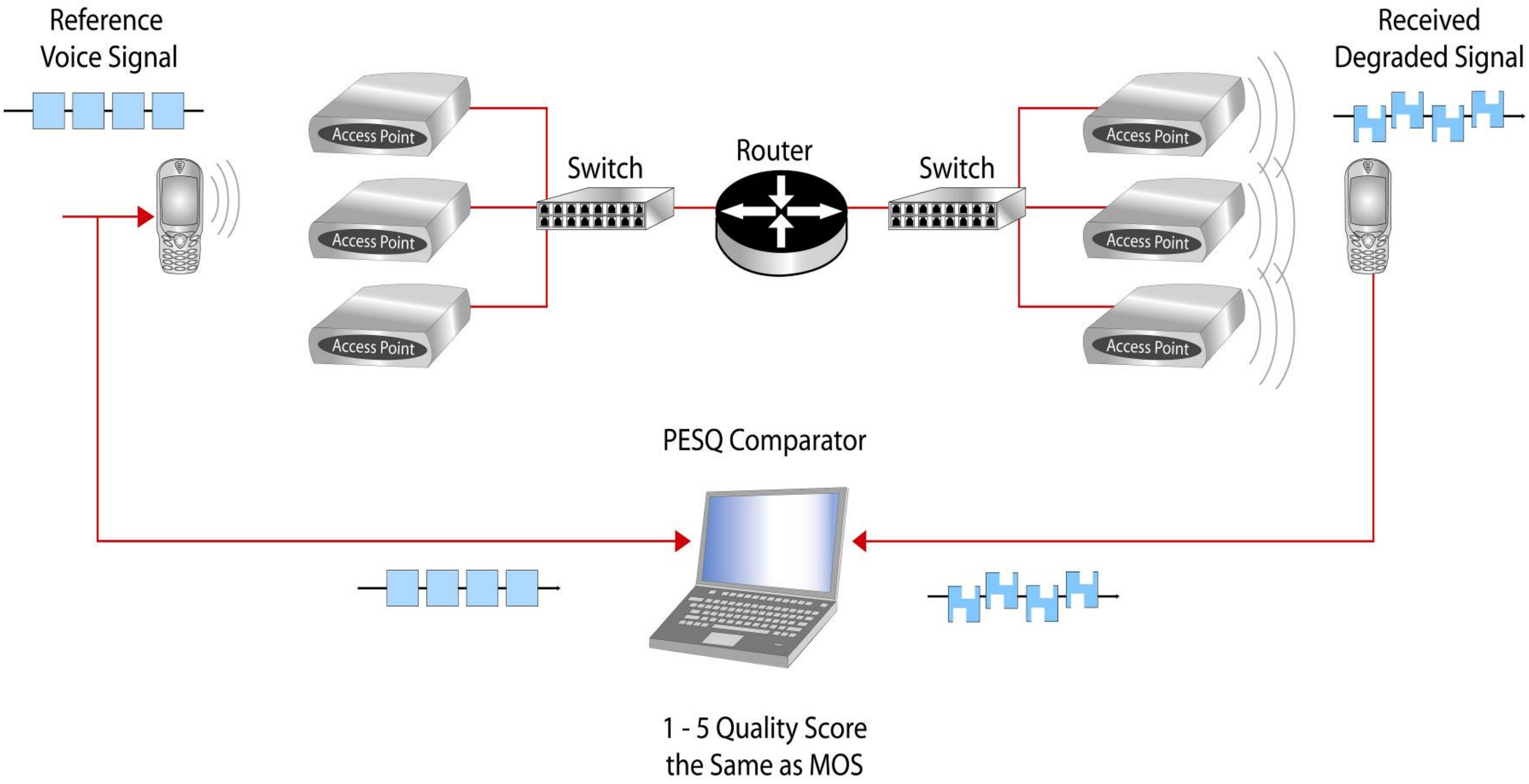
- **ITU-T: Telecommunication Standardization** is responsible for network aspects of IMT-2000, IMT-Advanced, FMC, mobility management, mobile multimedia functions, internetworking, interoperability and enhancements to existing ITU-T Recommendations.
- **ITU-R: Radiocommunications** is responsible for the radio frequency spectrum and radio system aspects of IMT-2000 and IMT-Advanced.



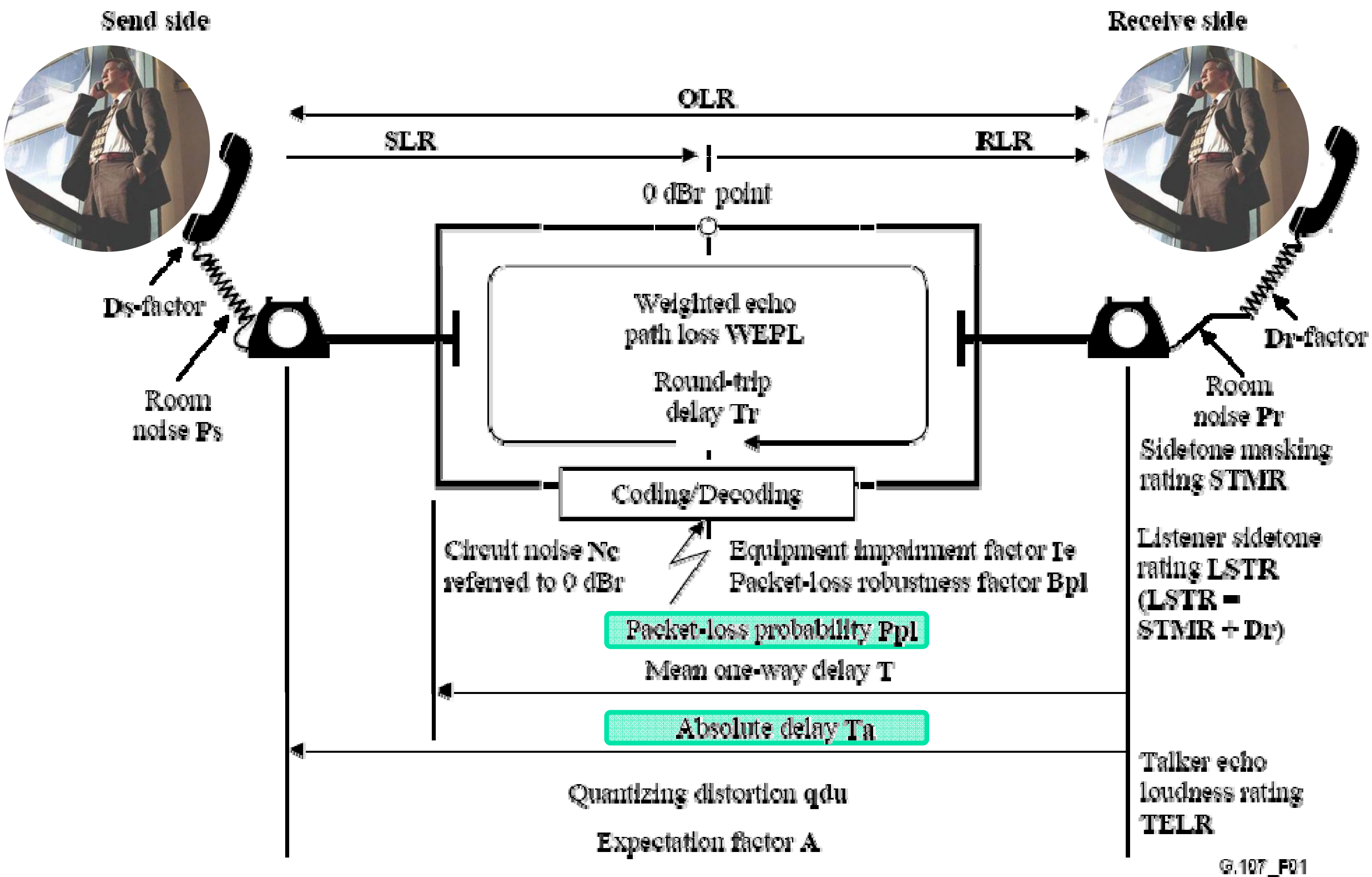
ITU-T Voice Quality Standards

- **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



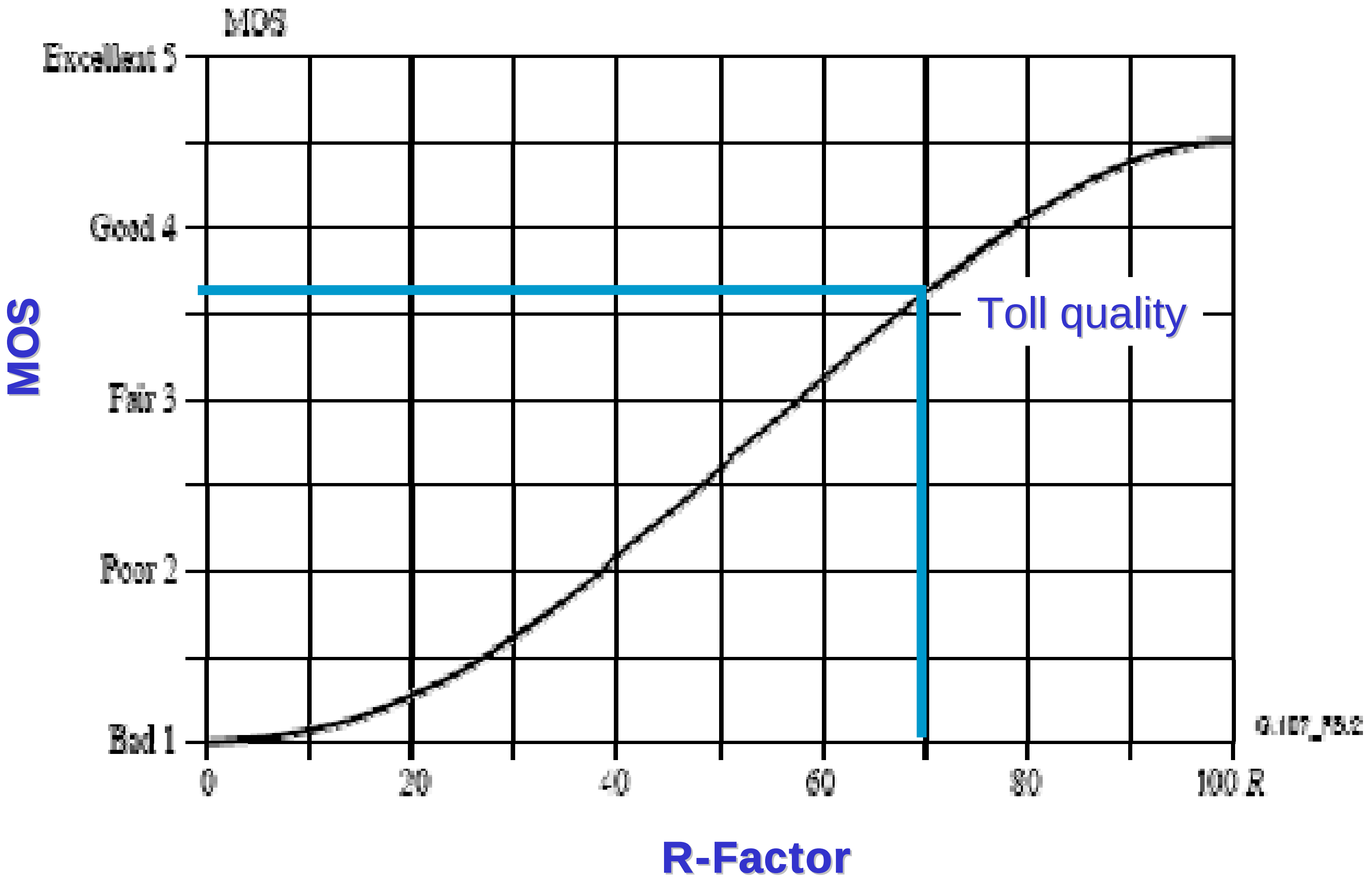
ITU-T E-Model (G.107) for Computing R-Factor



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

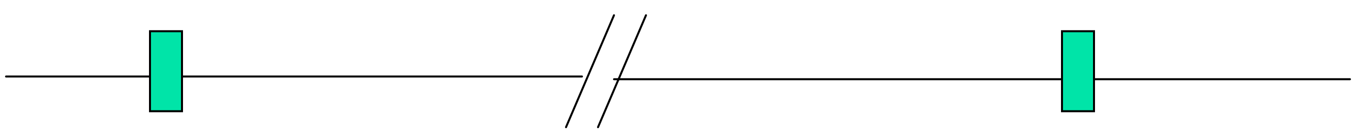
R-Factor to MOS Conversion



Packet Loss Consideration

- 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

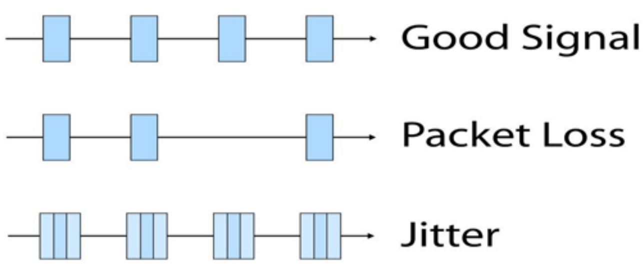
~20-30 millisecond gaps



~100 microsecond packets, depending on CODEC

IEEE 802.11 Specifications Enabling Voice over Wi-Fi

- Minimize bursty packet loss by controlling roaming time
  - 802.11r Fast Roaming
  - 802.11k Radio Resource Measurement (RRM)
  - 802.11v Wireless Network Management
- Manage power consumption
  - 802.11 APSD (automatic power save delivery)
  - 802.11n PSMP (power save multi-poll) protocol
  - 802.11v sleep mode
- Maintain isochronous nature of voice packet streams by controlling delay, jitter and packet loss
  - WFA WMM (wireless multi-media) prioritization protocol, IEEE QSE SG (QoS Extensions Study Group) looking to reconcile IEEE 802.11 with WMM



802.16 and WiMAX Certification

IEEE 802.16d-2004
Fixed
Broadband Wireless

IEEE WirelessMAN 802.16

IEEE 802.16e-2005
Mobile
Broadband Wireless

Mobile WiMAX
System Profile
Release-1

WiMAX FORUM CERTIFIED

- WiMAX Forum Release-1
  - Based on 802.16e-2005
  - 1.25, 5, 7, 8.75, 10 and 20 MHz channels
  - Initial profiles are 5 and 10 MHz
  - Licensed worldwide spectrum allocations include 2.3, 2.5, 3.3 and 3.5 GHz bands
- The IEEE 802.16e-2005 Wireless MAN standard is based on the concept of scalable OFDMA* (S-OFDMA), which provides a range of bands to accommodate available spectrum

* Orthogonal Frequency Division Multiple Access

IEEE 802.16d vs. 802.16e

	802.16d 2004	802.16e 2005
Cell radius	7 km NLOS 30 km LOS	5 km NLOS 30 km LOS
Bit Rate	Up to 10 Mbps / 3.5 MHz	Up to 15 Mbps / 5 MHz
Bandwidth	3.5, 7 MHz	5, 7, 10 MHz
Band	2.5, 3.5, 5.8 GHz	
Signaling	OFDM, 256 subcarriers	SOFDMA, 2048 subcarriers
Mobility	Fixed, nomadic	High mobility 60 km/h

4G: LTE

- LTE (Long Term Evolution) being developed as a 4G technology competing with 802.16
  - 100 Mbps uplink; 50 Mbps downlink
  - 5 km cells; 30 km with some degradation
  - Channels 1.25, 1.6, 2.5, 5, 10, 15, 20 MHz
- MIMO-based; smart antenna
- No products yet
- Proposed 4G migration path for WCDMA/HSDPA networks
- Verizon Wireless uses CDMA EV-DO technology, which is incompatible with HSDPA
- UMB (Ultra Mobile Broadband) is the proposed 4G migration path for CDMA EV-DO

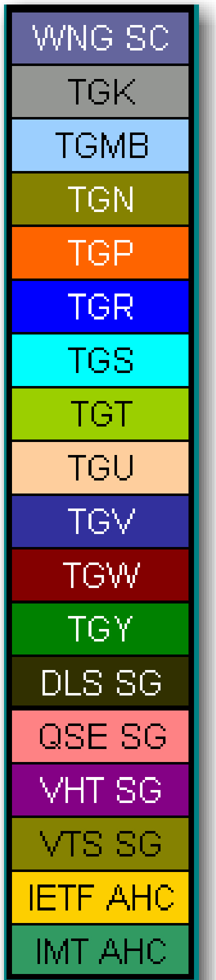
Next Generation Cell Phone

- GSM?
- CDMA?
- CDMA2000?
- W-CDMA?
- UMTS?
- Wi-Fi?
- WiMAX?
- LTE?

Can femtocells get ahead of dual mode Wi-Fi cell phones?

What's the Wi-Fi industry doing to support voice?

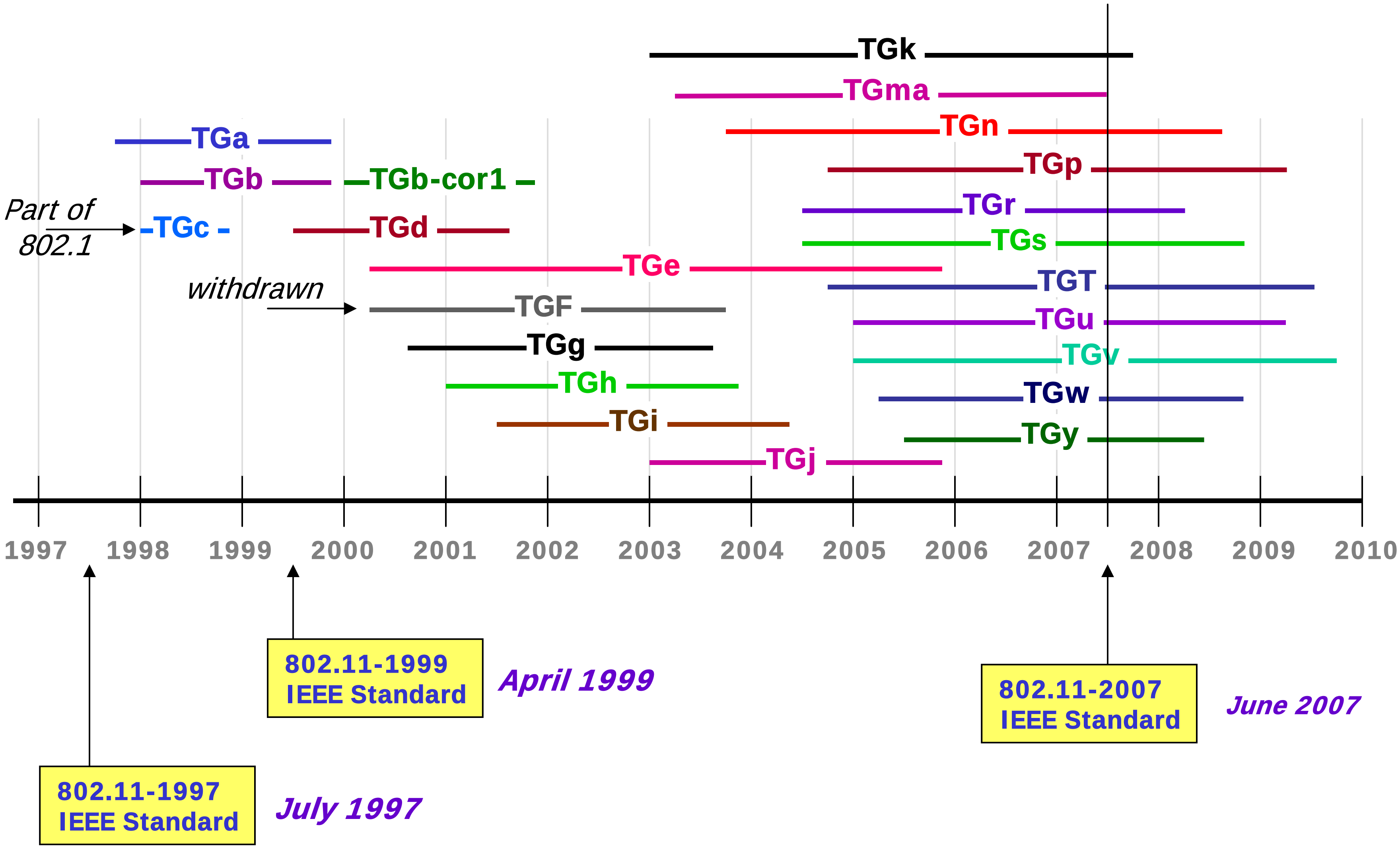
IEEE 802.11 Active Task Groups



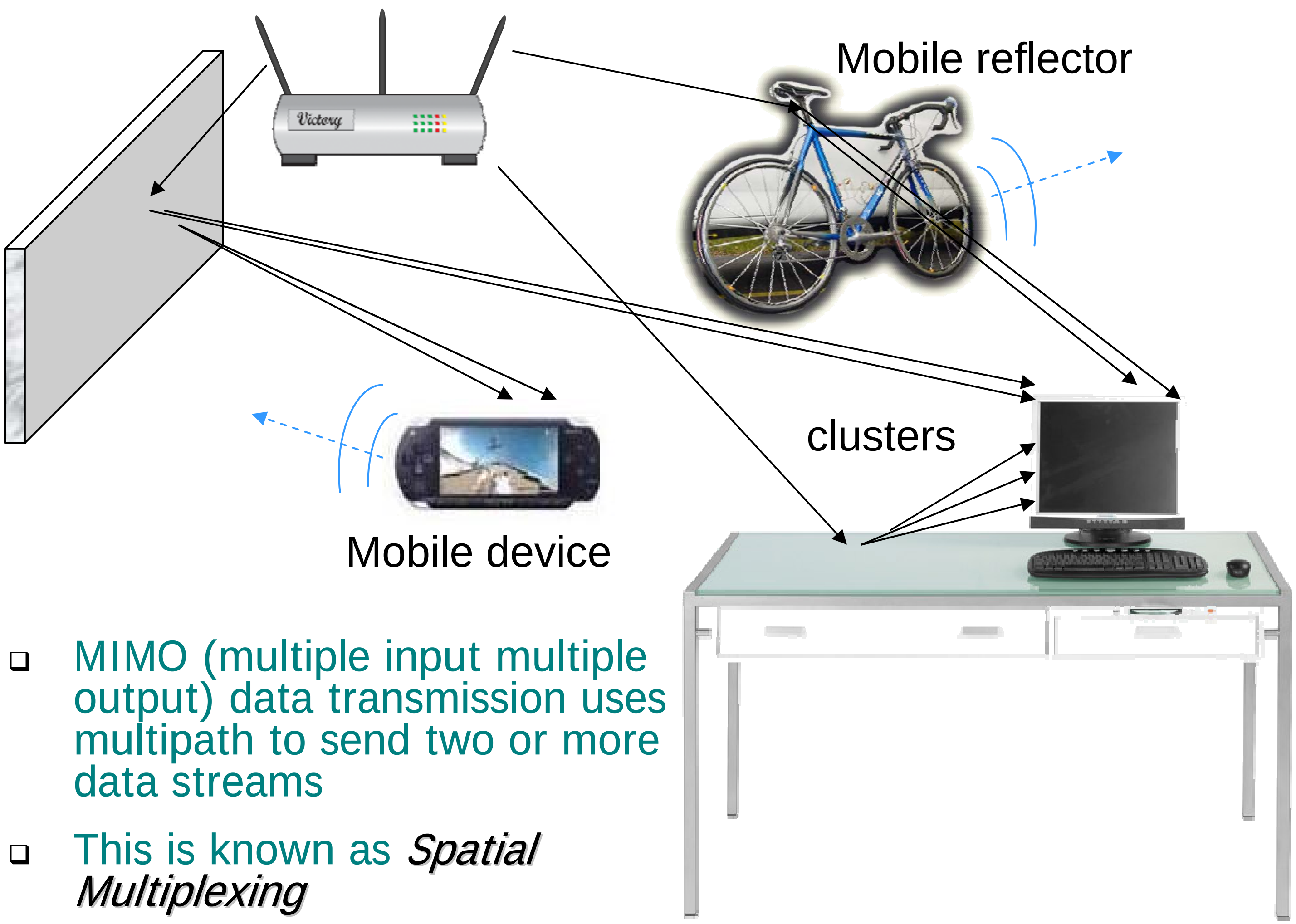
- **WNG SC** – Wireless Next Generation Standing Committee
- **TGk** – Radio Resource Measurements
- **TGn** – High Throughput
- **TGp** – Wireless Access Vehicular Environment (WAVE/DSRC)
- **TGr** – Fast Roaming
- **TGs** – ESS Mesh Networking
- **TGT** – IEEE 802 Performance
- **TGu** – InterWorking with External Networks
- **TGv** – Wireless Network Management
- **TGw** – Protected Management Frames
- **TGy** – 3650-3700 MHz Operation in USA
- **DLS SG** – Direct Link Setup Study Group
- **QSE SG** – QoS Extensions Study Group
- **VHT SG** – 1 Gbps Very High-Throughput Study Group
- **VTS SG** – Video Throughput Study Group
- **IETF AHC** – IETF Ad Hoc
- **IMT AHC** – IMT Ad Hoc

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

IEEE 802.11 Timeline



802.11n Uses Multipath for Spatial Multiplexing to Increase Data Rate



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

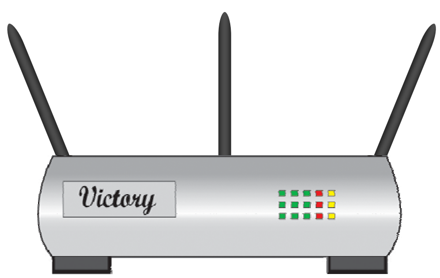
802.11n MIMO Technology

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

Real implementations use up to 2 spatial streams and the following MIMO configurations:

2x2, 2x3, 3x3

Extra transmitters or receivers implement diversity



802.11n Throughput Enhancements

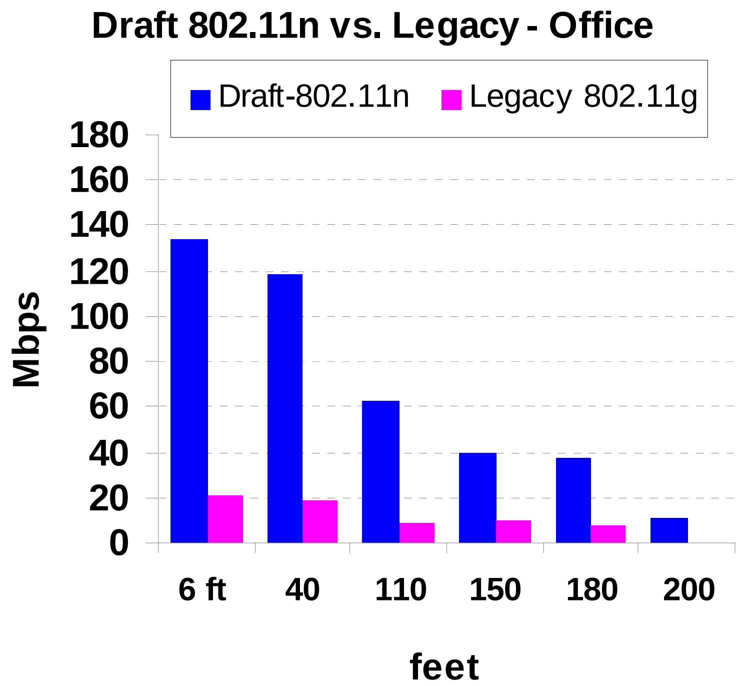
802.11n throughput enhancement	Description	Throughput enhancement over legacy
Spatial multiplexing	With 2 spatial streams throughput can be double that of a single stream.	100%
40 MHz channel width	Doubling the channel width over the legacy 20 MHz channel can double the throughput.	100%
More efficient 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

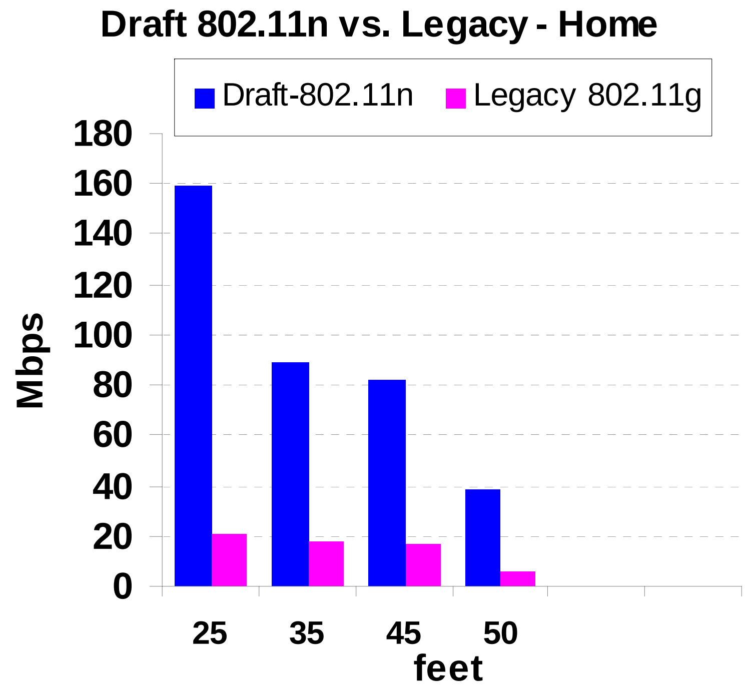
	20 MHz Channel		40 MHz Channel	
	1 stream	2 streams	1 stream	2 streams
	Data Rate, in Mbps			
802.11b 2.4 GHz	1, 2, 5.5, 11			
802.11a 5 GHz	6, 9, 12, 18, 24, 36, 48, 54			
802.11g 2.4 GHz	1, 2, 6, 9, 12, 18, 24, 36, 48, 54			
802.11n GI[1]=800ns 2.4 GHz	6.5, 13, 19.5, 26, 39, 52, 58.5, 65	13, 26, 39, 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.

Draft 802.11n vs. Legacy Throughput Performance

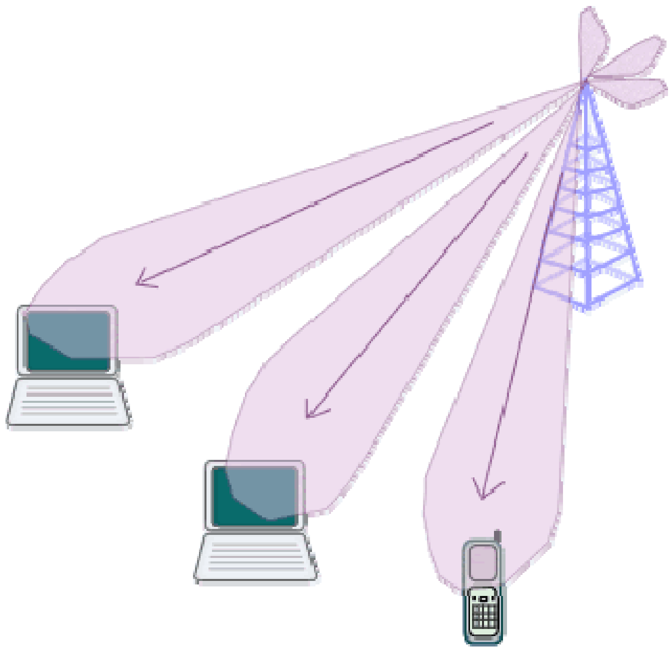


Vendor 1



Vendor 2

- **Spatial Multiplexing**
  - 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
- **Beamforming**
  - Use multiple-antennas to spatially shape the beam to improve coverage and capacity

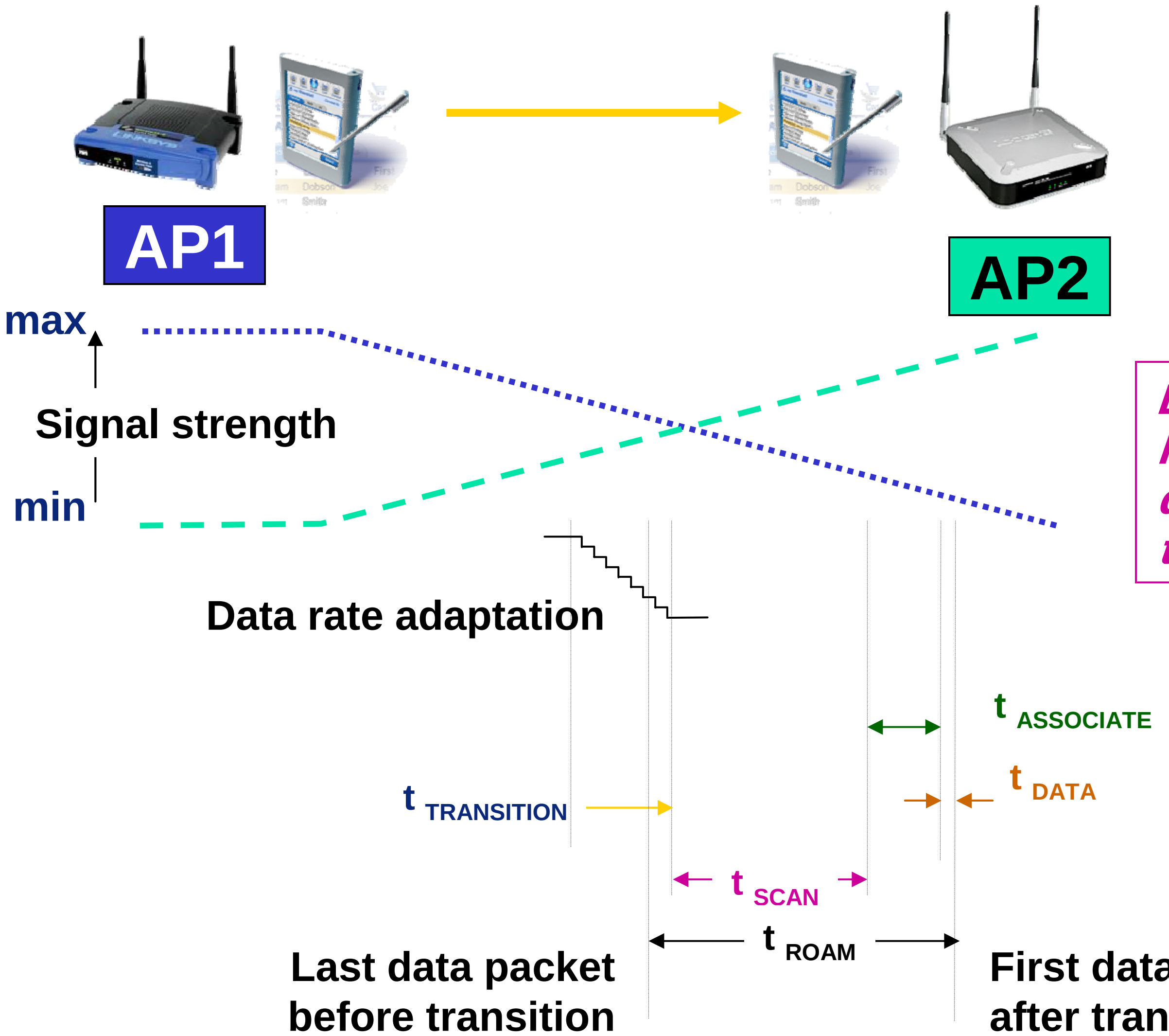


2x2 MIMO spatial multiplexing can double data rate by transmitting two data streams simultaneously

802.11r Fast Transition (Roaming)

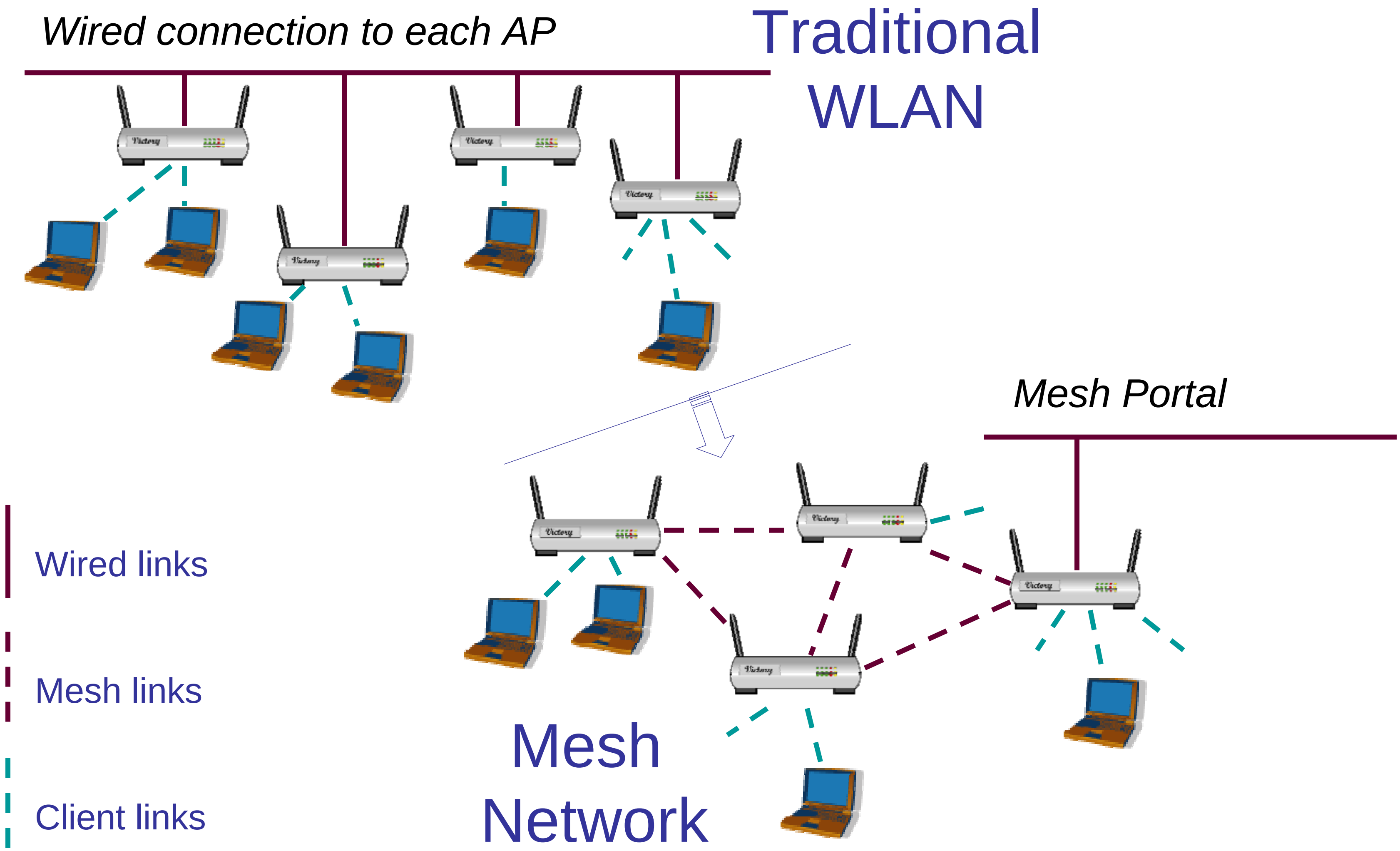
- Needed by voice applications
- Basic methodology involves propagating authentication information for connected stations through the ‘mobility domain’ to eliminate the need for re-authentication upon station transition from one AP to another
- The station preparing the roam can setup the target AP to minimize the actual transition time
- Roaming from one mobility domain to another requires authentication and is not considered fast transition

Traditional Roaming in 802.11



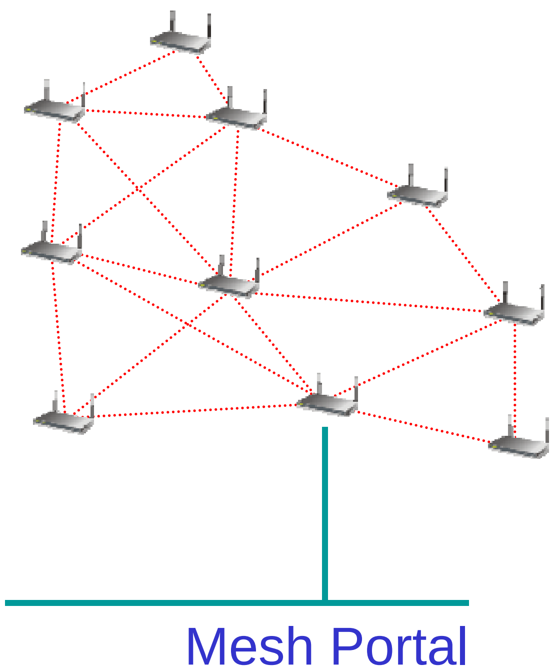
Bursty frame loss is likely during a transition

802.11s Wi-Fi Mesh



IEEE 802.11s Mesh Standard

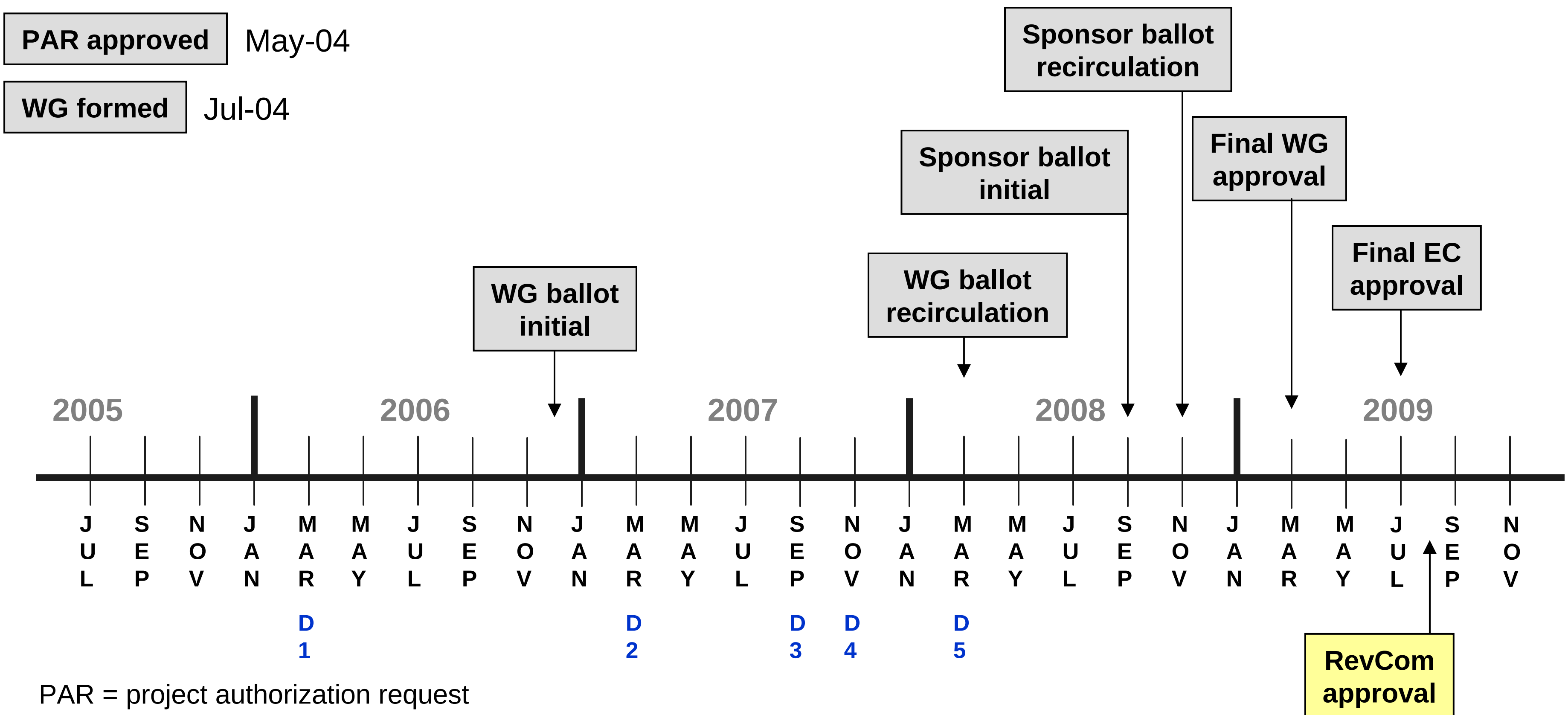
- Wireless Distribution System with automatic topology learning and wireless path configuration
- Self-forming, self-healing, dynamic routing
- ~32 nodes to make routing algorithms computationally manageable
- Extension of 802.11i security and 802.11e QoS protocol to operate in a distributed rather than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



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 Timeline



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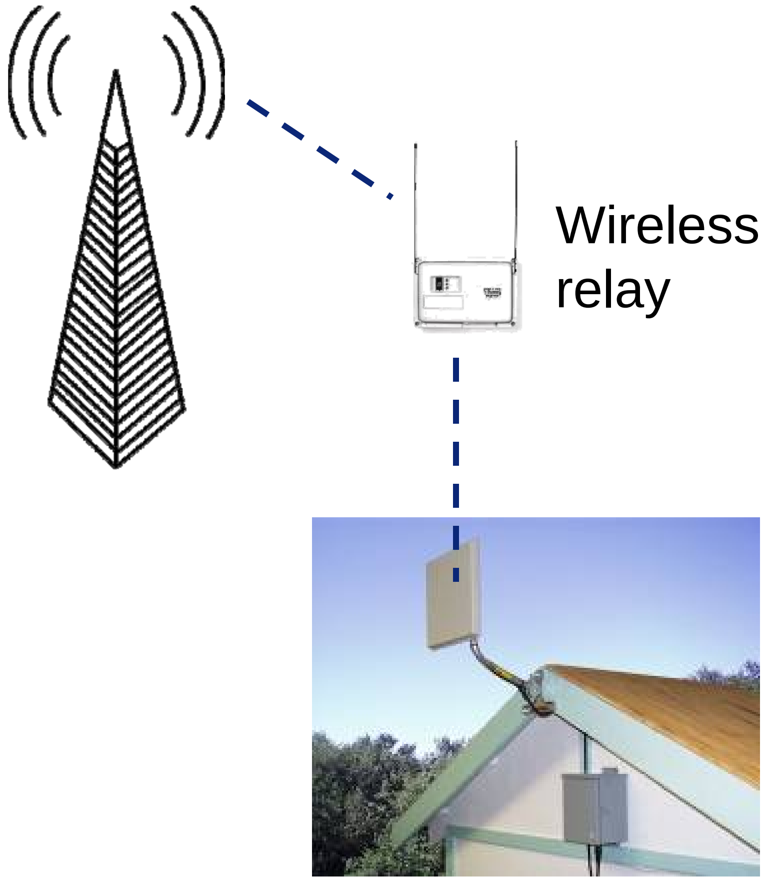
TGs timeline

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
- 802.16 links being planed in ad-hoc mesh networks

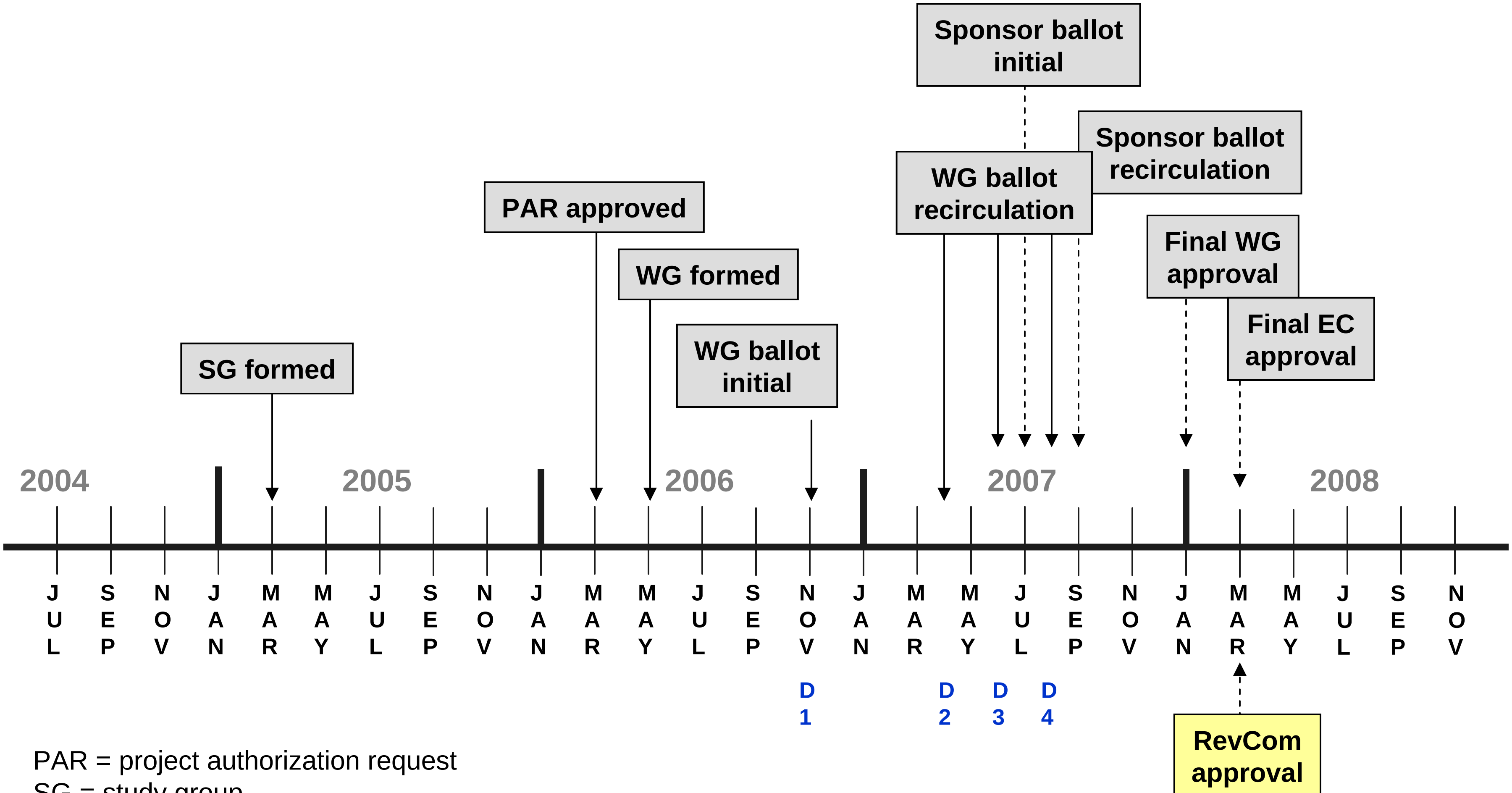


Lightly Regulated Band for 802.11, 802.16

- 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**

802.11y Timeline



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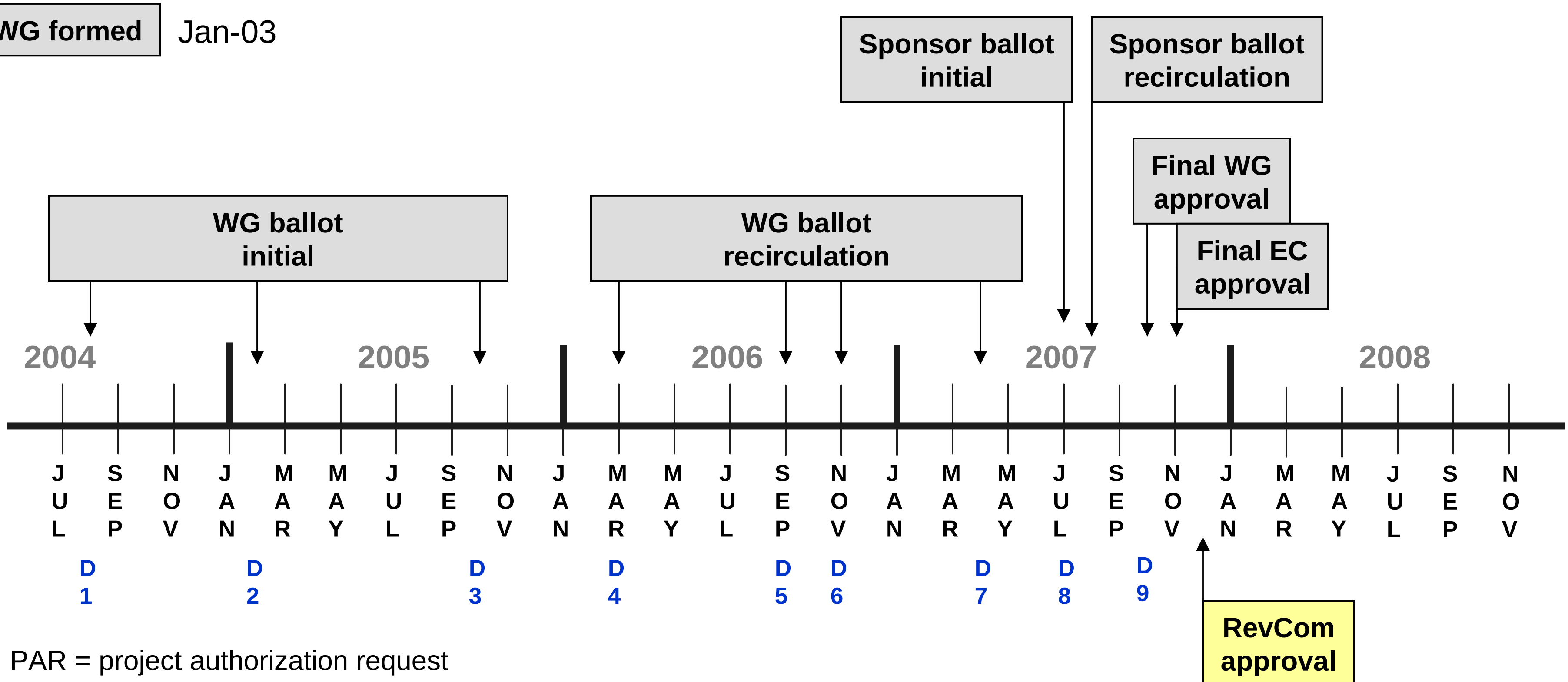
TGy timeline

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

802.11k Timeline

SG formed	Sep-02
PAR approved	Dec-02, Sep-06
WG formed	Jan-03



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TGk timeline

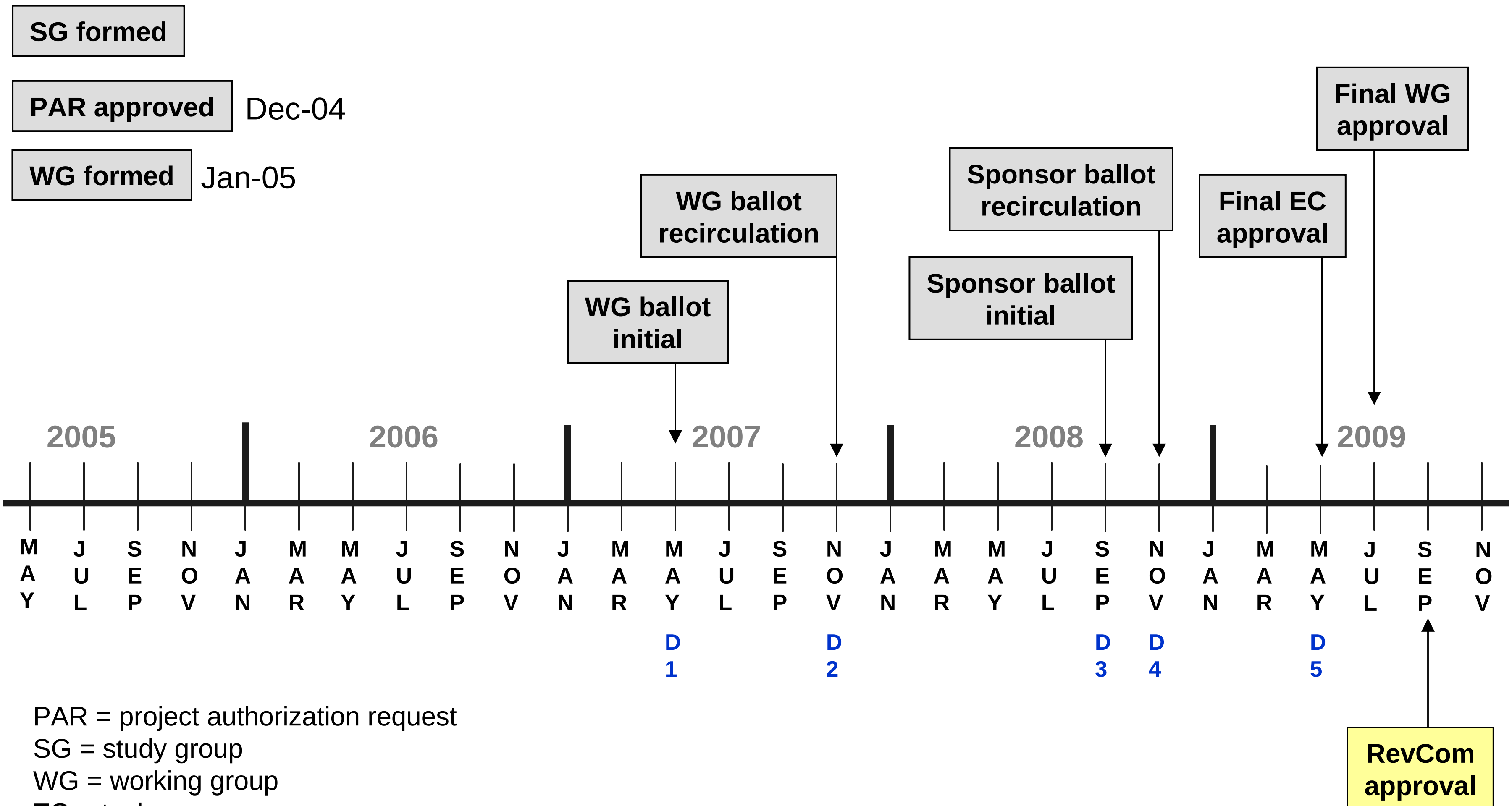
802.11v Wireless Network Management

- 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.
- Sleep mode is also part of 802.11n (PSMP) and 802.11u. TGs is also dealing with power conservation and sleep mode protocol, working to make this protocol distributed whereby a mesh point registers its sleep mode with the neighbors.
- TGv may extend the sleep mode protocol to include the ability of maintaining location awareness while in sleep mode.

801.11v Timeline



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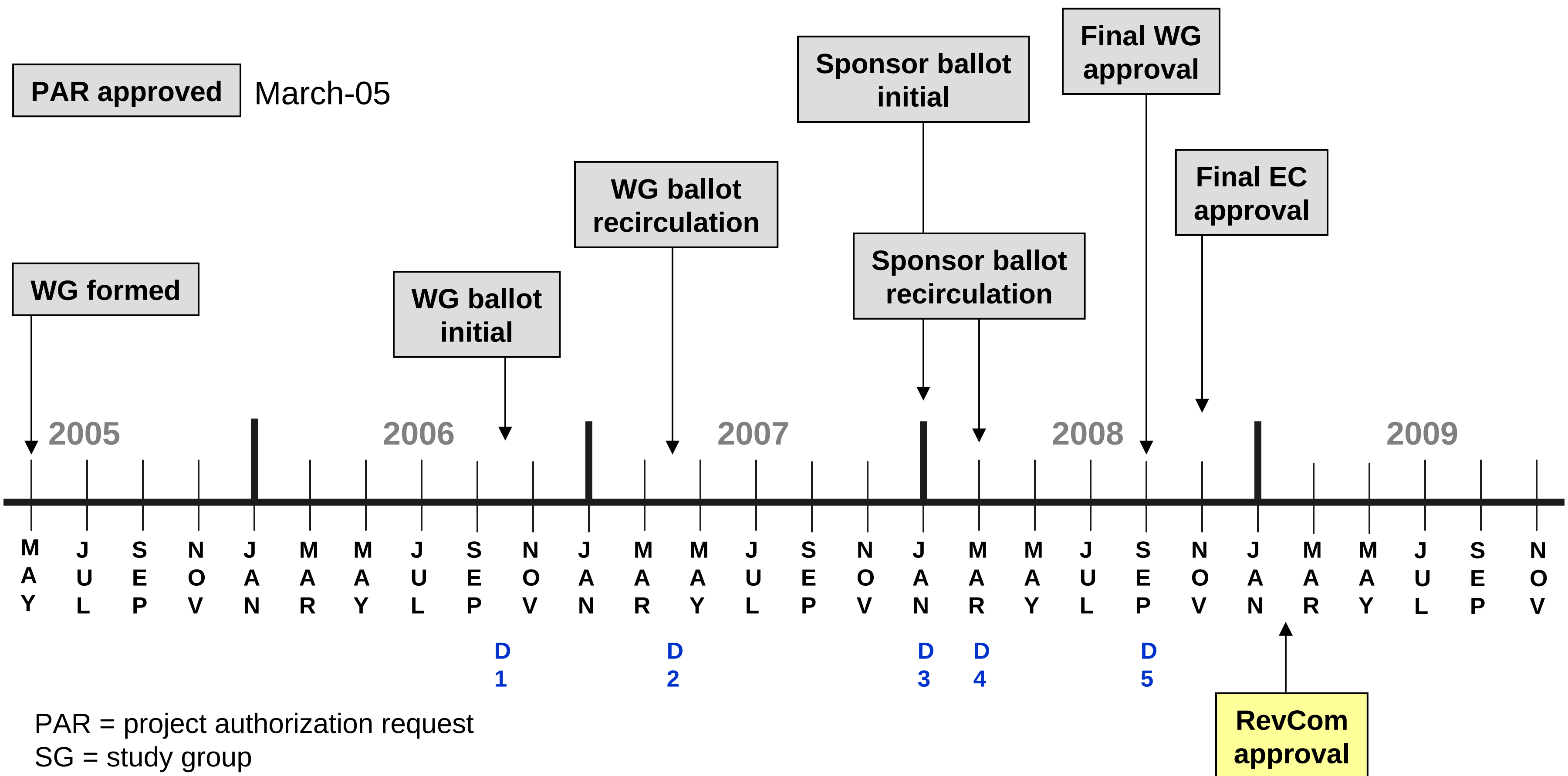
TGv timeline

802.11w Protected Management Frames

- 802.11w protects against the forgery of management frames
- 802.11k and now 802.11v are both adding new mgt frames that can exchange sensitive information
  - Information about network topology, location and loading
  - Configuration commands to optimize the network
- These frames can be easily forged by the attackers to disrupt the network
  - For example, an attacker can forge AP loading messages redirecting client associations or locking users out of the network
- TGw provides protection for the management frames after association and after keys have been set up through 802.11i or 802.11r mechanisms.

802.11w Timeline



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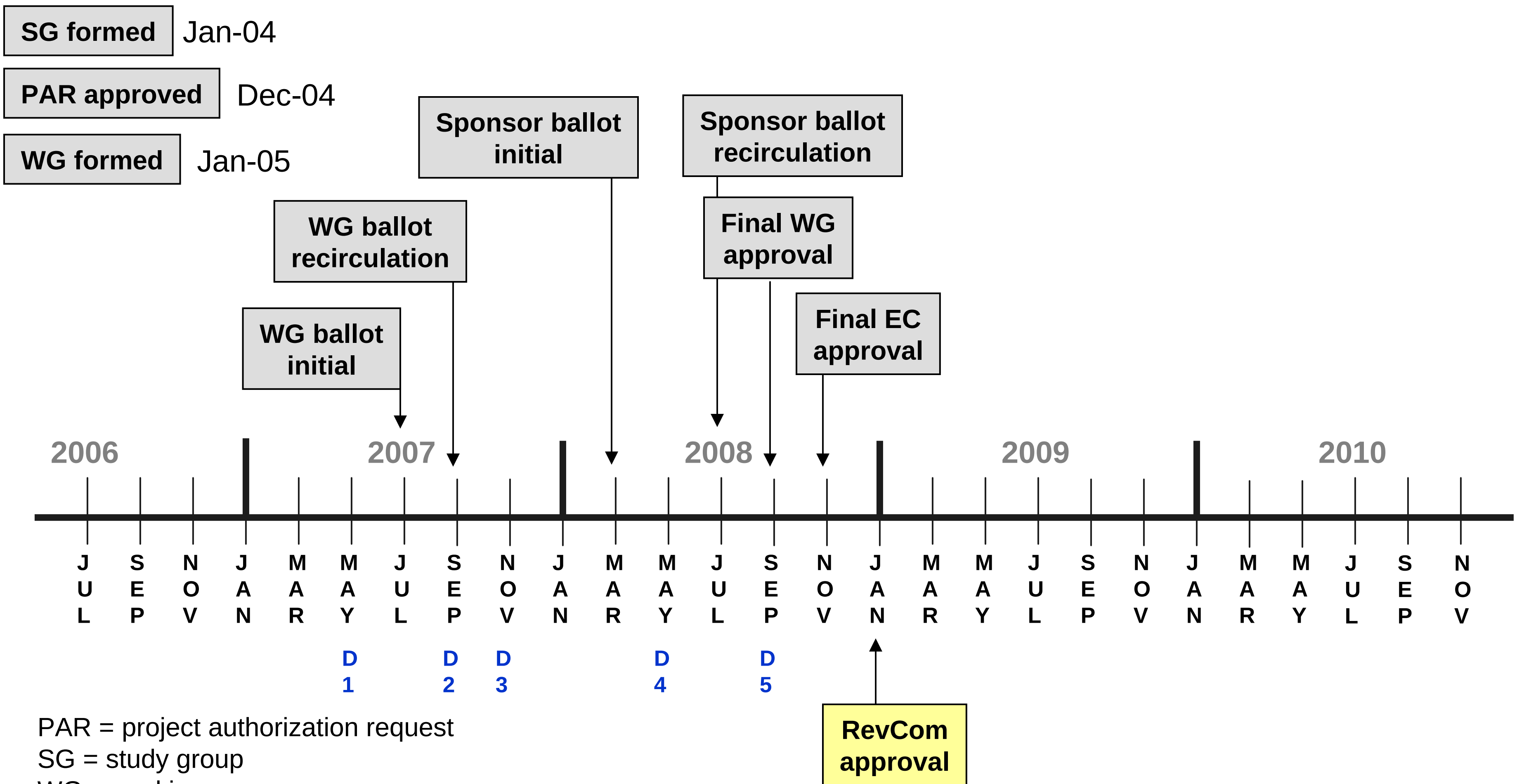
TGw timeline

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.
- TGu specification deals with
  - 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
  - Type of QoS that's available and whether the network is suitable for services like VoIP or video
- 802.11u makes 802.11 networks more like cellular networks where such information is provided by the infrastructure

802.11u Timeline



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TGr timeline

Missing Link between IEEE 802 and 3GPP IMS?

- Liaison exists between 802.21, 802.11u, 802.16g and 3GPP
- 802.21 – MIH (media independent handover)
  - GAS (generic advertising service) gives stations information about 802.11 and 802.16 networks – SSP, SSID, radio, available services, etc.
  - 802.11u and 802.16g are defining protocols to let a station to access the 802.21 information server
- 802.11u, 802.16g – Interworking
  - Cellular-like network discovery with information on service providers, QoS, emergency call support (e911), roaming, location and availability
  - SSP (service subscription provider) – carrier or operator

working to make 802 wireless networks more like cellular

Summary

- Voice is migrating to IP
- Femtocells are competing with dual mode Wi-Fi cell phones
- We have looked at the emerging Wi-Fi technology and standards aimed at making Wi-Fi voice grade and carrier grade
- Let's move on into the realm of Femtos!

Agenda

- 9:00 – 11:00 am **FMC and Femtocell history, architecture and standards**
  - Fanny Mlinarsky, President, octoScope
  - Asa Kalavade, Founder and CTO, Tatara Systems
- 11:00 – 11:15 am **Break**
- 11:15 – 12:00 noon **Femtocell regulatory issues**
  - Barlow Keener, Keener Law Group
- 12:00 – 1:00 pm **Lunch**
- 1:00 – 3:00 pm **Focus on the physical layer**
  - Vicki Griffiths, Product Manager, Cellular Applications, picoChip Designs
  - David Donovan, Analog Devices
  - Tim Counihan, Director of Product Marketing, BitWave Semiconductor
- 3:00 – 3:15 pm **Break**
- 3:15 – 5:00 pm **The Bridge from FMC to FMS**
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