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
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

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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)

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ITU International Mobile Telecommunications

**IMT-2000**
- Global standard for third generation (3G) wireless communications
- Provides a framework for worldwide wireless access by linking the diverse systems of terrestrial and satellite based networks.
- Data rate limit is approximately 30 Mbps
- Detailed specifications contributed by 3GPP, 3GPP2, ETSI and others

**IMT-Advanced**
- New generation framework for mobile communication systems beyond IMT-2000 with deployment around 2010 to 2015
- Data rates to reach around 100 Mbps for high mobility and 1 Gbps for nomadic networks (i.e. WLANs)
- IEEE 802.16m working to define the high mobility interface
- IEEE 802.11ac and 802.11ad VHT (very high throughput) working to define the nomadic interface

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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)

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GSM, CDMA, UMTS...

3GPP

Bluetooth

60 GHz

UWB

WAN

MAN

LAN

PAN

Personal

802.15.3

Bluetooth

60 GHz

UWB

Wide

Local

802.11

Wi-Fi

Regional

TVWS

802.22

Metro

802.16 WiMAX

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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](http://grouper.ieee.org/groups/802/11)

[www.octoscope.com](http://www.octoscope.com)
Draft 802.11n vs. Legacy Throughput Performance
## 802.11n Throughput Enhancements

<table>
<thead>
<tr>
<th>802.11n throughput enhancement</th>
<th>Description</th>
<th>Throughput enhancement over legacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial multiplexing</td>
<td>With 2 spatial streams throughput can be double that of a single stream.</td>
<td>100%</td>
</tr>
<tr>
<td>40 MHz channel width</td>
<td>Doubling the channel width over the legacy 20 MHz channel can double the throughput.</td>
<td>100%</td>
</tr>
<tr>
<td>More efficient OFDM</td>
<td>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</td>
<td>20%</td>
</tr>
<tr>
<td>Shorter GI</td>
<td>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%.</td>
<td>10%</td>
</tr>
<tr>
<td>Frame aggregation and Block ACK</td>
<td>64k bytes A-MPDU; 8k bytes A-MSDU</td>
<td>Up to 100%</td>
</tr>
</tbody>
</table>
## IEEE 802.11a, b, g, n

<table>
<thead>
<tr>
<th></th>
<th>20 MHz Channel</th>
<th>40 MHz Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 stream</td>
<td>2 streams</td>
</tr>
<tr>
<td><strong>Data Rate, in Mbps</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>802.11b</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 GHz</td>
<td>1, 2, 5.5, 11</td>
<td></td>
</tr>
<tr>
<td><strong>802.11a</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 GHz</td>
<td>6, 9, 12, 18, 24, 36, 48, 54</td>
<td></td>
</tr>
<tr>
<td><strong>802.11g</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 GHz</td>
<td>1, 2, 6, 9, 12, 18, 24, 36, 48, 54</td>
<td></td>
</tr>
<tr>
<td><strong>802.11n</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI=800ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 GHz</td>
<td>6.5, 13, 19.5, 26, 39, 52, 58.5, 65</td>
<td>13, 26, 39, 52, 78, 104, 117, 130</td>
</tr>
<tr>
<td><strong>802.11n</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI=800ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>802.11n</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GI=400ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 and 5 GHz</td>
<td>7.2, 14.4, 21.7, 28.9, 43.3, 57.8, 65, 72.2</td>
<td>14.4, 28.9, 43.3, 57.8, 86.7, 115.6, 130, 144.4</td>
</tr>
</tbody>
</table>

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[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

Data is organized into spatial streams that are transmitted simultaneously - This is known as *Spatial Multiplexing*

**SI SO**: 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 \(N \times M\) paths

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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

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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

Base Station (BS)

- **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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Avg 1st Wall Distance (m)</td>
<td>5</td>
</tr>
<tr>
<td>RMS Delay Spread (ns)</td>
<td>0</td>
</tr>
<tr>
<td>Maximum Delay (ns)</td>
<td>0</td>
</tr>
<tr>
<td>Number of Taps</td>
<td>1</td>
</tr>
<tr>
<td>Number of Clusters</td>
<td>N/A</td>
</tr>
</tbody>
</table>

- 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

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

<table>
<thead>
<tr>
<th>Channel Model</th>
<th>Speed</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITU Pedestrian B</td>
<td>3 km/hr</td>
<td>60%</td>
</tr>
<tr>
<td>ITU Vehicular A</td>
<td>30 km/hr</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>120 km/hr</td>
<td>10%</td>
</tr>
</tbody>
</table>

BWA = Broadband Wireless Access

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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

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IEEE 802.11 Timeline

Part of 802.1

- TGc -
withdrawn

TGa

TGb

TGb-cor1

TGc

TGd

TGe

TGf

TGg

TGh

TGi

TGj

TGk

TGma

TGn

TGr

TGp

TGs

TGT

TGv

TGw

TGy


802.11-1999 IEEE Standard April 1999

802.11-1997 IEEE Standard July 1997

802.11-2007 IEEE Standard June 2007

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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.

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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

Wired connection to each AP

Traditional WLAN
  Wired links
  Mesh links
  Client links

Mesh Portal

Mesh

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

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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

MP (Mesh Point)

Mesh Portal

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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](http://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

<table>
<thead>
<tr>
<th>WiMAX Forum™ Mobile System Profile</th>
<th>Release 1.0 Approved Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Revision 1.6.1: 2008-04-01)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Status</th>
<th>Release</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>Release 1.0</td>
<td>802.16e/TDD</td>
</tr>
<tr>
<td>Under development</td>
<td>Release 1.5</td>
<td>802.16e/TDD and FDD</td>
</tr>
<tr>
<td>Future</td>
<td>Release 2.0</td>
<td>802.16m (IMT Advanced)</td>
</tr>
</tbody>
</table>

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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

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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

~20-30 millisecond gaps

~100 microsecond packets, depending on CODEC
## Video Requirements

<table>
<thead>
<tr>
<th>Format</th>
<th>Average throughput required for high quality video</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>480i60</td>
</tr>
<tr>
<td>Broadcast Cable TV</td>
<td>MPEG-2</td>
</tr>
<tr>
<td>Windows Media Video</td>
<td>MPEG-4 Part 2</td>
</tr>
<tr>
<td>DivX</td>
<td></td>
</tr>
<tr>
<td>XviD</td>
<td></td>
</tr>
<tr>
<td>QuickTime</td>
<td></td>
</tr>
</tbody>
</table>
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

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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
4G Starts in the Home

xDSL, Cable Metro Ethernet

Broadband IP access

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Cell size shrinks as throughput and usage increase.
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.

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

Operators and vendors agreed to develop UMA in December 2003
Today’s cellular infrastructure is set up for \textit{thousands} of BSCs, \textit{not millions} of femtocells.

*Gateway Mobile Switching Center

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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

Applications

<table>
<thead>
<tr>
<th>Applications Servers (AS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSS</td>
</tr>
<tr>
<td>CSCF</td>
</tr>
</tbody>
</table>

Control

Media gateway

Transport

IP network, gateways to legacy networks

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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.

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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.
## LTE Frequency Bands - FDD

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

Source: 3GPP TS 36.104 V8.4.0 (2008-12)
## LTE Frequency Bands - TDD

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

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
Multiple orthogonal carriers
Frequency

TDMA
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.
**Fixed OFDMA**

- Frequency allocation per user is continuous vs. time

**Dynamic OFDMA**

- 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)
OFDMA symbol number

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

<table>
<thead>
<tr>
<th></th>
<th>WiMAX</th>
<th>LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channel bandwidth</strong> (MHz)</td>
<td>1.25  5  10  20  3.5  7  8.75</td>
<td>1.4  3  5  10  15  20</td>
</tr>
<tr>
<td><strong>Sample time</strong> (ns)</td>
<td>714.3  178.6  89.3  44.6  250  125  100</td>
<td></td>
</tr>
<tr>
<td><strong>FFT size</strong></td>
<td>128  512  1024  2048  512  1024  1024</td>
<td>128  258  512  1024  1536  2048</td>
</tr>
<tr>
<td><strong>Sampling factor</strong> (ch bw/sampling freq)</td>
<td>28/25</td>
<td>8/7</td>
</tr>
<tr>
<td><strong>Subcarrier spacing</strong> (kHz)</td>
<td>10.9375</td>
<td>7.8125  9.766</td>
</tr>
<tr>
<td><strong>Symbol time</strong> (usec)</td>
<td>91.4</td>
<td>128  102.4</td>
</tr>
</tbody>
</table>

[www.octoscope.com](http://www.octoscope.com)
## 3G/4G Comparison

<table>
<thead>
<tr>
<th></th>
<th>Peak Data Rate (Mbps)</th>
<th>Access time (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Downlink</td>
<td>Uplink</td>
</tr>
<tr>
<td>HSPA (today)</td>
<td>14 Mbps</td>
<td>2 Mbps</td>
</tr>
<tr>
<td>HSPA (Release 7) MIMO 2x2</td>
<td>28 Mbps</td>
<td>11.6 Mbps</td>
</tr>
<tr>
<td>HSPA + (MIMO, 64QAM Downlink)</td>
<td>42 Mbps</td>
<td>11.6 Mbps</td>
</tr>
<tr>
<td>WiMAX Release 1.0 TDD (2:1 UL/DL ratio), 10 MHz channel</td>
<td>40 Mbps</td>
<td>10 Mbps</td>
</tr>
<tr>
<td>LTE (Release 8), 5+5 MHz channel</td>
<td>43.2 Mbps</td>
<td>21.6 Mbps</td>
</tr>
</tbody>
</table>

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.

Control
Data

User
Data

One tunnel
HSPA

One tunnel
HSPA+

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LTE SAE (System Architecture Evolution)

**SAE includes RAN and EPS**

**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)
EPS (Evolved Packet System)

- 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.

*GPRS Gateway Support Node
Serving GPRS Support Node

Not hierarchical as GSM EDGE HSPA

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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.

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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

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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

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

Available Channels:
- Black: 1 or none
- Red: 3 or fewer
- Orange: 10 or fewer
- Yellow: 20 or more
- Green: 30 or more

duTreil, Lundin & Rackley, Inc.
Sarasota, Florida
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 IEEE 802.22
- 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

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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.
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 \( \frac{1}{4} \) wavelength
  - 3.3 feet for 70 MHz
  - 4” for 700 MHz
  - 1” for 2.4 GHz

- Longer antennas required for UHF may be problematic for handheld devices
Antenna Fresnel Zone

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

\[ r = 72.05 \sqrt{\frac{D}{4f}} \]

- \( r \) = radius in feet
- \( D \) = distance in miles
- \( f \) = frequency in GHz

**Example:**
- \( D = 0.5 \) mile
  - \( r = 30 \) feet for 700 MHz
  - \( r = 16 \) feet for 2.4 GHz
  - \( r = 10 \) feet for 5.8 GHz

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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 \( \geq 90\% \).
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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info@octoscope.com
+1 (978) 376-5841
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

Reference Voice Signal

Access Point

Switch

Router

Switch

Access Point

Received Degraded Signal

PESQ Comparator

1 - 5 Quality Score the Same as MOS
ITU-T E-Model (G.107) for Computing R-Factor

Send side

- Ds-factor
- Room noise P_s

Receive side

- Dn-factor
- Room noise P_r
- Sidetone masking rating STMR
- Listener sidetone rating LSTR (LSTR = STMR + Dr)
- Talker echo loudness rating TELR

Coding/Decoding

- Weighted echo path loss WEPL
- Round-trip delay T

Circuit noise N_c referred to 0 dBr

Equipment impairment factor I_e
Packet-loss robustness factor B_p
Packet-loss probability P_{pl}
Mean one-way delay T
Absolute delay T_a

Quantizing distortion q_{du}
Expectation factor A
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Abbr.</th>
<th>Unit</th>
<th>Default Value</th>
<th>Permitted Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send Loudness Rating</td>
<td>SLR</td>
<td>dB</td>
<td>+8</td>
<td>0 … +18</td>
</tr>
<tr>
<td>Receive Loudness Rating</td>
<td>RLR</td>
<td>dB</td>
<td>+2</td>
<td>-5 … +14</td>
</tr>
<tr>
<td>Sidetone Masking Rating</td>
<td>STMR</td>
<td>dB</td>
<td>15</td>
<td>10 … 20</td>
</tr>
<tr>
<td>Listener Sidetone Rating</td>
<td>LSTR</td>
<td>dB</td>
<td>18</td>
<td>13 … 23</td>
</tr>
<tr>
<td>D-Value of Telephone, Send Side</td>
<td>Ds</td>
<td>-</td>
<td>3</td>
<td>-3 … +3</td>
</tr>
<tr>
<td>D-Value of Telephone Receive Side</td>
<td>Dr</td>
<td>-</td>
<td>3</td>
<td>-3 … +3</td>
</tr>
<tr>
<td>Talker Echo Loudness Rating</td>
<td>TELR</td>
<td>dB</td>
<td>65</td>
<td>5 … 65</td>
</tr>
<tr>
<td>Weighted Echo Path Loss</td>
<td>WEPL</td>
<td>dB</td>
<td>110</td>
<td>5 … 110</td>
</tr>
<tr>
<td>Mean one-way Delay of the Echo Path</td>
<td>T</td>
<td>ms</td>
<td>0</td>
<td>0 … 500</td>
</tr>
<tr>
<td>Round-Trip Delay in a 4-wire Loop</td>
<td>Tr</td>
<td>ms</td>
<td>0</td>
<td>0 … 1000</td>
</tr>
<tr>
<td>Absolute Delay in echo-free Connections</td>
<td>Ta</td>
<td>ms</td>
<td>0</td>
<td>0 … 500</td>
</tr>
<tr>
<td>Number of Quantization Distortion Units</td>
<td>qdu</td>
<td>-</td>
<td>1</td>
<td>1 … 14</td>
</tr>
<tr>
<td>Equipment Impairment Factor</td>
<td>ie</td>
<td>-</td>
<td>0</td>
<td>0 … 40</td>
</tr>
<tr>
<td>Packet-loss Robustness Factor</td>
<td>Bpl</td>
<td>-</td>
<td>1</td>
<td>1 … 40</td>
</tr>
<tr>
<td>Random Packet-loss Probability</td>
<td>Ppl</td>
<td>%</td>
<td>0</td>
<td>0 … 20</td>
</tr>
<tr>
<td>Circuit Noise referred to 0 dBr-point</td>
<td>Nc</td>
<td>dBmOp</td>
<td>-70</td>
<td>-80 … -40</td>
</tr>
<tr>
<td>Noise Floor at the Receive Side</td>
<td>Nfor</td>
<td>dBmp</td>
<td>-64</td>
<td>-</td>
</tr>
<tr>
<td>Room Noise at the Send Side</td>
<td>Ps</td>
<td>dB(A)</td>
<td>35</td>
<td>35 … 85</td>
</tr>
<tr>
<td>Room Noise at the Receive Side</td>
<td>Pr</td>
<td>dB(A)</td>
<td>35</td>
<td>35 … 85</td>
</tr>
<tr>
<td>Advantage Factor</td>
<td>A</td>
<td>-</td>
<td>0</td>
<td>0 … 20</td>
</tr>
</tbody>
</table>
R-Factor to MOS Conversion

![Graph showing R-Factor to MOS Conversion](https://www.octoscope.com)
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