Demystifying IEEE 802 Standards

Wireless Standards

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802.11 Vice Chair

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“At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.”

IEEE-SA Standards Board Operation Manual (subclause 5.9.3)
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Acknowledgements

- Bruce Kraemer – chair 802.11
- Bob Heile – chair 802.15
- Phil Barber – chair 802.16m
- Wendong Hu – chair 802.22
Agenda

- **Segment 1 (10:30-12:10)**
  - 10:30 - 802.1, 802.3, 802.17
  - 11:40 - Introduction to Wireless Standards
  - 11:45 - 802.11 Wireless Lan
- **Break (12:10-14:00)**
- **Segment 2 (14:00-15:40)**
  - 14:00 - 802.15 Wireless PAN
  - 14:30 - 802.16 Wireless MAN
  - 14:55 - 802.18 Radio Regulatory, 802.19 Coexistence, 802.20 Mobile Broadband
  - 15:10 - 802.21 Media Independent Handover
  - 15:20 - 802.22 Wireless regional area network
- **Break (15:40-16:20)**
- **Segment 3 (16:20-18:20) – Standards process**
Opening remarks

- What’s so special about wireless?
Characteristics unique to wireless

- Propagation Characteristics
- Limited spectrum
  - Lansford’s Law: “Moore’s law does not apply to spectrum.”
- Must meet National Regulations
- Licensed / lightly licensed / unlicensed bands
- Protection of incumbents/primary users
  - DFS, TVWS
Air is a Poor Substitute for Wire or Fibre

- Large Scale fading
  - Attenuation (distance, obstructions)
  - Delay
- Small scale fading
  - Multipath (Reflections)
  - Doppler
  - Frequency selective fading
- Shared Medium
  - Cannot disregard legacy devices
  - In unlicensed bands - cannot control who else is using the medium
Wireless Constraints

- **Shannon-Hartley**

  \[ C = BW \times \log_2 \left( 1 + \frac{S}{N} \right) \]

  - \( C \) = channel capacity (bits/sec)
  - \( BW \) = channel bandwidth (Hz)
  - \( S \) = Signal
  - \( N \) = Noise
  - watts (not dB)

- **Friis path loss**

  \[ P_{rx} = \frac{G_{tx} G_{rx} c^2}{(4\pi d)^2 f_c^2} \times \frac{1}{\sigma N_f} \times P_{tx} \]
802 Wireless Ecosystem
IEEE 802 Organization

IEEE Standards Association

Standards Activities Board

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IEEE 802 Local and Metropolitan Area Networks (LMSC)

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802.1 Higher Layer LAN Protocols
802.3 CSMA/CD Ethernet
802.5 Token Passing Ring
802.11 Wireless WLAN
802.15 Wireless Personal Area Networks
802.17 Resilient Packet Ring
802.19 Co-existence TAG
802.16 Broadband Wireless Broadband Access
802.18 Radio Regulatory TAG
802.20 Mobile Broadband Wireless Access
802.22 Wireless Regional Area Networks

IEEE 802 Wireless Projects
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802.21 Media Independent Handoff
802.22 Wireless Regional Area Networks

IEEE 802.11: ~500 Participants
Voting Members ~250
www.ieee802.org/11
Market Size and Trends

- Both Consumer Electronics and Voice (VoIP) are forecast to make a huge impact.
- Market segment diversity continues to increase.

Source: In-Stat
Wi-Fi Hotspot Public Access

- 280K+ hot spots in 132 countries
  - Source: JiWire (2009)
- 1.2 Billion connects
  - Source: In-Stat
- 87% of US hotels offer Wi-Fi
  - Source: American Hotel & Lodging Assn
Expanding Uses - Airline Examples

- Airline Example
  - American Airlines
  - Lufthansa
  - Virgin America
  - Google
  - Aircell GoGo Inflight Internet

- Smart Grid
Activity History

- Feb 14, 1876: Bell files telephone patent
- June 1897: Marconi work- “Signaling through Space without Wires”
- 1970: ALOHAnet operational (Abramson, 9600 baud)
- 1980: Project 802 formed (1 Mbps initially, revised to 20 Mbps 1982) (Feb 1980, 125+ attendees)
- 1980: Ethernet Bluebook published (September, Digital, Intel, Xerox)
- 1981: FCC issues NOI for unlicensed spectrum
- 1983: First version of 802.3 10Base5 spec completed
- 1985: FCC opens ISM Band- spread spectrum allowed
- 1985: First version of 802.3 published (10 Mbps)
- 1987: Project 802.4L – Wireless Token Bus begins
- 1989: ISM frequency Bands 900MHz, 2.4GHz and 5GHz allowed
- 1990: IEEE 802 drops 802.4L starts 802.11 project
- 1990: 802.3 10BASE-T (802.3i) released
Activity History

- 1994: 1st wireless radios - Inventory control
- 1997: IEEE 802.11 standard approved (2.4GHz – 1Mbps)
- 1999: IEEE 802.11 standard achieved ISO/IEC approval
- 1999: IEEE 802.11a (5GHz – 54Mbps) - approved
  IEEE 802.11b (2.4GHz- 11Mbps)- approved
- 1999: Formation of WECA (now Wi-Fi Alliance)
- 2001: IEEE 802.11d Regulatory Domains - approved
- 2003: IEEE 802.11g (Higher rate 2.4GHz PHY) – approved
  IEEE 802.11i (Security) - approved
  IEEE 802.11h (Spectrum Mgmt) - approved
  IEEE 802.11f (interaccess point protocol) – approved
- 2005: IEEE 802.11e (MAC enhancements – QoS) – approved
The 802 LAN Architecture

OSI reference model

<table>
<thead>
<tr>
<th>Layer</th>
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<tbody>
<tr>
<td>7: Application</td>
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<tr>
<td>6: Presentation</td>
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<tr>
<td>5: Session</td>
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<tr>
<td>4: Transport</td>
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<td>3: Network</td>
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</table>

<table>
<thead>
<tr>
<th>Layer</th>
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<tbody>
<tr>
<td>2: Link</td>
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<tr>
<td>1: Physical</td>
</tr>
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</table>

End station (Higher Layers)

MAC Bridge

MAC

LLC

Phy

LAN

End station (Higher Layers)

MAC

LLC

Phy

LAN

Medium

Mac service user

Mac service provider

Mac sublayer

Llc sublayer
802.11 Project Scope (cont.)

Data Link Layer
- MAC Sublayer
  - MAC_SAP
- PHY Sublayer
  - PHY_SAP
  - PLCP Sublayer
  - PMD Sublayer
  - PMD_SAP

Physical Layer

Station Management Entity
- PHY Sublayer Management Entity
- MLME-PLME_SAP
- PLME_SAP

RSNA Key Management
- MAC Sublayer Management Entity
- MAC_SAP
- MLME_SAP
Summary of Major PHY Projects

- A - 20 MHz BW, 5GHz
- B - 20 MHz BW, 2.4 GHz
- G - 20 & 40 MHz BW, 2.4 GHz
- N - 20 & 40 MHz BW, 2.4 & 5GHz
- AC – 20 to 160 MHz BW, 5GHz
- AD – 2 GHz BW, 60 GHz
IEEE 802.11 – Key Technical Attributes

- Specifications for the **Physical** and **MAC** Layers
- Backward compatibility with legacy 802.11 standard
- Maximize spectral efficiency and performance
- Co-existence with other device sharing the 2.4GHz and 5GHz frequency bands

![802.11 Physical layer Data Rates – Mbps](image)

<table>
<thead>
<tr>
<th>11 orig</th>
<th>11b</th>
<th>11a/g</th>
<th>11n</th>
<th>11ac</th>
<th>11ad</th>
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<td>1000</td>
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5-May-10
Summary of Major MAC Projects

- D – Country information
- E - QoS
- F – Inter AP communication
- H – DFS, TPC Spectrum sharing with radars in 5GHz
- J – Japan spectrum @ 4.9 GHz
- K – Radio Measurement
- P – Vehicular Environments
- R – Fast roaming
- S – MESH Networking
- U – Inter-Networking
- V – Network Management
- W – Secure Management Frames
- Z – Tunneled Direct Link
- AA – Video Transport
- AE – QoS for Management Frames
802.11n - High Throughput

- 20 & 40 MHz channelization
- 1 to 4 spatial streams
  - 1 stream for Client (Mandatory)
  - 2 stream for Access Point (Mandatory)
- ½ GI
- 56 tones (in 20MHz)
- 5/6 coding
- Green Field preamble
- Maximum PHY throughput of 600Mbps (not yet a realistic product)
TGN

- **Media Access Control Layer Enhancements: Efficiency**
  - In legacy 802.11 a/b/g systems an acknowledgment (ACK frame) is sent from the receiving station to the transmitting station to confirm the reception of each frame. If the transmitter does not receive an ACK, it retransmits the frame until an ACK is received.
  - The ACK mechanism is also used in rate adaptation algorithms so that if too many retransmissions are required, the transmitting station drops to a lower data rate. The ACK mechanism adds robustness to 802.11 and ensures that all transmitted frames eventually get to the receiver, but this robustness comes at the price of protocol efficiency since for each transmitted frame, an additional ACK frame is also sent.

- 802.11e adds a Block Ack mechanism
- 802.11n adds two types of aggregation (A-MSDU & A-MPDU)
## TGn Throughput

<table>
<thead>
<tr>
<th>SS</th>
<th>No SGI</th>
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<th>No SGI</th>
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<td>40 MHz</td>
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<td>20 MHz</td>
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<td>40 MHz</td>
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<td>350%</td>
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<td>22%</td>
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<td>54%</td>
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<td>145%</td>
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<td>381%</td>
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<td>2 SS</td>
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<td>68%</td>
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<td>322%</td>
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<td>700%</td>
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<td>50%</td>
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<td>73%</td>
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<td>363%</td>
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<td>3 SS</td>
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<td>509%</td>
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<td></td>
<td>59%</td>
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<td>77%</td>
<td></td>
<td>564%</td>
<td></td>
<td>1095%</td>
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<table>
<thead>
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<th>Potential TCP throughput Improvement over legacy abg</th>
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</thead>
<tbody>
<tr>
<td>No A-MPDU</td>
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<td>20 MHz</td>
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<tr>
<td>1 SS</td>
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</table>
“Wireless Access in Vehicular Environments” (WAVE) refers to what was previously called Dedicated Short Range Communications (DSRC). The National ITS Architecture has identified DSRC as a primary means of communicating between the roadside and vehicles, and from one vehicle to another.

Applications planned within the ITS domain (ITS services), including:
- collision avoidance
- traveller information
- toll collection
- commercial vehicle operations
- transit operations
- traffic management
- connecting the vehicle to the Internet.
Wireless Access for the Vehicular Environment (WAVE)

- This Task Group will define enhancements to support data exchange between high-speed vehicles and between these vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz.

- **While there is a priority within North America to support the US National Intelligent Transportation System (ITS) Architecture, the intent is to develop an amendment to IEEE 802.11 that will be applicable on a global basis.**

- The US DoT, most of the major automobile manufacturers, public agencies throughout North America, DSRC device manufacturers, and many potential service providers have been involved in the DSRC program and actively support it.
802.11s MESH

- An amendment to create a **Wireless Distribution System** with automatic topology learning and dynamic wireless path configuration.
  - Target number of packet forwarding nodes: ~32
  - Support unicast and broadcast/multicast traffic
  - Use 802.11i security or an extension thereof
  - Extensible routing to allow for alternative forwarding path selection metrics and/or protocols
  - Use the 802.11 four-address frame format or an extension
  - Interface with higher layers and connect with other networks using higher layer protocols
Classic 802.11 Wireless LAN

Wired Infrastructure

- AP
- STA
- STA
- STA
- STA

ESS = Extended Service Set
≈ SSID

= radio link

Wireless Paradox: WLAN Access Points are Typically Wired
Unwire the WLAN with Mesh

Wired Infrastructure

Mesh AP

Mesh Point

Mesh AP

Mesh AP

Mesh AP

STA

STA

STA

STA

STA

STA

STA

ESS = Extended Service Set

≈ SSID

= mesh radio link
Tgu – Wireless Interworking

Background
- As IEEE 802.11 hotspot deployment has become more widespread throughout the world, several problem areas have emerged with the way in which the hotspot behaves regarding its connection to external networks (e.g. the internet, cellular networks) which could be solved by standardization.
- As the diversity of hotspots have proliferated, users have started to become frustrated with the non uniformity of interworking systems (e.g. poor service definition, disparate registration procedures, non-ubiquitous roaming).
- Within the IEEE 802.11 community it was felt that an amendment to the IEEE 802.11 standard would be in order to address these problem areas. Generically these issues have been referred to as interworking, which refers to the functionality and interface between an IEEE 802.11 access network and any external network.

Objectives
- The primary objective of IEEE 802.11u, is to create an amendment to address interworking issues between an IEEE 802.11 access network and any external network to which it is connected.
- Interworking, is actually a collection of different functionalities:
  - Online Enrolment
  - Network Selection
  - Security
  - Authorization from Subscriber Network
  - Media Independent Handover Support
U Interworking with External Networks

- Hotspot use is currently gaining interest not only with ISPs but also with Cellular operators. It will become an increasing larger issue in public communications and it is felt by many that the interworking of hotspots to external networks must be addressed by IEEE 802.11.

- Interworking will increase the range of services and market reach of IEEE 802.11 devices. This will stimulate more deployments of IEEE 802.11 networks. Additionally it will enable IEEE 802.11 devices to become high-end terminal devices allowing user access to services only available within the cellular communications market. It is felt that both terminal and access point manufacturers will benefit from this expansion.

- Compliance with the amendment will also enable the roaming of IEEE 802.11 terminal equipment into any hotspot throughout the world. Together with the work of 3GPP and 3GPP2, any cellular subscriber with compliant equipment could become a potential user.
802.11V  Network Management

- Explosive growth of 802.11 wireless LANs
- Maintaining network quality and security requires control
- The need to manage the RF environment is driven by interference from neighboring wireless networks
- The need to secure them by the desire to maintain privacy and prevent unauthorized use.
- In the enterprise these needs are similar, but security is much more than just privacy, it is the control of corporate secrets, customer profiles and other information that may be critical to the survival of the organization.
- Network manageability is also the key to maintaining network flexibility; the ability to shape the network
Objective

- To develop extensions to the 802.11 MAC/PHY to provide network management for STAs
- The current IEEE 802.11 specification implies that stations may be managed via a Simple Network Management Protocol (SNMP). The use of SNMP introduces the following problems:
  - 1. Very few stations in the market include SNMP capabilities.
  - 2. The use of secure SNMP protocol (e.g. SNMPv3) requires significant pre-configuration of the station.
  - 3. Management of a station may be required prior to the establishment of an IP connection.
TGv D3.0 Content

1. BSS Transition Management
2. Channel Usage
3. Co-located Interference Reporting
4. Diagnostic Reporting
5. Event Reporting
6. Location Services
7. Maximum Multicast Rate Processing
8. Multicast Diagnostic Reporting
9. Multiple BSSIDs
10. Proxy ARP
11. WNM-Sleep Mode
12. TIM Broadcast
13. Timing Measurement
14. Traffic Filtering Service
15. Traffic Generation
TGv Content – Increased Station Power Saving

- Traffic Filtering Service
  - Enables the AP to filter traffic for the station, and deliver only frames of a specified type.
- WNM-Sleep Mode
  - Provides an additional, extended power save mode.
  - When used with the Traffic Filtering Service, can provide significant station power savings, and provide a “Wake on WLAN” service.
- Flexible Broadcast/Multicast service
  - Enables multicast frames to be sent at longer delivery intervals and higher data rates, improving performance of multicast applications, and reducing station “awake time”
- Proxy ARP
  - Enables stations to remain in power save mode longer
- TIM Broadcast – Enables stations to check for queued traffic without receiving a full Beacon frame.
Example TGv Based Applications

- “Wake on WLAN” Service– Stations sleep and are “awakened” when specific frames are received
  - Example application: User leaves corporate desktop in “sleep mode”, goes home, uses VPN from home to corporate LAN, wakes up and uses desktop remotely
  - Reduces power consumption of end devices, even stationary ones
- Improved client power saving
  - Proxy ARP, TIM Broadcast, FBMS, Sleep Mode, Traffic Filtering
- “Wireless Speakers” – Use Location services timing measurements to support audio synchronization
- Improved Multicast Performance
- Network Diagnostic Analysis/Troubleshooting
  - Co-located Interference Reporting, Diagnostic Reporting, Event Reporting, Multicast Diagnostics Reporting
802.11w – Protected Management Frames

- One of the frame types defined in 802.11 is “Action” sub-type “Management”
- Management frames were previously less well protected than data frames.
- The objective of this was to improve the security by providing data confidentiality of action management frames, deauthentication and disassociation frames.
- This standard protects networks from attack by malicious systems that forge disassociation requests that appear to be sent by valid equipment.
802.11z Tunneled Direct Link

- The purposes of this amendment are to create a new DLS mechanism which:
  - a) Does not require access point upgrades (i.e. supports DLS operation with the non-DLS capable access points),
  - b) Which supports power save mode (when associated with either DLS or non-DLS capable access points), and
  - c) Continues to allow operation of DLS in the presence of existing DLS capable access points
The performance of video streaming is not always of acceptable quality. A set of enhancements to 802.11 MAC can improve video streaming performance significantly while maintaining data and voice performance. Enhancing the 802.11 MAC to address video streaming performance issues will extend the applicability to 802.11 and eliminate the need for proprietary implementation and/or competing standards. This amendment defines enhancements to the 802.11 MAC for robust video streaming, while maintaining co-existence with other types of traffic. The MAC enhancements specified in this amendment are:

- Interworking with relevant 802.1 mechanisms including, but not limited to, 802.1Qat, 802.1Qav and 802.1AS
- Enabling graceful degradation of video streams when there is insufficient channel capacity.
- Increasing robustness in overlapping BSS environments, without the requirement for a centralised management entity.
- Modifying EDCA timing and parameter selection for video transport
- Improving Multicast/Broadcast video streams for link reliability with low delay and jitter.
802.11AC  Very High Throughput <6GHz

- A multi-user BSS peak aggregated throughput of at least 1Gbps as measured at the MAC data service access point (SAP)
- Robust and flexible bandwidth management: native support for simultaneous multiple bandwidth operation (within a given frequency band)
- Add optional outdoor compatible delay spread resistance
- Below 6GHz carrier frequency operation excluding 2.4GHz operation and ensuring backward compatibility with legacy IEEE802.11a/n devices in the 5GHz unlicensed band.
802.11AD Very High Throughput

Market drivers for Very High Throughput wireless LAN, include:

Never ending quest for higher performance computing drives higher processing power. IO and Network speeds needs to grow proportionally to maintain comparable system level performance and cater to a positive user experience.

Media appliances are moving to HD content, driving 10X storage capacity and bandwidth requirements, wireless LAN throughput must grow in order to serve those media links at home and in the office.

Mainstream Wired LAN products have shifted to Gigabit per second speeds. The trend for a purely wireless campus drives the need for wired equivalent multi-Gigabit per second wireless solutions.

As wireless network density grows, there exists an increasing need for additional capacity and reduced cell sizes. Additional high bandwidth channels are needed for efficient support of high throughput usage.

Corporate computing is shifting to a centralized processing model with lower cost “thin” clients that act as “semi-dumb terminals”. With a motivation to reduce Capital and Operational Expenditures, this new model changes the nature of network traffic and drives much higher KVM (Keyboard, Video, Mouse) content, which in turn drives increases in bandwidth and reduction in latencies.
All IEEE 802.11 MAC management frames are transmitted at the highest priority.

IEEE 802.11 amendments ‘k’, ‘y’, ‘w’, ‘v’, and ‘u’ have introduced features that rely on management frames, which are essential for network operation.

In some cases, the management traffic will contend with network data traffic and reduce the performance of certain WLAN applications.

Providing a mechanism to prioritize management frames will enable improved performance of IEEE 802.11 networks.

This project will consider the classification and prioritization of management frames.

This project will consider management frames that are used in both pre- and post- association.

Management frames of subtype Action will be considered. Other management frame types may be considered.

These mechanisms should allow for administrative configuration of priorities.
With the global transition to Digital TV (DTV), sub-Gigahertz RF spectrum is becoming available, much of it for unlicensed, license exempt and/or lightly licensed use. This project will make the necessary MAC and PHY changes to enable 802.11 products to take advantage of this additional spectrum.

On November 4, 2008, the United States FCC approved Report & Order 08-260, allowing unlicensed use of TV band spectrum, in accordance with Part 15. Subpart H of FCC rules. Ofcom (UK) is in the process of making this Digital Dividend band available, and the EU has conducted a consultation on the band. Other regulatory domains are expected to follow.
Future Projects

- Security
- Low power consumption
- Higher speed
- Longer range
- Spectral efficiency
- QoS
- Spectrum Sharing/ Cognitive Radio/ SDR
- Beamforming/ Smart Antennas
802.11 References

http://grouper.ieee.org/groups/802/11
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Voting Members ~230
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In 1997, Fedex and several other companies were looking to have standards suitable for interconnecting devices typically worn.

In March 1998, an 802.11 Study Group was formed to address the issue.

In March 1999, 802.15 was created to develop standards for Wireless Personal Area Networks.
Initial activities focused on wearable devices hence “personal area networks”

Activities have proven to be much more diverse and varied
- Data rates from 2kbps to 2gbs
- Ranges from meters to kilometers
- Frequencies from 400MHz to 800THz
- Predominantly non TCP/IP applications

Focus is on “specialty”, typically short range, communications. If it is wireless and not a LAN, MAN, RAN, or WAN, odds are its 802.15

Only 802 Working Group with multiple MACs
802.15 Completed Projects

- 802.15.1-Bluetooth
- 802.15.2-Coexistence Recommended Practice
- 802.15.3-High Rate (55 Mbps) Multimedia WPAN
- 802.15.3c-High Rate (>1Gbps) mmWave 15.3 PHY
- 802.15.4-Low Rate (250kbps) WPAN
- 802.15.4a-Higher data rate 15.4 PHY
- 802.15.4c-Sub 1 GHz 15.4 PHY for China
- 802.15.4d-Sub 1 GHz 15.4 PHY for Japan
- 802.15.5-Mesh Networking Recommended Practice
802.15 Active Projects

- 802.15.4e- 15.4 MAC Enhancements
- 802.15.4f- 15.4 PHY for Active
- 802.15.4g- 15.4 PHY for Smart Utility Networks
- 802.15.6- Body Area Networking
- 802.15.7- Visible Light Communications
60 GHz WPAN
802.15.3c
IEEE 802.15.3c- High Rate (> 1Gbps) mmWave 15.3 PHY

- IEEE 802.15.3c, a 60GHz PHY Amendment for 802.15.3, began in September 2009 and published in October 2009
- Key attributes include:
  - Transmission speeds of at least 1 Gbps
  - Operation in new unlicensed bands such as 57-64 GHz in the USA and 59-66 GHz in Japan and parts of Europe
  - Support for very high data rates (up to over 5 Gbps) for applications such as uncompressed video transmission, large file down/up load, ultra high speed internet access
Typical Applications for a 60 GHz WPAN

1. Video Streaming: 3Gbps uncompressed video (transmission range : ~ 10 m)

   - TV Set, Display
   - Set top box, PC

2. Kiosk File Downloading (Synch and Go) @ 1-3 Gbps
   (transmission range : 1 – 2 m) - DVD Down Load in 10 sec (@3 Gbps)

   - Movie and Game Kiosk
   - Mobile device, PDA
   - STB, Game Consol
802.15.4e
MAC enhancements

OSI reference model

Application
Presentation
Session
Transport
Network
Link
Physical

802.15.4 application
(Higher Layers)

LLC
MAC
Phy

New and Improved
**802.15.4e- MAC enhancements**

- **Scope:** Amendment to the 802.15.4-2006 MAC adding:
  - **TDMA:** a) determinism, b) enhanced utilization of bandwidth
  - **Channel Hopping:** additional robustness in high interfering environments and enhanced coexistence with other wireless networks
  - **GTS:** a) Support for peer to peer, b) control over the length and number of slots
  - **CSMA:** improved throughput and reduced energy consumption
  - **Security:** support for options such as asymmetrical keys
  - **Low latency:** reduced end to end delivery
802.15.4e- MAC enhancements

This proposed functionality facilitates:

- Industrial applications (such as those addressed by HART 7 and the ISA100 standards)

- Enhancements defined by the proposed Chinese WPAN standard.

- MAC functionality needed for the applications served by
  - 802.15.4f PHY Amendment for Active RFID
  - 802.15.4g PHY Amendment for Smart Utility Networks
Active RFID
802.15.4f
Scope: 15.4 PHY for Active RFID readers and tags having:
- Very low energy consumption
- Support for a variety of active RFID tag operations including simplex and duplex transmission (reader-to-tag and tag-to-readers), multicast (reader to a select group of tags), uni-cast as in reader to a single tag, tag-to-tag communication, and multi-hop.
- Support for a large tag population (hundreds of thousands)
- High reliability for applications such as active tag inventory counting or auditing.
- World-wide usability, with or without licensing
- High tolerance to interference from other devices operating within the same band
- Proven coexistence with other 802 wireless standards operating in the same bands.
802.15.4f Proposed Draft Outline

- 802.15.4f MAC
  - UWB 802.15.4f PHY
  - 2.4 GHz 802.15.4f PHY
  - 433 MHz 802.15.4f PHY
  - 125 KHz 802.15.4f PHY
IEEE 802.15.4f Proposed Draft Outline

- Includes four frequency bands for global use
  - Ultra-Wideband (UWB)
    - 7 GHz (US), 6 or 8 GHz (EU), 10 GHz (Korea/Japan)
  - 2.4 GHz (up to 27 narrowband 750 KHz channels)
  - 433 MHz (single channel centered at 433.92 MHz)
  - 125 KHz (Magnetic) – pending verification that the 802.15.4 MAC will support this PHY.
- Requires the addition of a one-way ‘BLINK’ frame to the MAC
Smart Utility Networks
802.15.4g
802.15.4g-Project Scope

IEEE 802.15.4 PHY amendment for Wireless Smart Metering Networks supporting:
- Operation in any of the regionally available license exempt frequency bands, such as 700MHz to 1GHz, and the 2.4 GHz band.
- Data rates of at least 40 kbps but not more than 1000 kbps
- Principally outdoor communications
- Optimal energy efficient link margins given typical environmental conditions encountered in Smart Metering deployments.
- PHY frame sizes up to a minimum of 1500 octets
- Simultaneous operation for at least 3 co-located orthogonal networks
- Connectivity to at least one thousand direct neighbors characteristic of dense urban deployment
- Coexistence with other 802 systems in the same band(s)
- Mesh Networking
Addresses North America, Europe, Japan, Korea and Chinese Regulatory domains

Merged to 3 proposals - 1 FSK, 1 DSSS, 1 OFDM

Agreement to create a candidate draft in preparation for 802.15 letter ballot following the January meeting

Providing input to NIST Priority Action Plan #2
802.15.4g-Areas of current active debate
November 2009

- Technical issues still to be resolved as part of merging activity:
  - DSSS proposal
    - Harmonization of spreading modes
    - Mode selection mechanisms
    - Best method to support 802.15.4-2006 OQPSK
  - FSK proposal
    - Packet format for the PHY rate switching option
    - Define Start of Frame Delimiters & Preamble values and lengths
    - Agree on FEC solution for header and payload
    - Verify Option #2 Parameter - GFSK or FSK?
    - Agree on scrambling mechanism
    - Agree on data rate sets for Europe and China
    - Complete definition of PIB attributes
The group has agreed that it is unlikely that a single PHY definition can address such a broad application space,

- **Benefits of FSK are**
  - Low Risk--Robust, simple and proven technology for this application
  - Can use 1 watt transmit power, giving good range

- **Benefits of OFDM are**
  - Higher data rates-- future applications may require more data, lower latency etc
  - Multipath mitigation—potential problem with higher data rates using FSK

- **Benefits of DSSS are**
  - Extended range with lower data rates -- important for sparse, rural deployments

The details of coexistence and interoperability are still be agreed

- Coexistence and Interoperability is being studied in a subgroup

Aggressive schedule to have text ready in time to agree candidate draft at January meeting
Body Area Networks (BAN)
802.15.6 Overview
802.15.6 Body Area Networks

- **Scope:** Standard for short range, wireless communication in the vicinity of, or inside, a human body (but not limited to humans)
  - Uses existing ISM bands and/or bands approved by national medical and/or regulatory authorities
  - Supports QoS, extremely low power, & data rates up to 10 Mbps
  - Complies with strict non-interference guidelines where needed
  - Considers effects on portable antennas due to the presence of a person (varying with male, female, skinny, heavy, etc.)
  - Meets Specific Absorbed Radiation Limits
  - Accommodates user motions
802.15.6 BAN Applications

Physiological and vital signals monitoring

- Temperature monitor
- Blood pressure sensor
- Mechanical motion sensors
- Respiratory monitor
- Breathing monitor
- Saturation of Peripheral Oxygen (SpO2) - pulse oximeter
- Heart rate monitor
- Cardiac arrhythmia monitor/recorder
- Electro Cardiogram (ECG)
- pH value sensor
- Glucose sensor
- Electro Encephalography (EEG)
- Electromyography (EMG) (muscular)
- Brain liquid pressure sensor
- Fertility Monitor
- Endoscope (gastrointestinal)
802.15.6 BAN Applications

Stimulators

- Deep brain stimulator
- Cortical stimulator
- Visual neuro-stimulator
- Audio neuro stimulator
- Parkinson’s disease
- Epilepsy Stimulator
- Brain-computer interface
- Wireless capsule for drug delivery
802.15.6 BAN Applications

Remote control of medical devices

- Pacemaker
- Implantable Cardioverter Defibrillator (ICD)
- Actuators
- Insulin pump
- Deep brain stimulator
- Hearing aids
- Implantable Hearing Aids
- Cochlear implant
- Retina implants
- Muscular signal replacement
802.15.6 BAN Applications

Disability assistance

- Muscle tension sensing and stimulation
- Wearable weighing scale
- Fall detection
- Aiding sport training

Diagram of the new prosthetic arm, still under development, which will respond directly to the brain’s signals. (Credit: Journal of Neurophysiology)
802.15.6 BAN Applications

Elderly People Assistance

- Tilt sensors for monitoring accident fall-down.
- Foot sensors for monitoring steps.
- Breathing sensor for monitoring respiration.
- Blood pressure sensor.
- Movement sensors for monitoring activities.
- Heart rate
- Body temperature.
802.15.6 BAN Applications

Fitness Monitoring

- Speed
- Distance
- Heart rate
- Respiration monitor
- Temperature sensor
- Pacing information
- Location information
- Wristwatch display unit
802.15.6 BAN Applications

Wearable Audio - Video

- Central device is headset
  - Earset
  - Eyeset
- Stereo audio, microphone
- Video
  - Camera sensor
  - Display
- Connected devices
  - Cellular phone
  - Audio/Video Player
  - AP at home
  - AP in car
### 802.15.6 Channel Model Challenges

- The channel model will include body effects.
  - Specific Absorption Rate (SAR), health effects
  - Body shadowing causes severe attenuation at some frequencies
  - User motion causes large variations in channel

- New channel models are needed
  - Access point to surface of body
  - Surface of body to surface of body
  - Surface of body to inside body
  - Inside body to inside body

---

- Swallowable camera
- Implanted glucose sensor
- Implanted insulin pump
802.15.6 Potential Frequency Bands

- **Medical Implant Communications System (MICS)** band 402-405 MHz, USA, EU, Korea, Japan (FCC 47 CFR 95.601-95.673 Subpart E)
  - 10 channels of 300kHz
  - Adaptive frequency agility
  - 25uW EIRP

- **Med Radio** FCC proposed band 401 - 402 MHz and 405 - 406 MHz

- **Wireless Medical Telemetry Service (WMTS)** Band
  608 – 614 MHz (TV ch 37), 1395 –1400 MHz, 1427 – 1432 MHz

- **Industrial, Scientific & Medical (ISM) Band**
  868/915MHz, 2.4GHz, 5.8GHz

- **UWB Band**

- **RFID links:** 135kHz, 6.78MHz, 13.56MHz (ERC Rec 70-03)

- **Inductive** Link band 9kHz - 315kHz (ECC Report 12)

- **Capacitive** carrier less baseband transmission
802.15.6 Current issues to resolve

- **PHY**
  - Narrowband -- MICS in Japan, reconcile with ETSI rules in Europe
  - Ultra wideband -- Impulse Radio or FM
  - Skin Conduction -- reconcile with safety regulations

- **MAC**
  - Beacon versus polling
  - Security method
Visible Light Communications (VLC)
802.15.7
VLC history – Low speed

- Information delivery through reflection by mirror (Heliograph)
- The use of fire or lamp
  - Beacon fire, lighthouse, ship-to-ship comm. by Morse code
- Traffic light: signal discrimination by color (Walk/Stop)
Bell’s Photophone (1880)

- Optical source: sunlight
- Externally modulation by vibrating mirror
- Receiver: parabolic mirror with crystalline selenium cells
- 700 ft (213m) sound transmission
802.15.7 Visible Light Communications

- **Scope:** defines a PHY and MAC for short-range optical wireless communications using visible light in optically transparent media
  - Spectrum extends from 780 to 380 nm in wavelength (~400-800 THz)
  - Data rates supporting audio and video multimedia services
  - Adherence to any applicable eye safety regulations.
  - Fixed and mobile visible links
  - Resistance to noise and interference from sources like ambient light
802.15.7 Visible Light Communications

- Purpose: Provides means to
  - Access to several hundred THz of unlicensed spectrum
  - Avoid electromagnetic and RF interference
  - Provide additional security by allowing the user to see the communication channel
  - Augment and complement existing services (such as illumination, display, indication, decoration, etc.) from visible-light infrastructures.
802.15.7 Visible Light Communications

Need: Visible light is drawing great interest as a new (rediscovered?) communication medium due to the following recent developments.

- LED sources are rapidly replacing conventional ones in signaling, illumination and display infrastructures.
- Visible band is free from Radio Frequency (RF) regulations and interference.
- Well suited for use in RF crowded or RF restricted environments.
- Visibility can enhance the physical-layer security and offer intuitive usage.
- Potential applications include secure point-to-point communication, indoor Location Based Service (LBS), secure Point-to-Multipoint communication (office, hospital, airplane), Intelligent Transportation System (ITS), information broadcast, and etc.
802.15.7-VLC Application Scenarios

- **Bandwidth**
- **Security**

**Coverage**

- 1nm
- 380nm
- 780nm
- 100μm
- 3cm
- 1m

**Mobility**

- Peripheral Interface
- Information Broadcast
- RF Prohibited
- Visible LAN

- Contents Machine
- e-book
- Sign Board
- ITS (Navigation)
- Digital Hospital
- Security
- Banking
- Door Lock
- In Plane
- LAN

**Visible**

- Banking
- Door Lock
- In Plane

**IR**

- Visible
- UV
- RF

**30-Nov-2009**
802.15.7 - VLC, Ubiquitous Connectivity
Opportunity:

- Novel new wireless communications which does not fit in any real category within 802 - kind of thing 802.15 does

- Rapid adoption of a global base standard establishes a platform for consistent growth and development in a open standards environment as technology and application opportunities emerge

- Targeting end of 2010 for completion
802.16 is...
An IEEE-SA P802 Working Group (WG)

- IEEE 802.16 Working Group on Broadband Wireless Access
- Develops and maintains a set of standards
802.16 is...
A standard

- IEEE Standard 802.16: Air Interface for Broadband Wireless Access Systems
- The WirelessMAN® standard for Wireless Metropolitan Area Networks
The 802.16 Working Group
Overview

- Organized under IEEE
- Initiated in 1998; Formalized in 1999 (over 10 years old)
- Holds at least six sessions a year
  - Session duration: four days
  - 64 Sessions to date
- Open&Transparent process
  - Anyone can participate; become a Member
The 802.16 Working Group
Overview (continued)

- Members are individuals; people
- Membership earned by participation
- Currently: 437 Members, from around the world, from dozens of countries
The 802.16 Standard Overview

- “Air Interface for Broadband Wireless Access Systems”
- Developed since 1999 by IEEE 802.16 WG
- Evolves by amendments and revision
- Fixed non-line-of-sight OFDMA introduced in 2002
- Mobile-enabled OFDMA introduced in 2005 ("802.16e")
The 802.16 Standard
Key Evolution Steps

- IEEE Std 802.16-2001 (fixed access)
- + 802.16a OFDM/OFDMA 2003
- IEEE Std 802.16-2004
- + 802.16e Mobility 2005
- IEEE Std 802.16-2009
- + 802.16j Multihop Relay 2009

A dozen other Amendments and Corrigenda not shown
The 802.16 Standard
Latest Significant Activity: 16m

- “Advanced Air Interface” 16m Amendment project, initiated 2006
- Amend IEEE 802.16 WirelessMAN-OFDMA specification only
- meet the cellular layer requirements of IMT-Advanced next generation mobile networks
The 802.16 Standard
Latest Significant Activity: 16m (continued)

- support for legacy WirelessMAN-OFDMA equipment (i.e., backward compatibility)
- provide performance improvements to support future advanced services and applications
The 802.16 Standard
Latest Significant Activity: 16m (continued)

- Wide participation and interest
  - Over 1200 professionals
  - From about 240 organizations
  - From 23 countries
  - Contributed > 4400 documents to date since project inception
The 802.16 Standard
Latest Significant Activity: 16m (continued)

- Project Process
  - Evaluation Methodology Document (EMD)
  - System Requirements Document (SRD)
    - Stage 1
  - System Description Document (SDD)
    - Stage 2
  - Draft Amendment to IEEE 802.16-2009
    - Stage 3

In Process
The 802.16 Standard
Latest Significant Activity: 16m (continued)

- Draft Amendment to IEEE 802.16-2009
  - Stage 3 Draft Status
    - Four versions before P802.16m/D1
    - Current (March 2010) version P802.16m/D4

- Draft Progress and Completion
  - Likely enter Sponsor Ballot in 2010Q2
  - Likely project completion 2010Q4
The 802.16 Standard & ITU

- IEEE: ITU-R Sector Member
  - “Regional & other International Organizations”

- Relevant ITU-R Engagement
  - Fixed Wireless Access
    - Rec. F.1763: IEEE 802.16 in the Fixed Service
  - Land Mobile Radio
    - Rec. M.1801: IEEE 802.16 in the Mobile Service
The 802.16 Standard & ITU (continued)

- Relevant ITU-R Engagement (continued)
  - IMT-2000
  - IMT-Advanced
Relevant ITU-R Engagement (continued)

- IMT-2000
  - M.1457 Rev. 7 (2007) adds “OFDMA TDD WMAN”
    - Based on IEEE Std 802.16 (including 802.16e)
    - Implementation profile developed by WiMAX Forum
  - M.1457 Rev. 9 (2009) completed by WP 5D
    - Updates reference to IEEE Std 802.16-2009
    - Includes FDD as well as TDD updates
The 802.16 Standard & ITU (continued)

- Relevant ITU-R Engagement (continued)
  - IMT-Advanced
    - Contribution 8F/1083 (Jan 2007) notified ITU-R that 802.16m project is intended for future contributions on IMT-Advanced.
    - IEEE 802.16 Working Group developed many contributions to WP 5D regarding IMT-Advanced process and technical requirements.
Relevant ITU-R Engagement (continued)

- IMT-Advanced (continued)
  - 5D/356 (Feb 2009) and 5D/443 (May 2009) provided specific notice of intention to submit IMT-Advanced proposal, with additional details.
  - 5D/542 (October 2009): Submission of a Candidate IMT-Advanced RIT based on IEEE 802.16m
Relevant ITU-R Engagement (continued)

- IMT-Advanced (continued)
  - Presentation at the 3rd Workshop on IMT-Advanced as one of two Technology Proponents (Dresden, 15 Oct 2009)
    - 802.16m for both FDD and TDD; targeting meeting all four ITU IMT-Advanced test environments
      - Indoor Hotspot
      - Urban Microcell
      - Urban Macrocell
      - Rural Macrocell
The 802.16 Standard & ITU (continued)

Relevant ITU-R Engagement (continued)

- IMT-Advanced (continued)
  - Cooperating with national standards bodies in support of 802.16 candidate technology
    - Japan, ARIB; Korea, TTA
  - Large commercial support
    - Endorsement of candidate IMT-Advanced RIT based on IEEE 802.16 from 30 multinationals that participate in ITU-R
### The 802.16 Standard 16m Details: SRD Key System Requirements

<table>
<thead>
<tr>
<th>Requirements</th>
<th>IMT-Advanced</th>
<th>802.16m SRD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak spectral efficiency (b/s/Hz/sector)</td>
<td>DL: 15 (4x4)</td>
<td>DL: 8.0/15.0 (2x2/4x4)</td>
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<tr>
<td></td>
<td>UL: 6.75 (2x4)</td>
<td>UL: 2.8/6.75 (1x2/2x4)</td>
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<tr>
<td>Cell spectral efficiency (b/s/Hz/sector)</td>
<td>DL (4x2) = 2.2</td>
<td>DL (2x2) = 2.6</td>
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<tr>
<td></td>
<td>UL (2x4) = 1.4</td>
<td>UL (1x2) = 1.3</td>
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<tr>
<td></td>
<td>(Base coverage urban)</td>
<td>(Mixed Mobility)</td>
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<tr>
<td>Cell edge user spectral efficiency (b/s/Hz)</td>
<td>DL (4x2) = 0.06</td>
<td>DL (2x2) = 0.09</td>
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<td></td>
<td>UL (2x4) = 0.03</td>
<td>UL (1x2) = 0.05</td>
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<td></td>
<td>(Base coverage urban)</td>
<td>(Mixed Mobility)</td>
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<tr>
<td>Latency</td>
<td>C-plane: 100 ms (idle to active)</td>
<td>C-plane: 100 ms (idle to active)</td>
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<td></td>
<td>U-plane: 10 ms</td>
<td>U-plane: 10 ms</td>
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<tr>
<td>Mobility</td>
<td>0.55 at 120 km/h</td>
<td>Optimal performance up to 10 km/h</td>
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<tr>
<td>b/s/Hz at km/h</td>
<td>0.25 at 350 km/h</td>
<td>“Graceful degradation” up to 120 km/h</td>
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<td></td>
<td></td>
<td>“Connectivity” up to 350 km/h</td>
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<tr>
<td></td>
<td></td>
<td>Up to 500 km/h depending on operating frequency</td>
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<tr>
<td>Handover interruption time (ms)</td>
<td>Intra frequency: 27.5</td>
<td>Intra frequency: 27.5</td>
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<tr>
<td></td>
<td>Inter frequency: 40 (in a band)</td>
<td>Inter frequency: 40 (in a band)</td>
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<tr>
<td></td>
<td>60 (between bands)</td>
<td>60 (between bands)</td>
</tr>
<tr>
<td>VoIP capacity (Active users/sector/MHz)</td>
<td>40 (4x2 and 2x4)</td>
<td>60 (DL 2x2 and UL 1x2)</td>
</tr>
<tr>
<td></td>
<td>(Base coverage urban)</td>
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</table>
The 802.16 Standard
16m Details: SDD Key Features

- Protocol Structure
- Frequency Bands
- Convergence Sublayer
- Medium Access Control Layer
- Physical Layer
- Location Based Services
- Enhanced Multicast Broadcast Service
- Multi-Hop Relay
- FemtoBS
- Self-organization
- Multi-carrier Operation
- Interference Mitigation
- RF Requirements
- Inter-BS Synchronization
The 802.16 Standard
16m Details: Amendment: Protocol Structure
The 802.16 Standard
16m Details: Amendment: Frame Structure

- improved voice capacity and reduced channel response latency
The 802.16 Standard
16m Details: Amendment: Frame Detail

TDD Frame: 5 ms

- DL SF0 (6)
- DL SF1 (7)
- DL SF2 (6)
- DL SF3 (6)
- DL SF4 (6)
- UL SF5 (6)
- UL SF6 (6)
- UL SF7 (7)

TTG

6 OFDM symbol = 0.583 ms

- Type-1 Subframe

97.143

7 OFDM symbol = 0.680 ms

- Type-2 Subframe

RTG

FDD Frame: 5 ms

- DL/UL SF0 (6)
- DL/UL SF1 (7)
- DL/UL SF2 (6)
- DL/UL SF3 (6)
- DL/UL SF4 (7)
- DL/UL SF5 (6)
- DL/UL SF6 (6)
- DL/UL SF7 (7)

Idle
The 802.16 Standard
16m Details: Amendment: Preamble

- Primary (PA-) Preamble: For initial acquisition, superframe synchronization, etc.
- Secondary (SA-) Preamble: For fine synchronization, cell identification, etc.
The 802.16 Standard
16m Details: Amendment: Frame Header

- Superframe Header (SFH)
  - To carry the system configuration information for cell selection and system access
- Advanced MAP (A-MAP): RU Assignment A-MAP; HARQ Feedback A-MAP; Power Control A-MAP
# The 802.16 Standard
## 16m Details: Amendment: Numerology

<table>
<thead>
<tr>
<th>Nominal channel bandwidth (MHz)</th>
<th>5</th>
<th>7</th>
<th>8.75</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling factor</td>
<td>28/25</td>
<td>8/7</td>
<td>8/7</td>
<td>28/25</td>
<td>28/25</td>
</tr>
<tr>
<td>Sampling frequency (MHz)</td>
<td>5.6</td>
<td>8</td>
<td>10</td>
<td>11.2</td>
<td>22.4</td>
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<tr>
<td>FFT size</td>
<td>512</td>
<td>1024</td>
<td>1024</td>
<td>1024</td>
<td>2048</td>
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<tr>
<td>Subcarrier spacing (kHz)</td>
<td>10.937500</td>
<td>7.812500</td>
<td>9.765625</td>
<td>10.937500</td>
<td>10.937500</td>
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<td>Useful symbol time $T_u$ (µs)</td>
<td>91.429</td>
<td>128</td>
<td>102.4</td>
<td>91.429</td>
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<tr>
<td><strong>Cyclic prefix (CP)</strong></td>
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</tr>
<tr>
<td>$T_g = 1/8 \ T_u$</td>
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<tr>
<td><strong>FDD</strong></td>
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<tr>
<td>Symbol time $T_s$ (µs)</td>
<td>102.857</td>
<td>144</td>
<td>115.2</td>
<td>102.857</td>
<td>102.857</td>
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<td>Number of OFDMA symbols per frame</td>
<td>48</td>
<td>34</td>
<td>43</td>
<td>48</td>
<td>48</td>
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<tr>
<td>Idle time (µs)</td>
<td>62.857</td>
<td>104</td>
<td>46.40</td>
<td>62.857</td>
<td>62.857</td>
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<tr>
<td><strong>TDD</strong></td>
<td></td>
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<tr>
<td>Number of OFDMA symbols per frame</td>
<td>47</td>
<td>33</td>
<td>42</td>
<td>47</td>
<td>47</td>
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<tr>
<td>TTG + RTG (µs)</td>
<td>165.714</td>
<td>248</td>
<td>161.6</td>
<td>165.714</td>
<td>165.714</td>
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<tr>
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<tr>
<td><strong>CP</strong></td>
<td></td>
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</tr>
<tr>
<td>$T_g = 1/16 \ T_u$</td>
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</tr>
<tr>
<td><strong>FDD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symbol Time $T_s$ (µs)</td>
<td>97.143</td>
<td>136</td>
<td>108.8</td>
<td>97.143</td>
<td>97.143</td>
</tr>
<tr>
<td>Number of OFDMA symbols per frame</td>
<td>51</td>
<td>36</td>
<td>45</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>Idle time (µs)</td>
<td>45.71</td>
<td>104</td>
<td>104</td>
<td>45.71</td>
<td>45.71</td>
</tr>
<tr>
<td><strong>TDD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of OFDMA symbols per frame</td>
<td>50</td>
<td>35</td>
<td>44</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>TTG + RTG (µs)</td>
<td>142.853</td>
<td>240</td>
<td>212.8</td>
<td>142.853</td>
<td>142.853</td>
</tr>
</tbody>
</table>
The 802.16 Standard
16m Details: Amendment: PHY&MAC Improvements

- Advanced MIMO
- Reduced Overhead Resource Mapping
- Multi-carrier Operation
- Advanced Interference Mitigation
- Multi-RAT service
- Co-located Multi-RAT Coexistence
- Inter-BS Synchronization
- Enhanced MBS
- Multi-Hop Relay
- FemtoBS
- Self-organization
- Enhanced LBS
- Improved Privacy and Security
The 802.16 Standard
16m Details: Amendment: PHY&MAC
Improvements (continued)

- Improved Scalability and Flexibility in QoS
- Improved HARQ Integration
- Improved Control Message Integrity
- Enhanced Power Conservation Operation in All Modes
- Emergency Services and Notification support
### The 802.16 Standard
#### 16m Details: Amendment: Performance

<table>
<thead>
<tr>
<th>Designation</th>
<th>Test environment</th>
<th>Deployment scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>InH</td>
<td>Indoor</td>
<td>Indoor Hotspot</td>
</tr>
<tr>
<td>UMi</td>
<td>Microcellular</td>
<td>Urban micro-cell</td>
</tr>
<tr>
<td>UMa</td>
<td>Base coverage urban</td>
<td>Urban macro-cell</td>
</tr>
<tr>
<td>RMa</td>
<td>High speed</td>
<td>Rural macro-cell</td>
</tr>
</tbody>
</table>
### The 802.16 Standard

#### 16m Details: Amendment: Performance

**Table 7-5: DL cell spectral efficiency in bit/s/Hz/cell for TDD**

<table>
<thead>
<tr>
<th></th>
<th>InH</th>
<th>UMi</th>
<th>UMa</th>
<th>RMa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell spectral efficiency</strong></td>
<td>6.93</td>
<td>3.22</td>
<td>2.41</td>
<td>3.23</td>
</tr>
<tr>
<td><strong>ITU-R requirement</strong></td>
<td>3.0</td>
<td>2.6</td>
<td>2.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

**Table 7-7: DL cell spectral efficiency in bit/s/Hz/cell for FDD**

<table>
<thead>
<tr>
<th></th>
<th>InH</th>
<th>UMi</th>
<th>UMa</th>
<th>RMa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell spectral efficiency</strong></td>
<td>6.87</td>
<td>3.27</td>
<td>2.41</td>
<td>3.15</td>
</tr>
<tr>
<td><strong>ITU-R requirement</strong></td>
<td>3.0</td>
<td>2.6</td>
<td>2.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

**Table 7-9: UL cell spectral efficiency in bit/s/Hz/cell for TDD**

<table>
<thead>
<tr>
<th></th>
<th>InH</th>
<th>UMi</th>
<th>UMa</th>
<th>RMa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell spectral efficiency</strong></td>
<td>5.99</td>
<td>2.58</td>
<td>2.57</td>
<td>2.66</td>
</tr>
<tr>
<td><strong>ITU-R requirement</strong></td>
<td>2.25</td>
<td>1.8</td>
<td>1.4</td>
<td>0.7</td>
</tr>
</tbody>
</table>

**Table 7-11: UL cell spectral efficiency in bit/s/Hz/cell for FDD**

<table>
<thead>
<tr>
<th></th>
<th>InH</th>
<th>UMi</th>
<th>UMa</th>
<th>RMa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell spectral efficiency</strong></td>
<td>6.23</td>
<td>2.72</td>
<td>2.69</td>
<td>2.77</td>
</tr>
<tr>
<td><strong>ITU-R requirement</strong></td>
<td>2.25</td>
<td>1.8</td>
<td>1.4</td>
<td>0.7</td>
</tr>
</tbody>
</table>
### The 802.16 Standard
16m Details: Amendment: Performance

Table 7-13: VoIP capacity (users/sector/MHz) for TDD

<table>
<thead>
<tr>
<th>Test environment</th>
<th>DL</th>
<th>UL</th>
<th>Minimum {DL, UL}</th>
<th>ITU-R required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor (InH)</td>
<td>140</td>
<td>165</td>
<td>140</td>
<td>50</td>
</tr>
<tr>
<td>Microcellular (UMi)</td>
<td>82</td>
<td>104</td>
<td>82</td>
<td>40</td>
</tr>
<tr>
<td>Base coverage urban (UMa)</td>
<td>74</td>
<td>95</td>
<td>74</td>
<td>40</td>
</tr>
<tr>
<td>High speed (RMa)</td>
<td>89</td>
<td>103</td>
<td>89</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 7-14: VoIP capacity (users/sector/MHz) for FDD

<table>
<thead>
<tr>
<th>Test environment</th>
<th>DL</th>
<th>UL</th>
<th>Minimum {DL, UL}</th>
<th>ITU-R required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor (InH)</td>
<td>139</td>
<td>166</td>
<td>139</td>
<td>50</td>
</tr>
<tr>
<td>Microcellular (UMi)</td>
<td>77</td>
<td>102</td>
<td>77</td>
<td>40</td>
</tr>
<tr>
<td>Base coverage urban (UMa)</td>
<td>72</td>
<td>95</td>
<td>72</td>
<td>40</td>
</tr>
<tr>
<td>High speed (RMa)</td>
<td>90</td>
<td>101</td>
<td>90</td>
<td>30</td>
</tr>
</tbody>
</table>
## The 802.16 Standard
### 16m Details: Amendment: Performance

<table>
<thead>
<tr>
<th>Mode</th>
<th>Band</th>
<th>RIT</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDD</td>
<td>DL</td>
<td>17.79</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>UL</td>
<td>9.40</td>
<td>6.75</td>
</tr>
<tr>
<td>TDD</td>
<td>DL</td>
<td>16.96</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>UL</td>
<td>9.22</td>
<td>6.75</td>
</tr>
</tbody>
</table>

### Peak Spectral Efficiency (bit/s/Hz)
802.16 WirelessMAN®
Resources & References

- IEEE 802.16 Website
  - http://WirelessMAN.org
- IEEE 802.16 IMT-Advanced web page
  - http://WirelessMAN.org/imt-adv
- IEEE 802.16 Candidate Proposal for IMT-Advanced
  - L802.16-09/0114r4
WiMAX Forum®…

WiMAX Forum Vision:
Global adoption of WiMAX as the broadband wireless Internet technology of choice anytime, anywhere

WiMAX Forum Seeks to Achieve this Vision By:
• Promoting WiMAX to ensure spectrum availability and a favorable regulatory environment.
• Delivering a trusted certification process to achieve global interoperability.
• Publishing technical specifications based on recognized standards.
• Promoting the brand and technology to establish WiMAX as the worldwide market leader for broadband wireless
WiMAX Forum®

- WiMAX Forum <http://wimaxforum.org> is an international consortium of hundreds of leading companies from around the world.
- certifies broadband wireless products based upon IEEE Std 802.16, promoting compatibility and interoperability.
- dedicated to the global adoption of WiMAX as the broadband wireless Internet technology of choice anytime, anywhere.
- Over 150 WiMAX Forum certified Products
  - from 25 BS vendors and 42 SS vendors
- 518 deployments in 146 countries
  - coverage of more than 430 Million people
WiMAX Forum partners with IEEE in supporting IMT-2000 OFDMA TDD WMAN radio interface in ITU-R
- Approved in 2007
- Updated to include FDD in 2009 (awaiting adoption)

Endorses IEEE proposal to include 802.16m in ITU-R’s IMT-Advanced standard
- Issued supportive announcement
- Coordinated ecosystem news conference
- Developed supporting contribution to ITU-R and enlisted 50 companies to co-sign
WG18 activities

- **The IEEE 802.18™ Radio Regulatory Technical Advisory Group (RR-TAG)** supports the wireless Working Groups in the IEEE 802 community by interfacing with regulatory agencies and industry groups working on regulatory issues.

- Administrations constantly upgrade their radio rules and regulations, providing brief opportunities for public comment. The RR-TAG monitors those with potential impact on IEEE 802 wireless standards groups and creates appropriate comment documents.

- The RR-TAG is also the liaison to other standards bodies on radio regulatory matters of mutual interest.
What is IEEE 802.18?

- IEEE 802, the LAN/MAN Standards Committee, or LMSC, currently has 6 Working Groups with projects on standards for radio-based systems ... IEEE 802.11 (WLAN), IEEE 802.15 (WPAN), IEEE 802.16 (WMAN), IEEE 802.20 (Wireless Mobility), IEEE 802.21 (Handoff/Interoperability Between Networks), and IEEE 802.22 (WRAN).

- The monitoring of, and active participation in, ongoing radio regulatory activities, at both the national and international levels, are an important part of the LMSC's work. That is the job of the 802.18 Radio Regulatory Technical Advisory Group ("RR-TAG").
What does IEEE 802.18 do?

IEEE 802.18 doesn’t create wireless standards – but helps to create the correct regulatory environment
- Interfaces directly with national regulators as needed
- Conduit for IEEE 802 inputs to ITU-R
Recent Projects

- ITU-R: IMT Advanced, M.1801, M.1450
- 2.4 GHz rules: EN 300 328, EN 300 220
- FCC Broadband
- FCC NOIs: Broadband, Smart Grid, “White Spaces”
- Ofcom Digital Dividend, MGWS
- DFS, Weather Radar, Airplane operation
- U.S. FDA input on the use of wireless technology in medical devices
- ERO, European Radiocommunications Office,
  - Spectrum Engineering Working Group
    - SE21 - Unwanted Emissions - impact of radar spurious emissions
    - SE 24 - RLAN on board aircraft (SE24_32)
Typical IEEE 802.18 activities

- Provided input to the U.S. Food and Drug Administration on the use of radio frequency wireless technology in medical devices
- Provided input to regulators (e.g. Industry Canada, U.K. Ofcom, U.S. FCC) on proposed spectrum policy changes
IEEE 802.19
IEEE 802 Organization

IEEE Standards Association

Sponsor
IEEE 802
Local and Metropolitan Area Networks (LMSC)

Sponsor
802.3 CSMA/CD Ethernet

Sponsor
802.5 Token Ring

Sponsor
802.11 Wireless LAN

Sponsor
802.15 Wireless Personal Area Networks

Sponsor
802.17 Resilient Packet Ring

802.19 Co-existence TAG

802.18 Radio Regulatory TAG

802.20 Mobile Broadband Wireless Access

802.22 Wireless Regional Area Networks

802.16 Broadband Wireless Access

802.21 Media Independent Handoff

Voting Members ~25

www.ieee802.org/19
The IEEE 802.19™ Wireless Coexistence Working Group

IEEE 802.19 develops standards for coexistence between wireless standards of unlicensed devices.

Develops and maintains policies defining the responsibilities of IEEE 802 standards developers to address issues of coexistence with existing standards and those under development. As required, it offers assessments to the Sponsor Executive Committee (SEC) on how well standards developers have conformed to these conventions. It also may develop coexistence documentation for the technical community outside of IEEE 802.
Overview

- IEEE 802.19 addresses coexistence between unlicensed wireless networks
- The number and diversity of unlicensed wireless networks are both growing
  - Wireless local area networks (802.11)
  - Wireless personal area networks (802.15)
  - Wireless metropolitan area networks (802.16h) and wireless regional area networks (802.22)
- Many of these devices are mobile or portable and can cause harmful interference to other nearby networks
Activities

- IEEE 802.19 provides technical assistance to the working groups developing unlicensed MACPHY standards.
- Sometime the work involves working with multiple working groups (e.g. 802.11 & 802.15) to ensure that the standards operating in the same frequency band contain mechanisms (e.g. adaptive frequency hopping, dynamic frequency selection, etc.) to prevent causing harmful interference to other networks.
New Project – 802.19.1

- With the introduction by the FCC of the new TV white space (TVWS) spectrum several groups are developing MAC/PHY standards for operating in this frequency band
  - IEEE 802.22
  - IEEE 802.11af (TVWS)
  - Others
- IEEE 802.19 has a new standards project (802.19.1) to develop a standard for coexistence between wireless networks in the TV white space
- Some of the cognitive radio technology used in the TV white space may be utilized to provide coexistence between different TVWS networks
- The project started in January 2010
Web Site

You can find out more about IEEE 802.19 at the web site,
  - http://grouper.ieee.org/groups/802/19/

Besides face-to-face meetings 802.19 holds conference calls on coexistence topics

Anyone who is interested can sign up to the email reflector
  - http://ieee802.org/19/pub/subscribe.html
IEEE 802.20
802.20 Mobile Broadband Wireless Access (MBWA) Working Group

- Base standard IEEE 802.20-2008
- Two standards in one
  - TDD UMB design substantially based on 3GPP2/TIA FDD UMB
    - 3GPP2 C.S0084-0-000 thru C.S0084-0-009
  - Separate and unrelated 625kiloHertz-spaced MultiCarrier (625k-MC) enhancements to ATIS High Capacity-Spatial Division Multiple Access (HC-SDMA)
    - ATIS-070004.2005
802.20 Mobile Broadband Wireless Access (MBWA) Working Group

Current projects
- PICS
- Minimum Performance Requirements
- MIB
- Virtual Bridging
802.20 Mobile Broadband Wireless Access (MBWA) Working Group

- TDD UMB (Ultra mobile broadband)
  - DL OFDMA, UL CDMA/OFDMA based air interface PHY
802.20 MBWA
TDD UMB Layering Architecture

Figure 2 — Unicast Route Layering Architecture
802.20 MBWA
TDD UMB FL Superframe Structure

Figure 82 — TDD44 Forward Link Superframe Structure

Figure 83 — TDD63 Forward Link Superframe Structure
### 802.20 MBWA
TDD UMB FL Symbol Numerology

Table 154 — Forward Link Orthogonal Frequency Division Multiplexing Symbol Numerology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FFT Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$N_{FFT} = 512$</td>
</tr>
<tr>
<td>Chip Rate $1/T_{CHIP}$</td>
<td>4.9152</td>
</tr>
<tr>
<td>Subcarrier Spacing $1/(T_{CHIP}N_{FFT})$</td>
<td>9.6</td>
</tr>
<tr>
<td>Bandwidth of Operation</td>
<td>2.5–5</td>
</tr>
<tr>
<td>Cyclic Prefix Duration $T_{CP} = N_{CP}N_{FFT}T_{CHIP}/16$ (N_{CP} = 1, 2, 3, \text{ or } 4)</td>
<td>6.51, 13.02, 19.53, or 26.04</td>
</tr>
<tr>
<td>Windowing Guard Interval $T_{WGI} = N_{FFT}T_{CHIP}/32$</td>
<td>3.26</td>
</tr>
<tr>
<td>Orthogonal Frequency Division Multiplexing Symbol Duration $T_s = N_{FFT}T_{CHIP}(1 + N_{CP}/16 + 1/32)$ (N_{CP} = 1, 2, 3, \text{ or } 4)</td>
<td>113.93, 120.44, 126.95, or 133.46</td>
</tr>
</tbody>
</table>
# 802.20 MBWA

## TDD UMB FL Superframe Numerology

Table 155 — Forward Link Orthogonal Frequency Division Multiplexing Superframe Numerology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N\textsubscript{PREAMBLE}</strong> = Number of Orthogonal Frequency Division Multiplexing Symbols in the Superframe Preamble</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td><strong>N\textsubscript{FRAME}</strong> = Number of Orthogonal Frequency Division Multiplexing Symbols in a Forward Link PHY Frame</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

### Duplexing Mode = TDD44

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of FL PHY Frames in a Superframe</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Guard time between a FL PHY Frame and the subsequent RL PHY Frame</td>
<td>78.13</td>
<td>µs</td>
</tr>
<tr>
<td>(T_{E, TDD, F = 3N_{FFT}T_{CHP}/4})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guard time between a RL PHY Frame and the subsequent FL PHY Frame</td>
<td>16.28</td>
<td>µs</td>
</tr>
<tr>
<td>(T_{E, TDD, R = 5N_{FFT}T_{CHP}/32})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superframe Duration ((T_{SUPERFRAME})) for (N\textsubscript{CP} = 1, 2, 3, \text{ or } 4)</td>
<td>23.07, 24.37, 25.67, 26.98</td>
<td>ms</td>
</tr>
</tbody>
</table>

### Duplexing Mode = TDD63

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of FL PHY Frames in a Superframe</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Guard time between a FL PHY Frame and the subsequent RL PHY Frame</td>
<td>78.13</td>
<td>µs</td>
</tr>
<tr>
<td>(T_{E, TDD, F = 3N_{FFT}T_{CHP}/4})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guard time between a RL PHY Frame and the subsequent FL PHY Frame</td>
<td>16.28</td>
<td>µs</td>
</tr>
<tr>
<td>(T_{E, TDD, R = 5N_{FFT}T_{CHP}/32})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superframe Duration ((T_{SUPERFRAME})) for (N\textsubscript{CP} = 1, 2, 3, \text{ or } 4)</td>
<td>25.80, 27.26, 28.72 or 30.18</td>
<td>ms</td>
</tr>
</tbody>
</table>
802.20 MBWA
TDD UMB Superframe Preamble

- PBCCH – primary broadcast control channel
- SBCCH – secondary broadcast control channel
- QPCH – quick paging channel
- ACQCH – acquisition channel
- OSICH – other sector interference channel
802.20 Mobile Broadband Wireless Access (MBWA) Working Group

References
- http://grouper.ieee.org/groups/802/20/

IEEE 802.20-2008
802.21 Media Independent Handover (MIH) Working Group

- Base standard IEEE 802.21-2008
- Current projects
  - Security Extensions
  - Handovers for Downlink only Technologies
802.21-2008

- 802.21 ‘Shim’ Layer
  - event service (MIES)
  - command service (MICS)
  - information service (MIIS)

- Provide Inter-RAT services
  - Service continuity
  - Quality of service
  - Network discovery
  - Network selection
  - Power management
  - Handover policy
802.21-2008

- Management and control messaging primitives; enabled technology specific
- L2.5 Protocol defined
802.21-2008
Communication Model

PoS – point of service
PoA – point of attachment

Figure 2—MIHF communication model
Figure 4—General MIHF reference model and SAPs
802.21-2008
Protocol Reference Model for 802.3

Media independent
handover function
(MIHF)

MIH event service
MIH command service
MIH information service

MIH users
Layer 3 or higher
Mobility Protocol
(L3MP)

LSAP

LLC-Logical link control
or other MAC client

MAC

PHY
802.21-2008
Protocol Reference Model for 802.11
802.21-2008
Protocol Reference Model for 802.16

Layer 3 or higher Mobility Protocol (L3MP)

- CS_SAP
- Service-specific convergence sublayer (CS)
- MAC_SAP
- MAC common part sublayer (MAC CPS)
- Security sublayer
- PHY_SAP
- PHY

MIH_SAP

Media independent handover function (MIHF)

- MIH event service
- MIH command service
- MIH information service

Management entity
802.21 Media Independent Handover (MIH) Working Group

References

- http://grouper.ieee.org/groups/802/21/

IEEE 802.21-2008
IEEE 802.22
IEEE 802.22 Regional Area Networks

Network Type

RAN: "Regional Area Network"

30 km

IEEE 802.16
IEEE 802.15
IEEE 802.11a
IEEE 802.11b

HIPERMAN
HIPERLAN2
Wi-Max
Wi-Fi
HomeRF
Bluetooth

1-2 km (5 GHz)
33 m
20 m
10 m
20-50 m

10 Mbps
54 Mbps
11 Mbps
54 Mbps
2.4 GHz
5 GHz
< 60 GHz

54 - 862 MHz

Applications

Frequency

Range

European Standards

Industry Alliances

Maximum data rate

23 Mbit/s
BW = 6, 7, 8 MHz

N.A. based Industry Standards

IEEE 802.22

0.25 μsec
0.8 μsec
2.2 μsec
37 μsec

Multipath absorption Window (Cyclic prefix)

Bandwidth

BW = 6, 7, 8 MHz

IEEE 802.22

166
IEEE P802.22 specifies the air interface, including the cognitive medium access control layer (MAC) and physical layer (PHY), for unlicensed point-to-multipoint wireless regional area networks operating in the VHF/UHF TV broadcast bands between 54 MHz and 862 MHz, without disrupting the incumbent services.
Long-range Wireless Broadband Access: Currently Focused Application of WRAN

MAC
Long round-trip delays

PHY
Adaptive modulation

QPSK

16-QAM

64-QAM

QPSK

16 km

5 km

23 km

30 km

5 km
Why TV Broadcast Bands?

- TV broadcast Bands – **Ideal for covering large area in a variety of environments**
  - Low inherent free space propagation loss
  - Excellent foliage and building penetration
  - Desirable non-line-of-sight (NLOS) propagation characteristics

- **They’re available!**
  - So called “TV Band White Spaces”
    - TV spectrum not being used by licensed services
  - Amount available will increase with Digital TV transitions
Global Regulatory Rulings for unlicensed TV Bands Operations

- Regulatory bodies around the world are exploring and adopting rules for unlicensed operation in TV bands
  - United States, FCC [1]
  - Canada, Industry Canada [2]
  - United Kingdom, OfCom [3]
  - European Union

- Aim to promote both economic growth and more efficient and effective use of the TV spectrum
  - Allow the development of new and innovative types of unlicensed devices that provide broadband data and other services for businesses and consumers without disrupting the incumbent services
  - Benefit wireless internet service providers (WISP) by extending the service range of their operations
IEEE 802.22 Management Reference Model

IP Connectivity Provided by Service Provider

Customer Premise Equipment
MIB Managed Node

Base Station
MIB Managed Node

Base Station
MIB Managed Node

Network Control System

Network Management System

Customer Premise Equipment
MIB Managed Node
IEEE 802.22 Protocol Reference Model

Higher Layers: IP, ATM, 1394, etc.

CS SAP
Convergence Sublayer (e.g., 802.1d)

MAC SAP
MAC Common Part Sublayer (CPS)
Security Sublayer 1

PHY SAP

PHY

Spectrum Manager (BS)
Security Sublayer 2

SM-SSF SAP
SM-GL SAP

SSF
Geolocation

Cognitive Plane

Data Plane

Management / Control Plane

Network Control and Management System (BS)
Security Features (e.g., firewall, AAA services)

802.22 Entity

MAC

B1
B2
Frequency Agile Operations of IEEE 802.22 WRAN Systems

- Used by another 802.22 cell
- Allocated to PHY/MAC1
- Used by another 802.22 cell
- Allocated to PHY/MAC2

- Used by incumbents (e.g., TV stations)
- Vacant and available for use by 802.22
Key Technological Features of IEEE 802.22

- Optimized air-interface for long-range TV Band operations
- Efficient use of the spectrum
  - Cell-based centralized spectrum management
  - Collaborative self-coexistence mechanisms
- Cognitive Capabilities for
  - Identifying available TV channels
  - Protecting licensed incumbents
Optimized Air-interface for Long-range TV Band Operations

- **Long-range operation**
  - OFDMA-based PHY parameters are optimized to absorb longer multi-path excess delays up to 30km of coverage distance
  - TDMA-based MAC absorbs additional propagation delays for coverage distances of up to 100 km through intelligent scheduling

- **TV band operation**
  - Channel Bandwidth designed to be 6 MHz, 7 MHz or 8 MHz (same as TV channels) for frequency bands between 54 MHz and 862 MHz
Key OFDMA-based PHY Layer Parameters in IEEE 802.22

- **Sub-carrier Spacing**
  - 3.34 kHz (BW=6MHz); 3.90625 kHz (BW=7MHz) and 4.46 kHz (BW=8 MHz).
  - Optimized for multi-path and Doppler effect in TV band channels

- **Cyclic Prefix**
  - 75, 38, 19 and 9 μs (BW= 6 MHz), 64, 32, 16, 8 μs (BW= 7 MHz), 55, 28, 14 and 7 (BW= 7 MHz).
  - Four different lengths of CP are defined to allow for different channel delay spreads while utilizing the spectrum efficiently.

- **Advanced Modulation and Coding**
  - Combinations of 3 modulation schemes (QPSK, 16QAM, 64QAM) and 4 code rates (1/2, 2/3, 3/4, and 5/6);
  - Forward error codes: Mandatory convolutional codes and 3 optional advanced codes.
Cell-based Centralized Spectrum Management

- **Point-to-multipoint cell topology**: A central BS controls the medium access of a number of associated CPEs.

- Facilitates flexible bandwidth allocation and QoS support, and ensures efficient (intra-cell) spectrum use for data delivery.
IEEE 802.22
Frame Structure

Superframe n-1
Superframe n
Superframe n+1

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Frame Preamble
Superframe Preamble

DS-MAP
FCH
US-MAP

Burst 1
Burst 2
Burst 3

... Time...

US sub-frame
DS sub-frame

Ranging/BW request/UCS notification

26 to 42 symbols corresponding to bandwidths from 6 MHz to 8 MHz and cyclic prefixes from 1/4 to 1/32

IEEE 802.22 Frame Structure
Collaborative Self-coexistence Mechanisms

- **Coexistence Beacons**
  - Inter-WRAN communications

- **Spectrum etiquette**
  - Inter-WRAN channel selection (to avoid conflicting channel selection)

- **On-demand Frame Contention Protocol**
  - Inter-WRAN **Co-Channel Spectrum Sharing**
Coexistence Beacons

- To enable **over-the-air Inter-WRAN communications**.
- Transmitted during the **Self-coexistence Windows** at the end of data frames by the BS and/or some designated CPEs.

![Diagram of Coexistence Beacons]

**Coexistence Beacon**
Spectrum Etiquette

To enable least conflicting Inter-WRAN channel selection
On-demand Frame Contention Protocol

WRAN cells exchange contention messages, containing random contention numbers, to determine their rights of **Co-Channel Data Frames Access**
Cognitive Capabilities

- **Decision-making Policy Engines:**
  - Spectrum Manager
  - Spectrum Automaton

- **Identifying Available TV channels:**
  - Geo-location and Access to Incumbent Database
  - Spectrum Sensing

- **Protecting Incumbents:**
  - Dynamic Frequency Selection (DFS)
  - Transmit Power Control (TPC)
Spectrum Sensing

- Observing the radio frequency spectrum (during **Quiet Periods**) and processing the observations to determine if a channel is occupied by a licensed transmission.

- **Sensing Thresholds:**
  - Digital TV: -116 dBm
  - Analog TV: -94 dBm
  - Wireless Microphones: -107 dBm

- **Channel Detection Time:**
  - 2 seconds for all signal types

- **Probability of Detection:**
  - 90% for all signal types

- **Probability of False Alarm:**
  - 10% for all signal types
802.22 RF Mask

CPE RF Emission Masks

- 4 Watt EIRP
- 33 dB rejection if microphones in 1st adjacent channel
- 1 dB DTV RX desensitization

Channel Spacing

Level relative to in-band power density (dB)
Other Projects within the IEEE802.22 Working Group

- **IEEE 802.22.1**
  - Standard to enhance harmful interference protection for low power licensed devices operating in TV Broadcast Bands

- **IEEE 802.22.2**
  - Recommended Practice for the Installation and Deployment of IEEE 802.22 Systems
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Q & A