Next-Generation IEEE 802.11 WLAN Technologies and Standardization

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Talk Outline

- Introduction to IEEE 802.11 WLAN
- Overview of recent and current standardization
  - .11n for high throughput
    - Key techniques
    - Overview of .11n proposals
- Conclusion
WLAN vs. Other Solutions

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Outdoor</th>
<th>Indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>Wired LAN</td>
<td>Bluetooth</td>
</tr>
<tr>
<td>Walk</td>
<td>UMTS</td>
<td>802.11b</td>
</tr>
<tr>
<td>Fixed</td>
<td>Wideband Cellular</td>
<td>802.11a/g</td>
</tr>
<tr>
<td>Walk</td>
<td>GSM &amp; IS-95</td>
<td>802.11n</td>
</tr>
<tr>
<td>Fixed/Desktop</td>
<td>Indoor Mobility</td>
<td></td>
</tr>
</tbody>
</table>

WLAN vs. Other Solutions

- High performance WLAN
- Wired LAN
- 802.11n
- 802.11a/g
- 802.11b
- GSM & IS-95

WLAN

- Standard
- Mbps (Tx Rate)

Wired LAN
802.11 Standards as of 2004

- .11 MAC
  - .11b CCK @2.4 GHz
    - .11g OFDM @2.4 GHz
  - .11a OFDM @5 GHz
    - .11e MAC for QoS
      - .11i for Security
        - .11h for DFS and TPC

- above MAC

 existing
 finalized in 2003/2004
 finalizing
Enhance the current 802.11 MAC to expand support for applications with Quality of Service requirements, and in the capabilities and efficiency of the protocol.

Modifying both DCF and PCF to make Hybrid Coordination Function (HCF).

Status:
- 802.11e/D12.0
- Currently under sponsor ballot
To enable communications among APs from different vendors to form an infrastructure (called Distribution System)

- E.g., to support hand-off properly

A recommended practice using UDP/IP, TCP/IP, RADIUS, ...

Status
- Completed in 2003
TGg for Extended Rate PHY (ERP)

- To support over 20 Mbps at 2.4 GHz band
- Combination of .11b CCK & .11a OFDM (@2.4 GHz)
  - Optionally, DSSS-OFDM & ER-PBCC-22/33
- Status:
  - Completed in 2003
  - Today’s winner in market
- Defined Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC)
- To handle European regulation, which requires DFS and TPC at 5GHz
  - Can be useful for smart spectrum management
- Status:
  - Completed in 2003
TGi for Security Enhancement

- Enhance the current 802.11 MAC to provide improvements in security
  - Addressing known security problems
- New encryption (AEA), authentication (.1x-based), and key management
- Status:
  - Completed in 2004
On-going Standardization

- High Data Rate
  - 802.11n / TGn
- Radio Resource Measurement
  - 802.11k / TGk
- Fast Roaming
  - 802.11r / TGr
- ESS Mesh Networking
  - 802.11s / TGs
- Wireless Access for the Vehicle Environment
  - 802.11p / TGp
- Wireless Interworking with External Networks
  - 802.11u / TGu
- Wireless Performance Prediction
  - 802.11t / TGt
- Wireless Network Management
  - 802.11v / TGv
- Advanced Security
  - ADS SG
- AP Functionality
  - APF ADHOC
To define Radio Resource Measurement enhancements to provide interfaces to higher layers for network measurements

Original standard has radio resource measurements for internal use
- Make them available to external entities for, e.g., roaming, coexistence, and others

Status:
- 802.11k/D2.0
- 2nd letter ballot is on-going
Wireless access for vehicular environments (WAVE)

- Inter-car and car-to-road communications
- Extension of 802.11a for 5.9 GHz ITS band
- 5.850-5.925GHz Dedicated Short-Range Communication (DSRC) band
- Over line-of-sight distances within 1000 m

Status:

- 802.11p/D1.0 is available as of Nov. 2004
DSRC Performance Envelopes

5850 - 5925 MHz Band Performance Envelope

(Approximate)

Data Transfer and Internet Access Services

Safety Message Services

Emergency Vehicle Services

Toll and Payment Services

902 - 928 MHz Band Performance Envelope

Data Rate (Mbps)

Range (ft)
Multi-hop wireless

To provide a protocol for auto-configuring paths between APs over self-configuring multi-hop topologies
Other Task Groups

- 802.11r for Fast Roaming: Fast roaming and fast BSS transition
  - Fast Roaming
  - With QoS and security in mind
  - E.g.) fast handoff for VoIP flows

- 802.11u for Wireless Interworking with External Network
  - Interworking with 3G cellular
IEEE 802.11n for High-Throughput
To provide higher throughput, i.e., > 100 Mbps, at MAC SAP

- Enhance both OFDM PHY and MAC
  - Make the current MAC more efficient
  - Add MIMO (SDM, STC, beamforming), channel bonding, etc. to PHY

- Status:
  - Proposals made in Sept. 2004
  - As of Jan. 2005, two pending proposals
  - TGn Sync & WWiSE
- **OEM / System Vendors**
  - Cisco
  - Nokia
  - Nortel
  - Panasonic
  - Samsung
  - Sanyo
  - Sony
  - Toshiba

- **Semi Vendors**
  - Agere
  - Atheros
  - Intel
  - Marvell
  - Philips

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**Asia Pacific / Europe / North America**

- **PC**
- **Enterprise**
- **Consumer Electronics**
- **Public Access**
- **Handset**
- **Semiconductor**
WWiSE Members

- Airgo Networks
- Broadcom
- Buffalo
- Conexant
- ETRI
- Realtek
- STMicroelectronics
- Texas Instruments
- Winbond
T Gn Time Schedule (tentative)

- Milestone
  - 2004. 3Q : 11n proposal presentation
  - 2005. 2Q : 11n down selection process
  - 2005. 3Q : 11n baseline selection
  - 2005. 4Q : 11n Draft 1.0
  - 2006. 1Q : 11n 1st Letter Ballot
  - 2007. 1Q : 11n Standard publish
11n PHY Candidate Techniques

- **Channel bonding**
  - E.g., using 40MHz instead of 20MHz (of 11a)

- **Multi-Input Multi-Output (MIMO)**
  - Spatial channels of different antenna pairs are often uncorrelated
  - Data rate or reliability can be improved

Source: [Insider04]
Why is Legacy MAC limited?

- (DCF) with lots of overheads related to PHY and MAC
  - Preamble, PHY & MAC headers, backoff, IFSs, and ACK
  - See below for .11a
.11a & DCF theoretical throughput: ~110 Mbps with max payload=2304 octets & 5400 Mbps TX rate
Key Techniques for 11n MAC:
- 802.11e TXOP and Block ACK
- Frame Aggregation

Ref: [Tinnirello05], [Kim04]
Transmission Opportunity (TXOP)
- Multiple MPDUs (or MSDUs) can be transmitted back-to-back per a channel access

Block ACK
- Instead of immediate ACK
- Block ACK from receiver after a number of MPDUs from transmitter
- Allowing selective ARQ
Different Access Modes and ACK Policies

(a) BI

(b) BB

(c) RI

(d) RB

TXOP Limit

Access Overhead

Release Overhead

Transmission Unit
Throughput vs. TXOP Limit
Ref: [Tinnirello05]

- 8.5
- 8
- 7.5
- 7
- 6.5
- 6
- 5.5
- 5
- 4.5
- 4
- 3.5
- 10

Throughput [Mbps]
TXOP Limit [ms]

- Block ACK
- Unprotected block ACK
- Immediate ACK

-.11b 11Mbps, no channel error, 5 STAs
Theoretical Throughput

Preferred Operation Range
This statistics is from the measurement taken in IEEE 802.11 standard meeting in the morning of July 22nd 2003
Frame Formats (Example)
Ref: [Kim04]

Original

802.2 LLC

octets: 3 5 variable
LLC Header SNAP header IP datagram

802.11 MAC

octets: 2 6 6 6 2 variable
Frame Control Duration / ID Addr 1 Addr 2 Addr 3 Seq. Control Data FCS

With aggregation

802.2 LLC with aggregation

octets: 1 1 1 1 2 2 2 variable variable
DSAP (0x0d) SSAP (0x0d) Control Reserve Count (n) Size 1 ... Size n Etherframe 1 ... Etherframe n

802.11 MAC

octets: 2 2 6 6 6 2 variable 4
Frame Control Duration / ID Addr 1 Addr 2 Addr 3 Seq. Control Data FCS
Throughput vs. Payload via Frame Aggregation Ref: [Kim04]

- .11a PHY, no channel error, a single STA
11n MAC Proposals

(mainly TGn Sync proposal unless specified otherwise)
Ref: [Sync], [WWiSE]
Scalable MAC Architecture

BASELINE MAC
• Robust Aggregation
• QoS Support (802.11e)
• Rx assisted link adapt.

LEGACY INTEROP.
• Long NAV
• Pairwise Spoofing
• Single-Ended Spoofing

ADDITIONAL EFFICIENCY
• Header Compression
• Multi-Receiver Aggregation
• Bi-Directional Data Flow
• BA Enhancements

CHANNEL MANAGEMENT
• 20/40 MHz Modes

Robust & Scalable MAC Architecture
A-MSDU Aggregation

• Efficient Structure
• MSDUs of the same TID can be aggregated
• MSDUs with differing SA/DA can be aggregated
A-MPDU Aggregation

- Robust Structure
- Aggregation is a purely-MAC function
  - PHY has no knowledge of MPDU boundaries
  - Simplest MAC-PHY interface
- Control and data MPDUs can be aggregated
Sync vs. WWiSE Aggregation

A-MSDU

A-MPDU

A-PPDU

Transmit Burst

Upper MAC (TGnSync & WWiSE)

Lower MAC (TGnSync)

Upper PHY (WWiSE)

Lower PHY (WWiSE w/ RIFS TGnSync w/ SIFS)
RX Assisted Link Adaptation

Activity
MAC Tx
IAC
(RTS+MRQ)
**Enhanced Block Ack (BA)**

- Implicit BAR* – BAR can be omitted
- Compressed BA
  - Support for non-fragmented BA to reduce the bitmap size to 1 bit per MSDU
  - Truncation of the bitmap to reduce the number of MSDUs acknowledged in the bitmap
PHY Proposal Comparison

Ref: [Sync], [WWiSE]
**Mandatory Features:**
- 1 or 2 Spatial Streams
- 20MHz and 40MHz* channelization
- 1/2, 2/3, 3/4, and 7/8 channel coding rates
- 400ns & 800ns Guard Interval
- Full & seamless interoperability with a/b/g

**Optional Features:**
- Low Density Parity Check (LDPC) Coding
- 3 or 4 spatial streams

*Not required in regulatory domains where prohibited.*
**WWiSE PHY Summary**

- **Mandatory Features:**
  - 2 transmitters in 20 MHz
  - 1/2, 2/3, 3/4, and 5/6 channel coding rates
  - Rates 54, 81, 108, 121.5, 135 Mbps

- **Optional Features:**
  - 3 and 4 transmit antennas
  - Space-time block codes for longer range
  - 40 MHz counterparts of all 20 MHz modes
  - LDPC code
# Throughput Enhancement

<table>
<thead>
<tr>
<th>Features</th>
<th>TGnSync</th>
<th>WWiSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth extension 20MHz → 40MHz mode</td>
<td>(M) 20MHz mode</td>
<td>(M) 20 MHz mode</td>
</tr>
<tr>
<td></td>
<td>(M) 40MHz, whenever regulatory domain permits this extension</td>
<td>(O) 40 MHz mode</td>
</tr>
<tr>
<td>MIMO-OFDM-SDM</td>
<td>(M) 2 spatial streams @ 20MHz mode</td>
<td>(M) 2 spatial streams @ 20MHz mode</td>
</tr>
<tr>
<td>Guard interval (GI) shortening (0.8us → 0.4us)</td>
<td>(M)</td>
<td>(N)</td>
</tr>
<tr>
<td>Higher code rate (R)</td>
<td>(M) R= ½, 2/3, ¾, 7/8</td>
<td>(M) R= ½, 2/3, ¾, 5/6</td>
</tr>
<tr>
<td>Higher order modulation scheme</td>
<td>(O) 256 QAM (ABF-MIMO mode)</td>
<td>(N)</td>
</tr>
<tr>
<td>Adaptive modulation</td>
<td>(O) Bit loading (+ 256 QAM) + power weighting (ABF-MIMO)</td>
<td>(N)</td>
</tr>
<tr>
<td>Reserve more data tones</td>
<td>(M) 48 (4 pilots) @ 20MHz</td>
<td>(M) 54 (2 pilots) @ 20MHz</td>
</tr>
<tr>
<td></td>
<td>(M) 108 (6 pilots) @ 40MHz</td>
<td>(O) 108 (4 pilots) @ 40MHz</td>
</tr>
</tbody>
</table>

(M) Mandatory   (O) Optional   (N) Not available
## Tx Rate Comparison

*(Maximum achievable uncoded data rate @ 64QAM)*

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<thead>
<tr>
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<th>TGnSync</th>
<th>WWiSE</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(M) 108 (R=3/4)</td>
<td>(M) 121.5 (R=3/4)</td>
</tr>
<tr>
<td></td>
<td>(M) 140 (R=7/8 with ½ GI)</td>
<td>(M) 135 (R=5/6)</td>
</tr>
<tr>
<td><strong>20 MHz BW + 2 Tx</strong></td>
<td>(M) 280 (R=7/8 with ½ GI)</td>
<td>(O) 270 (R=5/6)</td>
</tr>
<tr>
<td></td>
<td>(M) 243 (R=3/4)</td>
<td>(O) 243 (R=3/4)</td>
</tr>
<tr>
<td></td>
<td>(M) 315 (R=7/8 with ½ GI)</td>
<td>(O) 270 (R=5/6)</td>
</tr>
<tr>
<td><strong>20 MHz BW + 4 Tx</strong></td>
<td>(O) 540 (R=7/8 with ½ GI)</td>
<td>(O) 540 (R=5/6)</td>
</tr>
</tbody>
</table>

### Observations:

1. **T > W**, between “R=7/8 with ½ GI” for T and “R=5/6” for W
2. **W >= T**, at “R=3/4 & 2Tx”

*(M) Mandatory  (O) Optional*
**Conclusion**

- IEEE 802.11 is evolving today
  - Up to 802.11v on-going
- Overviewed 802.11n core techniques and proposals
- Close interworking with other air interfaces, e.g., Wibro, should be one of key issues in the future!
References


