Advanced WLAN tutorial

AST – E. Filippi
March 05
General trends in wireless communications
1) Migration to “all IP” wireless

(enable network diversity)

Open service platform

Coexistence of multiple standards

ANY APPLICATION
(VoIP !!!)

IP LAYER

ANY NETWORK

A neutral broker layer connecting any application to any network

The IP layer breaks application-network roadmap bundling → independent service (fast) and connectivity (slow) evolution
2) worldwide Spectrum Reform  
    (enabling adaptive communication)

• Increase allocations for unlicensed use
• Fewer restrictions on licensed spectrum
• Exploration of “underlays” and “overlays”
  – Spectrum Sharing techniques
• Make rules and adoption more progressive
  – From Usage Based to Policy Based rules
• Harmonize Worldwide
3) Migration to OFDM++ systems
(towards Gigabit data rates)

- **Very efficient use of the available spectrum**
  - Good for high data rates

- **Very flexible use of the radio resource**
  - Good for variable-bit rate data traffic

- **Native broadcast**
  - Good for content distribution
Wireless Standards

IEEE 802.15.3
UWB, Bluetooth, Wi-Media, BTSIG, MBOA

IEEE 802.11
Wi-Fi Alliance

IEEE 802.16d
WiMAX

IEEE 802.16e
WiMAX

IEEE 802.20
WiMAX

IEEE 802.22
RAN (>40 km x cell, <10Mpbs)

IEEE 802.16d
3GPP (GPRS/UMTS), 3GPP2 (1X-CDMA2000)
GsMA, OMA

IEEE 802.15.4
(Zigbee Alliance)

IEEE 802.19
RFID
(AutoID Center)

IEEE 802.21
Sensors

IEEE 802.18
802.19

IEEE 802.20
MAN (2-5 km x cell, ~10Mbps)

IEEE 802.21
WAN (>10 km x cell, <10Mbps)

IEEE 802.16e
MAN (2-5 km x cell, ~10Mbps)

IEEE 802.11
LAN (~100m x cell, ~100Mbps)

IEEE 802.15.3
PAN (<10m x cell, ~100Mbps typ x user)

IEEE 802.18
IEEE 802.21, IEEE 802.18 802.19
New wireless technologies incubated @ IEEE802.xx

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE802.15</td>
<td>Wireless Personal Area Networks (WPAN)</td>
<td>UWB (Multi-band OFDM)</td>
</tr>
<tr>
<td>IEEE802.11</td>
<td>Wireless Local Area Networks (WLAN)</td>
<td>OFDM, MIMO-OFDM (multi-antenna OFDM)</td>
</tr>
<tr>
<td>IEEE802.16</td>
<td>Broadband Wireless Access (BWA)</td>
<td>OFDM, OFDMA</td>
</tr>
<tr>
<td>IEEE802.20</td>
<td>Mobile BWA</td>
<td>“flash” (coded) OFDMA</td>
</tr>
<tr>
<td>IEEE802.22</td>
<td>Wireless Regional Area Networks (WRAN)</td>
<td>“cognitive radio”</td>
</tr>
</tbody>
</table>
## Potential application Scenarios

<table>
<thead>
<tr>
<th>Technology</th>
<th>.11 Wi-Fi</th>
<th>.16 WiMAX</th>
<th>UWB</th>
<th>Bluetooth</th>
<th>3GPP/2</th>
<th>RFID</th>
<th>Zigbee</th>
</tr>
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<tbody>
<tr>
<td>LAN for Enterprise</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LAN for Home</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Home multiple A/V distribution</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>(audio streaming)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Backhauling and last mile</td>
<td>Proprietary sol’n</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wide Area Mobility</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cable/device Replacement</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mesh Networking</td>
<td>Enterp/H Home/N</td>
<td>Neighbor- hood Mesh</td>
<td>Home Mesh</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Sensor Networking</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>Inventory Control</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Automotive</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
A deeper look to the 802.11 (Wi-Fi) family evolution
Wi-Fi Industry Status

• Increased interest in cellular/Wi-Fi handsets.
• Price gap for .11g and .11a/g is decreasing rapidly; .11b only devices on steep decline
• Voice over Wi-Fi becoming reality with technical enhancements - WMM, .11i, .11k, .11r
• Security solutions acceptable (WPA2, PEAPv2); security deployment issues being addressed
• Hotspot roaming agreements identified as critical to carriers & ISPs
• Standardization started for 100Mbps WLAN (802.11n) with 2 strong proposals
• Standardization started for automotive extensions (802.11p)
Worldwide Wi-Fi Semiconductor Revenues by Application, 2003 - 2008 ($M)

802.11 WLAN baseline Standard suite

MAC Layer

- d: International Compliance
- e: QoS WME/WSM
- i: WPA Security
- 802.11 Base Protocol

Physical Layer

- a: OFDM 5GHz
- b: CCK 2.4GHz
- g: OFDM/CCK 2.4GHz
- n: MIMO-OFDM 5GHz

Protocol Enhancements
Growing 802.11 Standard improvements

- 1994
- 1995
- 1996
- 1997
- 1998
- 1999
- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007

- 802.11
- 11a
- 11b
- 11c
- 11d
- 11e
- 11f
- 11g
- 11h
- 11i
- 11j
- 11k
- 11n

ST current
Adv. R&D + active Std partic.
WLAN High Throughput extensions
802.11n – 100Mbps WiFi

- **The “fast Ethernet” of WiFi**
  - At least 100 Mbps “goodput” mandatory
  - Linear “obvious” point in any WLAN roadmap

- **High scalability of the solution**
  - PHY Data rate: from 54 up to 530 MBit/s
  - Tx, Rx antennas: from 1 to 4
  - channel bandwidth: 20 and 40 MHz
  - Backward-compatible with 802.11a/b/g

- **Flexible throughput/reliability tradeoff possible**
  - Diversity maximization ⇒ *Space Time Codes (STC)*
  - Data rate maximization ⇒ *Spatial Division Multiplexing*

- **Very high spectral efficiency**
  - Bit/s/Hz growing linearly with the number of antennas
802.11n Std Roadmap

• Activity started in Q4 ‘02
• Par/5 Criteria: March ’03
• Functional Requirements: Nov ‘03
• Usage Models: May ’04
• Comparison Criteria: May ‘04
• Proposals: Sept ’04
• … convergence, plug fests, beta, …
• Ratification: Sept ’06
• Wi-Fi Certification: Sept ‘06
802.11n MIMO-OFDM technology

spatial multiplexing + powerful outer code

= Tremendous capacity increase with the same total TX power

- MIMO
  - More bit/s/Hz and performances @ same total power
- OFDM
  - Robust vs multipath
  - Simplified equalization
- Advanced Channel Code (LDPC, TC)
  - Lower S/N
  - Higher Code Rate
- E-MAC
  - Higher system efficiency
MIMO wireless comms

- Different data sent on different transmit antennas
- The signal from each transmit antenna is received at ALL receive antennas
- Channel impulse response is a matrix
  - NxN matrix; where N is the number of TX and RX antennas
MIMO capacity

• Channel impulse response matrix is invertible
  – Provided sufficiently high dispersion in the environment
  – Invertible => N parallel and independent spatial channels exist

• Capacity of the Space-Time MIMO channel is much higher
  – Tremendous capacity increase with same total TX power
  – Data communication possible even with negative average SNRs per antenna
Is the 802.11 MAC sufficient for wireless high speed LANs?
802.11 Basics

- Fixed interframe spaces (IFSs)
  - aSlot, SIFS
  - All IFS others are sums of the above
- Multiple PHY modes
  - E.g. 802.11a, 802.11b, 802.11g
  - IFS constant for all PHY modes within same standard
    - 802.11 relies here on
Basic calculations

• Simple scenario
  – One receiving station, one transmitting station
• Backoff duration equal to $\text{DIFS} + 7.5\times a\text{Slot}$
• Error free wireless medium
PHY efficiency

- 802.11a
- BPSK $\frac{1}{2}$
- Highly efficient
IFS limiting throughput

- OFDM PHY
- IFS according to 802.11a
- Assuming infinite PHY speed
Assuming new PHY

- OFDM based
- Preamble = 12µs
- Header = 3µs
- tSYM = 3µs
- aSlot = 4µs
- SIFS = 8µs
- 1024Mb/s PHY
Performance problems

• Static overhead (e.g. OFDM)
  – Independent of PHY speed (IFS etc.)

• Protocol overhead
  – One ACK per one DATA frame
    • 802.11e Block ACK very important to increase efficiency!
  – Often transceiver turnaround
    • Duration limited by hardware

• Constant preamble duration (OFDM)
  – Can be become quite large compared to DATA
Design issues for future MAC

- Idle channel is unused capacity
- Develop collision free MAC
- Avoid signaling for channel competition
- Piggyback additional information

- Use all available information
  - Channel busy histogram (11-03/340r1a)
  - Listen to neighbors
  - QoS sensitive traffic may be “predictable”
  - RTS but no CTS reception enables parallel transmission
MAC design for high speed PHY

- Higher data rate → lower reception range
- Much bandwidth at high frequencies
  - High attenuation, especially walls etc.
- Avoid small frames
  - Concatenate frames
  - Multiplex data
- Interference range determined by transmission power
  - Regardless of PHY mode
- Incremental redundancy
  - Always highest PHY
  - Combine retransmitted & failed frame
MAC regarding higher layers

• WLAN drawbacks on TCP
  – TCP transmission window
  – MAC retransmissions
  ➔ Terminate TCP at AP
  – Possible? Connection tracking? How to replace TCP on wireless link?

• WLAN aware of applications?
  – VoIP
    • Discard than retransmit
  – Concatenation of frames
MAC regarding high attenuation

- Use attenuation to the benefit
- Spatial reuse possible
- Multi hop support needed
  - High speed links with limited range
Conclusions

• 802.11 MAC worked very well
  – Highly efficient at low speed PHY
  – Drawbacks at high speed
  – Today’s “ethernet” (802.3) is switched
    • WLAN is different

• Future WLAN will need new MAC
  – Support for multi hop, MAC routing
  – Increased efficiency
  – Avoid “legacy” backoff
What we can do for high throughput MAC

1. Reduce the overhead
2. Reduce the collisions
3. Optimize resources utilization
Reduce the overhead

• Features from 802.11e
  ➢ Packet bursting (TXop)
  ➢ Block-ACK
  ➢ Direct Link Protocol (DLP)

• Frame aggregation

• Others
  – E.g.: Turbo TCP / Piggybacking
802.11e WG recap

- Formed in Dep. 1999. The first draft was available in 2001
- Finalization expected for 2004.
- **Status:** Letter ballot #67. Draft 8.0, opens 24\textsuperscript{th} Feb, close March 10\textsuperscript{th}. Letter ballot #65, Draft 7.0 recirculation, from January 31\textsuperscript{st} to February 15\textsuperscript{th} 2004 (response ratio 94\%, approve 93\%)
- **Scope:** Enhance the 802.11 Medium Access Control (MAC) to improve and manage **Quality of Service**, and provide classes of service. Consider **efficiency enhancements** in the areas of the Distributed Coordination Function (DCF) and Point Coordination Function (PCF).
- **Requirement:** defining a new MAC backward compatible with the legacy MAC
What Does QoS Mean?

- Each application has a requirements tuple
  - max latency
  - min data rate
  - max packet drop probability
- The set of tuples define points that delimit the requirements curve
Why 802.11 does not guarantee QoS?

– DCF: Best-effort service with contention-based MAC

– PCF:

  • Inefficient and complex central polling scheme
  • Unpredictable beacon frame delay due to incompatible cooperation between CP and CFP modes
  • Transmission time of the polled stations is unknown
802.11 Distributed Coordination Function (DCF)

- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
DCF
stop-and-wait ARQ

• Receiver of a directed frame returns an ACK
• If ACK not received, sender retransmits after another backoff
PCF

- Poll-and-response MAC for nearly Isochronous service
- In infrastructure BSS only – Point Coordinator (PC) resides in AP
- Alternating Contention-Free Period (CFP) and Contention Period (CP)
Contestion Free Period

- Two consecutive frames are separated by SIFS
- CFP maximum length announced by AP; used for NAV set

Contention Free Period Repetition Interval (CFPRI) or Superframe

- Contention Period (CP) for DCF
- Contention Free Period (CFP) for PCF

Beacon
D1+Poll
U1+Ack
D2+Ack+Poll
U2+Ack
CF-End

Downlink
Uplink
PIFS
SIFS
SIFS
SIFS
SIFS
Reset NAV

Dx - downlink frame to STA x
Ux - uplink frame from STA x

CF_MAX_Duration

802.11e: QoS Support
802.11e: QoS Improvements

802.11e MAC – Hybrid Coordination Function (HCF) with two access mechanisms

- Contention-based channel access (Variation of legacy DCF)
  - Enhanced Distributed Channel Access (EDCA) for prioritized QoS
  - Distributed Admission Control

- Controlled channel access (CCA) (Variation of legacy PCF)
  - Polling mode plus HC’s prioritized channel access for parameterized
  - Centralized Admission Control
## QoS level in 802.11e

<table>
<thead>
<tr>
<th>QoS Level</th>
<th>Channel Access Mechanism</th>
<th>Scheduling policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2</td>
<td>HCF (EDCF and HCF controlled channel access)</td>
<td>Parameterized/prioritized</td>
</tr>
<tr>
<td>Level 1</td>
<td>HCF (EDCF only)</td>
<td>prioritized</td>
</tr>
<tr>
<td>Level 0</td>
<td>DCF, PCF</td>
<td>none</td>
</tr>
</tbody>
</table>
802.11e EDCA

- Access category (AC) as a virtual DCF
- 4 ACs implemented within a QSTA to support 8 priorities
- Multiple ACs contend independently for TxOp
- The winning AC transmits one or more frame (depends on TxOp value)
Differentiated Channel Access of 802.11e EDCA

- Each AC contends with
  - $\text{AIFS}[\text{AC}]$ (instead of $\text{DIFS}$) and $\text{CWmin}[\text{AC}] / \text{CWmax}[\text{AC}]$ (instead of $\text{CWmin} / \text{CWmax}$)

**Figure 49 - Some IFS Relationships**
Access Category

Table 20.1 – ACI to AC coding

<table>
<thead>
<tr>
<th>ACI</th>
<th>AC</th>
<th>Access Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>AC BE</td>
<td>Best Effort</td>
</tr>
<tr>
<td>01</td>
<td>AC BK</td>
<td>Background</td>
</tr>
<tr>
<td>10</td>
<td>AC VI</td>
<td>Video</td>
</tr>
<tr>
<td>11</td>
<td>AC VO</td>
<td>Voice</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(UP – Same as 802.1D User Priority)</th>
<th>Designation</th>
<th>Category (AC)</th>
<th>(Informative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>lowest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>BK</td>
<td>AC_BK</td>
<td>Background</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>AC_BK</td>
<td>Background</td>
</tr>
<tr>
<td>0</td>
<td>BE</td>
<td>AC_BE</td>
<td>Best Effort</td>
</tr>
<tr>
<td>3</td>
<td>EE</td>
<td>AC_BE</td>
<td>Video</td>
</tr>
<tr>
<td>4</td>
<td>CL</td>
<td>AC_VI</td>
<td>Video</td>
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<tr>
<td>5</td>
<td>VI</td>
<td>AC_VI</td>
<td>Video</td>
</tr>
<tr>
<td>6</td>
<td>VO</td>
<td>AC_VO</td>
<td>Voice</td>
</tr>
<tr>
<td>7</td>
<td>NC</td>
<td>AC_VO</td>
<td>Voice</td>
</tr>
</tbody>
</table>

ACI: access category index
802.11e: Throughput enhancements

- Continuation of TxOp
- Block Acknowledgement
- Direct Link Protocol
- No-ACK
Direct Link Protocol

• 802.11-1997 specification permits traffic in an AP-based network between clients and AP only

• 802.11e adds capability for clients to send traffic directly to each other
  – improves bandwidth efficiency, particularly in home networks
Direct Link Protocol

Station — AP — Station

802.11e: Efficiency enhancements
Block Ack

- The Block Acknowledgement (Block Ack) mechanism allows a block of QoS Data MPDUs to be transmitted, each separated by a SIFS period, between two QSTAs.

- A cumulative ACK is sent at the end of the burst transmission
Block Acknowledgment
ack policy

• Immediate
  – Suitable for high-bandwidth, low latency traffic.

• Delayed
  – Suitable for applications that can tolerate moderate latency.
  – Allow the existing implementations to use this feature with minimal hardware changes and also to allow inexpensive implementations that would use the processing power on the host
Block Acknowledgment
Block Acknowledgment Protection mechanism

- Collisions can cause many losses
- RTS/CTS used to protect a burst
Block Acknowledgment
Protection mechanism

• RTS/CTS used to protect a burst
• Response for the first frame to set NAV

Could be used to tx feedback information from the receiver
Frame Size Affects Throughput

- 802.11 MAC/PHY have big fixed overheads
  - MAC header, IFSs, ACK, and Backoff
  - PLCP preamble & headers
Frame Aggregation

Queue

MPDU Agg. (1)

3 PPDUs created

Queue

MPDU Agg. (2)

2 PPDUs created

Queue

PPDU Agg.

Preamble + PLCP header

MAC header

Dest.

FCS

Pad Bits + Tail

IFS

MSDU

MPDU/PSDU

PPDU
Further enhancements: optimize resources utilization

• Finer/tighter cross-layer interaction
  ➢ Link quality/Congestion estimation
  ➢ Extended MAC-PHY interface

• Link adaptation
Rate adaptation

• There are two approaches for solutions to the rate adaptation schemes:

  – Auto Rate Fallback (ARF) - Use history of previous transmissions to adaptively select future rates
    ✅ No changes to the protocols and standards
    ✅ They have to be carefully designed to achieve good performance

  – Receiver-based auto rate (RBAR) - use signal measurements for rate selection
    ✅ They achieve good performance
    ✅ Big overhead and changes to the Standard
Rate adaptation

• All the proposed schemes use static or near-static thresholds:
  – WaveLAN (-2, +10)
  – IBM (-1, +10/+3) – it is a bit more dynamic than WaveLAN because it is using two thresholds to account for different spread dopplers

• Further improvement: dynamically adapt the thresholds
  – 20-30% goodput improvement possible
WLAN mesh extensions
Today’s 1st generation wireless LANs have been architected as wire replacements.

**CHALLENGE:** Define and architect wireless networks to fully utilize “wirelessness”
Radio Networks

• Current Radios optimize point to point RF link performance
• Radio Networks optimize total performance of the network
  – Self-configuring mesh topology
  – Multi-hop
Mesh Network Types

Service Provider Networks
- Last mile broadband

Home
- High Bandwidth Home Networks

Enterprise
- Range Extension and Load balancing

Industrial
- Heterogeneous Sensor Networks
- 802.11 XScale™ technology
IEEE 802.11s – PAR

- To develop an IEEE 802.11 Extended Service Set (ESS) Mesh with an IEEE 802.11 Wireless Distribution System (WDS) using the IEEE 802.11 MAC/PHY layers that supports both broadcast/multicast and unicast delivery over self-configuring multi-hop topologies.
- To extend the IEEE 802.11 MAC. No physical layer is included.
- To provide a protocol for auto-configuring paths between APs over self-configuring multi-hop topologies in a WDS to support both broadcast/multicast and unicast traffic in an ESS Mesh using the four-address frame format or an extension.
- A target configuration is up to 32 devices participating as AP forwarders in the ESS Mesh.
- To utilize IEEE 802.11i security mechanisms, or an extension thereof, for the purpose of securing an ESS Mesh.
- 802.11s Project Authorization Request (PAR) = Doc #11-04-54r2
802.11s – Example of .11s Mesh Network

N_Mesh Point: Mesh Point without AP function or portal function
802.11s – Functional Requirements and Scope (1)

- Mesh Topology Learning, Routing and Forwarding
- Mesh Security
- Mesh Measurement
- Mesh Discovery and Association
- Mesh Medium Access Coordination
- Compatibility to 802.11 Service
- Interworking
- Mesh Configuration and Management
802.11s – Functional Requirements and Scope(2)

- High-level view on the system functions interactions
802.11s—Functional Requirements and Scope (3)

Mesh Topology Learning, Routing and Forwarding:

- Possible Routing Protocol
  - On-demand routing/proactive routing.
  - Topology-based protocol/distance-vector based protocol.
  - Uniform protocol/non-uniform protocol.
- Architecture to support alternative routing protocols
- Mesh routing in the presence of low-power mesh points
- Mesh routing with Multiple radio devices
- Broadcast/multicast/unicast data delivery support
Mesh Security:

- Secure association of Mesh Point
- Secure data message/management message/routing message
- Centralized/distributed authentication and key management
- Extension of 802.11i for mesh
Mesh Measurement:
- Specification of radio-aware metrics for use by mesh network
- Mesh link/path quality measurements
- Measurement to support channel selection
- Measurement to aid STAs in making roaming decision

Mesh Discovery and Association:
- Protocols to allow Mesh Points to discover Mesh Networks
- Protocols to allow Mesh Points to associate with a Mesh Network
- Protocols to allow Mesh Points to associate with other Mesh Points within a Mesh Network
Mesh Medium Access Coordination:

- Mitigate performance degradation caused by hidden nodes/exposed nodes
- Support of admission control
- Support of congestion control
- Improve spatial reuse
- Management of multiple classes of traffic
- Coordinating channel access across multiple nodes to avoid performance degradation
- Mesh link communication coordination
802.11s—Functional Requirements and Scope (7)

Compatibility to 802.11 Services:
- Mesh Point DS Services integration
- Mesh compatibility with STA mobility/roaming
- Techniques to meet 802.11r system requirement

Interworking:
- Interface with high level protocol
- Interface with other IEEE 802 LANs

Mesh Configuration and Management:
- Support for managed network management model
- Support for unmanaged network management model
- Self-configuration support
- Information exchange about Capability information of Mesh Points
- Mesh network channel selection
- Support for time synchronization
802.11s – Usage Models (Potential Markets) 1

- **Residential.**
  - Indoor environment.
  - Mesh point number: 8.
  - Easy Installation.
  - Coexistence with other Mesh networks/BSSs.

- **Office.**
  - Indoor environment.
  - Mesh point number: 32.
  - Higher device density and bandwidth requirements as compared with campus networks.
  - Support unmanaged mode and central managed mode.

- **Campus/Community/Public Access Network.**
  - Seamless connectivity over large geographic areas.
  - Mesh point number: 32-100.
  - Provide alternatives to traditional internet access methods.
  - Centralized management.
  - Scalability, automatic reconfiguration and reliability.
802.11s – Usage Models (Potential Markets) 2

• Public Safety
  – Semi-permanent infrastructure and Mobile mesh points coexist.
  – Mesh point number: 32.
  – Mostly outdoors.
  – Node mobility.
  – Dynamic variations in radio propagations.
  – Strong requirements of network self-configuration and self-management.

• Military.
  – Sensitive to energy conservation.
  – Mesh point number: 32.
  – Mostly outdoors.
  – Node mobility.
  – STAs need to become mesh AP temporarily.
802.11s – Major Deadlines

• Those wishing to submit a proposal must send the 802.11 TGS Chair a notice of intent to submit at the end of the Friday before the March 2005 Meeting.

• 11s will allocate some time for the voluntary preliminary presentation of proposals at the March and May 802.11 Meetings.

• An IEEE 802.11 submission or submissions describing the proposal in detail must be uploaded to the 802wirelessworld server by midnight Eastern USA time, at the end of 15 June 2005.

• All the proposals will be presented at the July 2005 meeting of 802.11.
Is the 802.11 MAC sufficient for wireless mesh?
Multi hop MAC issues

- Avoid hidden station problem
- Avoid “Neighborhood capture” (11-01/596r1)
- Multiplex data on streams
  - Avoid separate transmissions on same route

Multiplex Data at forwarder
Multi hop needs routing

- No information exchange between layers
- MAC layer routing instead L3 routing
- New routing aware of
  - PHY mode
  - Transmission power
  - Interference level, etc.

<table>
<thead>
<tr>
<th>Layer 3</th>
<th>ISO/OSI:</th>
<th>Internet:</th>
<th>Routing</th>
<th>Network Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wired</td>
<td></td>
<td></td>
<td>IP</td>
</tr>
<tr>
<td></td>
<td>BGP</td>
<td></td>
<td>Wireless</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OSPF</td>
<td></td>
<td></td>
<td>DSDV (proactiv)</td>
</tr>
<tr>
<td></td>
<td>etc.</td>
<td></td>
<td></td>
<td>AODV (reactiv)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TORA (pro-/reactiv)</td>
</tr>
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<table>
<thead>
<tr>
<th>Layer 2</th>
<th>ISO/OSI:</th>
<th>Internet:</th>
<th>Medium access</th>
<th>Data Link Layer</th>
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<tbody>
<tr>
<td></td>
<td>Wired</td>
<td></td>
<td>Wireless</td>
<td>MAC</td>
</tr>
<tr>
<td></td>
<td>CSMA/CD,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Full-Duplex</td>
<td>(switching)</td>
<td>CSMA/CA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Half-Duplex</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(collision)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Layer 1</th>
<th>ISO/OSI:</th>
<th>Internet:</th>
<th>Data Circuit</th>
<th>Physical Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wired</td>
<td></td>
<td>Wireless</td>
<td>PHY</td>
</tr>
<tr>
<td></td>
<td>Twisted Pair</td>
<td></td>
<td>DSSS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fibre Link</td>
<td></td>
<td>FHSS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coax cable</td>
<td></td>
<td>OFDM</td>
<td></td>
</tr>
</tbody>
</table>
ST/UCLA Partial Proposal

• Routing Protocol
• Congestion Control
• Neighbor-list LC-EDCA
• Admission Control
Routing Protocol Architecture

- Routing architecture allows proactive link state protocol and on-demand distance vector protocol to adapt to different usage scenarios.
  - On-demand distance vector is the default routing protocol, it also used for large mesh networks. AODV (Ad hoc On Demand Distance Vector) is the distance vector protocol being selected.
  - link state protocol is the option protocol, it is used for dense, high mobile network. OLSR (Optimized Link State Routing)+FSR (Fish Eye State Routing) is the link state protocol being selected.
- Routing architecture allows different routing destinations:
  - Routing to non-AP STAs is the default one.
  - Routing to Mesh Points is the optional one.
- Routing architecture allows different multicast routing protocol to adapt to different usage scenarios:
  - Multicast Ad-hoc On Demand Distance Vector (MAODV) is the default routing protocol.
  - ODMRP+MPR (On Demand Multicast Routing Protocol + Multiple Point Reply) is the optional routing protocol.
Unicast Routing Protocol----AODV

- AODV (Ad hoc On Demand Distance Vector) is an on-demand distance vector protocol.
  - Route Request (RREQ) and Route Reply (RREP) are used for finding a route from source to destination when the source has packets to send.
  - It is a loop-free routing protocol.
  - RREQ is a broadcast packet and RREP is a unicast packet.
Unicast Routing Protocol----
OLSR+FSR

• OLSR (Optimized Link State Routing) is a proactive link state protocol.
  – Link state information is broadcast in the network.
  – Each node establishes its routing table according to the link state it received.
  – To decrease the control packet overhead, MPR (multiple point relay) is used. Only the MPR of each node (MPR selector) broadcast MPR selector’s link state information.

• FSR (Fish-eye State Routing) decreases the control packet overhead further:
  – Link state information updates for a near destination are propagated more frequently than updates for a remote destination
Routing To Non-AP STA

- Each non-AP STA is the routing destination.
- The mesh AP is the routing proxy of its associated non-AP STA.
- The routing table includes non-AP STAs and mesh points as the destinations of the routes.
- 4 MAC addresses in the 802.11 header are enough to route the packet.

Mesh Point3’s routing table:
- Destination : Next Hop
- STA4 : Mesh AP2
- STA3 : Mesh AP2
- STA1 : Mesh Point2
- Mesh Portal2: Mesh Portal2

Mesh Portal1: Mesh Point2

Mesh AP2’s routing table:
- Destination : Next Hop
- STA1 : Mesh Point1
- STA2 : Mesh Point1
- Mesh Portal2: Mesh Point3
- Mesh Portal1: Mesh Point1
Routing To Non-AP STA

• Data Packet Forwarding
  – The source mesh point does the following functions:
    • Add 11s’ header
    • Fill the frame type and TTL
    • Look up the routing table to find the next hop mesh point, and send the packet out to the next hop
  – The destination mesh point does the following functions:
    • Delete 11s’ header
Routing To Mesh Point

- Only the Mesh Point is the routing destination.
- The mesh AP broadcasts its associated non-AP STAs to the border mesh points which include mesh portals and mesh APs.
- The routing table includes mesh points as the destination of the routes.
- A special map table which maps the non-AP STAs to the associated mesh AP is defined in each border mesh point.
- 6 MAC addresses are required to route the packet.

Mesh Point3’s routing table:
- Destination: Next Hop
- Mesh AP2: Mesh AP2
- Mesh AP1: Mesh Point2
- Mesh Portal2: Mesh Portal2
- Mesh Portal1: Mesh Point2

Mesh AP2’s routing table:
- Destination: Next Hop
- Mesh AP1: Mesh Point1
- Mesh Portal2: Mesh Point3
- Mesh Portal1: Mesh Point1

Mesh AP2’s Map table:
- Non-AP STA: Mesh AP
  - STA1: Mesh AP1
  - STA2: Mesh AP1
Routing To Mesh Point

• Data Packet Forwarding
  – The source mesh point does the following functions:
    • Add 11s’ header
    • Fill the frame type and TTL
    • Set the Destination STA MAC ADDR according to 802.11’s DA
    • Set the Source STA MAC ADDR according to 802.11’s SA
    • Set the 802.11’s SA according to the source mesh point’s MAC address
    • Look up non-AP STA map table to find the destination mesh point of the destination STA, set the 802.11’s DA according to the destination mesh point’s MAC address
    • Look up the routing table to find the next hop mesh point, and send the packet to the next hop
  – The destination mesh point does the following functions:
    • Set the 802.11’s DA according to the Destination STA MAC ADDR
    • Set the 802.11’s SA according to the Source STA MAC ADDR
    • Delete 11s’ header
Mesh Layer Header

- A new shim header (2.5 layer header) is added between MAC layer and LLC layer
  - Frame Type (2 Octets)
  - Reserved (1 Octet)
  - TTL (1 Octet)
  - Source STA MAC ADDR (6 Octets, optional field)
  - Destination STA MAC ADDR (6 Octets, optional field)
- Source/destination MAC address should be included in IP packets. 11s routing packets and other management frames do not include these two fields.
Multicast Routing----Tree-based Multicast Routing Protocol

• A tree is built for group communication.
• Only one path exists between any two multicast members.
• A multicast group leader maintains up to date multicast tree information by sending periodic hello information.
• It scales well for the sender number and multicast group number.
• In fast mobile network, the packet delivery ratio becomes worse.
Multicast Routing----Tree-based Multicast Routing Protocol

- MAODV (multicast Ad-hoc On-Demand Distance Vector) is a tree-based multicast routing protocol.
- A mobile node wishing to join a multicast group or having data to send to a multicast group originates a Route Request (RREQ).
- After receiving a RREQ, the intermediate node rebroadcasts RREQ and establish the reverse route if it is not the multicast group’s member.
- If the multicast group’s member receives a RREQ, it unicasts a Route Reply (RREP).
- As the nodes along the path to the source node receive the RREP, they add both a route table entry and multicast route table entry for the node.
- The source node activates the multicast route to it through unicasting a multicast activation (MACT).
Multicast Routing----Mesh-based Multicast Routing Protocol

- A mesh forwarding path is built for group communication.
- More than one path may exist between multicast sender and multicast receiver pair.
- Every source node will periodically send out route request through the network.
- It scales well for the sender number and multicast group number.
- The mesh-based multicast is more robust since alternative path exists.
Multicast Routing----Mesh-based Multicast Routing Protocol

- ODMRP (On-Demand Multicast Routing Protocol) is a mesh-based multicast routing protocol.
- While a multicast source has packets to send, it flood a JOIN QUERY with data piggybacked.
- When a node receives a non-duplicate JOIN QUERY, it stores the upstream node ID into the route table and rebroadcast the packet.
- When the JOIN QUERY packet reaches a multicast receiver, the receiver creates and broadcast a JOIN REPLY to its neighbors.
- When a node receives a JOIN REPLY and it is on the path to the source, it sets forwarding group flag and broadcasts its own JOIN REPLY until it reaches the multicast source.
Multicast Routing----ODMRP+MPR

- If OLSR is used as the unicast ad hoc network routing protocol, MPR is selected by each node.
- Only MPR of a node rebroadcast JOIN QUERY.
- This can decrease control packet overhead.
- ODMRP+MPR has the following features:
  - The proposed multicast routing protocol is more robust in mobile environment.
  - The proposed multicast routing protocol is more scalable to large multicast group.
  - MPR feature can only be activated if OLSR routing protocol is used as unicast routing protocol.
Congestion Control (1)

Actual Scheduling Result when load=700kb/s

<table>
<thead>
<tr>
<th>Rx</th>
<th>238k</th>
<th>1021k</th>
<th>899k</th>
<th>1052k</th>
<th>235k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx</td>
<td>674k</td>
<td>687k</td>
<td>702k</td>
<td>685k</td>
<td>697k</td>
</tr>
</tbody>
</table>

e2e throughput

Congested nodes

Wasted TX

Ideal Scheduling, when the network is overloaded

<table>
<thead>
<tr>
<th>Rx</th>
<th>430k</th>
<th>860k</th>
<th>860k</th>
<th>860k</th>
<th>860k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx</td>
<td>430k</td>
<td>860k</td>
<td>860k</td>
<td>860k</td>
<td>430k</td>
</tr>
</tbody>
</table>

e2e throughput
Congestion Control (2)

- 802.11e Access Category-based congestion control
- Each MP detects network congestion according to:
  - Delay.
  - Queue size.
  - Packet loss rate.
- When congestion occurs, random early congestion notification information is sent to the upstream MP.
- The upstream MP polices the packet transmission rate.
Congestion Control (3)

- Congestion control simulation result

Shadowing channel model in NS2 is used in the simulation.


- Simulation scenario is:

<table>
<thead>
<tr>
<th>PHY rate</th>
<th>54 Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDP 1</td>
<td>30 Mbps</td>
</tr>
<tr>
<td>UDP 2</td>
<td>30 Mbps</td>
</tr>
<tr>
<td>Block Ack</td>
<td>disabled</td>
</tr>
</tbody>
</table>
Admission Control(1)

- Admission control is used for real-time traffic.
- Admission control is done at the destination Mesh Point (MP).
  - A request message is used to get the available bandwidth of the selected path, and the requested bandwidth.
  - The destination decides if the request is admitted.
  - The forwarding information is established when the response message is sent back to the source MP.
- The available bandwidth equals the difference between the total bandwidth allocated to the real-time traffic and the bandwidth used by the real-time traffic.
- The bandwidth used by the real-time traffic at any node is measured based on the real-time packets the node detected.
Admission Control(2)

- The reasons for re-admission control.
  - Node mobility
  - False admission.
- The congested MP randomly selects some admitted traffic and notifies the source MP to request admission again.

The available bw of MP1: 5Mbps
The available bws of other MPs: 10Mbps
The bw requested by MAP1: 3Mbps
The bw requested by MAP2: 4Mbps