An Overview of the Hybrid Wireless MAC Protocol

Providing Asynchronous and Synchronous MSDU Data Delivery Services

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Agenda

- Summarize implicit assumptions/requirements
- Describe the Hybrid MAC Protocol
  - Media independent: RF and IR
  - Two classes of MSDU transport service:
    - Asynchronous data traffic
    - Synchronous data traffic
  - No required distribution system
  - Optional ESA distribution system provides
    - MSDU relaying to/from wired LANs and between adjacent BSAs
    - Station roaming through the distribution system
    - Access control
    - Power control
  - Validated performance of proposed protocol via simulation
- Evaluate w.r.t. "Twenty-One" Criteria

Implicit Assumptions

- Structure service to match expected traffic
  - Asynchronous Service for bursty traffic
  - Synchronous Service for "real-time" traffic
- Structure protocol for extensibility/scalability
  - Stations, load, service, coverage
- Don't burden all stations with unnecessary capability
  - All stations require bursty traffic data service
- Deal effectively with real environment
  - Robustness: noise, fades, jammers, overlap, movement
  - Adaptible: Size, capacity, traffic, configuration
- Trade optimal capacity/throughput for
  - Low average transfer delay
  - Robustness and flexibility

Requirements

- Source
  - IEEE 802 Functional Requirements
  - IEEE P802.11 Project Authorization Request
  - IEEE P802.11 Requirements
- Summary
  - Two classes of service: Asynchronous and Synchronous
    - Asynchronous: low average transfer delay - (as low as 2 msec transfer delay from MA-UNITDATA.request to MA-UNITDATA.indication)
    - Synchronous: low transfer delay variance (MSDU jitter) $\leq$ 10%
    - IEEE 802.2 LLC Support
  - Coverage area: < 100m (BSA) to > 1000m (ESA)
  - Network management, access control, power management, internetworking
  - ESA Roaming

Goals

- Support both classes of wireless traffic
  - asynchronous data services
  - synchronous data services
- Provide for
  - ad hoc, stand-alone networks
  - seamless integration into larger (wired) networks
- Target performance characteristics for expected traffic requirements
  - Low delay for asynchronous traffic
  - Low delay variance for synchronous traffic
- Robust operation imperative to deal with typical wireless transmission issues: errors, hidden terminals, adjacent BSAs
- Simulate to validate performance
- Minimize cost and complexity
- Provide for power management, access control: security/integrity/authentication, network integrity

Approach

The Three Fold Way

(1) The foundation service is a peer-to-peer asynchronous data service requiring no infrastructure, sufficient in itself tosupport ad hoc networks yet providing mandatory capabilities for (optional) synchronous data delivery and internetwork service sublayers (2) and (3)

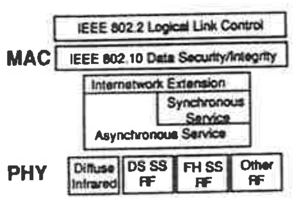
(2) Provide peer-to-peer synchronous data services as an incremental MAC sublayer above (1)

(3) Integration to wired backbone networks for (1) and (2)

PHY Layer

- Multiple media
  - ISM Band Spread Spectrum RF
    - Frequency hopping
    - Direct sequence
  - Diffuse Infrared
  - Others
- Simple interface
  - Half-duplex interface
  - Receive data and clock (PHY » MAC)
  - Transmit data and clock (MAC » PHY)
  - Signal detect/Channel Busy (PHY » MAC)
  - Channel select (MAC » PHY)
  - Quality of Service (PHY » MAC)

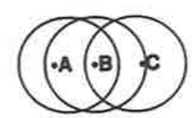
Protocol Architecture



- PHY Layer
  - Half-duplex, peer-to-peer
  - Muliple media
  - Single and multichannel PHYs supported
- MAC Layer
  - Asynchronous Data Service Sublayer
    - Peer-to-peer
    - Augmented LBT with positive acknowledgement
  - Synchronous Data Service Sublayer
    - Peer-to-peer
    - Reservation TDMA, using Asynch Service as mechanism
  - Internetwork Extension Sublayer
    - Relaying via wired backbone
    - Roaming across wired backbone
    - Access Control
    - Power Control

Asynchronous MAC Protocol - 1

- Goals
  - Robust operation on wireless PHY channels (typical 1-2% packet-error-rate, fading hidden stations)
  - Adjacent, overlapping BSAs
  - Simplicity => low cost
  - Low average transfer delay
- Approach
  - LBT core protocol design: nonpersistent with modified binary exponential backoff
  - Hidden station enhancements
  - Positive MAC acknowledgements
  - "Hooks" for synchronous service
    - Per-station channel allocation vector prevents asynchronous service transmissions during synchronous allocated time

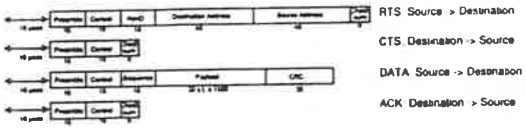


A hears B
B hears A & C
C hears B

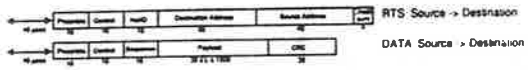
Asynchronous MAC Protocol - 2

- Protocol

Point-to-point MPDU



Multicast/Broadcast MPDU



Synchronous MAC Protocol - 1

- **Goals**
  - **Minimize complexity for asynchronous stations**
  - **Provide low transfer delay variance, allocated bandwidth service**
- **Approach**
  - **Defining RTDMA framing structure using asynchronous service MPDUs**
    - **Scheduler**
    - **Beacon MPDU: synchronizes stations and distributes bandwidth allocation**
    - **Per station bandwidth allocation vector**
  - **Synchronous station must implement asynchronous service**
  - **Asynchronous stations must process beacon MPDUs**

Asynchronous MAC Protocol - 3
Simulation Results

- Performance

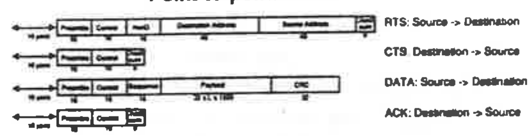
Minimum MPDU Payload	**32**
Maximum MPDU Payload	**1500**
Maximum Throughput	**86%**
Transfer Delay @ 10% Load	**1.3x Normalized MSDU size (1.7 msec @ 2 Mb/s)**
Transfer Delay @ 50% Load	**7.5x Normalized MSDU size (9.8 msec @ 2 Mb/s)**

Synchronous MAC Protocol - 2

- **Protocol**

Beacon MPDU

Point-to-point MPDU



Multicast/Broadcast MPDU

Synchronous MAC Protocol - 3
Simulation Results

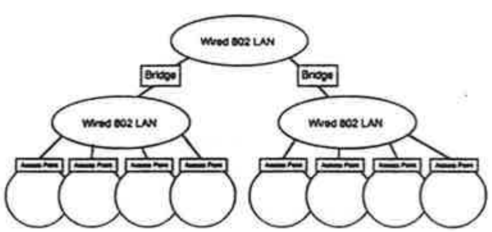
- Performance

Minimum MSDU Payload	32
Maximum MSDU Payload	1500
Maximum Throughput	83%
Transfer Delay @ 10% Load	11x Normalized MSDU size (14.3 msec @ 2 Mb/s)
Transfer Delay @ 50% Load	25x Normalized MSDU size (32.5 msec @ 2 Mb/s)

MSDU Relaying

- Goal: Transparent relaying of MSDUs
  - from wireless stations to stations on the wired infrastructure
  - from wired stations to wireless stations
  - between wireless stations in differing BSAs of same ESA
- Approach
  - Define access points connected to wireless channel and to wired 802 LAN distribution system
  - Access points perform relaying
- Protocol
  - Station registration uniquely enables forwarding for stations registered with access point
  - Promiscuous monitoring of MPDUs within BSA served by access point
  - Promiscuous monitoring of MPDUs on distribution system of MPDUs destined for stations registered with access point

Internetwork Extensions



- BSA defined by PHY coverage area
- Extended Service Area (ESA) defined by BSAs interconnected via distribution system of access points and wired LANs
- Extended services supporting growth
  - MSDU relaying
  - Station roaming
  - Access control
  - Power control
- Configurable as hierarchical or peer-to-peer

Roaming

- Goals
  - Enable registered wireless stations to maintain connectivity while moving through an ESA (e.g. access point to access point)
- Approach
  - Station registered in at most one access point
  - As station registers at new access point, deregistered at any previous access point
  - Access point relaying within ESA follows "quick" station movement
  - Bridge relaying in distribution system follows station with a longer time constant via 802.1D spanning tree learning process
  - Support for single and multichannel PHYs
- Protocol
  - Use existing protocol mechanisms
  - Access control registration process notifies access point to enable/disable roaming
  - MPDU relaying and/or <u>Awake</u> messages notify access point of continued presence

Access Control

- Goals
  - Control access to WLAN and distribution system to legitimate stations and users
  - Notify access points of those stations needing forwarding and roaming services
- Approach
  - Register stations in range of an access point with the access point
  - Access point authorizes access based on TBS authentication
- Protocol
  - Message (MPDU) exchange between station and access point
  - Announce: periodic multicast message from access point announcing its service to all stations in range
  - Register: point to point message from station to access point requesting access and containing digital signature authentication information
  - Authorize: point-to-point response from access point to station
  - Exit: explicit deregistration by station
- Data Privacy and Integrity
  - To be provided end-to-end by 802.10
  - 802.11 should provide standard encryption algorithm
- Authentication
  - Digital signatures validate stations and access points
  - Used during access point registration

Performance Simulation

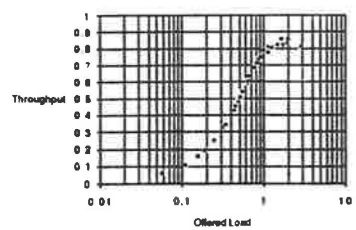
- Discrete event simulation models
  - Extend commercial simulation package for Macintosh
- Assumptions
  - 20 stations with identical traffic characteristics, exponential MSDU arrival rate, non-exhaustive service
  - Propogation delay dominated by transceiver R/T turnaround: 10 µsec
  - Bimodal size distribution: 60%/40% small/large MSDUs - 1000 bit small MSDUs, 5000 bit large MSDUs
  - Positive acknowledgements for all MSDUs
  - Offered load does not include retrys/retransmissions unlike analytical models
- Models
  - Asynchronous Service : augmented LBT (4-way handshake) with positive acknowledgement
  - Synchronous Service: Dynamic Reservation Time Division Multiplexed

Power Management

- Goals
  - Enable battery powered stations to conserve power by selectively powering down network hardware when not needed
- Approach
  - Under station control
  - Station announces power state to other stations and access points
  - Responsibility of higher level protocols to retry MSDU transmission when station repowers
- Protocol
  - Sleep: multicast message announcing station's intention to shut down for specified time period
  - Awake: periodic, multicast message announcing active presence of station

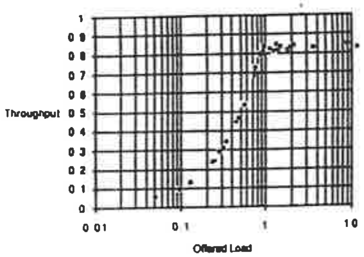
Asynchronous Service Simulation - 2 Mb/s

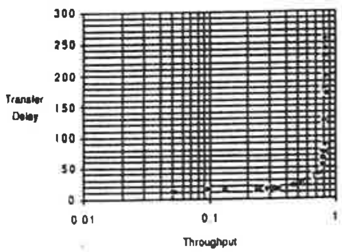
Low Error



- Assumptions
  - 10 µsec propogation delay
  - Standard traffic model
  - Zero PHY bit error rate
- Performance
  - 85%+ maximum throughput at 180% offered load
  - High stability at overload
  - Low average transfer delay (1-10x normalized) below maximum throughput

Synchronous Service Simulation - 2 Mb/s





Low error

- Peer-to-peer TDMA - direct station to station communcation with no forwarding through intermediate node that would further increase transfer delay
- 12.5 msec superFrame, fast turnaround slotted Aloha reservation requests, 500 µsec slot time
- Maximum throughput: about 83% at ≥90% offered load
  - 17% is both TDMA overhead and MSDU fragmentation loss
- Typical normalized transfer delay of 10-20 over normal load range and exponential at overload

Evaluation-1

1. Unauthorized Network Access on Throughput	1. Yes! MAC includes explicit access control mechanisms. In band interference reduces throughput per sensitivity of the PHY used.
2. Ability to establish Peer-to-peer connectivity w/o prior connection	2. Yes! A basic part of the Asynchronous Service. Connectivity via Asynch Service required to bootstrap Synch Service either peer-to-peer or through AP
3. Throughput	3. Traffic model dependent, but based on anticipated traffic - maximum throughput is between 80 and 90% for both the Asynchronous and Synchronous Service
4. Delay	4. Traffic model dependent. But simulations indicate 1-5x normalized for Asynch Service and 10-20x normalized for Synch Service
5. Maximum # of stations	5. Traffic load and PHY characteristic dependent. Little inherent limitiations in MAC.
6. Ability to service data, voice, and video traffic	6. Yes! Data generally serviced by the Asynchronous Service and voice/video by Synchronous Service. Critically important that servicing voice/video will not likely seriously degrade data delay performance
7. Transparency to PHY layer	7. Yes! Wide range of PHYs supported - IR, radio; single/multichannel

Evaluation-2

8. Robustness with co-sited networks	8. Yes! Quite robust with only modest degradation.
9. Power consumption	9. Yes! Explicit mechanism to manage use of power for battery conservation.
10. Delays limiting large area coverage	10. No critical delays.
11. Fairness of access	11. Fairness of Asynch Service coupled to fairness of PHYs. Asynch Service improves fairness of underlying PHY. Synch Service explicitly fair.
12. MAC enforcement of capture effect insensitivity	12. MAC improves performance of PHY w.r.t. capture effects. Synch Service quite insensitive.
13. Support for priority	13. Effective MSDU priority can be constructed using the Synchronous Service.
14. Ability to support one-way traffic	14. Yes! Both for Asynchronous and Synchronous Service
15. Time to market and complexity	15. Only modest increase in complexity over 802.3 yielding rapid time to market
16. Ability to work in simple, small and large systems	16. Yes! Same station supports full range of network size - from small stand-alone, "ad hoc" networks to large, internetworked installations

Evaluation-3

17. ?	17. Yes! or No!
18. Ability to support handoff/roaming between service areas	18. Yes! Also synthesized with access control and network management
19. Implication on complexity of PHY	19. Wide range of PHYs supported, in general, minimal requirements on PHY. MAC performs better with decreased BER and with more reliable channel busy indication.
20. Ability to support broadcast	20. Yes, and multicast as well. Reduced reliability over point-to-point since positive MSDU ACK not used.
21. Preservation of time order of MSDU's to end systems	21. Yes, even across roaming. Optional access point feature reduces probability of lost MSDUs during roaming at price of slightly increased probability of misordering MSDUs in flight during roam.

Other Evaluation Criteria

Robustness	Due to perceived uncertainties in wireless PHY propagation environments - key issue is to design a MAC that will work adequately even in abysmal conditions. And keep on working.
Security	Eavesdropping, tampering, service denial.
Authentication	Since little physical control over network membership, MAC must include mechanism to logically authenticate legitimate network users.
Cost Effectiveness	Preliminary studies suggest added logic conservatively ≤ 2x over an 802.3 CMOS protocol controller with no substantive increase in pin count.
Network Size	BSA size of about 100m supported based on PHY and ESA size of > 1000m supported through distribution system and roaming

Summary

- Goals
  - Wireless MAC serving both asynchronous as well as synchronous traffic
  - Realistic wireless PHY assumptions
- Approach
  - Hybrid, layered MAC: Asynchronous, Synchronous, Extended
  - Adaptive configuration: hierarchical, peer-to-peer.
- Results
  - Economical, simple design
  - Excellent performance
  - Robust design