IEEE 802.11

Wireless Access Method and Physical Layer Specifications

A Hybrid Wireless MAC Protocol

Supporting Asynchronous and Synchronous MSDU Delivery Services

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Abstract

Most contemporary LAN data services require low average transfer delay MSDU delivery while tolerating substantial delay variance. Many anticipated wireless LAN services - real time voice and video - as well as selected factory applications require data delivery services with predictable bandwidth and minimal transfer delay variance.

This paper proposes to address these hybrid requirements with a hybrid wireless data delivery service. The basic service provides asynchronous, low average transfer delay, statistical data services using a Listen-Before-Talk MAC protocol enhanced for improved error recovery and "hidden station" performance.

Layered atop the asynchronous data service is an optional synchronous data service providing reserved bandwidth with low transfer delay variance at the penalty of higher average transfer delay. Only stations offering the service to it's local applications need implement the complete synchronous service.

To confirm the efficacy of the proposed protocol a series of discrete simulation models of the dynamic performance of a range of candidate protocols has been constructed using realistic traffic loads and PHY transmission characteristics. Preliminary results are encouraging.

The proposals of this paper should be considered an initial design sketch for the proposed protocol. Much work remains to fully specify and performance model the outlined services. The author welcomes subsequent comments and collaboration to improve the protocol.

A glossary of defined terms is at the end of the paper.

1. Introduction

1.1 Requirements

The evolving set of requirements for wireless local area networks reflects a wide and seemingly conflicting range of needs.

A clear primary need is to support today's LAN applications both on current computer platforms but also as projected on future, smaller, more mobile platforms. These applications largely require asynchronous MSDU delivery with minimal transfer delay over as wide a range of channel load as possible. [1] [2] [3] [4] [6] For these applications, low average transfer delay is more important than minimizing delay variance.

The need for predictable transmission bandwidth and transfer delay is anticipated to be a mission critical requirement in some industrial applications. Consideration of possible future applications, particularly the integration of real-time voice and video sessions with asynchronous data access [5] [6] additionally supports a requirement to provide some mechanism for a synchronous data service that minimizes transfer delay variance for reserved bandwidth.

Wireless LANs are anticipated to be configured bimodally - both in small, ad hoc networks with no preexisting infrastructure as well as in larger enterprise networks as a complement to 802 compatible wired internetworks thus providing connectivity both for mobile stations as well as for stationary locations where it is inconvenient to run a wire. [2] [3] [6]

1.2 Approach

The integration of these services is a challenge. The chosen approach is to provide a hybrid MAC data delivery service that combines low delay services for asynchronous, statistical data applications (e.g. file access, file transfer, etc.) with a reservation based synchronous service for applications requiring known bandwidth and/or delay: interactive voice, video, industrial control. In many ways, the proposed systems can be considered an extensive refinement of the MAC architecture proposed earlier [11]. Additionally the author credits [10] and [12] for intriguing thoughts stimulating and enriching the proposal.

The proposed architecture is a layered design with:

- a peer-to-peer PHY layer supporting multiple media;
- a peer-to-peer MAC layer comprised of several sublayers: an asychronous data service, a synchronous data service and an internetwork extension.

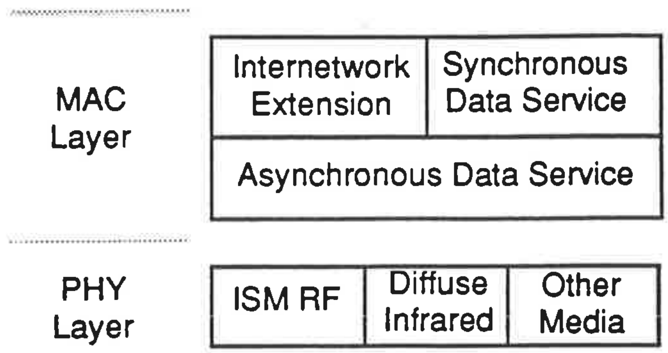


Figure 1.1: Hybrid Wireless Protocol Architecture

The foundation of the protocol is an asynchronous Listen-Before-Talk MAC protocol with specific enhancements for reliability, hidden stations and support for colocated wireless LANs. Explicit provision is made within the protocol to provide a foundation for the synchronous sublayer. This layer provides low-delay, asychronous MSDU delivery services between stations within direct media range of each other.

Atop the basic data delivery services of the asynchronous sublayer, the synchronous sublayer provides a data delivery service with guaranteed bandwidth and predictable delay between stations in direct media range of each other. It does this by imposing a coordinated, timed, frame system on the shared channel between nodes and an allocation system to dedicate timed sections of bandwidth to particular stations. This reservation time division multiplexed sublayer provides for an MSDU data delivery service for traffic that

- requires dedicated bandwidth that cannot be contended for and can tolerate higher average transfer delays; or
- requires lower delay variance among MSDUs but can tolerate higher average transfer delays.

The synchronous service is designed as an optional extension service. Stations not providing synchronous services to theirs applications need not implement the complete synchronous service though they need to implement the bandwidth reservation portion.

The internetwork extension sublayer adds four key services to the fundamental data delivery services of the asynchronous and synchronous delivery services.

Forwarding — The forwarding portion of the internetwork extension sublayer provides for MSDU delivery between stations out of direct media range of each other. This delivery is accomplished through the forwarding of MSDUs from one station to another via the intervention of store-and-forward, filtering MSDU packet switches, termed access points, interconnected via one or more standard 802 LANs. As a compatible extension of 802.1 bridging services, this wireless MSDU forwarding service transparently (except for increased transfer delay) interconnects stations. Stations of the same administration within direct media range directly communicate without the intervention of the access point.

Roaming — The roaming service provides continuity of MSDU delivery between a moving station and the wired backbone or between moving stations. Coordinated operation of stations and access points interconnected with a wired backbone provide for an MSDU delivery service that supports moving stations but requires no change to wired stations or (in most cases) higher layer protocols. While the proposed roaming service takes measures to prevent MSDU loss, it may occasionally lose an MSDU during transition from one access point to another - relying on reliable higher layer protocols for detection and retransmission.

Access control — The access control service provides basic mechanisms to control access to wired backbones from wireless subnetworks at the MAC layer. End-to-end MSDU privacy and integrity is anticipated to be provided by IEEE 802.10. Not considered here but worthy of additional study are network management tools to locate interference sources - an interferometer.

Power control — Tools are provided for a battery-powered station to inform other stations and access points that it will be powering down and subsequent power up. Mechanisms are defined to allow for minimal communications disruption while still permitting substantial power savings under station control.

In this version of the protocol, the mechanisms to support these services for the synchronous delivery service have not been defined. The sketch of the these services is limited to the asynchronous service.

2. PHY Layer

2.1 Multiple PHYs

It is prudent to plan on multiple, alternative PHY layer implementations. Today the only PHY layers that can be realistically considered are:

- ISM band spread spectrum RF of between 1-10 Mb/s with an indoor/outdoor range of approximately 50-100 meters, possibly augemented with multiple logical channels created via FDMA or frequency hopping; and
- diffuse infrared of between 1-2 Mb/s with an indoor range of approximately 10 meters.

These PHYs will have complementary market positions and should both be accomodated within an ultimate 802 standard.

The secondary data usage characteristics of the ISM band motivate long term dedicated LAN RF bands. However, regulatory delay precludes us from assuming their presence. However, we must not preclude their later inclusion.

2.2 PHY Interface

The proposed PHY interface exports the following signals where input denotes signals provided by the MAC layer to the PHY and output denotes signals provided from the PHY to the MAC.

Transmit Data	Input	Data bits transmitted by a station.
Transmit Clock	Input	Clocking for Transmit Data.
Receive Data	Output	Data bits received by a station.
Receive Clock	Output	Clocking for receive data. Implict is the assumption that PHY performs clock recovery.
Signal Detect	Output	Channel busy indication.
Channel Select	Input	Where multiple channels can be selected this input permits the station to "tune" the PHY to the desirec channel.

Figure 2.1: PHY Interface Signals

3. The Hybrid MAC Asynchronous Service

The asynchronous service of the Hybrid MAC supports data traffic that

- may have statistically bursty traffic bandwidth requirements;
- requires as low as possible average MSDU transfer delay; or
- can tolerate statistical variation in MSDU transfer delay.

The service provides high reliability transfer of "datagram" MSDUs between wireless stations within direct range of each other.

The current analysis focuses on 2 Mb/s PHY layers. At this speed, simulation results (still in progress) suggest the asynchronous service has the following performance.

Minimum MSDU Payload	32
Maximum MSDU Payload	1500
Maximum Throughput	86%
Transfer Delay @ 10% Throughput @ Typical Load	1.3x Normalized MSDU size (1.7 msec)
Transfer Delay @ 50% Throughput @ Typical Load	7.5x Normalized MSDU size (9.8 msec)

Figure 3.1: Asynchronous Service Characteristics

3.1 Concept of Operation

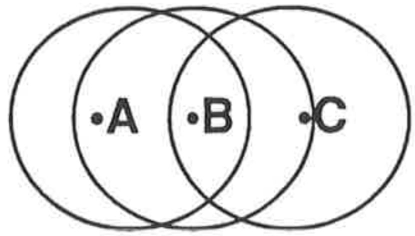
The MAC asynchronous sublayer protocol is based on a "Listen-Before-Talk" (hereafter LBT) distributed channel allocation algorithm augmented for:

reliability — with a positive MAC acknowledgement from the destination node; and

efficiency — with an early, positive go-ahead signal from the destination that potentially significantly improves the base LBT algorithm in the case of electromagnetically hidden nodes.

The basic asynchronous algorithm is a non-persistent LBT protocol [4] with a modified binary exponential backoff on busy deference and collision/error retransmission. In order to improve the delivered MSDU error rate in the presence of the higher PHY bit error rate of typical wireless channels w.r.t. wired channels - an explicit, positive MSDU acknowledgement is included in each MSDU.

In addition to higher BER, typical wireless PHYs will have nonhomogenous connectivity - not all stations are able to hear all other stations - some stations are "hidden". A typical configuration is illustrated below in which station A hears station B, station B hears both stations A and C, and station C hears only station B.



A hears B

B hears A & C

C hears B

Figure 3.2: Hidden Station

In the above example, consider the situation if both station A and station C were to attempt transmission of MSDUs at about the same time to station B using a simple LBT protocol. Both stations A and C would sense the channel free (since neither can hear the other's transmission) and their transmission would collide at station B resulting in both transmissions failing. As the simulations later in the paper illustrate, substantial numbers of such hidden stations (more than 5-10%) substantially degrade the performance of LBT protocols.

In order to improve this performance, either A or C needs to be informed of the other's transmission in order to defer usage of the channel to a later time. Yet, if, for example, C has a transmission to a station D that cannot hear station A, it would increase the overall capacity of the system to permit that transmission to occur in parallel with A's transmission to B.

The asynchronous service proposes a modification of an existing protocol mechanism to provide this information [8] [9] [10]. Each MSDU is comprised of four elements:

- a request to send (RTS) transmitted by the source station;
- a clear to send (CTS) transmitted by the destination station;
- the MSDU payload; and
- MSDU acknowledgement.

The short RTS and CTS transmissions propogate channel busy status to all stations that can hear <u>either</u> the source or destination station. In this way, within the propogation time of the RTS and the CTS all potentially interfering stations will have up-to-date information on channel busy status for those stations.

Each station has the responsibility to continuously listen for the channel. When a station hears a MSDU, whether it is addressed to the station or not, it listens sufficiently to hear either the sender's declaration of the payload length (in the RTS element of the

MSDU) or the receiver's acknowledgement of that length (in the CTS element of the MSDU). It remembers this length and defers any transmission it might have until this period is expired. In this way, contention for channel bandwidth is eliminated for all stations that heard and decoded all or part of the MSDU during the MSDU transmission period. Note that portions of the MSDU are transmitted by the MSDU source and a portion by the MSDU destination thus channel occupancy information is distributed to all stations within range of either the source or the destination. This advantage is paid for by modest additional bit overhead in each transmitted MSDU.

The transmission of the length by both the source (in RTS) and the destination (in CTS) means that both stations hidden from the destination but visible to the source (via the RTS) and stations hidden from the source but visible to the destination (via the CTS) will have knowledge of the occupied channel and for the duration of the transmission.

The mechanics of the most PHY layers will require some time for receive/transmit turnaround within the PHY transceiver. This time for many PHYs, in particular radios, will dominate propogation delay between stations. Good design can reduce this time to microseconds in duration. This paper assumes a 10 microsecond total propogation time.

3.2 MSDU Format

The asynchronous MAC sublayer has two MSDU formats: one for MSDUs addressed to more than one station - either multicast or broadcast, and a second format for point-to-point MSDUs addressed to a specific station.

3.2.1 Point-to-Point MSDU

Point-to-point MSDUs are addressed to a specific station from a specific station. They consist of four constituent elements: RTS, CTS, DATA, and ACK. They include 312 bits of overall control overhead per MSDU.

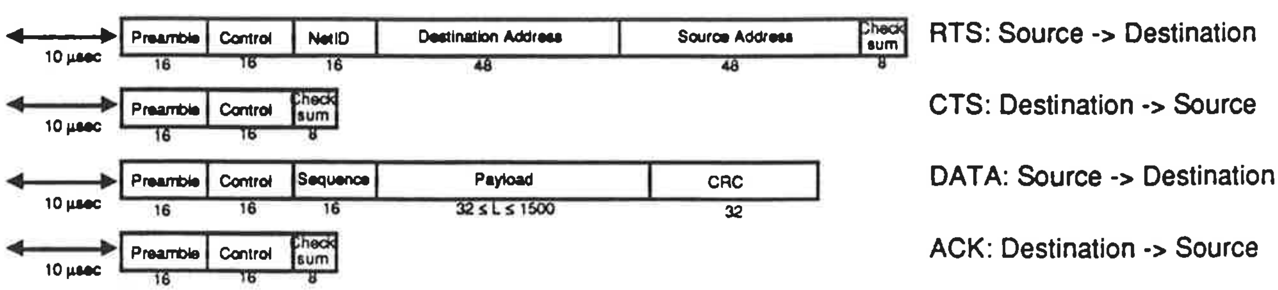


Figure 3.3: Point-to-Point MSDU Format

RTS, or Request-To-Send, is a transmission from source to destination initiating the MSDU. It has the following fields:

Preamble	A 16 bit preamble[1] for receiver bit synchronization. In addition, time must be allocated for receiver/transmit turnaround.
Control	A 16 bit control field with two subfields: a three (3) bit type field, three reserved bits and an ten (10) bit payload length subfield. The Type subfield has the value '0'.
NetID	A 16 bit WLAN network ID for distinguishing between adjacent LANs. MSDUs with matching NetID to the receiver are delivered to the receiver. If the NetIDs do not match, the receiver will not deliver the MSDU but will use the timing information for controlling channel access.
Destination Address	A 48 bit station unique ID of the destination.
Source Address	A 48 bit station unique ID of the source.
Checksum	An eight (8) bit checksum on the RTS MSDU element.

The RTS MSDU element is a fixed length 152 bit element.

CTS, or Clear-To-Send, is a transmission from destination to source granting the transmission.

Preamble	A 16 bit preamble for receiver bit synchronization. In addition, time must be allocated for receiver/transmit turnaround.
Control	A 16 bit control field with two subfields: a three (3) bit type field, three reserved bits and an ten (10) bit payload length subfield. The Type subfield has the value '1'.
Checksum	An eight (8) bit checksum on the CTS MSDU element.

The CTS MSDU element is a fixed length 40 bit element.

DATA is a transmission from source to destination and contains the data payload of the MSDU.

Preamble	A 16 bit preamble for receiver synchronization. In addition, time must be allocated for receiver/transmit turnaround.
Control	A 16 bit control field with two subfields: a three (3) bit type field, three reserved bits and an ten (10) bit

[1] A 16 bit preamble in combination with the R/T turnaround time is considered sufficient to obtain bit sync. However, further analysis may reveal a need to increase the length. Modest increases should have little impact on protocol performance.

	payload length subfield. The Type subfield has the value '2'.
Sequence	A 16 bit field set by the source labelling MSDUs for duplicate detection by the destination.
Payload	A variable length field of length specified in the payload length subfield of the control field of the RTS, CTS, DATA and ACK elements. Minimum payload is 32 octets with a maximum size of 1500 octets.
CRC	A thirty-two (32) bit IEEE 802 standard MSDU check sequence on the payload element.

The DATA element is variable length with fixed 80 bit control overhead plus payload length.

ACK is a transmission from destination to source and positively acknowledges receipt of the MSDU's data payload with a correct MSDU check sequence. A NAK is given to indicate MSDU loss or erroneous reception.

Preamble	A 16 bit preamble for receiver synchronization. In addition, time must be allocated for receiver/transmit turnaround.
Control	A 16 bit control field with two subfields: a three (3) bit type field, three reserved bits and an ten (10) bit payload length subfield. The Type subfield has the value '3' for ACK and '4' for NAK.
Checksum	An eight (8) bit checksum on the ACK element.

The ACK element is a fixed length element of 40 bits length.

3.2.2 Multicast and Broadcast MSDU

Multicast and broadcast MSDUs are addressed to a group of stations from a specific station. They consist of two constituent parts: RTS and DATA. They include 216 bits of control overhead per MSDU.

Since both multicast and broadcast MSDUs to not have a specific destination station to provide RTS and/or ACK, these features are removed from the MSDU format and operation for these MSDUs. Of course, the removal of these features further decreases the already degraded delivery reliability of multicast/broadcast MSDUs however this is not believed to be substantive. Further, since RTS is not used in these MSDUs, channel occupancy is not a widely distributed to (possibly) transmitter hidden nodes, thus (possibly) decreasing channel utilization. It should be noted however, that is occurs only for broadcast/multicast MSDUs and since these are (generally) proportionally rare for most applications, these should not have much practical impact on overall channel utilization.

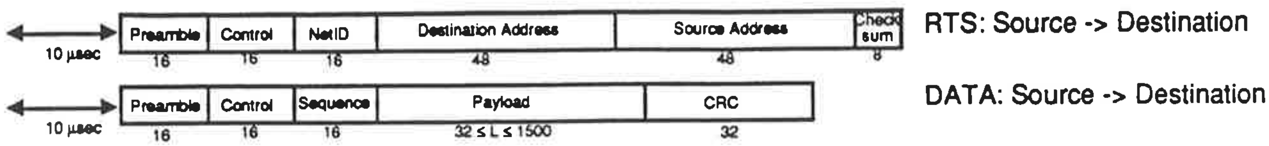


Figure 3.4: Multicast/Broadcast MSDU Format

RTS, or Request-To-Send, is a transmission from sender to receiver initiating the MSDU. It has the following fields:

Preamble	A 16 bit preamble for receiver synchronization. In addition, time must be allocated for receiver/transmit turnaround.
Control	A 16 bit control field with two subfields: a three (3) bit type field, three reserved bits and an ten (10) bit payload length subfield. The Type subfield has the value '0'.
NetID	A 16 bit WLAN network ID for distinguishing between adjacent LANs. MSDUs with matching NetID to the receiver are delivered to the receiver. If the NetIDs do not match, the destination will not deliver the MSDU but will use the timing information for controlling channel access.
Destination Address	A 48 bit multicast or broadcast address for the destination stations. A broadcast or multicast address in this field distinguishes a multicast/broadcast MSDU from a point-to-point MSDU.
Source Address	A 48 bit node unique ID of the source station.
Checksum	An eight (8) bit checksum on the RTS MSDU element.

The RTS MSDU element is a fixed length 152 bit element.

DATA is a transmission from source to destination and contains the data payload of the MSDU.

Preamble	A 16 bit preamble for receiver synchronization. In addition, time must be allocated for receiver/transmit turnaround.
Control	A 16 bit control field with two subfields: a three (3) bit type field, three reserved bits and an ten (10) bit payload length subfield. The Type subfield has the value '2'.
Sequence	A 16 bit field with a sender set MSDU sequence number used by a receiver to disambiguate possible duplicates due to loss of ACK.

Payload	A variable length field of length specified in the payload length subfield of the control field of the RTS, CTS, DATA and ACK elements.
CRC	A thirty-two (32) bit IEEE 802 standard MSDU check sequence on the payload element.

The DATA element is variable length with fixed 80 bit control overhead plus payload length.

3.3 Asynchronous MAC State

Each station maintains a set of asynchronous MAC state information describing it's knowledge about the network.

Net Allocation Vector	A boolean vector describing whether in each subsequent time slot, any station can contend for transmission. <TRUE> indicates that this is a free slot and any station may contend for it. <FALSE> indicates that this is a reserved or allocated slot and some other station is or will be using it. This data base is constructed from received RTS/CTS information and from synchronous MAC beacon MSDU bandwidth allocations.
Address	The station's own unique address.
Multicast	The set of multicast addresses to which the station will respond.
Sequence Cache	A cache of sequence numbers from recently received MSDUs so that duplicate MSDUs due to lost ACKs can be discarded without delivery to the next higher layer.

For 2 Mb/s channel speed with a 10 µsec R/T turnaround and signal acquisition time - 80 octet MSDUs will have a=0.02 and 600 octet MSDU will have a = 0.002. Both within reasonable performance bounds as evidenced by simulation results.

3.4 MSDU Receive Operation

Listen for all MSDUs. Each station uses the RTS/CTS payload (hence MSDU) length information and synchronous MAC beacon MSDU bandwidth allocation information (if any) to build station's net allocation vector of reserved times when local contention for transmission not allowed.

Received MSDUs with correct netID and local destination address are CTSed, received, acknowledged and delivered to the user of the sublayer. Multicast and broadcast MSDUs are not acknowledged nor is CTS used.

3.5 MSDU Transmit Operation

Format MSDU.

Check if transmission of this size MSDU is permitted by the station's net allocation vector. Essentially, this is a "first fit" algorithm. If allowed proceed, else defer to next allowable period.

Sense channel, if busy defer transmission, else proceed.

if point-to-point

Send RTS and wait for CTS.

Receive CTS.

else If CTS not received, backoff and resend MSDU.

Send DATA and wait for ACK.

Receive ACK and signal completion to the requesting layer

else if ACK not received, backoff and resend MSDU

else if multipoint/broadcast

send RTS.

send DATA.

4. The Hybrid MAC Synchronous Service

The synchronous service of the Hybrid MAC supports data traffic that

- may have periodic or predictable traffic bandwidth requirements; or
- requires as low as possible variance in MSDU transfer delay; and
- can tolerate higher average MSDU transfer delay.

The service provides high reliability, closely timed transfer of "datagram" MSDUs between wireless stations within direct range of each other.

The current analysis focuses on 2 Mb/s PHY layers. At this speed, simulation results (still in progress) suggest that the synchronous service will have the following performance specifications.

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

Figure 4.1: Asynchronous Service Characteristics

4.1 Concept of Operation

The synchronous service provides strong guarantees for bounded, low variance transfer delay and known throughput that the asynchronous service cannot provide. It provides these through a synchronized transmission timing structure with reserved bandwidth. The structure is essentially a reservation TDMA protocol.

The synchronous service timing structure is constructed by a specialized function, termed the scheduler, that is implemented within one (or more) stations within a WLAN BSA. A scheduler imposes a frame timing structure through "beacon" MSDUs - broadcast MSDUs transmitted at regular intervals. Beacon MSDUs provide several services:

- timing synchronization among receiving stations;
- advertisement of the identity of the scheduler (through the source address of beacon MSDUs); and
- distribution of each station's channel transmission allocations for synchronous MSDUs.

Individual stations within range of each scheduler listen to beacon MSDU(s) and reserve time intervals for the designated synchronous MSDU transmissions and will not schedule their asynchronous MSDUs during any of those intervals. Unreserved time is available for contention via the asynchronous MAC sublayer.

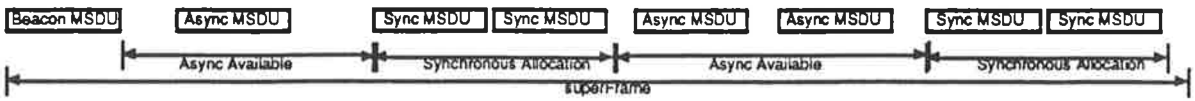


Figure 4.2: Typical Synchronous Service Frame Format

The timing structure constructed in this way is termed a frame illustrated above. Each frame begins with a beacon MSDU transmitted by a scheduler. The beacon MSDU synchronizes all stations receiving the MSDU.

Stations request reserved bandwidth from a scheduler via a MAC point-to-point MSDU containing the request. Each scheduler has a known MAC address advertised as the source address in a beacon MSDU.

A scheduler is likely resident in an access point roughly in the center of the coverage range of given BSA providing synchronous service.

4.2 MSDU Format

The synchronous data service requires three types of MSDUs:

- a beacon MSDU used to both delimit frame boundaries and distribute frame allocations;
- a bandwidth allocation request from a synchronous service station; and
- data delivery MSDUs.

4.2.1 Beacon MSDU

A beacon MSDU is essentially an asynchronous multicast MSDU transmitted, by a scheduler, periodically at the beginning of each frame with the source address of the transmitting scheduler. All stations, including asynchronous service only stations, must receive and decode beacon MSDUs in order to process bandwidth allocations to properly set each stations' allocation vector.

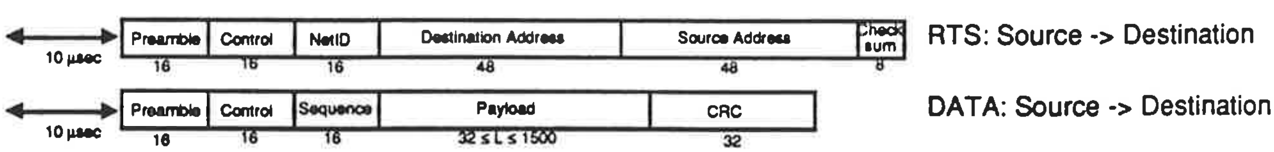


Figure 4.3: Beacon MSDU Format

RTS, or Request-To-Send, is a transmission from source to destination initiating the MSDU. The beacon MSDU is a superset of the asynchronous multicast MSDU with a control type uniquely identifying the MSDU as a beacon. It has the following fields:

Preamble	A 16 bit preamble for receiver synchronization.
Control	A 16 bit control field with two subfields: a three (3) bit type field, three reserved bits and an ten (10) bit payload length subfield. The Type subfield has the value '4'.
NetID	A 16 bit WLAN network ID for distinguishing between adjacent LANs. MSDUs with matching NetID to the receiver are delivered to the receiver. If the NetIDs do not match, the receiver will not deliver the MSDU but will use the timing information for controlling channel access.
Destination Address	The 48 bit beacon multicast address for the destination stations.
Source Address	A 48 bit station unique ID of the source, in this case the Scheduler..
Checksum	An eight (8) bit checksum on the RTS MSDU element.

The RTS MSDU element is a fixed length 152 bit element.

DATA is a transmission from source to destination and contains the data payload of the MSDU.

Preamble	A 16 bit preamble for receiver synchronization.
Control	A 16 bit control field with two subfields: a three (3) bit type field, three reserved bits and an ten (10) bit payload length subfield. The Type subfield has the value '2'.
Payload	A variable length field of length specified in the payload length subfield of the control field of the RTS, CTS, DATA and ACK elements.
CRC	A thirty-two (32) bit IEEE 802 standard MSDU check sequence on the payload element.

The DATA element is variable length with fixed 64 bit control overhead plus payload length.

The payload for the beacon MSDU contains the bandwidth allocation information for all stations it serves.

frame length	Length of the frame and, implicitly, the time between beacon MSDUs from this scheduler.
allocation unit	A four-tuple designating a bandwidth allocation for a specific station. It contains:

nodeID	48 bit unique address of the allocated station.
auStart	A 16 bit field designating the starting time relative to the beacon MSDU of the start of the allocation unit. The measurement unit of allocations is TBS however need not be more accurate than the underlying propogation delay.
auLength	A 16 bit field containing the length of the allocation unit.
auDuration	A 16 bit field containg the number of superFrames over which this allocation unit is valid.

The bandwidth allocation information is used by all stations, both asynchronous and synchronous, to update their copies of the net allocation vector reserving transmission times allocated to the synchronous service. In addition, each synchronous service station updates it's station allocation vector denoting that station's allocated transmission times.

4.2.2 Bandwidth Request MSDU

Bandwidth is requested by a synchronous MAC station via a request message transmitted to the Scheduler via a asynchronous MAC point-to-point MSDU.

4.2.3 Data MSDUs

All synchronous service data MSDUs - point-to-point, multicast, and broadcast - are formatted as for the asynchronous MAC sublayer. Each data MSDU must be transmitted within the allocation unit specified by the scheduler. Unused space should be returned to the asynchronous MAC service through the allocating scheduler though can in fact be used for multiple transmissions.

4.3 Synchronous Service State Information

In addition to the asynchronous MAC state, each synchronous service station maintains an additional set of state information describing it's knowledge about the synchronous MAC service.

Station allocation vector	Subset of the net allocation vector containing this station's transmission allocation.
Scheduler Address	The unique address of the local scheduler obtained from the last recognized beacon MSDU

4.4 Scheduler Operation

A scheduler has two functions:

- maintain the frame timing synchronization through periodic multicast transmission of beacon MSDUs; and
- receive synchronous service bandwidth requests from stations, allocate bandwidth and distribute allocations through beacon MSDU payloads.

While the scheduler's specific bandwidth allocation algorithm is TBS, schedulers should attempt to distribute synchronous service bandwidth allocations evenly throughout each frame so as to impose neither undue delays on asynchronous MSDUs nor undue fragmentation on the net allocation vector that may also cause undue synchronous MSDU delay.

It may be the case that a station can hear more than one scheduler. In that case, the station controls its transmissions through interaction with each. Such stations construct their net allocation vectors from the union of all beacon MSDUs received as well as the RTS/CTS allocations of received asynchronous MSDUs. However, a station will only register (see sequel access control) with one scheduler for bandwidth allocation and construct its station allocation vector from the allocations given by that scheduler. This is true both for cases in which multiple schedulers belong to the same or differing adminstrations.

Schedulers serving overlapping BSAs must coordinate their allocations using TBS mechanisms.

Schedulers are implemented within any access point serving a BSA offering the synchronous service. Access points can act as any combination of asynchronous forwarding, synchronous forwarding and synchronous scheduling.

4.5 MSDU Receive Operation

Listen for all (asynchronous and synchronous) MSDUs. Use RTS/CTS information and beacon MSDU information to build station's net allocation vector of reserved times when asynchronous service contention for transmission is not allowed. Use beacon MSDU information to build station allocation vector of transmission times allocated to this station.

Received MSDUs with correct netID and destination address are CTSed, received, acknowledged and delivered to the user of the sublayer. Multicast and broadcast MSDUs are not acknowledged nor is CTS used.

4.6 MSDU Transmit Operation

Format MSDU.

Check if transmission of this size MSDU is permitted by the intersection of the net and station allocation vectors. Essentially, this is a "first fit" algorithm. If allowed proceed, else defer to next allowable period.

Sense channel, if busy, defer backoff and retry transmission, else proceed.

if point-to-point

Send RTS and wait for CTS.

Receive CTS.

else if CTS not received, backoff and retransmit MSDU.

Send DATA and wait for ACK.

Receive ACK and signal completion to the requesting layer

else if ACK not received, backoff and retransmit MSDU.

else if multipoint/broadcast

send RTS.

send DATA.

4.7 A Synchronous Service Example

Consider a 32 Kb/s digitized full-duplex voice service, yielding 64 Kb/s for each session. Assume packetized voice with 80 MSDUs/sec digitization with a 12.5 msec frame rate. Assume a 2 Mb/s channel speed.

Each beacon MSDU is 984 bits plus 10+10 usec R/T switching time -> 512 usec (4% of frame). Each full duplex voice session requires 160 MSDUs/sec each of (312 + 400 bits + 10+10+10+10 usec) 396 usec with 2 MSDUs/frame/session. Each real-time voice session thus uses 792 usec/frame or about 6.3% of channel capacity per voice session including MSDU overhead. This implies that at least 8 and possibly as many as 16 concurrent voice conversations can be held using the synchronous service while still providing substantial bandwidth for data applications using the asynchronous service.

5. MAC Internetwork Extension Services

5.1 Services

MAC internetwork services provide extended services normally required when interconnecting wireless LANs with enterprise wired networks. This paper will only address these services for the asynchronous service. Internetwork services for the synchronous service are expected to be similar, but substantially more complex and will be addressed in a sequel contribution.

MAC internetwork services provide four service extensions.

Forwarding	Within a BSA, stations communicate directly. An Extended BSA (hereafter EBSA), in which stations not in direct PHY range communicate, is constructed to forward MSDUs between stations.Wired backbone interconnect.
Roaming	Permits stations to roam between BSAs of the same administration while retaining connectivity.
Access control	Controls which stations may make use of MAC services offered by a BSA or EBSA through access points.
Power control	Permits stations to temporarily power down their network interfaces while minimizing data loss for MSDUs in transit.

5.2 Concept of Operation

MSDU delivery for stations within direct PHY range of each other, within the same administration, communicate directly without intervention of the MAC extension sublayer. When required, the MAC extension sublayer creates a infrastructure providing the defined services.

This infrastructure is constructed from two components: a (likely) wired 802 compatible backbone network and a set of access points.

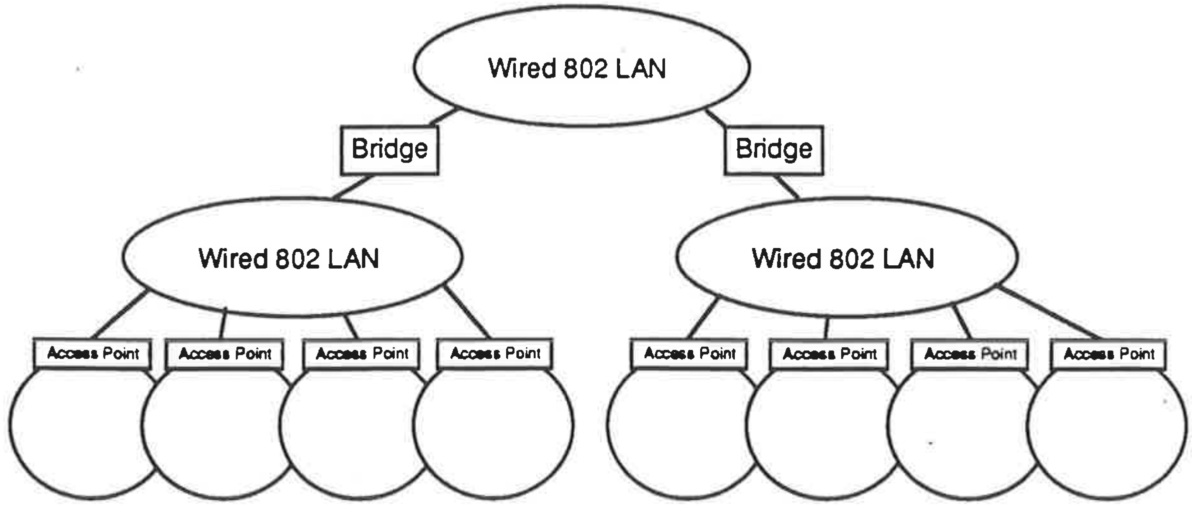


Figure 5.1: Wireless Internetwork Topology

Access points are stations that are connected both to the wireless MAC and to the infrastructure backbone. Access points implement extended MAC services as well as providing the network elements where synchronous service schedulers may be implemented. Figure 5.1 illustrates a single administration EBSA with one access point per BSA serviced by a backbone infrastructure implemented by a bridged internetwork of wired 802 compatible LANs.

In cases of small, mobile EBSAs, access points may be implemented within stations.

Access points announce the presence of the MAC extension service through multicast asynchronous MSDUs. A station desiring access to extended MAC services picks an access point from those whose announcements it can receive. It then attempts registration to the access point to get an netID and enable extended MAC services via the access point. All access points of a given network use a common, unique netId to identify themselves from possibly adjacent, but administratively independent networks.

5.3 Protocol

Stations access extended services by the exchange of messages with access points encapsulated within asynchronous MAC service MSDUs. Six such messages are currently defined.

Register — Point-to-point essage from station to access point requesting access to this access point. Processed when a station changes between access points during roaming or when first powered on. Station is required to pass TBS authentication information to access point within the message. Each station is required to do this for each access point it uses. This access point will now act as the forwarding point for this station - routing non-BSA traffic to/from the station. A station can only be registered on one access point at a time. The station awaits a matching authorize message from the access point granting service.

Stations determine which access point to attempt registration with by listening for announce messages.

Exit — Message from station to access point notifying the current access point when roaming to another BSA or when powering the station off. If a station does not explicitly exit, access points will implicitly remove a station when it has registered at a second access point. If the exit message designates that the station is roaming to another (unidentified) access point, any buffered traffic for the station is retained for a short period within the access point and subsequently forwarded back through the backbone for ultimate delivery through the station's new access point.

Authorize — Point-to-point message from access point to station in response to a logon request granting access to the access point. Access point assigns current NetId to station supporting subsequent access to stations within range of access point. The access point, in the authorize message, notifies the station of the netID it is to use for subsequent access.

Sleep — Multicast message from station to access point declaring that the node is going to sleep and requesting that the access point attempt to buffer MSDU's pending station's subsequent wakeup. This is the essence of the power management protocol and the station must advise the access point in this message of the expected sleep duration so as to prevent premature purging of routing tables.

Awake — Periodic multicast message sent from station to current access point announcing its' continued presence in the range of the access point. The access point uses the receipt of this message to keep forwarding tables current and to release any buffered traffic due to a previous sleep message for transmission to the station. Once per second is likely the appropriate period. If an access point does not receive an awake message from a currently registered station within a predetermined period, it will implicitly exit the station from the current access point.

Announce — A multicast message periodically sent from an access point to all stations within range announcing its presence. The source address of these MSDUs uniquely identify the access points. Once per second is likely the appropriate period.

5.4 Forwarding

Each access point promiscuously listens to all MSDUs on its BSA. Point-to-point MSDUs with source addresses of currently registered stations for which the access point does not detect an immediate CTS response from the destination are forwarded by the access point to the backbone including local CTS and ACK responses to the source. Multicast/broadcast MSDUs (other than MAC internal MSDUs) with source addresses of currently registered stations are forwarded to the backbone.

Each access point promiscuously listens to all MSDUS on the backbone LAN. MSDUs with a destination address of any currently registered station are received and forwarded to the BSA.

5.5 Roaming

Access points accomodate roaming stations by permitting stations to change their registration points. When a station detects that it has moved out of range of its currently registered access point[2], it will choose a new access point and register there. That access point will notify the old access point via a multicast MSDU[3], deregistering at the old access point and causing the old access point to retransmit any queued, undelivered MSDUs destined for the station back out onto the backbone. These should in turn be delivered to the new access point for forwarding to the station.

In any case, an access point will deregister a station for which is receives no awake message for a specified period of time.

The number of queued MSDUs so stored is an implementation dependent issue. SInce almost all higher layer protocols detect lost packets, it is likely an effective strategy to merely discard queued MSDUs for deregistered stations.

5.6 Access Control

Access points control access to the infrastructure. Stations register themselves with access points using an authentication algorithm. As currently specified, as stations move from access point to access point during roaming, they reauthenticate themselves at each access point.

The station authentication algorithm is TBS.

5.7 Power Control

Battery operated stations control their power consumption by selective turning off of unused hardware components, including the wireless LAN interface logic. The MAC extension sublayer provides the mechanism, through awake and sleep messages, to inform a station's communications partners (including access points) of a station's

[2]A station can detect this either by the failure to receive announce messages from the access point or by inference when higher layer sessions routed through the access point no longer pass traffic.

[3]If the backbone is interconnected via spanning tree bridges, this message will notify bridges throughout the spanning tree of the new direction of the station.

inability to receive subsequent MSDUs for a period of time. Other stations receiving a sleep message may buffer in transit traffic to the issuing station pending receipt of a subsequent awake or other packet sourced by the station.

The awake message serves the additional purpose, through it's periodic transmission, of notifying an access point of a station's continued registration.

6. Performance Simulation

It is clearly insufficient to judge the quality of any proposal for wireless MAC protocol without extensive analysis. The complexity of such protocols and their environment mandates either simulation or experimental implementation - likely both - to validate performance. Discrete simulation models of several protocols have been constructed and partially evaluated.

A common, asynchronous traffic model is applied to four types of data service channel allocation schemes under several station connectivity assumptions:

- a dynamic, slotted reservation Time Division Multiplexed scheme with low error rate channels emulating the hybrid MAC synchronous service;
- standard random access Aloha with no channel sensing with low error rate channels;
- a typical Listen-Before-Talk scheme with channel busy sensing for low, modest and high error rate channels, for hidden terminals and for adjacent, decoupled BSAs; and
- the proposed hybrid asynchronous MAC service under the same conditions as the above LBT protocol.

It should be emphasized that the these simulations consume substantial real-time for execution so the results are preliminary and require more extensive analysis.

6.1 Description of Model

The models are constructed using the discrete event based simulation package Extend running a on a network of Macintosh computers.

6.2 Model Assumptions and Parameters

- The number of stations is 20, 10 when partitioned into two adjacent BSAs, and 5 when partitioned into 4 adjacent BSAs.
- Average MSDU generation rate at each station is the same for all stations.
- MSDU arrival process for each station is exponential, more closely mirroring real networks.
- Medium bit rate was varied at 1, 2, and 5 Mb/s. Most simulations were chosen to operate at 2 Mb/s - an achievable speed for most PHYs.
- MSDU length distribution is bimodal, about 60% small at 1000 bits/MSDU and 40% large at 5000bits//MSDU with an average size of 2600 bits/MSDU.
- Service at each station is non-exhaustive, each MSDU is serviced independently.

- Propogation delay between stations is equal and is dominated by signal acquistion time assumed to be 10 µseconds.

- The LBT and hybrid simulations to date have not concentrated on channel busy/derence/retry algorithms. The essential algorithm is a non-persistent listen-before-talk with an exponential, random backoff.

- The effects of channel errors, hidden terminals and adjacent BSAs are evaluated.

- Offered load is measured only w.r.t. new traffic generated by stations and does not include retransmissions due to collisions or errors.

- Positive acknowledgements are included with each MSDU.

The simulations models to date only simulate either the asynchronous service or the synchronous service - not the hybrid of both. If allocated synchronous bandwidth is evenly distributed throughout the frame then synchronous traffic should appear to reduce the capacity of the asynchronous service and increase the average transfer delay appropriately.

6.3 Reservation TDMA

A model was constructed simulating a representative synchronous service using all the PHY channel capacity. It has the following characteristics:

- Immediate allocation response: capacity request granted within same frame
- 2 Mb/s PHY channel speed
- 12.5 msec frame length
- 25 500 µsec slots per frame
- Low PHY BER.

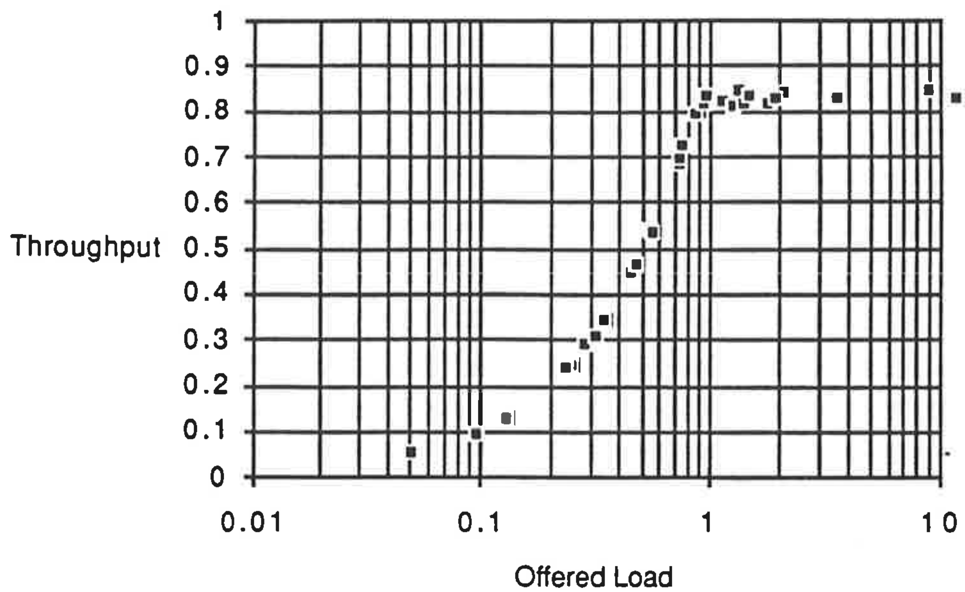


Figure 6.1: Throughput/Load for 2 Mb/s RTDMA (Low Error)

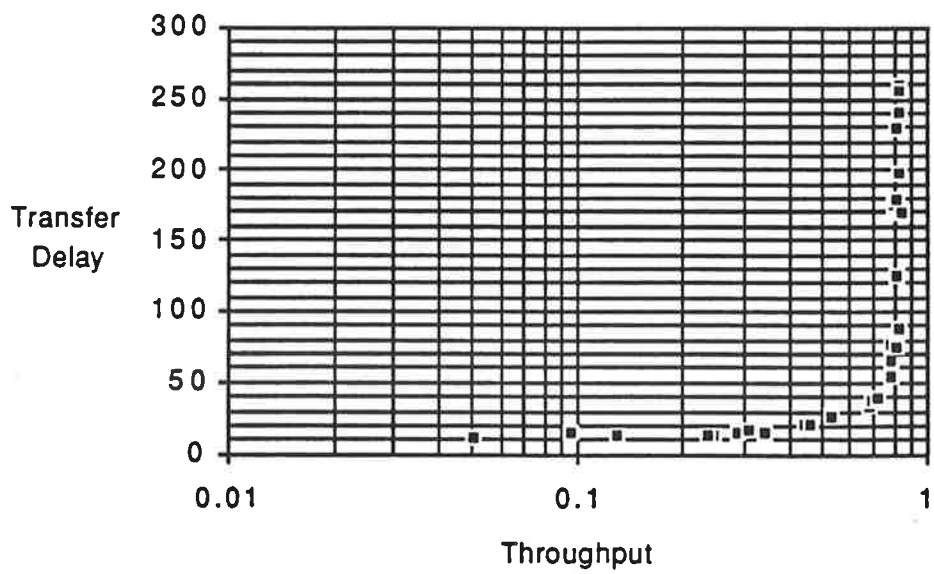


Figure 6.2: Transfer Delay/Throughput for 2 Mb/s RTDMA (Low Error)

The simulation indicates that this system is noted to have the following characteristics:

- stable, maximum throughput at high and overload offered load - 83%;
- exponential transfer delay at high offered load (above 83% throughput);

- high average transfer delay (10-20x transfer delay) over normal range of offered load (< 75%).

6.4 ALOHA

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- Aloha contention allocation
- Low PHY BER.

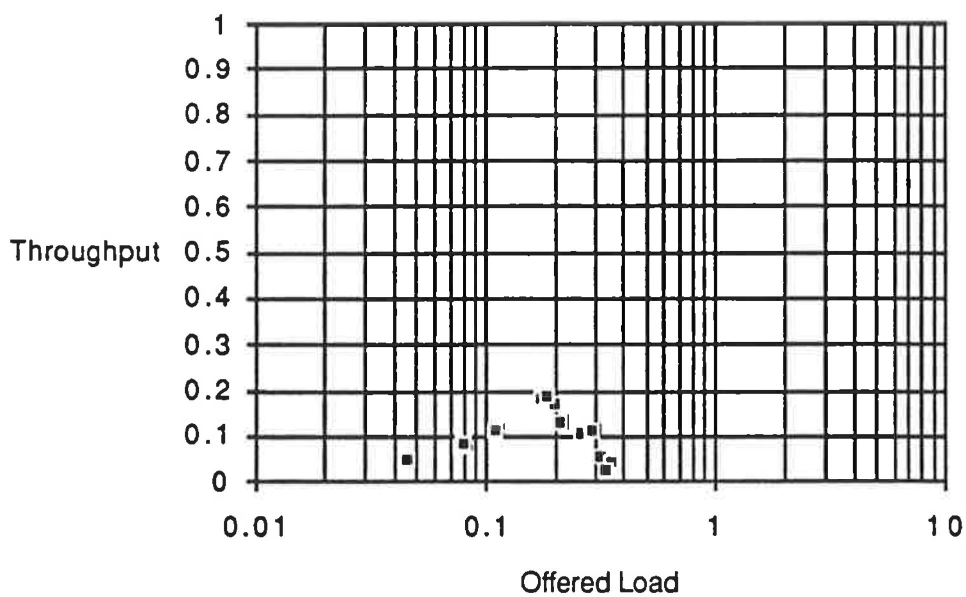


Figure 6.3: Throughput/Load for 2 Mb/s Aloha (Low Error)

The simulation indicates that this system is noted to have the following characteristics:

- unstable, maximum throughput of 18%; linear load/throughput response until maximum is achieved at about 18% offered load;
- exponential transfer delay at high offered load (above 18% throughput);
- low average transfer delay (1-10x transfer delay) over below maximum throughput.

6.5 Listen-Before-Talk

6.5.1 Listen-Before-Talk with Low Error Channels

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 1 Mb/s PHY channel speed
- LBT contention allocation
- Low PHY BER.

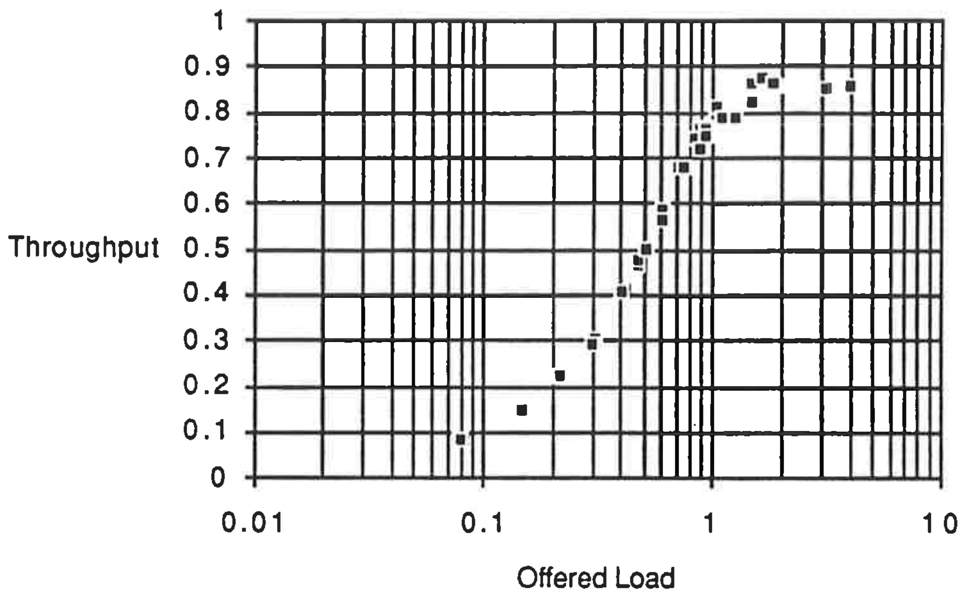


Figure 6.4: Throughput/Load for 1 Mb/s LBT (Low Error)

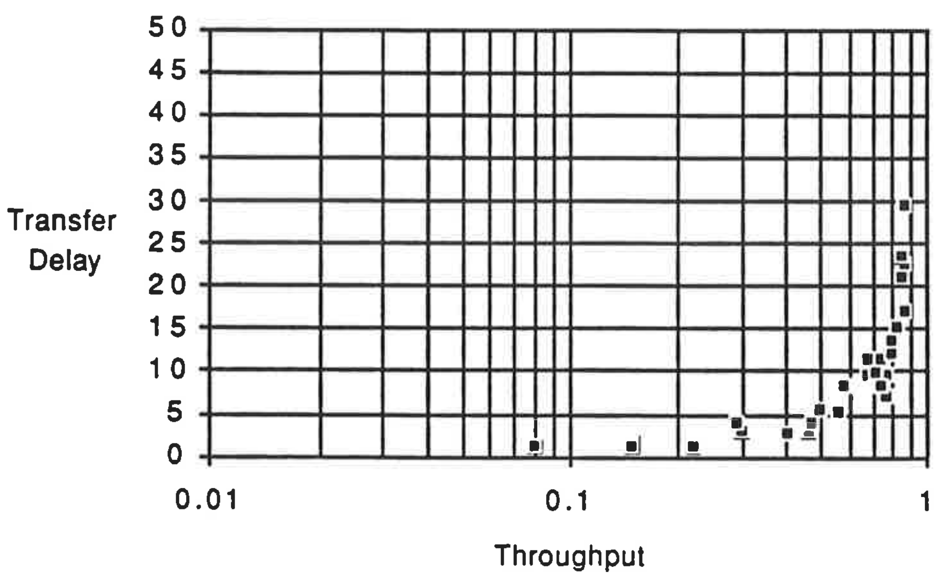


Figure 6.5: Transfer Delay/Throughput for 1 Mb/s LBT (Low Error)

The simulation indicates that this system is noted to have the following characteristics:

- relatively stable, maximum throughput of 87%; linear load/throughput response until about 180% offered load;
- exponential transfer delay at high offered load (above 87% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- LBT contention allocation
- Low PHY BER.

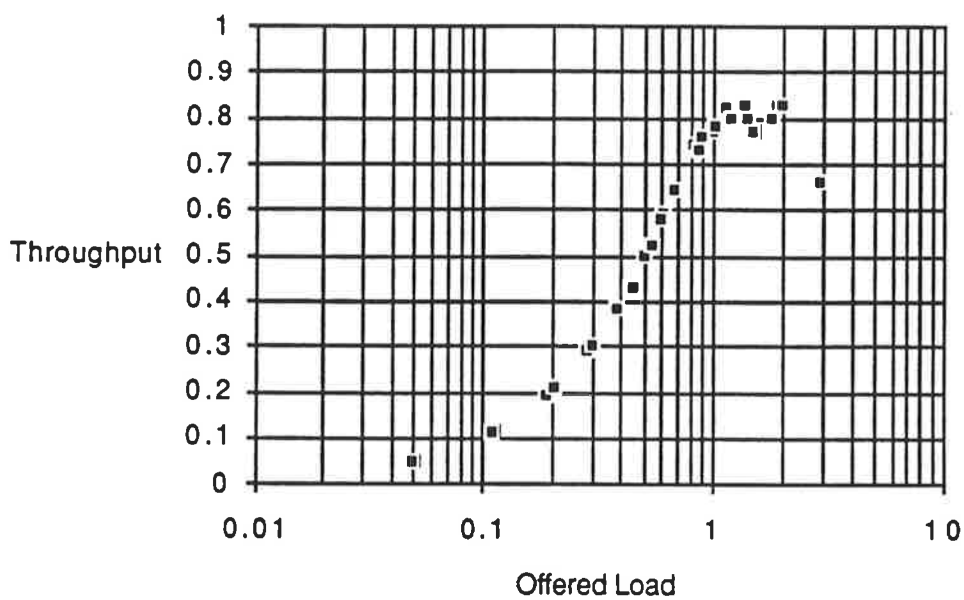


Figure 6.6: Throughput/Load for 2 Mb/s LBTLow Error)

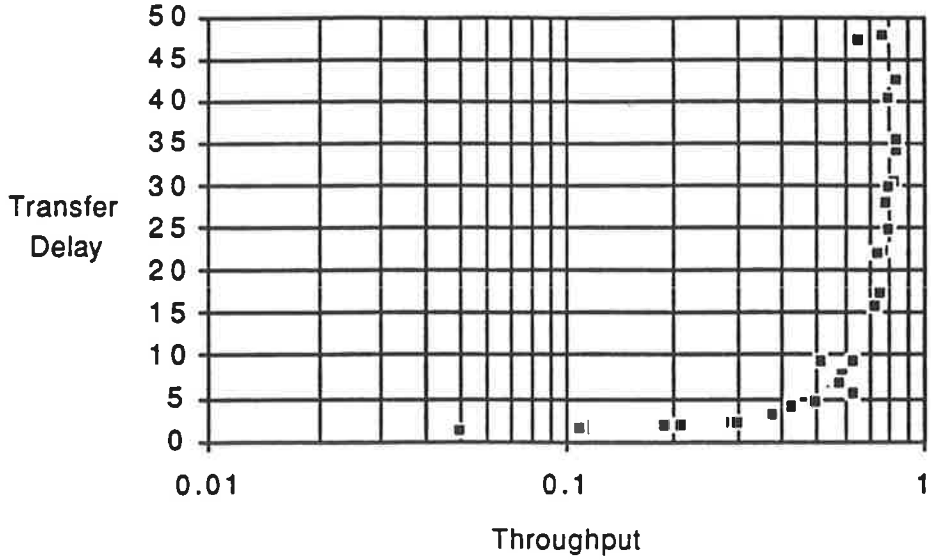


Figure 6.7: Transfer Delay/Throughput for 2 Mb/s LBT (Low Error)

The simulation indicates that this system is noted to have the following characteristics:

- relatively stable, maximum throughput of 83%; linear load/throughput response until maximum is achieved at about 120% offered load;
- exponential transfer delay at high offered load (above 83% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 5 Mb/s PHY channel speed
- LBT contention allocation
- Low PHY BER.

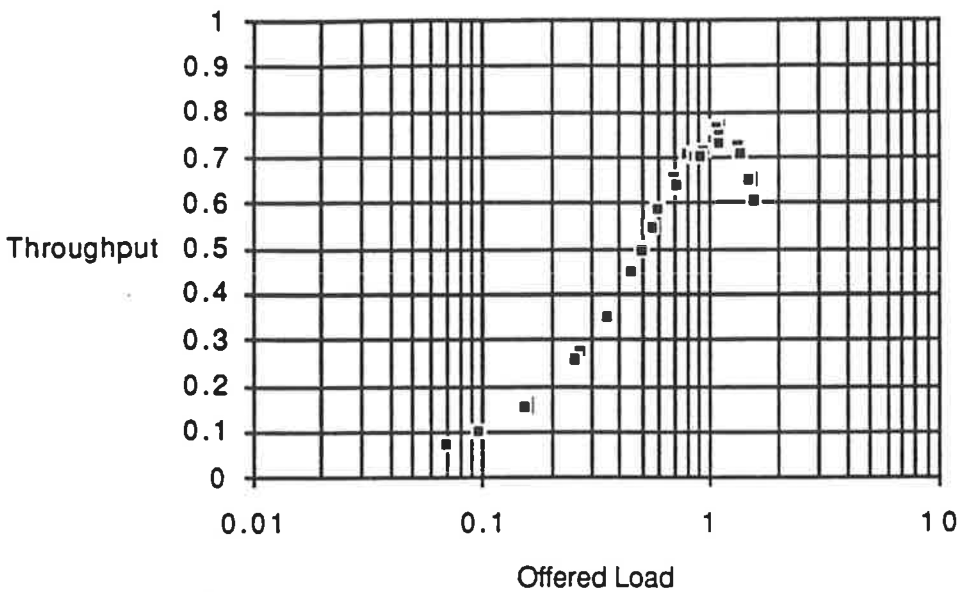


Figure 6.8: Throughput/Load for 5 Mb/s LBT (Low Error)

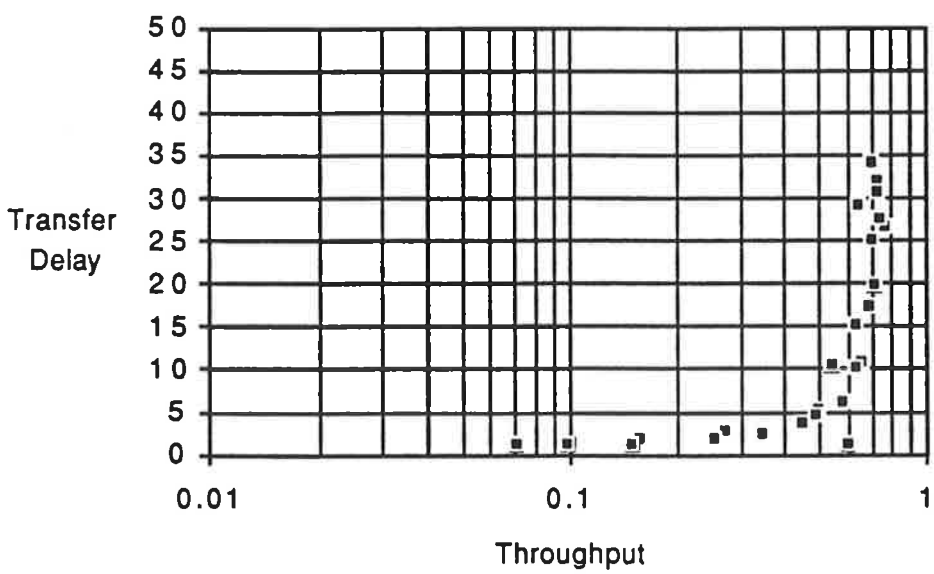


Figure 6.9: Tranfer Delay/Throughput for 5 Mb/s LBT (Low Error)

The simulation indicates that this system is noted to have the following characteristics:

- somewhat unstable, maximum throughput of 77%; linear load/throughput response until maximum is achieved at about 110% offered load; it is conjectured that more effective backoff and retransmission algorithms will improve throughput stability in overload conditions;

- exponential transfer delay at high offered load (above 77% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

The performance of the LBT algorithm diminishes with increases in PHY channel speed due to the increased proportion of propogation delay w.r.t. average MSDU size. The performance of the algorithm can be improved by either decreasing the propogation time or increasing the average MSDU size. While performance is still quite adequate at 5 Mb/s, subsequent analysis is performed for systems at 2 Mb/s.

6.5.2 Listen-Before-Talk with Error-Prone Channels

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- 2% channel sensing and MSDU error rate
- LBT contention allocation
- Low PHY BER.

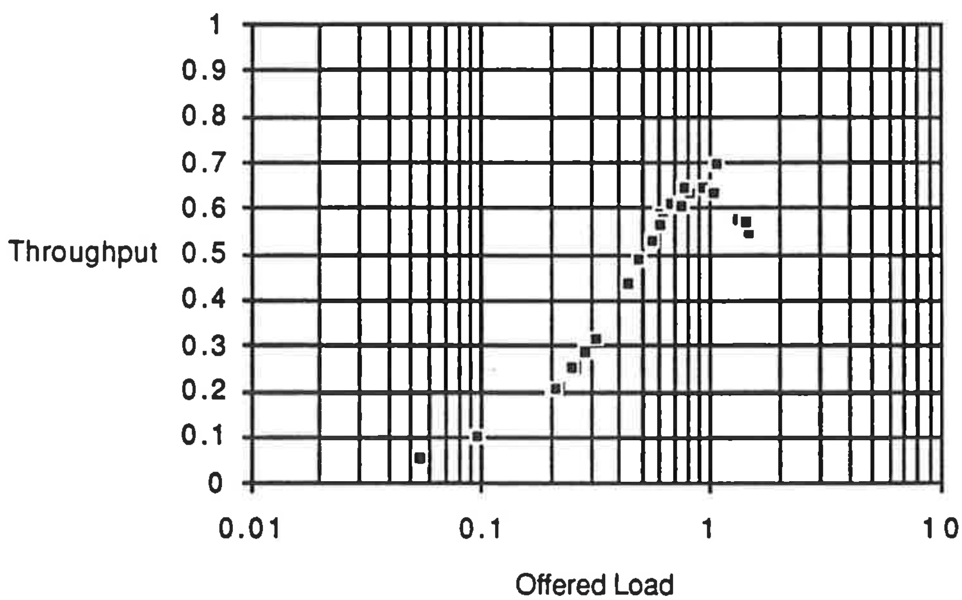


Figure 6.10: Throughput/Load for 2 Mb/s LBT (2% Error)

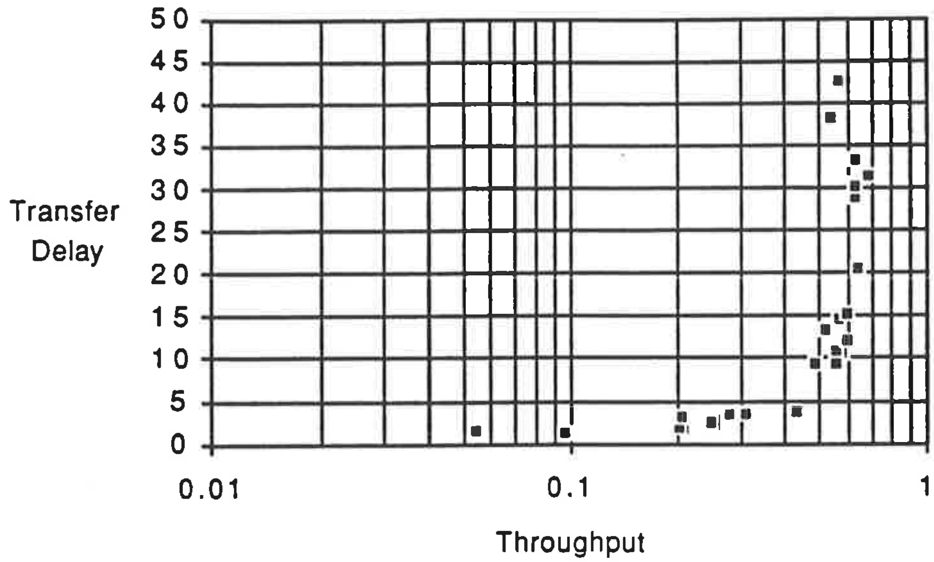


Figure 6.11: Transfer Delay/Throughput for 2 Mb/s LBT (2% Error)

The simulation indicates that this system is noted to have the following characteristics:

- relatively stable, maximum throughput of 65%; linear load/throughput response until maximum is achieved at about 90% offered load; note a degradation of almost 20% in relative throughput performance relative to a low error PHY;
- exponential transfer delay at high offered load (above 65% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- 10% channel sensing and MSDU error rate
- LBT contention allocation
- Low PHY BER.

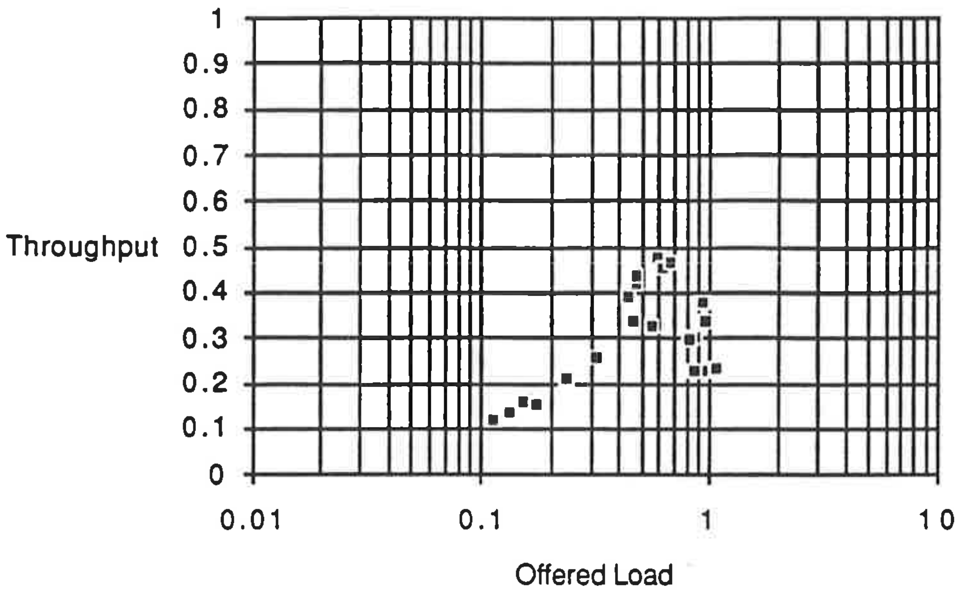


Figure 6.12: Throughput/Load for 2 Mb/s LBT (10% Error)

The simulation indicates that this system is noted to have the following characteristics:

- unstable, maximum throughput of 48%; linear load/throughput response until maximum is achieved at about 60% offered load; another 20% degradation compared to 2% error PHY;
- exponential transfer delay at high offered load (above 48% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- 25% channel sensing and MSDU error rate
- LBT contention allocation
- Low PHY BER.

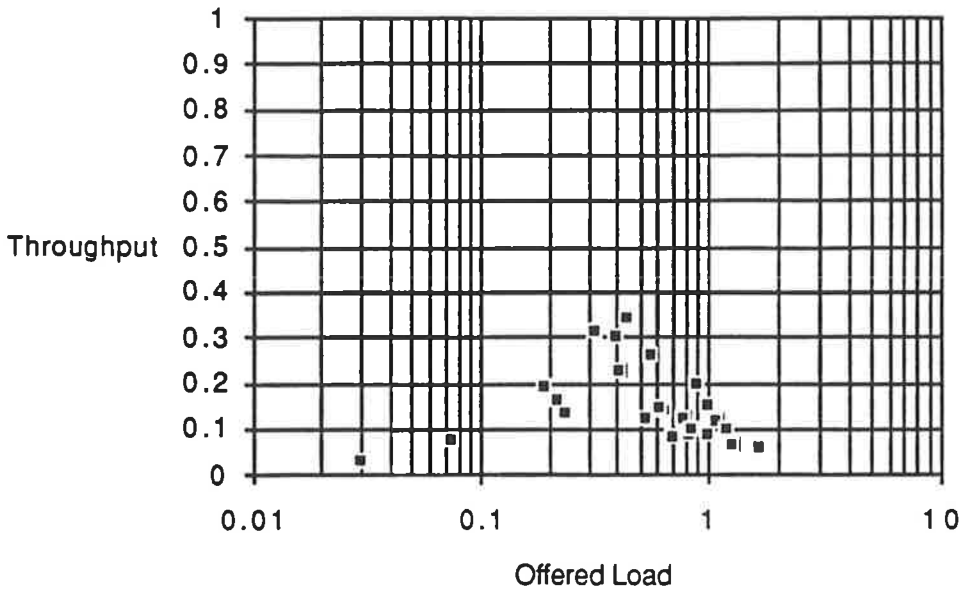


Figure 6.13: Throughput/Load for 2 Mb/s LBT (25% Error)

The simulation indicates that this system is noted to have the following characteristics:

- unstable, maximum throughput of 35%; linear load/throughput response until maximum is achieved at about 40% offered load;
- exponential transfer delay at high offered load (above 35% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

6.5.3 Listen-Before-Talk with Hidden Stations

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- 5% hidden stations
- LBT contention allocation
- Low PHY BER.

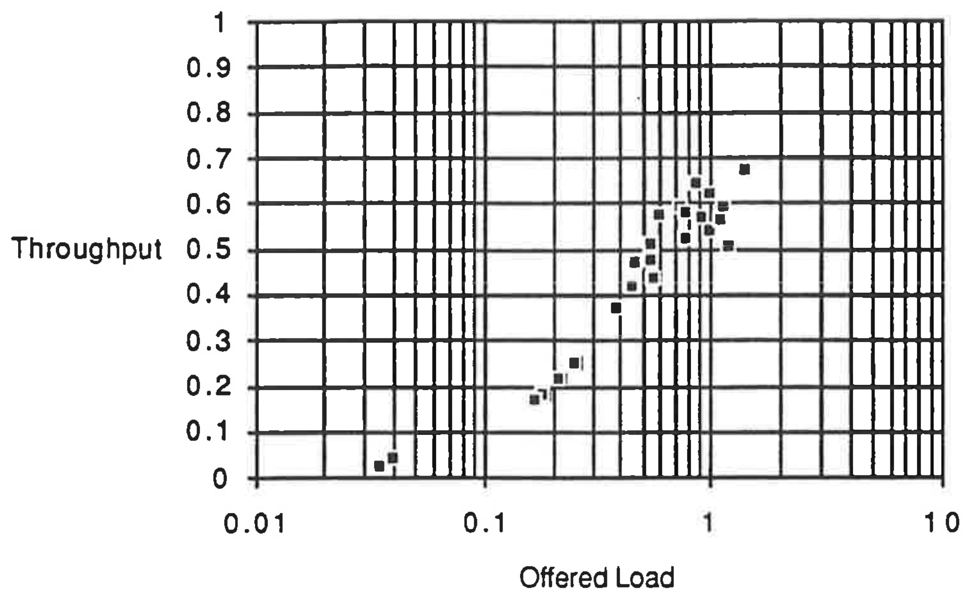


Figure 6.14: Throughput/Load for 2 Mb/s LBT (5% Hidden)

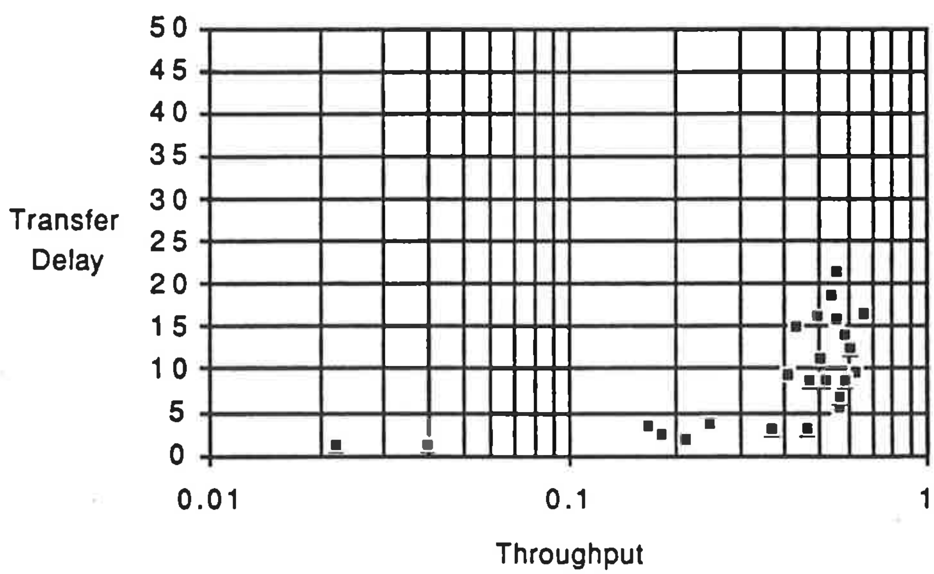


Figure 6.15: Transfer Delay/Throughput for 2 Mb/s LBT (5% Hidden)

The simulation indicates that this system is noted to have the following characteristics:

- relatively stable, maximum throughput of 62%; linear load/throughput response until maximum is achieved at about 85% offered load;

- exponential transfer delay at high offered load (above 50% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- 10% channel sensing and MSDU error rate
- LBT contention allocation
- Low PHY BER.

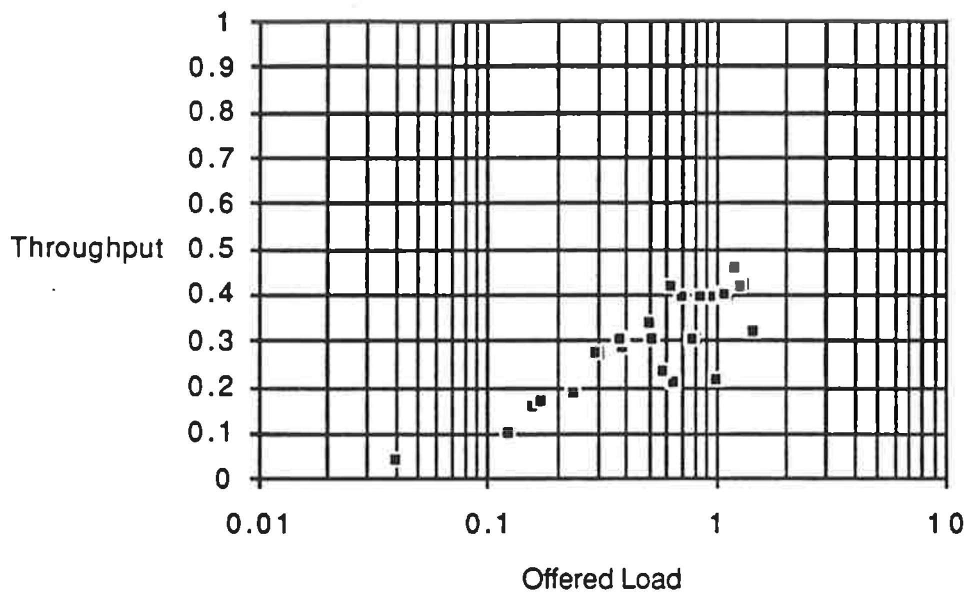


Figure 6.16: Throughput/Load for 2 Mb/s LBT (10% Hidden)

The simulation indicates that this system is noted to have the following characteristics:

- unstable, maximum throughput of 42%; linear load/throughput response until maximum is achieved at about 70% offered load;
- exponential transfer delay at high offered load (above 40% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- 25% channel sensing and MSDU error rate
- LBT contention allocation
- Low PHY BER.

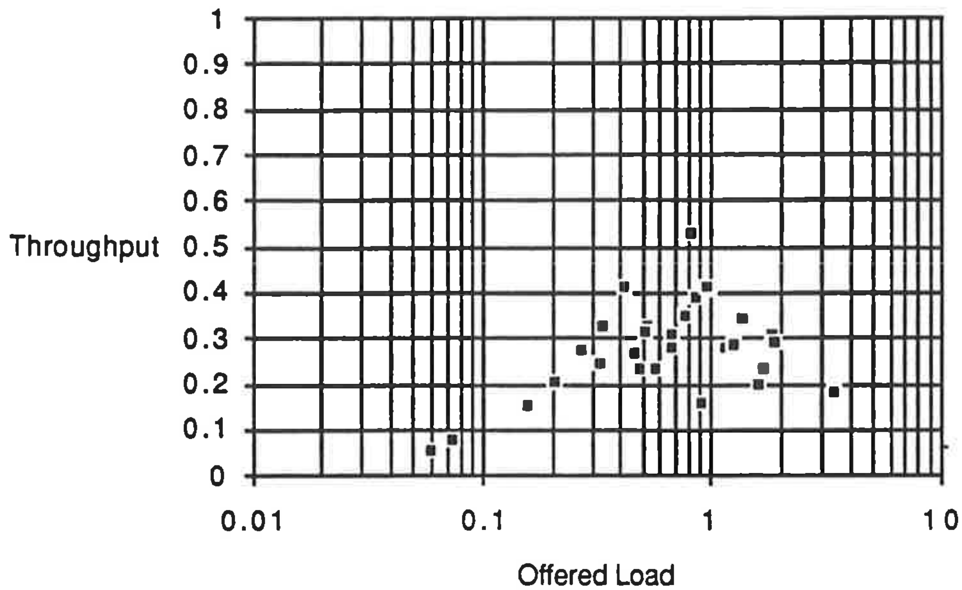


Figure 6.17: Throughput/Load for 2 Mb/s LBT (25% Hidden)

The simulation indicates that this system is noted to have the following characteristics:

- unstable, maximum throughput of 38%; linear load/throughput response until maximum is achieved at about 60% offered load;
- exponential transfer delay at high offered load (above 38% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

6.5.4 Listen-Before-Talk with Adjacent BSAs

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- 2 adjacent BSAs with overlapping media range - roughly equivalent to the interaction of two adjacent floors using a radio PHY with a BSA per floor
- LBT contention allocation
- Low PHY BER.

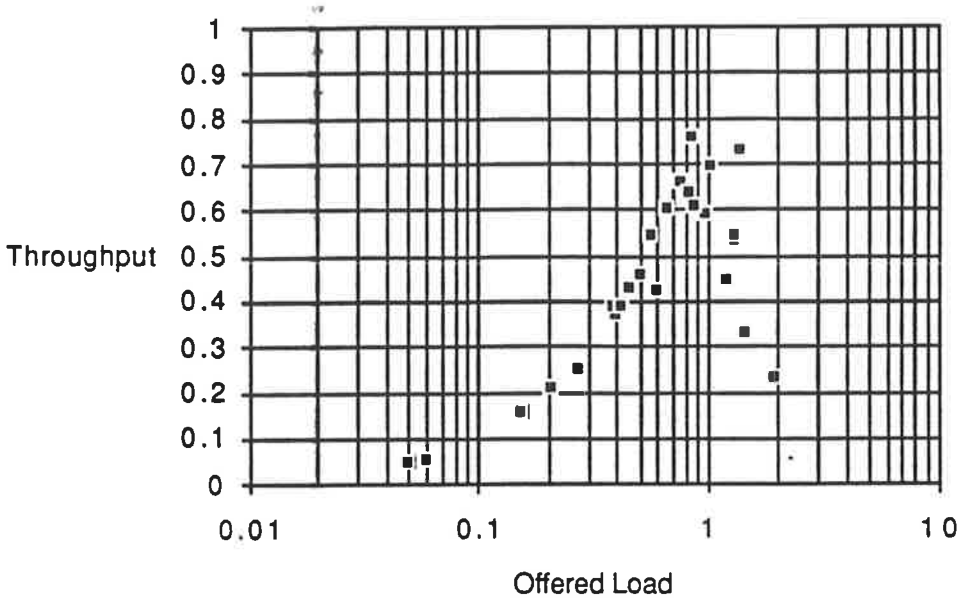


Figure 6.18: Throughput/Load for 2 Mb/s LBT (2 Adjacent BSAs)

The simulation indicates that this system is noted to have the following characteristics:

- unstable, maximum throughput of 70%; linear load/throughput response until maximum is achieved at about 85% offered load;
- exponential transfer delay at high offered load (above 70% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- 4 adjacent BSAs with overlapping media range - roughly equivalent to the interaction of a stack of four adjacent floors using a radio PHY with a BSA per floor in which each floor interacts with above and below floors
- LBT contention allocation
- Low PHY BER.

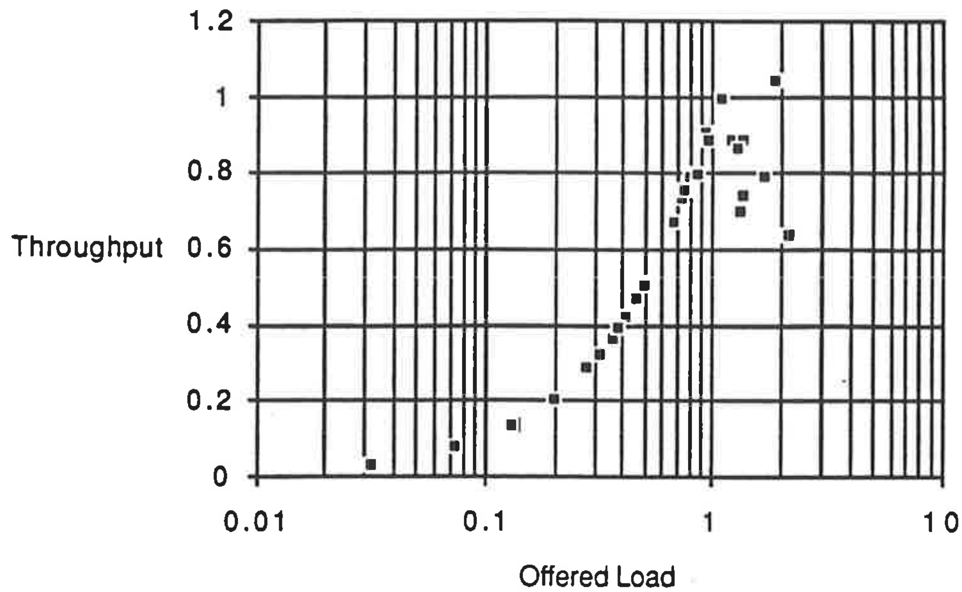


Figure 6.19: Throughput/Load for 2 Mb/s LBT (4 Linear Adjacent BSAs)

The simulation indicates that this system is noted to have the following characteristics:

- relatively stable, maximum throughput of 100%; linear load/throughput response until maximum is achieved at about 100% offered load;
- exponential transfer delay at high offered load (above 100% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

6.6 Hybrid Asynchronous MAC

6.6.1 Hybrid Asynchronous MAC with Low Error Channel

A model was constructed simulating a representative asynchronous service using all the PHY channel capacity. It has the following characteristics:

- 2 Mb/s PHY channel speed
- hybrid MAC asynchronous sublayer contention allocation
- Low PHY BER.

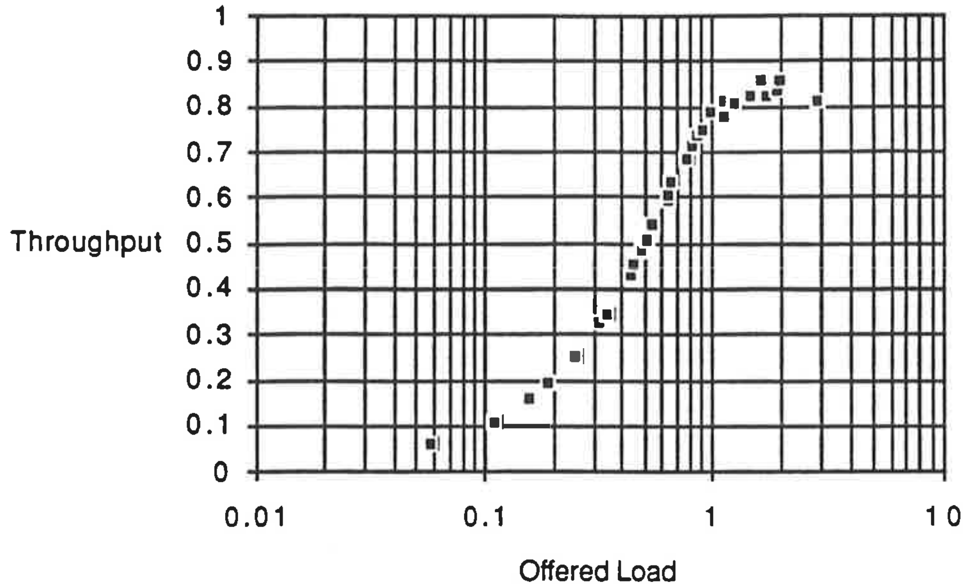


Figure 6.20: Throughput/Load for 2 Mb/s Hybrid (Low Error)

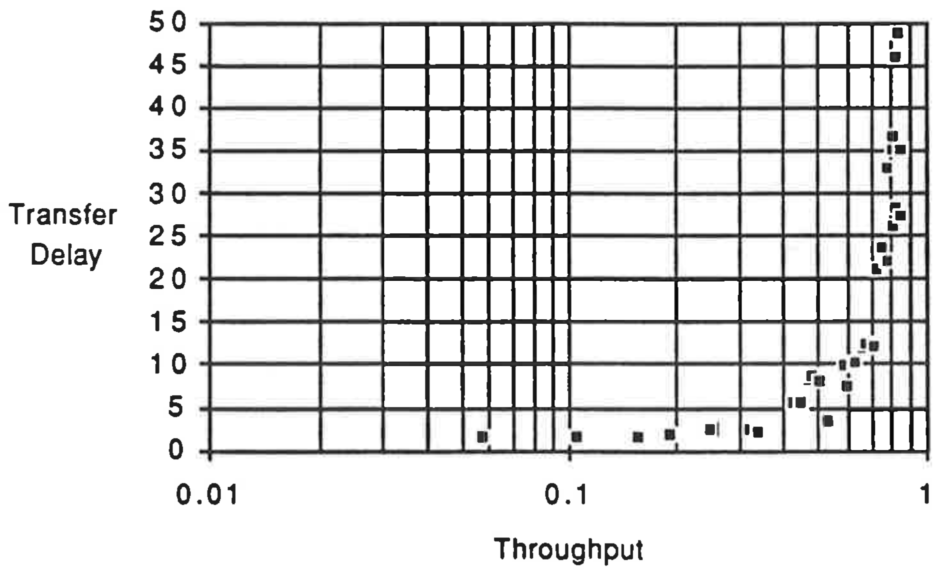


Figure 6.x: Transfer Delay/Load for 2 Mb/s Hybrid (Low Error)

The simulation indicates that this system is noted to have the following characteristics:

- relatively stable, maximum throughput of 85%; linear load/throughput response until maximum is achieved at about 180% offered load;

- exponential transfer delay at high offered load (above 85% throughput);
- low average transfer delay (1-10x transfer delay) below maximum throughput.

The simulation suggest the hybrid asynchronous MAC provides increased throughput, better stability at overload and no increase in transfer delay w.r.t. the simpler LBT mechanism.

6.6.2 Hybrid Asynchronous MAC with Error-Prone Channels

To be completed.

6.6.3 Hybrid Asynchronous MAC with Hidden Stations

To be completed.

6.6.4 Hybrid Asynchronous MAC with Adjacent BSAs

To be completed.

7. Glossary

Access Point	A station that provides internetwork MSDU forwarding, roaming, power control and access control services to either/both the asynchronous data service or/and the synchronous data service.
Address	A 48 bit entity that either uniquely identifies a station or signifies a multicast or broadcast destination.
Administration	A management entity distinguishing one enterprise from another. For example, two adjacent, independent businesses would be two administrations.
Allocation Vector	Per station database of allocated channel bandwidth. The net allocation vector defines all bandwidth, "visible" to the station, during which the station is prohibited from transmitting asynchronous service MSDU. The station allocation vector defines all bandwidth during which this station can transmit synchronous MSDUs.
Asynchronous	Data traffic that characteristically has a statistical arrival distribution. Typifies most LAN data traffic.
Beacon MSDU	Transmitted at the beginning of each frame by the scheduler, the Beacon MSDU
BSA	Basic Service Area. The fundamental wireless LAN service area defined by the unrepeated transmission range of the particular PHY layer.
CRC	Cyclic Redundancy Check. A 32 bit polynomial checksum calculated and appended by an MSDU's sender for use by the MSDU's receiver to detect errors in transmission.
EBSA	Extended BSA. A set of intercommunicating BSAs sharing a common administration interconnected via a infrastructure.
Frame	The overall timing structure the synchronous service imposes on the channel in order to synchronize station transmissions. Each frame begins with a beacon MSDU transmitted by the scheduler controlling the synchronous service.
Infrastructure	The intercommunications mechanism for an EBSA consisting of a (likely) wired backbone 802 compatible network serving a collection of access points.

MSDU	MAC layer Service Data Unit - the fundamental unit of data delivery between MAC entities.
LBT	Listen-Before-Talk. Label given to a class of distributed algorithms for channel allocation in which an attempted transmission is preceded by sensing current activity on the channel. If the channel is busy, the attempted transmission is deferred to a subsequent time.
LWT	Listen-While-Talk. Label given to a class of distributed algorithms for channel allocation in which an attempted transmission is both preceded by sensing current activity on the channel as well as comparing data sent by the current node with data contemporaneously received from the channel. If the channel is busy before transmission begins, the attempted transmission is deferred to a subsequent time. If during the transmission, channel received data does not match sent data, a collision is detected and the transmission is scheduled for retransmission.
NetID	A 16 bit, locally constructed, identifier for the EBSA's administration. It is allocated to a station when the station registers with the EBSA infrastructure.
Payload	The higher layer supplied contents of the MSDU.
Preamble	A known, fixed bit pattern preceding MSDU elements to provide for clock and bit synchronization between transmitting and receiving stations.
Scheduler	Centralized bandwidth allocation function for the synchronous service. At least one scheduler must be configured for each BSA offering the synchronous service. A scheduler is always implemented within an access point.
Slot	A fixed length unit of channel time. The quanta of allocation by the synchronous data service scheduler within a frame.
Synchronous	Data traffic that has a predictable, periodic characteristic and requires data transport services that minimize transfer delay variance of the traffic.

8. References

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