IEEE 802.11

Wireless Access Method and Physical Layer Specifications

Wireless Local Area Network Requirements

IEEE Project 802.11

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Abstract

An effective, consensus wireless LAN standard requires agreement on the service requirements that the wireless LAN should provide to its using entities.

This document presents an integrated set of wireless LAN MAC and PHY requirements. This document is subject to periodic revisions subject to decisions reached at plenary meetings of 802.11. These requirements will be used as a non-binding guide to evaluate subsequent development of wireless LAN MAC and PHY standards.

Quantitative examination of education, financial, office, industrial, retail, warehousing, multimedia and medical application areas is used to derive MAC and PHY service requirements.

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1. Introduction

1.1 Scope

An effective, consensus wireless LAN (WLAN) standard requires agreement on the service requirements that the wireless LAN should provide to its using entities.

This document presents an integrated set of wireless LAN MAC and PHY requirements. This document is subject to periodic revisions subject to decisions reached at plenary meetings of 802.11. These requirements will be used as a non-binding guide to evaluate subsequent development of wireless LAN MAC and PHY standards.

The goals of this effort include:

- To provide wireless connectivity to automatic machinery, equipment or, stations that require rapid deployment, which may be portable, or hand-held or which may be mounted on moving vehicles within a local area.
- To offer a standard for use by regulatory bodies to standardize access to one or more radio frequency bands for the purpose of local area communication.
- To develop a Medium Access Control (MAC) and Physical Layer (PHY) specification for wireless connectivity for fixed, portable and moving stations within a local area.

The MAC shall support multiple, alternative PHYs using electromagnetic waves through the air (i.e. radio waves as well as infra-red or visible light).

The standard shall support stationary stations, movable stations, and mobile stations moving at pedestrian and vehicular (local premises environment) speeds. This is to be implemented with one PHY if feasible.

Because the range of wireless transmission and reception may be smaller than the physical coverage area desired, a distribution system designed to provide range extensibility will be addressed as part of this standard.

The standard will include support of the following:

Basic Service Area (BSA)	in which each station can communicate with any other station in the BSA.
Extended Service Area (ESA)	in which each station can communicate with any other station via the defined and managed Distribution System.
Operability	in both BSA and ESA shall be defined.

Possible target environments include:

- in buildings and other premises such as offices, financial institutions, shops, malls, small and large industry, hospitals and residences,

- outdoor areas such as parking lots, campuses, building complexes and outdoor plants and storages.

The Wireless MAC shall support both connectionless service as defined in the MAC Service definition at rates between 1 and 20 Mbit/s as well as a service supporting packetized voice.

1.2 Methodology

The chosen method is to investigate a set of market areas, identifying in each characteristic applications and wireless network configurations. These market areas include: education, meetings, financial, office, medical, industrial, retail, warehousing and multi-media.

While there is substantial crossover of applications, in particular office applications are common in almost every market area, the following analysis has focussed on applications unique to each area. The analysis of office applications will likely apply to many of these market areas as well to each market area's unique applications.

For each such identified application we characterize the expected MAC traffic generated by an instance of that application via the criteria in Figure 1.1.

MSDU Size Distribution	Define distribution of MSDU size in octets.
MSDU Arrival Distribution	Define MSDU interarrival time probability distribution. Later we may wish to augment this description to describe specific, deterministic, request-response traffic models.
Nominal Transfer Delay	Transfer delay measures the time from when an MSDU is submitted for transmission at the source MAC interface until the completion indication is given by the destination MAC interface between two stations within the same BSA. Intermediate forwarding through a distribution system are not included in this measure. This is measured in milliseconds for the nominal MSDU size and by definition includes the transmission time for the MSDU itself as well as access delay to a shared wireless medium as well as (possible) additional delay due to MAC level ARQ and retransmission. This definition is equivalent to the time between the invocation of the MA-UNITDATA.request primitive at the transmitting MAC service layer boundary to the corresponding MA-UNITDATA.indication at the receiving MAC service layer boundary.
Transfer Delay Standard Deviation	The tolerated standard deviation in transfer delay of this application. This is measured in milliseconds.
Maximum Transfer Delay	The maximum tolerated MSDU transfer delay for the application. MSDUs delayed by more than this amount are considered by the application the same as lost MSDUs.
MSDU Loss Rate	Percentage lost MSDUs during an application session that the application can tolerate without unacceptable user performance. It is expected that higher layer protocols (e.g. transport) will provide additional, comprehensive end-to-end reliability. This is a measure of the detected MSDU loss rate, rather than undetected MSDU loss rate.
Service Initiation Time	The amount of time this application can tolerate in order to initiate link level MSDU delivery service between source and destination. This is measured in milliseconds. This can be considered additional delay required to set up the communication path between particular source and destination stations for the first time in a stream of MSDUs. Each subsequent MSDU does not suffer this additional delay. This measure can be considered a "connection setup time."
Station Speed	The possible movement speed of a station implementing this application.
Session Duration	The time, measured in milliseconds, for the duration of typical session for the application.
Send/Receive Ratio	The ratio of MSDUs sent by a wireless station implementing an application to the MSDUs received.
Destination Distribution	The percentage of this application's traffic that will typically be directly destined for wireless stations within the BSA and/or ESA rather than stations on an interconnected wired backbone.

Figure 1.1: MAC Service Parameters

For each market area, anticipated applications are described as above and typical wireless network configurations are described by supplying the following information.

Number of stations	The typical number of stations for this configuration.
Station density	The number of stations per hectare.
Dimension	The typical linear dimension of the wireless service area. Measured in units of meters. Considered to be the maximum distance between any two communicating stations.
Application List	The list of applications that this configuration would typically use. It is our intention to construct traffic load models using this information.
Application Initiation Distribution	Time distribution of the service initiation times for these applications in this configuration.
Application Duration Distribution	Application duration distribution for each application in this configuration.

Figure 1.2: MAC WLAN Configuration Parameters

Figure 1.2 defines the parameters defining typical configurations of applications on networks of stations. The combination of application initiation and duration distributions defines the duty cycle of applications on the configurations. The previous table defines the expected MAC service for each of these applications. The combination can be used to define a MAC traffic model for each network configuration.

This document is structured in five parts. This first part introduces the goals, definitions, conformance requirements, methodology and references used in the remainder of the document. Section Two documents overall general requirements and WLAN functional architecture summarized from the surveyed applications, the 802.11 PAR and overall Project 802 Functional Requirements. Section Three refines these requirements for MAC specific performance and functional requirements. Section Four refines these requirements for PHY specific performance and functional requirements. A series of appendices summarize the contributions of a number of individuals and organizations on the specific applications and wireless LAN market requirements in ten target market areas: education, financial, industrial automation, manufacturing, medical, meetings, office, retail, warehousing, and multimedia services. Finally, a series of appendices summarize the analysis of each of the MAC parameters w.r.t. the data accumulated for these applications.

1.4 Definitions and Abbreviations

access point — An 802.11 entity that provides connectivity between the wireless media and wired media.

administration — The user organization responsible for the management of the PLAN.

alien station	A station that is a member of an instance of an off premises local area network in the view of a specific PLAN user.
application	A user program executing on a station that makes use of the wireless network services defined by the 802.11 MAC and PHY.
attenuation distance	The path loss between stations experienced by a signal that conforms to the IEEE 802.11 PHY specification as it propagates between a transmitter and a receiver. This distance is measured in dB and it is typically a time varying quantity.
BSA	Basic Service Area. The basic wireless network coverage area within which any two stations can communicate without the intervention of a distribution system as intermediary.
channel	An instance of medium use that can coexist with other instances of medium use with each instance of medium use providing service to a separate set of stations.
coverage distance	The maximum attenuation distance separating stations at which a communication service of sufficent quality of service to meet these requirements is possible.
denial of service	Methods and procedures concerned with the prevention of unauthorized stations from denying WLAN service to authorized stations.
directed medium	A medium that propagates signals along a path that is primarily (although not entirely) confined to a solid angle that is small compared to 4π steradians. An example of a directed medium is a point-to-point microwave link. Signals propagating on a directed medium cannot be considered to be immune to interference from signals not intentionally imposed on the medium on which they are propagating.
distribution system	An out-of-band communications system (often wired) that extends the range and services to a BSA to provide for extended range and services.
ESA	Extended Service Area. The extended coverage area provided through means of a distribution system to extend the BSA of a station.

Euclidean distance	The classical measure of spatial separation that is calculated as Sqrt$[x^2+y^2+z^2]$ and is denominated in meters.
good signal	A signal that passes all the tests that an IEEE 802.11 PHY Layer Entity can perform on it to assure that the signal has been generated by an IEEE 802.11 conformant PHY Layer Entity.
guided medium	A medium that consists of a physical waveguide that confines signals impressed upon it to propagate only in the physical space occupied by the waveguide. A guided medium can only deliver signals to stations that are physically located along the path of the waveguide. Examples of guided media are coaxial and fiber optic cables. Signals propagating on a guided medium can be considered to be immune to interference from signals not intentionally imposed on the medium on which they are propagating.
infrared signal	A signal that consists of an electromagnetic disturbance with a wavelength in the range from 750 nm to 1 mm. This corresponds to frequencies between 40000 GHz and 300 GHz.
integrity	Methods and procedures for the prevention of unauthorized modification of transmitted data.
interference distance	The maximum attenuation distance separating stations at which a transmitted good signal can be detected as a good signal regardless of whether a sufficent quality of service to meet the IEEE 802.11 specifcation could be provided by that signal.
jammer	An entity that places signals that are observable by entities implementing an IEEE 802.11 PHY Layer Entity but do not conform to the IEEE 802.11 PHY Layer Specification.
local area network	A LAN is a group of stations that can communicate with each other through the use of a common medium.
MAC	Media Access Control. The part of a station that supports the medium access control functions that reside just below the LLC sublayer. The MAC procedures include framing/deframing data units, performing error checking, and acquiring the right to use the underlying physical medium.

medium	Anything upon which a signal is impressed or from which a signal is received. The term media is used only as the plural of medium.
microwave signal	A signal that consists of an electromagnetic disturbance with a wavelength in the range from 1 mm to 30 cm. This corresponds to frequencies between 300 GHz and 1 GHz.
MSDU	MAC Service Data Unit. The unit of data transfer between peer link level entities and is defined as a block of an integral number of octets transferred as a block between peer entities.
MSDU jitter	A measure of the delay properties of the MAC and PHY. It is represented as the ratio of the MSDU delay variance to nominal MSDU delay.
native station	A station that is a member of the specific instance of a premises local area network of concern to a specific PLAN user.
N-layer	A subdivision of the architecture, constituted by subsystems of the same rank (N).
N-user	An N+1 entity that uses the services of the N-layer, and below, to communicate with another N+1 entity.
obsequious station	A station that cooperates with alien stations for the purposes of sharing a single medium.
octet	A bit-oriented element that consists of eight contiguous binary bits.
off premises local area network	An OPLAN is a group of stations not under the administrative control of the specific instance of a PLAN of concern to a specific PLAN user.
pernicious jammer	An entity that places signals that conform to the IEEE 802.11 PHY Layer Specification but do not conform to the IEEE 802.11 MAC Layer Specification.
PHY	Physical layer. The physical layer mechanism for communicating symbols between communicating peer stations.
premises local area network	A PLAN is a group of stations under the control of a single administration that desires the ability to

communicate exclusively with members of this group of stations.

PLAN user	An entity that desires access to the services of a specific PLAN.
priority	A parameter used to convey the delivery priority required or desired.
radio frequency signal	A signal that consists of an electromagnetic disturbance with a wavelength in the range from 10 m to 1 cm. This corresponds to frequencies between 30 MHz and 30 GHz. (Note: This definition delibrately excludes signals that might be considered radio frequency in other environments in order to maintain a reasonable relationship between the physical size of objects in the environments in which the IEEE 802.11 standard is expected to operate and the wavelength of a signal)
recalcitrant station	A station that does not cooperate with alien stations for the purposes of sharing a single medium.
restricted medium	A medium that consists of a physical cavity in which all signals that originate within the cavity are contained and from which all signals that originate outside of the cavity are excluded. A room without openings through which infared signals can pass is an example of a restricted medium. Signals propagating on a restricted medium can be considered to be immune to interference from signals not intentionally imposed on the medium on which they are propagating.
security	Methods and data for the protection of transmitted data from observation by unauthorized stations.
service	The capabilities and features provided by an N-layer to N-user.
service class	A parameter used to convey te class of service required or desired.
signal	A detectable disturbance.
station	Any entity that imposes signals that conform to the IEEE 802.11 PHY specification on a medium in a manner that conforms to the IEEE 802.11 MAC specification and receives signals that conform to the

IEEE 802.11 PHY and MAC specifications from a medium is considered a station whether or not it has any functionality beyond the reception and transmission of signals.

station density	The number of stations per hectare.
station speed	The linear speed (in meters/second) of stations that require wireless LAN services while in motion.
transfer delay	Transfer delay measures the time from when an MSDU is submitted for transmission at the source MAC interface until the completion indication is given by the destination MAC interface between stations within the same BSA. Intermediate forwarding through a distribution system are not included in this measure. This is measured in milliseconds and by definition includes the transmission time for the MSDU itself as well as access delay to a shared wireless medium as well as (possible) additional delay due to MAC level ARQ and retransmission. This definition is equivalent to the time between the invocation of the MA-UNITDATA.request primitive at the transmitting MAC service layer boundary to the corresponding MA-UNITDATA.indication at the receiving MAC service layer boundary.
throughput	Throughput is measured in two ways. First, it is a measurement per unit time of the number of MSDUs transferred between peer entities within the same BSA. Secondly, it is also the number of octets successfully transferred from a transmitting station to a receiving station within the same BSA based on the MSDU size.
undirected medium	A medium that propagates signals in a manner that is not confined to a known physical path. An example of an undirected medium is cluttered space in the vicinity of radio frequency signals emitted from common dipole antennaes. Signals propagating on undirected medium cannot be considered to be immune to interference from signals not intentionally imposed on the medium on which they are propagating.

1.5 Conformance

The specification shall meet the following standards and documents.

IEEE P802	Functional Requirements including section 5.6.1 (in version 6.5) as defined below: "5.6.1 The MAC Service Data Unit (MSDU) loss rate shall be less than 4*10E-5 for an MSDU length of 512 octets." A minimally conformant IEEE P802.11 network will meet all of the P802 requirements except that 5.6.1 will be met at least 99.9 % of the time on a daily basis, in 99.9 % of the total geography of the service area. IEEE P802.11 will define approaches to allow a minimally conformant network to achieve full conformance over the total geography of the service area.
IEEE 802.2	MAC Service Definition
ISO 10039	MAC Service Definition
IEEE 802.1	Overview and Architecture
IEEE 802.1 B	LAN/MAN Management
IEEE 802.1 D	T and SRT bridges
IEEE 802.1 F	Guidelines for the Development of Layer Management Standards
IEEE 802.10	Secure Data Exchange

The standard shall anticipate restrictions on Electromagnetic fields and pulsing of Electromagnetic fields due to potential biological hazards. The standard shall conform to the following safety standards.

IEEE C95.1-1990	Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz
IEEE C95.2-1981	Radio Frequency Radiation Hazard Warning Symbol; Reaffirmed in 1989
IEEE C95.3-1973	Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies; Reaffirmed in 1979
IEEE C95.4-1978	Safety Guide for the Prevention of Radio-Frequency Radiation Hazards in the Use of Electric Blasting Caps

IEEE C95.5-1981 Recommended Practice for the Measurement of Hazardous Electromagnetic Fields - RF and Microwave

1.6 References

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[3] ISO 10039 MAC Service Definition

[4] IEEE Standards for Local and Metropolitan Area Networks: LAN/MAN Management, IEEE 802.1B-1990, 1991.

[5] IEEE Standards for Local and Metropolitan Area Networks: Media Access Control (MAC) Bridges, IEEE 802.1D-1990, March 1991.

[6] IEEE Standards for Local and Metropolitan Area Networks: Guidelines for the Development of Layer Management Standards, IEEE 802.1F-1990, 1991.

[7] IEEE Standards for Local and Metropolitan Area Networks: Secure Data Exchange, IEEE 802.10-1990, 1991.

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1.7 Revision History

Original version January 1992.

2. General Requirements

This section summarizes overall requirements common to most application/market areas. These requirements are synthesized from

- the IEEE 802 Functional Requirements,
- the P802.11 Project Authorization Request and
- the wireless LAN requirements from the applications scenarios documented in the appendices to this document.

2.1 Overview

The following summarize some key, overview requirements.

Data Delivery Services	The results of the application survey indicate the need for two classes of data delivery services: an asynchronous service for the substantial majority of anticipated applications requiring MSDU delivery services emphasizing low average transfer delay; and a synchronous service for the minority of applications requiring MSDU delivery services emphasizing low MSDU transfer delay jitter.
Station mobility	The standard shall support moving stations and shall support continuity of sessions while stations are in motion. The supported velocity required is "pedestrian speeds" and local premises vehicular. Faster speeds may be optionally supported.
Ease of use	The end user shall be able to install, move and operate his equipment without cumbersome licensing procedures or site surveys.
Independent network operation	The standard shall support two or more networks in geographical proximity to operate independently, and without the need for external coordination. For example, two companies who share an office building should be able to operate their wireless networks independently without the need for coordination. This does not mean that one or more of the networks has to change to a different channel. It may mean that the performance may degrade. The degradation needs to be graceful.
Distribution system	The standard shall allow two or more stations to communicate wirelessly without the need for a wired

distribution system. Users may (optionally) add a distribution system based on standard IEEE 802 LAN systems to extend the range and capacity of the wireless LAN. The same station implementation shall work in a system with and without a distribution system.

Power drain	Battery operation is a requirement for many applications, the standard must be designed to permit minimal power consumption implementations.
Size	The size of portable computers continues to decrease. The standard must be designed such that wireless LAN adaptors within portables can be implemented in very small sizes. A future goal is the support of credit card size devices (e.g. PCMCIA).
Security/Integrity	The inability of wireless media, in general, to control physical access to the media by alien stations requires special procedures for protecting transmitted information from unauthorized reception (e.g. transmission security) and unauthorized modification (e.g. transmission integrity).
Internetworking	Wireless networks will coexist and complement wired LANs and WANs and must provide seamless interconnectivity with both de jure and de facto LAN and WAN standards.
Multiple PHY Support	It is anticipated that for regulatory, safety, security, coverage, performance and consumer taste that a variety of PHYs will be required. The standard must support alternative PHYs throughout the electromagnetic spectrum.
Cost Effectiveness	The range of wireless applications is substantial. It is desired that the standard provide for both low cost, high volume implementations as well as higher cost, higher performance, lower volume implementations.

2.2 Architecture

The protocol architecture for wireless LANs anticipates a single Media Access Control (MAC) Link Layer supporting multiple, alternative Physical Media (PHY) Layers. These alternate physical media layers are anticipated to include a range of wireless media including radio, microwave and light - particularly infrared. This architecture is illustrated in Figure 2.1.

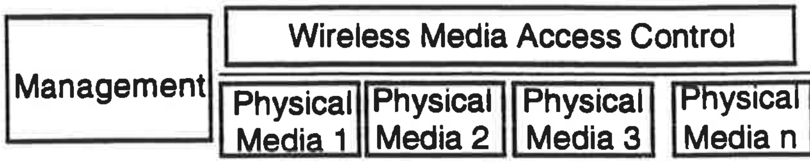


Figure 2.1: Narrow Architectural Scope of 802.11

As with all other IEEE Project 802 protocol stacks, the 802.11 wireless architecture will support common 802 services including end-to-end data security and integrity defined by 802.10 and common data link protocols, bridging and exported MAC services defined by 802.2. This expanded architecture is illustrated in Figure 2.2.

The Link Layer is partitioned into three sublayers: the 802.2 Link Layer Control (LLC) sublayer, the 802.10 security and integrity sublayer, and the 802.11 MAC sublayer. In the sequel, the user entity of the 802.11 MAC sublayer will often be denoted as the LLC sublayer.

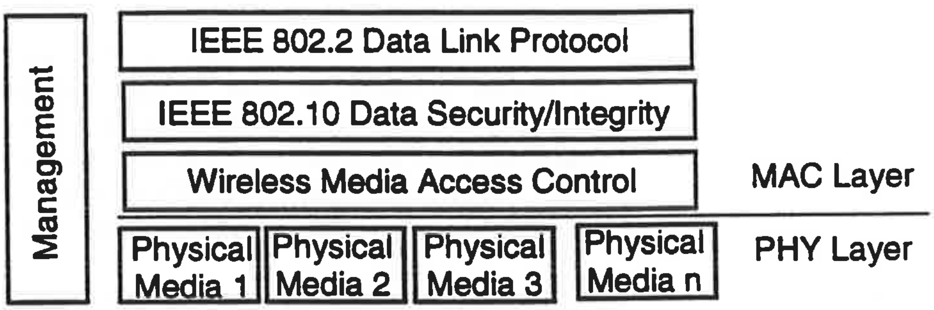


Figure 2.2: Complete Architectural Scope of 802.11

Note that this architecture does not yet fully encompass the anticipated synchronous data delivery services to be provided by 802.11 (see below). These services may require additions/modifications to higher sublayer services (e.g. 802.2 LLC and 802.10) in order to define a complete, exportable service interface for both the asynchronous and synchronous services.

3. Media Access Control Layer

3.1 Introduction

The Media Access Control Layer provides the following functions: MSDU data delivery, shared PHY media arbitration and allocation, security, integrity, authentication, internetworking; and network management. These will be more fully described in the following sections.

The MAC Service Requirement is described in the following parts. The first describes the exported services of the MAC to higher layers. The second describes the services required by the MAC from each of several alternative PHYs. The third defines in some detail the required MAC exported and internal services. MAC requirements are generated from overall Project 802 Functional Requirements, specific requirements defined in the P802.11 Project Authorization Request, and derived from the over 50 anticipated wireless applications surveyed for this document.

3.2 MAC Exported Services

The MAC provides the mechanism for the delivery of MSDUs submitted at the sending station's MAC/LLC sublayer interface at the receiving station's MAC/LLC sublayer interface. These are internally packaged as MSDUs for transmission between peer MAC Layers in sending and receiving stataions. Additional features may be added to the interface to support extended MAC services.

The 802.11 PAR and the included application survey strongly point to the provision of two classes of exported data delivery service: an asynchronous service for the substantial majority of anticipated applications requiring MSDU delivery services emphasizing low average transfer delay; and a synchronous service for the minority of applications requiring MSDU delivery services emphasizing low MSDU transfer delay jitter. More informally, the former service provides a "datagram" delivery service highly oriented towards support of both the 802.2 LLC and typical LAN applications. The latter service provides a "stream" delivery service highly oriented both towards anticipated real-time multimedia voice and video services as well as a minority of data applications requiring strong constraints on the variance in MSDU transfer delay.

Three primitives are defined:

MA-UNITDATA.request
MA-UNITDATA.indication
MA-UNITDATA-STATUS.indication.

It is anticipated that additional primitives will be required to fully define the synchronous service class.

3.2.1 MA-UNITDATA Request

This primitive defines the transfer of an MSDU from a local MAC sublayer entity to a single peer MAC sublayer entity, or multiple peer MAC sublayer entities in the case of group addresses.

The semantics of the primitive are as follows:

```
MA-UNITDATA.request (
                        source_address,
                        destination_address,
                        data,
                        priority,
                        service_class
                        )
```

The source_address parameter shall specify an individual MAC sublayer entity address. The destination_address parameter shall specify either an individual or a group MAC sublayer entity address. The data parameter specifies the MAC service data unit to be transmitted by the MAC sublayer entity including sufficient information to derive all MAC sublayer internal control information as well as the length of the data unit. The priority parameter specifies the priority desired for the data unit transfer. The service_class parameter specifies the class of service desired for the data unit transfer.

This primitive is generated by a the LLC sublayer entity whenever an MSDU must be transferred to a peer LLC sublayer entity or entities. This can be as a result of a request from higher layers of protocol, or from a MSDU generated internally to the LLC sublayer, such a required for LLC Type 2 operation.

The receipt of this primitive shall cause the MAC sublayer entity to append all MAC specified fields, including DA, SA and fields unique to 802.11's access method, and pass the properly formatted frame to the lower layers of protocol for transfer to the peer MAC sublayer entity or entities.

3.2.2 MA-UNITDATA Indication

This primitive defines the transfer of a MSDU from the MAC sublayer entity to the LLC sublayer entity, or entities in the case of group addresses. In the absence of errors, the contents of the data parameter are logically complete and unchanged relative to the data parameter in the associated MA-UNITDATA.request primitive.

The semantics of the primitive are as follows:

```
MA-UNITDATA.indication (
                        source_address,
                        destination_address,
                        data,
                        reception_status,
                        priority,
                        service_class
```

)

The source_address parameter must be an individual address as specified by the SA field of the incoming frame. The destination_address parameter shall be either an individual or a group address as specified by the DA field of the incoming frame. The data parameter specifies the MAC service data unit as received by the local MAC sublayer entity. The reception_status parameter indicates the success or failure of the incoming frame. The priority parameter specifies the priority desired for this data unit transfer. The service_class parameter specifies the class of service desired for the data unit transfer.

The MA-UNITDATA.indication primitive is passed from the MAC sublayer entity to the LLC sublayer entity or entities to indicate the arrival of a frame at the local MAC sublayer entity. Frames are reported only if at the MAC sublayer they are validly formatted, received without error, and their destination address designates the local MAC sublayer entity.

If the local MAC sublayer entity is designated by the destination_address parameter of an MA-UNITDATA.request primitive, the indication primitive will also be invoked by the MAC sublayer entity to the local LLC sublayer entity. This full duplex characteristic of the MAC sublayer may be due to unique functionality within the MAC sublayer or full duplex characteristics of the lower layers (e.g. all frames transmitted to the broadcast address will invoke MA-UNITDATA.indication primitives at all stations in the network including the station that generated the request).

3.2.3 MA-UNITDATA-STATUS Indication

This primitive has local significance and shall provide the LLC sublayer with status information for a previous associated MA-UNITDATA.request primitive.

The semantics of the primitive are as follows:

```
MA-UNITDATA-STATUS.indication (
                        source_address,
                        destination_address,
                        transmission_status,
                        provided_priority,
                        provided_service_class
                        )
```

The source_address parameter must be an individual MAC sublayer entity address as specified in the associated MA-UNITDATA.request primitive. The destination_address parameter shall be either an individual or a group MAC sublayer entity address as specified in the associated MA-UNITDATA request primitive. The transmission_status parameter is used to pass status information back to the requesting LLC sublayer entity. The types of status that can be associated with this primitive are to be supplied. The provided_priority parameter specifies the priority that was used for the associated data transfer. The provided_service_class parameter specifies the class of service provided for the data unit transfer.

The MA-UNITDATA_STATUS.indication primitive is passed from the MAC sublayer entity to the LLC sublayer to indicate the status of the service provided for a previous associated MA-UNITDATA.request primitive.

It is assumed that sufficient information is available to the LLC sublayer entity to associate the status with the appropriate request.

3.2.4 MAC Sublayer Synchronous Service Support

To be supplied.

3.2.5 MAC Sublayer Management Function Interface Service Support

To be supplied.

3.2.6 MAC Sublayer Bridge Support

To be supplied.

3.3 MAC Requirements of the Physical Media Layer

Any particular PHY layer entity may implement one or more logical channels. The MAC sublayer must be capable of operation with as little as one channel, even in the presence of adjacent, independent wireless networks, though it can make use of more than one channel if provided by a particular PHY Layer entity.

A PHY Layer entity must provide the following information to the MAC entity. The following tables may not fully reflect required management information between layers and will be subsequently revised.

Signal Name	Direction	Description
Receive Symbol	PHY»MAC	Data symbols received and decoded by a station's PHY Layer Entity and supplied to the its' MAC Layer Entity.
Receive Clock	PHY»MAC	Clocking for received symbols from the PHY Layer Entitiy to the MAC Layer Entity. Implict is the assumption that PHY performs clock recovery.
Quality of Service	PHY»MAC	Indication of the channel signal propagation characteristics. PHY Layer dependent interpretation.
Signal Detect	PHY»MAC	A channel busy indication supplied from the PHY Layer to the MAC Layer.

Figure 3.1: PHY Layer Supplied Information to the MAC Layer

The MAC entity must provide the following information to a PHY Layer entity.

Signal Name	Direction	Description
Transmit Symbol	MAC»PHY	Data symbols transmitted by a station's MAC Layer Entity.
Transmit Clock	MAC»PHY	Clocking for transmitted symbols from MAC Layer Entity to PHY Layer.
Control Information	MAC»PHY	Additional information that the MAC provides to the PHY to control PHY operation.
Channel Select	MAC»PHY	For PHY Layers where multiple channels can be selected this signal permits the station's MAC Layer Entity to "tune" the PHY Layer Entity to the desired channel. This signal is PHY Layer interpretation dependent. For FDMA radio PHY Layers, this signal can represent frequency information; for CDMA radio PHY Layers this signal can represent coding sequence information.

Figure 3.2: MAC Layer Supplied Information to a PHY Layer

3.4 MAC Service Requirements

3.4.1 Core Function

MSDU delivery. The core service of the standard is the prompt, successful delivery of MSDUs from the transmitting station to the receiving station(s). Both point-to-point service directed from a single transmitting station to a single receiving station and multipoint and broadcast (in which as MSDU is directed from a single transmitting station to (possibly) several receiving stations must be supported.

The standard will support (justified in sequel) two classes of MSDU delivery service: an asynchronous service providing for low average transfer delay MSDU delivery and a synchronous service providing for low transfer delay variance MSDU delivery. These classes of service shall use maximum common mechanism in the procedures implementing these services.

An important factor is support for de facto high level protocol standards: IPX/SPX (Novell), NDIS (LAN Manager and others), AppleTalk, ODI (Novell & Apple), TCP/IP, DECNet, SNA, and IEEE 802.2 LLC. Effective support of IEEE 802.2 LLC, particularly Type 1, by the asynchronous service will insure that these protocol standards (and the applications based on them) will be supported by the 802.11 wireless LAN.

Error detection. It is the responsibility of the MAC sublayer to detect erroneous reception of transmitted MSDUs and to indicate (wherever possible) such a circumstance to the transmitting station. The number of MSDUs that cannot be successfully delivered on a given transmission attempt will likely be greater than for wired LANs due to the inherent characteristics of the wireless media (see Section 4).

The wireless application survey (see sequel and Appendices) indicates that most applications are far more tolerant of lost MSDUs (undelivered on a given attempt) than the P802 default standard in large part due to ubiquitous transport layer protocol procedures providing for end-to-end reliability in the presence of inherent increased link and network layer unreliability for bridged and internetworked LANs. The most important reliability measure is the undetected MSDU error rate.

A minimally conformant IEEE P802.11 network will meet all of the P802 requirements excepting that the MAC Service Data Unit (MSDU) loss rate shall be less than 4*10E-5 for an MSDU length of 512 octets at least 99.9 % of the time on a daily basis, in 99.9 % of the total geography of the service area.

IEEE P802.11 will define approaches to allow a minimally conformant network to achieve full conformance over the total geography of the service area.

3.4.2 Performance

The Appendices survey over 50 LAN applications with substantial potential to make effective use of a wireless LAN. Figure 3.3 documents the range of values the nine MAC service measures among the applications considered.

	Mean Value	Median Value	Standard Deviation
MSDU Size Distribution (octets)	759.96	512.00	736.17
MSDU Arrival Distribution (msec)	5359.76	60.00	25119.21
Nominal Transfer Delay (msec)	62.09	20.00	155.10
Transfer Delay Standard Deviation (msec)	100.52	20.00	250.47
Maximum Transfer Delay (msec)	749.00	250.00	1509.31
MSDU Loss Rate	0.23%	0.10%	0.33%
Service Initiation Time (msec)	908.49	1000.00	390.85
Station Speed (m/s)	2.54	2.00	2.96
Destination Distribution	0.48	0.50	0.45
MSDU Jitter	2.40	2.00	1.94

Figure 3.3: Summary Parameters of Surveyed Applications

Further analysis of these applications (see Figure 3.4 plotting MSDU jitter - delay tolerance - vs. nominal transfer delay) suggest that their performance requirements fall into two categories based on the delay tolerance (e.g. MSDU jitter) tolerated by the application. The first is an asynchronous service with low average MSDU transfer delay and relatively large MSDU delay tolerance (greater than or equal to the average MSDU transfer delay) and the second is a synchronous service with very low MSDU delay tolerance (much less than the average MSDU transfer delay).

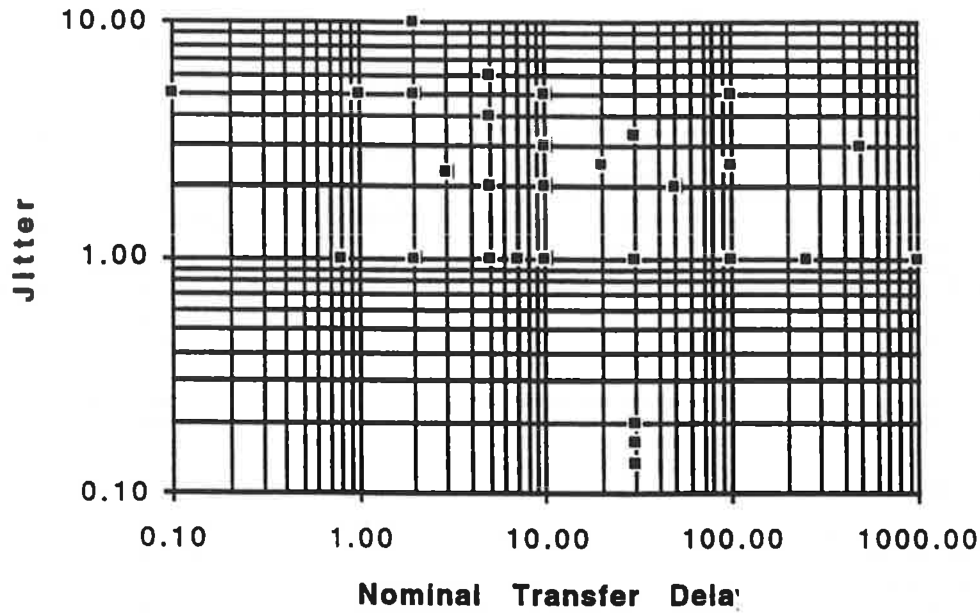


Figure 3.4: MSDU Jitter vs. Transfer Delay for Surveyed Applications

Of the 53 applications surveyed, 6 have a delay tolerance « 1, 16 have a delay tolerance of about 1 and 31 have a delay tolerance > 1. Note two different methods of real-time voice and video are described assuming differing nominal transfer delay and station buffering capability. These different methods have substantially differing MSDU jitter tolerance.

The data suggest two broad categories of data delivery service differentiated by the application's tolerance for MSDU delay jitter. The first category of service is termed the asynchronous service and is characterized by applications that desire as low as possible MSDU transfer delay, however are quite tolerant of occasional or load dependent stochastic MSDU delay variance.

The second category of service is termed the synchronous service and is characterized by applications that, in general, are intolerant of stochastic MSDU delay variance beyond rather narrow bounds.

When we reanalyze the range of MAC services required by applications classified as using these two types of services, we find the following summary tables for the asynchronous service (Figure 3.5) and for the synchronous service (Figure 3.6).

	Range	Mean Value	Median Value	Standard Deviation
MSDU Size Distribution	10 octets 4096 octets	726.26	512.00	730.75
MSDU Arrival Distribution	2 msec 180000 msec	6038.66	100.00	26629.22
Nominal Transfer Delay	2 msec 500 msec	66.19	10.00	164.45
Transfer Delay Standard Deviation	10 msec[1] 1500 msec	112.64	30.00	263.79
Maximum Transfer Delay	60 msec[1] 2000 msec	837.59	250.00	1582.49
MSDU Loss Rate	10^{-3} [2]	0.13%	0.10%	0.19%
Service Initiation Time	250 msec 2000 msec	896.81	1000.00	414.07
Station Speed	2 m/s 10 m/s	2.30	2.00	2.69
Destination Distribution	Mixed	0.48	0.50	0.44

Figure 3.5: Asynchronous Service Values for Surveyed Applications

The median value of MSDU jitter for these asynchronous applications is 2.0 with a mean value of 2.69.

[1]Two special manufacturing cases require low data rate, very small MSDUs (< 100 octets) but very low delay variance: < 2 msec.

[2]Three manufacturing control cases require very low MSDU loss rate (10^{-6}), however their very long acceptable transfer delays (> 250 msec) suggest that 802.2 Type 2 error recovery procedures could provide this level of reliability at the link layer.

	Range	Mean Value	Median Value	Standard Deviation
MSDU Size Distribution	512 msec 2048 octets	1024.00	512.00	793.19
MSDU Arrival Distribution	5 msec 60 msec	41.67	60.00	28.40
Nominal Transfer Delay	30 msec	30.00	30.00	0.00
Transfer Delay Standard Deviation	5 msec	5.50	6.00	0.84
Maximum Transfer Delay	30 to 60 msec	55.00	60.00	12.25
MSDU Loss Rate	10^{-2}	1.00%	1.00%	0.00%
Service Initiation Time	1000 msec	1000.00	1000.00	0.00
Station Speed	2 m/s 10 m/s	4.42	2.25	4.41
Destination Distribution	Mixed	0.50	0.50	0.55

Figure 3.6: Synchronous Service Values for Surveyed Applications

The median value of MSDU jitter for the surveyed synchronous applications was 0.2 with a mean value of 0.18.

Hereafter, these two classes of 802.11 data delivery service shall be labelled the asynchronous service and the synchronous service of the 802.11 MAC.

Appendices J through S analyze the data from these application surveys in order to better understand their implication on 802.11 MAC requirements. Figures 3.7 and 3.8 summarize market and engineering judgements, based on these analyses, of target values for 802.11 MAC performance for each of these parameters for the asynchronous service and synchronous service respectively. The values are targets - that is, they represent and estimate of the desired performance of the MAC and do not per se preclude MAC implementations that exceed or not meet these targets.

\	Target
MSDU Size (octets)	0≤X≤2048
Nominal Transfer Delay (msec)[3]	2 msec
Transfer Delay Standard Deviation (msec)	5 msec
Maximum Transfer Delay (msec)	250 msec
MSDU Loss Rate	.001
Service Initiation Time (msec)	0 msec
Station Speed (m/s)	7 m/s
Destination Distribution	Mixed

Figure 3.7: Target Values of MSDU Service Measures for the Asynchronous Service

The specified target values of these measures for the standard asynchronous service are in Figure 3.7.

	Target
MSDU Size (octets)	0≤X≤2048
Nominal Transfer Delay (msec)	10 msec
Transfer Delay Standard Deviation (msec)	1 msec
Maximum Transfer Delay (msec)	15 msec
MSDU Loss Rate	.001
Service Initiation Time (msec)	500 msec
Station Speed (m/s)	7 m/s
Destination Distribution	Mixed

Figure 3.8: Target Values of MSDU Service Measures for the Synchronous Service

The specified target values of these measures for the standard synchronous service are in Figure 3.8.

Robustness. A key aspect of wireless LANs - dictated by the limits of physical control on the signal propagation environment - is the robust operation of a wireless LAN in the presence of both artificial and natural interference: high traffic load, co-located networks sharing a PHY channel, uncontrolled PHY propagation, malicious PHY jamming, unintentional PHY jamming.

[3]The transfer delay targets are nominally for 50 octet MSDUs for wireless LANs that are at 10% aggregate load.

The standard shall provide for robust operation of the network under these conditions. Robust operation likely will include decreased throughput and increased transfer delay while maintaining throughput greater than zero and transfer delay within an acceptable range.

3.4.3 Configuration

In addition to surveying the MAC service characteristics of a number of applications, the Appendices also document the expected configurations of these applications. Figure 3.9 summarizes the measures for number of stations, station density and typical linear dimension between stations. Note the substantial difference between mean and median and the substantial standard deviation in all these measures.

	Mean	Median	Standard Deviation
Number of Stations	573.38	25.00	1616.50
Station Density	1357.50	60.00	3710.75
Dimension	389.85	100.00	895.47

Figure 3.9: Network Size Application Survey Results

More detailed analysis of the data reveals a bimodal network size of either rather modest size (10s of stations) or quite large (1000s of stations) size. Correlating number of stations with station density reveals four classes of anticipated wireless network size based on anticipated station density - Figure 3.10. Not surprisingly, as the number of stations increases, station density increased and typical linear dimension decreases.

Number of stations	21 or 5000	36 or 1000	45	116 or 5000
Station density	≤10/hectare	≤100/hectare	≤1000/hectare	>1000/hectare
Dimension (Median)	100	100	50	15
Dimension (Mean)	819	230	159	42

Figure 3.10: Configuration Parameters Survey Results

In many cases, the required physical network size is substantially larger than anticipated unrepeated PHY coverage distances of less than 100 meters. Thus, it is a requirement of the standard to provide a distribution system that extends the range of a wireless LAN beyond the simple limits of the PHY coverage distance.

Independent network operation. As analyzed above, the standard is required to support independent network operation of physically adjacent networks belonging both the same network administration as well as to other network administrations where the coverage areas of the two networks intersect. Such cooperative network operation must be performed with the least amount of external, manual network management.

3.4.4 Data Security and Integrity

Data security. The widespread adoption of the wireless LAN standard increases the vulnerability of wireless LANs to eavesdropping - the unauthorized reading of MSDU information. Yet, in order for adjacent, independent networks to operate, cooperative sharing of bandwidth must take place "in the clear". Such constraints strongly suggest that the standard incorporate encryption of MSDU user information - not MAC control information - in order to protect the data from unauthorized reception and decoding.

IEEE Project 802 has defined such a facility in the work of 802.10. The 802.11 standard shall use the data security services of 802.10 to protect its' information from unauthorized reception. This standard shall define a standard encryption algorithm to be used in conjunction with 802.10 so as to permit inoperability.

Data integrity. The widespread adoption of the wireless LAN standard increases the vulnerability of wireless LANs to tampering - the unauthorized modification of MSDU information.

IEEE Project 802 has defined via 802.10 mechanisms to provide data integrity for MSDU information. This standard shall use the data integrity services of 802.10 to protect its' information from unauthorized modifcation. This standard shall define a standard encryption algorithm to be used in conjunction with 802.10 so as to permit interoperability.

Denial of service. Wireless LANs are inherently more vulnerable to incidental and malicious interference that might deny a native station access to network services. This standard shall incorporate procedures to minimize the cases in which the actions of alien stations, incidental interference as well as malicious interference shall deny network access to a legitimate native station.

Authentication. In most wired LANs, the ability to physically connect to the network medium with a compatible station implementation is implicit authorization to make use of network services since physical security is often deemed adequate to protect the network.

However, in most wireless LANs, physical procedures are entirely inadequate to only permit native stations with the coverage distance of a wireless LANs. The standard shall incorporate procedures to authenticate stations as legitimate native stations and to prevent access to network resources by alien stations. However, this must be balanced with the requirement for cooperative sharing of a shared PHY channel where the coverage area of two independent wireless LANs overlaps.

3.4.5 Range Extension and Internetworking

Range extension. From the analysis of the surveyed wireless network applications and configurations it is clear that many wireless LAN configurations require premise coverage that far exceeds the likely unrepeated good signal distance for anticipated PHY Layers. The standard shall include a distribution system based on IEEE 802 conformant LANs that relays 802.11 MSDUs and so extends the range of a conformant wireless LAN.

The coverage area defined by the unrepeated good signal distance of a collection of native stations is termed a Basic Service Area. The coverage area defined by a collection of native stations with range extended by a standard distribution system is termed an Extended Service Area.

Mobility. The 802.11 PAR and the analysis of wireless applications mandate support for moving stations. The standard shall provide for continued data transfer services for stations at rest or in motion at 7 meters/second or less throughout a BSA or ESA in which the station is an native, authenticated station.

Co-located networks. The inability of purely physical means to separate independent wireless networks with overlapping coverage areas mandates that the standard define procedures for such co-located networks to effectively share channel bandwidth while maintaining separation of each network's native stations.

Internetworking. The analysis of anticipated wireless network applications mandates seamless integration of wireless network stations into IEEE 802 conformant wired LAN networks. The standard shall provide data transfer services that do not require stations to have specially designed high level protocols (differing from similar protocols already in existence for wired LANs), or to understand the network topology in order to communicate equally with wireless stations or interconnected wired stations.

The standard shall support such interworking through 802.1D conformant bridges to 802.3, 802.4, 802.5, 802.6, and 802.9 conformant wired LANs. In addition the standard shall support such interworking with non-IEEE specified, such as ANSI X3T9.5 FDDI and CDDI and LAN/WAN interconnects.

3.4.6 Network Management

Network management. The standard shall define databases and procedures for the implementation of IEEE 802.1B conformant network management augmented with wireless network unique requirements.

Power management. As the application survey indicates, many of the configurations of wireless applications will include battery powered platforms. For all of these configurations, prolonging battery life is of high importance. Procedures for minimizing power drain including mechanisms for cooperatively and selectively unpowering and repowering all or portions of the implementation of the wireless network station should be considered.

Transmit power control. Procedures for dynamically adjusting transmit power should be considered for reasons of spectral efficiency, minimizing possible health considerations, and co-user interference.

4. Physical Media Layer

4.1 Introduction

The PHY Layer is responsible for the physical encoding, transmission, reception and decoding of symbols between peer PHY Layer Entities. Symbols to be transmitted are submitted to the source PHY Layer Entity by the source MAC Layer entity. Received symbols are indicated to the destination MAC Layer Entity by the receiving PHY Layer Entity.

Multiple, alternative PHY Layers may be defined within the standard each conforming to a common MAC/PHY interface. Each station implements only a single instance of a MAC and PHY combination at any one time - that is, the standard does not support multiple, simultaneous PHY support in a single station.

The assertions about PHY performance in this document are intentionally conservative and subsequent quantification of the precise level of service a PHY can provide to the MAC will be provided in subsequent revisions.

4.2 PHY Layer Exported Service to the MAC Layer

The physical medium over which an instance of an IEEE 802.11 MAC Layer Entity must operate is a broadcast medium. The properties of IEEE 802.11 medium differ from those of the traditional coax cable based broadcast media of IEEE 802.3 and IEEE 802.4. These differences have an impact on MAC Layer Entity design. The characteristics detailed in this section of the requirements document relate to what a MAC Layer Entity can and cannot assume when it requests service from a PHY Layer Entity or receives indications from a PHY Layer Entity.

In order to adequately quantify a particular MAC's capability to deal with the generic requirements imposed by the PHY Layer Entity a significantly more complex model that provides a probablistic picture of the degree to which the various restrictions imposed by the generic requirements apply is needed. The data needed to develop a model of this type would require a substantial effort on the part of the committee to obtain. Although benchmark models may need to be developed in the future it is doubtful whether a large scale effort to quantify the probability distributions associated with the generic PHY requirements would yield results that are more useful than heuristic evaluations of the impact of the generic requirements.

The generic interface between MAC and PHY Layer Entities provides for the signal interfaces of Figure 4.1.

Signal Name	Direction	Description
Transmit Symbol	MAC»PHY	Data symbols transmitted by a station's MAC Layer Entity.
Transmit Clock	MAC»PHY	Clocking for transmitted symbols from MAC Layer Entity to PHY Layer.
Receive Symbol	PHY»MAC	Data symbols received and decoded by a station's PHY Layer Entity and supplied to the its' MAC Layer Entity.
Receive Clock	PHY»MAC	Clocking for received symbols from the PHY Layer Entitiy to the MAC Layer Entity. Implict is the assumption that PHY performs clock recovery.
Quality of Service	PHY»MAC	Indication of the channel signal propagation characteristics. PHY Layer dependent interpretation.
Signal Detect	PHY»MAC	A channel busy indication supplied from the PHY Layer to the MAC Layer.
Control Information	MAC»PHY	MAC/PHY control.
Channel Select	MAC»PHY	For PHY Layers where multiple channels can be selected this signal permits the station's MAC Layer Entity to "tune" the PHY Layer Entity to the desired channel. This signal is PHY Layer interpretation dependent. For FDMA radio PHY Layers, this signal can represent frequency information; for CDMA radio PHY Layers this signal can represent coding sequence information. For infrared PHY Layers, this signal may be ignored since that PHY Layer may not support selectable channels.

Figure 4.1: MAC/PHY Interface Signals

Figure 4.1 does not fully reflect Mac/PHY management information and will likely require subsequent revision to fully specify these services.

4.3 PHY Characteristics

The standard anticipates multiple, alternative PHY Layers taking advantage of the unique properties of each part of the electromagnetic spectrum as well as differing cost effective implementations for differing propagation environments.

This section summarizes general information about anticipated PHY Layers. First, generic characteristics, anticipated common to all PHY Layers are described. Second, unique characteristics of ISM band spread sprectrum PHYs are described. Third, unique characteristics of diffuse infrared PHYs are described. Fourth, unique characteristics of 18 GHz microwave PHYs are described. Fifth, unique characteristics of 60 GHz PHYs are described.

4.3.1 Generic Characteristics Common to All PHY Layers

The following generic characteristics are intended to provide a non-quantitative statement of what MAC implementations can and cannot depend on from PHY layers that may be developed by IEEE 802.11. These characteristics vary among target environments for 802.11 WLANs with many environments being more benign, and some - particularly industrial environments - more hostile. Alternative PHYs can provide transmission services tailored to the unique characteristics of the target propagation environment.

1) Stations are connected in parallel to the medium's channel. Thus, when a station transmits, its signals have the potential to be received (or "heard") by some or all of the other stations on the channel. Other stations on the channel can interfere with the transmission of a station but cannot predictably alter its contents.

2) A station can not guarantee that any other particular station will receive (or "hear") its transmissions when it transmits.

3) Stations can not be guaranteed to have a common perception of what other stations are participating in the network at any instant in time.

4) There is some attenuation distance at which the transmissions from a station will be of sufficent quality to provide communications service meeting 802.11 requirements to stations that are within this distance. This distance is defined as the coverage distance. Attenuation distance is non-Euclidian and as such individual sets of stations that are the same Euclidian distance apart can not be assumed to be the same attenuation distance apart.

5) There is some attenuation distance at which the transmissions from a station will not be of sufficent quality to provide communications service meeting 802.11 requirements to stations that are within that distance, but will be of sufficent quality to be detected as good signal. This distance is defined as the interference distance.

6) If a station receives (or "hears") a particular transmission from another station it cannot guarantee that it will be able to receive the next transmission from that same station.

7) If a station receives (or "hears") a particular transmission from another station it cannot guarantee that the transmitting station can receive transmissions that the receiving station originates.

8) If a station detects a good signal it cannot guarantee that any station has transmitted that signal.

9) A measurement of interference level at one station is not a universally reliable indicator of the interference level at another station.

10) When a native station transmits it can not be assured that an alien station will not receive its transmission.

4.3.2 Special Considerations for ISM Band Spread Spectrum PHY Layers

To be supplied.

4.3.3 Special Considerations for Infrared PHY Layers

The following clarifications to the generic PHY characteristics detailed above apply to infrared PHY's.

1) The propagation characteristics of infrared signals make it possible that through reasonable effort on the part of the administrator of a premises local area network item 10 above can be removed from the list of PHY Characteristics. In other words it is possible to design a restricted medium using IR signaling.

2) It is also possible to design a directed medium using IR signalling techniques.

3) Euclidean distance is more closely associated with attenuation distance if IR signalling is used than if RF signalling is used.

4) Diffuse reflection indoor infrared propagation tends to produce coverage areas free of fading.

4.3.4 Special Considerations for 18 GHz PHYs

1) It is possible to design a directed medium using RF signalling at 18 GHz.

4.3.5 Special Considerations for 60 GHz PHYs

1) It is possible to design a directed medium using microwave signalling at 60 GHz.

2) Due to absorption characteristics of the atmosphere, propagation at 60 GHz, attenuation distance is strongly related to Euclidean distance if this type of signalling is used.

Appendix A. Education

A.1 Introduction

Education encompasses three substantially-different environments.

Classroom — which resembles an office LAN with two exceptions: 1) high station density with 30-40 stations in a small classroom and 100-500 stations in a large lecture hall; and 2) exceedingly bursty due to synchronization of activity shifts in the class (e.g., everyone accessing files on a new topic simultaneously).

Campus — Mobility, while mobile or stationary, anywhere on campus providing information access to the electronic library, and E-mail, including faculty/student conferencing.

Field Study — (aka "The Field Trip") providing 1) information access via a mobile database server in an accompanying van 2) real-time collaboration (with others in the group) - may include voice, image and video and 3) data collection, including bulk transfer to a central repository.

The classroom environment is dominated by the need for large (1 MByte) simultaneous file transfers from server to user station. This is dominated by large packet sizes and will be a broadcast mode with individual stations requesting retransmission of lost MSDUs at the completion of the transfer. Traffic will be primarily from servers directly attached to the WLAN.

The campus internet covers a large (5 km x 5 km) area consisting of many subnets. Traffic over the wireless portion of the internet will be typical of normal LAN traffic except that a high percentage (80%) will be destined for and received from off-wireless network servers.

A.2 Applications

	Collaboration	Data Collection	File Transfer
MSDU Size Distribution	90% 600 byte 10% 80 byte	40% 600 byte 60% 80 byte	40% 1024 byte 60% 80 byte
MSDU Arrival Distribution	Poisson distribution 30 msec average	Poisson distribution 100 msec average	Poisson distribution 40 msec average
Nominal Transfer Delay	5 msec	5 msec	5 msec
Transfer Delay Standard Deviation	20 msec	20 msec	20 msec
Maximum Transfer Delay	1000 msec	1000 msec	1000 msec
MSDU Loss Rate	10^{-3}	10^{-3}	10^{-3}
Service Initiation Time	400 msec	400 msec	400 msec
Station Speed	2 m/s	2 m/s	4 m/s
Destination Distribution	80%	95%	20%

A.3 Configurations

	Field Study	Classroom	Campus Internet
Number of stations	50	200	5000
Station density	50/hectare	2000 /hectare	2 /hectare
Dimension	100 m	30 m	5000 m
Application List	• Collaboration • Data Collection • File transfer	• Collaboration • Data Collection • File transfer	• Collaboration • File transfer
Application Initiation			
Application Duration			

Appendix B. Finance

B.1 Introduction

The principal users are banks and stock or commodity trading floors. They can be viewed as a special class of offices. Their specific requirements are:

- emphasis on interactive / transaction processing
- require a quick response to requests
- 802.10-like confidentiality, integrity and data origin authentication are mandatory. Digital signatures and non-repudiation are also important security services. Immunity to jamming/denial of service is critical.
- small packet sizes of about 80 octets buyer, seller, quantity, price
- peak request rate 1/10 sec or 1/15 sec per user
- low to moderate overall system throughput
- mobility at pedestrian speed
- Platforms: Pen-based, palmtop computers small weight, power, size
- small cost desirable
- Robust.
- High station density, where the distance between adjacent transceivers can be quite small (< 30 cm). Density can be very crowded (e.g., 40 people per 10 m^2).
- Station population is dynamic between 200 to 4000 stations on a trading floor at any one time
- Power consumption is important. Devices must operate continuously for 8 hours; traders don't take breaks.
- logging of all voice and data traffic is required today
- a mobile station may need to be in a circumscribed location (the proper trading pit) for a specific application operation.
- Links to a back-end system are required. The Chicago Board of Trade (CBOT) permits up to 20 seconds of delay in reporting to the back-end system, but all transactions must be time-stamped. Explicit standards support required for (802.3, 802.5) - 802 LAN backbones

Data flows between wireless stations and the wired LAN. No appreciable traffic directly between stations using wireless media.

The description below is for a financial terminal station used by a trader in an open-outcry, crowded environment. It requires a small, handheld, tetherless computer. Battery power is critical for this application--the computer has to be able to operate 8 (or more) hours without recharging.

Data flow is between the traders and clearing houses. Current scenarios do not include data exchange between traders, but that is a future possibility.

A transaction involves the following steps:

1) An order to buy or sell a financial instrument is communicated to the trader on the floor from the brokerage firm --OR-- the trader decides to trade for him/herself.
2) The trader checks the current price for the type of instrument
3) The trader negotiates (through gestures) with another trader to agree on price/quantity/delivery.
4) The transaction is logged on both trader's computers and then transmitted to a clearing house for resolution (make sure that both sides of the transaction agree).
5) A notification of the trade is simultaneously sent to the brokerage firm, if that was the origin of the transaction.

A high degree of reliability is required for the entire system. Data transmission to portable devices, such as orders must be received in a timely (within 2 seconds) and current trade prices must be available. There is much less pressure to resolve trades, but it is still deemed to be very important.

Fault tolerant, multiple redundancy systems are frequently specified for this type of application.

B.2 Applications

Only two types of applications are common - Transaction delivery processing and File transfer. Their characteristics are listed below:

	Transaction Processing	File Transfer
MSDU Size Distribution	80 octets	60% 1024 octets 40% 80 octets
MSDU Arrival Distribution	Poisson 10 sec mean	Poisson 5 msec mean
Nominal Transfer Delay[4]	100 msec	10 msec
Transfer Delay Standard Deviation	250 msec	< 30 msec
Maximum Transfer Delay	500 msec	1000 msec
MSDU Loss Rate	10^{-3}	10^{-3}
Service Initiation Time	1000 msec	1000 msec
Station Speed	< 2 m/s	< 2 m/s
Destination Distribution	0%	0%

[4]The transfer delay times apply to the highest priority messages.

B.3 Configuration

	Small Trading Floor	Large Trading Floor
Number of stations	200	10000
Station density	20000/hectare	8000/hectare
Dimension	10 m	200 m
Application List	• Trading • Order entry • File transfer	• Trading • Order entry • File transfer
Application Initiation	1 sec	1 sec
Application Duration	4 hours	4 hours

Appendix C: Industrial Automation/Manufacturing

C.1 Introduction

The anticipated set of applications which fall into the IndustrialAutomation category have been divided as follows:

- Service areas and remote sites
- Service and mobile equipment
- Production (assembly)-line carriers
- Monitoring/controlling dispersed or inaccessible process equipment
- Material handling
- A mobile terminal requiring access to an existing LAN
- Computer Aided Manufacturing (CAM) download

The issues of privacy, authenticity, and security are generally much less of a concern for this set of applications than for other market segments. The jurisdiction is owned and controlled by network owner and physical or wireless intrusion is much more unlikely.

As with other network installations, the issue of integrity and denial of service is of concern. The data must be able to get through correctly and not be able to be shut down by accidental or purposeful jamming. As for other markets and applications, it is assumed that higher layer protocols, in particular transport protocols, have the responsibility for end-to-end reliability. The responsibility of the link level MAC protocols is to provide a reasonably robust environment so that the likely mechanisms of the transport layer can be effective.

Distances in an industrial LAN are, in general, much larger than a typical office environment. "Local" may be inside a 1 kilometer long by 1/2 kilometer wide building. The WLAN may require an extended system reach (range) and may need to function in a high-noise environment.

The wireless solution to the LAN problem is attractive because it is the only solution, not just the most convenient or cost effective

For the applications in the industrial sector the data generally flows between wireless stations and a wired enterprise LAN. There is no appreciable traffic between stations using wireless media.

Membership in this setting varies between 1 and 1500 stations per wireless LAN. The distribution of the applications tends towards one end of the range or the other.

Most data is time-critical with a time constant typically on the order of 1 second, but different remedies are required for late packets. In some cases "late" data must be destroyed (e.g.sensors), in other cases it must not be lost (e.g. control). Some of the data is real-time, most of the data is human-time, and a small portion of the data is batch.

Graceful degradation is required. Predictability of effective data rates is often more important than high burst-rate speed.

For each such identified application, the following data characterize the expected MAC traffic and constraints.

C.2 Service areas and remote sites

Offices or service areas which are not physically connected to the plant information system will use wireless connections to close that gap. These applications will typically use many of the same applications as the specified for the Office market area.

Application	Service and remote sites
Description	Office or maintenance area which is disjoint from information infrastructure
Platform	Work stations, PCs, laptops,notebooks
Stations/installation	5-10
Station Density	5-10/hectare
Land speed of station	0
Range of travel	0
Data rate per station	Application dependent:slow scan video (19.6Kb/s); data base access (100 bytes/5 sec), MS-Windows or X-Windows display (1Kb/s)
Dist. of data traffic	(noted above)
Transfer Delay	Effective response rate must not be greater than 2X wired LAN (802.3, 802.5)
Variance	Same as wired LAN
Special constraints	Reliability is very important; system will be viewed as an extension of wired LAN

	Slow-Scan Video	Transaction Processing	Terminal Emulation
MSDU Size Distribution	1024 octets	50% 600 octets 50% 80 octets	90% 80 octet 10% 600 octet
MSDU Arrival Distribution	Poisson 300 msec mean	Poisson 2 sec mean	200 msec
Nominal Transfer Delay	100 msec	< 5 msec	5 msec
Transfer Delay Standard Deviation	100 msec	< 10 msec	< 10 msec
Maximum Transfer Delay	300 msec	1000 msec	1000250 msec msec
MSDU Loss Rate	10^{-2}	10^{-3}	10^{-3}
Service Initiation Time	1000 msec	1000 msec	1000 msec
Station Speed	0	0	0
Destination Distribution	0%	0%	0%

	Service & Remote Sites
Number of stations	5-10
Station density	5-10/hectare
Dimension	100 m
Application List	• Slow scan video • Terminal emulation (X-Windows) • Transaction processing (DataBase Access)
Application Initiation	
Application Duration	

C.3 Service and mobile equipment

Large mobile equipment such as a crane or tug boat are not able to physically connect to the local information infrastructure. They have the need to send and receive control and sensor information as well as some operator information.

Application	Jerry Car in a steel mill
Description	Mobile materials handler needing to monitor weight of material currently gathered.
Platform	Terminal attached to/integrated with machine
Stations/installation	2-3
Station Density	1-2
Land speed of station	9 m/s
Range of travel	6 meterspath
Data rate per station	80 bps
Transfer Delay	1/10 sec
Variance	1/10 sec
Special constraints	Losing 1 packet is acceptable(up to perhaps 10%) but 2 in a row is unacceptable

Application	Strap Crane
Description	Mobile scale connected wirelessly to mobile crane. Operator input (button push); receiving screen of data.
Platform	Terminal attached to/integrated with machine
Stations/installation	?
Station Density	?
Land speed of station	9 m/s
Range of travel	120 meters path
Data rate per station	1 bps transmit/9600 bps receive
Traffic periodicity	infrequent
Transfer Delay	1/2 sec
Variance	1/2 sec
Special constraints	Transmitted data must be received by host

Application	Pit Crane
Description	Heap profile video image.
Platform	Terminal attached to/integrated with machine
Stations/installation	1
Station Density	1
Land speed of station	> 2 m/s
Range of travel	120 meters path
Data rate per station	3 Mb / sec
Dist. of data traffic	Constant rate
Transfer Delay	0
Variance	0
Special constraints	Real-time video (system was not fielded because of wireless bandwidth constraints)

Application	Scrap Crane
Description	voice channel
Platform	Terminal attached to/integrated with machine
Stations/installation	
Station Density	
Land speed of station	6 m/s
Range of travel	800 meters
Data rate per station	<64Kbs
Dist. of data traffic	Constant
Transfer Delay	
Variance	
Special constraints	POT quality desired

	Jerry Car	Strap Crame	Pit Crane Video (Uncompressed)	Scrap Crane Voice (Uncompressed)
MSDU Size Distribution	128 octets	50 % 600 octets 50% 80 octets	100% 2048 octets	100% 512 octet
MSDU Arrival Distribution	Poisson 10 sec mean	Poisson 1 sec mean	Constant 5 msec mean	Constant 60 msec mean
Nominal Transfer Delay	100 msec	100 msec	< 30 msec	< 30 msec
Transfer Delay Standard Deviation	100 msec	100 msec	4 msec	6 msec
Maximum Transfer Delay	250 msec	250 msec	60 msec	60 msec
MSDU Loss Rate	10^{-3}	10^{-3}	10^{-2}	10^{-2}
Service Initiation Time	1000 msec	1000 msec	1000 msec	1000 msec
Station Speed	10 m/s	10 m/s	2.5 m/s	10 m/s
Destination Distribution	100%	100%	100%	100%

	Jerry Car	Strap Crane	Pit Crane	Scrap Crane
Number of stations	2-3	?	1	?
Station density	1-3/hectare	?	1/hectare	?
Dimension	10 m	100 m	100 m	1000 m
Application List	Jerry Car	Strap Crane	Pit Crane Video	Strap Crane Voice
Application Initiation				
Application Duration				

C.4 Production-line carriers

Unmanned vehicles which transport parts or assemblies in a discrete manufacturing environment receive their orders from a centralized control facility via the WLAN and the enterprise wired LAN. They tend to "clump" in a small area in groups of 30 to 40 units. When members of the "clump" get orders to go to another area, they are usually all told at nearly the same time.

Application	AGV
Description	Automated Guided Vehicle delivers material to assembly sites
Platform	Terminal attached to/integrated with machine
Stations/installation	1500
Station Density	up to 40/.01 hectare
Land speed of station	.3 m/s on well defined paths
Range of travel	1.4 km^2 area
Data rate per station	100 bits/sec, every 100 millisec; 1Mb downloads
Dist. of data traffic	clusters of 32 bursts typical in 1 min.
Transfer Delay	
Variance	500 ms

Special constraints

Packet sent to vehicle must eventually get it, order must be preserved. I t is assumed that the responsibility for reordering and end-to-end reliability lies with the transport layer.

	AGV Control	AGV Downloads
MSDU Size Distribution	80 octets	50% 1024 octets 50% 80 octets
MSDU Arrival Distribution	Poisson 100 msec mean	Poisson 5 msec mean
Nominal Transfer Delay	10 msec	< 30 msec
Transfer Delay Standard Deviation	50 msec	30 msec
Maximum Transfer Delay	100 msec	250 msec
MSDU Loss Rate	10^{-3}	10^{-3}
Service Initiation Time	1000 msec	1000 msec
Station Speed	.5 m/s	.5 m/s
Destination Distribution	0%	0%

	AGV Control
Number of stations	1500
Station density	4000/hectare
Dimension	15 m
Application List	• Control • File transfer and download
Application Initiation	
Application Duration	

C.5 Monitoring and controlling

Applications such as a storage tank farm or very hostile or mobile sensors require a wireless connection. Two classes of these devices are summarized: the simple transducer and the Programmable Logic Controller (PLC). They differ mostly in the amount of data produced/consumed.

Application	Transducers
Description	Sensors on production lines
Platform	Terminal attached to/integrated with machine
Stations/installation	20-30 per line
Station Density	100/hectare
Land speed of station	0
Range of travel	0
Data rate per station	5 bytes/sec
Dist. of data traffic	
Transfer Delay	20 ms
Variance	50 ms max delay
Special constraints	

Application	Programmable LogicController (PLC)
Description	If data can't be delivered on time, it must be destroyed. Can afford to lose radio link sensor and the controlling entity
Platform	Terminal attached to/integrated with machine
Stations/installation	10-15 per line
Station Density	100/hectare
Land speed of station	0
Range of travel	0
Data rate per station	100 byte/sec; 1 Mbyte burst
Dist. of data traffic	Constant 100 bps; 1-3 /day of 1 Mbyte
Transfer Delay	20 ms
Variance	50ms delay max.
Special constraints	If not delivered on time, packet must be destroyed. Can not afford to lose radio link sensor and the controlling entity

	Transducer Data Collection	PLC Control	PLC Download
MSDU Size Distribution	10 octets	80 octets	50% 1024 octets 50% 80 octets
MSDU Arrival Distribution	Poisson 1000 msec mean	Poisson 500 msec mean	Poisson 10250 msec msec mean
Nominal Transfer Delay	20 msec	20 msec	< 30 msec
Transfer Delay Standard Deviation	< 50 msec	< 50 msec	30 msec
Maximum Transfer Delay	250 msec	250 msec	250 msec
MSDU Loss Rate	10^{-3}	10^{-3}	10^{-3}
Service Initiation Time	1000 msec	1000 msec	1000 msec
Station Speed	0	0	0
Destination Distribution	100%	100%	100%

	Transducer Data Collection	PLC Control
Number of stations	20-30	10-15
Station density	100/hectare	100/hectare
Dimension	100 m	100 m
Application List	• Collection	• Control • File transfer and download
Application Initiation		
Application Duration		

C.6 Material Handler

Human-operated material handlers, such as forklifts, must be scheduled from a central material-flow control function. The central control may either be another human or a computer-based scheduling system. Information to the operator is the bulk of what must be transported. Information from the operator is essentially acknowledgment of receipt of order and confirmation of completion.

Application	Material handler
Description	Delivers material to production line, distribution center, warehouse. Usually operates a fork lift. Accurate, timely, delivery of materials is often critical. In some industries proper rotation of stock is also critical so that accuracy may defined as transporting a specific pallet.
Platform	Terminal attached to fork lift
Stations/installation	50-100
Station Density	5/.01 hectare
Land speed of station	4-5 m/s
Range of travel	1 Km
Data rate per station	80 bytes/sec

Dist. of data traffic	1-5 min
Transfer Delay	1-3 sec
Variance	1-3 sec
Special constraints	

	Material Handler Control
MSDU Size Distribution	80 octets
MSDU Arrival Distribution	Poisson 180000 msec mean
Nominal Transfer Delay	500 msec
Transfer Delay Standard Deviation	< 1500 msec
Maximum Transfer Delay	10000 msec
MSDU Loss Rate	10^{-3}
Service Initiation Time	1000 msec
Station Speed	7 m/s
Destination Distribution	0%

	Material Handler Control
Number of stations	50-100
Station density	500/hectare
Dimension	1000 m
Application List	
Application Initiation	
Application Duration	

C.7 Mobile Terminal

Two classes of roving operator are characterized in the mobile terminal category. The process control supervisor travels fromline to line and monitors the state of each one. This is combined with physical inspection of the process assures correct operation of the facility.

When problems are identified with a line, a maintenance person is called to correct the situation. In the majority of cases (90%) the maintenance repair person needs little or no assistance from the information infrastructure.When such help is needed, however, often takes the form of downloads of current schematics and diagnostic procedures.

Application	Process control supervisor
Description	Responsible for overall functioning of a manufacturing line or lines in a process (or batch process) industrial environment.
Platform	Portable graphical display terminal
Stations/installation	10
Station Density	10/hectare
Land speed of station	.5 m/s
Range of travel	1 Km
Data rate per station	1-2 Kb bursts
Dist. of data traffic	2-5 sec intervals
Transfer Delay	1-3 sec
Variance	1-3 sec
Special constraints	Battery powered; 3-4 hour battery life required

Application	Maintenance and repair person.
Description	Responsible for preventative maintenance of complex equipment and repair offailed or malfunctioning equipment. Failures are usually on equipment which the person has had no recent experience and which costs hundreds or thousands of dollars per minute of downtime.
Platform	Portable graphical display computer
Stations/installation	3-5
Station Density	3-5/hectare
Land speed of station	1-2 mph
Range of travel	1 Km
Data rate per station	1-20 Kb bursts
Dist. of data traffic	5-60 sec intervals
Transfer Delay	1-3 sec
Variance	1-3 sec
Special constraints	Battery powered; 6-8 hour battery life required. Computer is required because interactive diagnostics or highly detailed schematics may be downloaded.

	Process Control Supervisor	Maintenance and Repair Technician
MSDU Size Distribution	40% 600 octet 60% 80 octet	40% 600 octet 60% 80 octet
MSDU Arrival Distribution	Poisson distribution 5 msec	Poisson distribution 5 msec
Nominal Transfer Delay	5 msec	5 msec
Transfer Delay Standard Deviation	< 30 msec	< 30 msec
Maximum Transfer Delay	1000 msec	1000 msec
MSDU Loss Rate	10^{-3}	10^{-3}
Service Initiation Time	100 msec	100 msec
Station Speed	< 1 m/s	< 1 m/s
Destination Distribution	0%	0%

	Process Control Supervisor	Maintenance and Repair Technician
Number of stations	10	3-5
Station density	10/hectare	2/hectare
Dimension	1000 m	1000 m
Application List		
Application Initiation		
Application Duration		

C.8 Computer Aided Manufacturing

CAM communications consist of program downloads to a robot or numerically controlled manufacturing device and uploads of a record of the work done.

Application	Welder robot
Description	When AGV brings chassis to welderstation, the welder robot performs a complex series of movements and welds. QC information about the welds is communicated to base
Platform	Integrated with device.
Stations/installation	1000
Station Density	
Land speed of station	effective 0
Range of travel	9 meter radius
Data rate per station	100 byte/sec; 1Mb downloads
Transfer Delay	
Variance	not time critical
Dist. of data traffic	constant
Special constraints	

	Welder Robot Control	Welder Robot Download
MSDU Size Distribution	80 octets	50% 1024 octets 50% 80 octets
MSDU Arrival Distribution	Poisson 500 msec	Poisson 10 msec
Nominal Transfer Delay	100 msec	< 30 msec
Transfer Delay Standard Deviation	100 msec	30 msec
Maximum Transfer Delay	250 msec	250 msec
MSDU Loss Rate	10^{-3}	10^{-3}
Service Initiation Time	1000 msec	1000 msec
Station Speed	0	0
Destination Distribution	0%	0%

	Welder Robot
Number of stations	1000
Station density	100/hectare
Dimension	100 m
Application List	• Control • Download
Application Initiation	
Application Duration	

C.9 Other Manufacturing Applications

C.9.1 Applications

	Manufacturing Monitoring	Manufacturing Coordination	Distributed Manufacturing Control	Process Control Alarm Reports
MSDU Size Distribution	25% 512 octets 40% 1024 35% 4096	50% 1024 50% 4096	40% 64 octets 40% 16 20% 256	50% 128 octets 50% 1024
MSDU Arrival Distribution	50% quasi sync 50% irregular	50% irregular 50% Poisson	20 msec 100 msec	50% 5000 msec 50% irregular
Nominal Transfer Delay	250 msec	1000 msec	2 msec 10 msec	250 msec
Transfer Delay Standard Deviation	250 msec	1000 msec	2 msec 10 msec	250 msec
Maximum Transfer Delay	1000 msec	5000 msec	6 msec 30 msec	1000 sec
MSDU Loss Rate	10^{-6}	10^{-6}	10^{-4}	10^{-6}
Service Initiation Time	2000 msec	2000 msec	1000 msec 2000 msec	250 msec
Station Speed	2 m/s	2 m/s	2 m/s	2 m/s
Destination Distribution	85%	95%	70%	90%

C.9.2 Configurations

	Manufacturing Monitoring	Manufacturing Coordination	Distributed Manufacturing Control	Process Control Alarm Reports
Number of stations	5-200	5-20	5-200	5-200
Station density	5-50/hectare	2-10/hectare	5-50	5-50
Dimension	100 m	100 m	100 m	100 m
Application List	Trouble Detection Event Driven Shop Floor Control	Upload Download Cell coordination	Control Data Gather	Alarm Reporting - Polled
Application Initiation	1.4×10^{-4} sec^{-1} 3×10^{-7} sec^{-1}	2.8×10^{-3} sec^{-1} 1.2×10^{-4} sec^{-1}	3.5×10^{-5} sec^{-1} 3×10^{-7} sec^{-1}	2×10^{-1} sec^{-1} 3.5×10^{-5} sec^{-1}
Application Duration	∞	1.2×10^{2} sec ∞	∞	3 sec

Appendix D: Medical

D.1 Introduction

Two major application areas are considered: diagnostic imaging and patient care information systems.

Portable stations used by staff such as nurses should not require a battery change during a 12 hour shift.

Data security and integrity are important. System availability is important.

Stations will typically consist of such platforms as notebook and notepad computers. Antennas on hand-carried devices may need to be integrated into enclosures. Devices will be used 7 days per week, 24 hours per day.

Most traffic will likely be from wireless station to (wired) backbone, hence internetworking capabilities are required.

Certain staff are often assigned to a specific area of the hospital - a nurse will work on a particular ward or nursing unit. Depending on the range of the wireless system, it may be necessary to have more than one bridge to the backbone. Transparent roaming is required. Further, a device must be able to reconfigure itself on power-up to operate in one of several cells.

Physical environment is characterized by many small rooms - this is not an "open office" environment. Depending on the age of the facility there may be substantial masonry construction. Nursing units (wards) are laid out in various plans: long corridors with rooms on either side is common; rectangle shapes with rooms on the outside and offices in the middle; spoke shapes with nursing stations at the hub with hallways radiating out from it.

D.2 Applications

	Medical Imaging	Patient Care Information System
MSDU Size Distribution	60% 2048 Octets 40% 80 octets	60% 80 Octets 40% 600 Octets
MSDU Arrival Distribution	Poisson 5 msec	Poisson 1000 msec (Normal) 200 msec (Peak)
Nominal Transfer Delay	< 30 msec	10 msec
Transfer Delay Standard Deviation	30 msec	20 msec
Maximum Transfer Delay	1000 msec	60 msec
MSDU Loss Rate	10^{-2}	10^{-3}
Service Initiation Time	1000 msec	1000 msec
Station Speed	90 % 0 m/s 10% 3 m/s	80 % 3 m/s 20% 0 m/s
Destination Distribution	30%	20%

D.3 Configurations

	Medical Imaging	Patient Care Information Systems
Number of stations	100	1000
Station density	10/hectare	100/hectare
Dimension	500 m	500 m
Application List	• Medical Image Management System • X-Rays • Ultra-sonograms • CT Scan • MRI Scan • Digital Subtraction Angiography • Intensive/Emergency Care	• Medical Record & Chart Retrieval - Past medical history - Demographics - current interventions/meds/tests - status of tests, Doctor's orders, etc. • Data Collection - Remote telemetry of patient monitoring system data - Documentation of interventions by care provider - Documention of supplies used • E-mail • Terminal emulation to access other information systems
Application Initiation		Poisson $6x10^5$ msec
Application Duration		Poisson $3x10^5$ msec

Appendix E: Meetings

E.1 Introduction

Meetings are new application area that is enabled by the combination of low cost portable computing and wireless local area networks. One characteristic of these networks is that will most often be *ad-hoc* networks that exist for the duration of the meeting and highly dynamic configurations. In addition, they will not always be confined to company premises - in fact for spontaneous meetings communication might be required in many different situations both on private premises (e.g. offices, hotels, conference facilities) and even in public places (e.g. airports, trains). In some cases services might be provided via a fixed infrastructure. These might be as simple as communication between meeting rooms, or to a company wide LAN/WAN. In hotels and conference suites, such services might be provided at a cost. In these situations access to wide area networks might also be provided to allow delegates to gain access to home networks.

Three basic types of meetings were identified:

1. Conference meeting (such as IEEE 802)

2. Structured meetings

    a) business meetings
    b) professional meetings

3. Spontaneous meetings

    a) working groups

A conference meeting is typically a large structured group (e.g., seating, chairman, secretary) comprising between 30-500 participants with the following characteristics:

- large transfers of text and graphics, and image data in some applications (e.g., a WLAN replacement for the "pigeon hole" system of document distribution)

- communications back to home office

- the following application services

    - file distribution and retrieval
    - database access, both intra-conference and off-site
    - E-mail
    - file sharing
    - print server
    - image distribution (real-time image?)
    - access to WANs
    - electronic "conferencing"
    - voting

- platforms

  - personal computers luggables and portables, laptops, notebooks This is truly a multi-vendor environment, with a wide range of capabilities.
  - PC-based servers print, file,communications.

- connection types

  - point-to-point delegate/delegate and delegate/chair
  - point-to-multipoint delegate/delegates and chair/delegates
  - point-to-servers

- transient population, but very limited mobility

- 802.10-like confidentiality and data origin authentication

- acknowledged (local) broadcast, with a high peak/mean traffic ratio

- communication between separate work-groups [e.g., multicast]

The need for an access point to a (wired) backbone network was questioned. Access points are not necessarily required for a small room, but are useful to extend coverage in large rooms or to provide inter-room communications.

A voice capability, simulating a chairman-controlled wireless microphone, would be useful. A voice capability could also assist simultaneous translations.

A "structured" meeting would typically be a formal, or semi-formal meeting involving 5-30 people. More formal meetings would have a concise agenda and a secretary. A board meeting would be a fair example of this type of meeting. A structured meeting could also be less formal and concern a "professional" group. Many people take part in such meetings - from a group of engineers holding a technical meeting to a group of journalists holding an editorial meeting. Such meetings have a clear purpose, but may not necessarily have a structured agenda. The number of people involved would again be between 5 and 30 - but would tend to be towards the lower bound of this range. Structured meetings take place in on-premises meeting rooms with participants seated around a table. Meeting rooms are likely to be between 10 and 50 square meters in size. While the variety of platforms will be wide and varied, company buying policy will introduce some uniformity (in manufacturer at least). Meetings of this style tend to be more discussion than presentation orientated, with much cross communication. This is particularly true for professional meetings. Communication will be orientated to the business of the meeting and there will be little, or no secondary communication. Unlike the conference meeting, communication will not necessarily be bounded by the meeting - applications and data might be drawn from a company wide LAN for presentation, distribution or discussion in the meeting. The following services might be used:

- Access to applications

- File sharing and distribution

- Print server
- Database access
- Access to WANs - "electronic conferencing"
- Multi-media capabilities - e.g. image distribution.

The last class of meeting is a spontaneous or workgroup meeting. The meeting might involve solving a problem, drafting a document, or simply reviewing and exchanging data - such as a budget or project plan. Such an *ad-hoc* meeting would typically involve less than 5 people. It could take place almost anywhere - around a desk in the office, in a meeting room or study, even in a hotel room or airport lounge. The primary service in such a meeting would be file sharing and distribution, but on a company premises might involve access to applications, print servers and databases.

E.2 Applications

	File Access	File Transfer
MSDU Size Distribution	50% 1024 octets 50% 80 octets	90% 1024 octets 10% 80 octets
MSDU Arrival Distribution	Poisson 500 msec	Poisson 5 msec
Nominal Transfer Delay	< 20 msec	5 msec
Transfer Delay Standard Deviation	< 50 msec	< 20 msec
Maximum Transfer Delay	250 msec	250 msec
MSDU Loss Rate	10^{-3}	10^{-3}
Service Initiation Time	1000 msec	250 msec
Station Speed	0	0
Destination Distribution	.7	.7

E.3 Configurations

	Working group	Structured	Conference
Number of stations	≤5	5-30	30-500
Station density	1200 stations/hectare	600 stations/hectare	2500 stations/hectare
Dimension	< 5 m	5-50 m	50 m

Applications	• File transfer • File access • Print server • Database access	• File transfer • File access • Database access • Print server • WAN access • Image distribution • Application load	• File transfer • File access • Database access • Print server • WAN access • Image distribution • Application load • E-mail • Voting
Application Initiation			
Application Duration			

Appendix F: Office

F.1 Introduction

F.2 Applications

F.2.1 Application Services

The following applications have been currently identified as present in the office. The anticipated network traffic of many applications can be generally represented by a subset of of these applications.

File access/sharing	Shared, block demand file access. Unit of access is a random access data block - about 1K bytes.
Program paging	Block demand backing store swap of program execution images. Unit of access is the page - about 1K bytes.
Program access/sharing	Shared program file access. Performance is often similar to either file transfer or file access (paged access).
File transfer	Bulk file copy - unit of access is the entire file as a stream of packets.
Printer/Facsimile sharing	Sharing of common network resource. Traffic model is often similar for file transfer with bulk file copy of a disk buffered fileimage to the network resource.
Electronic mail	File transfer of compound documents consisting of text, voice, image, graphics, video. Often two file transfers are required - one from the originating station's email agent to the post office, andthe second from the post office to the destination station's agent.
Terminal emulation	These applications includes advanced terminal emulation services such as X-terminal as well as more mundane modem sharing.
Data entry	Low volume entry of forms information. The traffic model is assumed to be a low volume transaction processing application.
Environmental control	Distributed control of building facilities HVAC, etc. It is speculated that this application's traffic can be generally represented by alow volume distributed computation application.
Database access	A specialized case of transaction processing and/or file access in which requests for database access are made of database servers by database client stations.The transaction processing traffic model is anticipated to adequately model this application.

Transaction Processing	A class of applications in which client stations request services of server stations using a Remote Procedure Call paradigm (e.g.request/response).
"Collaborative" computing	A class of applications in which multiple stations simultaneously manipulate shared objects. These applications will likely be implemented as high resolution access to common shared storage objects. It is speculated that their traffic model will resemble high utilization file access.
Image manipulation	Shared manipulation of digitized images. It is speculated that this application can be modelled by the file access traffic model for very large files.
CAD/CAM	CAD/CAM contains a number of applications within its broad scope. Design can be modelled as image manipulation. Evaluation and modelling can be modelled as distributed computation using compute servers. And distribution of results can be modelled as file transfer.
Distributed computation	A class of generalized applications in which an application is distributed across a number of nodes communicating via a Remote Procedure Call protocol. It is speculated that the traffic model will resemble transaction processing.
Real-time voice (POTS)	Digitized packetvoice. Anticipates requirements where a portable data station integrates a real-time voice service.
Real-time video (TV)	Digitized packet television. Anticipates requirements where a portable data station integrates a real-time video service.

These applications can be abstracted to a smaller set of archtypal applications:

File access	A random access file service providing for block-at-a-time access to shared network files. A common base for many applications including: word processing, program paging, "collaborative computing", shared database access, etc.
File transfer	A bulk data transfer service copying entire files from one station to another. Such transfer is often pipelined minimizing end-to-end connection management. A common base for many applications including: program loading, electronic mail, CAD/CAM, etc. Non-real-time voice and video can be transferred using a file transfer service underlying an electronic mail service.
Terminal Emulation	An interactive data transfer service providing terminal emulation between clients and servers. Generally transactions occurs at human interaction rates.

Transaction Processing	A Remote Procedure Call service serving as the foundation for data entry, environmental control, client/server applications including shared database management, and some distributed/collaborative applications.
Real-time Voice	A real-time digitized, packetized voice service providing POTS quality service.
Real-time Video	A real-time digitized, packetized video service providing broadcast television quality.

F.2.2 Explicit Standards Support

Office wireless LANs must support transparent interworking with other, wired, industry standard local area networks including IEEE 802.3, 802.4, 802.5, 802.6, 802.9 and FDDI. In addition, services common to all these networks such as 802.1, 802.2 and 802.10 must be supported.

F.2.3 Implicit Market Requirements

Successful office LANs, in addition to the de jure support of standards, must support de facto network standards. Of particular importance is the support of industry standard network operating systems including:

- o Novell Netware
- o TCP/IP/NFS
- o AppleTalk
- o LAN Manager;
- o SNA; and
- o DECNET

Privacy/Security

Integrity/Denial of Service

Seamless application portability in relation to 802.3, 802.5, and other office networks.

Maintain voice, video, and data connections while moving (e.g. Pen-based computers, wireless device can complete its communications session while user is moving/not entering data into his laptop).

Efficient Broadcast Mechanism for Electronic Mail, Distributed Database Applications, and Teleconferencing (receive-only, interactive).

F.2.4 Platforms and Configurations

The applications identified above will be implemented on arange of user stations including the following.

Desktop PC	
Workstations	
Portables	
Handhelds	Ranging from notebooks -> palmtops
Bridges/gateways	
Servers	
Network peripherals	with built-in network attachments (FAX, printers, communication servers, etc.)

Telephones (portable, stationary)
TVs, Graphics Terminals (portable, stationary)

F.2.5 Node Population

- Small Company or workgroup: ≤ 10 nodes
- Medium Company or department: 20-50 nodes
- Large Company or office floor: 100-200 nodes
- Campus Environment: 200-5000 nodes

F.2.6 Node Distribution

- High Density (e.g. back office worker layout or small business): 1 station/ 30 sq.ft.
- Average Office Density: 1 station/ 100 sq.ft.
- Campus/Enterprise Density: 1 station/1000 sq. ft.

F.2.7 MAC Service Requirements

	File Access	File Transfer Windowed Protocol	Transaction Processing	Real-Time Voice	Real-Time Video	Terminal Emulation
MSDUSize Distribution	60% 80 octet 40% 1024	30% 80 octet 70% 1K octet	60% 80 octet 40% 1024	512 octet	2048 octet	90% 80 octet 10% 600 octet
MSDU Arrival Distribtuion	20 msec	4 msec	200 msec	60 msec	5 msec	200 msec
Nominal Transfer Delay	2 msec	2 msec	5 msec	< 30 msec	< 30 Msec	5 msec
Transfer Delay Standard Deviation	< 10 msec	< 20 msec	< 10 msec	6 msec	5 msec	< 10 msec
Maximum Transfer Delay	250 msec	250 msec	250 msec	60 msec	3 msec	250 msec
MSDU Loss Rate	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-3}$	$< 10^{-2}$	$< 10^{-2}$	$< 10^{-3}$
Service Initiation Time	1000 msec	1000 msec	1000 msec	1000 msec	1000 msec	1000 msec
Station Speed	< 2 m/s	< 2 m/s	< 2 m/s	< 2 m/s	0 m/s	0 m/s
Destination Distribution	100% (Small) 10% (Campus)	100% (Small) 10% (Campus)	100% (Small) 10% (Campus)	0	0	100% (Small) 10% (Campus)

F.3 Configurations

	Small Business	Department	Enterprise
Number of stations	5	50	1000
Station density	1000/hectare	300 stations/hectare	30 stations/hectare
Dimension	10 m	100 m	1000 m
Application List	• File access • Transaction • File transfer • Terminal emulation	• File access • Transaction • File transfer • Terminal emulation	• File access • Transaction • File transfer • Terminal emulation • Voice • Video
Application Initiation			
Application Duration			

Appendix G: Retail

G.1 Introduction

Retail includes two main application domains POS (point of sale) and hand-held (for pricing and receiving).

G.2 Applications

Hand-held stations require a sub-second response time from servers that are likely resident on an enterprise wired LAN. They can be moving while transmitting, and may move between access point coverage ranges while waiting for a reply to a previous request. They power-up only while transmitting. Their critical need is low response delay; they have only very small throughput requirements.

Normally services are provided by a client/server configuration with communications initiated by the client stations. Many services are provided locally by a POS server, while some require remote access to distant services.

POS (point of sale) applications include:

- Data collection
- Price lookup
- Credit card check, both of a local "hot card" file and via WAN
- Program load
- Financial point-of-sale transactions (e.g., debit card)

	Department store	Discount checkout	Supermarket checkout (UPC-code scanner)
peak transaction rate for N items	1/3 min for 2.5 items	1/min for 7 items	1/3 min for 50 items
number of enquiries/responses per transaction [== N+1 /sec.]	3.5	8	51
network area	0.25/2 hectare	clustered	clustered
user response delay desired within required within	 1 sec 5 sec	 1 sec 5 sec	 50 msec 200 msec
Message size per transaction (in octets) sent by POS terminal sent to POS terminal total	 120 50 170	 120 50 170	 25 50 170
number of terminals	60 / hectare	20	20

POS stations are movable but not mobile. They need not work while being moved, but a move must not necessitate any user reconfiguration.

A department store thus requires 26.4 bit/s/terminal = 1.6 kbit/sec/hectare.

Supermarket checkout requires 167 bit/s/terminal = 3.3 kbit/sec/hectare.

Download to a diskless terminal requires 512 koctets/10 sec = 40 kbit/sec + overhead. With multicast (e.g., 802.1E), a total system load requires only 68 kbit/sec. 60 POS terminals loaded individually require 60 x 68 kbit/sec = 4+ Mbit/sec when a multicast protocol is not used.

Most POS terminals have an associated telephone, used primarily for in-store intercom. This gives rise to a small voice requirement. There may also be an in-store announcement channel [e.g., "Attention K-Mart shoppers"] requiring voice. And some stores may add a few graphics displays whose controllers are on the WLAN.

The environment changes with the change in the merchandise content creating variable propagation environments. Same in the airports with luggage check and airplanes movement.

Some applications are both indoors and outdoors: shipping/receiving, sidewalk sales, rental car check out, baggage match with travellers on the plane.

Most of the traffic with the exception of the file transfers is initiated by the remote stations. There is almost no peer to peer traffic but rather primarily client to server traffic.

Data security and integrity important.

Robustness required in mall or airport environment.

Most transactions are short 30 to 200 bytes. In the future it is foreseeable to have 1 kbyte records. This does not include resident software downloading which consists of a small percentage of the daily traffic. Downloaded software could be as big as 4 Mbytes.

Subsecond response time on the screen required by most customers. Customers would accept slower response time in the initial stage of downloading which happens normally once a day.

Battery life is very important. Users would prefer no battery change or charge during an eight hours shift.

Access point antenna location is important and could be limited by considerations other than optimal propagation.

Safety considerations could affect access point antenna location.

	Financial POS	Program Download	Real-time Voice
MSDU Size Distribution	120 octets	90% 1024 octets 10% 80 octets	512 octets
MSDU Arrival Distribution	Poisson 30000 msec	Poisson 50 msec	60 msec
Nominal Transfer Delay	100 msec	50 msec	< 30 msec
Transfer Delay Standard Deviation	500 msec	100 msec	6 msec
Maximum Transfer Delay	2000	1000	60
MSDU Loss Rate	10^{-3}	10^{-3}	$< 10^{-2}$
Service Initiation Time	500 msec	500 msec	1000 msec
Station Speed	< 2 m/s	< 2 m/s	< 2 m/s
Destination Distribution	80%	100%	100%

G.3 Configuration

	Department Store	Discount Checkout	Supermarket Checkout
Number of stations	60/hectare	50	75
Station density	60/hectare	2000/hectare	2000/hectare
Dimension	100 m	100m	100 m
Application List	• POS • Price check • Program download • Inventory • Shipping	• POS • Price check • Program download • Inventory • Shipping	• POS • Price check • Program download • Inventory • Shipping
Application Initiation			
Application Duration			

Appendix H: Warehousing

H.1 Introduction

Warehousing overlaps other "vocational" uses. Offices in warehouses are like other offices. Manufacturing Automation and Process Control aspects of warehousing are like other Manufacturing Automation / Process Control uses. In addition to these, warehouses have some distinctive aspects

1. Areas of relatively-low user density, so it is possible to have more access points than users.
2. Greater mobility - speeds of at least 30 km/hr or 20 miles/hr will require active changing of access points.
3. Voice, which replaces or complements traditional voice (now almost entirely walkie-talkie). The emphasis is on local communication, not PSTN (Public Switched Telephone Network) access.
4. In some cases, a willingness to reduce raw data rates to extend the reach of the wireless system.
5. A harsh environment, in which it may be hard to wire access points.

H.2 Applications

Applications are similar to those in the office environment. Mobile communications in warehousing is relatively simple today, but functionality would grow if higher data rates were available. 1 - 2 Mbit/s seems adequate.

Package handling and racking systems are similar, but include a good deal of down-loading and up-reading. This may also be true of AGVs (automated guidedvehicles).

Warehousing overlaps other vocational uses. Offices in warehousesare like other offices. Manufacturing Automation and Process Control aspectsofwarehousing are like other Manufacturing Automation / Process Control uses.

The main application addressed in the table below is the handheld or vehicle mounted terminal used throughout the warehouse. Short transactions are a main characteristic of warehouse applications. The numbers presented below are indicative of present and near future installations. Robotics and highly automated applications, which require limits on the maximum delay have not been considered.

1. The overall application response delay to the user should be less than 0.25 secondfor the large majority of transactions. Delays up to several seconds are acceptable for a small percentage of cases (< 2 %?). For most handheld terminals

it is acceptable to require re-initiation of the transaction in a very small percentage of cases(< 0.1 %?) .

2. Applications in warehousing

Present:
- Data collection
- Data Base Access
- Terminal emulation (limited)
- Voice

If Robotics are included:
- Real Time video
- Tele-control
- Tele-command

	Data Collection	Data Base Access	Real-time Voice
MSDU Size Distribution	50% 120 octets 50% 80 octets	50% 600 octets 50% 80 octets	512 octets
MSDU Arrival Distribution	Poisson 20000 msec	Poisson 20000 msec	60 msec
Nominal Transfer Delay	50 msec	50 msec	< 30 msec
Transfer Delay Standard Deviation	100 msec	100 msec	6 msec
Maximum Transfer Delay	1000 msec	1000 msec	60 msec
MSDU Loss Rate	10^{-3}	10^{-3}	10^{-2}
Service Initiation Time	500 msec	500 msec	1000 msec
Station Speed	< 10 m/s	< 10 m/s	< 10 m/s
Destination Distribution	0	0	0

H.3 Configuration

Number of stations	10-40
Station density	3-15 hectare
Dimension	100 m
Application List	• Data collection • Database access • Real-time voice
Application Initiation	
Application Duration	

Appendix I: Multimedia Services

I.1 Introduction

Computer systems and networks are increasingly capable of manipulating and transporting not only traditional textual, numeric and graphic data, but also multi-media information comprised of voice and video. This appendix describes anticipated traffic characteristics for this type of application.

I.2 Applications

The following tables summarize both real-time and non-real-time multi-media applications. Real-time applications define only one direction (side) of a possible conversation (e.g. an n-person video-conference would likely consume n times the described bandwidth).

	Real-Time Video Conf. (Compressed)	Real-Time MPEG NTSC Video (Compressed)	Real-Time HDTV Video (Compressed)	Real-Time Voice (Compressed)	Real-Time MPEG Voice (Compressed)
MSDU Size Distribution	2048 octets	2048 octets	2048 octets	512 octets	512 octets
MSDU Arrival Distribution	250 msec (constant)	11 msec (constant)	.8 msec (constant)	250 msec (constant)	16 msec (constant)
Nominal Transfer Delay	30 msec	5 msec	.8 msec	30 msec	7 msec
Transfer Delay Standard Deviation	100 msec	5 msec	.8 msec	100 msec	7 msec
Maximum Transfer Delay	250 msec	11 msec	.8 msec	250 msec	16 msec
MSDU Loss Rate	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Service Initiation Time	1000 msec	1000 msec	1000 msec	1000 msec	1000 msec
Station Speed	2 m/s	2 m/s	2 m/s	2 m/s	2 m/s
Destination Distribution	.5	.1	.1	.5	.1

Non-real-time applications bulk deliver a multi-media document, movies or pictures, between stations. These are essentially a file transfer applications. In the case of movies, a 15 minute response time is assumed - nominally less than going to the video store to rent a VCR tape. In the case of photos and X-ray, reasonable response times for delivery of the entire object is assumed.

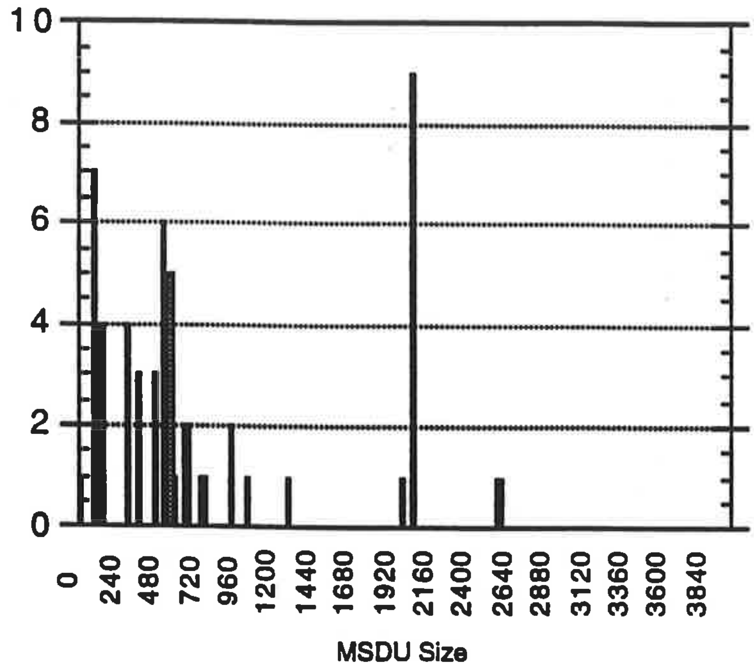
	Non-Real-Time MPEG NTSC Movie (Compressed) (900 second response)	Non-Real-Time HDTV Movie (Compressed) (900 second response)	Non-Real-Time JPEG Photo (Compressed) (1 second response)	Non-Real-Time JPEG X-Ray (Compressed) (10 second response)
MSDU Size Distribution	2048 octets	2048 octets	2048 octets	2048 octets
MSDU Arrival Distribution	1.3 msec mean	.1 msec mean	7 msec mean	7 msec mean
Nominal Transfer Delay	1 msec	.1 msec	3 msec	3 msec
Transfer Delay Standard Deviation	5 msec	.5 msec	7 msec	7 msec
Maximum Transfer Delay	30 msec	3 msec	30 msec	30 msec
MSDU Loss Rate	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Service Initiation Time	1000 msec	1000 msec	1000 msec	1000 msec
Station Speed	2 m/s	2 m/s	2 m/s	2 m/s
Destination Distribution	.1	.1	.5	.1

I.3 Configurations

Number of stations		
Station density		
Dimension		
Application List		
Application Initiation		
Application Duration		

Appendix J: MSDU Size

The observed range of average MSDU sizes for the surveyed wireless applications is graphed in the following histogram.

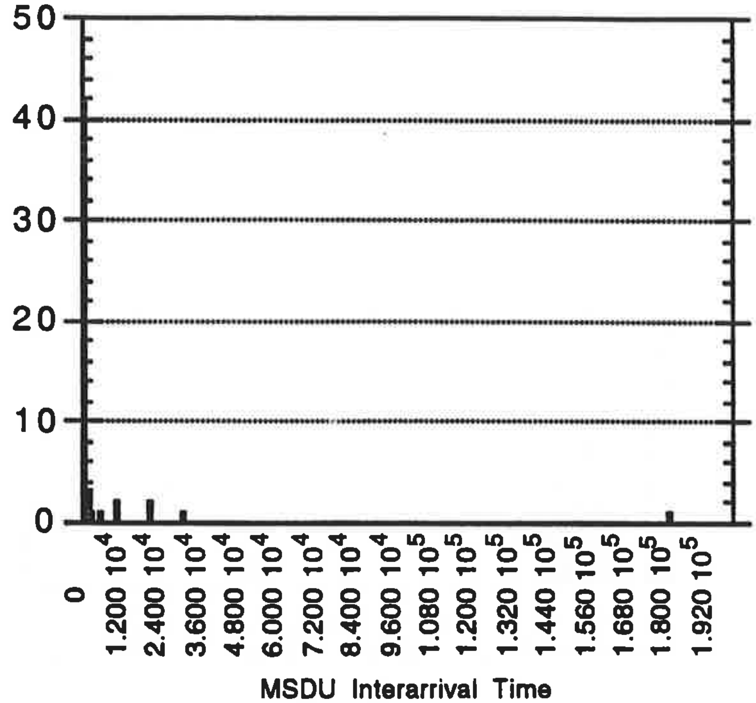


A basic bimodal distribution is observed: either ≤ about 500 octets or about 2000 octets. The statistics of these data follows.

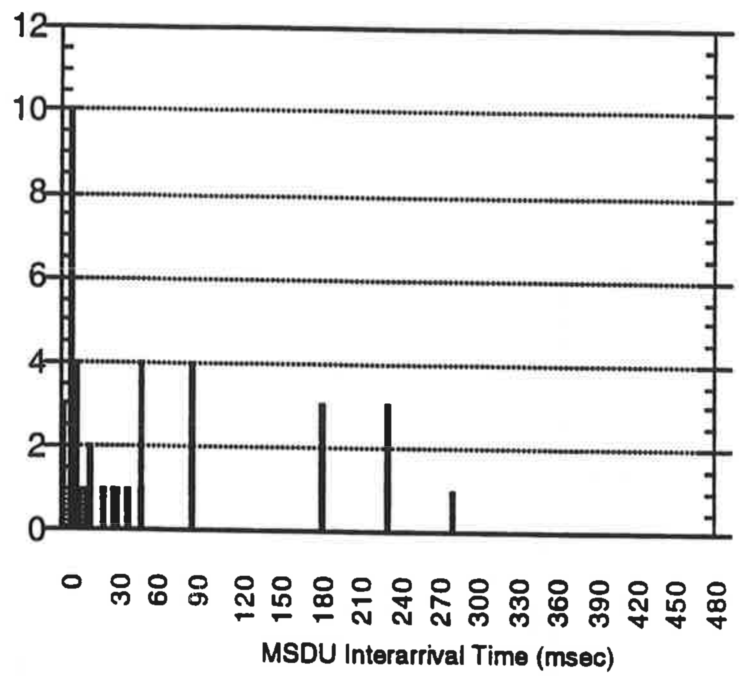
Minimum	10
Maximum	2560
Mean	759.96226
Median	512
RMS	1053.2163
Std Deviation	736.17079
Variance	541947.43
Std Error	101.12084
Skewness	1.0809338
Kurtosis	-0.29887845

Appendix K: MSDU Arrival Time

The observed range of MSDU interarrival times for the surveyed wireless applications is graphed in the following histogram.



A wide range of interarrival times is noted documenting the wide range of performance requirements anticipated for wireless applications. However, note the substantial cluster towards higher performance applications. A more detailed view of these applications yields the following graph.

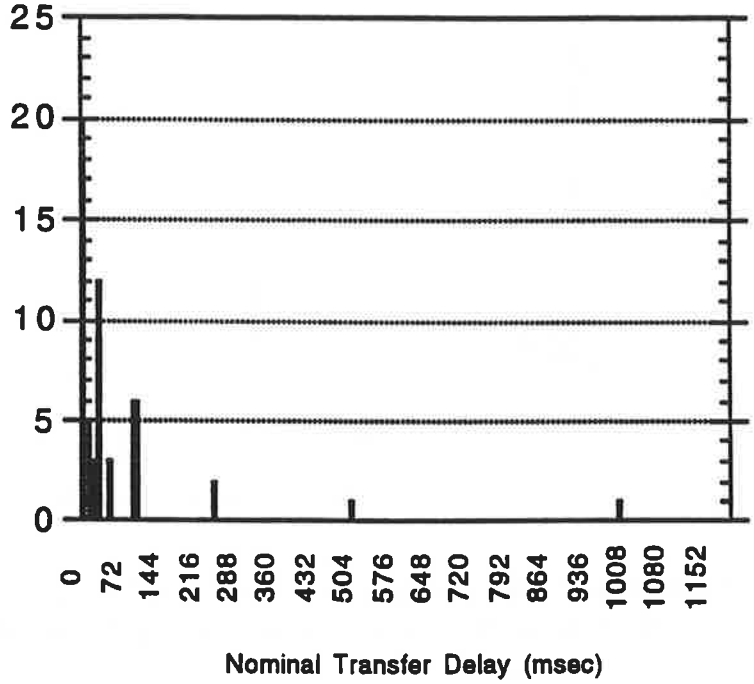


Note the substantial cluster of applications having MSDU interarrival times ≤ 20 msec. The statistics of these data for all surveyed wireless applications follow.

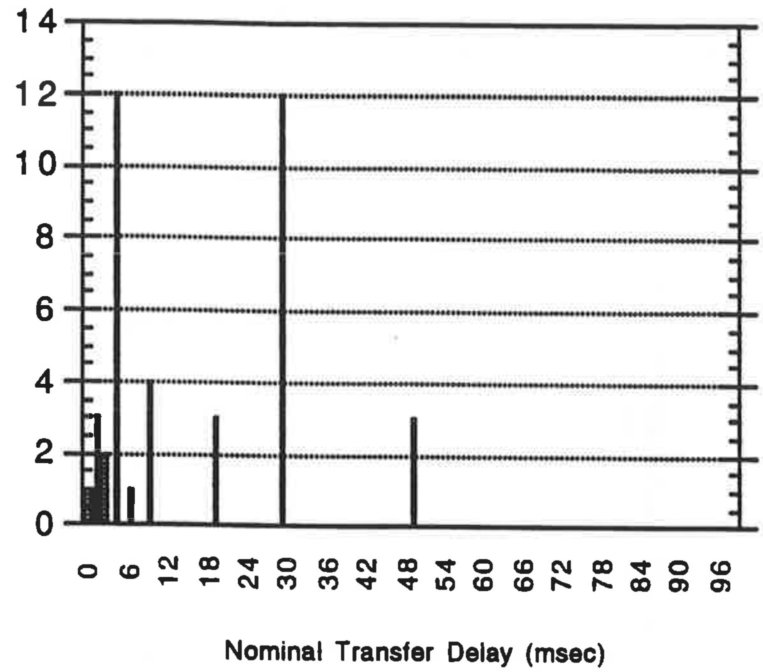
Minimum	0.1
Maximum	180000
Mean	5359.7585
Median	60
RMS	25451.845
Std Deviation	25119.207
Variance	6.3097456e+08
Std Error	3450.3884
Skewness	6.5429046
Kurtosis	42.819866

Appendix L: Nominal MSDU Transfer Delay

The observed range of nominal MSDU transfer delay times for the surveyed wireless applications is graphed in the following histogram.



Again, note the wide range of tolerated transfer delay times and the clustering below about 100 msec. Closer examination of the data in that range yields the following graph.



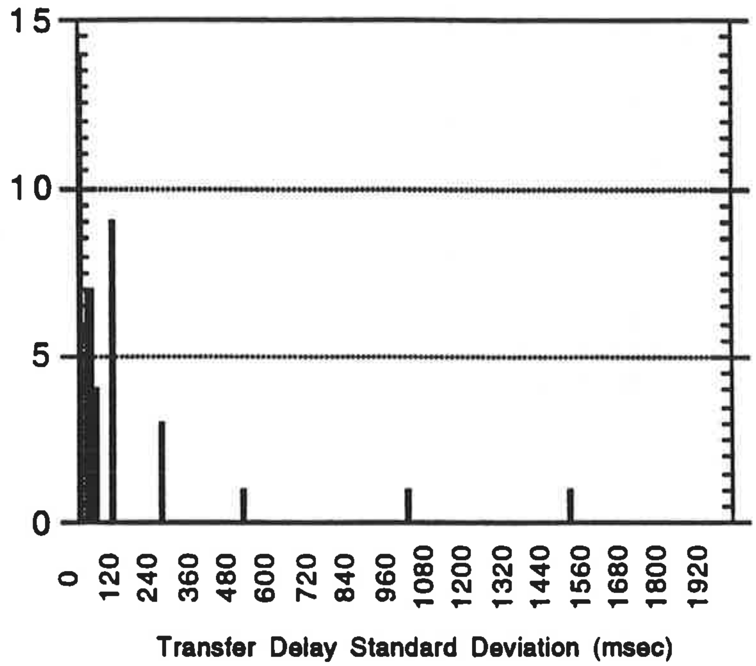
Note the strongly bimodal nature of the data with about half the surveyed applications requiring transfer delays ≤ 5 msec and about half tolerating transfer delays of ≥ 10 msec.

The statistics of these data for all surveyed wireless applications follow.

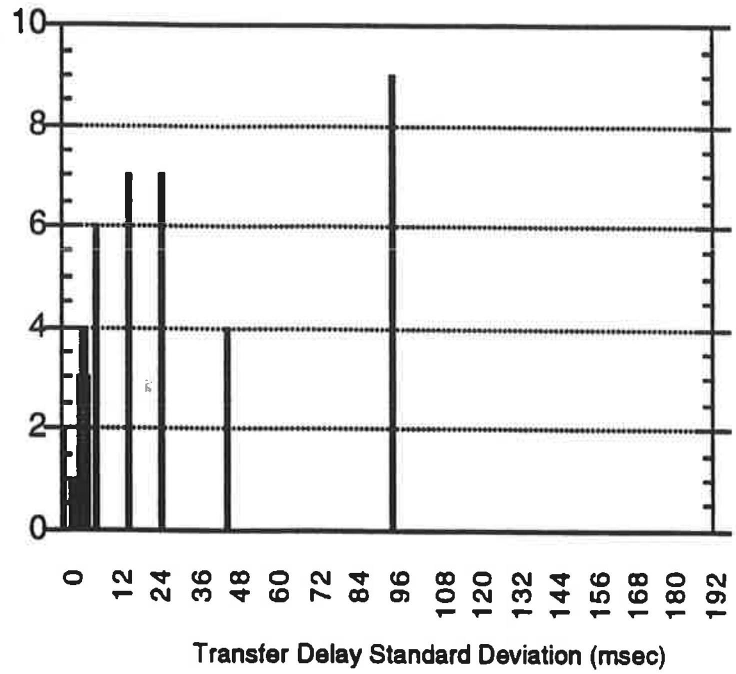
Minimum	0.1
Maximum	1000
Mean	62.092453
Median	20
RMS	165.70493
Std Deviation	155.10174
Variance	24056.55
Std Error	21.304863
Skewness	4.7728704
Kurtosis	24.548847

Appendix M: Transfer Delay Standard Deviation

The observed range of the tolerated MSDU transfer delay times standard deviation for the surveyed wireless applications is graphed in the following histogram.



Again, note the wide range performance requirements of wireless applications yields a wide range of tolerated transfer delay variation. However, the bulk of applications require rather modest variation in transfer delay, clustered < about 200 msec. The following graph examines these data more closely.

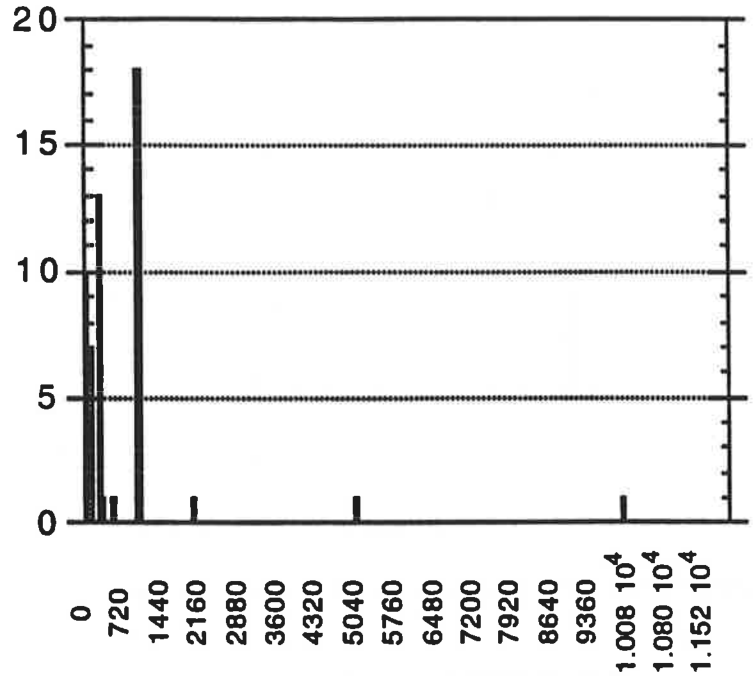


Note the rather wide range of tolerated transfer delay variance. The statistics for these data follow.

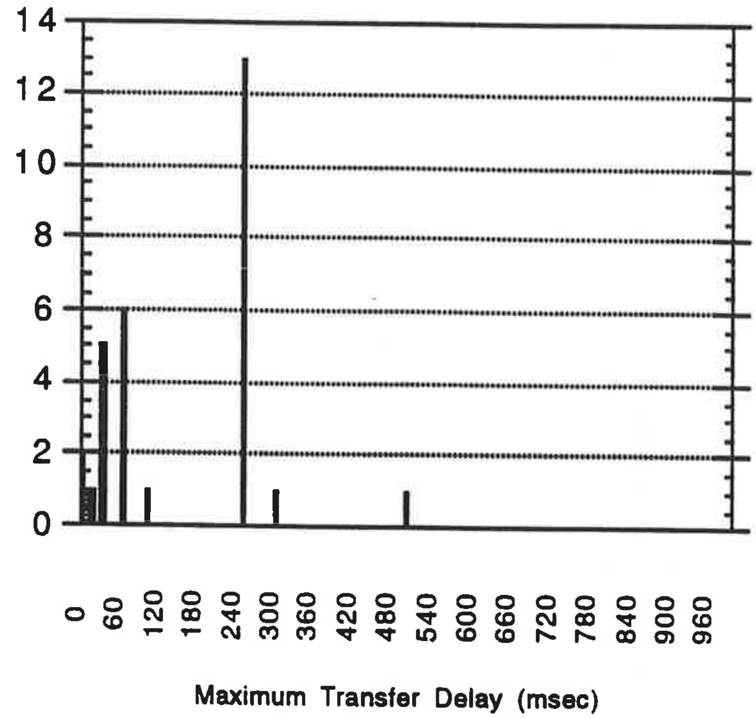
Minimum	0.5
Maximum	1500
Mean	100.51509
Median	20
RMS	267.68
Std Deviation	250.46544
Variance	62732.939
Std Error	34.404075
Skewness	4.3483533
Kurtosis	19.510072

Appendix N: Maximum Transfer Delay

The observed range of the maximum tolerated MSDU transfer delay times for the surveyed wireless applications is graphed in the following histogram.



Again, note the wide range of maximum transfer delay tolerated. However, the clustering below about 1200 msec is noteworthy and is examined more closely in the following graph.

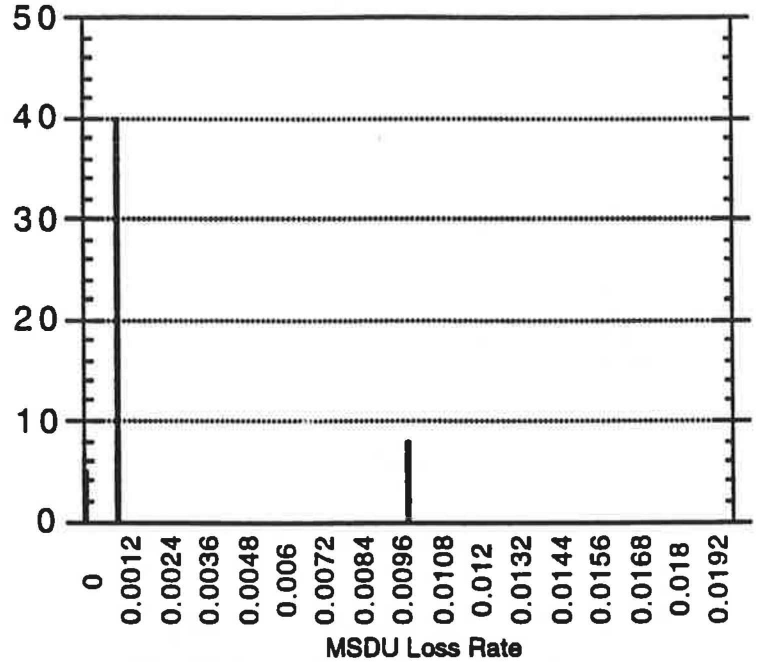


Note the bimodal nature of the maximum transfer delay: it is either rather modest (≤ 10 msec) or about 256 msec. The statistics for these data follows.

Minimum	0.80000001
Maximum	10000
Mean	748.99623
Median	250
RMS	1672.1302
Std Deviation	1509.3062
Variance	2278005.2
Std Error	207.31915
Skewness	4.8727077
Kurtosis	25.926749

Appendix O: MSDU Loss Rate

The observed range of the tolerated MSDU loss rate for the surveyed wireless applications is graphed in the following histogram.



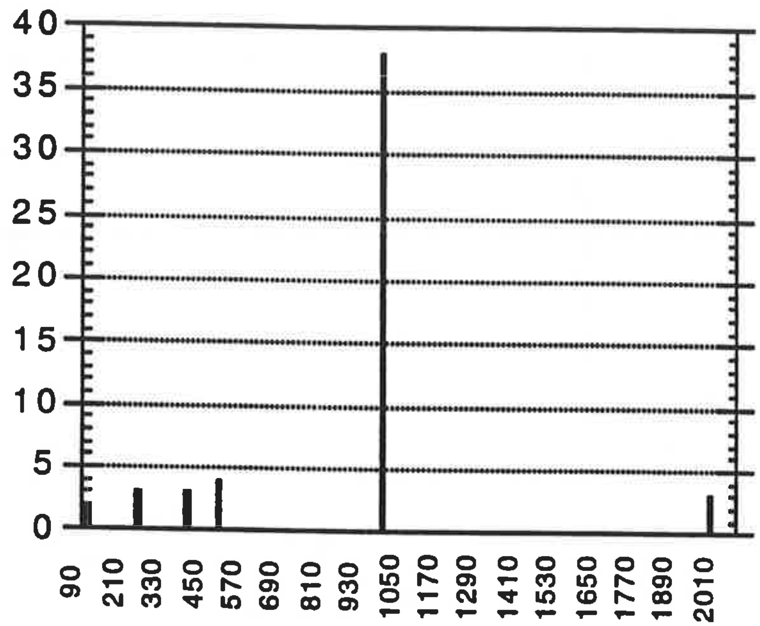
The data are moderately bimodal with the vast majority of surveyed applications requiring a low loss rate ≤ .1% and a few applications tolerating a higher loss rate of about 1%.

The statistics for these data follow.

Minimum	1.0000000e-06
Maximum	0.01
Mean	0.0022679811
Median	0.001
RMS	0.0039811347
Std Deviation	0.0033032671
Variance	1.0911574e-05
Std Error	0.00045373864
Skewness	1.918186
Kurtosis	1.7444667

Appendix P: Service Initiation Time

The observed range of the tolerated MSDU service initiation time for the surveyed wireless applications is graphed in the following histogram.



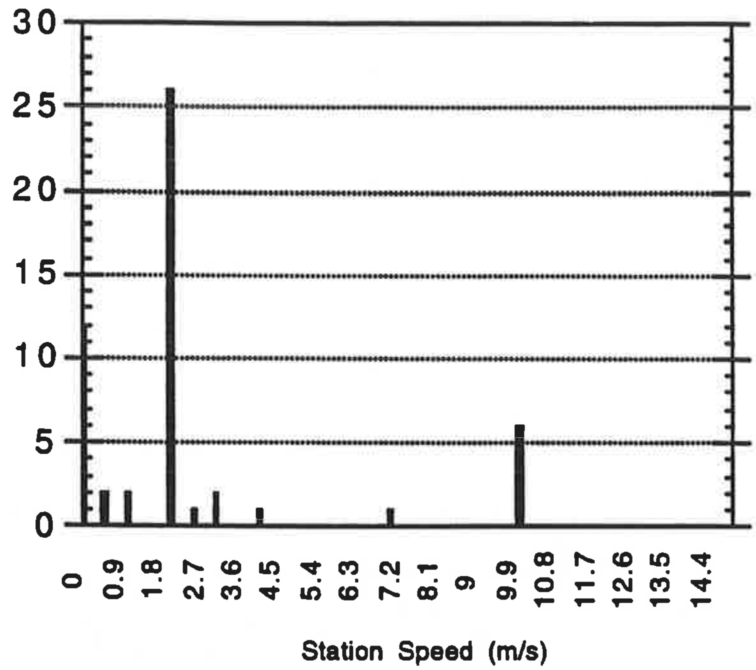
The data suggests that the vast majority of surveyed applications are relatively tolerant of initial "setup" delay in initiating MSDU delivery service - tolerating over 500 msec service initiation delay. A small minority of applications require less than 100 msec service initiation delay.

The statistics for these data follow.

Minimum	100
Maximum	2000
Mean	908.49057
Median	1000
RMS	987.5403
Std Deviation	390.84916
Variance	152763.06
Std Error	53.68726
Skewness	0.43889423
Kurtosis	2.0322687

Appendix Q: Station Speed

The observed range of the station speed for the surveyed wireless applications is graphed in the following histogram.



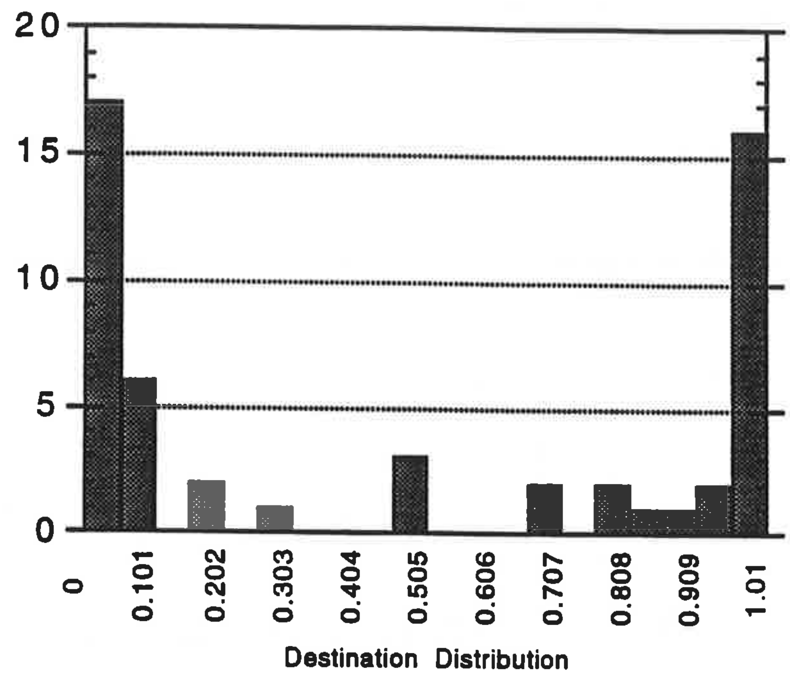
The vast majority of surveyed applications require support for moving stations in which any station may be motion ≤ 2 m/s - or approximately pedetrian walking speed. A small minority of applications require support for stations moving at up to 10 m/s - or approximately forklift speed.

The statistics for these data follow.

Minimum	0
Maximum	10
Mean	2.5377358
Median	2
RMS	3.8748098
Std Deviation	2.9561687
Variance	8.7389332
Std Error	0.406061
Skewness	1.7743978
Kurtosis	2.018112

Appendix R: Destination Distribution

The observed range of the destination distribution for the surveyed wireless applications is graphed in the following histogram.



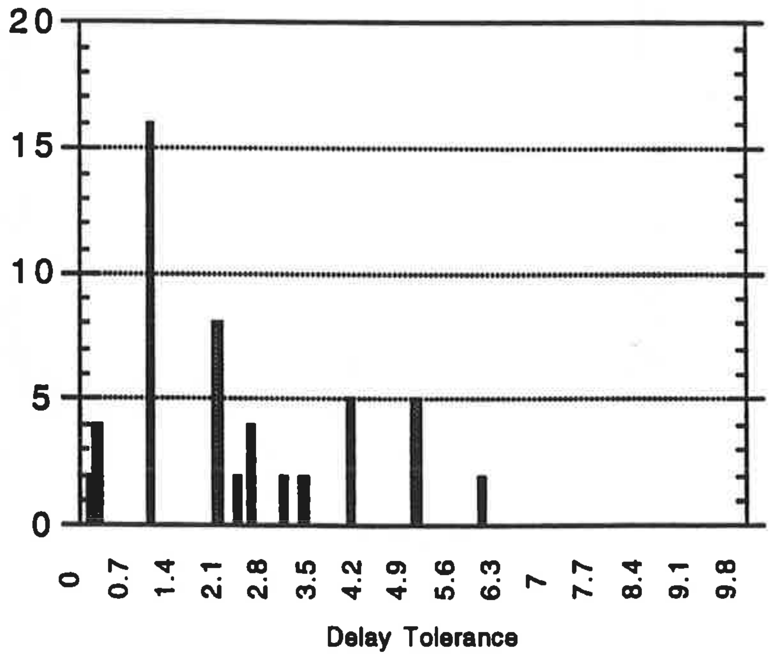
The data are strongly bimodal suggesting that the surveyed applications anticipate either - in a given configuration - all stations are communicating to stations on a wired backbone or all stations are communicating directly to wireless stations.

The statistics for these data follow.

Minimum	0
Maximum	1
Mean	0.48018868
Median	0.5
RMS	0.65267953
Std Deviation	0.4462816
Variance	0.19916727
Std Error	0.061301493
Skewness	0.08826119
Kurtosis	-1.8222418

Appendix S: Delay Tolerance

The observed range of the MSDU delivery delay tolerance time for the surveyed wireless applications is graphed in the following histogram. Delay tolerance is computed as the ratio of standard deviation of transfer delay to nominal transfer delay and is considered a measure of how tolerant an application is of occasional variance in the transfer delay of delivered MSDUs.



Note a small minority of application having a delay tolerance « 1.0 with the substantial majority of surveyed applications having a delay tolerance ≥ 1.0.

The statistics for these data follow.

Minimum	0.13333
Maximum	10
Mean	2.4044024
Median	2
RMS	3.075517
Std Deviation	1.9360728
Variance	3.748378
Std Error	0.26594005
Skewness	1.4188091
Kurtosis	2.7648907