IEEE P802.11

Wireless Access Method and Physical Layer Specifications

A Modest Proposal for a Asynchronous, Data Intensive, Wireless Local Area Network

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Executive Summary

The Wireless Local Area Network is an exciting, immature technology looking for its proper place in the overall LAN marketplace. This paper draws from the experience of wired LANs and the expected wireless LAN applications to lay the foundation for a simple wireless LAN architecture focussed on the market pull for such products. Key requirements include:

- network services necessary to support anticipated WLAN applications including backward compatibility with wired LAN applications;
- feasible wireless media implementation;
- anticipated volume cost consistent with market expectations; and
- scaled architecture supporting both small (2 node) networks as well as enterprise-wide WLANs.

The proposed architecture has the following key elements:

- use of existing media (diffuse infrared, Part 15.247 spread spectrum radio, Part 15.249 low power radio and to-be-defined PCS radio) technology and FCC regulation;
- support of existing and envisaged wireless LAN applications; providing low delay, CSMA MAC datagram services needed by these applications enhanced by services, including roaming, needed for mobile wireless LAN applications;
- minimal new invention permitting quick development of standards and products to the market;
- configuration alternatives for intelligent EBSAs based on existing 802 LAN systems and industry-wide experience in bridging and routing;
- low power, low overhead designs well suited for mobile implementation; and
- backward compatibility with existing 802 LANs and prevalent LAN operating systems.

It is recognized that this architecture is not yet complete with a number of important mechanisms still to be specified. Subsequent contributions will elaborate on this foundation.

I. Introduction

The Wireless Local Area Network is an exciting, immature technology looking for its proper place in the overall LAN marketplace. This paper draws from the experience of wired LANs and the expected wireless LAN applications to lay the foundation for a simple wireless LAN architecture focussed on the market pull for such products.

These expected wireless LAN applications impose some important requirements.

Mobility	User components can be expected to move - often. Users expect not only to initiate communications sessions in new locations, but also to maintain existing communications sessions while in motion.
Functionality	Users expect contemporary enterprise and local area network functionality: file access/transfer, remote terminal access, reliable virtual circuits, datagrams and remote procedure calls. Underlying these services must be effective techniques for resource naming, routing, and network management. This must be accomplished without reinventing contemporary LAN operating systems.
Reliability	Users expect both reliable communications - session error detection and recovery - as well as robustness of the underlying communications internetwork - alternate routing, load sharing, and reconfiguration.
Security	Users expect that their wireless transmissions are perceived to be at least as secure as their wired communications with no substantive cost increase.
Interoperability	Users demand interoperability with other manufacturer's equipment. Such interoperability provides both a basis for application interconnection as well as long term system growth and support. The use of standard communication protocol suites and interfaces provides the foundation for interoperability.
Cost	Users will, today, pay a premium for the above services for mobile applications. However, the choice of technologies should introduce no inherent cost increases. In any case, wireless LAN services will not be popular until (as a rule of thumb) the incremental cost of the (wireless) LAN interface is less than 20% of the cost of the serviced computer.
Time-to-Market	If wireless LAN products are to provide some measure of wire replacement, some urgency is required since it is clear

that wired LANs are becoming cheaper, faster and ubiquitous[1].

This paper proposes a simple architecture for a wireless LAN, optimized for a "least invention" world-view. It is based on classic CSMA LAN designs, contemporary wireless media and networks systems technology.

This introduction to the architecture is presented in four pieces:

Introduction	Requirements and overview.
Topology	Key architectural concepts, topology, definitions.
Physical Layer	The architecture can be implemented with any of several wireless media choices. The most promising are identified here.
MAC Layer	The architecture is glued together with a substantial MAC frame delivery service that is simple for small BSAs and scales in complexity for large, multi-BSA WLANs supporting roaming stations.

Some reader familiarity with contemporary LAN operating systems, protocols suites and internetwork architecture and routing is presumed.

It is recognized that this architecture is not yet complete with a number of important mechanisms still to be specified. Subsequent contributions will elaborate on this foundation.

1.1 Requirements

Wireless LANs inherit many of the performance and market requirements of wired LANs since many of the same applications will be run on both. In addition, there are requirements unique to their anticipated use for mobile computer systems as well as ones that reflect the state-of-the-art in wireless data transmission.

Applications	Essential to support existing desktop LAN applications plus anticipated wireless LAN applications. Minimal need for real-time synchronous services. Substantial interactive datagram services are required. Major anticipated application area is the support of mobile, handheld applications rather than desktop wired LAN replacement.

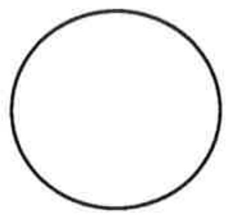
[1] K. Biba, "Local Area Network Market and Forecast", IEEE P802.11/91-17, March 1991.

Services	Essential to provide datagram services with roaming. Consistent with existing 802.2 Type I and Type II services, optimized for datagram services.
Scale	Minimal initial setup for small networks, easily scaling for capacity and/or area coverage to support large populations and/or large areas. Architecture should not unduly constrain size either geographically or in terms of numbers of stations. Minimum network size should be two (2) stations and/or 2000 m^2 and maximum network size should be about 10^4 stations over $3x10^6$ m^2.
Performance	Burst channel rate no less than 1 Mb/s, preference for channel speeds of between 4 and 10 Mb/s. Low frame transmission delay (< 5 msec) at low to moderate load. Congestion control at high load. Capacity that scales with network size.
Power	The highest volume WLAN applications are anticipated for mobile computers where (battery) power consumption is extremely important. Low average power usage is therefore of great interest. Simplicity of implementation can, in general, reduce power consumption.
Integrity	System should be robust against interference from 802.11 conforming adjoining WLANs as well as non-conforming interferers anticipated in the environment.
Security	Casual data theft should be discouraged. High security mechanisms should be (optionally) provided by 802.10 conforming services.

II. Topology

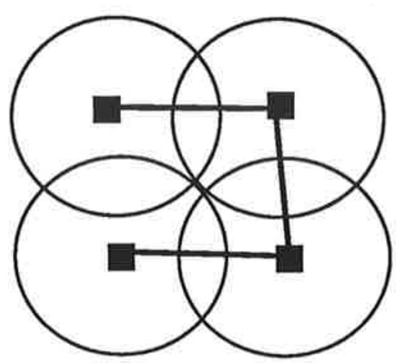
The smallest wireless network consists of two directly communicating stations. Such a network is termed a Basic Service Area (BSA). Additional stations can be added to a BSA such that they are within wireless range of all existing stations. IntraBSA communications provide direct one-hop connectivity between all stations within the BSA.

A BSA is graphically depicted as a circle although it is understood that the precise shape is a three-dimensional object, generally not regular, limited both by the transmission characteristics of the media (e.g. light does not pass through opaque walls) and by the characteristics of the environment (e.g. building construction, furnishings and people).

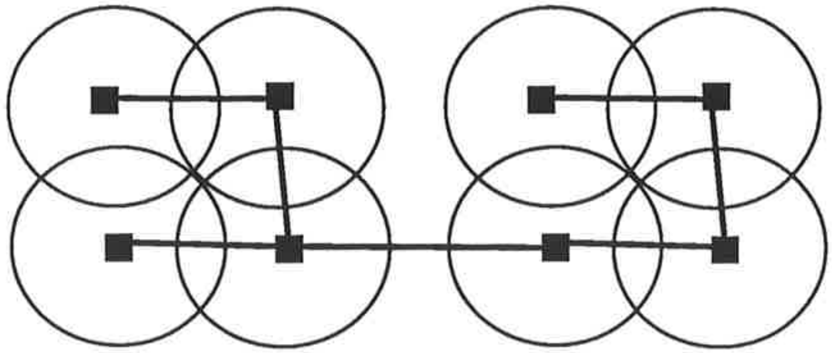


Generally, each BSA will have a locally unique transmission media - a channel - defined by one or more of: geographic area, radio frequency, infrared color frequency, transmission power, building construction (e.g. walls), spread spectrum spreading code, etc.

Once a single BSA network can be constructed, it is a natural step to consider a micro-cellular architectural extension of the WLAN to an Extended Basic Service Area (EBSA) for the purposes of increased area coverage, increase the robustness of communications while in motion, and to increase the overall capacity of a WLAN installation through space division multiplexing.



BSAs within an EBSA are connected with an EBSA interconnect that provides for seamless communications between stations anywhere within the EBSA. This interconnect will make use of standard IEEE 802 LANs to provide communications services between BSAs.



Mobility can be considered on two scales: local and global. Local mobility is movement within a single EBSA. Global mobility is between EBSAs. The proposed architecture provides for mobility within an EBSA while global mobility is left to the user's chosen end-to-end network layer protocols.

If stations are stationary within two-way media transmission range of each other, then communications will in general be quite robust, with industry standard higher layer LAN protocol suites providing reliable end-to-end communications. When stations are in motion, it is possible to move out of relative media transmission range, and communications will likely be lost. Ensuring the continuation of communications while in motion is a prime motivator for the extension of the EBSA to provide a micro-cellular architecture, within which stations can move from BSA to BSA while always remaining within media range of a least one station or EBSA interconnect in each BSA.

Contemporary higher layer LAN operating system protocols are designed to provide end-to-end, reliable communications services not just across one LAN, but across an interconnected "internetwork" of LANs and WANs. These protocols have the ability to cope with variable delay, throughput, alternate routing, and occasional packet loss that such an internetwork can introduce. The proposed architecture takes advantage of the "best effort" packet delivery requirements these protocols place on individual MAC layers to provide simple mechanisms supporting sophisticated services - such as roaming.

Roaming is a communications service that permits stations to continue communications services while in motion within an EBSA. This capability will place certain constraints on physical media design as well as rather more serious constraints on the MAC layer design. The relaxed constraint that occasional packet loss (for instance, crossing an intraEBSA BSA boundary) can be detected and recovered by the end stations with no intervention by the intervening EBSA interconnect, substantially simplifies the network design.

The following terms are defined for the architecture.

Station — A station is any user device communicating over the wireless LAN. Each station has a unique LAN address and a wireless transceiver permitting alternate data transmission and reception.

BSA

A Basic Service Area is a wireless LAN in which each communicating station can communicate directly over the wireless media with every other station with no intervening equipment or processing. At least two stations define a BSA and if two compatible stations are within media range, they are sufficient to define a BSA without other external equipment. The size of a BSA is directly related to the transmission distance of the chosen physical layer media in a particular geographic area. These media typically support indoor transmission ranges less than 100m yielding typical BSAs of between 5000 and 10000 m^2.

An open BSA is one in which any architecture conforming user can introduce a station and share MAC level transmission services.

A closed BSA is one in which not only must a station conform to the architecture, it must also possess a valid access key in order to share MAC level transmission services.

EBSA

An Extended Basic Service Area is an interconnected collection of (generally adjacent) BSAs in which each communicating station can communicate with every other station within its own BSA as well as each interconnected BSA via an EBSA interconnect.

The proposed architecture for the EBSA interconnect will accommodate station populations of up to 10^4 with up to 10-20% simultaneously roaming. The anticipated algorithms will scale supporting more stations if fewer roam and conversely, more roamers for smaller populations.

Channel

A partition of the transmission media permitting isolation between adjoining BSAs. For radio media such channels can be provided in the frequency domain or in the code domain for spread spectrum systems. Each BSA generally has a locally unique channel allocated to it by the network plan.

Adjoining

The property of two BSAs that are geographically abutting. Such BSAs may or may not belong to the same enterprise.

Adjacent	Two adjoining BSAs supporting intercommunication between stations within both BSAs. Such BSAs are likely, but not required, to belong to the same enterprise.
Roam	The ability of a station within an EBSA to move (either discontinuously or continuously), within the geographic area of the EBSA and both maintain existing communication sessions as well as create new ones. Stations may clearly move between EBSAs. However, no explicit roaming capabilities between EBSAs are encompassed within this proposed architecture.
Local roaming	Local roaming is within a single EBSA and hence the MAC mechanisms proposed for this architecture will accommodate local roaming.
Global roaming	Global roaming is between EBSAs which may or may not be externally interconnected. This problem is not considered within this architecture and is left for network layers making use of this architecture.
Overlap	The property of two adjoining BSAs in which some stations within one BSA can have a direct communication path with some stations within the other BSA thus creating the potential for interference.
Frame	The fundamental LAN unit of data transmission and reception. It is a variable length object consisting of a fixed length header (containing source and destination addresses), a body containing MAC user data, and a trailer containing error detection information.
Fragment	The unique needs of a particular physical media type may require the decomposition of a transmitted frame into smaller units, termed fragments, for transmission. Such an ordered sequence of fragments can be reassembled into a frame by the receiver before delivery to the MAC receiver user process.
Session	A bidirectional sequence of frames between two stations over a period of time. A session may have a lifetime of only several frames within a few milliseconds (a transaction) ranging to millions of frames over days (bulk file transfer).
Address	Unique IEEE 802 compatible label for each station.

EBSA Interconnect — A intelligent transmission system connecting all BSAs within an EBSA and providing frame relay services between any two stations within the EBSA or between any EBSA station and the outside network. EBSA interconnects are assumed to be IEEE 802 conformant LANs.

Bridge — A network component providing store-and-forward frame communication between BSAs within an EBSA and between a WLAN (either a BSA or an EBSA) and other IEEE 802 compatible LANs. A bridge may contain an addressable station for purposes of network management.

BSAs can be organized into EBSAs in a number of ways and the proposed architecture accommodates several variants. However, not all perform as well. The two key distinguishing issues are: 1) the degree of isolation between two adjacent BSAs and 2) the degree of organization of the EBSA and its interconnect.

If the channels assigned to adjacent BSAs are sufficiently isolated so as to permit simultaneous, non-interfering transmissions on all channels even if the BSAs substantially overlap, then a regular, micro-cellular BSA layout becomes possible as described above. Such an EBSA scales in transmission capacity roughly linearly w.r.t. number of its component BSAs through space division multiplexing and channel reuse[2]. Since adjacent, overlapping BSAs do not interfere with each other, transmissions within one BSA do not cannibalize bandwidth of its neighbor.

If, however, the chosen wireless media does not support such isolation between adjacent BSAs (e.g. diffuse infrared in very large rooms) then adjacent BSAs will cannibalize bandwidth from their neighbor. This cannibalization will decrease the load capacity and increase average frame delay of each such BSA and hence the capacity of the EBSA will not scale linearly with size. It is highly desirable to isolate adjacent BSAs in order to maximize EBSA capacity and minimize frame delay.

The degree of EBSA organization can be considered to have two poles: an established infrastructure and and ad hoc infrastructure. An established EBSA will have a regular BSA layout with an organized EBSA interconnect. For example, providing a WLAN service for a typical single story office building using an established infrastructure could consist of partitioning the building into individual BSAs (based on media transmission range) so that all desired portions of the building are within a BSA. Secondly, assigning, in an automated

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[2]It is presumed that there will always be fewer possible media channels than the number of BSAs within many EBSAs. In that case channels must be multiply assigned to BSAs such that immediately adjacent BSAs are isolated and propagation loss sufficiently isolates BSAs having a common media channel assignment.

manner, media channels to each BSA. Thirdly, connecting the BSA with the EBSA interconnect (using, for example, a wired IEEE 802.3 backbone LAN). The BSA arrangement, the EBSA interconnect and the media channel assignment to BSAs will govern the operation of individual stations within the EBSA.

An ad hoc infrastructure is one that is provided by the stations themselves by nature of their collective proximity at a particular time. For example, a collection of handheld pen computers, each with a wireless station, in a large room of dimensions greater than the individual range of each station's transceiver could define an ad hoc EBSA architecture providing for communication between any stations. In this case, the stations themselves must construct an infrastructure. This type of system can be accommodated by the proposed architecture using promiscuous routing of frames.

The anticipated types of EBSA interconnection will be discussed below in the MAC section as routing of frames within the EBSA is considered.

III. Physical Layer

The alternative media richness of many successful LAN standards (particularly IEEE 802.3 and 802.5) suggest the importance of providing a standard that can accommodate a variety of alternative media choices. At this time, at least four wireless LAN media choices are viable: diffuse infrared, Part 15.247 spread spectrum radio, Part 15.249 low power radio and other, to-be-specified, radio spectrum.

Of course, it will be required to have a common interface between the physical layer and the MAC layer in order to support alternative physical layers. Some of these common interface requirements include the following.

- It is desirable that each station's MAC layer have the ability to "tune" each station's physical layer to the channel assigned to any accessible BSA. This ability to move from BSA to BSA is required in order to support roaming and simple installation and configuration. Stations without this capability would only be able to support a subset of the LAN's capability and would likely be installed only in fixed locations.
- It is required that the physical layer export "frame sense" and received data to it's MAC layer.
- It is required that the physical layer import transmitted data from it's MAC layer as well as necessary frame control signals.
- Further, it is desirable to have received power and/or signal level exported to the MAC layer from the physical layer. This information can be useful in designing simple, distributed roaming algorithms.

3.1 Infrared

Infrared communication has been long considered a candidate for a short range wireless communication media. Historically, it has been considered to have the advantages of possible low power operation, safety, and lack of regulatory intervention. However, these advantages have been balanced by the rather substantial disadvantages that optical line-of-sight communications and narrow-beam, "aimed" communications place on in-building, mobile applications.

Recent experience suggests that short distance, "unaimed" diffuse transmissions work reasonably well on the scale of individual rooms at speeds up to 10 Mb/s with low power, low cost implementations. At this time, these implementations still have directionality, distance and room construction difficulties. These limitations likely include:

- 90° transmission/reception directionality; and
- limited capability for "bounced" signal reception subject to room construction limitations - e.g. bouncing from a window does not work.

However, these "features" together imperfectly approximate an omnidirectional media.

However, despite these limitations, diffuse infrared can provide a compact, low-power, room-sized wireless LAN appropriate for certain applications: so-called "conference room LANs" and wireless "docking stations" for portable computers.

A BSA is constructed from the limited line-of-sight and "line-of-bounce" properties of the infrared signal. Physical, optical separation, such as room walls, is used to construct non-interfering, adjoining BSAs.

3.2 FCC Part 15.247 Spread Spectrum Radio

The most commonly considered media for wireless LANs is that available under Part 15.247 of the FCC regulations in the United States and related regulations in some other parts of the world. Almost all extant wireless LANs operate under these regulations.

While most implementations of low-power spread spectrum have concentrated on direct sequence implementations, recent 1990 updates to the regulations have made other solutions more attractive. In particular, current rules permit the use of frequency hopping in 1 MHz hopping channels in the 2.4 GHz and 5.8 GHz ISM bands.

The currently most interesting spread spectrum physical layer would thus have the following properties:

- operation in the 2.4 GHz band (optionally 5.8 GHz band though cost would bias towards 2.4 GHz);
- frequency hopping design with 1 MHz hopping channels;
- omnidirectional antenna; and
- choice of an encoding method permitting operation up to 4 Mb/s (more likely 1-2 Mb/s) in the 1 MHz channel with asynchronous operation supporting a CSMA access method.

Each BSA is defined by a unique channel hopping sequence shared by all stations within the BSA. The use of different hopping sequences permit the construction of non-interfering, adjacent/overlapping BSAs. To-be-specified for this physical layer will be algorithms for a) the time and hopping sequence synchronization of all stations within a BSA, and b) time and hopping sequence coordination of overlapping BSAs.

This physical layer has the power restrictions of Part 15.247 limiting the characteristic diameter of a BSA in a typical building to several hundred meters, depending on the chosen output power.

It is possible to consider that the 802.11 committee petition the FCC to increase the allowed width of hopping channels from the current 1 MHz to 2.5-10 MHz (while still maintaining equivalent energy density) thus permitting 10 Mb/s communications without resorting to an overly expensive modulation method.

3.3 FCC Part 15.249 Low Power Radio

An alternative unlicensed radio media is the use of an ultra low power, less than 1 mW, CSMA radio channel under Part 15.249. Such a system would have the following properties:

- operation in the 2.4 GHz band (optionally 5.8 GHz band though cost would bias towards 2.4 GHz);
- multi-frequency channel design with several 10 -20MHz wide channels; channels are used to construct adjacent BSAs;
- omnidirectional antenna; and
- choice of an encoding method permitting operation up to 10 Mb/s in each channel with asynchronous operation supporting a CSMA access method.

Each BSA is defined by a distinct frequency with distance attenuation being used to permit frequency reuse. The use of different frequencies permit the construction of non-interfering, adjacent/overlapping BSAs. To-be-specified for this physical layer will be algorithms for a) the frequency synchronization of all stations within a BSA, and b) frequency coordination of overlapping BSAs.

This physical layer has the power restrictions of Part 15.249 limiting the characteristic diameter of a BSA in a typical building to about 25 meters. While this limited BSA size may appear to restrict the utility of this media choice, the omnidirectional transmission characteristics and inherent low power operation make this media choice attractive for portable stations particularly when used in combination with a wired backbone to construct a wider area EBSA.

3.4 Other Radio Spectrum

The previous media choices are based on existing regulation. Anticipating new spectrum allocation, perhaps in the 1.7 GHz to 1.9 GHz band, sufficient spectrum for multiple 10 Mb/s channels can be envisaged. Such a system might have the following properties:

- multi-frequency channel design with several 10 -20MHz wide channels; channels are used to construct adjacent BSAs;
- omnidirectional antenna; and
- choice of an encoding method permitting operation up to 10 Mb/s in each channel with asynchronous operation supporting a CSMA access method.

Each BSA is defined by a distinct frequency with distance attenuation being used to permit frequency reuse. The use of different frequencies permit the construction of non-interfering, adjacent/overlapping BSAs. To-be-specified for this physical layer will be algorithms for a) the frequency synchronization of all stations within a BSA, and b) frequency coordination of overlapping BSAs.

This physical layer has to-be-specified power restrictions limiting the characteristic diameter of a BSA in a typical building to a to-be-determined size. However, it is likely that a choice of omnidirectional transmission characteristics and low power operation will make this media choice attractive for portable stations particularly when used in combination with a wired backbone to construct a wider area EBSA.

IV. Media Access Control Protocol

Simple access methods are best when permitted by the requirements of the applications. Previous analysis of expected wireless LAN applications[3] suggest that these applications will be dominated by asynchronous, datagram intensive data usage. Experience and performance modelling for wired networks have demonstrated the adequacy and sometime superiority of CSMA based protocols for channel speeds below 10 Mb/s for this type of traffic.

This proposal is based on already defined IEEE 802 wired LAN standards, enhanced to include services unique to the wireless environment. These unique enhancements include: framing, security, robustness, EBSA interconnect and roaming.

4.1 Media Access Control Method

Carrier Sense Multiple Access protocols have the historical high-ground for wireless LANs, having been used in most prototype implementations over the past two decades and having demonstrated their effectiveness. Their performance has been well studied with well known advantages and disadvantages.

Advantages include:

- Implementation simplicity;
- Improved performance with smaller LAN diameter, larger average frame size, and lower LAN channel speeds;
- Low frame transmission delay at low to moderate traffic loads; and
- Low power operation possible since only when a station needs to communicate does it need to apply power to its transmit LAN interface;

Disadvantages include:

- Degraded frame transmission delay and throughput performance at extreme loads; and
- Variance in frame transmission delay at moderate to high traffic loads makes synchronous, real-time applications, where required delivery variance is comparable to frame transmission times, difficult at these loads.

There are four basic types of CSMA-type protocols differentiated primarily on the amount of information available to a station.

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[3]K. Biba, "Local Area Network Market and Forecast", IEEE P802.11/91-17, March 1991.

Aloha

Aloha protocols, strictly speaking, are not a CSMA protocol. An Aloha transmitting station, when it has a frame to transmit, will activate its transmitter, transmit the frame and await an explicit acknowledgement from the receiver. If no acknowledgement is receiver, the frame is rescheduled for transmission at a future time.

Under typical loads, Aloha managed channels have at most 18% of raw channel capacity available for user traffic.

Slotted Aloha

The performance of an Aloha managed channel can be improved through greater synchronization of transmitting stations. If transmitting stations are time synchronized so that channel transmission attempts are confined to quantized intervals (i.e. slot time) standardized across all stations.

Under typical loads, slotted Aloha managed channels have up to approximately 36% of channel capacity available for user traffic.

CSMA

Carrier Sense protocols dramatically improve on slotted Aloha performance by the simple technique of listening to the channel before a transmission attempt. If a frame is detected in the process of transmission (from another station), a station will defer its attempted frame transmission to a future time where the algorithm is repeated. Substantial variants of CSMA protocols exist that attempt to optimize performance.

Under typical loads, CSMA managed channels have approximately 80+% of channel capacity available for user traffic. In many LAN configurations, implicit congestion control provided by higher layer LAN operating systems protocols will throttle overall LAN traffic load so this level is rarely reached in practice.

CSMA/CD

Carrier Sense Multiple Access with Collision Detection further improve on CSMA performance by adding the ability to detect colliding frames and aborting the complete transmission of these frames. It requires that a transmitting station can simultaneously listen to the channel and effectively compare received data with transmitted data to detect corrupted frames.

Under typical loads, CSMA/CD managed channels have approximately 95+% of channel capacity available for user traffic. However, the wide dynamic signal range encountered in wireless systems makes implementation of CSMA/CD difficult without centralized stations within each BSA to equalize signal levels between stations.

Wired LAN experience yield several observations and "rules-of-thumb" about LAN load.

- All networks' performance degrade under heavy load and usually the network operating systems will provide for higher level congestion control - adjusting offered load in response to real response time and throughput.

- Most LANs begin to degrade when offered load approaches 50% of its effective load carrying capacity.

- The vast majority of LANs operate at very low load levels (less than 10% of capacity). For most LANs, typical congestion points are not the transmission media, but rather the performance of attached computers, particularly file server performance.

Available analysis suggests that wireless LAN applications will be an extension of existing wired LAN applications and the major opportunity is the support of wireless LAN access for mobile, handheld computers using successors to today's industry standard network operating systems. It is expected that many BSAs will be small in terms of number of station members, similarly to their wired cousins.

Therefore, for reasons of size, time-to-market, adequacy of services and simplicity of design (yielding power and size reduction), a CSMA protocol is recommended as an effective compromise between performance and implementation ease. The access protocol will include to-be-specified methods of frame backoff, retransmission and collision avoidance.

4.2 Framing, Addressing

The proposed architecture would use the general outline of the 802.3 framing structure. This has the additional advantage of permitting the use of existing silicon designs for 802.3 controllers as the core of 802.11 controller designs. The detailed symbol and frame synchronization coding is to-be-specified.

The proposed architecture uses standard 802.1 station addressing including broadcast and multicast.

If a frequency hopping Part 15.247 physical media system is used, the proposed standard may require a frame fragmentation and reassembly protocol for frames split across a frequency hop.

4.3 Security

A wireless LAN is susceptible to several threats to its security at the MAC and physical layers.

Interference	The presence of uncoordinated transmissions within a BSA have the potential to destructively interfere with a wireless LAN's operation and deny service to its stations. Depending on the nature of the interfering transmission and the wireless LAN design, such interference has the potential to have no effect, to increase the observed BER/FEC, and/or close down the operation of the wireless LAN.
Bandwidth use	Non-coordinated, overlapping BSAs unintentionally sharing bandwidth can deny service to members of both BSAs since the overall capacity and operation of both BSAs may be reduced.
Data theft	The availability of standard wireless LAN interfaces essentially increases the potential for "wireless Bearcat scanners" permitting both casual and intentional data theft.

Additional threats are possible at higher layers that must be dealt with at those layers.

Several possible mechanisms are available to provide protection against these low-level threats.

Regulation	Governmental regulations governing the proper usage of spectrum is the strongest protection against non-802.11 conforming transmissions within a BSA.
Distance	Attenuation due to distance adds additional protection against both 802.11 conforming and non-conforming transmissions interfering with LAN operation or with LAN transmission being improperly captured.
Coordination	Proposed 802.11 network management algorithms for coordinating adjoining BSAs can afford sufficient protection from unintentional interference from conforming 802.11 LANs. An essential component of the 802.11 standard will be the algorithms for providing this coordination.
Access Control	Protection from improper bandwidth use by stations not properly part of a wireless LAN can be afforded by a to-be-specified access control algorithm contained within a

proposed 802.11 standard. It is recommended that such a mechanism be incorporated within the standard.

Scrambling — Protection from casual data theft can be afforded by a to-be-specified simple data "scrambling" algorithm contained within a proposed 802.11 standard. This algorithm can be part of the above access control mechanism. It is recommended that such a mechanism be incorporated within the standard.

Encryption — High grade protection against intentional data theft can be afforded by the proposed encryption mechanisms specified by IEEE 802.10. It is recommended that 802.11 make use of 802.10 mechanisms for this high-grade protection rather than designing special purpose mechanisms within 802.11.

4.4 Reliability and Robustness

The wide range of uncontrolled operational environments is likely to have an adverse effect on BER and hence frame error rate. It is likely that the effective frame error rate, and hence the overall packet transmission delay, will need improvement over the raw, best-effort delivery frame datagram rate. Likely the best method will be an optimized, low-level, MAC positive acknowledgement with timeout and retry that minimizes the extra overhead of these acknowledgements compared to the use of standard Type II MAC layer services.

4.5 EBSA Interconnect, Roaming and Network Management

BSAs are interconnected via an EBSA interconnect to make an EBSA. The interconnect is "intelligent" - providing transparent MAC level routing of frames within an EBSA and to/from an EBSA and other interconnected LANs. The intelligence of the interconnect provides for self-configuration of BSAs into an EBSA, forwarding of station frames within the EBSA, forwarding of frames to/from the EBSA and other LANs, minimization of redundant frame transmissions, and support for station movement and roaming.

The architecture supports three possible EBSA interconnects:

Inband — An inband interconnect forwards frames between BSAs using the same physical media as the BSA itself. A regular array of BSAs are used to provide a structured interconnect.

Backbone — A backbone interconnect forwards frames between BSAs using an alternative physical media, generally a wired IEEE 802 LAN.

Promiscuous — A promiscuous interconnect forwards frames between BSAs using the same physical media as the BSA itself. Frame forwarding paths between stations within an EBSA are formed dynamically from stations within the EBSA that double as bridges.

These interconnects are implemented from the following LAN components:

Bridges — A bridge is an intelligent network component that provides frame routing services between a BSA and its interconnect.

802 LANs — Standard LANs are used within this architecture to provide the primary transmission medium for EBSA interconnect.

802.11 Protocols — IEEE 802.11 protocols provide for link protocol access control, frame transmission and reception, BSA configuration, frame routing within the EBSA between bridges and routing updates between bridges.

An overview of the interconnect architecture, roaming structure and routing protocols is contained below. A follow-on paper will describe in greater detail possible EBSA routing and roaming protocols.

4.5.1 Routing

Extensions to 802.2 provide for station transparent MAC level routing within an EBSA in support of transparent roaming and station movement and configuration. Two protocols are required:

1) between stations and bridges in order to determine which BSA a station is in and how to establish communications and

2) between bridges maintaining a database of stations and routes to stations within an EBSA.

Each bridge maintains a database describing the location and route to each station within the EBSA served by the bridge. The proposed routing protocols have two components:

intraBSA — Stations interact with bridges to determine which bridges are within range and their respective link quality. For destination stations within the same BSA frame transmission is direct. For destination stations that are within the EBSA, the bridge will provide frame forwarding services within the EBSA using the EBSA interconnect. For destination stations that are unknown within the EBSA, the bridge will provide forwarding outside outside the EBSA.

interBSA — As the station configuration within a BSA changes, the bridge(s) serving the BSA initiates routing updates that are then propagated to all bridges within the EBSA. The protocol provides for dynamic, distributed reconfiguration around failed bridges. Installation and configuration of replacement stations can be automatically performed.

Bridge performance can be quite fast if reception and transmission of frames can be pipelined. The bridge is only required to receive the destination address of a frame in order to have sufficient information to make a routing decision and begin frame forwarding onto the interconnect. Thus in the case of lightly loaded, 10 Mb/s BSAs and EBSA interconnects - a properly designed intelligent routing bridge may introduce as little as 2-5% additional average frame delay for typical traffic. Heavy loads on the interconnect will add additional queuing delay.

This EBSA routing architecture presumes that each bridge is aware of the current location of each station within the EBSA. It is limited w.r.t. the speed in which routing updates can be propagated through the EBSA. In practice this will be a function of the number of stations within the EBSA and the number of routing events/second - where the most common routing event is likely due to a station roaming from one BSA within the EBSA to another. Preliminary analysis of this routing event load suggests that EBSAs containing up to several thousand stations with up to 10-20% of this population simultaneously roaming can be accommodated.

4.5.2 Roaming

Station roaming is supported through the above provisions for routing updates. As a station roams through the EBSA, it is continually updating its routing database - as are the individual BSA bridges. As a station moves from one BSA to another, it will no longer be "heard" within the previous BSA and will now be "heard" within the new BSA. The new BSA bridge, as well as the old BSA bridge, will initiate a routing update recognizing the shorter route to the now local station. This routing update will propagate throughout the EBSA within a short period of time. While some frames may be lost while roaming, particularly when crossing BSA boundaries, the persistence of the higher layer protocols should retain communications integrity. Further, the volume of routing update traffic - assuming modest numbers of concurrently roaming stations (say 10-20% of the total number) - seems acceptable.[4]

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[4]The rate of routing updates due to roaming is related to the characteristic BSA dimension as well as the speed of roaming station. It is indeed fortunate that environments that support fast rates of change (e.g. outdoors) also support a greater characteristic BSA dimension. For example, a jeep

4.5.3 Inband EBSA Interconnect

An inband EBSA interconnect uses the wireless transmission capability itself to forward frames between BSAs.

Between adjacent, overlapping cells are placed bridges consisting of BSA LAN interfaces to each of two BSAs. Bridges are placed so as to forward packets from stations located in one BSA to stations located in other BSAs. Communications between stations within the same BSA occur directly without bridge assistance. BSA dimensions are such that the range of a bridge covers all stations within the entire BSA. In practice, due to the necessity of overlap to keep continuous coverage the characteristic BSA dimension is about .75 of the physical media range.

The multiple transmissions needed for radio relay will substantially decrease this maximum capacity, perhaps by at least a factor of 2, to a lower effective capacity[5]. This will be further exacerbated in single frequency plans by adjacent cell bandwidth cannibalization by bridges.

The inband architecture provides the infrastructure to insure that as long as a station remains in range of a bridge it will be able to initiate communications and will be able to maintain that communication, even while in motion, as long as the station remains in range of a least one bridge.

Further, the inband architecture provides for multiple routes from one cell (and its currently resident station population) and another BSA. This redundancy makes the inband architecture exceptionally resistant to single and multiple bridge failures, and interference.

The principal incremental cost of this architecture is the bridge infrastructure. Expected indoor BSA dimensions of 50-100m and bridge costs of $1-2000/bridge yield an expected EBSA interconnect infrastructure cost of about $.25/m^2.

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traveling at 100 km/hr will require about 18 seconds to traverse an outdoor BSA with characteristic dimension of 500 meters. Similarly, a person walking at 10 km/hr will require a similar time to traverse an indoor BSA with a diameter of 50 meters.

[5]Calculation of effective capacity is a complex one. It requires assumptions about the distribution of traffic (intra-cell versus inter-cell) as well as media propagation assumptions. Subsequent analyses and measurements will be required.

4.5.4 Backbone EBSA Interconnect

A backbone EBSA interconnect uses an external transmission capability to forward frames between BSAs. In almost all cases it is anticipated that this capability is another IEEE 802 compatible LAN.

Each BSA component of an EBSA has a dedicated bridge serving the BSA. Stations within a BSA are always within range of the bridge. If two communicating stations are within the same BSA, they transmit directly without the aid of the bridge. If in different BSAs, the respective bridges - through the backbone LAN - will forward and deliver the frames.

Each bridge has two communications interfaces: one to its BSA and the second to its backbone LAN.

The routing of transit traffic "out-of-band" through the backbone recovers substantial capacity used in the inband architecture for trunking frames through the array. Further, the use of the backbone substantially decreases network delay through the "short-cut" of the backbone since all interBSA frames are always 3 hops. These latter advantages are so substantial as to strongly recommend the backbone architecture whenever it is possible to construct a wired backbone.[6]

The backbone topology limits EBSA robustness to the reliability of each BSA's bridge and the reliability of the backbone - both possible single points of failure. Of course, it is relatively inexpensive to provide redundant backbones, and the loss of a particular BSA's bridge only impacts that BSA[7] and sessions originating or terminating within that BSA.

The principal incremental cost of this architecture is the bridge infrastructure and the wired backbone interconnecting them. Expected indoor BSA dimensions of 50-100m and bridge costs of $1-2000/bridge (similar to today's bridges) yield an expected EBSA interconnect infrastructure cost of about $.25/m^2. Of course, integration and high volume production of these bridges could substantially reduce the manufacturing cost of these bridges.

[6]Factories, runways, buildings, etc. are all prime candidates for the wired backbone plan.

[7]Further, redundant BSA bridges can be configured.

4.5.5 Promiscuous EBSA Interconnect

Promiscuous EBSA interconnect means that each station may act as a bridge to forward frames to stations that are not in mutual direct radio range but are each in range of the given station.

BSA dimensions are on the order of physical media range but with no regularity. Each station acts as a bridge on a "catch-as-catch-can" basis.

The same routing algorithm applies. The path taken by a frame depends on the momentary configuration of the interconnected stations. Station roaming will cause routing updates. The lack of an organized array of cells makes continuous coverage for roaming stations impossible to provide. Gaps and connectivity drops are likely, particularly for roaming stations.

No additional bridges are required since each station also acts as a bridge. Hence, there is no increased infrastructure cost. The lack of a structured interconnect and BSA layout does increase the likelihood of communications outages.

Further, the non-regular array will often result in cannibalization of bandwidth and redundant frame transmission. This can substantially reduce effective LAN capacity. As for other configurations, each frame forwarding will result in 5-20 msec of increased end-to-end, one-way frame delay. However, the total amount is hard to predict and is dependent on the particular configuration.