IEEE 802.11
802 LAN Access Method for Wireless Physical Medium

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TITLE: "MORPHING" THE DFWMAC INTO AN INTEGRATED SERVICES "SAM" (SEQUENTIAL ASYNCHRONOUS MAC)

INTRODUCTION

A more acceptable medium access method (SAMAC) could be derived by starting with the DFWMAC making successive changes which ultimately provide a valid system. Possible steps in this process are shown in Table I. Examination of these steps suggests that there are important differences in basic assumptions and priorities which must be addressed as well as the form of the technical changes.

It is descriptively more efficient to pick the major areas of difference in assumptions, concepts and execution and address each of these directly. The end result will be little different than the SAMAC which has been previously described to 802.11 (see Footnote 8).

Primary Assumptions

The primary assumptions used for SAMAC are mostly different from those of the DFWMAC, and are as follows:

1) 100% coverage of large areas must be possible for both packet and connection-type services.

2) The PHY is a single high rate channel with all separation functions accomplished by time multiplexing.

3) Autonomous ad hoc groups are permitted where there is no infrastructure, and may be optionally supported or allowed when infrastructure is present.

4) The services provided are 802 LLC compatible packet LAN and N x B channels of virtual circuit service all with specified worst case transfer delay across the wireless network.

5) The primary mode is at least an elemental BSA[1] is supported by a single AP (access point) and managed by a PCF (Point Coordination Function) independent of the physical location of the AP.

6) The composite coverage area of many BSAs is an ESA which is managed by an added ECF (Extended-area Coordination Function), and within which each user station has a single network address to external sources regardless of location. The composite of all system users is an ESS.

7) To provide a capability of meeting or coming close to the target access and transfer delays described in IEEE 802.11 user survey evaluations.

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7) To provide a capability of meeting or coming close to the target access and transfer delays for both synchronous and asynchronous services described in IEEE 802.11 user survey evaluations.

8) A high capacity in Mbps/hectare is required for systems proportional to any given medium transfer rate.

9) The radio criteria for communication is that the desired signal is sufficiently above interference level to enable accurate transfer, and that some set of interference-based criteria may inhibit transmission considering particularly the status of independent co-users of a managed channel.

Tabulation of Major Changes Required

These criteria require a reversal of the position of the DFWMAC on primacy of peer-to-peer autonomous mode and distributed coordination function, and the addition of a planned approach to interference-limited radio system design. Frequency, time or code division channelization to solve overlapping coverage and frequency reuse problems is also excluded.

These criteria optimize: **station simplicity, power drain and stability of function** as well as maximizing capacity and minimizing delay in the communication services provided. A goal is to make changes to the DFWMAC as required to conform to these criteria.

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1 "An Introduction to IEEE 802.11 Concepts and Definitions," D. Bagby, IEEE P802.11-92/66, Jul '92. This is the source of logical descriptions and terminology of the wireless network architectures used.

Table I -- "MORPHING" THE DFWMAC INTO AN INTEGRATED SERVICES SAMAC

1. Start by redefining the existing contention mode as secondary for use by spontaneous autonomous groups -- only where service is not available from existing infrastructure.
2. Define as a minmal primary mode (that which is non-optional) one where all stations in a cluster work through a common repeater with privileged antenna. Destination stations receiving a source transmission directly may ACK to inhibit unnecessary repetition. It is no longer necessary for all stations to hear all other stations. The CSMA access method remains, and the 4-step RTS, CTS, Xfr. ACK becomes mandatory rather than optional.
3. Delete any form of channelized PHY (e.g. FH) by using time/capacity sharing rather than frequency as a solution to overlapping radio coverage. Accept that contending repeaters must time share.

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4. Activate a PCF function at the AP (formerly an enhanced repeater) which substitutes a transmit enabling message for the station channel monitoring function retaining the 4-step transfer for station-originated transfers..

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5. Enhance the PCF function to include:
   - a. Delete frame, time slots and time partitions, and NAV function.
   - b. Replace with sequential asynchronous one-at-a-time complete transfers to reduce transfer delay from wait-states and status changes between transfer steps. This make the medium packet mode usable for connections as well as packets.
   - c. Background polling at one second intervals to:
     - i. determine a priori all associations and radio settings before a data transfer is initiated.
     - ii. manage sleep mode in stations with status available in PCF data base.
   - e. Association and screening functions
   - f. Segmentation for 802 LLC-1 traffic (at station and at any interconnection to external networks)
     - i. to limit time investment in faulty transfers and reduce length-proportion error probability.
     - ii. to enable capacity sharing under high-load.
     - iii to greatly reduce worst case access delay by providing more frequent access opportunities.
   - g. Retain and improve immediate ARQ function for flawed segments with reduced length repeats.
   - h. Add auto-grant/CTS message function for continuing segments of long packets.
6. Create ECF function to create common gateway for numbers of AP/PCF operated as a group, and to:
   - a. Create and support registration and security functions common to a system of APs.
   - b. Create and store addressing, internal route/association and status in a shared data base.
   - c. Provide common-point protocol conversion for external network interfaces.
   - d. Replace AP Search function with ECF function -- best AP selected without using channel time.

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7. Activate integrated services features including MAC level multiplexing
   - a. Create segmenter for connections and multiplexer to combine connection and packet segments for a common MAC and transmission medium.
   - b. Add auto-grant message function for continuing segments of connections.
   - c. Add D-channel packet function recognition directed to connection protocol stack.
   - d. Add prioritization and message type recognition to the PCF.

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8. Add capacity enhancement features to ECF
   - a. Add MAC level bridging between AP/PCF within one ESA.
   - b. Add diversity selection of redundant copies when associated path failes.
   - c. Implement smart sensing of internal interferers to transmit enable.
   - d. Implement dynamic positioning of capacity among contiguous AP/PCF.
   - e. Implement smart APs which have more detailed radiation control.

CONCEPT AND TECHNOLOGY MODIFICATIONS

Primary dependence on Point Control Function
Minimal station function for better system flexibility, ease of description and power drain
Implementation of Positive Control of Station Access
Use of MAC Level Multiplexing
Transaction-at-a-time Sequencing
Addition of the ECF (Extended-area Control Function) to manage AP selection and interior routing
Interference Limited Radio System Design with Managed Overlapping Coverage
Sequential Use of Overlapping Access Points

CRITICAL DETAIL OPERATING FUNCTIONS

Polling Function to Predetermine Station Status and Location
Resolution of Contention on Request
Sleep Mode Management via Polling
Capacity Rather than Time Reservation for Priority Services with Asynchronous Frame Structure
Space Diversity from Overlapping AP Coverage
Direct Peer-to-Peer Capability within Infrastructure-based System
Broadcast Capability

Adoption of these principles will result in major improvement of LAN performance for a 2.4 GHz DS PHY, and far greater improvement with better or high capacity PHYs in this or other radio bands. The proposed MAC is directly usable and interchangeable for optical wireless directed to the same area and functional service definitions. All of these matters are addressed in the following sections of this paper.

These changes are expressed more specifically in Tables II and III following.

Table II -- Property Comparison for DFWMAC and SAMAC in Primary Operating Mode

PROPERTY	IN THE DFWMAC	IN THE SAMAC, CHANGED TO
All properties below apply to *PRIMARY MODE* for both MACs		
Peer-to-peer	Primary mode--always available	Secondary mode--permitted only when PCF is unavailable.
PCF (Point Coordination Function)	Option, and only when "contention-free" services required.	Always required for permanent wireless access environment. Peer-to-peer transfer supported when destination can receive directly from source.
Channelization	MAC must support both NB multi-chnl with FEC and wider-band single channel. BSS only with single channel PHY. Overlapping coverage only available with NB channelized PHY.	Single channel operation only within one ESS (Extended Area Set). Overlapping coverage resolved by time division managed at ECF (Extended-area Coordination Function).
Request enable	Sensing of absence of carrier to enable	Enable following message from PCF
Request-to-send "handshake"	4-step = RTS, CTS, XFR, ACK in primary mode	After enabling message from PCF, 4-step
Contention on RTS resolution	Backoff algorithm	Poll only when required -- other methods possible
Settings for diversity, power, receiver thresh.	Made during preamble or setup of each transaction	Made during background polling with data kept in PCF and ECF as required.
ARQ	Try-again using same MAC with priority	MAC try-again provision is immediate.

Table III– Property Comparison for DFWMAC and SAMAC in Contention-free Service

PROPERTY	IN THE DFWMAC	IN THE SAMAC, CHANGED TO
For both MACs, all properties below apply to CONTENTION-FREE OR CONNECTION-TYPE SERVICES		
Area coverage	Limited to one BSA within an unspecified ESS that is cochannel. 100% area coverage requires FD channelized PHY.	100% area coverage with a single channel PHY.
PCF (Point Coordination Function)	Optional secondary mode for "contention-free" services.	Inherent and the same as for primary mode
MAC	Added and different than primary mode	Identical for primary mode
Request	Permanent polling algorithm managed at PCF. Association for poll uses primary mode.	Enabled following message from PCF
Contention on RTS resolution	Backoff algorithm	Poll only when required -- other methods possible
Settings for diversity, power, receiver thresh.	Made during preamble or setup of each transaction	Made during background polling with data kept in PCF and ECF as required.
Isochronous frame	Beacon timing broadcast, setup management and time allocation from added PCF.	Asynchronous access for packet transfers. Required timing management in PCF.
4-step sequence	Steps may be separated by "super" frame period.	All steps in one transaction are immediately sequential.
Integration of Services	Above periodically slotted PHY layer with separate slots for voice and packet services.	Above MAC layer--common packet MAC and PHY for all services
Segmentation	None described	Defined for payload range of 0-288 octets. 53 octets supported.

The target transfer delays proposed in the 802.11 Functional Requirements document are taken seriously, howver the nominal standard deviations given are not meaningful. The sum of the target median and standard deviation are taken as reasonable approximations of desired worst case.

Table IV -- Selected Results from Tables 3.5-3.8 in P802.11/92-20

Parameter	Asynchronous		Synchronous	
	Median	Std dev	Median	Std Dev
Nominal Transfer Delay	10	164	30	0
Target Nominal Transfer Delay	2	5	10	1
Units	millisec	millisec	millisec	millisec

CONCEPTS AND TECHNOLOGY MODIFICATIONS

Starting from the 802.11 approved "foundation" MAC (DFWMAC), a number of different technological concepts must be incorporated replacing some of those now in place. The key concepts and associated technology which make possible satisfying all of the above criteria consistently with understandable and low cost implementation are as follows:

Addition of the ECF (Extended-area Control Function)

By providing a place to resolve interaction between PCFs (Point Control Function logically associated with one BSS/BSA/AP), a number of important problems become soluble. These include the frequency reuse algorithm, use of redundant copies of received messages, dynamic and central updating of status and association between stations and PCFs, monitoring and time sharing for contiguous and unrelated systems and dynamic capacity division between BSAs.

There is no such function as ECF in DFWMAC, and so problems requiring this function cannot be addressed.

Implementation of Positive Control Through PCF

Stations may transmit only when enabled and immediately thereafter within the constraints of the MAC protocol. Station transmission only follows receipt of one of the following successfully decoded enabling message from the PCF via the associated access point:

1) Invitation-to-register/associate
2) Invitation-to-request (station service)
3) Poll (for station status)
4) Grant (CTS for data transfer)
5) End-of-transfer (for station ACK)

In contrast, DFWMAC uses measured amounts of absence of signal with a floating (adaptive) criteria for the level of activity which will be above threshhold. The measured amounts of absent time form a priority system. The algorithm for the practice of this criteria is in every station.

DFWMAC performs service type sort functions in partitions of a frame period for "contention-free services" where the time-position of the partitions is broadcast by the beacon and each station maintains counter/timers to select allotted time space. Where SAMAC sends an invitation message, DFWMAC sends a beacon reference in which there is a time interval for asynchronous request in the contention period, then a time offset measured out by the station after which the station may hear a grant or poll marking the instant at which the transfer may begin. Because of distributed logic and minimal dependence on the PCF, the DFWMAC must go through the multi-step handshake for both station originate and terminate messages using the contention-free period.

If the DFWMAC uses signal level for carrier sensing, a large set of problems arise from unrelated interferers and high usage radio system problems. If valid signal criteria are used the recognition and separation of valid signals will take considerably more time further increasing access delay.

Transaction-at-a-time Sequencing

Some previous protocols have used a 4-step handshake (RTS, CTS, XFR, ACK) but with time gaps between CTS and XFR or between other steps. The **first** way in which the present SAMAC differs from these is by adding a transmit enabling transmission before the RTS (IVT, REQ, GAT, XFR, ACK) to replace silence monitoring in the DFWMAC. A **second** way is that all steps in the transaction are completed without interposed time gaps.

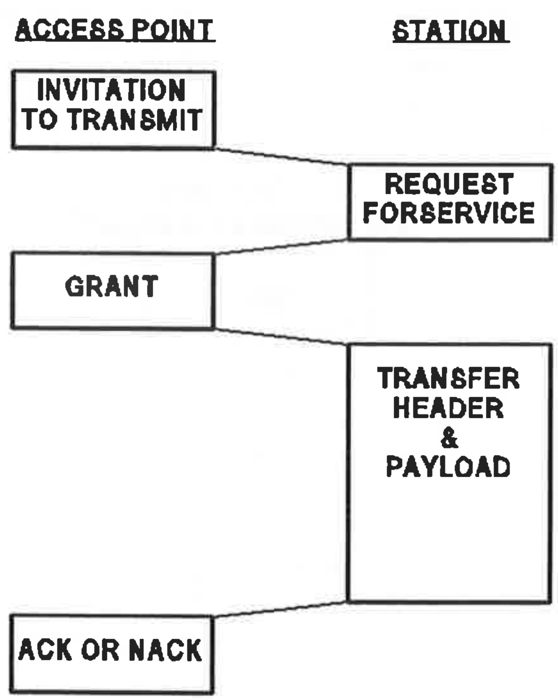

Figure 1 5-Step Handshake--Station Originate

The DFWMAC receives requests in the contention period and send grants at the beginning or during a defined non-contention period. One transaction may be distributed over one frame or more. The DFWMAC for contention-free space must have wait-states to bridge time gaps in protocol sequences.

A main distinguishing characteristic of SAMAC is that all transactions are completed in a single, uninterrupted sequence. There are no wait states necessary for the appropriate part of the frame to come around next time.

As a direct result of this approach, there is no fragmentation of unused time space making it unrecoverable. One way these space fragments are formed is when duration of transactions does not match the length of predefined slot boundaries.

A **third** way in which SAMAC differs is that the multi-step handshake is not required on all station terminate transfers as it is for DFWMAC in the contention-free services. Since the PCF knows which stations are ready to receive and what the backlog of traffic is for that BSA and station, the PCF may transmit to the station when it chooses using only a 2-step sequence (XFR, ACK). The 4-step handshake will be used for connections or long packets with setup information (short address assignment).

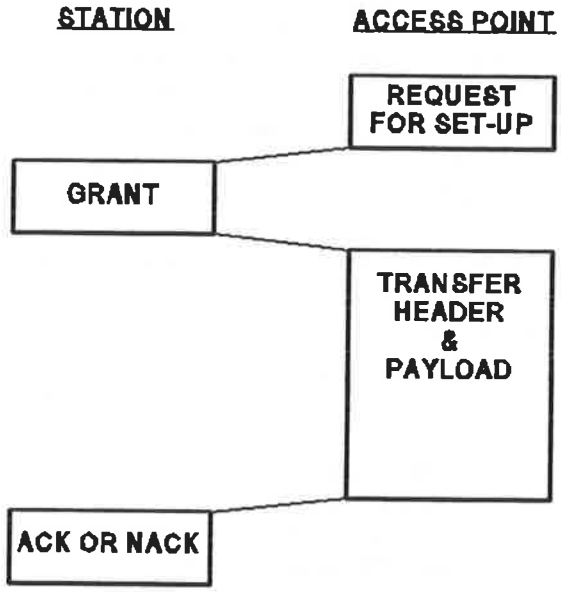

Figure 2 4-Step Handshake--AP Originate for Setup of Connection or Long Packet

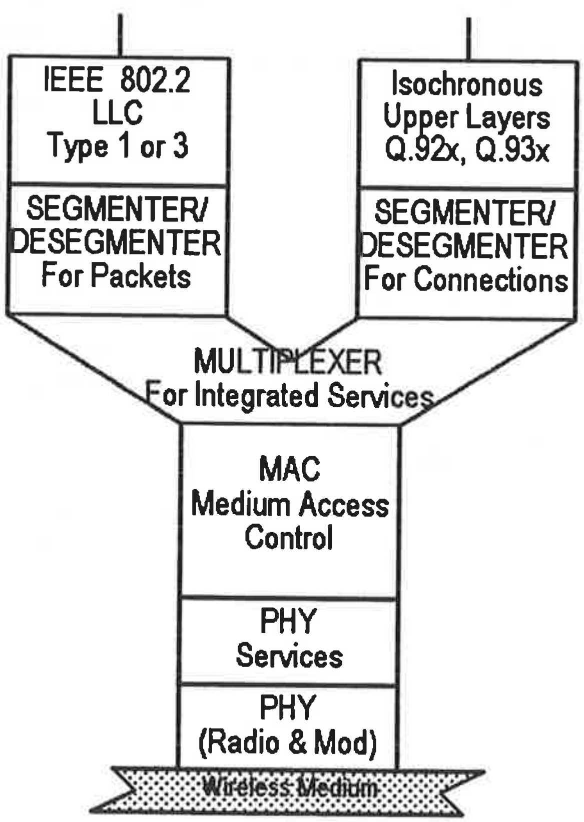

Figure 3 Station Protocol Stack for MAC Level Multiplexing of Integrated Services

Choice of MAC Over PHY Level Multiplexing

The choice between PHY and MAC level multiplexing in an IS (Integrated Services) LAN is fundamental. The DFWMAC is a PHY level mux, and the SAMAC is MAC level mux. The two possibilities are described as follows:

PHY Level Multiplex:

The physical medium is synchronous or isochronous with a periodic frame structure, usually an integer multiple of 125 µseconds. Portions of the frame are defined for 1) overhead and management, 2) packet services, and 3) isochronous or connection-type services. There may be other partition definitions than these such as up/down and contention free or not.

The processing for traffic in each partition can be processed independently and is not constrained by the protocol in the other partitions. There is no required commonality for the use of the partitions other than at the physical medium level.

Generally, PHY level multiplex is well suited to point-to-point mediums where clock synchronization is a small problem. It is difficult to make a synchronous system operative in the upward direction for a multi-drop (multiple transmitter) medium where different stations transmit consecutively at different times, however it can be done as illustrated by IEEE 802.6 (dual queue, dual bus).

MAC Level Multiplex:

The physical medium can be asynchronous without a periodic time structure enabling a packet medium in which clock is recovered independently for each transmission. This property allows multi-drop operation with multiple source transmitters on a common medium. It requires that the length of each transmission be bounded (<<infinity) to enable capacity sharing by multiple users with definable access delay.

Using a medium which is ***natively asynchronous packet mode***, there is a single MAC and PHY which is common to all offered services. The multiplexing of the high level separate protocol stacks for 802 packet and telecom isochronous services is above the MAC and below 802 LLC. The multiplexer must include the segmentation of connections and long packets into bursts with new headers for transmission over the shared medium.

Commonality of MAC for All Services

If only the Packet mode services are supported, everything for levels 1 and 2 is already provided without change in the station and in the infrastructure. It already is what is minimally needed for packet mode without baggage for the connection type services. An exception may be the segmentation provision, however this may prove to be essential anyway to limit time investment in flawed transfers and their probability. *This commonality of protocol for connections and packets not only saves cost, but will vastly simplify the production of the standard by simplifying descriptions which are necessary for the three types of access with interlocking states necessary to describe the DFWMAC.*

Avoiding Secondary Addressing for Time Offset Allotments

A major disadvantage of DFWMAC and all other periodic slot allocating MACs is that a secondary addressing system is created in which the address dimension includes a time offset from a broadcast (beacon) time reference. This adds a layer of factors which must be considered for time loss and the impact of failed functions. It is no small matter to create a new (and unnecessary) physical medium address space which must be managed by both ends of the transmission path.

A more subtle disadvantage is that the allotment of a time slot may require agreement from the station. The time offset is a fact which cannot be differently understood without the parties jeopardizing there ability to communicate. Moreover, the management of multiple connections makes the allocation of other than the default slot width a matter that interacts with all other connections on the same channel. It is particularly painful to complete a connection in one slot, and then have to move higher offset connections down to get a larger contiguous bandwidth for a wider band connection.

There is already a probability of a short address space in the extended set of users which might include pointers for path and long E.164 or 802 addressing. The definitions of address spaces and their scope was very well spelled out by D. Bagby.[2] In particular, the dimensioning of time offset as a form of path or addressing, is highly constraining on possible architecture.

Frequency Reuse, Overlapping Coverage and Interference Limited Design

For continuous coverage of a large area with many access points, these approaches are used:

Case 1 An intending user listens for quiet channel (or doesn't) and transmits a message to a known peer station within a local cluster. (DFWMAC with DS PHY). [3]

Case 2 A sufficient number of separate radio channels for access points (or user clusters) is used to cover the area in such a way that the reuse of a channel at a distance results in negligible interference. The radio channels may be derived by frequency, time or code division. (DFWMAC with FH PHY)

Case 3 One radio channel is used consecutively by the same number of access points as would be required to use different channels with channelization. (SAMAC)

For Case 1, the "hidden" transmitter is often described as the main impediment when it is actually the transmitter that is "unhidden" causing the channel to appear busy when communication would be successful for the particular destination.

Starting in 1963 and embodied in present cellular systems, there has been recognition that interference-limited systems, in which a clear channel rarely exists, is the only way a maximum use of radio spectrum can be obtained.

2 "Further Exploration of Transactions and Name Spaces," D. Bagby, AMD, IEEE P802.11-93/22

3 "Packet Switching in Radio Channels: Part I--Carrier Sense Multiple-Access Modes and Their Throughput-Delay Characteristics," and "... Part II--The Hidden Terminal Problem in CSMA and the Busy Tone Solution," L. Kleinrock & F. Tobagi, IEEE Trans. Comm., Vol. COM-23, No. 12, Dec 75

LBT/CSMA Reuse – Distributed Function

In May '92, Diepstraten[4] presented an analysis directed at taking into account a necessary signal-to-noise ratio based on experimental results with NCR DS modulation and simulation for propagation, distance and traffic. Using two clusters of users each operating as independent networks, he observed the aggregate traffic carried as a function of spacing between the clusters. When close or overlapping, the available channel capacity was divided. When sufficiently separated, aggregate traffic carried was slightly less than double the overlapping case.

Using his data, the conclusion[5] was drawn that a central cluster capacity was diminished by each contiguous cluster at a distance of 10 x the service radius of the central cluster about 10%. This corresponds to the geometry shown in Figure 4. To obtain this spacing between reused channels, would require 25 independent channels. If all clusters were on the same channel, each cluster would carry 40% of 4% of the traffic that it would carry stand-alone.

This amount of loss would be reduced considerably by the introduction of power control and adaptive threshhold techniques as later described by Diepstraten.[6] With this technique in place, a reuse factor as small as 16 might operate with moderate loss (25%) of capacity relative to standalone. This work pushes the CSMA MAC method as far as likely by skillful engineering.

Case 1 The CSMA MAC operating per-to-peer with a single wideband channel result in each cluster operating peer-to-peer will carry much less than 4% of its standalone capacity in a continuous area coverage.

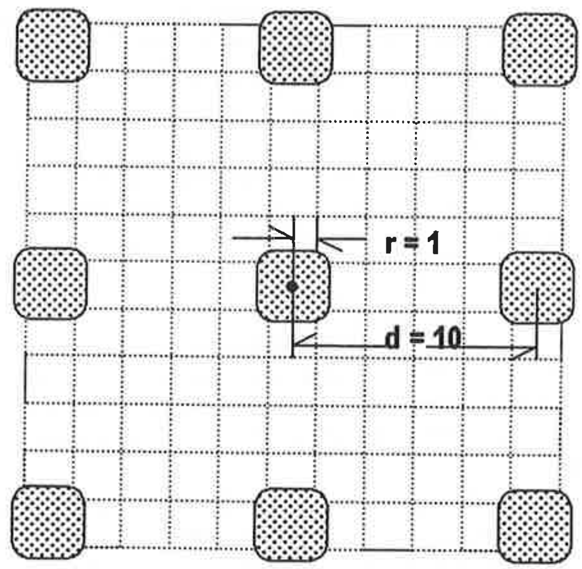

Figure 4 Location of Reused Channels with 25 Channel Plan

Case 2 Using a 19 channel frequency hopping PHY with optimal spacing of independent clusters on each channel, the capacity of each channel will be diminished to 40% of its standalone capacity from cochannel interference alone if this PHY were operable with the same signal-to-noise ratio as the DS PHY. Considering the increased signal-to-noise ratio required for narrowband, no-FEC channels, a minimum reuse factor of 36 is necessary. With 19 channels, each channels capacity will be reduced a further 19/36ths.

Some improvement was thought possible by Diepstraten for the case of client-server only radio paths. However he did not associate a different or better radio function for servers associated with access points so this difference is small. Putting the server antenna on the ceiling rather than a desktop would make a large overall system difference.

There is considerable unjustified optimism about radio reach. Consider one of the more informative contributions from Ishifuji[7] opinion that with SFH, Reed-Solomon FEC, 600 mw and QPSK, the expected reach is about 20 m. *Consideration of frequency reuse is absolutely unavoidable for coverage of any significant floor area even with artful PHY.*

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4 "A Wireless MAC Protocol Comparison," W. Diepstraten, NCR, IEEE P802.11-92/51, May '92. [This paper also deals with different LBT protocols, but is limited in generality because of unnecessarily long preamble assumptions]

5 "Discussion of NCR CSMA/CA Presentations at ... May 11-14 ...," C. Rypinski, privately distributed, 13Jun92 – Available on request. [File 1CSMA26C]

6 "The Potential of Dynamic Power Control," W. Diepstraten, NCR, P802.11-92/76, July '92

7 **"Retransmission Probability and Throughput of SFH in Rayleigh Fading Indoor Channel of Multi-cell environment," T. Ishifuji, Central Research Lab, Hitachi, IEEE 802.11-93/36 Mar '93**

Sequential Use of Access Points in the SAMAC [8]

Key assumptions of the SAMAC are:

1) at all APs, there is one and only one radio channel operating at maximized transfer rate.

2) two interfering or mutually exclusive APs are not used at the same time.

3) the default definition of mutually exclusive is that time is partitioned dynamically into a number of segments equal to the reuse factor each used at a different AP.

4) access points use privileged antennas so that the AP-Sta range is much greater than Sta-Sta. This means that BSA boundaries are defined by AP cochannel interference observed at stations and *independent of low probability Sta-Sta interference.*

5) The algorithm defining reuse factor and the definition of mutually exclusive BSS resides in the ECF (Extended-area Coordination Function) and is nowhere used in station logic or in the PCF associated with one AP/BSS.

6) The time interval which is allowed for consecutive transfers at one AP is limited by the defined worst case system access delay.

Important points resulting from the use of the above principles are:

a) diminishing station-station interference to a minor consideration.

b) retaining flexibility for the overall system design with unchanged station design.

c) keeping interference-limited system design considerations entirely out of the station.

d) enabling dynamic allotment of channel time to each AP based on traffic demand.

The DFWMAC contains no effective approach to interference limited design beyond recognizing interference from contiguous BSAs, and it will not be changeable by further evolution without affecting stations. A most basic reason is the dependence on maximally distributed logic including the attempt to move some essential infrastructure functions into it. It is in matters where the status of contiguous BSSs is significant to one PCF. When compared with the SAMAC function, it may be seen that distributed logic may foreclose important system improvements for the life of the standard, but which could be implemented if the improvements were only in a few places in the infrastructure and did not affect stations.

The SAMAC approach is to keep the station simple, and place all of the system time and space utilization algorithms in smart controllers in the infrastructure.

Separation of Independent Systems Using a Common Channel with SAMAC

This problem must be addressed in large part as a PHY implementation matter. A great deal can be done to separate coverages by the use of directive antennas and intelligent use of natural barriers. These possibilities were considered for two cases called "twin towers" and "shopping mall." [9]

This problem may be overstated for an AP based system near an autonomous system with a CSMA protocol. Because of superior radio performance, the AP system will be much less affected than the reverse.

Assuming two like-type systems, there will be areas where capacity-sharing is the only option. It is possible to develop automatic and adaptive methods of doing this with smart infrastructure. This function does not need to be in the Standard, and its description is therefore deferred until needed.

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8 The SAMAC access method was first described in the following contributions by C. A. Rypinski:

"Access Protocol for IVD Wireless LAN," IEEE P802.11/91-19, Mar '91

"Access Protocol for IVD Wireless LAN--Part II," IEEE P802.11/91-80, Jul '91

"Sequentially-Used Common Channel Access Method," IEEE P802.11/91-95, Sep '91

"Further Discussion of Detail Functions in the Sequential Asynchronous-access Method (SAM)," IEEE P802.11-92/31

9 "Independent Contiguous Radio LANs," C. Rypinski, P802.11/91-76, Jul '91

Capacity Comparisons

A criteria for comparing systems is the channel transfer rate for one BSA (cell) which gives a peak value. Of equal importance is the capacity per unit area which is a measure of how closely APs may be concentrated, the limits of which are not obvious. The estimates shown in Table V attempt to normalize both MACs to comparable assumptions. The Table is raw capacity, and therefore does not take into account protocol efficiency which of course is a bias toward the DFWMAC. It does show the effect of a plan for frequency reuse and a benefit for dynmaic capacity allocation between sites. The disadvantage of the narrow bandwidth is partially shown in the large reuse factor and the FEC derating, but the dead time for channel switching is not considered. The two center columns are quite level on the RF PHY.

The SAMAC advantage is quite large when its capabilities are fully used as shown in the right column. While the 50 meter reach of the DFWMAC systems might be typical (as a goal), it is expected the SAMAC would be much more used with shorter reach (15 m) and much higher capacity. (see Footnote 7)

Table V – Relative Raw Capacity of DFWMAC and SAMAC[6] in 2.4 GHz ISM Band

PARAMETER	DFWMAC	DFWMAC	SAMAC	SAMAC
PHY	1 Mbps FH	2 Mbps DS	2 Mbps DS	6 Mbps DS
Reach--mtrs:	100	50	50	35
AP Illumination:	Omni	Omni	Omni	Corner
Cell area--m^2:	20000	5000	5000	625
Reuse factor:	36 (19 chnls)	16 (3 chnls)	9 (3 chnls)	4 (1 chnl)
Raw cap/cell:	1 Mbps	2 Mbps	2 Mbps	6 Mbps
Raw cap after reuse factor:	0.528 Mbps/chnl	0.125 Mbps/chnl	0.222 Mbps/chnl	1.5 Mbps/chnl
Cells/km^2:	50	200	200	1600
Raw capacity--Mbps/km^2:	26.4/chnl 501.4/band	25/chnl 75/band	44.4/chnl 133.3/band	2,400/chnl 2,400/band
Dynamic cap'ty partition & gain:	no	no	yes 2:1	yes 1.5:1
Loss for 'Geiger'[2] channel coding:	x 0.4 (required for BER)	none	none	none
Adjusted raw capacity--Mbps/km^2:	10.56/chnl 200.6/band	25/chnl 75/band	88.8/chnl 266.6/band	3,600/chnl 3,600/band
Notes:	1, 2	37	47	5

Notes:

1. 19 channels available based on ±3 adjacent channels (76/4 = 19) taboo for contiguous peer-to-peer systems.
2. Channel coding is considered mandatory for narrow band modulations as per or equivalent to *E. Geiger, Apple Computer, "Wireless Access Methods and Physical Layer Specifications," IEEE P802.11-93/104*
3. Direct sequence is interpreted from current PHY group proposals and NCR presentations indicating 3 independent channels are derivable in the 2.4 GHz band. For comparison the capacity of all three sub-allocations is considered. Also the client-server propagation path only is assumed to reduce reuse factor.
4. Identical PHY and assumptions as for DS DFWMAC except that interference-limited design reduces reuse factor allowable. Adjustment made for dynamic capacity allocation between APs in one reuse group.
5. PHY is 3X the present proposed DS PHY providing 6 Mbps in one channel. AP illumination is quandrantal corresponding to room illumination from diagonally opposite corners, and providing redundant coverage of more than half the area. Adjustment made for dynamic capacity allocation between APs in one reuse group. Includes transfer success probability improvements from segmentation, diversity, PHY ARQ in lower reuse factor.
6. The Sequential Asynchronous MAC has been described and explained in many P802.11 contributions including: *C. Rypinski, LACE, "Sequentially-used Common Channel Access Method," IEEE P802.11/91-95, Sep '91 (also 91-19 March '91).* Since the above table is a "raw" capacity estimate, it does not take into account protocol advantages in the SAMAC from queued access upon blocking, *a priori path* and radio settings determination, and several other factors.

CRITICAL DETAIL OPERATING FUNCTIONS

The following DFWMAC detail functions require modification or replacement as described.

Polling Function

The main purpose of polling in SAMAC is to determine necessary a priori information required for the infrastructure to transfer data to a station. These predetermined affects avoid adding time for this process to the access delay system performance factor. In addition, the poll is used as the communication function for sleep mode management in stations. Poll is not directly associated with the channel access function.

A subfunction of polling is the opportunity for stations to associate. Primarily, this function will be limited to those users who are known to the database, though the system could be open to association with limited use privileges to unknown stations. The data base for an area is a function in an ECG.

Once associated with a network and an AP/PCF, a station can move from one BSA to another without repeating the association process. It is a duty of the infrastructure to select and refresh the selection of the associated AP/PCF for each station. The primary use of this information is to designate the AP and subselection for originating management and data transfer messages to that station.

In SAMAC, the purpose of polling is quite different from DFWMAC where it is used as a primary access method for "contention-free" services, and therefore must be very frequent. In SAMAC polling is a background function with compulsory answer. Departed and failed stations that do not positively disassociate are detected. The path to a station is update by the poll and possibly auto-switches the association to another AP/PCF.

Responsibility for measuring and comparing signal levels for a given station is an infrastructure function. The station needs no facility for determining the AP with which it should associate beyond the fact that the AP signal level is adequate for clock acquisition.

Resolution of Contention on Request

The SAMAC issues an IVT (invitation-to-transmit) message after which any station, whether associated with that AP or not, can request access for a specified service with an REQ message. At this point there is a possibility of contention. SAMAC does not provide an extended interval for use of staggered backoff to reduce the contention possibility though it could. There are various approaches to this problem in all MACs proposed:

1) randomized delay after enable
2) failure detect and then randomized backoff for retry
3) dedicated request time slots defined by AP frame structure
4) slotted Aloha request time slots and reservation transfer space
5) polling (or token passing) with contention type 2) to get on the polling list
6) failure detect and polling thereafter (SAMAC)

Only 3) "CODIAC" [10] is a certain solution (excluding overlapping coverage considerations). A somewhat similar scheme 4) [11] was described to IEEE 802.11 using slotted Aloha for the request interval followed by the reserved transfer space, but it is still probabalistic to save channel time for request slots.

The reason for not using polling directly or reserved slots is that considerable air time must be used for this function for which response is infrequent. Since the interval between polls of one station is a component of access delay, the frequency of poll is desired to be 20 milliseconds or less. The aggregate energy of continuous polling is also non-negligible in some circumstances. The 3) and 4) methods avoid transmit energy on the channel except when it is useful, and so they are a valuable improvement.

The DFWMAC in the contention period uses 2) and for contention-free uses 5) above. This is a disadvantaged combination either for minimizing access delay or aggregate transmitted energy. Polling is also undesirable for its impact on channel time sharing for the contention-free period.

10 "The CODIAC Protocol--Centralized or Distributed Integrated Access Control, A Wireless MAC Protocol," C. Heide, Spectrix, IEEE P802.11-93/54

11 "Analysis of a Wireless MAC Protocol with Client-Server Traffic," R. O. Lamaire et al, IBM Research Division--Submitted to INFOCOM '93 and copied to IEEE 802.11 July '92

Factors governing preference are the assumptions about the number and frequency of access request polls. Also *the longer requests are accumulated, the greater the probability of contention on request.* Generally, most systems assume more users per access-point than does SAMAC.

For SAMAC, there is considerable weight given to minimizing access delay. Since contention is an infrequent event that can be made even less frequent by minimizing time between opportunities, contention is allowed to be possible on the first try. Contention on first try can be unfair, since the radio capture will process a stronger signal when two signals are present. However, the unsuccessful will have another opportunity within a short interval. While it is imaginable that a weaker signal could be perpetually at a disadvantage, the amount and format of traffic requests that it would take to do this is not imaginable. A station that thinks that is locked out would also have the possibility of using another access point or requesting in response to a poll.

SAMAC may use artful methods to discover contention-on-REQ which do need to be described to understand the plan. Nonetheless, when REQ contention is observed, SAMAC is able to go into a poll of those stations associated with that AP/PCF. The poll sequence and its makeup are not random. At a PCF or ECF there is a great deal that can be done to order the poll by probability of activity and proximity. It is thought that this capability will be rarely used.

Sleep Mode Management

It is imperative that the ECF/PCF knows the sleep mode status of a station before sending a message to it. This is not a function that can be distributed. Now defined are two levels of sleep:

- deep: specified for sleep states of greater duration than one second--requires 250 milliseconds or more to activate from command. Near zero battery drain.
- light: specified for sleep states lasting less than one second--requires less than 10 milliseconds to activate from command. Battery drain low.

Light sleep is required, and is used for power saving during activity. Deep sleep is for associated but otherwise inactive stations. A station can be awakened by the user at anytime considering the two different response times. Generally, screen blanking would be associated with light sleep. Sleep mode in the wireless function is managed by the PCF except for station defaults.

Each time a station is polled, it is sent a parameter specifying the time interval that it may sleep after which it must wake up and be ready for any normal transmission but most likely to be another poll. The AP is not obligated to send the next poll precisely when the station wakes up, but must send it within one sleep period after the station is scheduled to awake.

An active station might be allowed to sleep 500 milliseconds, and an inactive station might sleep 15 seconds between polls. This parameter is at least configurable and is assigned by the PCF. There may be default parameters in the station which is a subject for further consideration.

A further default parameter is how long a station must stay awake following a transmission or receipt of message. The obvious answer is until it is next polled, however other choices may be desirable.

What cannot be considered is a low current receiver which initiates wakeup on detection of received carrier. In high density contexts, such a station would never sleep.

Capacity Reservation for Priority Services

The PCF for DFWMAC and all other *MACs which use a PHY level multiplexing reserve a periodic time allocation for the use of the medium.* The time position of one allocation at times will interlock with other contiguous time allocations. In some cases the reserved time will not always be used, and this time is lost. The consequences of a failure of formal disconnect can seriously impair the system capacity.

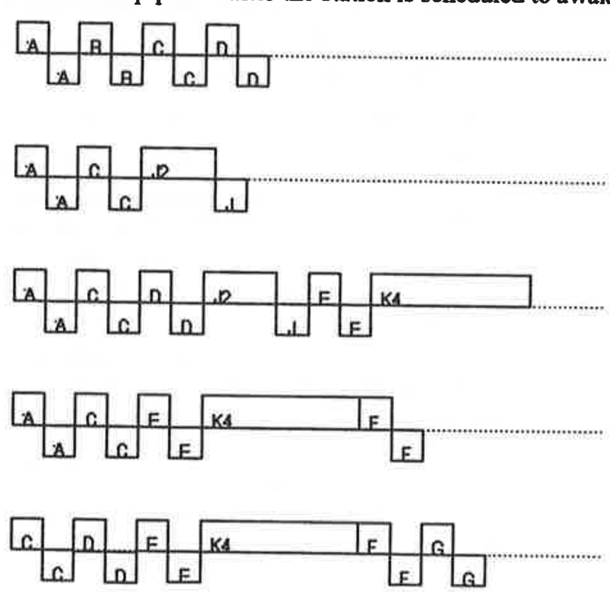

Figure 5 Use of Reserved Space in Consecutive Frames. A, B, C, E, F, G normal BW, D half rate, J2 double rate down, K4 double rate down only.

The PCF for the ***SAMAC reserves capacity for the next and following asynchronously periodic bundles.*** In the presence of a number of reserved capacities, each bundle transfer can be accomplished sequentially without a reconfiguration problem.

In figure 5 above, the frames shown are representative of intervals of 6 milliseconds -- the period of 48 octet payload bundles at 64 Kbps. Higher rates require either more frequent or longer transfers. Fractional rates would use less frequent transfers of normal bundles. The alternating appearance of the D channel symbolizes half rate. The J channel is double rate to the station and normal rate back. K channel is to the station only at quadruple rate.

The left boundary is the beginning of availability at an AP where the PCF works off the backlog in order of priority starting with the reserved capacity functions. The right boundary can be both the maximum reservable capacity and the upper limit for delayed transfer. The plan is dependent on requiring bundles to be delivered with a worst case or maximum access delay. The conversion back to a continuous bit stream is now addressed.

Virtual Circuits from a Packet Medium

Radio transmission requires that transfers be in bundles large enough to dilute out overhead and short enough for acceptable access and transfer delay. Their are hardware advantages in buffer memories if there is a normal fixed length and the possibility of integer multiples for better handling of long packets and higher bandwidth connections.

The problem is defined as packet transfer from a continuous isochronous bit through the wireless network and back out as a restored replica, but with a fixed delay. The example in the Figure below is for an 8 Mbps medium and a 64 Kbps circuit.

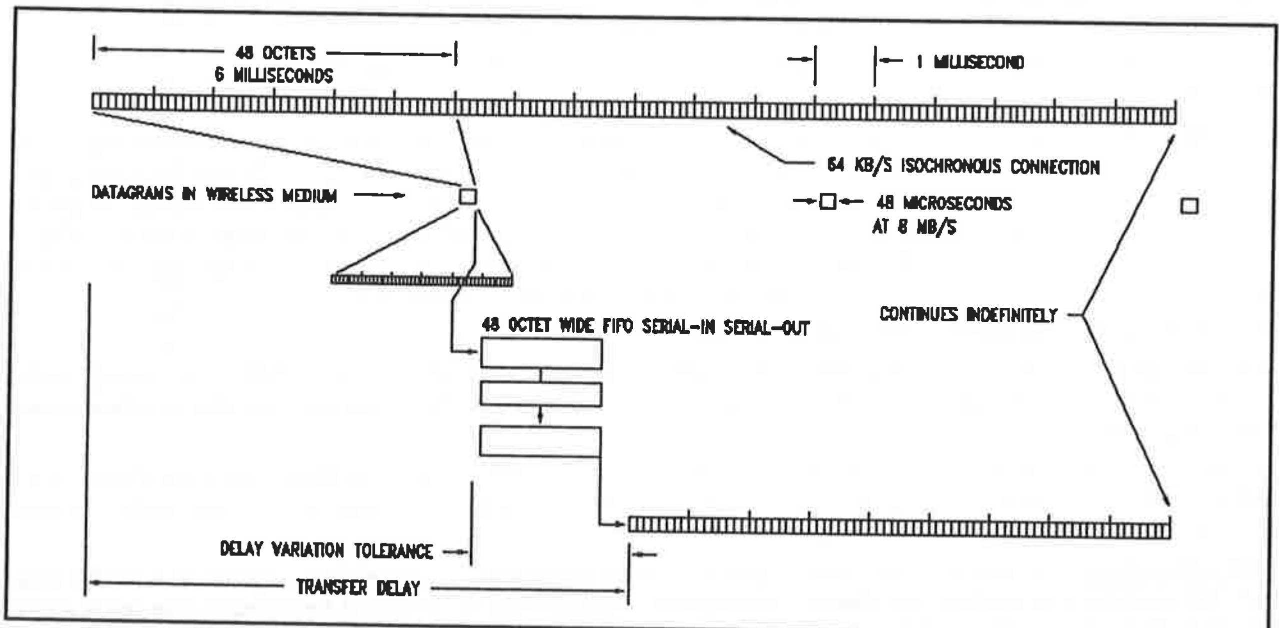

Figure 6 Diagram showing 48 octet sized packet transfer of an isochronous data stream of 64 Kb/s over an 8 Mbps medium to approximate scale. (Figure taken from P802.11-92/31)

After accumulation over 6 milliseconds for transmission, the 48 octet bundles require only 48 μsec for transmission over the radio medium once access has been gained. The starting position of the small block is positioned at the earliest instant at which it could be transmitted. The end of the FIFO blocks are shown at the last instant at which the block could be received and used. The difference between these instants is captioned 'delay variation tolerance.'

As shown, 3 milliseconds of permanent transfer delay is built-in to provide tolerance for up to 2.4 milliseconds of variation in the arrival instant of the bundle received at the FIFO (or 48 octet wide UART). This tolerance is represented by the width of the FIFO blocks. The readout of the last stage shift register of the FIFO is normally controlled by the clock at the using point.

The radio system can pass precise clock if the PCF/ECF is connected to a precise telecom facility. Each receipt of a bundle is a trigger for the transmission of a bundle. This trigger can be averaged to crank out long term error buildup over a period of several seconds, given an accurate station clock.

The possibility of loss or addition of a 48 octet block from timing difference must be minimized by adequate buffering. The slip provisions in SONET react to slip of ± ½ bit. In this case, slip does not need to be considered until the offset is at least 4 octets (32 µsec @ 1 Mbps) after which it uses up some of the delay uncertainty margin. Slip will not occur until all of the margin is consumed which will can occur at up to 24 octets. A station clock error of 2.5 PPM will slip 2.5 µsec/sec. It is important to lock the rate of a station clock to an isochronous source at standard rate within 10 seconds. Occasional loss of an bit or octet is not important to an uncompressed voice only service, but it is to digital applications.

Space Diversity from Overlapping AP Coverage

It is inherent in a system with 100% area coverage that stations will be received part of the time at two or more APs creating duplicate copies of the same message. If the PCFs are linked through an 802 backbone LAN, it automatically required that copies of a message from a non-associated station be deleted regardless of the success of that transfer at the associated AP.

It is probable that SAMAC systems will be designed with deliberately overlapping coverages as for example when APs illuminate a room from two or four corners. The redundant coverage provides space diversity reception of station transmissions with combining at logic level.

If the outputs of all PCFs are assembled at a common point where the ECF is operating it is possible to sort and classify all accurately received messages from non-associated sources. Those that are from a station associated with another PCF may be checked against the storage at the home PCF and replaced by the valid copy if there is not one there. This mechanism will allow an ACK for a message received only at an alternate AP.

An association or registration message can be processed from any point at which it is received

Direct Peer-to-Peer with Infrastructure

In SAMAC the concept of direct peer-to-peer is not a requirement but a convenience when the destination station can hear the source station directly. By direct ACK, the destination can inform both source and PCF that the message has been received directly. That ACK inhibits the retransmission of the message by the AP that would happen otherwise. There is some potential for this happening between stations which are geographically close but are members of different BSS. It is then possible for the ACK of the destination station to be unheard by the associated AP, and a redundant message will be sent anyway. It is possible for the station to recognize such redundancies.

Support of Spontaneous Autonomous Mode in SAMAC

This function is different from direct peer-to-peer capability which is supported within the SAMAC in primary mode, though it is expected that such groups will also use peer-to-peer. There are two cases corresponding to infrastructure absent or present.

In either case essentially the same message set and protocol (less the invitation and association/registration function) are usable. With no infrastructure, it is expected that offered traffic in the autonomous group will be a tiny fraction of what would be present in a loaded business system.

With infrastructure, a handful of users might operate in Aloha mode with accommodation occurring in a limited area with the error recovery mechanisms inherent in the system. Alternatively, the owner of the infrastructure might allow the APs to be used as repeaters only by stations that can associate but not register (visitors).

Without infrastructure, it is possible for a first station to provide a minimal PCF function acting as an AP. It is also feasible to simply use Aloha. A by-product of operation without an AP may be much more difficulty in defining a sleep mode for the station.

Broadcast

A broadcast message must have bounded scope not exceeding that of the ESA. At this maximum, it will be transmitted from every AP but not necessarily at the same instant. Stations originating a broadcast message will address transmit to the ECF for distribution. For ACK, it is possible for polled stations to list broadcast messages received since the last poll.

CLOSING COMMENT

Many points in this paper that appear to be the Author's opinion are really the teaching of decades of experience. Matters such as avoiding action based on absence states, simplifying the station by placing system algorithms in infrastructure, and basing coverage on an access point with a privileged antenna are widely known and demonstrated facts on how best to do radio systems. The 802.11 Committee would do well to consider these matters for their substance, because the mistakes in these areas will be very costly if not avoided.