IEEE 802.11

802 LAN Access Method for Wireless Physical Medium

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TITLE: **EVALUATION OF THE DFWMAC**

NOTE: A draft presentation with this title was distributed to many active voting members of 802.11 in Dec '93. The January submission P802.11-94/12 was a summary in the form of bullet lists and slides. Certain misunderstandings of the operation of the DFWMAC appearing in these papers have been corrected in this paper in sections marked [revised]. New text has been [added]. This paper is offered as an attachment to the base contribution.

SUMMARY

The DFWMAC is deficient and flawed if measured against the stated objectives of the 802.11 Committee defined in its first year of existence. One approach to a remedy is to amend the requirements until there is a partial fit to the capabilities. To aid in further analysis of this assertion, many of the deficiencies are identified and described.

The general thrust of the points chosen, are those which are architectural rather than detailed. Examination of these objections will show fundamental philosophical differences with much of the constituency for the DFWMAC--specifically:

- ✗ The primary service requirement is not "peer-to-peer." More applications will generate traffic that is "client-server" oriented, and large gains may be made by taking advantage of this fact. This assertion does not exclude peer-to-peer for default or secondary use.
- ✗ Negative or absence of information cannot be used in a radio wireless system as a criteria permitting transmission without grave limitations on reliability and capacity
- ✗ Interference limited-radio-system-design including the accommodation of co-channel use is an absolute requirement for high spectrum utilization not met by any form of LBT.
- ✗ The DFWMAC is a PHY layer multiplexer with a separate MAC for each of the subdivision services, rather than a common packet MAC for all services.

Those who believe that this proposal must be adequate because of the constituency that supports it, may gain insight by examining these objections and by considering alternative philosophies described in contribution -- IEEE P802.11/94-13. These issues will be raised as long as this proposal is in the process of drafting and acceptance, so anticipation of these questions may result in earlier resolution.

EVALUATION OF THE DFWMAC

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EVALUATION OF THE DFWMAC[1]

Part I -- PROLOGUE

MOTION ADOPTING DFWMAC

The MAC subcommittee of 802.11 on November 11 voted 35, 30, 7 to bring the DFWMAC proposal as a "foundation" plan to the plenary for acceptance. The plenary acted on the motion below voting 43, 14, 4 (75.44, 24.56 %) to pass by 75%.

MOTION BY 802.11 PLENARY ON MAC METHOD -- November 11, 1993
The plenary session directs the MAC subgroup to accept the DFW MAC as the direction of the 802.11 working group.

1. **Proceed to study and enhance this proposal by vote.**
2. **Answer and resolve questions relative to performance.**
3. **When a subgroup has something that can pass by a simple majority, that it be offered back to the plenary session for 75% approval.**

This protocol was possibly accepted, when uncertain members accepted the advice of some respected committee members that the market window and the patience of the Executive Committee were passing. Because a number of competent 802.11 members believe that the principles of the DFWMAC are correct, this paper undertakes description of the inadequacies and consequences of this choice to motivate necessary major changes.

Non-responsive to 802.11 Functional Requirements

3.2 Point Coordination Function

DFWMAC optionally supports a Point Coordination Function (PCF) which can provide Contention Free services. The use of this PCF is restricted because it can only be used in certain environments.

The basic restriction is that a PCF cannot overlap with another PCF on the same channel, so sufficient isolation between multiple PCF's is needed. *This is because contention between multiple overlapping PCF's cannot be resolved by the* [this] *protocol. This will limit the useability of the PCF to either operation in a single BSS of an ESS, or to multiple channel environments that can assure sufficient isolation between neighboring PCF's.*

2 From page 27, 802.11-93/190 (*Italics for emphasis*) [author comment]

The emphasized statement is accurate. *This plan cannot provide its required services over a large percentage (99.9% required) of the service area provided by the contention service.* Even with the 15-25 channels that the FH PHY might provide for separation of coverages, this would only be enough to reduce the malfunctions to a minor proportion of transactions. If in their uncoordinated way the user clusters associated with these separate channels should fail to distribute themselves uniformly over the area, the condition in the box above would be violated with increased loss of capacity.

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1 "**DFWMAC** Distributed Foundation Wireless Medium Access Control," W. Diepstraten NCR WCND-Utrecht, G. Ennis--Symbol Technologies, P. Belanger Xircom; IEEE P802.11-93/190; November '93. See also 802.11-93/191, 802.11-93/192 and 802.11-93/193.

Consequences

Moving the proposed DFWMAC in its present form to the basis for a standard will probably have the following results:

1. The amount of time and effort to document this protocol in standards form is much larger than is either necessary or appropriate when compared with a MAC level multiplex.
2. Using present technical methods, the resulting system will be inadequate to unserviceable for:
   a. connection-type services because of: 1) undefined excess amounts of setup and transfer delay, and 2) interference or medium contention from contiguous user clusters within the same system; and for
   b. connectionless services requiring equivalence (within an order of magnitude) to 802 defined accuracy and transfer rate with the presently proposed PHY layers; and for
   c. sustainable user density and capacity demand levels limited to a decade or more inferior to infrastructure-based and interference-limited alternative system designs.
3. With large scale use, only the contention mode will have practical usefulness, and the remaining time-bounded and contention-free services will be unfulfilled promises..
4. If the system implements distributed adaptive power control and receiver threshold together, the system will degenerate into an Aloha protocol under medium to high load conditions making redundant most of the detail measures to prioritize and to minimize internal interference..
5. User cost will be higher than expected because of early inadequacy of function and consequent short useful product life.

Remedial Possibilities

To define not only a working system, but one in which the standards document can be drafted with achievable time and effort, the 802.11 committee should now take at least one of the following steps:

1. ***For those who believe that the capability of the CSMA portion is adequate, a remaining alternative is to delete time-bounded and contention-free services from this MAC-PHY carrying it forward as an interim plan for 2.4 GHz only.***
2. Undertake to convert the present plan to a usable plan providing true connection-type services and based upon well known principles of high capacity radio system design.

Further summary is given in the "CONCLUSIONS" of this document.

> It is very important that those who support this protocol should examine the arguments given. Some them involve extreme narrowing of the conditions under which adequate and predictable performance can be obtained. Others lead to such drastic limitations on capacity and to exposure to long setup and transfer delays that marketability can be questioned. The inevitable appearance of other more competent competitive systems should be considered. The capacity and spectrum utilization "gap" is at least a decade and probably much more--it is not ten's of percent.

Part II -- DFWMAC OPERATING CONCEPTS

The choices made on some of the fundamental matters below for the DFWMAC prevent the realization of a competent system plan:

1. Selection of the distributed control functions (DCF) optimized for peer-to-peer operation as the primary mode. The point control function (PCF) is then used only for functions that cannot be distributed rather than all of those for which it is advantageous.
2. No provision for interference-limited system design even for the non-contention capacity partitions.
3. Separate access methods for each of the three service types after physical medium multiplex/demultiplex. Two of these include polling in the distributed logic time space for access to the reservation type space.

After incorporating these conceptual points, a number of specific functional difficulties appear which are more specifically described in the following sections.

The conversion of this plan to one which is workable requires reversal of these philosophies and correction of the stated major problems. If this need is not accepted, the remaining minor improvements that are possible and desirable will still not yield an adequate plan.

SELECTION OF PEER-TO-PEER OPERATION AS PRIMARY MODE

Peer-to-peer, as used in the DFWMAC, is an architecture with maximized distributed logic--it is not a description of a necessary user service. The main difficulty of DFWMAC is defining peer-to-peer architecture for the primary operating mode, and then attempting to provide non-contention services by extension. In fact, the subframe time described as "contention-free" for both connectionless and connection-type service cannot comply with that description in a large scale system. Even within the limitations described, only the degree of interference/contention is abated.

The main difficulty comes from the add-on PCF (point coordination function) which does not provide all of the essential infrastructure functions though retaining most of the same disadvantages. Neglecting cost and complication, the attempt to distribute many of the inherent PCF functions to all stations results in creating many more opportunities for failure and increases access delay.

> **Tom Baumgartner: "Conclusions: For station-to-station traffic using a point coordination function to relay data is the most effective method by a factor of 2. For station-to-access-point-traffic the point coordination functions is about 4 time more effective than other methods."**
> **"The Watts per kilobyte-hectare method of evaluating wireless may not yield exact numbers but can yield ratios."**
> **"All proposals for battery power conservation, short of simply shutting down for a period of time, utilize a coordination function. Since power saving operation by the mobile station is so vital this alone presents an overriding case for a coordination function."**

3 From "A Measure of Performance: Watts per Kilobyte-Hectare," T. Baumgartner, Spectrix, IEEE P802.11-93/214, Nov '93

Autonomous Ad Hoc Groups

It has been agreed that autonomous ad hoc groups will be permitted. Any alternative must have this provision. The potential disagreement is about whether the proportion of traffic carried in this mode is: a) the preponderance, or b) a small part.

The extension of ad hoc group support to mean that any station can transmit whenever it believes the channel to be vacant, is unworkable and unnecessary in any area where an infrastructure exists. Stations can only transmit when granted permission from that infrastructure. If there is no infrastructure near enough to experience interference and to manage orderly access, then CSMA or LBT access may be used. The practical meaning is that if both forms are properly supported in the standard, the partitioning will be adaptively proportioned. The user will decide proportioning by how the stations and environment are configured.

Market Need for Peer-to-peer Services

The need for direct peer-to-peer is a different question than autonomous ad hoc groups though such groups may work in that mode. Even with infrastructure, direct peer-to-peer may be supported when stations are within necessary radio range. There will be some saving in channel time from avoiding an access point repeat. The market information that 802.11 has gathered has not shown that peer-to-peer is needed as a function. *Peer-to-peer seems to be a rallying slogan for those who find any form of common equipment abhorrent regardless of economic or functional benefits.*

In late 1991, large efforts were made to determine user requirements. One of these was a Committee-approved Questionnaire-type user survey implemented by NCR among some of its customers.[2] When the data was analyzed, ***no respondent reported a need for peer-to-peer operation.*** There was considerable use of departmental communication between stations and servers and between stations and external networks or host computers. *This result is not recalled to show zero need for peer-to-peer, but to assert that the dominant communication in companies makes little use of this pattern of traffic flow.*

> **Dale Buchholz:** "CSMA as an access method works well under light loads, either when the number of users is small or the applications being used generate little traffic. While this may be typical of 'quickly-created-and disbanded' work groups, it is not typical of some of the loads generated by some desktop applications that run on fixed or portable computers."
> "The trend is rather apparent: *as the throughput for a particular CSMA technique increases toward the maximum for that method, the delay increases exponentially toward infinity.*" [referring to Fig 9.23 from Kleinrock et al]

4 From "Comments on CSMA," D. Buchholz, Motorola, IEEE P802.11/91-49

Advantages of Making Client-Server Path Preeminent

An access-point related to a server cluster is an architectural configuration that corresponds to a large proportion of large scale business installations. Considerable advantage can be taken of the inevitable traffic concentration at the server ports. One of the most important is the use of an advantaged location for the access-point antenna. As has been described, the radio system performance is far better if all communication is to/from a server even without an advantaged antenna.

The DFWMAC acquires nearly all of the disadvantages of an infrastructure when it puts in place the "beacon" with PCF function for the asserted "contention-free" services without obtaining the major advantages then available. It is hard to imagine that the beacon function is simpler than an access point.

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2 "Analysis of Returns on 'IEEE 802.11 Design Goals Questionnaire P802.11-91/82B," C. Rypinski, March 92 (Questionnaire 91/82B by L. van der Jagt and C. Rypinski)

INTERFERENCE LIMITED RADIO SYSTEM DESIGN NOT IMPLEMENTED

The DFWMAC does not recognize the need for and limitations of interference-limited radio system design. An interference-limited system design (e.g., cellular) is one that maximally crowds together stations and access-points using and reusing a given channel. The transmission criterion is that the desired signal is sufficiently greater than the aggregate interference to allow successful communication. *This criteria is absolutely required to come within octaves of maximizing the capacity obtained from a given amount of radio spectrum.*

A 4-step handshake is a start in the right direction, since it includes a test of receivability at the destination address, but much more must be done. It is reasonably efficient applied to Station-originate traffic, and unnecessary and redundant if applied to Station-terminate traffic. Time separation between the steps of the handshake is harmful to performance.

These considerations were recognized and described by Diepstraten as shown in the following box..

"DYNAMIC POWER CONTROL POTENTIAL

- Problem addressed
  - Environment is <u>INTERFERENCE LIMITED</u>
  - In single channel environment, medium needs to be shared with a significant number of different BSA's
  - In multi channel environment a large number of channels may be needed for re-use isolation,
  - For large cells, need 6-10 channels
  - For small cells, need around 20 channels
- Proposed solution
  - Reduce the co-channel interference.
  - Limit TX Power level to a value needed for reliable reception.
  - Learn proper level per individual Destination.
  - Use Defer threshold as function of power level."

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

The statements made are generally accurate. If this level of knowledge were general and accepted in 802.11, a large step would be taken toward reaching agreement on a workable solution. However, his assertion that power control and adaptive thresholds are an implementation of interference-limited system design are in error.

In later parts of the same reference, Diepstraten introduces 20 dB of obstacle loss between cochannel uses. The obvious result is even greater isolation and independence. This use recognizes the value and need for isolation between clusters, and more particularly clusters with limited function PCF as previously described. Proper consideration of these factors for an interference-limited system design provides many octaves of improvement in system capacity, with much more effect than differences between the number of steps in a handshake for each transfer.

PHY LAYER MULTIPLEXING OF INTEGRATED SERVICES

When a common system is used for packet and connection-type services (integrated services = IS), the first decision is about the degree of commonality between them. The layer two and higher protocol stacks are inevitably separate, and the sharing of the physical medium is inherent in the definition. What can be chosen is whether the multiplexing of the two services will be just the PHY layer or both PHY and MAC layer.

A PHY layer multiplex is generally based on a fixed length frame time divided into subframes for overhead and management, connection-type and packet-type services. The packets are mapped into the available slots as a payload for the PHY layer frame. The internal boundaries can be adaptive. A current example of an IS PHY layer mux is the IEEE 802.9 standard.

The apparent model for the DFWMAC is shown below. It should be noticed that there is a recursive aspect where the information decoded in the received messages may change the dimensions of the frame structure.

THE MAC SERVICE MODEL

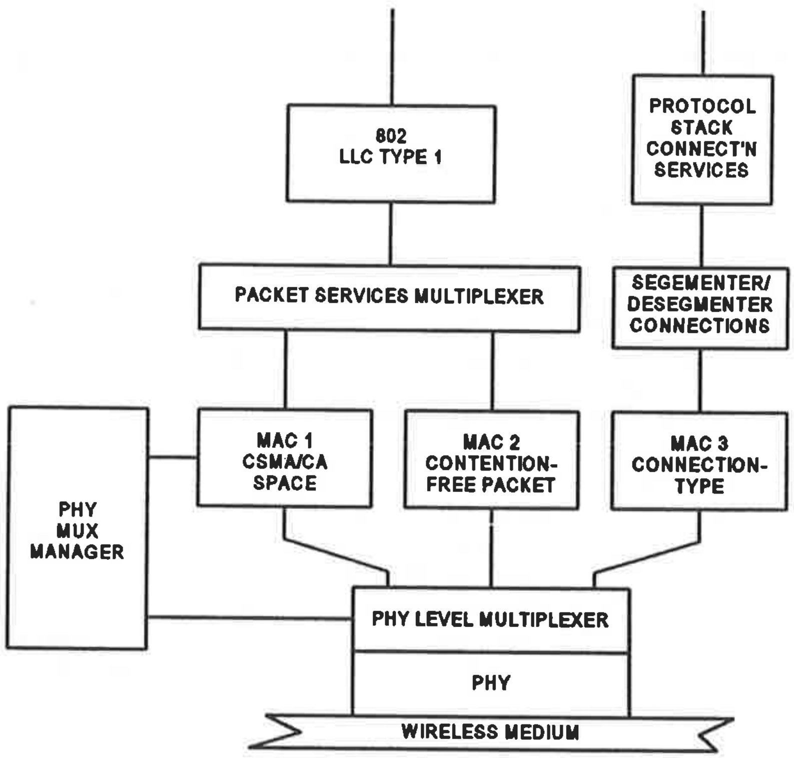

Figure 1 Suggested alternate diagram for the DFW Protocol Stack shown in Figure 3-5 of P802.11-93/190.

The different MACs must interact with each other. A fundamental problem is the interlocking of allocation events between the multiple services. Use of the acronym "time-bounded" provides the benefit of avoiding responsibility for limitations on setup and transfer delay and on lost segments that might be imposed if compatibility with well known telecom standards were necessary.

In a MAC level multiplexed protocol, the PHY and MAC are common above which is a MAC level multiplexer that assembles/splits the packet and connection-type services. The diagram for the MAC level mux is shown in 802.11-94-13. The implementation of a MAC level mux generally means that there is a packet medium and an access manager that can prioritize packets and reserve future capacity (not time slots) in response to service demands. This function cannot be distributed, and it cannot be efficient unless support of these functions is an integral part of the MAC design.

Part III -- PROBLEMS

Most of the following described problems arise from starting with the peer-to-peer form of CSMA, and then doing add-ons to expand the function to include non-contention and reservation services. *Under the next heading, three considerations are shown, each of which taken by itself is considered disqualifying.*

Early in its life 802.11 adopted a set of Functional Requirements that included delay, mobility and services factors. The DFW protocol and concurrent PHYs cannot meet these and other key parameters in these requirements. *The operational limitations that result from disregarding these requirements is addressed* rather than the legalistic argument around non-compliance.

DISQUALIFYING PROBLEMS

The PHY context is a 1 Mbps transfer rate. Adjustments may be made for necessary channel coding losses or a 2 Mbps physical transfer rate gain.

1. Absence of Frequency Reuse Plan--Need for ECF (Extended-area Coordination Function)

The mere assertion that additional channels will be used to create distance between the reference user cluster and the interferers is of little value unless associated with the effect on total capacity. The immediate conclusion is that the capacity will be reduced by a factor equal to the number of channels required (not used). Using data from the Diepstraten analysis, ***this factor is greater than 25*** *for Direct Sequence spread spectrum modulation with the benefits of channel coding discrimination and diversity already considered* and which are not present in the FH PHY. *Regardless of the number of channels used but considering the division of spectrum for 100% area coverage, the capacity per cluster is less than 4% of what that cluster would have in isolation using all of the spectrum available.*

This situation can be improved by adaptive power control and receiver threshold,[3] however it will be found that these two factors are at best an improvement, not a cure. To the degree that unnoticed interferers (because of high threshold setting) cause interference, the system is operating in "Aloha" mode.

If the system uses a single channel, then there must be a plan for that frequency to be reused. With multiple distributed user clusters, the capacity of one cluster must be shared 10 to 25 ways minimum.

With the current 802.11 *frequency hopping PHY* it is possible to have 15-25 conditionally orthogonal channels which potentially could make possible 100% area coverage. However, the DFWMAC would use these channels as separate unrelated and uncoordinated systems, probably each with its own beacon. There is no method offered to coordinate these N channels into one plan. It is possible that each access-point with its own bridge to a common backbone LAN is considered a plan, but this function is impossible without intelligence and data base common to all the access-points in addition to that which is for each access point. *One casual consequence is that external networks must use a different station routing address for each hopping pattern. Stations moving from one BSS to another will require updating of external routing tables.*

Without a frequency/channel reuse strategy, there is no possibility of acceptable reliability and spectrum utilization with near 100% area coverage on a large scale. *The reuse strategy must be implemented in a ECF managing that which is common to many access-points or depends upon status in contiguous BSAs.*

This deficiency applies to CSMA LAN in the uncontained medium where the consequences are diminished capacity and unreliable access to stations moving between (basic) coverage areas. It also applies to

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

connection-type services where the assignment of an exclusive slot within one coverage may be effective, but has no influence on the interference from surrounding coverages within one system.

Attachment A (last page) is a Table about *the capacity consequences of not considering frequency reuse. It is not about a protocol comparison. It is normalized for common data rates and modulation technology.* This Table is very optimistic about the capacity of an FH system in allowing simultaneous use of most of the available hopping patterns without considering intermodulation limits.

The Table compares raw capacity (before protocol overhead and traffic advantages from queuing of requests) of the DFWMAC with the FH and DS PHY and using the same or derivative PHYs for DS with the Sequential Asynchronous MAC--a proposal using interference-limited design and fully exploiting the advantages of infrastructure and extended area coordination. The peak transfer rate at a station is the medium transfer rate per cell. Capacity is sustained average aggregate capacity available to all stations before considering overhead from MAC functions.

This chart is exceedingly optimistic about the channelization capabilities of the frequency hopping PHY relative to DS. Like-signal cochannel interference is much more degrading to narrow than wideband modulations. The apparent advantages of the narrowband modulation is also reduced by intermodulation and other consequences of crowding many radios in a small space. Nonetheless, the differences are very large, and will have competitive implications in the market.

2. Use of Negative Information

The CSMA access method and the contention-free property of the non-contention frame subdivisions depends upon each and every peer station using ***absence-of-signals (ordinary, priority and DCF space content of RTS and CTS for NAV)*** *as a valid logic state* to enable transmission. The teaching of many decades of radio system design is that action can only be initiated upon positive presence of information as an enabling signal.

The nomenclature of "hidden station problem" is a symptom of a possible failure to understand the problem. The reverse case is the problem where a station is heard and presumed to be capable of causing interference, but would not. The term for sustained loss of channel time in this way is "busy-lockout." What may be less obvious is that while the frequency of invalid busy indications may be reduced in many ways, it can not be made so small that a system is efficient. This is an inherent limitation of the CSMA/CA access method in the contention period.

> **Dr. K-C Chen:** "We analyze the nonpersistent CSMA with imperfect sensing (thus hidden terminal) and overlapping cell coverage in infrastructure based wireless LANs. The results which have been justified by simulations show that CSMA delivers much lower throughput (unstable peak value) than known by traditional analysis."

6 From "Performance of Non-persistent CSMA with Cell Interference and Imperfect Sensing," Kwang-Cheng Chen, National Tsing Hua University (Taiwan), IEEE P802.11/93-195, Sep '93

The CSMA/CA priority scheme is wholly dependent on absence of signal apart from those defined and expected for its operation. It requires a near flawless channel status assessment function for it to work. If there are contiguous systems contributing background signal present indications, the function will lockout and be incapable of rendering the priority access functions. Since the PCF functions begin in the DCF space, the reservation type services are exposed to this type of failure, delay or loss.

3. Unacceptable Transfer Delay for Connection-type Services

Transfer delays of up to two superframe periods are inherent in this plan for the connection-oriented service. The primary cause is that received octets must be accumulated for at least one superframe period before the burst is available for transmission. On top of this delay is the delay before they can be transferred after the octers are available. This is many times the values which were understood as 802.11 objectives at the culmination of considerable effort in 1991 and of what is actually required.

Superframe Structural Delay

Using the stated superframe period of 20-30 milliseconds, it is possible to estimate the worst case transfer delay *assuming that there is no delay or loss from interference and contention (an isolated and below-capacity-loaded system).* The frame period assumed for estimates is 12 and 24 milliseconds. Zero delay for speech coding is assumed though this only true for minimal compression.

For one DFW connection, there might be at best one transfer per superframe. The quantizing delay (the delay necessary to accumulate the received octets into a bundle for transmission) is at best equal to one frame period. After the burst is ready, the worst case access delay is one frame period. While this delay may average half the worst case value, long delays will be common. Once the transfer delay is established by slot allotment at setup, it will remain approximately the same thereafter.

The worst case transfer delay for connections is then up to twice the frame period or about 24 or 48 milliseconds independent of transfer rate except as it influences frame period. To improve this value in the present structure, one step is to diminish the superframe length.

A further step would be to better interleave transfers for voice and data. This might be a benefit of using the same MAC for connections and packets abolishing the superframe and its associated delays entirely.

If the actual operation, allows successive transmissions for a particular connection to be spaced more than one frame, the problem described becomes even more acute.

WLAN Requirements of January 1992

The "Wireless Local Area Network Requirements[4]" document shows for all surveyed applications a nominal transfer delay median requirement of 20 milliseconds (Figure 3.3). The statistics used in this analysis are misleading. The averaging and summing of different kinds of critical and uncritical users with 10:1 or more spread is confusing particularly for standard deviation. The importance of time critical users is diluted out. The following table selects values from this reference to infer what 50% of the applications might find adequate and the performance the editor thought adequate.

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

Parameter Time delays in milliseconds	Asynchronous		Synchronous	
	Median	Std dev	Median	Std Dev
Nominal Transfer Delay:	10	164	30	0
Target Nominal Xfer Delay:	2	5	10	1

4 "Wireless Local Area Network Requirements," (Version 1.0) K. Biba, Editor, IEEE P802.11/92-20, Jan '92 -- see "3.4.2 Performance" pages 21-25

The desires of asynchronous users are certainly faster than for the synchronous users, however poor performance can be hidden under the large suggested standard deviation which would be acceptable to only a fraction of users. For synchronous users, there is no such flexibility in the tolerance.

Those in 802.11 who worked to actually meet these target values were ***misled*** if much longer delays were actually permissible. This critic cannot claim to have been misled, because he thought and still believes *the target values are near what is necessary to meet the preponderance of market need.*

SERIOUS PROBLEMS

There are several lesser problems which do not prevent operation but which if corrected increase capacity, reliability and clarity of function. Most of them are the result of a minimal PCF which misses many of the benefits of a well-structured PCF.

4. NAV *(network access vector)* Functionality in Contention Space [revised]

The NAV (network access vector) is maintained at all stations using the **DCF time space** to provide a local estimate of the amount of time the channel will remain in use by observing RTS and CTS messages received. The presence of this function recognizes that something may be gained if station transmit is conditioned by knowledge of committed channel use. This function as implemented will cause as much trouble as benefit.

The effect of the NAV function is to inhibit station transmit attempts within the interval that the channel is committed to use for the case where a station hears only one of the two parties to the transfer. The concept is immediately limited by the need to receive in order to defer (not transmit). Unsuccessful receipt of the RTS or CTS information enables transmit (use of negative information).

This concept could work for one cluster without interference from any other like cluster. Undoubtedly dependence is placed on the channelization property of FH to enable independence of uncoordinated groups. There are other difficulties with that assumption, most particularly that there will no interference from like-pattern hoppers.

With a single channel PHY or when the independence capacity of the FH PHY is exhausted, there will be many RTS and CTS signals from unrelated systems to be dealt with. Then a decision must be made as to whether the inhibit property of the NAV applies to all signals heard or just to the related group. Neither choice is satisfactory.

If the NAV considers only RTS and CTS from its own group, then many of the messages will inevitably be lost from interference. This function requires decode of the group identifier as well as the message facts. It is not clear whether this function can be performed quickly enough to filter only the relevant signal information from all signals heard.

If the NAV considers all RTS and CTS received, it will then be falsely delayed with considerable loss of channel access when the channel could be used. Since the interference range is many times the service range, messages are unlikely to reach all of the stations in contiguous systems capable of interference during the protected intervals.

The assertion of the protection function of the NAV depends upon *reliable receipt of the NAV information in the RTS and CTS messages by all other stations*, because action is enabled by their absence and inhibited by their decoded content. Given 100% (theoretical) area coverage, the number of readable stations is many times the number involved in one autonomous group. If information needed for NAV is always transmitted from an access-point, the success probability is much higher. This is the only way channel status and availability can or should be made known to stations.

5. Wait-state in Contention-free Packet Transfers [revised]

For the class of packet data transfer described as "non-contending" with a **PCF (point coordination function)**, the access procedure is similar to that for connections. Since the request[5] is made in the "contention space," the absence of contention from stations within the same coverage area is obtained only after the request has been honored. The concept is defined as one where the use of contention-free space is coupled with indeterminate access delay.

The first conceptual flaw is that there is no bound on the necessary access delay. The alternative is to say that the traffic capacity of the system is defined by the level at which delay is beyond limits. Without this restraint, there is no motivation for time and protocol efficiency.

The detail implementation flaw is the frequent possibility of carry-over of one transaction from one superframe to the next introducing avoidable wait-states. The most obvious of these is the wait-state between RTS and CTS which can be as much as one superframe period. This is not consistent with minimized transfer delay.

A further important difficulty occurs if and when ARQ must be invoked. Failure to receive ACK must cause resend as a continuation of the current transfer, in particular avoiding deferral until the same sub-frame comes up in a following "super frame.[6]" Since the remaining time within the frame may have been used by the initial transfer, the extension of the current subframe may not be allowed causing the resend to be putover to the next frame. This delay is a further possible wait-state which is increasingly probable the longer the permitted packet length and which is certain with higher layer error recovery. If a physical medium is used (FH narrowband) which does not have strong measures to mitigate radio transmission errors, a large proportion of transfers will fail invoking ARQ.

6. Segmentation and Maximum Packet Length

While ordinary connections will be intrinsically limited to transfers of 64 octets or less by acceptable quantizing delay, there is no such limit for 802 packets. The maximums permitted by 802.3 are about 1500 octets. Proprietary netware often uses transfer sizes of 512 and 1024 octets.

The advantage of a longer maximum is the dilution of access overhead for greater utilization of the medium; and the disadvantage is increased access delay and probability of transmission error.

There must be a MAC level segmentation plan for both connection and packet type services limiting transfer length. This is an acute requirement for systems with delay limited services and desirable for pure connectionless systems to minimize flawed packet transfers.

As soon as segmentation is understood to be essential, a larger proportion of channel time is in overhead, but also problems in DFWMAC with waste time space from fragmentation of unused time, deferrals and truncation are diminished.

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5 "RTS" and "CTS" as used in the DFW have a long use precedent as part of the RS-232 interface. In this context, their value is Boolean. When the function is more complex requiring association with source and destination address as well as traffic descriptors, RTS and CTS become multiple octet messages which are better called **"request" and "grant."** In the context of an Integrated Services document, this nomenclature is used in the present IEEE 802.9 draft standard. Use of RTS and CTS may mislead some individuals with experience in other fields.

6 "Superframe" is properly used for frame-to-frame differences within a regular pattern. Just frame would be preferred for the period of one beacon interval. The subdivisions may be and are here called subframes.

7. Proper Definition of Connection-Type Services

The PCF proposal does not address connection-type services appropriately. DFWMAC assumes that octet bundles delivered periodically meet that need provided each bundle is delivered at the expected instant within a tolerance specified by a "jitter" parameter. The DFWMAC requires the PCF to allot time when it should be reserving capacity. Failure to practice this philosophy is a cause of fragmented idle channel time.

The essential property of a digital connection is a virtual circuit which to the user is or could be indistinguishable from the digital stream used in or provided by a PCM channel bank. Such banks transfer one octet of a channel at precisely 125 μsecond intervals. In this context, it is necessary to introduce quantizing delay while octet bundles are accumulated for 2 to 8 milliseconds (larger values limit use in public network connections). This quantizing delay is inevitable, but its size is a tradeoff.

At the receiving end there will be a FIFO or UART function to decouple the level of synchronization with the signal source. The essential function at the output of this device is to reconstruct the original serial bit-stream of the connection source except delayed in time by the minimum achievable amount. The difference between source and destination must and can be small, but it does not have to be absolutely identical. In PCM channel banks, unmatched clocks which accumulate ½ bit of mismatch, cause the loss or addition of a bit in the regenerated stream. There may still be a need to transmit network clock across the radio path to the wireless station, but it need not be instantaneous.

It is absolutely required that the MAC enables a new bundle be delivered to the receive FIFO or UART input before it is needed. *There is no use for a jitter specification, but there is for a worst case access delay* which if exceeded will cause the bundle of octets to arrive to late for the current output dump from the FIFO or UART.

The essential properties of a connection-type service are quite unrelated to those necessary to transmit a recognizable voice. Copying circuit definitions from DECT, GSM or digital cellular is not a usable guide because these networks the digital transmission paths are different from those in the public network. The precedents are better taken from ISDN or from IEEE 802.9. There is guidance in 802.6 on Integrated Services using a 48 octet cell payload and integrated 802/E.164 addressing.

The proper role for 802.11 is to provide at least one 64 Kbps clear B-channel and a parallel D-channel which may be transferred in the packet mode. Compression of voice is neither an 802.11 responsibility or a functional need, though having a connection-type service at 16 or 32 Kbps would be useful.

The use of **ADPCM (adaptive differential pulse code modulation)** speech in estimating transfer capacity in voice channels is not proper. The economy of half-bandwidth is not there because of increased overhead per transfer or else quantizing delay is doubled. The advantage of compression is not available when the limit for transfer delay is already invoked. The minimum relevant transfer rate for multi-media applications is one 64 Kbps B-channel--clear and an unimpaired..

8. "Talk Spurt" Voice Circuit Capacity Enhancement

The voice channel capacity given assumes that the voice channel activity factor is 0.4, however nothing is said about the probability that all channels will be simultaneously active without peak capacity to carry that load. Such techniques were called TASI (time assignment speech interpolation) when used on trans-oceanic cables, and there are since many further applications. All of these applications have in common trunk groups of the order of 30 or more channels, and that they experience peak clipping distortion or delayed cut-through when fully loaded. None of them claim advantage above 0.5 with 48 channel trunk groups. Because of peak demand probabilities, this technique is not beneficial with only 4 to 8 full-time channels in the available trunk group. In a cellular alternative, a channel holding rate of 1/8th was considered necessary during silence.

The concept is inapplicable to an 802.11 LAN. The savings from talk spurt, if available, are an application level function strictly limited to speech, and a fatal degradation for any other service. The traffic estimates should be for clear duplex 64 Kbps digital channels, or fractions thereof, and associated with a defined quantizing and access delay. The introduction of speech compression at levels 1 and 2 (in the MAC) may be a violation of the definition of a connection-type service.

Because of the talk spurt and ADPCM assumptions, *the estimates of capacity shown in "6.1.4 Estimates of time-bounded capacity" are considered to be irrelevant and 4:1 overstated.*

9. Polling Method of Access Control

In the DFWMAC, a request in the contention interval will put a station on the polling list for access to the contention-free space. More specifically, it is described as a token passing scheme in which the token is always returned from the station to the PCF, however it is also described that the station has the option of not answering if it has no traffic.

The period of one station's poll and use of the channel is given as an integer number of "superframes." If that number is two and the length of a superframe is 24 milliseconds, *the setup could add a transfer delay of 96 milliseconds by extension of the estimate in Disqualifying Problem 3 unless the start of the connection is truncated.* Delays are already over limits before introducing this further degradation.

Polls of all eligible stations will then take place every 1-to-N superframes and should be so diagrammed. A poll every 24 milliseconds for each station at a 1 or 2 Mbps will use a considerable part of the frame time. *It is well that a short address was chosen for identification of stations after accessing the contention-free function. This is useful step towards the virtual circuit and path identifiers in the ATM cell headers.*

The period for connection bursts is then one "superior superframe." If the period with the superframe is based on a timer/counter position from a beacon reference, it follows then that the period of a superframe can be synchronized to an integer multiple of a precise 125 µseconds obtained from a connected network. Otherwise the correct time position for the transfer will drift over time relative to the information source or the network connection eventually slipping ahead a frame or losing a burst.

A station could reserve connection-type space, possibly use it for a while, but lose power during or after the last connection. *There is no explanation of how the PCF removes a disappeared station from the polling list or discovers that it needs to considering that a response is not required.*

Polling in and of itself is not good or bad. The technique must be associated with necessary functions and proportioned to have a low duty cycle use of the channel. *A frequent poll has energy consequences not only for one station but for the aggregate of all stations in a wide area.* It is easy to ignore this consideration for small "one-up" systems but not for nationwide standards.

A differently proportioned polling function for a different purpose is a necessary change in the DFWMAC.

10. Increased Risk of Early Obsolescence from Use of Distributed Logic

A somewhat more subtle matter is the importance of simplicity in the station and its relation to the probability or early obsolescence. If the algorithms for partitioning time between two or three medium access methods and of reacting to apparent perpetual busy-channel condition are in the station, it is certain that station logic will have to be iterated after operating experience is obtained. The cost, speed and added protocol complexity of anticipating this need by providing downloadable software for stations would be a considerable negative.

Yet more subtle is the consequence of placing functions in the station that depend upon system facts not readily known to individual stations. Because, the station has inferior radio coverage compared with a fixed access-point, the observation of activity of other stations and access points is necessarily incomplete. Perhaps less than 10% of the relevant activity is readable at a station. The cost and complexity of relaying necessary decision facts to every station through a backbone common to several access points would be unbearable in transmission delay and complexity.

The adjustment to new knowledge on these considerations will require revision of station logic, possibly more than once. This is an unnecessary consequence of distributed logic. The alternative is placing system algorithms in infrastructure hubs where modification and adaptation are feasible, and uniformly affect all stations.

The necessary information must be kept in data bases convenient to where they are gathered--point and Extended-area coordination functions within the infrastructure. Matters of judgement on timing and the probability of interference with adjoining user clusters is better left to point and Extended-area Coordination Functions within the infrastructure. ***It is then possible and desirable to limit station function to the protocol of sending and receiving messages from a short list of types.***

> Keep the more numerous stations simple, and absorb complexity into infrastructure equipment common to many stations. The effort to avoid natural Point and Extended-area Coordination Functions in infrastructure is uneconomic for anything but the simplest of networks.

11. Susceptibility to Malicious Jamming and Impolite Access

The ease with which the LBT/CSMA access logic can be jammed is obvious; and if it can be done, it will happen. The possibilities are similar for "channel grabbers.[7]" If the measure of channel activity is decodability or clock acquisition, there would be an improvement; however, this would foreclose the possibility of mixed system types (or the FCC/WINTech etiquette).

With some implementations, the "listen" function can be forced into an "always idle" indication at a point between radio and logic. Sooner or later a station will be modified to block the busy indication so that station can always access. The goodwill and sense of community of the users can no longer be relied upon to protect the essential business tools which computers have become.

Any technology which reduces susceptibility to transmission errors also can be beneficial in reducing the scope and effect of simpler jamming and grabbing techniques.

12. Deficiencies of Omission

There are a number of necessary but omitted functions many of which are related to implementing a PCF function that is competent for 100% area coverage with interference limited radio system design and for integration of packet and connection services which are contention-free. Many of these are explained in an associated paper IEEE 802.11-94/13 '"Morphing" the DFWMAC ...'

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7 In the 1964-1980 IMTS mobile telephone system (Bell MJ and MK), idle tone was transmitted on the next channel to be used for a connection. If all channels were busy there was no idle tone until one of the channels disconnected. The station logic specified a randomized delay after appearance of idle tone to reduce simultaneous access requests. After several years of service and the systems became fully loaded, entrepreneurs devised a bypass for the backoff delay and marketed the modification as "channel grabber."

CONCLUSIONS

The DFW MAC is neither an adequate or a functionally responsive choice for 802.11 Standards recognition because of flawed primary premises. The functional needs motivating its preference by many members can be met in other ways without making autonomous peer-to-peer the primary operating mode. This emphasis has resulted in choices for the other modes which are grossly inadequate. When coupled with an equally poor choice of frequency hopping 2.4 GHz PHY, the result will be of small value to most users.

> This deliberately permitted deficiency in area coverage for reservation-type services gives the appearance that the supporters of the DFWMAC do not take either, "contention-free" or "time-bounded" services as a commercially significant requirement.
>
> It is important to recognize these functional shortfalls, and more importantly the mechanisms which cause them; and then to get on with corrections or evolving a better choice. Failure to do this will result in wasted effort and financial resources and poor service to the public that depends upon our standards process.

When the full implications of these matters are understood, it should be understood that the benefits of proceeding with the DFWMAC will be short-lived. There is incentive to consider and develop the architectural and logical changes proposed in IEEE 802.11-94/13 "'Morphing' the DFWMAC ..."

Additional References (unless otherwise noted contribution numbers are IEEE 802.11...)
on detail technical considerations and on the Sequential Asynchronous MAC.

93/105 "Hidden Terminal Problems in Wireless LANs," R. Allen, Apple, Jul 93

This paper includes discussion an analysis of the various LBT protocols offered to 802.11. See the inset paragraph on page 1.

91-95 "Sequentially-used Common Channel Access Method," C. Rypinski, Sep '91

This contribution updates the 91-19 presentation of the sequential asynchronous MAC.

93/163 "Comparison and Commonalities of Asynchronous Sequential Access and Adaptively Partitioned Periodic Frame MAC Proposals," C. Rypinski, Sept 93

Compares sequential asynchronous against a class composed of regular-frame time slotted proposals of which the, IBM proposal is a particularly competent representative.

93/151 "Necessary Conditions for Support of Connection-Type and Connectionless Services...," C. Rypinski, Sept 93

Asserts that a common controller is essential to provide reservation capability against future capacity without which a connection type service is unreliable.

93/101 "Data Capacity of Radio Spectrum," C. Rypinski, Jul 93

Estimates spectrum capacity in Mbps/hectare for several proposed 802.11 PHY methods. A central point is that this capacity is a separate matter from its utilization. (expanded and revised version in preparation)

(These and other references on this subject can be supplied by the Author)

Attachment A – Relative Raw Capacity of DFWMAC and SAMAC[6] in 2.4 GHz ISM Band (pg 8)

PARAMETER	DFWMAC	DFWMAC	SAMAC	SAMAC
PHY	1 Mbps FH	2 Mbps DS	2 Mbps DS	6 Mbps DS
Reach--meters:	100	50	50	35
AP Illumination:	Omni	Omni	Omni	Corner
Cell area--m^2:	20000	5000	5000	625
Reuse factor:	36 (19 channels)	16 (3 channels)	9 (3 channels)	4 (1 channel)
Raw capacity/cell:	1 Mbps	2 Mbps	2 Mbps	6 Mbps
Raw capacity after reuse factor:	0.528 Mbps/channel	0.125 Mbps/channel	0.222 Mbps/channel	1.5 Mbps/channel
Cells/km^2:	50	200	200	1600
Raw capacity--Mbps/km^2:	26.4 per channel 501.4 per band	25 per channel 75 per band	44.4 per channel 133.3 per band	2,400 per chnl 2,400 per band
Dynamic capacity partition and 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
Raw cap'y adjust--Mbps/km^2:	10.56 per channel 200.6 per band	25 per channel 75 per band	88.8 per channel 266.6 per band	3,600 per chnl 3,600 per band
Notes:	1, 2	3	4	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.* 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 and a priori path and radio settings determination.