IEEE P802.11
Wireless Access Method and Physical Layer Specification

Preamble Modification for Improved Selection Diversity

Ronald Mahany
Norand Corporation
550 Second Street SE
Cedar Rapids, IA 52401
Telephone: (319)369-3552
Facsimile: (319)369-3299
email: mahanyrl@norand.com

Abstract

The Frequency Hopping and Direct Sequence PHY groups have selected preamble characteristics with the expectation that some 802.11 compliant implementations will use some form of antenna diversity, or some other form of multipath compensation. In both cases, preambles with uniform data content were chosen -- a *dotting pattern* of 1-0-1-0... for FH, and a *marking pattern* of 1-1-1-1... (at the input to the scrambler) for DS. While these uniform patterns meet the basic requirements of receiver synchronization and channel busy detection, they may not be the most appropriate for implementing antenna diversity. Insertion of a time stamp within the preamble is proposed to improve performance of antenna selection diversity algorithms, with potential application to other multipath compensation or channel optimization alternatives as well.

Introduction

A number of papers related to preamble characteristics, synchronization words, clear channel assessment, have been submitted before the FH and DS PHY ad hoc groups. The subject of antenna diversity was discussed in some detail in a recent contribution -- IEEE P802.11-94/70, by Dean Kawaguchi. Document 94/70 provides excellent groundwork for further work in this area. While it was presented within the FH group, its content is not unique to frequency hopping, and concepts presented within should be considered relevant to the DS PHY as well.

The implications of antenna diversity may not have been fully considered when the respective RF PHY groups selected preambles for their PHY headers. This paper is intended to highlight this issue, and offer an alternative that provides more flexibility in addressing this problem.

Assumptions:

The discussion of diversity within this paper is based upon a particular view of diversity's place within the standard. The perspective of the author can be summarized in the following list of assumptions.

1. While most contributors who have discussed methods of channel optimization within the working groups tend to focus on two-antenna selection diversity, the standard should not preclude alternatives such as *n* antenna selection diversity, adaptive equalization, maximum ratio combining, or RAKE approaches for direct sequence. All of these techniques generally benefit from training during the preamble period. The preamble should provide a reasonable amount of flexibility to implement alternative approaches to address the wireless channel.

2. Use of diversity, or any of the alternative methods, is not a requirement of either 802.11 RF PHY. The purpose of including preamble support for them is to provide means for manufacturers whose target customers can benefit from (and will pay for) them to use them, not to dictate use, or mandate algorithms.

3. Because of the broad interest in selection diversity, it is a good litmus test for evaluating whether we have selected satisfactory preambles.

4. CCA and diversity approaches are interrelated, and cognizance of diversity issues is important in specifying CCA detect time, P_{det} and P_{fa} requirements for preamble reception. As a fairness issue, CCA conformance testing must not be specified in a way that favors either diversity, or single antenna implementations.

5. Diversity selection on a per transmission basis is appropriate given the propagation characteristics of the channel, and the boundless variety of potential interference scenarios that need to be considered with like and unlike devices operating in proximity, in an ISM environment. Diversity must be viewed in both noise-limited and interference-limited contexts.

6. Throughput using the foundation MAC protocol, like other LBT protocols, can be expected to be sensitive to increases in transmission overhead. In both FH and DS, PHY overhead exceeds MAC payload for some message types. It is desirable to enable channel compensation techniques within the PHYs, yet it is undesirable to extend preamble length boundlessly to do so. (Note that in the case of DS, PHY overhead is now approaching 200 symbols per packet.)

7. Given the usual implementation constraints, of size, cost, power consumption, etc., anything that can be done at the transmitter to make the receiver's job easier, should be done.

Background:

Document 94/70 details two basic classes of two-antenna selection diversity algorithms. The *best antenna* algorithm requires that both antennas be scanned and assessed for signal quality during the preamble period, with the receiver returning to the best antenna with sufficient time remaining in the preamble to attain synchronization prior to the unique word. The *satisfactory antenna* class of algorithm stops scanning as soon an antenna with acceptable signal quality is found.

For asynchronous traffic, the foundation MAC does not provide prior knowledge of frame boundaries, therefore antenna sampling algorithms must consider the worst case timing relationships between start of transmission, and antenna sampling. This results in the preamble period being divided into five sampling periods for the *best antenna* algorithm, and three sampling periods for the *satisfactory antenna* algorithm. These sampling periods, less switching and synchronization times for the receiver, specify an observation window in which to make an assessment of the presence, and/or quality of the received signal.

Frequency Hopping

Discussion of 94/70 -- Noise Limited Channel

The previously approved 80 bit preamble length for FH places severe constraints on the *best antenna* class of algorithms, allowing (after receiver settling time) only eight to ten symbols of preamble for clock synchronization and channel assessment. The antenna selection settling time indicated in 94/70 is realistic, and clock lock within the allotted number of bits within the P_{det}, P_{fa} limits indicated is possible under the conditions simulated. However, it is not realistic to expect to make signal quality comparisons between antennas when such a short sampling period is available. This is clearly the case in figure 3 of 94/70, where the simulation shows P_{fa} in noise of 5% to 10%. The P_{det} statistics for the ten-symbol observation window are pretty good, but may substantially degrade if the clock detector bandwidth is widened to contend with multipath induced jitter. More significantly, the ten-symbol observation window P_{det} results in 94/70 were based on a noise-limited channel providing a 1×10^{-5} BER. P_{det} at lower channel BER is also important, if the ability to detect clock is to be used as a means of comparing two or more antennas. With short observation windows, measurable P_{det} will be attained at poor channel bit error rates that will not sustain payload transfer. Detection of clock alone cannot be used with certainty to determine the best antenna.

The *best antenna* algorithms in figures 5 and 6 of 94/70 implicitly recognize the detection uncertainty issue, and attack it by requiring clock lock to initially ascertain presence of desired signal, then using energy in band (RSSI) comparisons to determine the best antenna. With the preamble length and content already selected, there aren't many degrees of freedom. Given these constraints, the illustrated algorithms do as well as any in solving the problem for the noise limited case.

Discussion of 94/70--Interference Limited Channel

The weaknesses of energy-based antenna selection have been discussed previously within the PHY ad hoc groups. Even within the noise-limited case, there are issues with using RSSI for determining best antenna. The difference in signal strength between a 1 x 10^{-3} channel and a 1 x 10^{-5} channel is two to three dB. This places a burden on RSSI measurement accuracy.

Document 94/70 did not address detection performance in the presence of interference. The C/I limited case is similar to the C/N limited case--short observation windows introduce more detection uncertainty. Again, within short windows, clock will be detected in interference limited channels with unsatisfactory BER. In this case, RSSI based decisions can result in the wrong antenna being selected, since using RSSI optimizes for C+I, not C/I or pre-detection SNR. (The FH PHY chairman's immortal example of locking to the strongest microwave comes to mind.)

It is clearly desirable to use the longest observation window possible for channel characterization. This provides better detection certainty, and potentially allows qualitative, SNR based antenna selection algorithms. Low modulation index FM is known to have substantial intrinsic jitter that must be averaged out. Interference and multipath induced jitter complicate this problem, again requiring longer observation windows to make comparative measurements. Personal experience with clock recovery for discriminator demodulated GMSK, at similar data rate and BT to that of the draft standard GFSK modulation, indicated that about 20 bits of transitions are needed to obtain a useful indication of recovered SNR. This appears to be reasonably consistent with the low uncertainty in the 20μsec window clock detector simulation statistics in figure 3 of 94/070.

Truncated Preambles

Antenna selection algorithms also need to function in cases where some of the beginning of the preamble is obscured on both antennas by interference, or the end of another transmission. The five-window, best antenna scheme is extremely vulnerable in this case, and will frequently miss transmissions that single antenna systems will receive.

Direct Sequence Issues

While 94/70 was not presented in the context of the direct sequence PHY, there are significant parallels between FH and DS selection diversity requirements. The *best antenna* algorithm in 94/70 is similar to that discussed in a DS context in 93/37. DS diversity algorithms must also contend with noise limited, interference limited, and truncated preamble cases.

For DS, acquisition and clock detection are a combined process, and P_{det}, P_{fa} are replaced by P_{acq},, $P_{false\ acq}$. Like their FH counterparts, DS receivers will acquire and track signal under low BER conditions unsuitable for data transfer. In general, it can be expected that DS receivers will take longer than FH receivers to acquire signal each time an antenna is selected, but a shorter period to evaluate the received signal after acquisition. The approved 128 bit preamble for DS is about 50% longer than that for FH. The difference in preamble length between the two

PHYs is necessary to account for the incremental requirements of DS synchronization (AGC training, code acquisition, scrambler flushing, etc.), and may already reflect a perceived need within the DS community for longer observation periods for acceptable preamble detection performance

The *best antenna* algorithm of 94/70 could be applied directly in the DS case, using pre-despreader signal strength measurement to compare antennas, if a quick measurement is desired. Alternatively, post-despreader signal quality estimation may be performed readily in a DS receiver, e.g., as the measure of correlated to uncorrelated energy at the depreader output, integrated over several adjacent bit intervals. Some of the implementation issues differ, but the choice of *best antenna* vs. *satisfactory antenna* approaches for DS is the same conceptually, as it is for FH.

An Alternative Preamble Concept

Preamble length, asynchronicity between antenna scanning and start of transmission, and antenna switching time dictate the duration of preamble observation windows. As stated in the assumptions, it is undesirable from an overall system performance standpoint to make the preamble any longer. It is also not possible to reduce antenna switching time below some minimum number of symbol times for either DS or FH PHYs.

The one area where is some recourse, is in reduction of the timing ambiguity between antenna scanning and start of message. With the currently specified uniform preambles in both PHYs, a receiver, synchronizing to preamble for the first time, has no knowledge of whether it has synchronized to the first bits of the preamble, the center, or the end. The worst possible timing relationship between start of transmission and antenna sampling must be assumed in designing switching algorithms. For example, in the best case, where antenna scanning and start of transmission happen to coincide, the *best antenna* algorithm requires only two or three observation periods to make a decision, not five. Each period could be longer increasing confidence in the information obtained. The assumption of worst case timing can be eliminated by the giving the receiver diversity algorithm more information. This information can easily be inserted into the preamble as a timestamp, as shown in figure 1. The timestamp information can be used to facilitate a hybrid *best or satisfactory* (BOS) diversity algorithm.

A proposed timestamped preamble for frequency hopping is shown in figure 2. It consists of 32 bits of alternating 1-0 followed by 48 bits of 0-1. The time stamp is centered at the boundary between bits 32 and 33. It can be easily distinguished by simple pattern recognition circuits keyed to **1001** (distance 2, from preamble) or **010010** (distance 3 from preamble). This preamble represents minimal departure from the current FH PHY dotting pattern preamble.

The proposed timestamp for direct sequence is shown in figure 3. DS differs from FH, in that clock can be extracted directly from the despreader, eliminating the need for transitions in the data for timing recovery. The preamble below would be scrambled to provide spectral whitening, per the DS PHY draft.

↓ Timestamp

m bits preamble	T	n bits preamble	16 bits Unique Word

← 80 bits FH or 128 Bits DS →

Figure 1: Timestamp Concept

m bits **Preamble A**	T	n bits **Preamble B**	Frame Sync
1010101........01010101**0**	**0**10101010101...............01010101010101		Unique Word
32 bits	48 bits		16 bits

Figure 2: Proposed FH Preamble with Timestamp

m bits **Preamble A**	T	**Preamble B**	Frame Sync
00000000........0000000**0**	**1**11111111111...............11111111111111		Unique Word
48 bits	80 bits		16 bits

Figure 3: Proposed DS Preamble with Timestamp

An SNR based *Best or Satisfactory* (BOS) Diversity Algorithm Example

The flow chart in figure 4 illustrates a possible application of the timestamp in a hybrid algorithm improve selection diversity performance. For comparative purposes, it is modelled in the context of frequency hopping. This is an adaptation of figure 4 of 94/70. Assumed system parameters, illustrated in Figure 5, were also selected for consistency with 94/70. Also, the flow chart assumes a circuit implementation with continuously available clock lock and SNR outputs. In other words, once clock lock and SNR outputs are valid, their status is updated continuously until the detection circuits are reinitialized.

Parameter:	Value	Notes
Antenna Switching Time:	8 µsec	
SYNC (Clock) Detect Observation Interval:	10 µsec	
Minimum Length SNR Observation Interval until SNR valid:	20 µsec	(Concurrent with SYNC detect)
RSSI Threshold	Arbitrary	

Figure 5 Assumed System Switching and Detection Parameters