IEEE 802.11
Wireless Access Method and Physical Layer Specifications

Title: **Preamble Length Considerations for a Frequency Hopped Phy**

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Abstract

A preamble suitable for a frequency hopped radio is presented. The preamble length is estimated by evaluating the number of symbols required for carrier detection/antenna diversity selection, baseband dc offset adjustment, and symbol timing recovery for a given performance.
The performance is specified as the probability of missing a data packet due to an unsuccessful acquistion. A short preamble is desired because the packets will be on the order of 1000 symbols due to the expected raw bit error rate of the channel. The proposed preamble is estimated to provide a probability of acquisition significantly better than 0.99 operating at a signal-to-noise ratio of 14 dB in a 1 MHz bandwidth.

1. Introduction

This paper proposes a preamble suitable for a frequency hopped radio. The preamble length is 56 symbols. The preamble provides for the following operations prior to actual data recovery:

o carrier detection / antenna diversity selection
o baseband dc offset adjustment
o symbol timing recovery

Frame synchronization is not included in the above list as this is assumed to be part of the MAC function. The carrier detection / antenna diversity selection is based on computing signal energy, a noncoherent detection process. For carrier detection the signal energy is computed and compared against a threshold. For the antenna selection process the receiver switches between two antennas and computes signal energy for each antenna pattern. The relative energies are compared and the antenna with the highest energy is selected. Figure 1 shows a timeline for the worst case receiver acquisition. Two antenna patterns are assumed for diversity. The preamble length chosen allows for consecutive antenna measurements on a single receiver (as compared to parallel receivers) to perform the antenna selection.

As a worst case, 4 measurement slots are required to perform the carrier detect and antenna diversity selection. The correct antenna is assumed to be antenna1, i.e. antenna2 is assumed to be in a null. In measurement slot1, with antenna1 selected, the signal comes on in the middle of the slot, too late for the carrier to be detected. In slot2 with antenna2 selected, no carrier is detected. In slot3 a carrier detection occurs. At the same time a measurement of the signal strength on antenna1 is performed. In slot4 a signal strength measurement for antenna2 is performed. The results of the antenna1 and antenna2 measurements are compared to select the best antenna.

Carrier detection and antenna selection are two separate processes but the same time is allowed for a carrier detection trial as for the antenna signal strength measurement. This time is 9 symbols/measurement slot. Note, this time includes one extra symbol time for settling due to switching between antenna patterns. Given the worst case 4 measurement slots described above the time required for carrier detect and antenna diversity selection is 36 symbols.

Following the carrier detection/antenna diversity selection is the dc offset settlement/ measurement time. The receiver baseband can either be ac or dc-coupled. For ac-coupled designs there is a settling time associated with the high pass filter. For dc-coupled designs there is the potential to have significant dc offset due to the receiver implementation. In addition this offset can be channel and receive frequency dependent (otherwise these could be removed as part of an initial calibration). In this case it will be necessary to estimate the receiver offset and provide a correction before symbol timing recovery and data detection can occur. This time is indicated in Figure 1 to be 8 symbols.

The final function required of the preamble is symbol timing recovery. The time required for symbol timing recovery is estimated to be 12 symbols. The frequency uncertainty of the clock should be small since the symbol clock can be derived from the crystal reference. Given a reasonable crystal uncertainty a first order timing recovery loop can be used.

The performance is specified as the probability of missing a data packet due to an unsuccessful acquistion. The proposed preamble is estimated to provide a probability of acquisition significantly better than 0.99 operating at a symbol energy-to-noise density, Es/No, that is consistent with a BER of 10^{-4} to 10^{-5}. A discussion of the the expected performance for carrier detection, antenna selection, dc adjustment and symbol timing recovery follows.

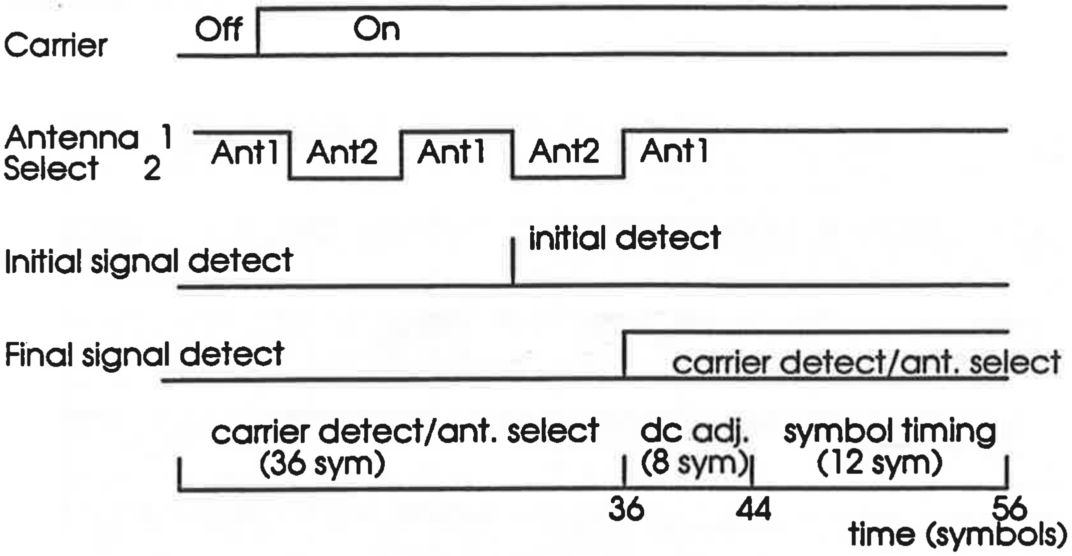

Figure 1 Preamble Timeline

2. Estimate of Preamble Length

The time required for each of the processes described above is estimated. A signal-to-noise ratio, SNR = 14 dB in a 1 MHz bandwidth is assumed. This value is reasonable given the requirements for a raw bit error rate of 10^{-4} to 10^{-5}. This is equivalent to a radio with a 15 dB noise figure and a minimum input signal level of -85 dBm.

The structure of the preamble is assumed to be a 1010... pattern to allow for maximum transitions for symbol synchronization at a 1 Msps symbol rate.

Carrier Detect

The preamble of 1010.... results in a spectral component. The carrier detection performance is based on results for envelope (noncoherent) detection of a CW signal in narrowband gaussian noise. The receiver IF bandwidth is assumed to be 1 MHz. Robertson [1] has evaluated the performance of this system as a function of the following parameters:

o Pd, the detection probability of a single trial
o Pfa, the probability of a false detection for a single trial
o M, the number of independent samples of the envelope signal that are averaged (post detection summing) for each trial
o SNR, the signal-to-noise ratio in the detection bandwidth

Using the results from Robertson, Figure 2 shows the probability of a miss (1- Pd) versus SNR for M = 8 (symbols) and a false alarm probability of 4e-6 (per trial). For Pd = 0.999, the required SNR is approximately 7.5 dB. Therefore, for an SNR of 14 dB there is 6.5 dB of margin to account for implementation losses, etc. The basis for selecting the detection probability and false alarm probability is discussed below.

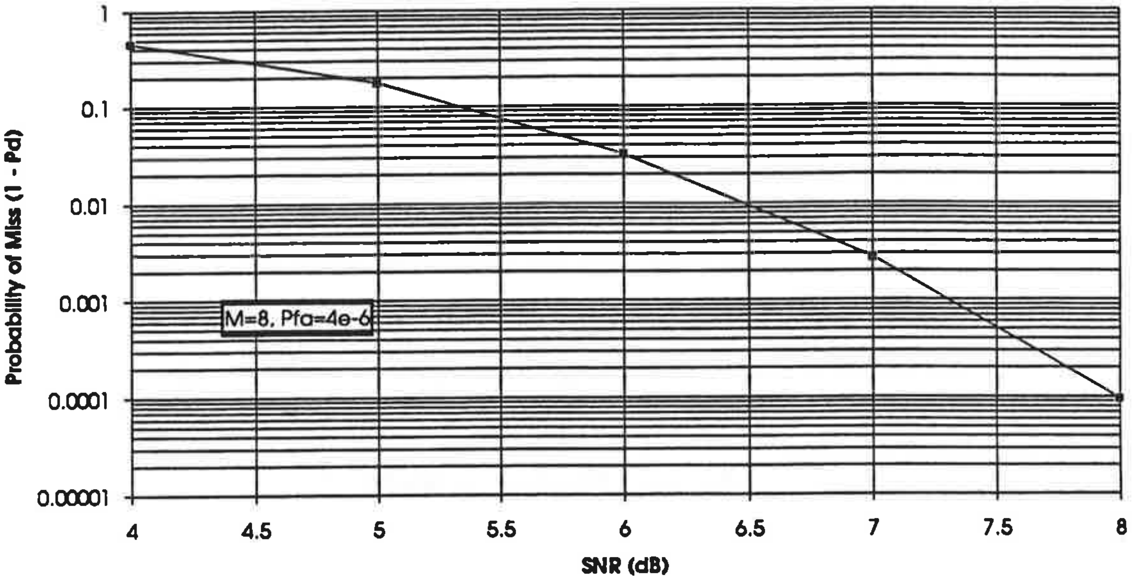

Figure 2 Carrier Detection Performance versus SNR

Detection Probability: For a raw bit error rate of 10^{-5} and a packet length of 1000 bits the packet error rate is 10^{-2}. The miss probability (1- the detection probability) should be significantly less than the packet error rate.

False Alarm Probability: In the normal operating mode the receiver and transmitter will be fairly close in time. The two will drift with respect to each other due to the difference of their respective crystal frequencies. A search over 1000 symbol times should be more than adequate. This is equivalent to being off for 25 seconds without a time synchronization update and the transmitter having a +20 ppm error and the receiver having a -20 ppm error.

The time between independent samples is approximately 1/B where B is the filter (RF) bandwidth. For a filter bandwidth equal to the raw symbol rate the time between independent samples is approximately equal to the symbol time. Given post detection summing of M samples per trial then there will be 1000/M trials over the total search time. If Pfa is the false alarm rate per trial then the overall false alarm probability is Pfa*(1000/M) for all the trials. A false alarm will result in a missed packet so a low overall false alarm rate is required. Let (1000/M)*Pfa = 0.1*(1-Pd), where Pd is the detection probability. Choosing Pd = 0.999, the required Pfa is $M*5 \cdot 10^{-7}$. For M = 8 then Pfa = $4 \cdot 10^{-6}$.

Antenna Diversity Selection

For antenna diversity, two antenna patterns will be assumed. The antenna pattern selection amounts to making the choice between the highest received signal power between the two patterns.
The performance of the diversity selection will be a function of the following parameters:

o SNR, the signal-to-noise ratio of the stronger signal
o Δ, the power difference between signal levels for each antenna pattern
o Pe, the probability of making an error in the selection, i.e. selecting the lower power
o M, the number of independent samples that are averaged (post detection summing) for each trial

The performance is estimated by considering the output of a linear envelope detector. Let P1 and P2 be the output of a linear envelope detector for antenna 1 and antenna 2 respectively. Assume that antenna 1 is the desired antenna to be selected because antenna 2 is in a null. Figure 3 shows the probability of selecting the wrong antenna as a function of SNR for M = 8 (symbols) and a 6 dB difference in power between the two antenna patterns.

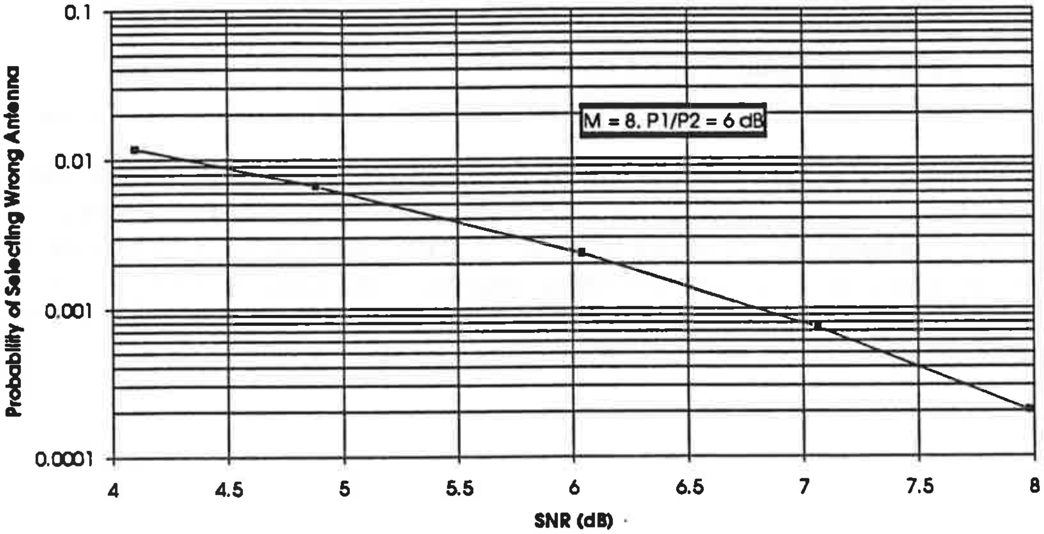

Figure 3 Antenna Diversity Selection Performance

DC Offset Adjust

To estimate the time required for dc offset adjustment ac coupling of the baseband signal using a simple RC highpass network is assumed. A a short time constant for the highpass filter is desired to remove the dc offset as quickly as possible. However, a short time constant will also result in distortion of the baseband waveform particularly for a baseband waveform that has a long period without transitions. Since the preamble has a maximum transition density the effect highpass filter is minimized during the preamble. For the actual data sequences the highpass filter time constant may need to be increased.

A dc offset equal to 50% of the baseband signal amplitude is assumed. Selecting a filter time constant equal to 5 symbol times results in this dc offset being reduced to 10 % of the baseband amplitude in 8 symbol times. The 3 dB cutoff frequency of this highpass filter is 0.1*Rs/pi (Hz), where Rs is the symbol rate. This will result in minimal distortion of the baseband signal during the preamble.

Symbol Timing Recovery

The time required for symbol timing recovery is based on a first order bit synchronizer loop implementation. The loop time constant, *t*, and the loop noise bandwidth, BL, (one-sided) for a first order loop are related by:

$t = 0.25/BL$

An adequate settling time, for the loop is 4 loop time constants, or 1/BL. The maximum loop noise bandwidth is limited by:

- o the bit sync loop signal-to-noise ratio, SNRl
- o sync maintainence for strings of data with no transitions.

A timing jitter of 0.03 of the symbol time will be assumed. This should result in less than 1 dB degradation in the bit error rate performance due to the timing jitter. Figure 4 shows the required, normalized loop bandwidth, BL*T versus SNR (in a 1 MHz bandwidth) to acheive a timing jitter of 0.03 of the symbol time. For BL*T = 0.08, the required SNR is approximately 7.5 dB. This results in a 6.5 dB margin for implementation losses etc. For BL*T = 0.08 the loop settling time is 12 symbols.

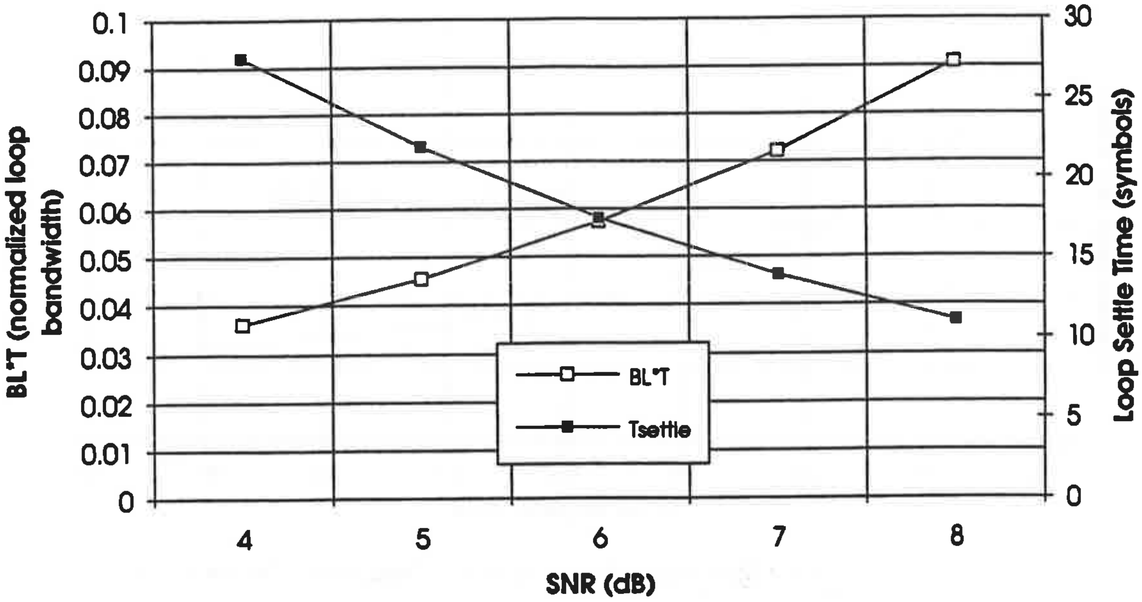

Figure 4 Symbol Timing Recovery Performance

Preamble Length Effect On Efficiency

For a raw bit error rate of 10^{-5} the packet length is limited to approximately 1000 bits (the resulting packet error rate is 10^{-2}). Figure 5 is a plot of the proposed preamble length as a percent of the packet versus packet length.

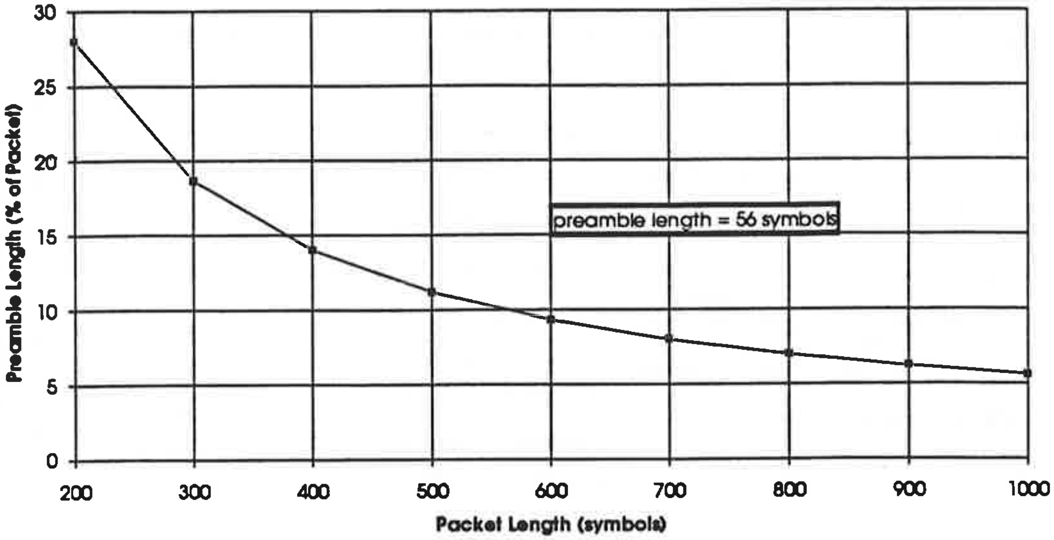

Figure 5 Proposed Preamble As A Percent of Packet Length

Summary

A preamble suitable for a frequency hopped radio has been presented. The preamble length is 56 symbols. This allows for the following receiver functions:

o carrier detection/antenna diversity selection- 36 symbols worst case
o baseband dc offset adjustment- 8 symbols
o symbol timing recovery- 12 symbols

The performance is specified as the probability of missing a data packet due to an unsuccessful acquistion. The proposed preamble is estimated to provide a probability of acquisition significantly better than 0.99 operating at a symbol energy-to-noise density, Es/No, that is consistent with a BER of 10^{-4} to 10^{-5}.

A short preamble is desired beacause the expected raw bit error rate or the channel will force the packets to be on the order of 1000 symbols or less based on a 10^{-5} raw bit error rate. The proposed preamble is 5.6 % of the packet length for a packet size of 1000 symbols.

References

[1] Robertson, G.H., "Operating Characteristics for a Linear Detector of CW Signals in Narrowband Gaussian Noise, The Bell System Technical Journal, April 1967, pp 755-774.