Preamble Design Problematic with 802.11a IEEE Standard (Minn's Training Sequence Approach)

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Abstract. *Generally OFDM systems use a predefined signal pattern, called preamble [2] [3], which helps the receiver to achieve a better signal detection (coarse, fine time synchronization) with the frequency offset and channel estimation. In most of the time having all these conditions fulfilled the receiver achieves relatively a good performance while keeping as low as possible the total consuming power and the BER (Bite Error Rate).*

This paper presents the results obtained while combining a part of the preamble [2] [3] and the Minn's training sequence. We have got interesting performance results comparable to those results obtained for the relatively new standard 802.16a.

Keywords

OFDM, 802.11a, WiFi, WiMax, LAN, preamble design, IDFT/ DFT, FFT.

1. Introduction

Frame detection is one of the most important tasks at any OFDM receiver. In the case of a false-detection the receiver does not have the useful data (the initially sent data) and logically the radio link seems to not be reliable. For this reason many technical papers have analyzed the OFDM receiver requirements. Among of these requirements, the preamble design is one of the most important for the receiver conception. The preamble design is essential for the received signal processing. We have integrated the Minn's training sequence into the classical 802.11a preamble while keeping the preamble length unchanged. In this paper the results obtained for the coarse time synchronization based on the proposed mixed preamble and 802.16a preamble are compared.

2. System Model

We consider a simple SISO (Single Input Single Output) system model (Fig. 1). Information bits are processed as prescribed by the 802.11a standard [1]. The only noticeable difference is at the preamble design. For our simulation needs, we followed the different steps shown in Fig. 1. The most important parts of the signal processing are:

1 data and channel coding/decoding,

2 sub-carriers modulation (mapping of each L=log2M binary bits into M constellation points) and their framing (each frame containing N constellation points).

3 At the transmitter part, the IDFT converter generates N time dependent waveforms. Each of these waveforms is extended by cyclic prefix (i.e. Ng=N/4). At the receiver part, the DFT converter generates N frequency dependent signal.

4 converting to/from RF.

Based on the fact that the cyclic prefix length is larger than the channel length, we assume the channel to be flat. Then, the received OFDM signal is only affected by phase noise $\Phi(n)$ and AWGN (Fig. 2):

$$r(n) = x(n)e^{j\Phi(n)} + w(n) \tag{1}$$

where e $^{j\Phi(n)}$ is the channel impulse response, $w(n)$ is the additive white Gaussian noise (AWGN), N is the number of samples and $x(n)$ is the transmitted signal.

$$x(n) = \sum_{k=0}^{N-1} s_k e^{j\frac{2\pi kn}{N}} \qquad n = 0,1 \ldots N-1 \tag{2}$$

where n is the sample index, N is the total number of sample per OFDM symbol, and s_k is the k-th component modulated signal.

2.1 OFDM Packet Structure

In Fig. 3 the 802.11a preamble is described. This preamble is composed of ten short training symbols and two long training symbols. Each short training symbol contains sixteen samples (0.8 µs). Each long training symbol has got sixty four samples (3.2 µs). Both two long training symbols are separated from the short training symbols by a cyclic prefix of 32 samples size (1.6 µs). Our simulated OFDM packet (Fig. 5) is similar to the 802.11a with the difference that the first four short training symbols are replaced by the Minn's training sequence (3.2 µs). In

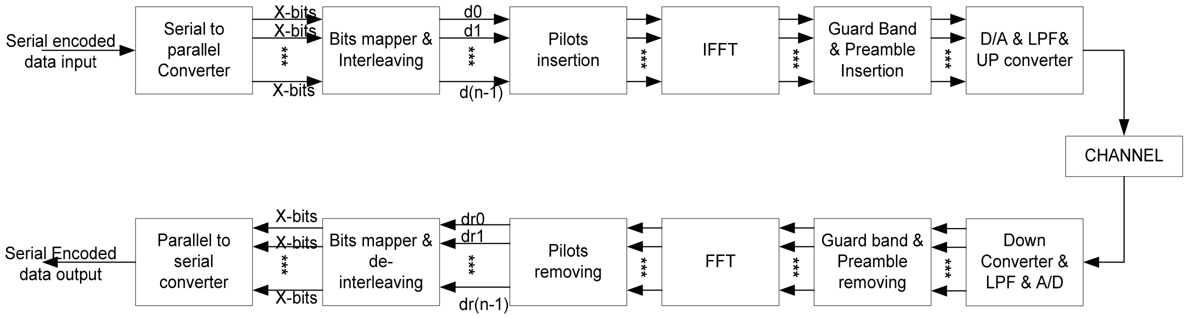


Fig. 1. Block diagram of an OFDM system using FFT, pilot PN sequence and a guard bit insertion.

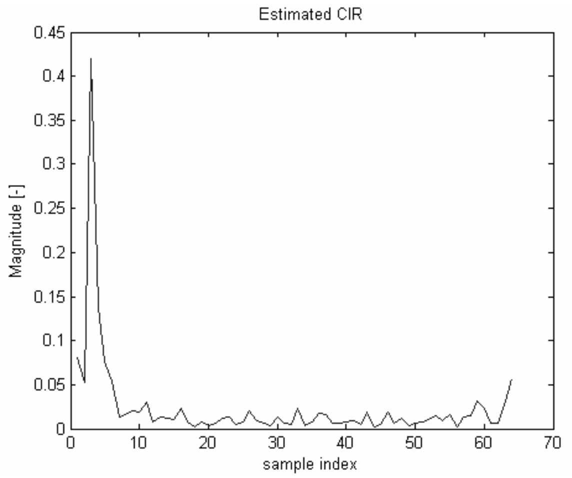


Fig. 2. Estimated channel impulse response.

our case, where the Minn's sequence was tested only for the coarse synchronization issue, we decided to keep the rest of the 802.11a packet identical regarding the 8092.11a standard. This issue is clearly shown in Fig. 3 and Fig. 5.

Basically the 802.11a recommends the Schmidl and Cox algorithm for computing the frame start. This algorithm is described by:

$$M(k)=\frac{|P(k)|^2}{(E(k))^2} \tag{3}$$

where $P(k)=\sum_{n=0}^{L-1}(r_{k+n}^{*}r_{k+n+L})$, $0\le n\le L-1$

is the correlation of the received training sequence by the original copy of the training sequence, and

$$E(k)=\sum_{n=0}^{L-1}|r_{k+n+l}|^2,\ 0\le n\le L-1,\ 0\le k\le 2\cdot l-1$$

is the received training sequence energy. $2l$ is the length of the observing windows, and L is the selected length of the received signal r. * is the complex conjugate operator.

The Schmidl and Cox metric $M(k)$ is shown in Fig. 4. The expected frame start is computed as a unique sample index k, which minimizes the metric $M(k)$. Unfortunately by observing the metric $M(k)$, it shares an unstable plateau, which size and form are depending on *SNR* values. This makes any direct extremis computation irrelevant or without sense because by taking max($M(k)$) we obtain a set of extremis. From this set of extremis we cannot select anyone, which index k is actually the right one that minimizes the time metric; and at the same time represents the expected frame start. That is the reason why both the frame detection false alarm and the receiver *BER* increase (Fig. 9). Actually WIFI devices, which are available on the market, definitely don't use this Schmidl and Cox algorithm without using their own refinement algorithms (or any third party algorithm). These algorithms are not published by these firms because they represent their know-how and what they are actually selling.

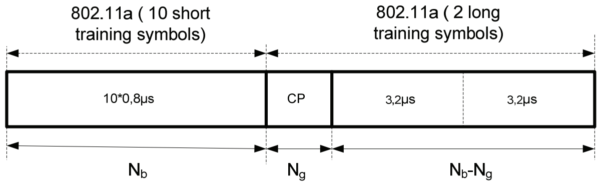


Fig. 3. 802.11a preamble [2] [3].

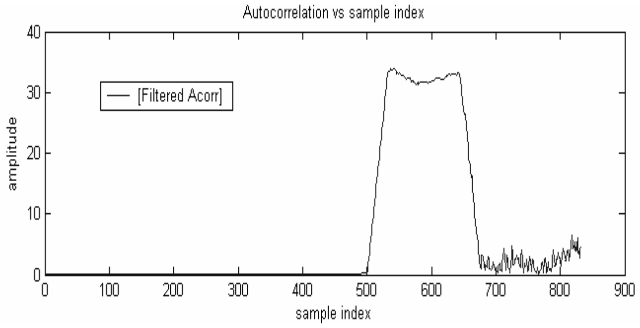


Fig. 4. Schmidl and Cox time metric.

The Minn's training symbol is composed of P identical parts, each with M samples. These P identical parts may differ exactly by their sign (±). The choice of this pattern predefines how the correlation metric looks like (peak sharpness) [3]. This pattern is shown in Tab. 1. The following normalized auto-correlation function $C(r(k),M)$ is the synchronization detection metric or Minn's metric:

$$C(r(k),M)=\frac{(P+1)\left|\sum_{k=-M}^{P\cdot M-M-1} r\ (k+i)\cdot r(k+M+i)\right|}{P\|r(k)\|^2} \tag{4}$$

where $r(k)$ is the received signal. P is the number of identical parts or pattern size (in our case P=4). M is the number of sample per part (in our case M=16).

The frame start (*F_start*) or the beginning of *FFT* windows for the received signal in burst communication mode is defined to be the singleton k, which minimizes the Minn's metric $C(r(k),M)$:

$$F_{start} = \min_{k}(C(r(k),M)) . \tag{5}$$

P	Pattern
4	(– + – –) (+ + + –)
8	(+ + – – + – – –) (– + + – – – + –)
16	(+ – – + + + – – + – + + – + – –) (– – + + – + + – – – – + + + + –)

Tab. 1. Minn's training sequence pattern [3].

For the coarse synchronization, we were mainly interested in the preamble structure.

- Minn+802.11a preamble overview
  The Minn+802.11a preamble is shown in Fig. 3.
- preamble usage
  The preamble was used in our simulation to compute only the coarse time synchronization. The fine time synchronization, frequency offset estimation and the channel estimation were computed using the 802.11a training sequence. As it is known the first four short training symbols for the 802.11a standard are also used for RSSI (Received Signal Strength Indication). During our test case we've replaced these four training symbols by the Minn's training sequence so we cannot say if the received signal strength detection may be done or not. For our simulation we didn't investigate this possibility.
- preamble processing
  Using (4) and (5) we computed the estimation of the frame start with acceptable tolerance (in practice when the expected frame start is found to be at worst inside the cyclic prefix. i.e. $CP=N\_IDFT/4$, where N_IDFT=64).

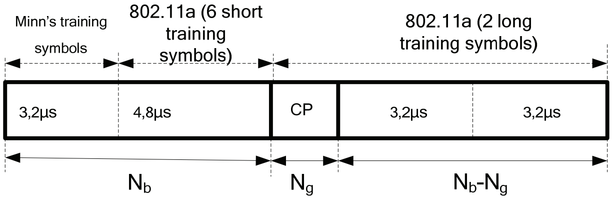


Fig. 5. Mixed Minn+802.11a preamble [2] [3].

The autocorrelation characteristics of the short training sequences (Minn and mixed Minn+802.11a) are shown in Fig. 6 and Fig. 7.

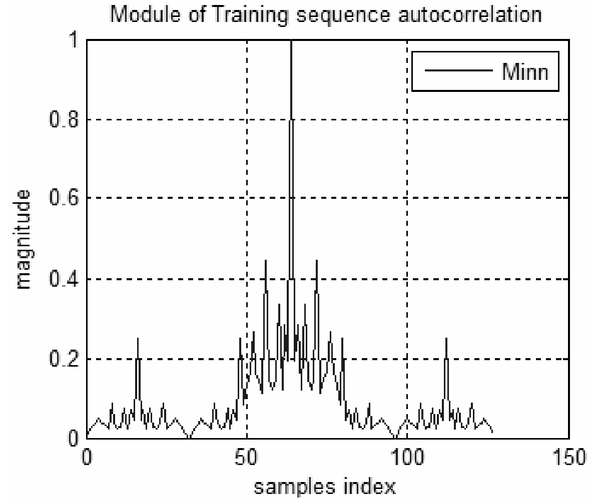


Fig. 6. Minn training autocorrelation.

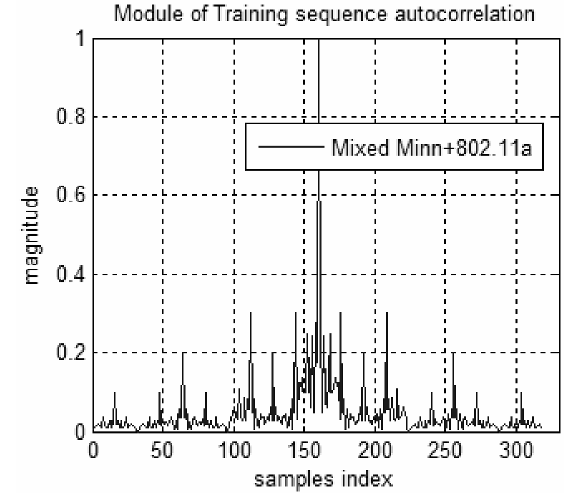


Fig. 7. Minn+802.11a training autocorrelation.

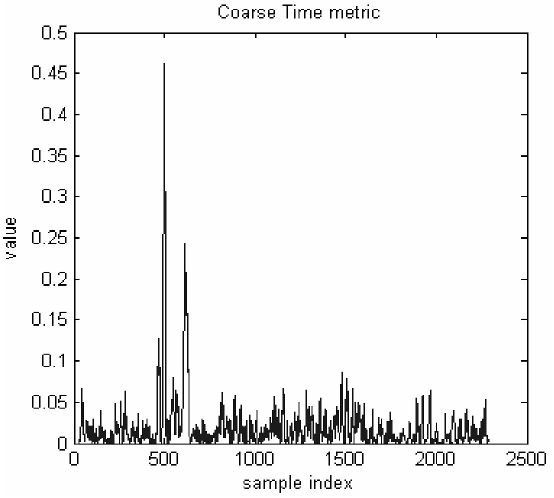
2.2 Receiver Coarse Synchronizer

For the coarse synchronization we've used the Minn's metric $C(r(k),M)$ [3]. The computed metric is plotted for two selected *SNR* values in Fig. 8 (a and b). It is seen that the $C(r(k),M)$ metric has got only one global extremis. This fact reduces the frame start estimation complexity since in this case we've a unique sample index (one global extremis), which minimizes the $C(r(k),M)$ metric. In addition considering that this index is unique, the frame start is computed very easily and more precisely.

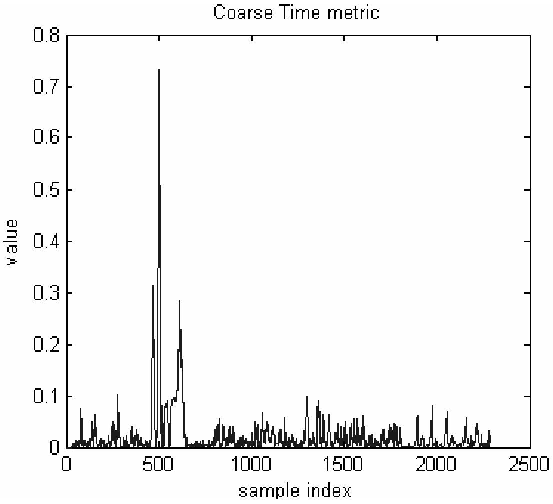
3. Results

To compare the efficiency of these two built training sequences, we've used the 802.11a PHY (physical layer) description. Then we've swapped the preamble for each of the tested preambles and compare the obtaining results. We have tested the performance of the system, when using the Mixed Minn+802.11a training sequence and the standard

802.11a training sequence. A *BER* analysis has been made for comparing the performance of the used synchronization algorithms (respectively Minn's metric and Schmidl and Cox metric for each preamble) from the qualitative point of view. Tab. 2 shows the simulation parameters.



a) SNR=5 dB



b) SNR=20 dB

Fig. 8. Minn's Metric (the frame start is supposed to be *n*=500).

Parameter	Value
Modulation	OFDM
Bandwidth	20 MHz
Carrier spacing	31.25 kHz
Sampling Frequency	320 MHz
Modulation	BPSK, QPSK, 16QAM,64QAM
Cyclic Prefix size	16 samples
FFT size	64 samples
Minn's pattern P	4

Tab. 2. Simulation parameters.

3.1 Algorithm Performance

We've analyzed and compared the overall coarse synchronizer performance for the mixed Minn+802.11a preamble and 802.11a preamble versus *SNR*. The graphs (Fig. 8) show the estimated frame start index (coarse synchronization). The false alarm detection using both preambles is plotted in Fig. 9. These graphs are drawn for both cases, mixed Minn+8021.11a preamble case (Fig. 9 [Optimal]) and 802.11a standard (Schmidl & Cox) preamble case (Fig. 9 [Max]). The performance analysis has been done on four types of digital modulation.

The main remark is that the mixed training sequence even at low *SNR* values is able to find the frame start with a good tolerance by more than 95% whereas the classical 802.11 preamble (using only the Schmidl and Cox algorithm) has got a performance less than 15-20%. This is a considerable improvement against the classical 802.11a receiver with Schmidl and Cox's algorithm. By using the classical Schmidl and Cox's algorithm the performance decreased by more 70% due to the large uncertainty plateau of the time metric characteristic [1].

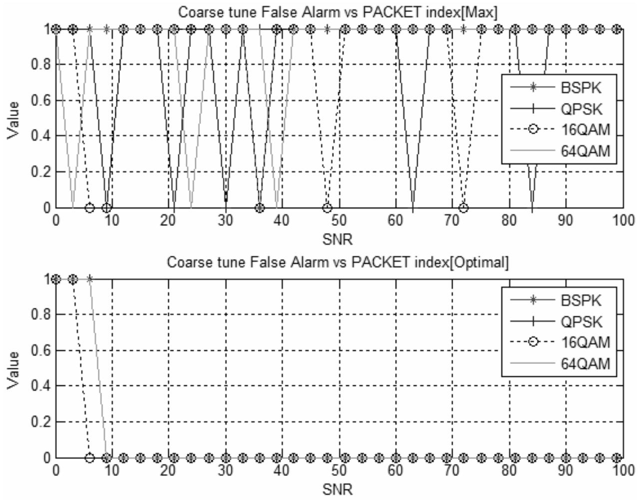


Fig. 9. Coarse synchronization (mixed Minn+802.11a) (Actual_Value=500) and False alarm estimation (Estimated_Value=Actual_Value±35samples).

3.2 Data Error Analysis

For a qualitative comparison of both simulated preambles (regarding also their algorithms) we have investigated the *BER* dependence on *SNR*. Here we have to emphasize that, once we've missed to get the right frame start (miss-detection), we do not have any chance to recover the exact transmitting information data since we do not have any actual knowledge on that, when we should start collecting the received packets (burst transmission mode). In such a case we just collect some wrong data (a mixed of useful data and noise). As a result the *BER* performance radically decreases. Fig. 10 depicts the *BER* dependency on *SNR* for these two methods. Analyzing the graphs we could say that the Minn+802.11a preamble base system performs better than the 802.11a based system.

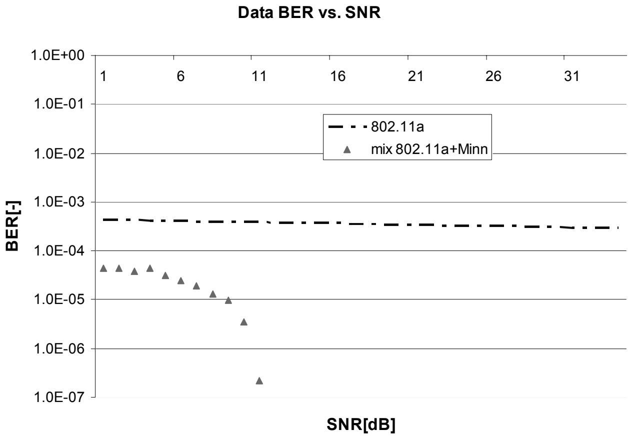


Fig. 10. Received Data BER vs. SNR.

4. Conclusion

Regarding the simulated results we would say that the Minn's training sequence (included the Minn's algorithm) can be used for building more robust OFDM receiver and we do not need to use extra algorithm for refining inaccurate estimations. Moreover it keeps higher the receiver performance. Taking the case, when was used only the Schmidl & Cox's algorithm [1], the receiver suffers from lack of accuracy during frame detection. In contrast to this, by using the mixed Minn+802.11a preamble (included the Minn's coarse synchronization algorithm), the coarse synchronization was almost determined with optimal accuracy even at very low *SNR*. Another use of the Minn's algorithm may be its application to WiMax (802.16a standard).

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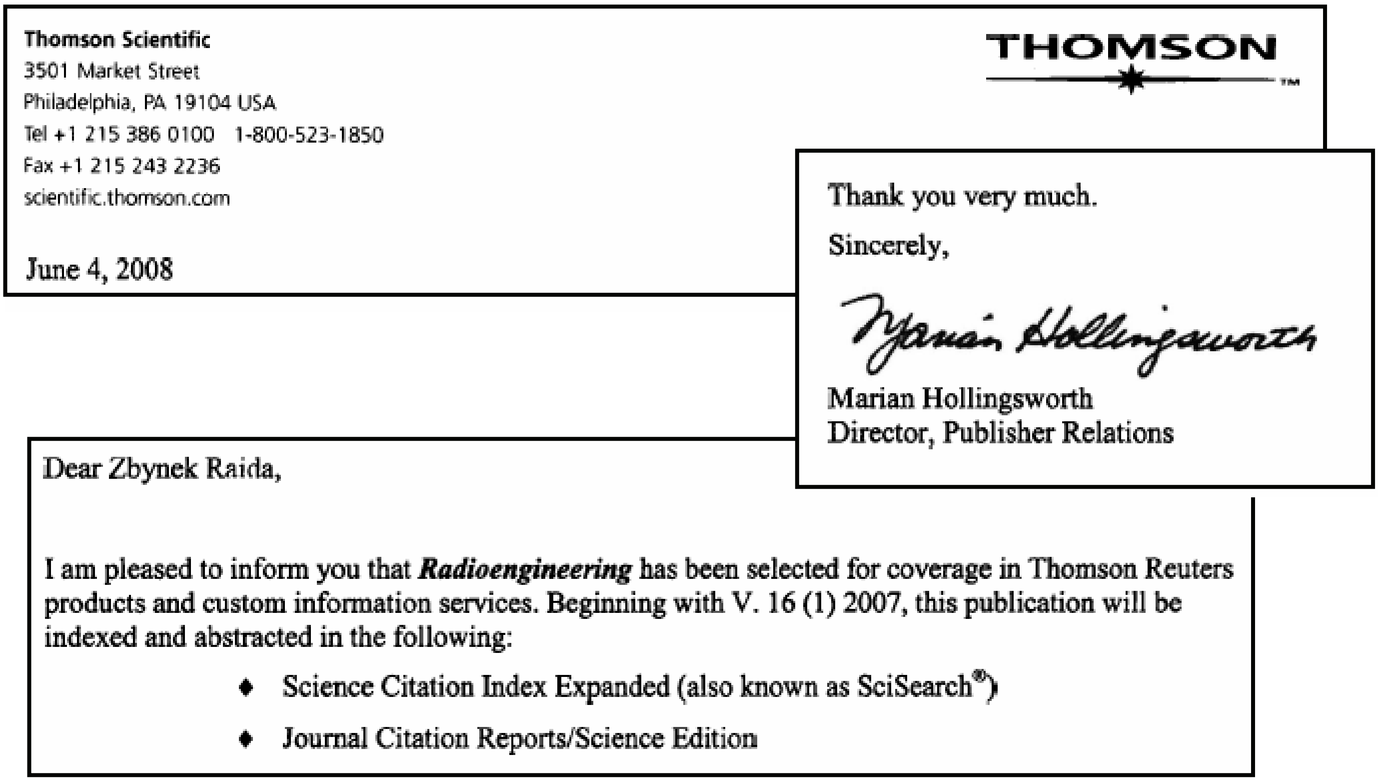
Romeo ONI was born in Benin in 1976. He obtained his master degree in 2003 in Radio Engineering (field UMTS modeling using MIMO channel type) at the Czech Technical University of Prague. He is currently studying a Ph.D (external form) at the Department of Radio Engineering, Czech Technical University of Prague. His research interest includes OFDM systems signal processing (software) and optimization (estimation and synchronization).



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