A Novel Preamble Structure for Robust Timing Synchronization in OFDM system

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***Abstract*- In burst mode OFDM system symbol timing synchronization is done by detecting the long preamble boundary. Under a time dispersive channel the long preamble boundary detection performance deteriorates. In this paper we propose a modification to the conventional preamble structure of burst mode OFDM system for robust symbol timing synchronization. We present through simulation a comparison of the performance of the proposed modified preamble against the conventional preamble in terms of symbol timing synchronization robustness under AWGN and channel condition.**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has gained popularity in high speed wireless and wired digital communication because of its bandwidth efficiency (bits/s/Hz) and inherent ability to mitigate the time dispersive and frequency selective channel at low hardware complexity. Among many applications of OFDM technique, OFDM burst mode communication is gaining more interest in indoor as well as outdoor environment. It has been adopted as a modulation scheme for standards like IEEE 802.11a [1], IEEE 802.16 [2-3] and ADSL [4] etc. This is even being considered as the modulation scheme for IEEE 802.11n standard along with MIMO technology.

OFDM is a multi-carrier modulation where data is transmitted in parallel on overlapping but orthogonal sub-carriers. To maintain the orthogonal nature of the sub-carriers, OFDM symbols are cyclically extended using cyclic prefix (CP) which acts as the guard interval (GI) between the adjacent OFDM symbols and helps mitigate inter symbol interference (ISI) under time dispersive channel. However under a severe time dispersive channel any error in boundary alignment reduces the effective guard interval hence this requires an accurate symbol timing synchronization to detect the OFDM symbols reliably. In conventional burst mode OFDM system the symbol timing synchronization is achieved by detecting the boundary between the short preamble and long preamble exploiting the poor correlation between them through threshold detection. However the performance of this detection scheme deteriorates under time dispersive channel.

In this paper we propose a modification in the preamble exploiting the structure of the short preamble. This modification in the preamble structure helps achieve more robust symbol timing synchronization especially under time dispersive channel compared to a conventional preamble structure.

II. OFDM SYSTEM

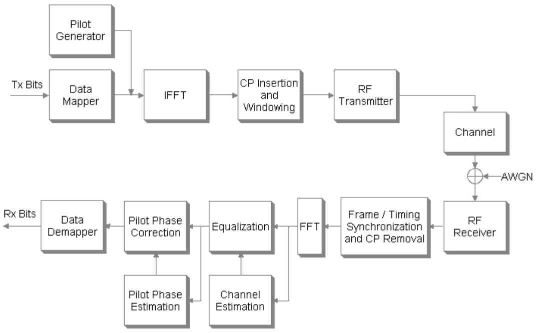

Figure 1 Block Diagram of OFDM System.

Figure 1 shows the simplified block diagram of OFDM transmitter and receiver. The OFDM signal can be generated by taking the Inverse Discrete Fourier Transform (IDFT) of the mapped constellation points (PSK or QAM). Normally the IDFT size is selected as the power of 2 and hence can be implemented using the efficient IFFT algorithm. The output of the IFFT is cyclically extended to generate the OFDM symbol. The time domain OFDM symbol can be expressed as

$$x(t) = \sum_{k=0}^{N-1} X(k) \cdot e^{j\frac{2\pi k \cdot (N - N_{CP} + n) T_s}{N}} \cdot g(t - nT_s)$$

$$t \in \Re \wedge 0 \le t < (N + N_{CP}) \cdot T_s$$

Where g(t) is a pulse shaping filter.

Frame structure for burst mode (packet-based) communication is designed considering Automatic Gain Control (AGC) locking, fast and accurate acquisition of synchronization and channel parameters at the receiver end to detect and decode the transmitted data reliably. These synchronization parameters may include carrier frequency offset, carrier phase offset, symbol timing and sampling frequency offset. To help this packet based communication system frame structure includes preambles (known data) at the beginning of each burst. Conventional burst mode OFDM communication system packet format includes Short Preamble (SP) and Long Preamble (LP) for coarse synchronization and fine synchronization respectively. The Figure 2 below shows the frame format for IEEE 802.11a standard.

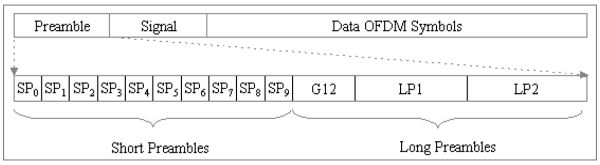

Figure 2 Frame format for IEEE802.11a.

In IEEE802.11a frame format, there are 10 identical repetitive patterns (SP0 to SP9) in short preamble each of duration 0.8µs. The long preambles (LP1 and LP2) are of duration 3.2µs each. Also to be observed that long preamble is pre-pended with GI of duration (1.6µs) double the normal GI duration (0.8µs). From a receiver processing time line perspective, the short preambles are used to train the amplifier gain, detect the frame and estimate coarse synchronization parameters. Long preambles are used for fine synchronization and channel estimation. The receiver has to synchronize the FFT window position to received OFDM symbol for demodulation. This is done by detecting the long preamble boundary through a threshold detection exploiting the poor correlation of SP with LP.

III. SYMBOL TIMING SYNCHRONIZATION

Various threshold detection schemes have been proposed for OFDM symbol timing synchronization [6-11] of burst mode system. This section describes the one used for benchmarking the proposed preamble structure against the conventional preamble. The timing synchronization exploits the good correlation property of short preambles and the poor correlation between the short preamble and long preamble samples. The equations below gives the expression for delay copy correlation (DCC) and local copy correlation (LCC) of the short preamble samples SP(k) with period N and x(n), the received samples.

$$DCC(n) = \sum_{k=0}^{N} x(n+k) \cdot x^{*}(n+k+N)$$

$$LCC(n) = \sum_{k=0}^{N} x(n+k) \cdot SP(k)$$

The Figure 3 and Figure 4 below show the delayed correlation and local correlation of the received frame with conventional preamble structure.

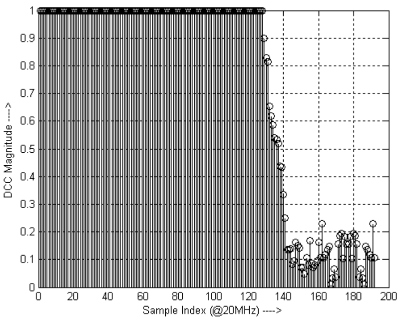

Figure 3 Delay Copy Correlation of received frame.

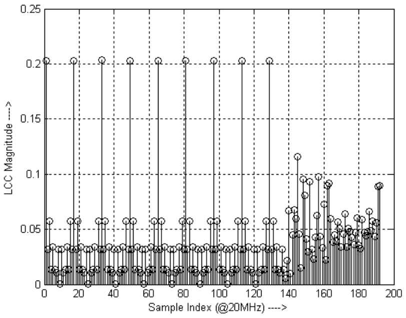

Figure 4 Local Copy Correlation of received frame.

The OFDM symbol boundary is estimated as a threshold detection of the delay correlation along with the maximum local correlation index information.

$$\hat{k} = \arg\max_{k} \{LCC(k) : DCC(k+N) < Th\}$$

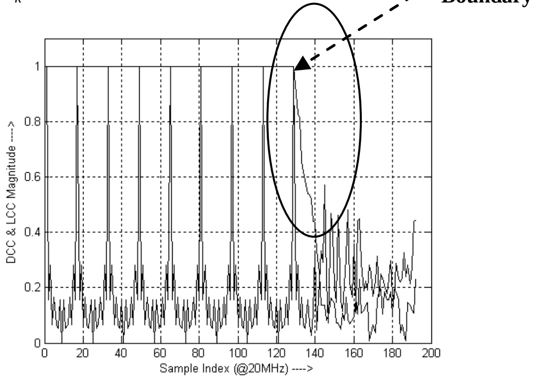

Figure 5 Timing Synchronization in OFDM system.

IV. MODIFIED PREAMBLE

Conventional burst mode OFDM system has short preamble followed by long preamble. Figure 6 shows the frequency domain sub-carrier loading pattern for IEEE802.11a short preamble. Every 4th sub-carrier within the signal bandwidth is loaded except for the DC sub carrier. Because of this loading pattern the IFFT output samples has a periodicity of N/4. The samples corresponding to one period constitute one short preamble. These recurring samples are repeated 10 times to form the short preamble of IEEE 802.11a frame (Figure 2).

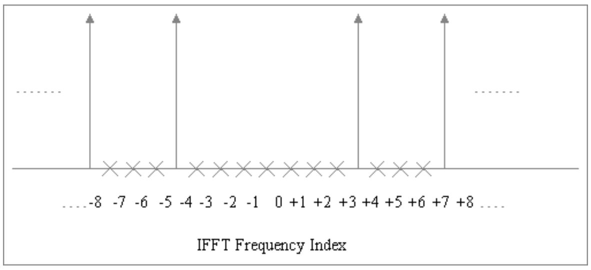

Figure 6 IEEE802.11a short preamble loading pattern.

Because of the particular loading pattern the short preamble samples have the following property. The IFFT output samples are represented by x(n) and is of length N

(=64 for IEEE802.11a). The IFFT output samples for short preamble are periodic with a periodicity of N/4.

$$x(n) = x(N/4 + n)$$

The sum of the first half of one short preamble period is negative of the sum of the later half of the short preamble period.

$$\sum_{n=0}^{N/8-1} x(n) = -\sum_{n=N/8}^{N/4-1} x(n)$$

The power of the first half of the one short preamble period is equal to the power of the later half of the short preamble period.

$$\sum_{n=0}^{N/8-1} \left|x(n)\right|^2 = \sum_{n=N/8}^{N/4-1} \left|x(n)\right|^2$$

Based on these properties we propose the modification of the short preamble by phase reversing the first half of the last short preamble samples as shown in Figure 7.

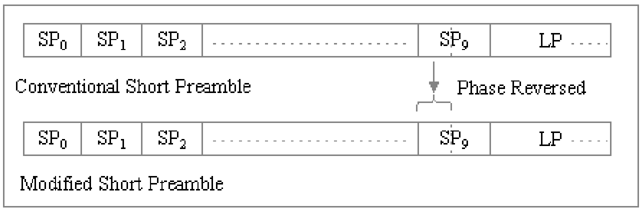

Figure 7 Modified Short Preamble.

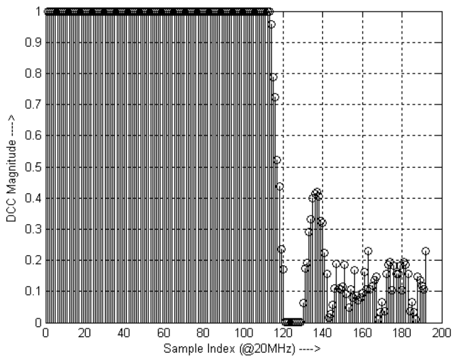

Figure 8 DCC with Modified Short Preamble.

This modification creates a sharp fall in the delayed correlation of the samples at the last short preamble period (Figure 8) and hence helps more reliable estimation of the long preamble boundary especially under high time dispersive channel.

V. SIMULATION RESULTS

The simulation uses the IEEE802.11a preamble and the proposed preamble structure. Channel model used is AWGN and a Rayleigh fading multipath channel with exponential power profile. The fading is modeled as a Wide Sense Stationary Uncorrelated Scattering (WSSSUS) process. We use the timing failure probabilities as defined below to benchmark the performance.

$$P_{tf}(m) = \Pr\{\left|\hat{k} - \mathrm{E}(\hat{k})\right| > m\}$$

$\hat{k}$ is the estimated symbol boundary.

The figures below ([9] to [12]) show the timing synchronization performance in terms of timing failure probability within half the GI duration, i.e., m = 8. It is observed that the proposed preamble structure performs better compared to the conventional preamble structure under all channel conditions.

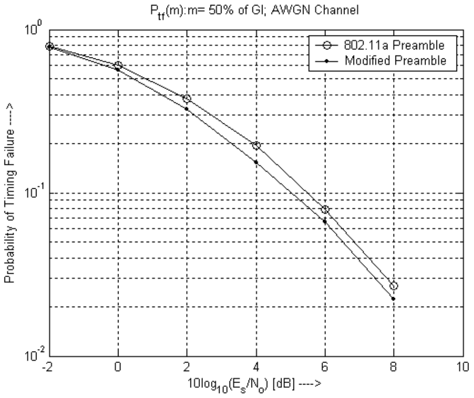

Figure 9 Timing Failure Probability under AWGN Channel.

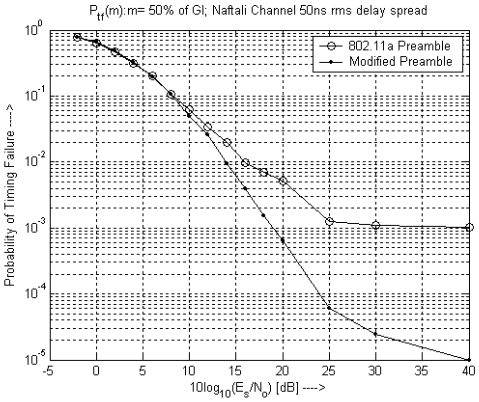

Figure 10 Timing Failure Probability under 50ns RMS Delay spread Rayleigh Fading Channel.

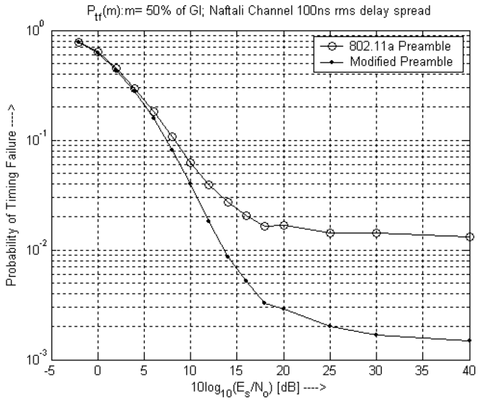

Figure 11 Timing Failure Probability under 100ns RMS Delay spread Rayleigh Fading Channel.

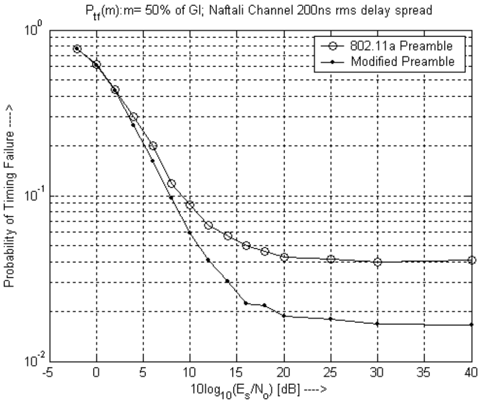

Figure 12 Timing Failure Probability under 200ns RMS Delay spread Rayleigh Fading Channel.

VI. CONCLUSION

A modified preamble structure for burst mode OFDM system has been proposed exploiting the property of the short preamble loading pattern. This modified preamble has been simulated along with the conventional preamble structure under AWGN and Rayleigh fading multipath channel conditions and the simulation results have been presented. It has been observed that the proposed preamble structure gives better performance in terms of timing synchronization failure probability.

REFERENCES

[1] IEEE, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High-Speed Physical Layer in the 5GHz Band", *IEEE Std. 802.11a*, Sept. 1999.

[2] IEEE, "Air Interface for Fixed Broadband Wireless Access Systems – Amendment 2: Medium Access Control and Additional Physical Layer Specification for 2-11 GHz"

[3] IEEE "Air Interface for Fixed and Mobile Broadband Wireless Access Systems – Amendment 2: Physical and Medium Access Control for combined Fixed and Mobile Operations in Licensed band"

[4] "Series G: Transmission Systems and over Media, Digital Systems and Networks. Digital transmission systems – Digital sections and digital line systems – Access Networks. Asymmetric Digital Subscriber Line Systems (ADSL)"

[5] Yasamin Mostofi and Donal C Cox "Mathematical Analysis of the Impact of Timing Synchronization Error on the Performance of an OFDM System", *IEEE Transaction on Communication*, Vol. 54, No. 2, February 2006

[6] Stefan H. Muller-Weinfurtner, "On the Optimality of Metrics for Coarse Synchronization in OFDM: A Comparison", *International Symposium on Personal, Indoor and Mobile Radio Communication (PIMRC'98), Boston, USA*

[7] M. Sandell, J.J. van de Beek, and P.O. Borjesson, "Timing and Frequency Synchronization in OFDM System Using the Cyclic Prefix", *Proceedings of International Symposium of Synchronization*, pages 16-19, Essen, Germany, 1995

[8] T. Keller and L. Hanzo, "Orthogonal Frequency Division Multiplexing Synchronization Techniques for Wireless Local Area Network", *Proceedings of International Symposium of Personal, Indoor and Mobile Radio Communication (PIMC'96)*, pages 963-967, Taipei, Taiwan, 1996

[9] T. M. Schmidl and D. C. Cox, "Robust Frequency and Timing Synchronization for OFDM", *IEEE Transaction on Communication*, vol. 45, no. 12, pp. 1613-1621, 1997

[10] J. J. van de Beek, M. Sandell, and P.O. Borjesson, "ML Estimation of Timing and Frequency Offset in Multi Carrier System", *Research Report, Div. of Signal Processing, Lulea, University of Technology, 1996*

[11] Stefan H. Muller-Weinfurtner, Jurgen F. Robler, and Johannes B. Hubler, "Analysis of a Frame and Frequency Synchronizer for (Bursty) OFDM", *Proc. Of thr 6th Communication Theory Mini Conference (CTMC at Globecom'98)*