IEEE802.11n Time Synchronization for MIMO OFDM WLAN

A. Ali, W. Mahmood, I. Javed, and I. Ur Rehman

***Abstract*—In this paper, a reference time synchronization method [1] is adopted with introduced changed and improved fine and refined time estimation step. The communication system on which it is tested is MIMO OFDM based wireless local area network system. The WLAN standard adopted is of IEEE 802.11n, each data packet starts with a preamble, which consists of short as well as long training symbols. Simulation is implemented with C++ eclipse and tested for AWGN, Exponential Rayleigh Decaying and TGN fading channels. The plots generated by the simulation clearly show the improved performance of the introduced scheme.**

***Index Terms*—IEEE 802.11n, MIMO, OFDM, time synchronization, WIFI, WLAN.**

I. Introduction

The Orthogonal Frequency Division Multiplex-OFDM is an efficient technique for encoding data on multiple carrier frequencies. It has received popularity for wideband digital communication. On different channels or on several parallel data streams spaced orthogonally into sub carriers signals which carry data. For the reason OFDM has the capability to with stand different and severe channel distortions. Although it allows high data rates achievable in fading environment but still it is sensitive to timing errors produced during reception on receiver end. Due to inaccurate frame detection the system performance could degrade. The considered wireless communication system has combined the MIMO spectral efficiency with the robust high data rate throughput of OFDM. Correct time estimation is a complex problem for multiple transmitter and receiver antennas.

In this paper, the algorithm [1] is implemented with modification introduced at the fine and refine time estimation phase after computing AGC (automatic control gain) that reduce computation and improves performance. The present system follows the preamble structure of the IEEE 802.11n [2].

The improved time synchronization technique detects the start of first LTF packet arrival.

There are number of different time synchronization methods for OFDM signals in the literature. This paper introduces some modification at fine time estimation step as well a new refine time estimation step.

Rest of the paper is organized as follows. The Section II describes the systems model. In Section III MIMO Pseudo-Multipath problem is discussed. Section IV explains the proposed improved method. Finally Section V shows results of the simulation. Section VI provides conclusions and references.

II. System Model

A. IEEE 802.11n

The considered wireless system uses wireless LAN standard IEEE 802.11n which provides higher data rates. Also IEEE 802.11n allows wide bandwidth channels with block acknowledgements and frame aggregation for better throughput efficiency. For performance gain it uses multiple-input and multiple-output (MIMO) technology that uses spatial multiplexing and spatial diversity which increases the data rate.

B. Preamble Structure

IEEE 802.11n system supports three physical layers modes. They are Legacy mode, Mixed mode and Green Field mode. This wireless communication system implemented Greenfield mode. This mode does not imply 802.11a/b/g on same channel. Therefore 802.11a/b/g implemented device cannot communicate with Greenfield AP. The preamble structure shown in Fig. 1 is implemented as follow:

L_STF(2 symbols) + HT_LTF_1(2 symbols) +

HT_SIG(1 symbol) + HT_LTF(4 symbols) + Data

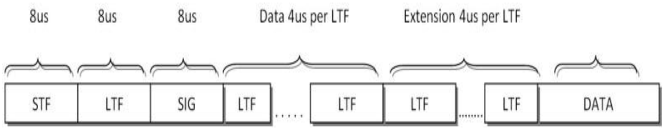

Fig. 1. IEEE 802.11n Preamble Structure

C. MIMO Frame Format

In the considered system the MIMO transmission is implemented by

1) Spatial diversity
2) Spatial Multiplexing

Data subcarriers are encoded over time and space using above listed methods while STFs, LTFs and SIG fields are encoded through OFDM matrix over time and space.

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III. MIMO Pseudo-Path Error

When implementing MIMO wireless system more than two transmitter antennas are used. To avoid beamforming in IEEE 802.11n the system is introduced with cyclic delay diversity CSD scheme. The side effect of this technique may produce pseudo multipath peak detection in MIMO Wlan after cross-correlation [3]. The received signal at one or more than one receiver antennas is the sum of all the transmitted signals through multipath fading channel. The received signal of two transmitter antennas with one receiver can be expressed as follows:

$$m(t) = (T_{11}(t) \times s_1(t)) + (T_{12}(t) \times s_2(t))$$
$$m(t) = \varphi s_1(t) + \phi s_2(t) \quad (1)$$

The above equation shows the correlation function of the two signals transmitted by different transmitters. The resultant signal is the combined of the two transmitters. To attain a highest peak of first transmitter during time estimation, an error can be produced as two or more than two peaks could be produced depending on the number of transmitter used which can be determined through ϕ and φ as expressed in (1) which are channel gains of flat fading channel.

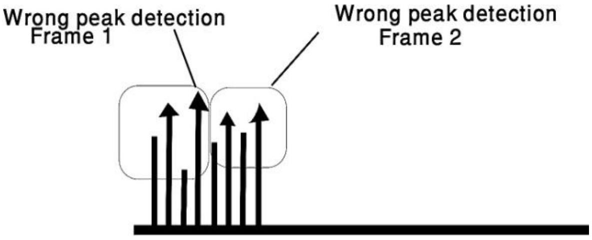

Fig. 2. Pseudo-Multipath Problem.

In the above Fig. 2, a pseudo multipath error is shown. For instance the received signal is combinations of two transmitter antennas stream therefore four peaks are detected. The maximum peak is of second transmitter antenna (as depicted in Fig. 2 whereas for correct time synchronization first peak i-e of first transmitter antenna arrival preamble is expected. Further cyclic shift diversity is explained in sub section A.

A. CSD-Cyclic Shift Delay

Cyclic shift delay diversity is added in the transmitted signal by rest of the transmitters except first transmitter to avoid intra interference of transmitted signals. It is a process implemented during spatial multiplexing. Fig. 3 shows the concept visually.

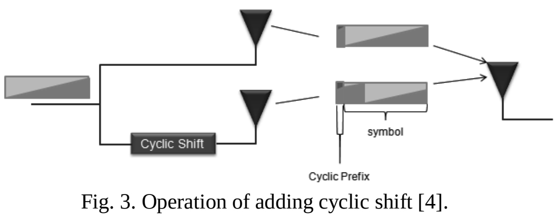

Fig. 3. Operation of adding cyclic shift [4].

IV. Improved Method

In this approach time synchronization is performed using the short and long preamble. The improved algorithm included three steps, first is the estimation of coarse time delay, second step finds fine time estimated delay and second max index and third step performs comparison on the fine estimate time delay to find the refine time estimate delay.

A. Coarse Time Synchronization

After doing AGC control, auto-correlation is performed according to [1].

$$\Theta_a^{\,j}(n) = \sum_{l=0}^{L_1-1} \Big\{ |rj^*(n+l)rj(n+l+Ls)| \ldots - \frac{\psi_{SNR}}{2}\left(|rj(n+l)|^2 + |rj(n+l+Ls)|^2\right) \Big\} \quad (2)$$

Further the generated metric by (2) is updated by performing Maximum Ratio-Combining (MRC) as explained in [1]. After performing sliding differentiator operation on the MRC updated metric, metric $\Xi_a(n)$ is obtained. Maximum value is selected to detect a peak for coarse time estimation, mathematical form is shown in (3).

$$t_a = \arg\max_n \{\Xi_a(n)\} \quad (3)$$

B. Fine Time Synchronization

Next step is to calculate fine time estimate value. Fine time estimate is achieved by performing in (4) cross-correlation between known long preambles and received signal [1]. Window size can be adjusted according to the different situations.

$$\Theta_c^{\,j} = \left| \sum_{l=0}^{Lt-1} r_j^*(n+l) s_{LTS}(l) \right| \quad (4)$$

Again after performing MRC on the computed cross-correlated metric for combining the result based on different number of receivers, Signal-to-interference Metric is generated by [1]. According to [1] the signal-to-interference-ratio (SIR) metric is concatenated to cross-correlated metric. Hence a metric $\Xi_c(\tau)$ is computed. The highest peak is detected from the resultant metric which is defined as fine time estimate value. The equation is written in (5).

$$t_c = \arg\max_{\tau \in Wc} (\Xi_c(\tau)) \quad (5)$$

In the improved introduced method a second highest peak is detected as well which is referred to as second index I_2 obtained in (6).

$$I_2 = \arg\max_{\tau \in Wc} \{\Xi_c(\tau)\} < t_c \quad (6)$$

C. Refine Time Synchronization

Refine time estimation process is divided into small three comparison cases. In refine time estimation phase a comparison is performed between fine time estimate value "t_c" and calculated second index "I_2". There is an assumption that is considered in this approach that is according to the preamble structure which is used during transmission according to packet transmission long preambles are sent more than one time.

Furthermore during cross-correlation (4) the LTF preambles are correlated repeatedly with different parts of the signal for precise detection of the first occurrence of long preamble. In the above method the fine time index "t_c" is assumed to be the peak of detected long preamble. So the next or previous repeated long preamble should or should have occurred with a difference of one long preamble length in an ideal case and the second long preamble peak would be calculated second index "I_2".

Now let's consider the following situations that might be able to possibly occur.

Case 1: $t_c - I_2 = L_{Ltf}$

Case 2: $t_c - I_2 > L_{Ltf}$

Case 3: $t_c - I_2 < L_{Ltf}$

In all of the above cases, where L_{Ltf} is length of LTF and the fine estimated value "t_c" is examined through some checks before considering it the final estimated time delay or refine time estimate value. Before calculating the refine time estimate, a threshold is created according to following computation.

$$A = \frac{1}{n}\sum r \quad (7)$$

Through equation (7) an average is calculated where "n" is the length of the received signal that is known at the receiver end and "r" is the received signal. For processing through the threshold the value is divided by the average "A" to get the percentage value with reference to the rest of the received signal. According to the computed value of "A" threshold is set to 10. For further steps, computed metric $\Xi_c(\tau)$ is used.

Pseudo-Multipath Check:

In this step fine estimate value "t_c" is processed to check whether it is peak detected from second transmitter antenna or the original one.

$$(\Xi_{tc} / A \times 100) / (\Xi_{tc-CSD} / A \times 100) > threshold \quad (8)$$

If (8) results true then it is considered that the detected peak is not the original one and CSD value is subtracted from fine time estimate index. Therefore the new or refine time index will be (9)

$$t_f = t_c - CSD \quad (9)$$

First long preamble Check:

In this scenario the purpose is to detect first occurred long preamble.

$$(\Xi_{tc+(L_{LTF}\times 2)}) > (\Xi_{tc} \times 0.3) \quad (10)$$

In (10) results true then it is considered that the detected peak is not first original one and long preamble value is subtracted from fine time estimate index. Therefore the new index i-e refine time estimate will be (11)

$$t_f = t_c - (L_{Ltf} \times 2) \quad (11)$$

Second long preamble Check:

In this scenario the purpose is to detect second occurred long preamble.

$$(\Xi_{tc+L_{LTF}}) > (\Xi_{tc} \times 0.3) \quad (12)$$

If (12) results true then it is considered that the detected peak is not the first original one but second long preamble detected and long preamble value is subtracted from fine time estimate index. Therefore the refine time estimate will be (13).

$$t_f = t_c - (L_{Ltf} \times 3) \quad (13)$$

Third long preamble Check:

In this scenario the purpose is to detect third occurred long preamble.

$$(\Xi_{tc-L_{LTF}}) > (\Xi_{tc} \times 0.3) \quad (14)$$

In (14) results true then it is considered that the detected peak is not the first original one but third long preamble detected and long preamble value is subtracted from fine time estimate index. Therefore the refine time estimate will be (15).

$$t_f = t_c - (L_{Ltf} \times 4) \quad (15)$$

V. Simulation and Results

The simulation was achieved through Visual C++. For testing, different modulation techniques were applied at different Eb/No values on approximately 8 million data packets in AWGN and Exponential Rayleigh Decaying Fading Channel as well. Testing was also achieved for TGN Fading Channel for profile B and D where similar results were obtained.

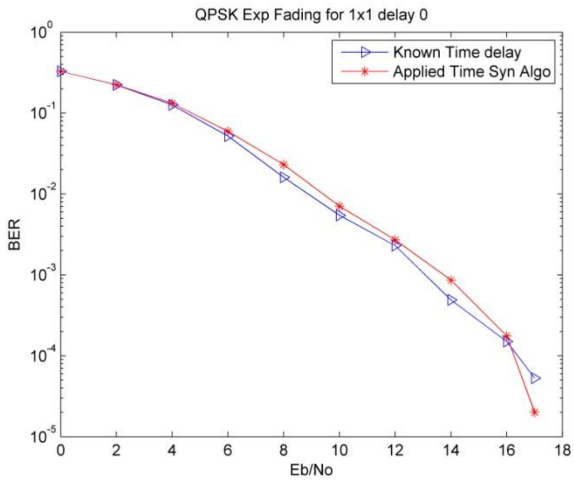

Fig. 4: QPSK T×R(1×1) in Exp Rayleigh Fading.

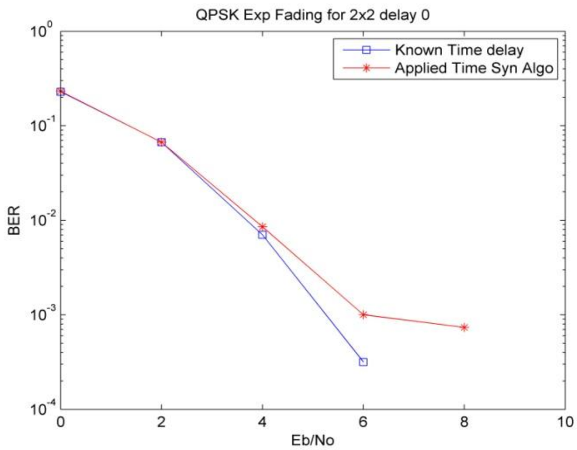

Fig. 5. QPSK T×R(2×2) in Exp Rayleigh Fading.

Fig. 4 clearly shows the variation between perfect time synchronization (known time delay) and the applied time synchronization technique. The simulated curves are similar to perfect time synchronization with little difference in Exponential Rayleigh decaying fading channel for one transmitter and one receiver.

In this Fig. 5 MIMO- meaning multiple number of transmitters and receivers are used. The result is similar to perfect time synchronization plot with little deviation for two transmitter antennas and two receiver antennas.

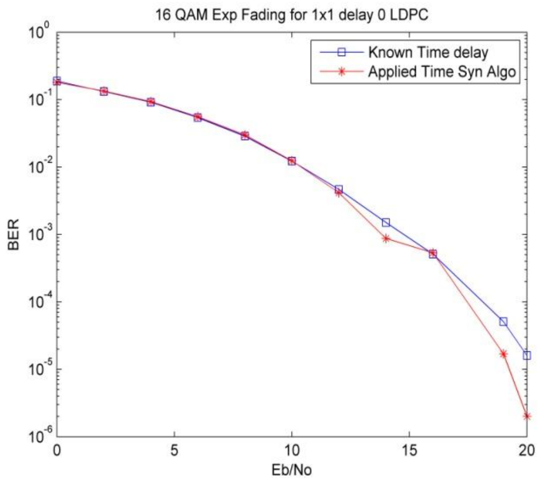

Fig. 6. 16QAM T×R(1×1) LDPC

Fig. 6 clearly depicts the improved performance of applied time synchronization technique with LDPC decoder in Exponential Rayleigh fading channel using 16 QAM modulation approach.

VI. Conclusion

The applied improved technique clearly shows from the simulation plots that it can perform near perfect in both single and multiple transmitter antennas in MIMO OFDM wlan system using standard IEEE 802.11n. The unique part of this technique is its good performance in lower SNR values for both single as well as multiple antennas in fading channels and TGN fading channels [5].

References

[1] D. Wang and J. Zhang, "Timing Synchronization for MIMO-OFDM WLAN Systems," *IEEE Wireless Communication and Networking Conference 2007*, pp. 1177-1182, March 2007.

[2] IEEE 802.11n D9.0,"Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," March 2009.

[3] M. Cho, Y. H. Jung, and J.-S. Kim, "Symbol Timing Synchronization for IEEE 802.11n WLAN Systems," in *Proc. First Asian Himalayas International Conference 2009*, pp. 1-6, 2009.

[4] K. Chen, *Linear Networks and Systems*, Belmont, CA: Wadsworth, 1993, pp. 123-135.

[5] P. Thomas and O. Tokunabo, "Wireless LAN Comes of Age: Understanding the IEEE 802.11n Amendment," in *Proc. Circuit and Systems Magazine 2008*, IEEE vol. 8, issue 1, March 2008, pp. 28-54.

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