

New Timing Metric for the Frame Synchronization in WiMAX OFDMA Applications

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Abstract— This paper studies the frame synchronization of Orthogonal Frequency Division Multiple Access-Time Division Duplexing (OFDMA-TDD) systems and proposes a new method for downlink of IEEE 802.16 to improve frame synchronization performance. In this paper, we adapt three existing timing metrics for frame synchronization in OFDM mode of WiMAX. Among the methods considered, it is shown that direct application of these metrics, is not possible for frame synchronization in OFDMA mode of WiMAX. Modifications to these timing metrics are done to adapt them for OFDMA mode. Simulations are conducted for AWGN and frequency selective channels to demonstrate the performance of the modified timing metrics. Simulation results show that the proposed method outperforms the existing algorithms in both frequency selective and AWGN channels and is robust to the range of the timing offsets and carrier frequency offset (CFO).

Keywords— OFDM, OFDMA, Timing synchronization, AWGN, Rayleigh fading channel, correlation

1. INTRODUCTION

Nowadays, Orthogonal Frequency Division Multiple Access (OFDMA) has attracted a lot of attention due to its high spectrum efficiency and intrinsic robustness to narrowband interference [1]. It has been adopted in the uplink of wireless communication systems [2], [3] and cable TV networks [4]. OFDMA has been accepted as the downlink technique for evolved universal terrestrial radio access (EUTRA) systems. Also, in the most recent standardization effort of the 3rd generation partnership project, both frequency division duplexing and timing division duplexing are considered as duplex modes to be supported. However, similar to Orthogonal Frequency Division Multiplexing (OFDM), OFDMA is highly sensitive to symbol timing errors. Synchronization is an important issue in transceiver design, especially for coherent wireless transmission. In WiMAX systems, based on the IEEE 802.16e OFDMA physical layer specifications, synchronization involves synchronization of carrier frequency and timing as well as identification of the preamble index. Various algorithms have been proposed for the synchronization in OFDM systems. But some problems appear, when we want to use them in OFDMA synchronization. This problem originates from the special structure of WiMAX preamble, which limits a big group of

mentioned methods. Some of these solutions are modified for WiMAX synchronization, and several methods have proposed specially for WiMAX. J. J. Van de Beek et al. [5] was the first one who observed that the data itself contains sufficient information in the form of cyclic prefix (CP) for OFDM symbol synchronization. Beek et al. extended the maximum likelihood (ML) estimator based on the redundancy introduced by the cyclic prefix. But it has a good performance, only in AWGN channels, and fails to work in Inter-Symbol Interference (ISI) channels. In recent years, Schmidl and Cox (S&C) [6], Nanda Kishore and Reddy [7], and Meng wu [8] proposed more accurate methods for OFDM synchronization. But all of above methods either have a plateau or some sub peaks that make uncertainly in timing synchronization. Timing synchronization is the first action in OFDM, OFDMA receiver because if the FFT window doesn't match on a window of data, we will lose the subcarriers orthogonally and detection will be impossible. We propose a receiver algorithm for downlink of IEEE 802.16 [9]. In our proposed method; we use two sub metrics, which one of them can remove sub peaks of other metric. As a result, our main metric will have one peak, and the mean square error (MSE) of our method will decrease significantly in multipath fading channels.

The following sections of this paper are organized as follows: in Sect. 2, we have a review on OFDMA downlink. In Sect. 3, we present the existing methods and their advantages and disadvantages. In Sect. 4, we introduce our proposed algorithm. In Sect. 5, we present the simulation results. Finally, in Sect. 6, we will provide the conclusions.

2. FUNDAMENTALS OF OFDMA

In this section we will have a review on OFDMA and downlink structure for WiMAX applications. The first symbol of the downlink transmission is the preamble (Fig. 1.1). There are six types of preamble carrier-sets, witch are defined by allocation of different subcarriers for each of them. The subcarriers are modulated using a boosted BPSK modulation with a specific Pseudo-Noise (PN) code [9]. The preamble carrier-sets are defined using below Equation:

$$\text{Preamble Carrier Set}_n = n + 3 \times k$$

Where:

- *Preamble Carrier Set_n* specifies all subcarriers allocated to the specific preamble.
- *n* is the number of the preamble carrier-set indexed 0, 1, 2.
- *k* is a running index 0, 1, ..., 567.

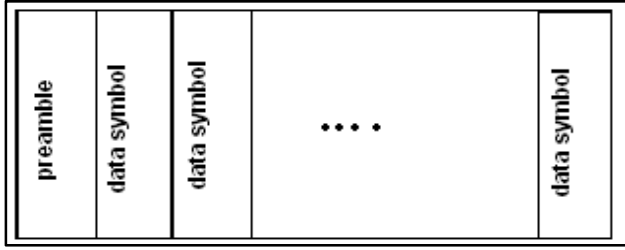


Fig. 1.1 An OFDMA downlink symbol [9].

Each segment uses a preamble composed of a carrier-set out of the three available carrier-sets in the following manner: (In the case of segment 1, the DC carrier will not be modulated at all, and the appropriate PN will be discarded; therefore, DC carrier shall always be zeroed. For segment 2, the last carrier shall not be modulated).

- Segment 0 uses preamble carrier-set 0
- Segment 1 uses preamble carrier-set 1
- Segment 2 uses preamble carrier-set 2

Therefore, each segment eventually modulates each third subcarrier. As an example, Fig.1.2 depicts the preamble of segment 1.

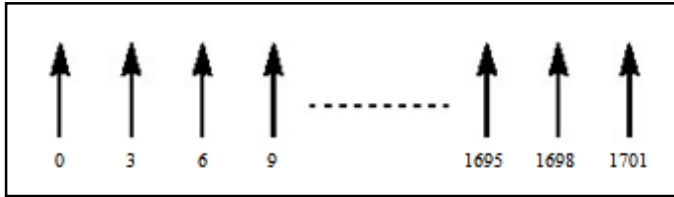


Fig.1.2 Preamble structure for segment 1 [9].

The PN series modulating the pilots are defined in [9]. The series modulated depends on the segment used and ID-cell parameter. The defined series shall be mapped onto the preamble subcarriers in ascending order. Mentioned reference ([9]) includes the PN sequence in a Hexadecimal format. The value of the PN is obtained by converting the series to a binary series, and starting mapping the PN from the MSB of each symbol to the LSB (0 mapped to +1 and 1 mapped to -1). The preamble length, 2048, is not divisible to 3, thus we have three blocks (A, B, and C) with length of 682 in time domain that are not similar to each other, but have good cross correlation. Blocks A, B, and C begin from 0 to 681, 682 to 1363, and 1366 to 2047 respectively. In WiMAX, the segment in a cell is known by ID-cell and number of segment. Each segment has its own preamble.

3. SYNCHRONIZATION ALGORITHMS

In this section we will have a short review on four adopted methods for OFDM applications and will consider their advantages and disadvantages.

3.1 BEEK'S METHOD

J. J. Van de Beek et al. [5] observed that the data itself contains sufficient information in the form of cyclic prefix (CP) for OFDM symbol synchronization. Exploiting this additional information provided by CP, they obtained the log-likelihood function for joint estimation of symbol timing error and frequency offset. The timing metric $M(d)$ used for this purpose is:

$$M(d) = |P(d)| - \alpha R(d) \quad (1)$$

Where $P(d)$ represents the correlation between two sequences of CP interval length, spaced N samples apart in the received sample stream, given by:

$$P(d) = \sum_{k=0}^{N/2-1} r^*(d+k) \times r(d+k+N) \quad (2)$$

Where $r(d)$ represents samples of baseband equivalent received signal. The term $R(d)$ is given by:

$$R(d) = 1/2 \sum_{k=0}^{N/2-1} [|r(d+k)|^2 + |r(d+k+N)|^2] \quad (3)$$

And α represents the magnitude of the correlation coefficient between $r(n)$ and $r(n+N)$, which is expressed as:

$$\alpha = \frac{E_b}{E_b + N_0} = \frac{SNR}{SNR + 1} \quad (4)$$

There are some problems with this method. In the fading scenarios, the number of uncorrupted samples of CP available is small which can lead to erroneous results with this CP based method. Because of CP corrupting that happens in multi path channels, we should work on methods that consider some blocks for timing synchronization.

3.2 SCHMIDL AND COX METHOD

A popular approach is the use of some reference blocks exhibiting a repetitive structure in the time domain. S&C, employed reference block composed by two identical halves at the beginning of each frame. The Schmidl's timing estimation method shows the start of the frame as the maximum point of the following metric:

$$M(d) = \frac{|P(d)|^2}{(R(d))^2} \quad (5)$$

Where

$$P(d) = \sum_{k=0}^{N/2-1} r^*(d+k) \times r(d+k+N/2) \quad (6)$$

And

$$R(d) = \sum_{k=0}^{N/2-1} |r(d+k+\frac{N}{2})|^2 \quad (7)$$

This timing metric has a large plateau that reduces the accuracy of the timing metric (Fig.2) [10].

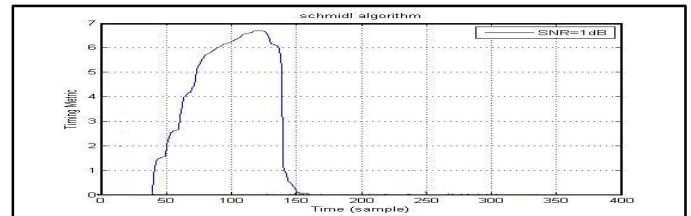


Fig.2. Plateau of Schmidl method.

3.3 REDDY METHOD

Nanda Kishore and Reddy [7] assumed that the PN sequence loaded in the transmitted preamble is known to the receiver and proposed a method for frame synchronization algorithm.

Let $B(n)$ for $n = 0, 1 \dots M - 1$, represents the transmitted time domain samples in one-half of the preamble which are known to the receiver. Mathematically, Reddy's frame boundary estimator is given by (7).

$$P(d) = \sum_{k=0}^{M-1} [r(d+k)B(n)]^* \times [r(d+k+N)B(n)] \quad (8)$$

Reddy's frame boundary estimator eliminates the plateau present in Cox's frame estimator and yields a sharp peak at the frame boundary. One drawback with this frame synchronization algorithm is that the transmitted PN sequence should be known to the receiver, which is not possible in many applications. Especially in WiMAX, we have 113 different preamble structures (due to [9]). So a WiMAX system that works with Reddy's method should do this operation on 113 different preambles and registers their results, compares them together to find the proper preamble that is used for transmitting. After these heavy operations, the frame start point could be found. Also this method shows very high distortion in some multipath fading channels (it will be showed in sect. 5) that limits its operation only for AWGN channels and some quasi-static channels.

3.4 MENG METHOD

Meng Wu and Wei-Ping Zhu [8] proposed complex conjugate symmetry method as a part of frame boundary estimation using the preamble suggested in OFDM mode of WMAN [11]. This preamble consists of two parts, referred to as short preamble and long preamble. The short preamble consists of four repeated 64-sample blocks, and the long preamble consists of two repeated 128-sample blocks. Meng Wu applied Cox's method on the short preamble to get an initial timing estimate. Then he exploited the complex conjugate symmetry in the first and second halves of the long preamble. The output of the timing metric yields two peaks. It was the result of below metric:

$$P(d) = \sum_{k=0}^i r(d+i) \times r(d-i+M) \quad (9)$$

Where, M is length of summation. Wu and Wei-Ping Zhu have not specified any detection procedure to identify the frame boundary, which lies at the first peak. We modified this method for WiMAX application (part 5) and as you will see in simulation part, it has some peaks in irrelevant points. It is very hard to detect main peak between sub peaks, so this method doesn't functionality with its own.

3.5 NEW RESEARCHES ON SYNCHRONIZATION

In recent years, many new methods are proposed for timing synchronization in wireless systems. These new methods have an unquestionable operation, in comparison with old methods (a sharp peak, without sub peaks). But these methods increase the complexity of system. In this part we have a look on some of them.

3.5.1 KWANG SOON KIM'S METHOD

Kwang Soon Kim and his coworkers [12], proposed a novel preamble-based synchronization method for OFDM cellular systems. The preamble is composed of the S-field and the C-field. The corresponding synchronization algorithm is constructed in a hierarchical approach. The synchronization algorithm includes the initial symbol-timing estimation, the initial frequency-offset estimation, the frame detection, the fine symbol-timing estimation, and the frequency-offset estimation.

3.5.2 TEJAS BHATT'S METHOD

Tejas Bhatt and his coworkers [13] proposed an initial synchronization scheme for time and carrier frequency synchronization and cell identification in 802.16e OFDMA downlink. The proposed method does not require knowledge of actual transmitted preamble, but only utilizes the preamble structure and inverse Fourier transform properties to obtain time/frequency synchronization. They showed that the proposed synchronization method is suitable in multipath as well as multi-cell environment.

3.5.3 ERNEST SEAGRAVES' METHOD

Ernest Seagraves, Christopher Berry, and Feng Qian proposed modification to the metric calculations that increases the dynamic range by about 1 dB. Also, they proposed detection metric that utilizes the redundancy in the preamble and its cyclic prefix using a masking scheme, which offers an improvement of about 3dB over existing techniques [14].

3.6 SUMMARY

The common factor in most preamble-based techniques is repetitive parts in the preamble. But, IEEE standards for OFDMA mode of WiMAX specify loading on every third subcarrier of the preamble with FFT size 2048. There are not identical parts of the preamble as 2048 is not divisible by 3. Thus, direct application of existing timing metrics for frame boundary estimation of OFDMA mode of WiMAX is not possible. In the section to follow, we present a new method that uses the modifications to the existing frame algorithms to suit to the preamble corresponding to OFDMA.

4. PROPOSED METHOD

In sect.3, we saw the advantages and disadvantages of three kinds of methods. First group (S&C and their modified versions) has a high value in the frame start point (with unwanted plateau) and has low value in other points. Second group has a peak in start point but also has some sub peaks in other points that make it hard to find the main peak. The third group (mainly new methods) has a sharp peak without sub peaks, but with an intolerable complexity. Our method is using sub metric with plateau to remove sub peaks that appears in sharp metrics. We design our method base on partial product of two sub metrics that have opposite operation. $P_1(d)$ has a plateau in correct point and has very little value in other points. But $P_2(d)$ has some peaks in irrelevant points

and one main peak in correct point. We can remove sub peaks with using $P_1(d)$ as a filter. So our metric is as below:

$$P_1(d, i) = \sum_{k=0}^i r^*(d + k) \times r(d + k + L) \quad (10)$$

$$P_2(d, i) = \sum_{k=0}^i r(d + k) \times r(d - k + N) \quad (11)$$

$$P(d) = \sum_{i=0}^M P_1(d, i) \times P_2(d, i) \quad (12)$$

$$M(d) = |P(d)|^2 \quad (13)$$

$$\hat{\tau}_{sto} = \underset{d}{\operatorname{argmax}} [M(d)] \quad (14)$$

Where, L and M are length of summation and time delay for correlation respectively. Our metric is consisting of two sub metrics. One of them is a modified version of Meng Wu that has some peaks in irrelevant points, and the other is a modified version of S&C method, and finally our main metric combines this two metrics. For obtaining a better performance, we can combine sub metrics with different powers. Base on many simulations in different situations, we conceived that using 4, as the power of P_2 , and using 2, as the power of P_1 , eliminates sub peaks seriously. So, we will have a tradeoff between complexity and accuracy. The new form of (10) yields to more accurate results, but it increases the complexity of system.

$$P(d) = \sum_{i=0}^M P_1(d, i)^4 \times P_2(d, i)^2 \quad (15)$$

This combination helps our metric to have advantages of both of sub metrics and remove disadvantages of both of them. Two sub metrics and our main metric are depicted Sect. 5.

5. SIMULATION RESULTS

The performance of the proposed Metric will be examined in this section, and it would be compared with 2 other metrics that were explained in sect.3. (Reddy and Meng Wu). For our simulations, we consider WiMAX system with its special preamble. Without losing generally, we will use the first preamble that is described in table (302) [9]. This preamble (in hexadecimal format) is as follow:

C12B7F736CFFB14B6ABF4EB50A60B7A3B4163EA3360F697
C45075997ACE17BB1512C7C0CEBB34B389D8784553C0FC60
BDE4F166CF7B04856442D9753 9FB915D80820 CEDD 85848 3

For our metric, we assume the M (summation length) =682, L (delay for correlation) =682. Operation of our metric is examined under AWGN and multipath fading Rayleigh channels. The specifications of two different multipath fading channels are in below:

Channel Type: 'Multipath Fading Rayleigh 1' → 'MFR1'

Input Sample Period: 1.0000e-005

Max Doppler Shift: 130

Avg. Path Gain dB: [0 -3 -3]

Path Delays: [0 1.5000e-005 3.2000e-005]

Path Gains: [-1.3801 - 0.1370i -0.0255 - 0.0551i -0.5203 - 0.3983i]

Channel Type: 'Multipath Fading Rayleigh 2' → 'MFR2'

Input Sample Period: 1.0000e-005

Max Doppler Shift: 130

Path Delays: [0 1.5000e-005 3.2000e-005 3.2000e-007 3.2000e-009]

Avg. Path Gain dB: [0 -3 -5 -7 -10]

Path Gains: [-0.0820 + 0.1132i -0.2719 + 0.1635i 0.1374 + 0.0963i 0.2384 + 0.2673i 0.0057 + 0.0949i]

Performance of this metric is evaluated with calculating the MSE of Meng Wu, Reddy, and proposed metric. Schmidl's method has a big MSE and we don't consider it in our calculations. In Fig.3, proposed method and mentioned methods is compared base on the sharpness of peak which is a sign of accuracy in performance.

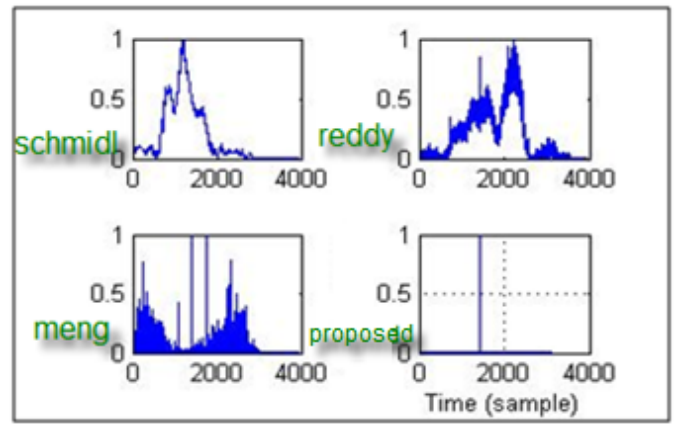


Fig.3. Comparison between Schmidl, Reddy, Meng Wu, and proposed methods in Multipath Fading Rayleigh Channel.

Fig. 4 illustrates the STO acquisition MSE in AWGN channel where it is readily apparent in the graph that the proposed symbol timing offset estimation algorithm can obtain obvious CAP enhancement compared with Reddy and Meng Wu method at any SNR range. Similarly, Fig.5, 6 demonstrates the same simulation in multipath fading channels that was described before. Can be seen in Fig.6, in quasi static channels, Reddy, Meng Wu and proposed metric have acceptable performance but in low SNR, operation of Reddy is not reliable. In Fig. 6, we examined Reddy, Meng Wu, and proposed Method in second configuration of Multi Rayleigh Fading channel (MFR2). It is clear that Reddy method has the worst functionality in this channel, even in high SNR. But Meng Wu and Proposed method have their best operation in this channel.

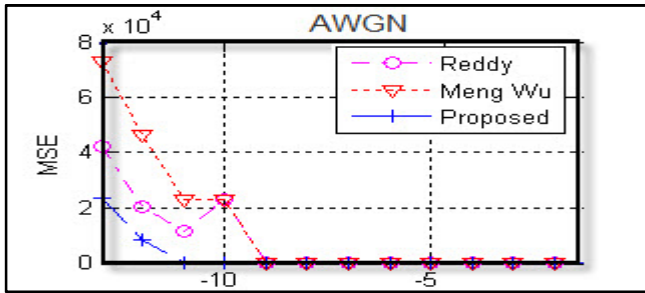


Fig.4. Comparison between MSE of Reddy, Meng Wu, and Proposed Method in AWGN channel. The proposed method has the least MSE.

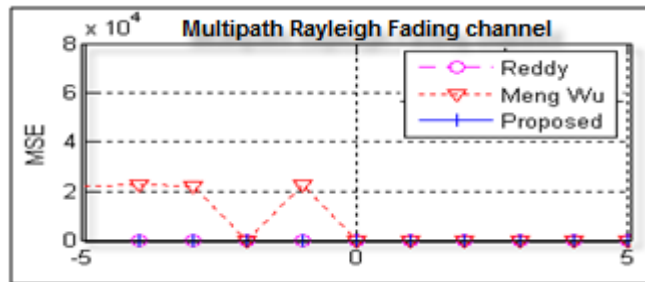


Fig. 5 Comparison between MSE of Reddy, Meng Wu, and Proposed Method in Multipath Fading Rayleigh channel that described before (MFR1). This channel is quasi-static. Operation of Reddy in low SNR is not reliable, and Meng Wu has some irrelevant peaks in this channel.

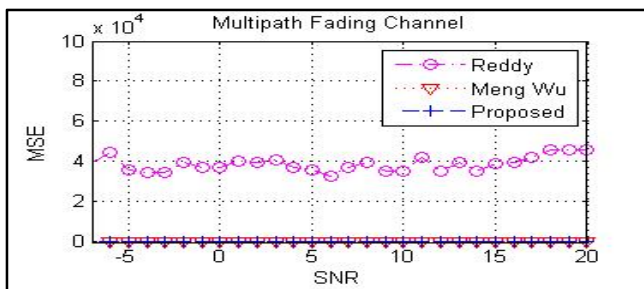


Fig. 6 Comparison between MSE of Reddy, Meng Wu, and Proposed Method in Multipath Fading Rayleigh channel that described before (MFR2). This channel is frequency selective and the Reddy Method has a poor performance in it.

Probability of error (or correct) detection is another aspect which can show the accuracy of performance.

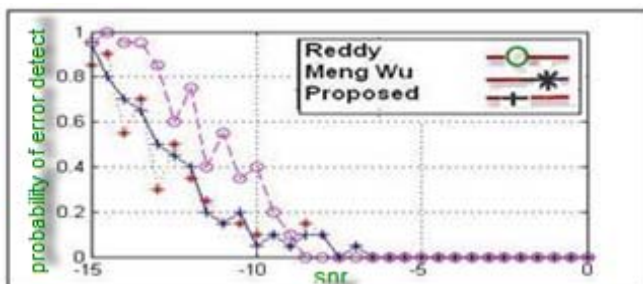


Fig. 7. Comparison between probability of **error** detection in Reddy, Meng Wu, and Proposed Method in AWGN channel. The proposed method has the least error probability between all.

In Fig. 7, this probability is calculated for mentioned metrics in AWGN channels. Also, Fig. 8 shows probability of correct

detection in multipath fading channels. Proposed method outperforms the existing algorithms, in both multi-path fading and AWGN channels.

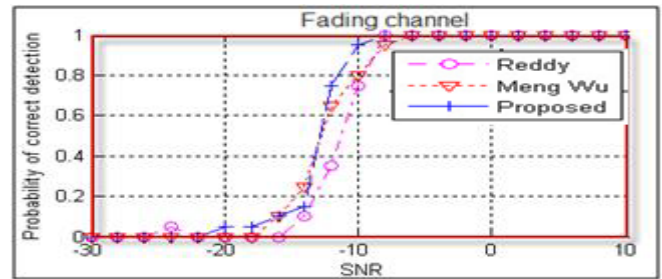


Fig.8. Comparison between probability of **CORRECT** detection in Reddy, Meng Wu, and Proposed Method in AWGN channel. The proposed method has the highest correct probability between all.

Finally, we introduce a new parameter for comparing timing metrics. In this simulation, we divide the amplitude of main peak to the amplitude of highest sub peak. It is clear that, a metric with a sharp peak in correct point and without sub peaks, has grater Mp/Sp (Main peak /Sub peak). In Fig. 9 we compare Reddy, Meng Wu, and Proposed metrics versus our new parameter, Mp/Sp in AWGN channel.

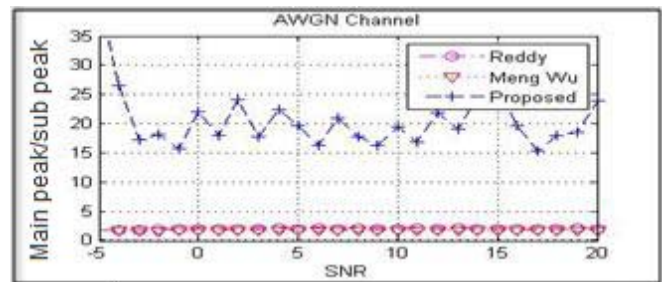


Fig.9. Comparison between Reddy, Meng Wu, and proposed method in AWGN channel versus Mp/Sp. As depicted, in proposed metric, we have sub peaks with very low amplitude, that can't be troublous. But the others have sub peaks in the same order of main peak.

6. CONCLUSION

This paper puts forward a novel frame timing synchronization algorithm for timing synchronization in WiMAX OFDMA applications. The special structure of OFDMA makes it hard to use most of present methods for its synchronization. One of the famous methods in this field is Reddy's method that has two problems: (1).We should have the preamble in receiver. (2). It has poor functionality in Multipath Fading Rayleigh Channels. The other metrics; Meng Wu, has some sub peaks in irrelevant points, and S&C method has a big plateau. Also, there are some new complex methods which have a sharp peak without side peaks. Our new metric has a sharp impulse in correct point without any sub peaks and has a good functionality even in very low SNR without any complexity. The performance of our algorithm and other algorithms are evaluated in terms of MSE between exact and estimated start of a frame. Our simulations show that proposed metric has a better performance in both AWGN and multipath fading channels.

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