Gold Sequence Based Time And Frequency Synchronization For Generalized Frequency Division Multiplexing in 5G Communication System

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Abstract -- **In 5G wireless communication system there are many waveform contenders. In this paper Generalized Frequency Division Multiplexing (GFDM) is chosen as a candidate waveform for 5G. GFDM is more competitive, advantageous in 5G communications and flexible non-orthogonal multicarrier technique. Compared to OFDM the only difference is the data block structure in GFDM.A good synchronization approach is necessary, because a loss of synchronization has great impact on the system reliability. There are many synchronization approaches for GFDM.CP based synchronization is a common approach. But it is restricted to GFDM due to GFDM block structure.A gold sequence based synchronization for GFDM is chosen in this paper. Symbol Timing Offset(STO) and Carrier Frequency Offset(CFO) can be detected.This proposed approach has the lower mean square error and symbol error rate.**

Keywords—5G, STO, CFO, GFDM, OFDM, CP, Gold sequence.

I.INTRODUCTION

In 4G mobile communications, Orthogonal Frequency Division Multiplexing (OFDM) is widely used as the modulation technique of physical layer due to its high spectrum utilization, strong capability to combat interference and fading. But the 5G mobile communications, demands on flexibility, reliability, spectral efficiency, robustness and scalability higher than 4G mobile communications. For example, the Enhanced Broadband needs a transmission rate upto 10Gbps; Wireless Regional Area Network (WRAN) requires greater coverage. Hence OFDM cannot adapt to different applications and scenarios in 5G communication system. Therefore, OFDM is not the best waveform for future 5G physical layer. Both Filter Bank Multi-Carrier (FBMC) and Generalized Frequency Division Multiplexing (GFDM) are waveform contenders for 5G.Both do not require orthogonality and power loss can be reduced. FBMC uses modulation and demodulation, It does not require strict synchronization between subcarriers. However the design of prototype filter has to meet specific requirements of frequency response, which leads to high complexity of system implementation. In contrast, GFDM is a flexible waveform, its data block has two dimensional structure in time and frequency domain. Compared with FBMC, GFDM has the lower equalization complexity at the receiver and is more suitable for burst signal transmission. Therefore, GFDM is chosen as the waveform contenders for 5G.

Multipath effect and Doppler shift in Wireless Communications would lead to Symbol Timing Offset (STO) and Carrier Frequency Offset(CFO), which have great impacts on the reliability and effectiveness of signal transmission. In OFDM many solutions are used for synchronization problems. A reduced-complexity maximum likelihood estimation synchronization approach proposed [1]. A symbol timing synchronizer for OFDM system based on Pseudo-Noise (PN) sequence was proposed [2].

There are similarities between GFDM and OFDM, but their data block structures are different. Synchronization approach used in OFDM cannot be applied directly in GFDM. Thus synchronization for GFDM is an urgent problem to be solved. A mathematical model that evaluates the Signal-to-Interference Ratio performance between GFDM and OFDM are compared in presence of STO and CFO was proposed [3]. A coarse CFO estimation in a wide range even in a tough multipath environment was proposed [4].Comparing isolated and embedded midamble approach influenced by dominant correlation metric influence and estimation of STO and CFO at various Signal-to-Noise Ratio (SNR) was proposed [5].BPSK technique is used to perform the analytical model the Bit Error Rate (BER) performance in case of imperfect synchronization was proposed [6].

As analyzed above, CP-based synchronization is a common approach. Due to particularity of GFDM block structure, the direct application of CP-based synchronization to GFDM system is restricted. A Gold sequence based synchronization approach is proposed in this paper. The main contributions of this paper are given as follows,

- Preamble consisting of two identical Gold sequences. STO and CFO can be detected

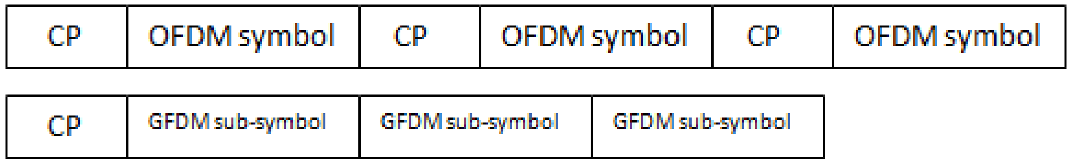

Fig.1:Structural difference between OFDM and GFDM symbol

inside the preamble to achieve higher detection accuracy without involving GFDM data part.

- The STO detection can be improved by using the proposed preamble because of its good autocorrelation and cross correlation. A sliding window is used to make slide point to point.STO can be calculated by calculating the correlation coefficient between the Gold sequence of receiver and the corresponding part of the sliding window, the STO value can be obtained by the peak of correlation coefficient.

- The CFO detection can be improved by using fourier transform to simplify the calculation of phase difference between the two Gold sequences and the CFO value can be obtained. Since the two Gold sequences are contiguous, the possible phase flip caused by successive GFDM sub symbols can be eliminated. Thus the detection range is expanded.

II.CP BASED TIME SYNCHRONIZATION APPROACH

The difference between OFDM and GFDM system is data block structure. It implies a great impact on synchronization.Fig.1 demonstrates that the structural difference between OFDM and GFDM symbol. CP based synchronization model is non-data assisted approach. Without adding additional assistance data, it requires only data itself and has the higher efficiency than the data assisted synchronization approaches.Fig.2 shows the CP-based synchronization model.

The GFDM data has the length of 128.The CP length is denoted as N_{CP} . The double sliding windows w1 and w2 whose length is N_{CP} slide point by point from front to back.

The cross-correlation coefficient of the corresponding data parts of *w*1 and *w*2 is calculated as

$$R_{CP}(n) = \sum_{i=n}^{n+K-1} r(i) * r(i+N)$$

Where *N* =*K* **M*, *r* represents the data parts of *w*1 and *w*2.

STO can be detected by detecting the peak of correlation which is expressed as

$$n_{CP} = \arg\max R_{CP}(n)$$

When n_{cp} =0,the double sliding windows are exactly at the standard point that means perfect synchronization. When $n_{cp} < 0$,the data is ahead of the standard point. When $n_{cp} > 0$, the data lags behind the standard point.

Fig.3 shows the correlation coefficient curve of CP-based time synchronization. With a CP length of 32 samples. The sliding windows are 128 samples . Since CP is copied from a part of GFDM data block, the judgement accuracy based on the correlation coefficient between *w*1 and *w*2 is low. In Fig.3 the symbol time offset (STO) can be obtained as 11.The error value can be determined by

∈ =original offset-estimated offset

The mean square value can be calculated for the different values of SNR using STO value is expressed as

$$MSE_{STO} = \frac{\sum_{i=0}^{N-1} [\in]^2}{N}$$

Where N represents the detection time on premise of fixed SNR.Fig.4 represents performance plot of CP-based time synchronization.

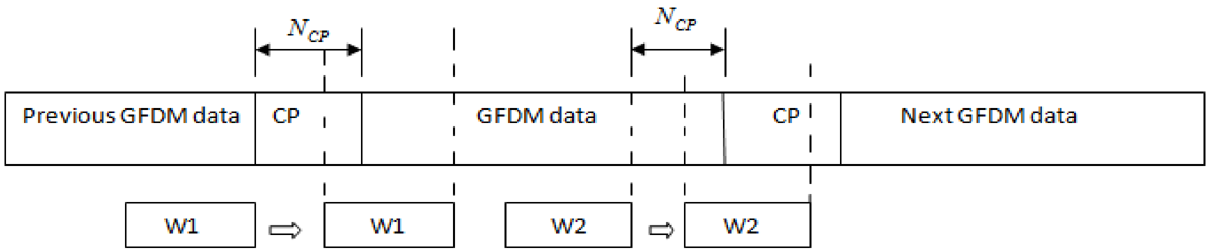

Fig.2: CP-based synchronization model

In summary, CP-based synchronization has the disadvantages of insignificant correlation peak and possible phase flip. To overcome these limitations, a PN sequence based synchronization is proposed in the next section.

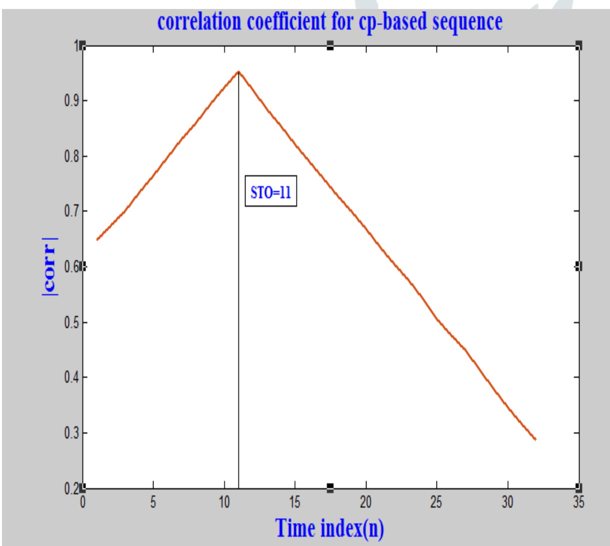

Fig.3:Correlation curve of CP-based synchronization

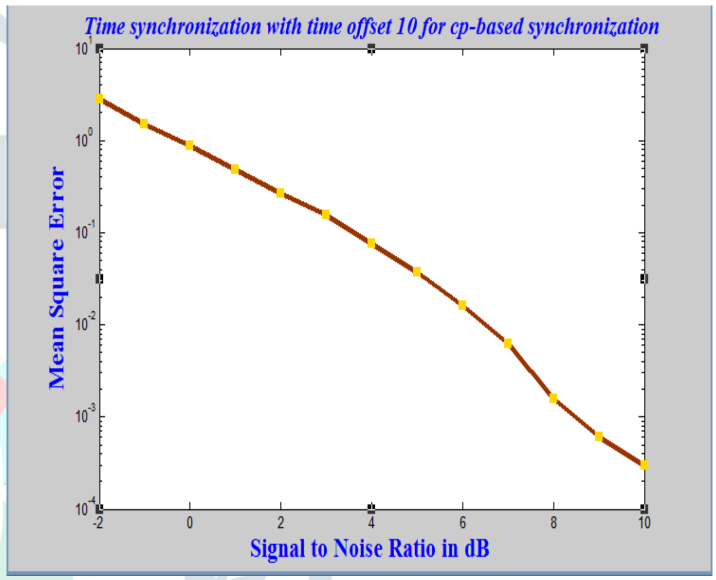

Fig.4 Performance plot for CP- based time synchronization

III.GOLD SEQUENCE BASED SYNCHRONIZATION

Gold sequence is one of the type of PN sequences whose advantage lies in its good auto correlation and cross correlation. The synchronization model based on gold sequence is shown in Fig.5

The gold sequence in Fig.5 contains two gold sequences y1 and y2 with same length of K . Here the length of gold sequence is 32 .

The noise N is added with the gold sequences. The corresponding received signal is expressed as ,

$$Y_{gold} = Y_{gold} + N$$

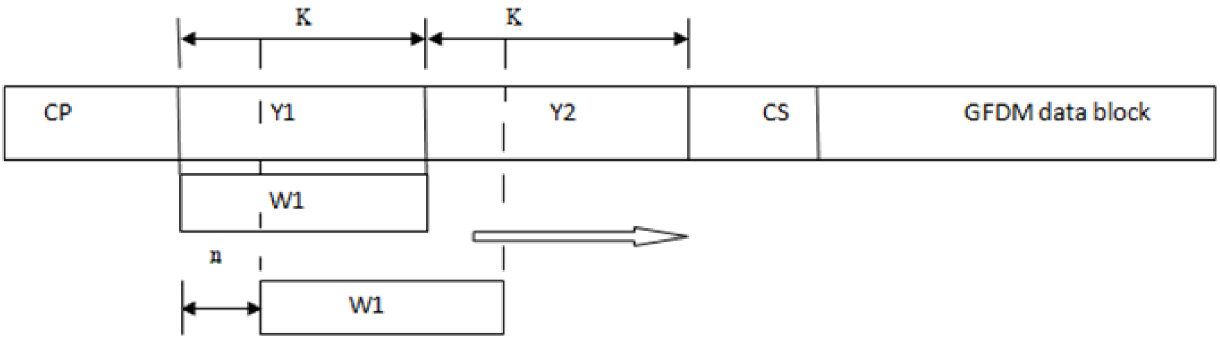

Fig.5:Synchronization model for Gold sequence based time synchronization

The sliding window w1 of length K slides point by point, and then the cross correlation coefficient between the corresponding part of w1 and gold sequence is calculated as

$$R(i) = \sum_{i=n}^{n+K-1} \sum_{d=0}^{K} (\mathrm{y(i+d)}) * (\mathrm{y(i+K+d)})$$

When K=32 the moving distance of the sliding window is only 32 samples .The correlation coefficient curve of gold sequence based time synchronization is shown in the Fig.6. It conforms the good correlation of gold sequence.

STO can be detected by detecting the peak of correlation which is expressed as

$$n_{GOLD} = \arg\max R_s(n)$$

However, the obtained STO cannot be directly used for synchronization because it is necessary to judge whether the STO is leading to or lagging behind the standard point.

In Fig.6 the symbol time offset (STO) can be obtained as 11.The error value can be determined by

$\in$ =original offset-estimated offset

The mean square value can be calculated for the different values of SNR using STO value is expressed as

$$MSE_{STO} = \frac{\sum_{i=0}^{N-1}[\in]\hat{}2}{N}$$

Where N represents the detection time on premise of fixed SNR.Fig.7 represents performance plot for gold sequence based time synchronization.

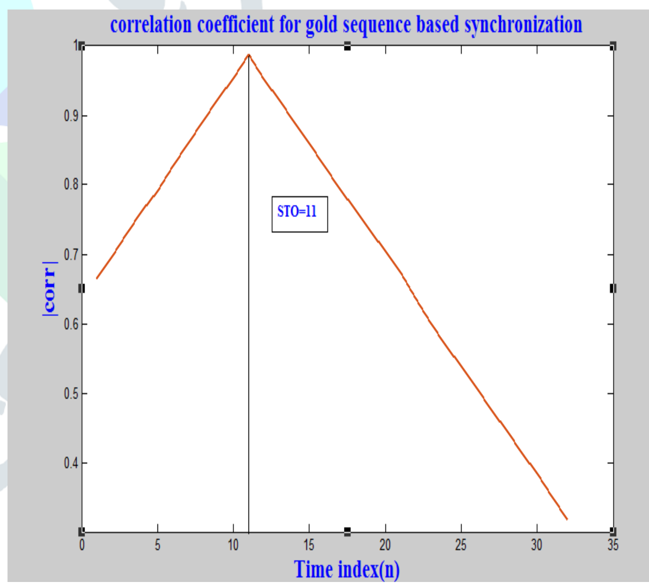

Fig.6: Correlation coefficient curve of Gold sequence based time synchronization

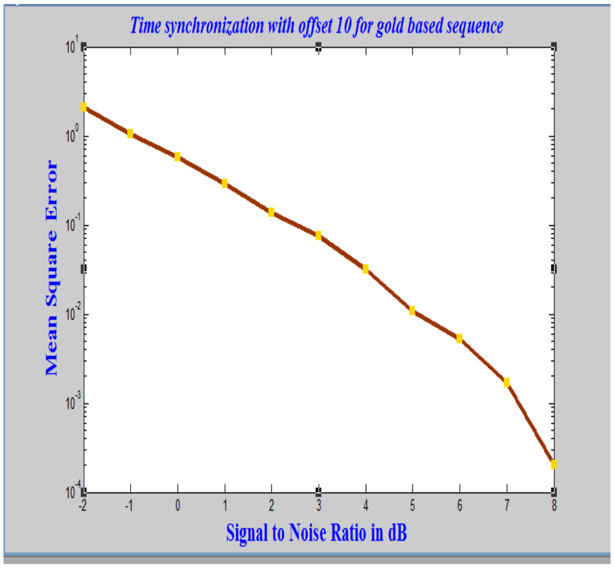

Fig.7: Performance plot Gold sequence based time synchronization

The comparison of the performance of time synchronization with time offset 10 for CP and Gold sequence based synchronization plot is shown in Fig.8.The STO error is large in the case of low SNR for the CP-based synchronization. In contrast, the PN-based synchronization has small STO error and keeps stable MSE for both low and high SNR because of the good correlation of PN sequence.

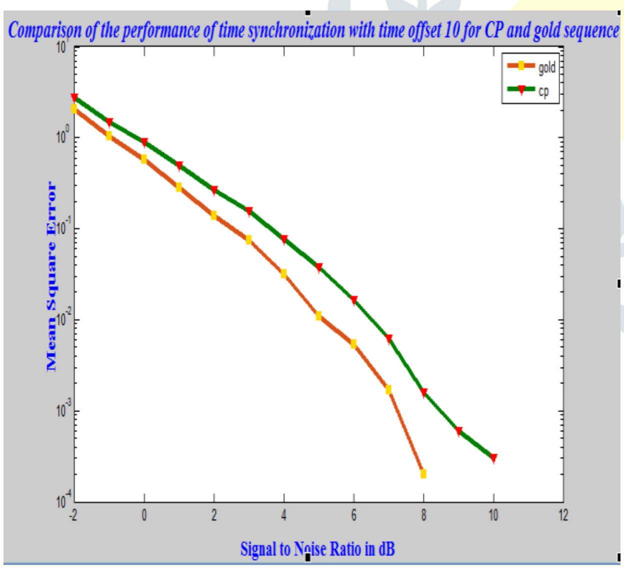

Fig.8:Comparison plot of CP and gold sequence based time synchronization

In frequency synchronization, the receiver receives two gold sequences $y1$ and $y2$, whose relationship is shown as

$$y_2(k) = y_1(k) * e^{j*offset}$$

The CFO value can be detected by,

$$S=\sum(y1.*y2)$$

$$CFO=angle(S)$$

The offset can be assumed as 0.9.The error $\in$ value can be determined by

$$\in = offset - CFO$$

The Mean Square Error can be calculated as

$$MSE_{STO} = \frac{\sum_{i=0}^{N-1}[\in]^2}{N}$$

Where N represents the detection time on premise of fixed SNR.Fig.9 represnts the performance plot of gold sequence based frequency synchronization.

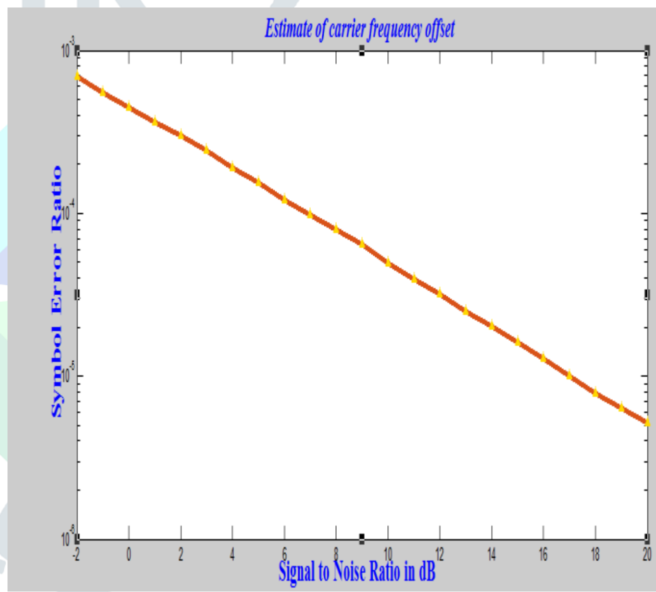

Fig.9:Performance plot for frequency synchronization based on Gold sequence

For frequency synchronization, if sub symbol M is large, the CFO detection range for CP-based synchronization will be reduced. But in gold sequence based synchronization, it maintain the detection range stable.

IV.SIMULATION AND RESULT

Gold based synchronization approach simulation parameters are given in the below table as follows,

Sub carriers, K	128
Sub symbols, M	5
CP length	32
Modulation	BPSK

V.CONCLUSION

In this paper gold sequence based synchronization approach for GFDM communication system is proposed. First, in time synchronization the STO error is large in the case of low SNR for the CP-based synchronization. In contrast, the gold sequence based synchronization has small STO and keeps stable MSE for both low and high SNR because of the good correlation of gold sequence. Second, in frequency synchronization , if sub symbol M is large, the CFO detection range for CP- based synchronization will be reduced. But in gold sequence based synchronization, it maintain the detection range stable. Although the Gold sequence based synchronization may occupy a little more bandwidth than CP-based synchronization, the approach based on Gold sequence can be a qualified candidate for GFDM synchronization.

VI.REFERENCES

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