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A Novel Synchronization Algorithm for MIMO-OFDM based Wireless Communication

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Abstract— **We propose a synchronization technique, which is more reliable even under 6db SNR. Unlike the conventional synchronization approaches, more number of preamble symbols are used to achieve accurate frame boundary. An algorithm has designed and modeled in MATLAB to calculate the frame boundary of MIMO-OFDM frames which has 16x20 antennas. The algorithm will continuously keep track of the frames and rapidly do the calculation and also detects the delay and corrects it. This algorithm can be used for initial timing offset estimation in any wireless communication techniques with minor modifications.**

Keywords— Synchronization; MIMO-OFDM; SNR; Frame boundary; Preamble; Initial timing offset estimation.

I. INTRODUCTION

Synchronization is a key issue in MIMO-OFDM based systems, as a small error would lead to the loss of orthogonality of the subcarriers and also the degradation of the system with the introduction of multiple antenna transmission systems which uses spatial multiplexing the limit is crossed and a very high data rate can be achieved which crosses the tight upper bound set by the shannon's channel capacity theorem.

Orthogonal frequency division multiplexing (OFDM) is sensitive to timing and frequency errors [1]. To guarantee the fast and accurate data transmission, the Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI) caused in the transmission should be reduced as much as possible. In OFDM system, ISI can be minimised by inserting cyclic prefix with length greater than the channel impulse response, and the ICI can be reduced by maintaining the orthogonality of carriers under the condition that the transmitter and the receiver have the exact same carrier frequency. However, in the real world, frequency offsets will be arising from the frequency mismatch of the transmitter and the receiver oscillators and the existence of Doppler shift in the channel. In addition, due to the delay of signal when transmitting in the channel, the receiver in general starts sampling a new frame at the incorrect time instant. Therefore, it is important to estimate the frequency offset to minimize its impact, and to estimate the timing offset at the receiver to identify the start time of each frame and the FFT window position for each OFDM.

Feng Guo et al [2], proposed a novel timing synchronization method utilizing Unequal Period Synchronization Pattern (UPSP), which is capable of distinguishing the various time delay between the transmitter and receiver antennas effectively. The synchronization probability for a two-transmitter one-receiver OFDM system is evaluated when communicating over an AWGN channel. The rate of successful synchronization exceeds 99% at an SNR of -3dB.

En Zhou et al [3], proposed that synchronization algorithm only needs one preamble transmitted in all transmit antennas in the same OFDM time instant. The preamble can also be cooperated for channel estimation reducing the overall overhead. The synchronization is accomplished sequentially by coarse time synchronization, fractional frequency offset estimation, integral frequency offset estimation and fine time synchronization. The synchronization algorithm proposed shows satisfactory performance even at a low SNR in rich multipath environment.

N. Mody et al [4], proposed a time and frequency synchronization technique for a Q transmit and L receive (Q x L), MIMO OFDM system. The synchronization is achieved using training symbols which are simultaneously transmitted from Q transmit antennas. The training symbols are directly modulated orthogonal polyphase sequences. The synchronization algorithm shows satisfactory performance even at a low SNR and in a frequency selective channel. The training sequence structures specialized such that channel parameters in terms of channel coefficients and noise variance can be estimated once synchronization is achieved.

To avoid the ambiguity caused by plateau of timing metric, Minn et al [5] modified Schmidl and Cox's method and proposed two new methods. The first method uses two modifications: 1) all samples over one symbol period (excluding guard interval), are used in calculating the half symbol energy required in the timing metric and 2) the timing metrics is averaged over a window of guard interval length. Thesecond method uses a training symbol containing four equal length parts but last two with different sign. They all give smaller estimator variance than [6], but still have large MSE in ISI channel.

Considering a preamble consisting of two OFDM symbols, Schmidl and Cox [6] proposed a method for time and frequency synchronization respectively. Two training symbols are placed at the beginning of the frame. The first symbol has identical halves in time domain, so that the correlation between these two halves can be carried out to find out the timing metric in the receiver. However, the metric suffers from a plateau, which leads some uncertainty in determining the start of the frame. To alleviate this, the authors propose a 90% averaging method to finalize the start time. At the optimum symbol time, the phase of the numerator term of the timing metric is examined, if its absolute value is less than π, the frequency offset can be estimated as a fraction of the OFDM symbol rate. Otherwise, the frequency offset will be greater than the OFDM symbol rate.

II. MIMO-OFDM SYSTEM MODEL

For high data- rate transmission, the multipath characteristic of the environment causes the MIMO channel to be frequency-selective. OFDM can transform such a frequency-selective MIMO channel into a set of parallel frequency-flat MIMO channels, and therefore decrease receiver complexity. The combination of the two powerful techniques, MIMO and OFDM, is very attractive, and has become a most promising broadband wireless access scheme.

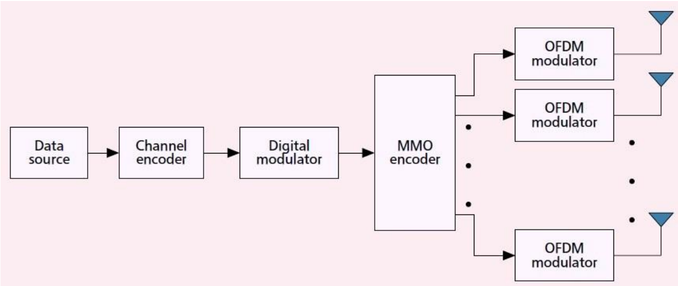


Fig. 1. Simplified block diagram of MIMO-OFDM transmitter.

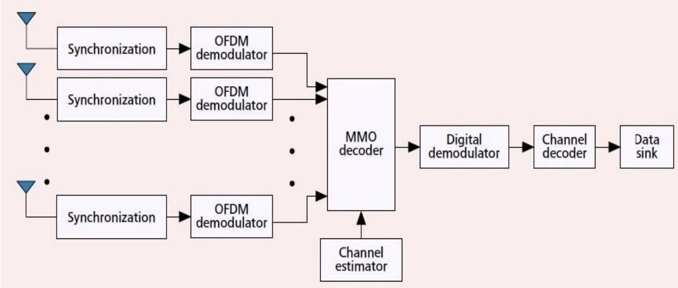


Fig. 2. Simplified block diagram of MIMO-OFDM receiver.

A. *Transmitter*

Figure 1 shows a simplified block diagram of a MIMO - OFDM transmitter. The source bit stream is encoded by a forward error correction (FEC) encoder. After that, the coded bit stream is mapped to a constellation by the digital modulator, and encoded by a MIMO encoder. Then each of the parallel output symbol streams corresponding to a certain transmit antenna follows the same transmission process. First, pilot symbols are inserted according to the pilot patterns. Then the symbol sequence in frequency is modulated by inverse FFT (IFFT) to an OFDM symbol sequence. A cycle prefix (CP) is attached to every OFDM symbol to mitigate the effect of channel delay spread, and a preamble is inserted in every slot for timing. Finally, the constructed data frame is transferred to IF/RF components for transmission.

B. *Receiver*

Figure 2 shows a simplified block diagram of a MIMO-OFDM receiver. The received symbol stream from IF/RF components over the receive antennas are first synchronized, including coarse frequency synchronization and timing aided by the preamble. After that, the preambles and CP are extracted from the received symbol stream, and the remaining OFDM symbol is demodulated by FFT. Frequency pilots are extracted from the demodulated OFDM symbol in the frequency domain, and fine frequency synchronization and timing are carried out to extract pilots and data symbols accurately for the following processing. The refined frequency pilots from all the receive antennas are used for channel estimation (CE). The estimated channel matrix aids the MIMO decoder in decoding the refined OFDM symbols. The estimated transmit symbols are then demodulated and decoded. Finally, the decoded source bit streams are transmitted to the sink [7].

III. SYNCHRONIZATION ALGORITHM

A. *Proposed frame structure*

Instead of single Pilot symbol or preamble symbol as in [4], [5] & [6] four preamble symbols are used in the OFDM preamble frame as shown in Fig. 3 which consists of same data and rest of the symbols will be NULL symbols which is transmitted by the master at initial boot up continuously until the slave detects it and do the initial timing offset estimation after this data frames will be transmitted which will have two preamble symbols followed by three headers and rest of the symbols will be dataas showed in Fig. 4.

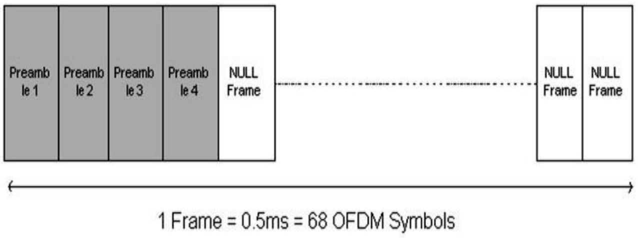
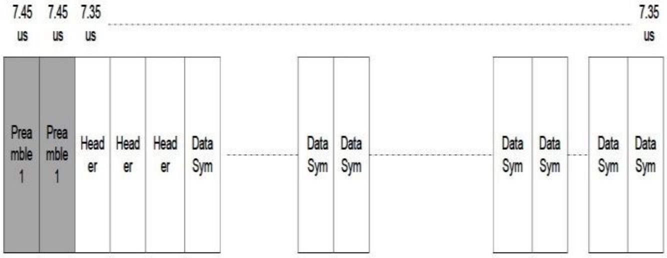


Fig. 3. Preamble frame structure



B. *Proposed algortithm*

Timing estimation needs to be done in the receiver for the frame boundary synchronization. The synchronization is required because there will be a finite propagation delay between the transmitter and the receiver. The proposed large MIMO (16x20) system is based on OFDM technology.

The baseband signal is generated by taking iFFT after mapping the complex modulation symbols on the frequency subcarriers. The specification and other parameter defining the OFDM baseband signal is given the Table 1.

Timing offset value is computed in two stages,

- Stage 1- Number of symbol timing delay is computed.
- Stage-2- Exact sample timing delay is computed.

TABLE I. BASEBAND SIGNAL SPECIFICATION

Parameter	Value
Bandwidth of Baseband signal	40 MHz
FFT Size	256
No. of DC sub-carriers	1
No. of Guard sub-carriers, Left	16
No. of Guard sub-carriers, Right	15
No. of Data sub-carriers	224
Cyclic Prefix to be added to each OFDM Symbol	42 (for preamble) 38 (for others)
Transmission Frame duration	0.5 msec
No. of OFDM Symbols per Frame	68
Sampling Frequency	40MHz
Sub-carrier spacing in Baseband signal	156.25 KHz
OFDM Symbol time (Ts)	usec (for preamble) sec (for others)

a) Stage-1

In stage 1, auto-correlation will be performed between 1st two received preamble symbol and 2nd two received preamble symbols (also known as delayed correlation) to find the correlation peak using the following equation (1),

$$R(i) = \sum_{j=0}^{N-1} yk(i+j) * conj(yk(i+j+N)) \qquad (1)$$

Where, N = 2 symbols (592 samples) the symbol starting index(τ) will calculated as below,

$$[value\ ,\ \tau]=max(R(i)) \qquad (2)$$

max is the matlab function which will give the peak value and the index as (τ) of the peak value.

The stage one estimation is only coarse search, with accuracy in symbol boundary. This coarse search for the frame boundary is done only for one antenna, as there will not be major deviations in the time delay among the different antennas.

- Samples of symbol 1 are multiplied with samples of symbol 3 and samples of symbol 2 are multiplied with samples of symbol 4.
- Next, samples of symbol 2 are multiplied with samples of symbol 4 and samples of symbol 3 are multiplied with samples of symbol 5.
- Samples thus obtained (from the 2 symbols) will be added to each other and accumulated each time for calculating the correlation output.
- The above process is repeated 69 times for incoming 72 symbols
- Among the 69 values, maximum value is the index value, which is used to calculate the symbol delay of the preamble frame.

Fig. 5 shows the timing diagram of stage 1, , a case of 3 symbol delay is considered, that is, out of 72 symbols, symbol number 4, 5, 6, and 7 contain the preamble symbols where as all other symbols contains null.

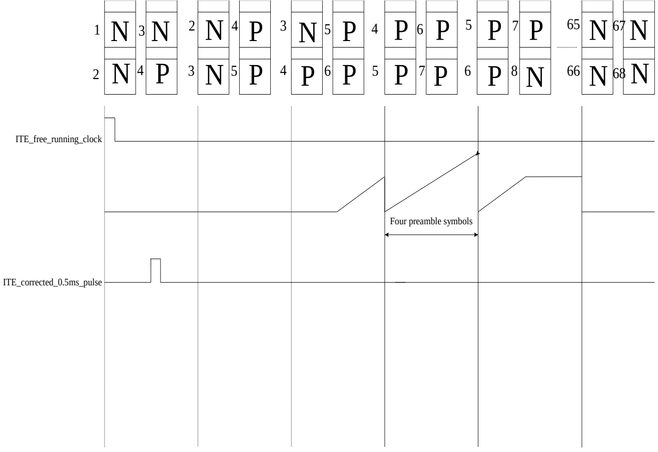


Fig. 5. Stage 1 timing diagram

b) Stage-2

As mentioned in the previous section, the stage-1 estimation is only approximate, in the stage-2 the accuracy is increased to sample level from symbol level. Using stage-1 approximate estimation, one symbol before and after are considered for the fine estimation of the timing offset that is., the coarse estimation is carried out on the 6 symbol buffer starting from one symbol previous to the one determined by the coarse estimate.

- In stage-2, cross correlation is performed between 6 received preamble symbols and 4 transmitted (locally stored) preamble symbols.
- Cross correlation is performed for each received stream with all 16 transmitted preambles (locally stored).This way each received stream has 16 correlated outputs and the one with highest peak value among them is selected.
- So after all 20 x 16 such correlations only 20 correlation peak values will be selected. From these 20 correlation peaks the corresponding delay is calculated for all receiver antennas.
- After detecting the frame boundary if there is any delay in the samples they will be simply discarded.

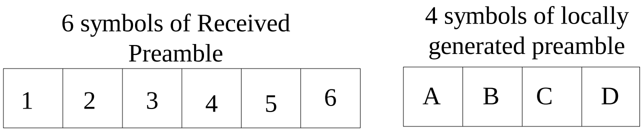


Fig. 7. Received and locally stored preamble symbols

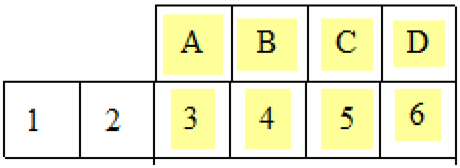


Fig. 8. Cross correlation operation

IV. EXPERIMENTS AND RESULTS

The proposed algorithm was modelled in MATLAB and extensive tests were conducted whose results are shown in Table 2.

From first stage output take 6 symbols of data and cross correlation will be performed with 4 transmitted preamble symbols to gets the peak at the frame boundary. In second stage the cross correlation will be performed exhaustively for each received stream with all 16 transmitted preambles since 16 antennas transmit the 16 preambles and all of them are getting added in the MIMO channel before reaching receive antenna. Because of this there will be some kind of uncertainty in the dominant preamble. So it is suggested to do correlation with all the preamble and select the preamble which gave the maximum correlation PAPR. This way each received stream we will have 16 correlation output and the one with highest PAPR will be selected from these 16. So after all 20 x 16 such correlations only 20 correlation PAPR values will be selected. From these 20 correlation PAPRs the corresponding delay is calculated for all receiver antenna's. From these 20 delays detected chose the one which is most frequently occurred and declare it as the delay estimate. This way the error in detection is further reduced.

After multiplying samples of conjugated with locally generated symbol D, C, B, A with received symbols 6, 5, 4 and 3 respectively, the 1192 results are summed to generate 1 value. (Value 1) Likewise 597 values are obtained by shifting the samples of first 2 symbols one after another.

- Peak value is the maximum value among the 597 values and the position of the peak is the index value.

- 16 peak values are obtained based on each of the 16 locally stored preamble symbols.

Fig. 9 & 10. Shows the peak obtained for stage 1 and stage 2 in MATLAB.

From the fig.9 we will know symbol wise frame boundary is known at the first stage 1 but we still don’t know the exact sample wise frame boundary for that stage 2 is performed anf from the fig, 10 it is confirmed that the sample wise frame boundary is also detected and any other delay in the samples will be discarded. Satisfactory results were obtained when introduced at different power levels in all the antennas which are shown in Fig.11, 12, 13 and 14.

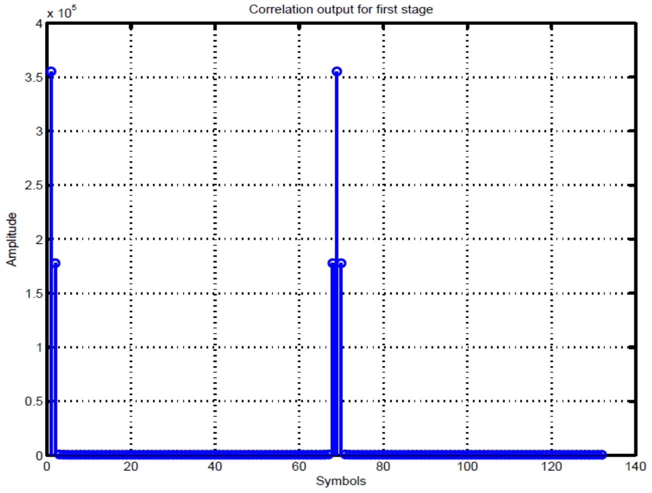


Fig. 9. Stage 1 Output

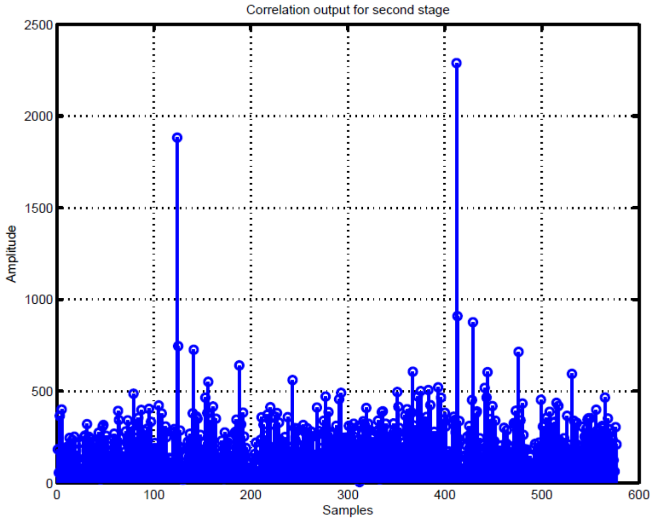


Fig. 10. Stage 2 output

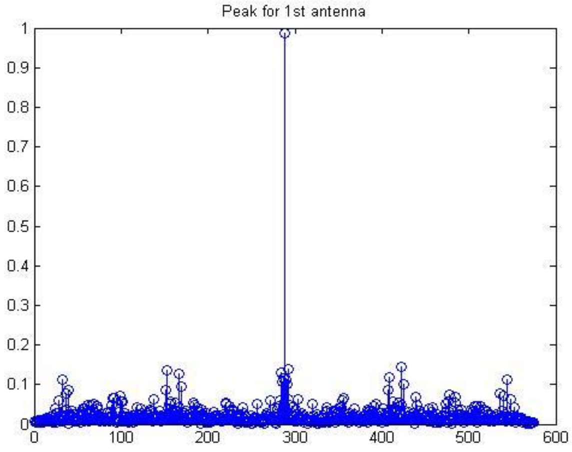


Fig. 11. Peak at 1 st antenna with 0 db AWGN

As it is seen in these figures even at different power levels this algorithm will maintain to obtain the peak .

TABLE II. PERFORMANCE STATISTICS

SNR	Freq. Offset	Pass (%)	Fail (%)	Max Error(In samples)	Freq. Offset	Pass (%)	Fail (%)	Max Error(In samples)
0	-21 kHz	2	98	292	21 kHz	2	98	292
3		1	99	292		0	100	292
6		1	99	292		0	100	292
9		0	100	292		0	100	292
12		4	96	292		0	100	292
15		0	100	292		0	100	292
0	-18 kHz	69	31	292	18 kHz	75	25	292
3		88	12	292		87	13	292
6		97	3	292		91	9	292
9		99	1	292		100	0	0
12		98	2	292		100	0	0
15		100	0	0		100	0	0
0	-15 kHz	100	0	0	15 kHz	100	0	0
3		100	0	0		100	0	0
6		100	0	0		99	1	1
9		100	0	0		100	0	0
12		100	0	0		100	0	0
15		100	0	0		100	0	0
0	-12 kHz	100	0	0	12 kHz	100	0	0
3		100	0	0		99	1	1
6		100	0	0		100	0	0
9		100	0	0		100	0	0
12		100	0	0		100	0	0
15		100	0	0		100	0	0
0	-9 kHz	100	0	0	9 kHz	100	0	0
3		100	0	0		100	0	0
6		100	0	0		99	1	1
9		100	0	0		100	0	0
12		100	0	0		100	0	0
15		100	0	0		100	0	0
0	-6 kHz	100	0	0	6 kHz	100	0	0
3		100	0	0		100	0	0
6		100	0	0		100	0	0
9		100	0	0		100	0	0
12		100	0	0		100	0	0
15		100	0	0		100	0	0
0	-3 kHz	100	0	0	3 kHz	99	1	1
3		100	0	0		100	0	0
6		100	0	0		100	0	0
9		100	0	0		100	0	0
12		100	0	0		100	0	0
15		100	0	0		100	0	0

As can be seen the pass percentage is almost 100% even with co-existence of the MIMO channel and AWGN.

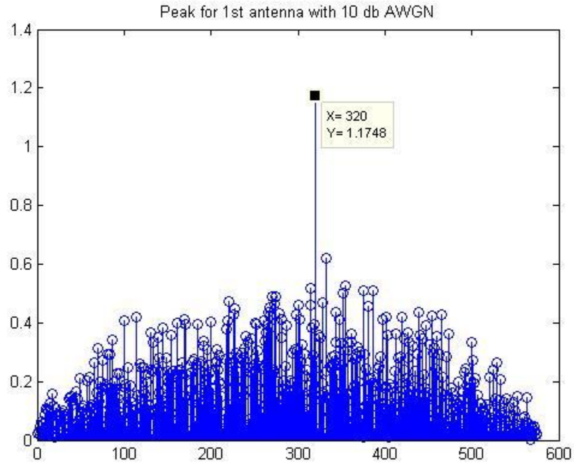


Fig. 12. Peak at 1 st antenna with 10 db AWGN

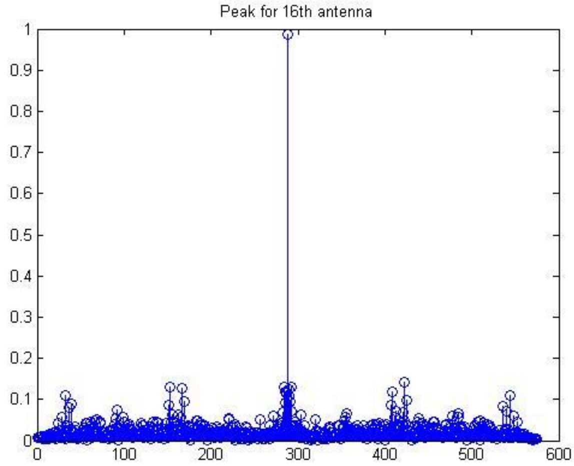


Fig.13. Peak at 16 th antenna with 0 db AWGN

V. CONCLUSION

Cross-correlation method is showing better performance compare to Park's method since it is little more reliable below 6 dB SNR.

If the restriction of selecting one antenna signal for correlation is removed, and done for all the antennas the resulting timing offset estimation is more reliable. The simulation shows pass percentage is very close to 100%.

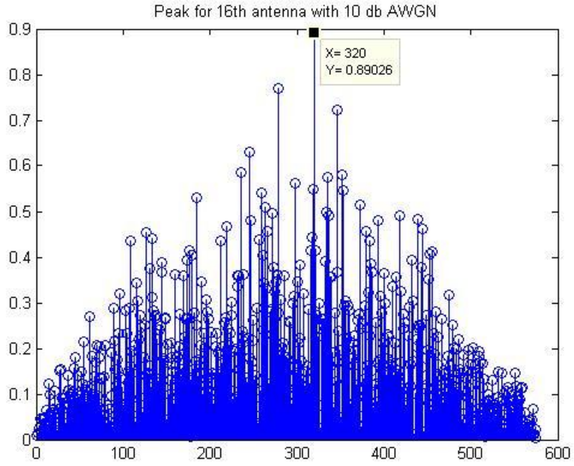


Fig. 14. Peak at 16 th antenna with 10 db AWGN

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