Implementation of Timing Synchronization in Vehicle Communication System

Sang-Yub Lee, Chul-Dong Lee and Jae-Min Kwak, *Member, KIMICS*

***Abstract*— In the vehicle communication system, transferred information is needed to be detected as possible as fast in order to inform car status located in front and rear side. Through the moving vehicle information, we can avoid the crash caused by sudden break of front one or acquire to real time traffic data to check the detour road. To be connecting the wireless communication between the vehicles, fast timing synchronization can be a key factor. Finding out the sync point fast is able to have more marginal time to compensate the distorted signals caused by channel variance. Thus, we introduce the combination method which helps find out the start of frame quickly. It is executed by auto-correlation and cross-correlation simultaneously using only short preambles. With taking the absolute value at the implemented synch block output, the proposed method shows much better system performance to us.**

***Index Terms*— Timing Synchronization, Vehicle Communication System, Carrier Frequency Offset (CFO) Estimation, Symbol Timing Offset (STO) Estimation, Wireless Local Area Network (WLAN), IEEE802.11p.**

I. INTRODUCTION

Vehicle communication system is a network that vehicles and roadside units are transferring data. Due to the importance of road safety in recent years, the research demand on Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication is increasing. And due to the limitation of the existing (WLAN) wireless local area network service served to fixed devices only, vehicle communication system has been developed by IEEE802.11p in the purpose to go beyond the limitation. OFDM is effective modulation technique in high bit-rate wireless communication, but these systems are extremely sensitive to receiver synchronization imperfections [1], which can cause the degradation of system performance.

In order to recover this weakness and consider the occurrence of fading in the existing OFDM system, several approaches [2-4] have been proposed on the basis of using preamble symbols for the channel equalization.

This paper is organized into four sections. Section Ⅱ describes the conventional method and proposed algorithm. Section Ⅲ introduces the implementation of proposed algorithm. SectionⅣ evaluates performance and concludes in SectionⅤ.

II. TIMING SYNCHRONIZATION ALGORITHM

A. General Coarse Timing Synchronization

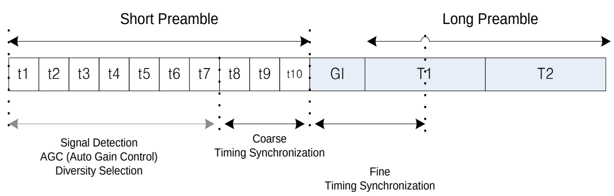

Fig. 1. Training Sequence.

To do initial coarse timing synchronization, we calculate normalized auto-correlation timing metrics [5]. The correlation value is made between the received signal and itself with a delay 16 sample times. This process executed from t8 to t10 in Fig 1. It shows the structure of the frame for IEEE802.11p which is defined the vehicle communication standard in IEEE, each short symbol being 16 samples long and 5 over sampling decimation are applied. The symbols needed to obtain the correlation are repeated 2 times (16×5×2=160 samples).

$$AC(s) = \frac{\sum_{m=0}^{N_s-1} r(s+m)\times r^*(s+m+N_s)}{\sum_{m=0}^{N_s-1} |r(s+m)|^2} \qquad (1)$$

Where, r is the received signal, s is the sample position and m is the shifting value that is movable within 16 samples N_s, defined window size.

$|r|$ and r^* represent the norm and complex conjugate. AC(s) is maximized when the received short symbol and delayed itself are matched. If there is no symbol timing error, the peak correlation value is represented at the first of short preamble area t9. Fig 2. describes the auto correlation results between the t9 and t10.

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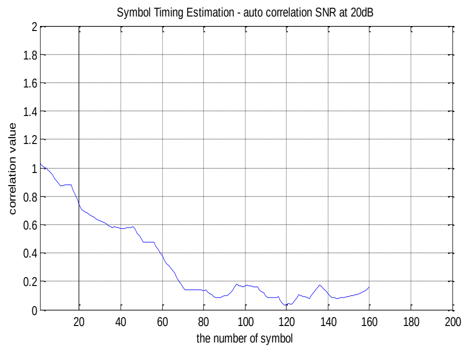

Fig. 2. Auto-Correlation (AC) values.

B. General Fine Timing Synchronization

After performing the coarse timing synchronization scheme, the estimated symbol time is moved earlier by a few samples to avoid ISI [6]. The conventional method applied to fine timing synchronization calculates cross correlation value generated with product the received signal and local samples with known long training symbols. But, the conventional cross-correlation fine timing estimator is not used in this paper.

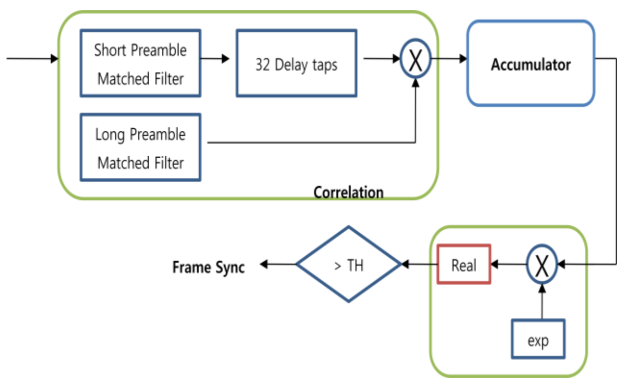

Fig. 3. Conventional Symbol Timing structure.

In general correlation block, there are two cross correlation outputs. The one is long preamble cross correlation output, and the other is the average of 9th and 10th short preamble cross correlation output. When these two cross correlation outputs are obtained, they are going to be multiplied. After accumulating the output of cross correlation block, there is a CFO compensator which is approximately correct the CFO distortion. And then sync point could be found by searching maximum point of the real value of the CFO compensated output.

When a new maximum value is found and there is no larger output during 40 sync outputs afterward, we can say that we find the sync point. To avoid infinite searching the maximum point, there is a counter which is started when carrier sensing is done, and searching maximum point is terminated when the counter reaches certain value.

C. Proposed Timing Synchronization

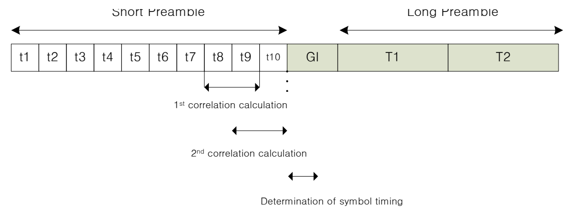

Fig. 4. Timing Synchronization using Auto and Cross correlation.

In order to estimate the path delay and decide the start point of frame, we adopt this method that auto correlation between the t8 and t9 is executed and cross correlation which is processed with received one short preamble symbol and known short preamble area is obtained into t9 and t10 simultaneously in Fig 5.

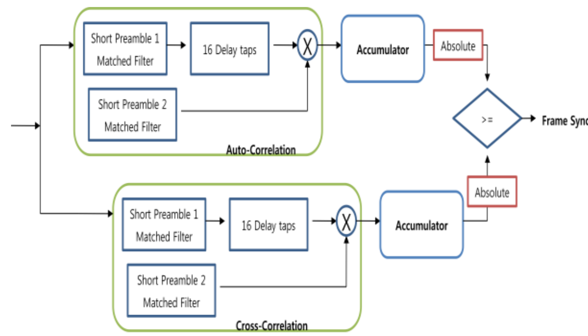

Fig. 5. Timing Synchronization using Auto and Cross correlation.

Furthermore, in order to decide threshold without defined level needed to know where the maximum peak value point can be obtained from cross correlation value estimated at t8 and t9 and phase shifted cross correlation applied conjugation operation. And then, they are compared that which one has bigger value as shown in Fig 6. Especially, in case of phase shifted cross correlation method, it makes destructive interference with itself during cross correlation calculation. It is described in Fig. 7. When there is not matching point which can be constructive correlation value between the conjugated signal and delayed oneself, as indicated in Fig 7, the level goes down into low correlation.

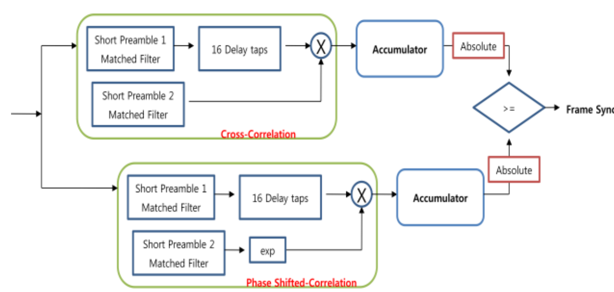

Fig. 6. Timing Synchronization using Phased shift Cross correlation.

Although, the repeated short preambles cause the degradation of performance since the correlation metric goes into flat shape as taking correlation process. But, we can get over the degradation as controlling the changing phase of the preamble.

Generally, the conventional method is required to define the exact threshold level to reduce the obscure timing error. But, in vehicle communication system, severe time varying channel caused threshold change fast That means, determining threshold level is hard to apply in vehicle communication system. Thus, with phase shifted cross correlation as described in Fig 7, we assure that the area indicated into black solid line is validate to check the timing sync and presume the noise variance according to channel status.

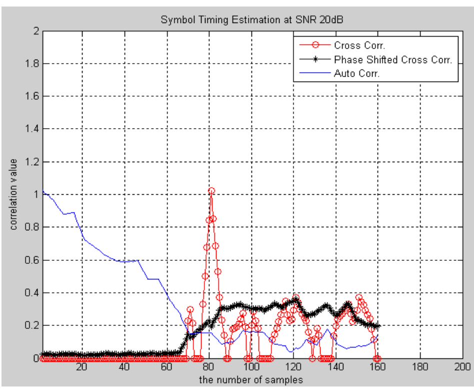

Fig. 7. Symbol Timing Estimation

$$\mathrm{PXC(s)} = \frac{\sum_{m=0}^{N_s-1} r(s+m)\times R^*(s+m+N_s)e^{-j2\pi\frac{k}{N_s}}}{\sum_{m=0}^{N_s-1}|r(s+m)|^2} \quad (2)$$

$$\mathrm{XC1(s)} = \frac{\sum_{m=0}^{N_s-1} r(s+m)\times R^*(s+m+N_s)}{\sum_{m=0}^{N_s-1}|r(s+m)|^2} \quad (3)$$

As you can see the Fig. 5 and Fig. 6, the reason taking absolute value is that we want to reduce the noise effect. Since the received signal is linearly rotated by carrier frequency offset, we need to correct them more exactly. In determining symbol timing area, we need to multiply CFO estimation by short preamble between 9th short preamble and long preamble guard interval. However, large number multiplication of estimated CFO could make another problem. When we estimate CFO by short preamble, it has some estimation error so that the error would be magnified. Therefore, we need to find out other structure using small multiplication for CFO.

The received signal is represented

$$r_k = d_k e^{j2CFO\times k} + n_k \quad (4)$$

Where, $d_k = c_{rem(k,N)}$, c_l is l^{th} preamble sequence with $l=1,2,\cdots,16$ for short preamble. N is the preamble period and n_k is noise.

Also, as known that, if we apply $\left(c_n e^{j2CFO_{shr}n}\right)^*$ for the received signal (5) and accumulate them,

$$\begin{aligned}\sum_{n=1}^{N} r_{k+n}\left(c_n e^{j2CFO_{shr}n}\right)^* &\approx \sum_{n=1}^{N}\left(d_{k+n}e^{j2CFO\times(k+n)}\right)\left(c_n e^{j2CFO_{shr}n}\right)^* \\ &\approx \left\{\sum_{n=1}^{N}\left(d_{k+n}c_n^*\right)\right\}e^{j2CFO_{shr}k}\end{aligned} \quad (5)$$

After the 2nd cross correlation with CFO compensation, we can remove the phase offset $e^{j2CFO_{shr}k}$ by taking absolute calculation. Also, from (6), we can expect,

$$\left(d_{k+n}c_n^*\right) = \left(c_{rem(k+n,N)}c_n^*\right) = |c_n|^2 \text{ when } k = mN,\ m = 0,1,\cdots \quad (6)$$

$$\left|d_{k+n}c_n^*\right| < |c_n|^2 \text{ when } k \neq mN,\ m = 0,1,\cdots \quad (7)$$

To find out the exact and fast sync point, we need two correlation value estimated between short preambles and add tuning CFO compensation that we apply to take absolute operation of sync output as you can see in Fig 5 and Fig 6 block diagrams. Since we could assume the correlation level through the proposed correlation method and expect to enhance the peak value from taking absolute scheme of sync output mentioned above, we just check out the sync point faster and more exact than normal method.

III. IMPLEMENTATION OF PROPOSED ALGORITHM

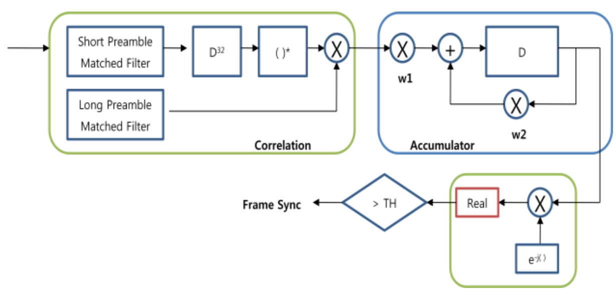

Fig. 8. Conventional Timing Synchronization

As you know that, conventional method described in Fig. 8, taking real value from accumulation output could not be enough for determining symbol timing. In Fig. 9 and Fig. 10, we can see that the imaginary part of accumulation output at sync point has large peak, but the real part of accumulation output has very little peak This can be happen especially when SNR is low and the CFO estimation by short preamble has large error. In Fig 8, the real output of accumulation is still good because the error of the CFO estimation by short preamble is small. If we need to keep most of current symbol sync structure, we can think about taking absolute value of accumulation instead of real value of it. Also, the general symbol synchronization block is not a design to compensate CFO correctly.

Since the received signals have linearly increased carrier offset, one time CFO compensation for the output of normal correlation is not enough for high CFO error.

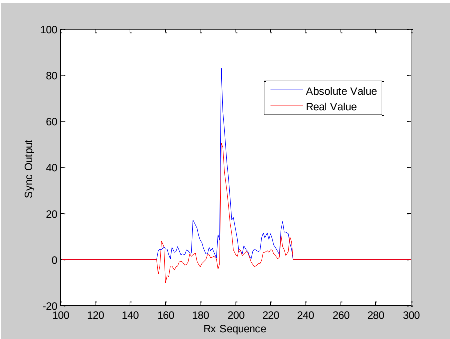

Fig. 9. Case 1 of accumulation output at SNR 0dB

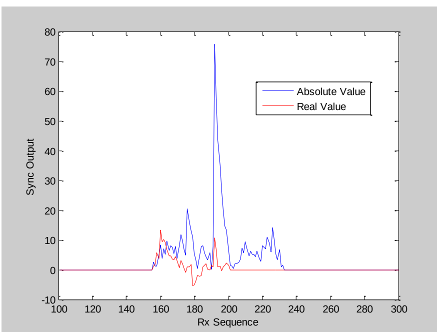

Fig. 10. Case 2 of accumulation output at SNR 0dB

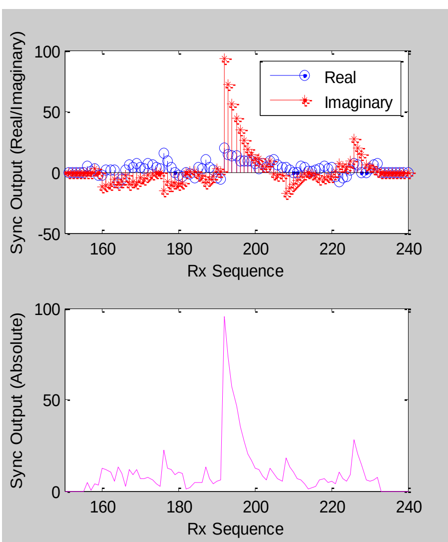

Fig. 11. Comparison of absolute and real/imaginary accumulation output at SNR 0dB

Fig. 11 described that absolute value of sync output plots the higher than real value. Imaginary components can be magnifying the sync output value to be detected sync point easily. In this paper, it presents the result if the conventional sync timing method is applied to absolute calculation instead of real that, it should be have better system performance. Also, it is expected that the proposed timing synchronization and absolute calculation, as depicted in Fig. 6, has the advantages of being shorten processing time, reducing memory size and being lower error rate.

IV. RESULTS

A. Simulation

The performance of the proposed algorithm is evaluated by computer simulation. The results can be seen in Fig 12. There are comparisons between conventional symbol timing method which is used with short preamble applied to auto correlation and long preamble for the cross correlation. On the other hands, the proposed scheme used combination timing synchronizations. Where, property of STO means that STO is expressed into the quantity of sample time variance. If symbol timing offset value has 80, it means out of the range of guard interval area built for preventing inter symbol interference (ISI). Through the mean square error, we assure that the proposed algorithm is comparable to conventional scheme. Above all, timing synchronization is executed in short preamble section only, it can reduce the memory size assigned buffer to calculate cross correlation as much as long preamble size. And as using the phase shifted cross correlation, we do not need to define the threshold in order to find out the sync point compared to one of conventional method which can be required with exact reference value.

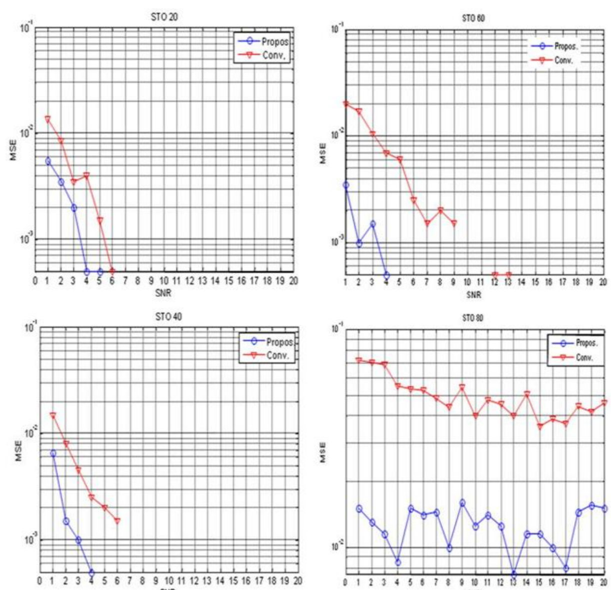

Fig. 12. Mean Square Error Comparison

And in these simulations, we assume AWGN channel, 5GHz carrier frequency, -5dB ~ 4dB SNR, 0/±20/±40ppm CFO, and 10,000 times simulation.

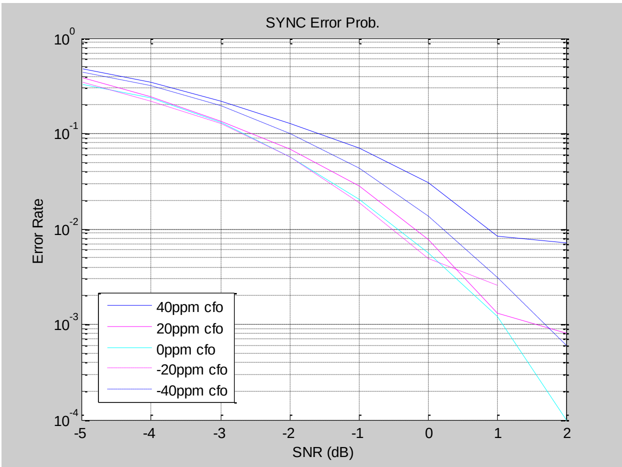

Fig. 13. The Sync Error Rate of general symbol sync and real value calculation of sync output

Fig. 13 is about the results of general algorithms; CFO estimation by short preamble and long preamble, taking real output of accumulation.

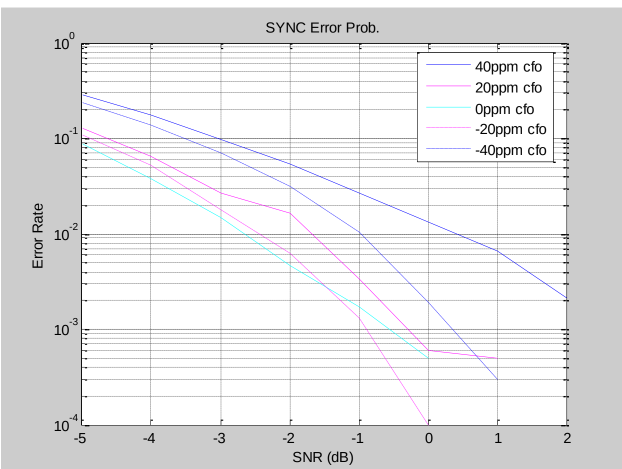

Fig. 14. The Sync Error Rate of general symbol sync and absolute value calculation of sync output

In Fig. 14, normal sync timing method and taking absolute accumulation output are used. We can see the performance is better than taking real accumulation output scheme. However, high carrier frequency offset has some performance degradation rather than low CFO cases.

In Fig. 15, proposed timing scheme and taking absolute accumulation output are applied. The performance of this scheme is almost same as normal timing and taking absolute output. The reason two schemes described in Fig. 14 and Fig. 15 have similar system performance is that taking absolute calculation is effect on to be up timing peak directly, but fast sync timing method using short preambles only is less related with system performance. It aids to detect sync point as soon as possible.

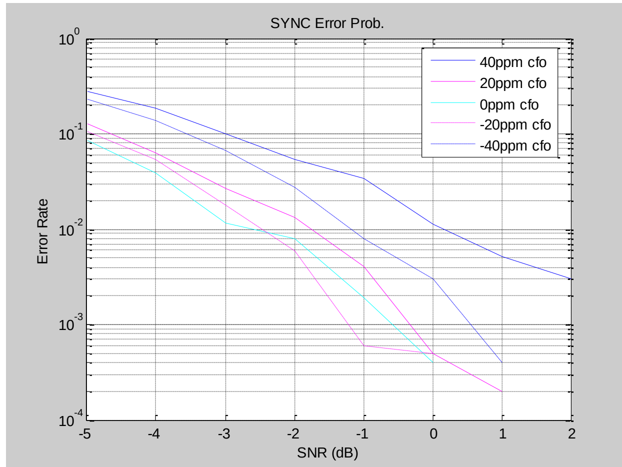

Fig. 15. The Sync Error Rate of proposed symbol sync and absolute value calculation of sync output

B. Implementation

Received signals from decimation filter are synchronized to 20MHz clock frequency and they are taken by cross correlation. Through the correlation process we proposed in this paper, sync done signal is occurred when the peak value is detected. As shown in Fig. 16 and Fig. 17, sync done is checked after taking absolute value calculation of sync output.

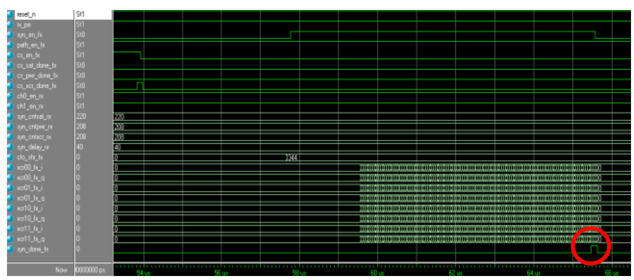

Fig. 16. Timing diagram of sync done

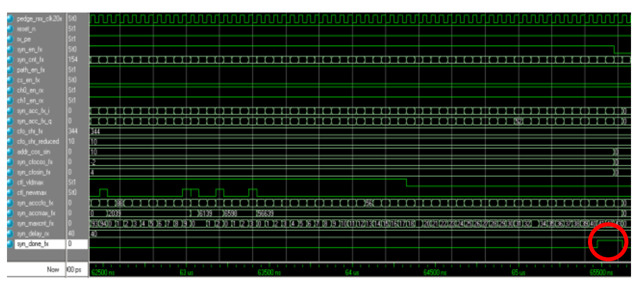

Fig. 17. Sync done signal of sync output

IV. CONCLUSIONS

In this paper, we have presented a combined timing synchronization method which can be executed in only short preamble section. The proposed scheme is adaptive and straightforward compared to the conventional one that used long preamble. Besides, it is further demonstrated that the performance of the new approach is comparable to that of conventional scheme under the condition of various symbol timing offsets on moving vehicle. And we can have enough time to find out the timing sync point which means it could be adaptable to rapid change of channel environment for the vehicle communication system. Also, the new approach is more efficient in memory side not to store the long preamble buffer. And the cross correlation method exhausted calculation complexity less than autocorrelation. For the implementation, auto correlation uses memory of reading and writing according to the received signal. But, cross correlation is operated to memory reading to calculate correlation that uses the stored short preamble sequences. Also, proposed method can be reduced the processing time compared to conventional one used by long preamble training sequence. Short processing time in the timing sync block, has a benefit that it has more marginal time to tune the received signal through the offset compensation algorithm.

Especially, the implementation method with taking absolute value of sync output has much better system performance than taking real value one. Thus, from proposed finding sync point scheme, it gives enough marginal processing time to compensate offset caused by channel variation and from taking absolute value of sync output, it has been maximized peak value to determine symbol sync point.

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