Frame Synchronization Method for Adaptive Frame Length System

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Abstract: Aiming at the difficult for identifying the alterable length frames, a specific method of frame synchronization is proposed to solve the problem of frame synchronization for the adaptive frame length system. In the novel method, the core innovation about new frame format has been done. Based on the new frame format, the alterable length frames are demarcated by searching Frame Synchronization Header bit by bit and checking Frame Synchronization Header frame by frame. Then the relevant performance parameters are analyzed and educed. Finally, a simulation system is designed to verify the proposed method. By simulating, the reference values for the rear protect time and the ahead protect time are given to ensure the probability of frame synchronization method. The significance of solving the problem is to ensure the reliability of data transmission and processing for the adaptive frame length system. Compared with previous work, the novel method can enter the frame synchronization more easily.

Keywords: Adaptive frame length, false alarm, false leakage, frame synchronization, reliability, *z* transform.

1. INTRODUCTION

The frame synchronization technique of wireless communication is to insure the reliability for backside data disposal. It affects the whole performance of a communication system firsthand. The technique of frame synchronization has gained a mass of research productions, such as the selecting standard for synchronization header model [1], the searching method for synchronous header [2, 3], design of appointed frame synchronization system [4], optimizing performance of frame synchronization [5], and so on. With the development of wireless technique, the technique of adaptive frame length is produced to increase the system throughput [6-8]. But the variation characteristic of frame length adds the difficulty of frame synchronization enormously, and the existent method of frame synchronization can not be usable on the adaptive frame length systems [9]. Aiming at the problem, a novel frame synchronization method is proposed and verified to realize frame synchronization of the adaptive frame length system

2. DESIGN ON NOVEL METHOD

The difficulty is that receiver must identify variation of frame length (L_f) automatically to find Frame Synchronization Header (FSH). So a new frame format is designed as shown in Fig. (**1**). Frame Length Header (FLH) is defined between frame data and FSH. FLH of L_{FLH} bits can mark 2^{LFLH} kinds of L_f.

During the process of data transmission in wireless channel, bit error can be produced in data. That may induce the FSH, with bit, error to be leaked by receiver. It is a false leakage phenomenon. The random bit sequence may induce the similar code with FSH appearing non-synchronized. If receiver mistakes it as FSH, the false alarm phenomenon triggers. Considering the effect of false leakage and false alarm, the error bit tolerance in FSH is defined to be *M* bits. The bit error rate of wireless channel is set as *r*. The false leakage probability induced by bit error in FLH is set as P_{FLH}. The false leakage probability induced by bit error in FSH is set as P_{FSH}. The false alarm probability is set as P_{FA}.

$$P_{FSH} = 1 - \sum_{j=0}^{M} \binom{L_{FSH}}{j} (1-r)^{L_{FSH}-j} r^{j} \tag{1}$$

$$P_{FLH} = 1-(1-r)^{L_{FLH}} \tag{2}$$

$$P_{FA} = \sum_{j=0}^{M} \binom{L_{FSH}}{j} 0.5^{L_{FSH}} \tag{3}$$

The design idea is searching FSH bit by bit and checking FSH frame by frame based on the new frame format. The frame synchronization states of novel method are introduced as follows. And the states transfer process is shown as Fig. (**2**).

- Searching (S) state is the state of searching FSH bit by bit in the origination time of incepting data.
- Checking (C) state is the state of reading frame length information in FLH and checking the next FSH frame by frame.

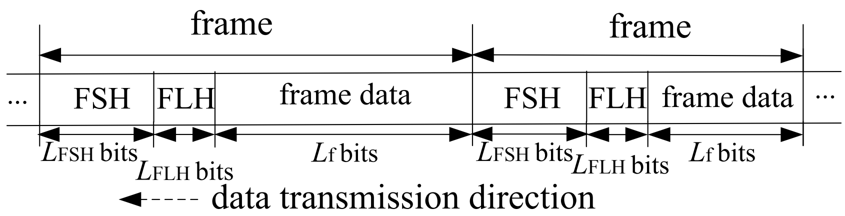

Fig. (1). Serial bit sequence of adaptive frame length system.

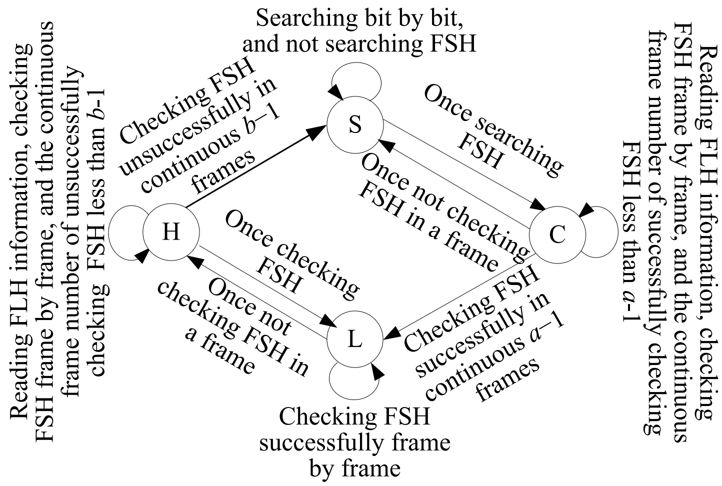

Fig. (2). States transfer process of the novel method.

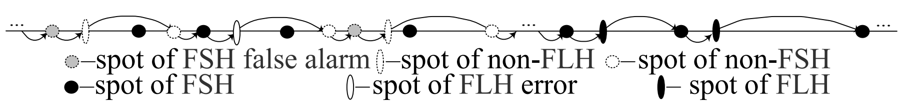

Fig. (3). Searching and checking process.

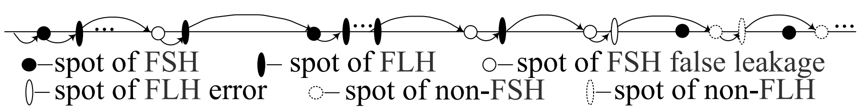

Fig. (4). Locking and holding process.

- Locking (L) state is the state of locking the frame synchronization and dealing with data.
- Holding (H) state is the state of reading FLH, checking the next FSH and taking count of holding synchronization.

Where, a is rear protect time, and b is ahead protect time. To reduce the false synchronization caused by FSH false alarm, system locks frame synchronization only as checking out FSH in continuous a frames. To reduce the false synchronization loss caused by FSH false leakage, system determines frame synchronization loss only as not checking out FSH in continuous b frames.

2.1. Frame Synchronization Search and Checking Process

The frame synchronization searching and checking process of the novel method is shown as Fig. (**3**).

In S state, once searching FSH bit by bit, system will enter C state. In C state, system obtains the L_f information from FLH and checks FSH in the beginning of next frame. If not checking out FSH, the previous FSH will be considered as false alarm. Then system returns S state and the checking counter is reset. If FSH is being checked successfully in the start of continuous $a-1$ frames, system will enter L state. The time in searching and checking process is defined as T_{EL} (time of entering lock).

2.2 Frame Synchronization Lock AND Keep Process

The frame synchronization locking and holding process of the novel method is shown as Fig. (**4**).

Once entering L state, system starts to deal with frame data from the previous a frame, and still checks FSH frame by frame. As losing FSH in one frame, system enters H state. In H state, system reads L_f information in FLH and checks FSH in next frame. If not checking out FSH in continuous $b-1$ frames, system determines synchronization loss and enters S state. Otherwise, system returns L state. False leakage and code sliding will lead to "cannot check" out FSH. Only considering bit error, the holding process can be separated into holding process I (H_I) caused by FLH error and holding process II (H_{II}) caused by FSH false leakage. Obvi-

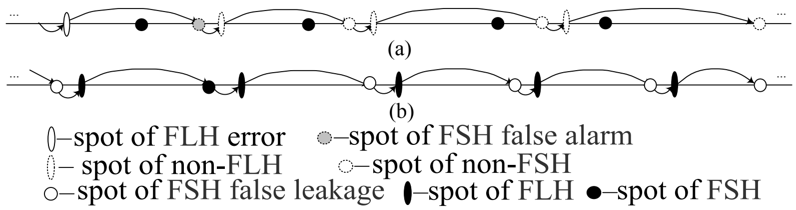

Fig. (5). Frame synchronization holding process.

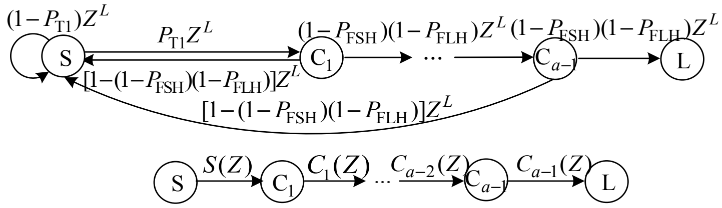

Fig. (6). States transfer of searching and checking.

ously, the influence of FLH error is same as code sliding. The processes of H_I and H_{II} are shown as Fig. (**5a** and **b**) respectively.

As FLH error, the real FSH will not exist in the start of next frame specified by FLH. So the FSH loss caused by FLH error is true. If not checking out FSH for false alarm in continuous *b* frames, system enters S state. If checking out FSH for false alarm, system enters the error locking state L_{err}. Obviously, during H_I process, the frame data are false. So the time through H_I process is defined as T_{CL} (time of releasing from error lock). T_{CL} and T_{EL} are defined as T_L (time of frame synchronization loss). The FSH loss only caused by FSH false leakage is false. But if FSHs of continuous *b* frames are not checked out for false leakage, system enters S state. Obviously, during H_{II} process, the frame data are correct. Then the time through H_{II} process and locking process is defined as T_H (continuance time of frame synchronization).

3. PERFORMANCE ANALYSIS

Without considering the influence of code sliding, the transfer probabilities within four states are constant. So the *z* transform will be used for the performance analysis. Assuming system checking FSH from any bit, the average probability for searching out true FSH and not reading FLH in one frame is given.

$$P_{T1} = \frac{1-P_{FSH}}{L_f}\sum_{k=1}^{L_f}(1-P_{FA})^{k-1} = \frac{(1-P_{FSH})[1-(1-P_{FA})^{L_f}]}{L_f P_{FA}} \tag{4}$$

The probability of entering locking P_{EL} is given.

$$P_{EL} = P_{T1}(1-P_{FSH})^{a-1}(1-P_{FLH})^{a-1} \tag{5}$$

The adaptive frame length is used in slow fading channel generally. Based on the great frame quantity, the average L_f is assumed as *L* bit. In the novel method, the states transfer of frame synchronization searching and checking is shown as Fig. (**6**).

The *z* transformation for each state transfer probability is given respectively.

$$S(Z) = \sum_{m=0}^{\infty}\left[(1-P_{T1})Z^L\right]^m P_{T1}Z^L = \frac{P_{T1}Z^L}{1-(1-P_{T1})Z^L} \tag{6}$$

$$C_i(Z) = \sum_{m=0}^{\infty}\left[[1-(1-P_{FSH})(1-P_{FLH})]Z^L S(Z)\prod_{j=1}^{i-1}C_j(Z)\right]^m$$

$$\bullet(1-P_{FSH})(1-P_{FLH})Z^L$$

$$= \frac{(1-P_{FSH})(1-P_{FLH})Z^L}{1-S(Z)\prod_{j=0}^{i-1}C_j(Z)[1-(1-P_{FSH})(1-P_{FLH})]Z^L} \tag{7}$$

Where i=1, 2, … , $a-1$, $C_0(Z)$=1. T_{EL} normalized to *L* is obtained.

$$T_{EL} = \frac{1}{L}\left[d\left(S(Z)\prod_{i=1}^{a-1}C_i(Z)\right)\Big/ dZ\right]_{Z=1}$$

$$= \frac{P_{T1}+[1-(1-P_{FSH})(1-P_{FLH})]-P_{T1}(1-P_{FSH})^{a-1}(1-P_{FLH})^{a-1}}{P_{T1}[1-(1-P_{FSH})(1-P_{FLH})](1-P_{FSH})^{a-1}(1-P_{FLH})^{a-1}} \tag{8}$$

Searching and checking out FSH in continuous *a* frames for false alarm, the system will enter error lock state. The probability of entering error lock is defined as P_{EEL}. The average probability about searching out false alarm FSH before true FSH and not reading FLH in one frame is given.

$$P_{E1} = 1-\frac{1-P_{FSH}}{L_f}\sum_{k=1}^{L_f}(1-P_{FA})^{k-1} \tag{9}$$

Then, P_{EEL} can be given.

$$P_{EEL} = P_{E1}\left(\frac{P_{FA}}{2^{L_{FLH}}}\right)^{a-1} \tag{10}$$

If false alarm FSHs are not checked in continuous *b* frames after entering error lock, system releases from error lock fast. The corresponding probability $P_{CL}=(1-P_{FA})^b$. The states transfer of H_I process is shown as Fig. (**7**).

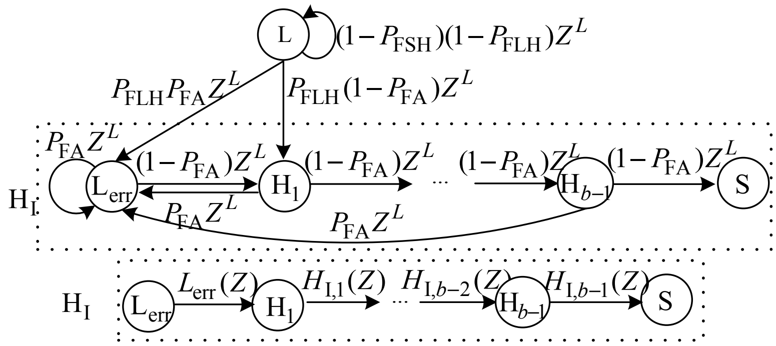

Fig. (7). States transfer of HI process.

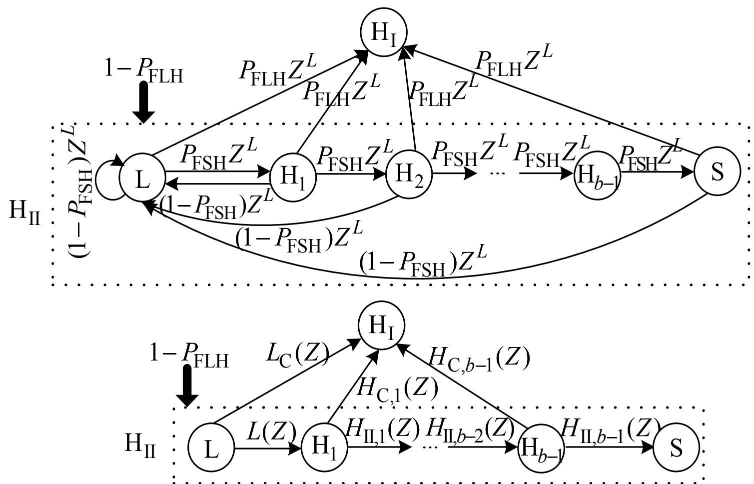

Fig. (8). State transfer of locking and HII process.

$$L_{\text{err}}(Z) = \frac{(1-P_{\text{FA}})Z^L}{1-P_{\text{FA}}Z^L} \tag{11}$$

$$H_{\text{I},q}(Z) = \frac{(1-P_{\text{FA}})Z^L}{1-P_{\text{FA}}Z^L L_{\text{err}}(Z)\prod_{j=0}^{q-1} H_{\text{I},j}(Z)} \tag{12}$$

Hereinto, q=1,2,…,b−1, $H_{\text{I},0}(Z)$=1. The normalized time T_{CL1} from L_{err} to S state and T_{CL2} from H_1 to S state are given.

$$T_{\text{CL1}} = \frac{1}{L}\left[d\left(L_{\text{err}}(Z)\prod_{q=1}^{b-1} H_{\text{I},q}(Z)\right)\Big/dZ\right]_{Z=1} = \frac{1-(1-P_{\text{FA}})^b}{P_{\text{FA}}(1-P_{\text{FA}})^b} \tag{13}$$

$$T_{\text{CL2}} = \frac{1}{L}\left[d\left(\prod_{q=1}^{b-1} H_{\text{I},q}(Z)\right)\Big/dZ\right]_{Z=1} = \frac{1-(1-P_{\text{FA}})^{b-1}}{P_{\text{FA}}(1-P_{\text{FA}})^b} \tag{14}$$

Normalized time T_{CL} is obtained as

$$T_{\text{CL}} = P_{\text{FLH}}P_{\text{FA}}T_{\text{CL1}} + P_{\text{FLH}}(1-P_{\text{FA}})T_{\text{CL}} \tag{15}$$

The state transfer of frame synchronization locking and H_{II} process is shown as Fig. (**8**).

$$L(Z) = \frac{P_{\text{FSH}}Z^L}{1-(1-P_{\text{FSH}})Z^L} \tag{16}$$

$$H_{\text{II},q}(Z) = \frac{P_{\text{FSH}}Z^L}{1-L(Z)\prod_{j=0}^{q-1} H_{\text{II},j}(Z)(1-P_{\text{FSH}})Z^L} \tag{17}$$

Hereinto, $H_{\text{II},0}(Z)$=1. The normalized time T_{H11} from L to S state is given.

$$T_{\text{H11}} = \frac{1}{L}\left[d\left(L(Z)\prod_{q=1}^{b-1} H_{\text{II},q}(Z)\right)\Big/dZ\right]_{Z=1} = \frac{1-P_{\text{FSH}}^b}{(1-P_{\text{FSH}})P_{\text{FSH}}^b} \tag{18}$$

Then, the normalized time T_{H1} of FLH without error but FSH false leakage is obtained.

$$T_{\text{H1}} = (1-P_{\text{FLH}})^{b+1}T_{\text{H11}} = \frac{(1-P_{\text{FLH}})^{b+1}(1-P_{\text{FSH}}^b)}{(1-P_{\text{FSH}})P_{\text{FSH}}^b} \tag{19}$$

$$L_{\text{C}}(Z) = \frac{(1-P_{\text{FLH}})P_{\text{FLH}}Z^L L(Z)}{P_{\text{FSH}}Z^L} = \frac{(1-P_{\text{FLH}})P_{\text{FLH}}}{P_{\text{FSH}}}L(Z) \tag{20}$$

$$H_{\text{C},q}(Z) = \frac{(1-P_{\text{FLH}})^{q+1}P_{\text{FLH}}}{P_{\text{FSH}}}H_{\text{II},q}(Z) \tag{21}$$

Normalized time T_{H2} from H_{II} to H_{I} process is

$$T_{\text{H2}} = \frac{1}{L}\frac{dL_{\text{C}}(Z)}{dZ}\bigg|_{Z=1} + \frac{1}{L}\frac{d[L(Z)H_{\text{C},1}(Z)]}{dZ}\bigg|_{Z=1} + \ldots$$

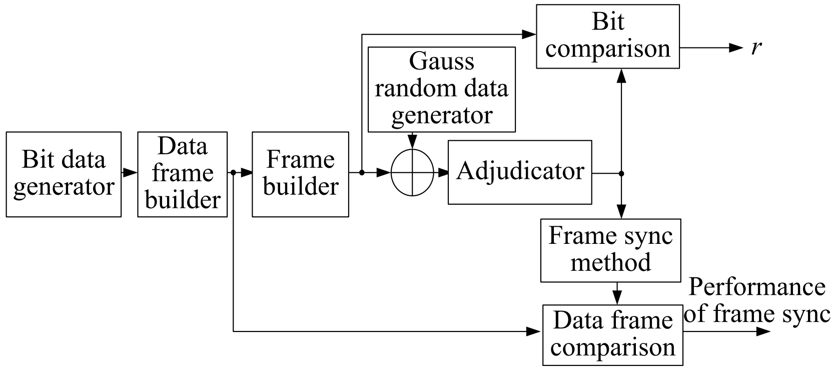

Fig. (9). Simulation system of frame sync.

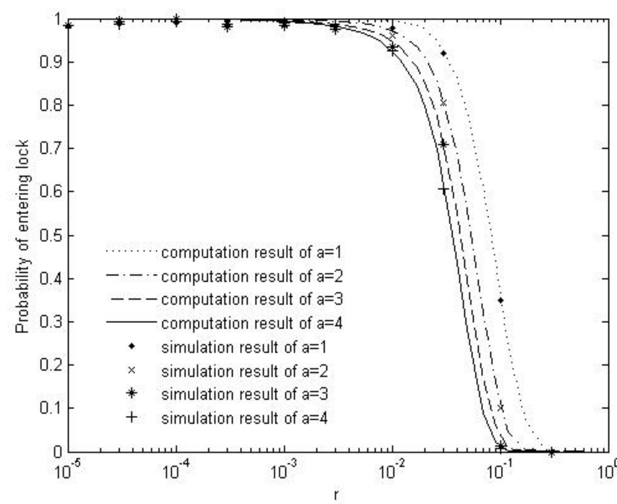

Fig. (10). Probability of entering lock P_{EL}.

$$+\frac{1}{L}\frac{d[L(Z)\prod_{j=1}^{b-2}H_{\mathrm{II},j}(Z)H_{\mathrm{C},b-1}(Z)]}{dZ}\Bigg|_{Z=1} \tag{22}$$

Letting $T_{\mathrm{H2}}(0)=0$, $T_{\mathrm{H2}}(b)$ can be expressed as

$$T_{\mathrm{H2}}(b)=\sum_{k=0}^{b-1}T_{\mathrm{H2}}(k)+\frac{P_{\mathrm{FLH}}(1-P_{\mathrm{FLH}})^{b}}{P_{\mathrm{FSH}}^{b+1}}\sum_{i=1}^{b}P_{\mathrm{FSH}}^{b-i} \tag{23}$$

Then $T_{\mathrm{H}}=T_{\mathrm{H1}}+T_{\mathrm{H2}}$.

Once FLH error or FSH false leakage in continuous b frames without FLH error, system will lose frame synchronization. The average probability and time of frame synchronization loss is

$$P_{\mathrm{L}}=P_{\mathrm{FLH}}+(1-P_{\mathrm{FLH}})P_{\mathrm{FSH}}^{b} \tag{24}$$

$$T_{\mathrm{L}}=T_{\mathrm{EL}}+T_{\mathrm{CL}} \tag{25}$$

4. PERFORMANCE SIMULATION

To verify the proposed frame synchronization method, a simulation system is designed just as Fig. (**9**). The bit data generator produces 10^{10} bit data each time. L_{f}\{100 byte, 200 byte, 500 byte, 1000 byte\} and each L_{f} has equal probability to appear. L=450 byte, M=2 bit, L_{FLH}=2 bit and FSH□ \{00, 01, 10, 11\} represents each L_{f} separately. The format of FSH is selected as 00011010110011111-111110000011101 [10]. L_{FSH}=32 bit and $P_{\mathrm{FA}}\approx 10^{-7}$. Then $P_{\mathrm{CL}}\approx 1$. The results of computation or simulation about other performances are shown as Fig. (**10**) to Fig. (**17**).

Obviously, P_{EL} decreases but T_{EL} increases with r increasing as shown in Fig. (**10**) and Fig. (**11**). And a is greater, P_{EL} depressing or T_{EL} increasing is faster. Because, during searching FSH bit by bit and checking FSH frame by frame, the increase of r and a leads FSH and FLH to be leaked frequently. So P_{EL} is reduced and T_{EL} is prolonged. When the channel condition is good (namely r is smaller), P_{EL}=1 and T_{EL} is only related to a ($T_{\mathrm{EL}}=a$). Therefore, for increasing P_{EL} and decreasing T_{EL}, the smaller a should be taken.

Obviously, when channel condition is good, the probability of leaking true FSH but searching out false alarm FSH (*Pe* for short) is low as shown in Fig. (**12**). So as $r\leq 10^{-2}$, P_{EEL}=0 no reference to a. when channel condition is worse, *Pe* is bigger. If there is not checking process (a=1), P_{EEL} will increase until to close 1 with r increase. But if there is a checking process ($a\geq 2$), the probability of checking out false alarm FSH is extremely low, so P_{EEL}=0. Therefore, in order

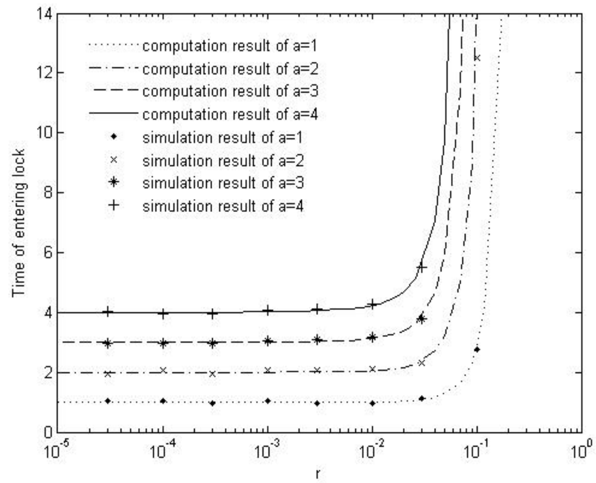

Fig. (11). Time of entering lock T_{EL}.

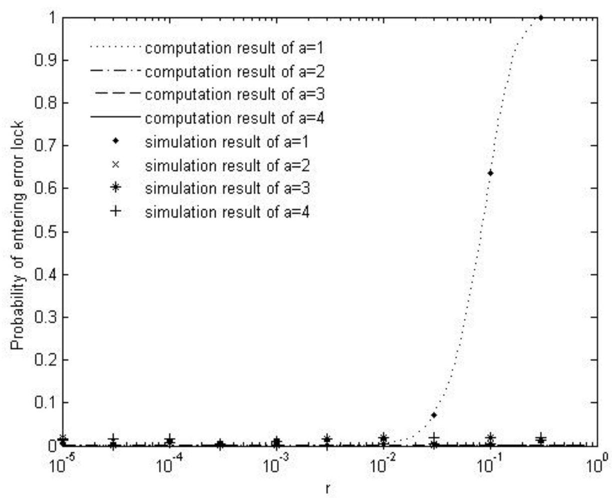

Fig. (12). Probability of entering error lock P_{EEL}.

to ensure the reliability of entering lock and the validity of dealing with data, $a \geq 2$ should be selected. Based on comprehensive analysis of P_{EL}, T_{EL} and P_{EEL} a=2.

As shown Fig. (**13**), as b=1 H_I process will not exist and T_{CL}=0. As $b \geq 2$, if $r > 10^{-2}$, T_{CL} will enhance rapidly with r increasing until reaching $b-1$ else $T_{CL} \approx 0$. Because when channel condition is worse, P_{FLH} is higher than P_{FA}. The probability of entering H_I is higher than that of entering L_{err}, so T_{CL} will be larger until equaling the checking number with r increasing. When channel condition is good, T_{CL}=0 for low probability of entering H_I.

Obviously, when channel condition is good, P_{FLH} and P_{FSH} are low and $P_{FSH} << P_{FLH}$ as shown in Fig. (**14**). System will keep in H_{II}. And when b is larger the time in H_{II} is longer, then T_H is larger as well. When channel condition is bad, FSH will be lost frequently and T_H is small. To improve T_H, the larger value of b should be taken.

As shown in Fig. (**15**), when $r \leq 10^{-2}$then $P_L \approx 0$, no matter what value b is. When $r > 10^{-2}$ then P_L increases along with enhancing of r until close to the maximum 1. And when b is smaller, then P_L increases more rapidly. The reason for this is that when channel condition is good, P_{FLH} and P_{FSH} are small. System can keep in L or H state and P_L is low. As channel condition becomes bad, P_{FLH} and P_{FSH} increases gradually. If b is smaller, the probability of keeping in L or H state is lower and P_L is higher. To reduce P_L, the larger value of b should be taken. Combined with Fig. (**11**, **13** and **16**), it can be seen that $T_L \approx T_{EL}$ for the lower T_{CL}. So when channel condition is good, T_L=a=2.

However, L_f is not fixed in adaptive frame length system. Once losing FSH for FLH error, system will lose all data contained in the frame. Therefore, to increase data reliability, b should not be too large. In conclusion, b=3.

The performance computation results of novel and original method in [11] are shown as Fig. (**17**).

Obviously, the novel method performance is superior to the original method. In novel method, system can enter the frame synchronization more easily.

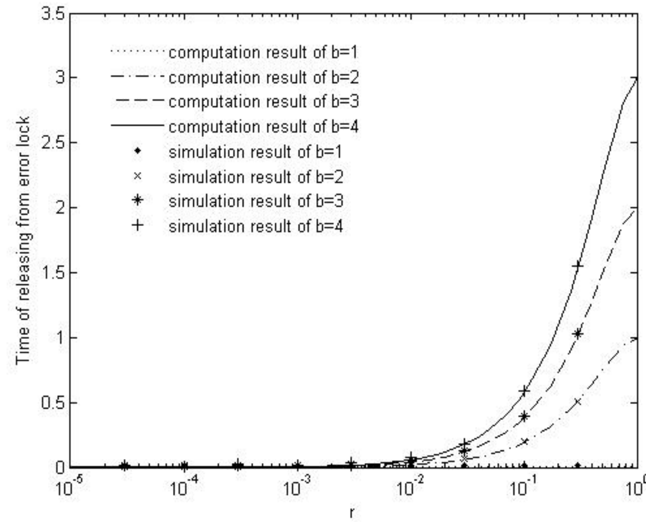

Fig. (13). Time of releasing from error lock T_{CL}.

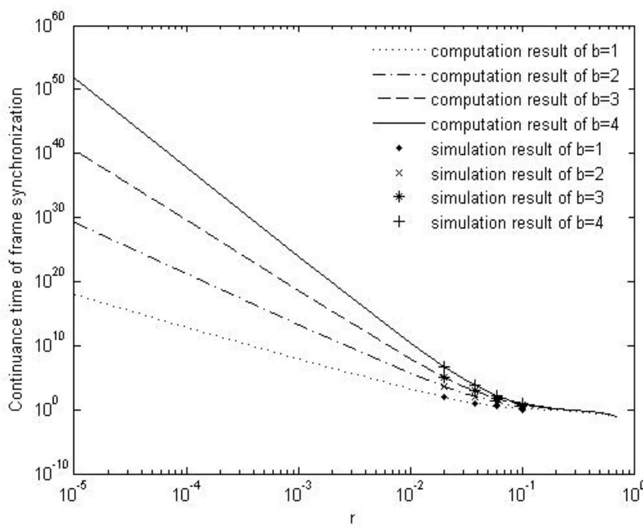

Fig. (14). Continuance time of frame synchronization T_H.

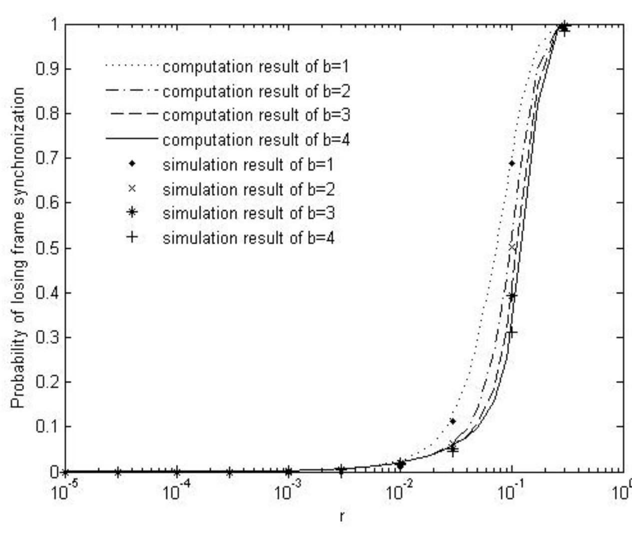

Fig. (15). Probability of losing frame synchronization P_L as a=2.

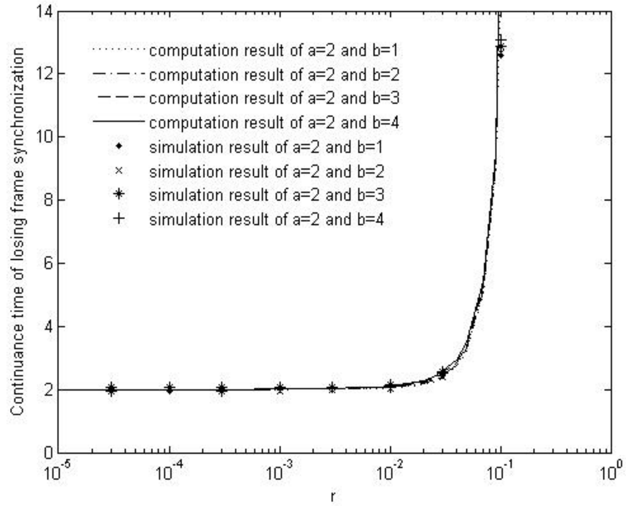

Fig. (16). Continuance time of losing frame synchronization T_L as a=2.

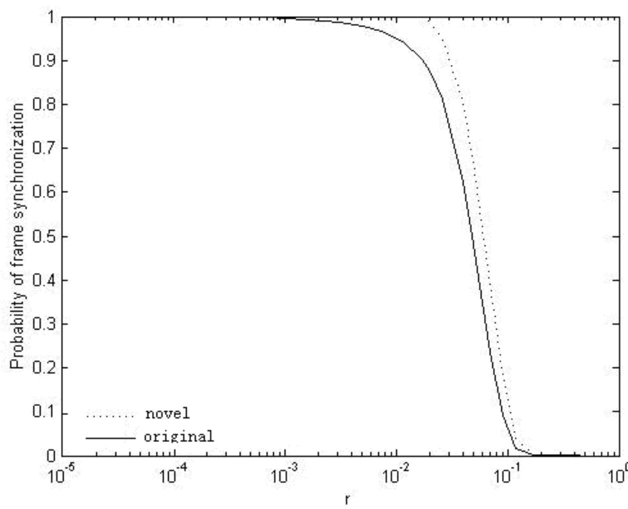

Fig. (17). Frame synchronization probability.

CONCLUSION

The traditional frame synchronization methods can not identify variation length frame. In view of this problem, a novel method is presented. The traditional frame format is improved by setting FLH of L_{FLH} bits to market $2^{L\mathrm{FLH}}$ kinds of L_{f}. According to the L_{f} information in FLH, system searches FSH bit by bit and checks FSH to lock or hold frame synchronization frame by frame. The performance parameters of novel method are educed, such as, probability of entering lock and frame synchronization loss, the continuance time of frame synchronization and frame synchronization loss, and so on. Then the reference values of a and b are given by simulating. Compared with original method the system can enter frame synchronization more easily by novel method.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

This work was funded by the Science Technology Bureau Applied Basic Research Plan of Shenyang City (F14-231-1-31), NSFC (61301256), the Dr. Start fund of Shenyang Ligong University, and the Science Public Research Funded Projects in Science Department of Liaoning Province GY2014-D-024.

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Received: September 22, 2014 Revised: November 02, 2014 Accepted: November 05, 2014