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Optimizing IEEE 802.11a Preamble Design for Vehicle-to-Vehicle Communication

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Abstract. The popularity of the autonomous driving requires to establish a data communication path among vehicles. Due to its low price and easy deployment, the WiFi device is a possible approach. Motivated by this, in this paper, we study the performance of IEEE 802.11a for vehicle-to-vehicle communication. We especially focus on the impact of multi-path and Doppler spreading to the time synchronization, which is the main challenges in the vehicle-to-vehicle communication due to the high mobility. We also propose the possible approach to improve the time synchronization performance in the IEEE 802.11a by optimizing the preamble design. We evaluate the average synchronization error of our proposed methods through simulation. Simulation result shows that replacing the preamble with the Zadoff-Chu sequence can obtain the best time synchronization performance.

Keywords. IEEE 802.11a, Multi-Path, Doppler Spreading, Vehicle-to-Vehicle, Time Synchronization

1. Introduction

Autonomous driving has been becoming more and more popular in recent years [1]. To better support autonomous driving, a data communication path among vehicles has to be established such that the vehicle can be aware of the driving intent of its neighboring vehicles. Due to the low price and easy deployment, one possible approach is to install the WiFi device in the vehicle to support data communication.

However, the WiFi device is especially designed for the indoor communication [2]. In the indoor environment, due to the low movement of the pedestrian, the impairment from multi-path and Doppler spreading is much slight compared with the vehicle-to-vehicle environment, which typically has a much higher mobility. Thus, its communication performance in vehicle-to-vehicle communication has to be evaluated.

As a typical WiFi standard, IEEE 802.11a adopts the OFDM modulation in the physical layer design, and it is especially suit for the multi-path environment [3]. Thus, applying IEEE 802.11a for the vehicle-to-vehicle communication is a good option.

Motivated by the above, in this paper, we especially focus on the impairment from multi-path and Doppler spreading to the fine time synchronization of IEEE 802.11a. Considering the impairment from multi-path and Doppler spreading to the fine time syn-

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chronization, we also give the possible approach to improve the time synchronization performance in the vehicle-to-vehicle environment and evaluate its performance.

The rest of this paper is organized as follows. In Section 2, we present the IEEE 802.11a preamble structure. In Section 3, we give the possible approach for optimizing IEEE 802.11a preamble to improve vehicle-to-vehicle communication performance. In Section 4, we evaluate the time synchronization performance for the proposed approach. We conclude this paper in Section 5.

2. IEEE 802.11a Preamble Structure

To assist for the frame detection, time synchronization, and frequency offset estimation, as in figure 1, the preamble of IEEE 802.11a consists of short training field (STF) and long training field (LTF). For the STF, it consists of 10 repeated sequences, and the sequence length is 12. Each symbol is mapped into the QPSK constellation and carried over 12 subcarriers in an OFDM symbol, and the subcarrier spacing is 1.25MHz. While for the LTF, it consists of 2 repeated sequences, the sequence length is 64. Each symbol is mapped into the BPSK constellation and carried over 64 subcarriers in an OFDM symbol, and the subcarrier spacing is 312.5kHz.

For the STF, it is designed for automatic gain control [4], frame detection, and coarse frequency offset estimation. Correcting the coarse time and frequency offset through the STF, the LTF can be further exploited for fine frequency and time synchronization.

Since IEEE 802.11a is especially designed for the indoor environment, if we apply it for a vehicle-to-vehicle communication scenario, its performance should be carefully evaluated.

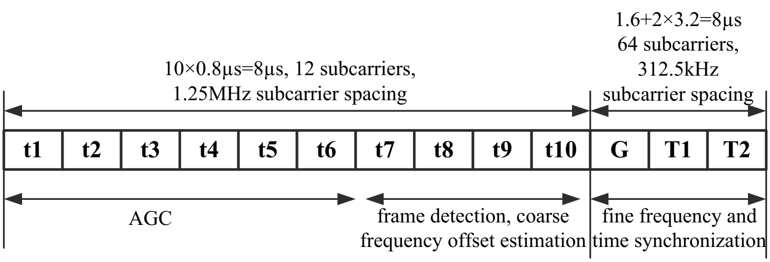

Figure 1. Preamble Structure of IEEE 802.11a

3. Optimizing IEEE 802.11a Preamble Design for Vehicle-to-Vehicle Communication

In this section, we first give the fine time synchronization method using LTF in the IEEE 802.11a, and then optimize the preamble design to improve the symbol synchronization performance.

3.1. Symbol Synchronization Method Using LTF

To achieve fine time synchronization, the cross-correlation $C(n)$ between the received signal $Y(n)$ and the LTF sequence $L(n)$ is calculated first as

$$C(n) = \sum_{m=0}^{63} Y(n+m) \bigotimes L^{\star}(m),$$

where $\star$ denote the complex conjugate. Since the LTF field has two repeated sequences, as in Figure 2, after calculating the cross-correlation, there should have two peaks. We denote the peak index as $\hat{n}_1$ and $\hat{n}_2$ separately. In the AWGN channel, since the LTF length is 64, such two peaks should have an index difference of 64. Further considering the error in locating the peak index, the index difference could be between 62 to 64, i.e., $62 \leq \hat{n}_2 - \hat{n}_1 \leq 64$. Using this rule, the receiver can precisely determine the start of the LTF sequence [5].

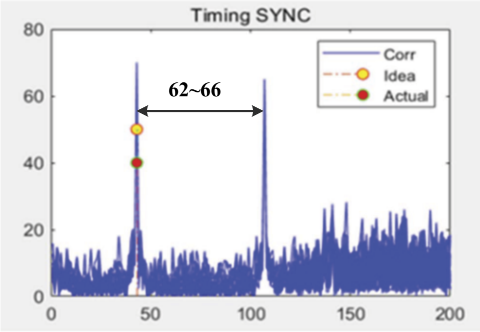

Figure 2. Cross-correlation for Fine Time Synchronization

3.2. Challenges for the Time Synchronization in Vehicle-to-Vehicle Communication

For the vehicle to vehicle communication, due to the high mobility, the challenges in the fine time synchronization come from the multi-path and Doppler spreading effects [6]. For the multi-path, especially when the gap between the first path and the non-first paths is small, the cross-correlation peak difference among paths is small. Combining the effect of Doppler spreading, which can severely disturb the peak in a small time period, the peak cannot be precisely determined, and this can degrade the time synchronization performance. Especially when the SNR is low, the time synchronization performance can be severely degraded.

3.3. Improving IEEE 802.11a Preamble Design

To improve the IEEE 802.11a performance in a vehicle-to-vehicle communication, we optimize the preamble design by three approaches as follows.

3.3.1. Increasing the LTF Sequence Length

To improve the time synchronization performance in the low SNR regime, we increase the LTF sequence length from 64 to 128, and extend the LTF from one OFDM symbol to two OFDM symbols. By increasing the LTF length, the matching gain can be increased, and this would increase the cross-correlation peak gap among paths, which may improve the fine time synchronization performance.

3.3.2. Skipping the Multi-path Effect in the Cross-correlation

To avoid multiple peaks induced by multi-path, one possible approach is to locate the last path, which cannot be impaired by other path. To achieve this, given the maximal path delay τ, we can derive its path delay in terms of the sampling point $\lceil \frac{\tau}{T_s} \rceil$, where $\lceil x \rceil = \min_{y \in \text{integer}}\{y \geq x\}$, and T_s is the sampling period.

Given $\lceil \frac{\tau}{T_s} \rceil$, after reaching the coarse time synchronization through the STF, before implementing cross-correlation to the LTF for fine time synchronization, we jump $\lceil \frac{\tau}{T_s} \rceil$ sampling points.

3.3.3. Replacing the Cross-correlation with the Auto-correlation

The benefit of using cross-correlation for fine time synchronization is that it can produce sharp peak, which can assist for the time synchronization. However, due to the multi-path and Doppler spreading effect, we cannot precisely locate the peak. While for the auto-correlation

$$A(n) = \sum_{m=0}^{63} Y(N+m) \bigotimes Y^{\star}(m),$$

where N is the LTF sequence length, it can mitigate the multi-path effect. Thus, one possible approach for improving the fine time synchronization is to replace the cross-correlation with the auto-correlation.

3.3.4. Replacing the LTF Sequence by the ZC Sequence

Since the Zadoff-Chu(ZC) sequence has better correlation performance in terms of main-lobe and side-lobe, and it has been widely used in the LTE system, which is originally designed to support mobility [7]. Thus, we replace the LTF sequence with ZC sequence to expect better performance in dealing with the multi-path and Doppler spreading.

4. Simulation Results and Performance Evaluations

In this section, we evaluate the proposed fine time synchronization methods through simulation. We denote cross-correlation method as XC N,where N is the LTF sequence length, skipping multi-path effect method as *XC SKIP*, auto-correlation method as *AC Th*, and ZC sequence cross-correlation method as *zc XC*.

Table 1. Channel Multi-path Parameters

Path Delay (μs)	Relative Gain (dB)
0	0
0.5	-3
1	-6
1.5	-9

4.1. Simulation Setup

To evaluate the proposed algorithm performance, we set the channel model as in Table 1.

We set the Doppler spreading spectrum as Jake spectrum. We set the maximal Doppler frequency offset as 1000Hz, which corresponds to a velocity of 207km/h in the 5.2GHz band.

4.2. Performance Analysis

We evaluate the time synchronization error in Figure 3 versus the signal to noise ratio (SNR). We run each test 500 times, and give the averaged time synchronization error. We can observe that the *zc XC* method has the best performance. While for *XC 128*, it has the worst performance, and this demonstrates that increasing the LTF length is not an option. While for the *XC SKIP* and the *AC Th*, it has a better performance compared with the *XC 64* when the SNR is above 15dB.

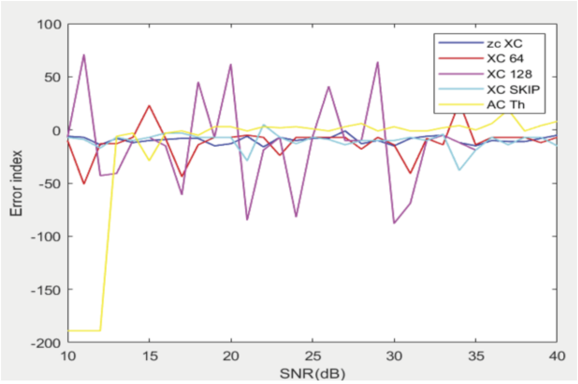

Figure 3. Time Synchronization Error

5. Conclusions

We study the time synchronization performance of IEEE 802.11a for for vehicle-to-vehicle communication. Considering the impact of multi-path and Doppler spreading to the fine time synchronization, we propose three approaches to improve the fine time synchronization performance in the IEEE 802.11a by optimizing the preamble design. Simulation result shows that replacing the preamble with the Zadoff-Chu sequence can obtain the best time synchronization performance.

References

[1] S. Chen et al., ”Vehicle-to-Everything (v2x) Services Supported by LTE-Based Systems and 5G,” in IEEE Communications Standards Magazine, vol. 1, no. 2, pp. 70-76, 2017.

[2] L. Que, H. Ju, X. Fang, Y. Long, R. He and L. Huang, ”Could IEEE 802.11bc Enhance Data Broadcast Performance for Moving Station: A Frame Loss Perspective,” 2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring), pp. 1-6, 2022.

[3] Y. Wu, K. Yip and T. Ng, ”ML frame synchronization for IEEE 802.11a WLANs on multipath Rayleigh fading channels,” 2003 IEEE International Symposium on Circuits and Systems (ISCAS), 2003.

[4] Y. Lee, D. Kang and W. Oh, ”AGC Algorithm for IEEE 802.11a Based on Correlator and Threshold Detector,” 2012 International Conference on Control Engineering and Communication Technology, pp. 933-935, 2012.

[5] Z. Wang, B. Zhao and F. Jeung, ”Design and implementation of timing acquisition in IEEE 802.11a wireless LANs,” Fourth International Conference on Information, Communications and Signal Processing, 2003 and the Fourth Pacific Rim Conference on Multimedia, pp. 554-558, 2003.

[6] C. Gamier, M. Loosvelt, V. Le Thuc, Y. Delignon and L. Clavier, ”Performance of an OFDM-SDMA based system in a time-varying multi-path channel,” IEEE 54th Vehicular Technology Conference. VTC Fall 2001, pp. 1686-1690, 2001.

[7] S. Kim, K. Joo and Y. Lim, ”A delay-robust random access preamble detection algorithm for LTE system,” 2012 IEEE Radio and Wireless Symposium, 2012, pp. 75-78, 2012.