Threshold Selection Algorithm of Joint Metric for TOA Estimation in 60GHz Sensor Networks

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Abstract: Impulse radio (IR) 60GHz signal has been applied in ranging and localization systems because of higher multipath resolution. In order to improve the precision of the TOA estimation, a threshold selection algorithm based on a Joint Metric of the Skewness and Kurtosis after Energy Detection is proposed. According to the algorithm, a function used to describe the relationship between joint metric and normalized threshold is built and the performance compared to other algorithms is analyzed via IEEE802.15.3c CM1.1 channel. The result shows that the threshold selection algorithm proposed in this paper provides higher precision and robustness with different SNR environment in 60GHz sensor networks.

Introduction

With apparent advantages of the several GHz license-free spectrums, 10W maximum transmit power, Impulse radio (IR) 60GHz wireless communication technology has become the first choice for Gbps level short-range positioning technologies for indoor environment [1,2]. The duration of the pulse signal usually lasts hundreds of picoseconds or less, thus the multipath signal can be separated at the end of receiving effectively, leading to a higher time and multipath resolution. The positioning precision using this technology can reach to millimeter.

Time of Arrival (TOA) is one of the time-based positioning technologies and it can make full use of the high time resolution [3]. For TOA estimation, an Energy Detector (ED) receiver doesn't need a correlative template, which resulting in lower sampling rate and lower complex [4].

In Energy Detector, the major problem is selecting a suitable threshold based on the received signal. In [5], a normalized threshold algorithm was proposed which using the minimum and maximum sample values. In [6], a threshold selection algorithm exploiting Kurtosis of received signal in Ultra-Wide Band system was proposed. These approaches have limited TOA precision because the strongest path is usually not the first path.

In this paper, considering the influences caused by the channel environment, statistics of the received signal are analyzed, such as Kurtosis and Skewness. Then, a threshold selection algorithm for IR-60GHz estimation based on a joint metric of Skewness and Kurtosis was proposed and a function based on the proposed algorithm was built. The remainder of this paper is organized as follows. In section 1, TOA estimation is introduced. In section 2, a threshold selection algorithm based on the joint metric is introduced. Finally, section 3 concludes the paper.

TOA Estimation

TOA Estimation Based on Energy Detector

In ED, the received signal is amplified and squared, then inputs to an integrator with integration interval of T_b, after that, the integrator output is z[n]. The threshold selection algorithm is applied before TOA estimation. There are many TOA estimation algorithms based on ED for determining the start block of a received signal. The simplest is Maximum Energy Selection (MES), which chooses the maximum energy value to be the start of the signal value. The TOA is estimated as the center of a corresponding integration period and is given by

$$\tau_{MES} = [\arg\max_{1 \le n \le n_b}\{n \mid z[n]\} - 0.5]Tb \tag{1}$$

However, the maximum energy value may not be the first energy block. On average, the first energy value is received before the maximum energy value. Thus, the Threshold-Crossing (TC) TOA estimation is proposed, which the received energy values are compared to an appropriate threshold ξ. The TOA estimation is given by

$$\tau_{TC} = [\arg\min_{1 \le n \le n_{\max}}\{n \mid z[n] \ge \xi\} - 0.5]Tb \tag{2}$$

So the problem is how to set up an appropriate threshold ξ. It is difficult to determine a ξ directly, so a normalized threshold ξ_{norm} is applied. The relationship between ξ and ξ_{norm} is given by

$$\xi = \xi_{norm}(\max(z(n)) - \min(z(n))) + \min(z(n)) \tag{3}$$

τ_{TC} is obtained via equation (11).

Error Analysis of TOA Estimation

The Mean Absolute Error (MAE) is defined to evaluate the quality of an algorithm. MAE is given by

$$MAE = \frac{1}{N}\sum_{n=1}^{N} | t_n - \hat{t}_n | \tag{4}$$

where t_n is the nth true TOA. $\hat{t}_n$ is the nth TOA estimation. N is the number of TOA estimation.

Joint Metric Threshold Selection Algorithm

Joint Metric J

During ranging process, threshold selection algorithm is a method aimed to find the accurate time when $z[n]$ is obtained. Analyzing the statistical characteristics of $z[n]$ can help us building a suitable relationship between $z[n]$ and threshold value. And for each SNR, there are 1000 IEEE802.15.3c CM1.1channel responses. In addition, the signal propagation delay is from zero to T_f. Other parameters are set up as: $f_c = 60GHz, T_f = 200ns, T_c = 1ns, Tb = 4ns, N_s = 1$.

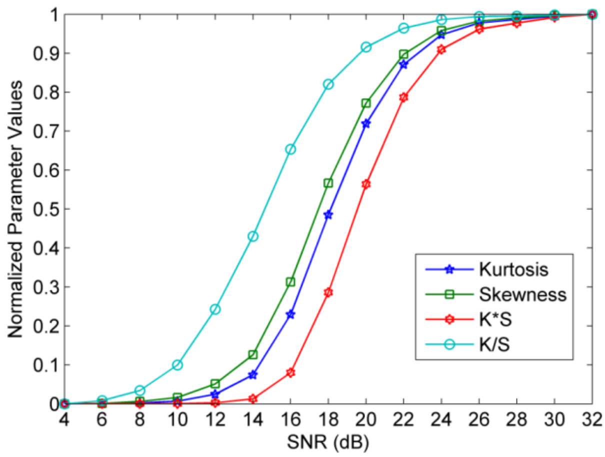

Fig.1. Normalized Statistical Parameters Via CM1.1.

The simulations of the statistical parameters are showed in Fig.1. K*S and K/S represent the multiplication and division of Kurtosis and Skewness, respectively. From the Fig.1, we learn that normalized values of the four characteristic parameters tend to increase as SNR increases, but the K/S changes more rapidly than the others, which means, it is more sensitive to the environment. Thus, a joint metric based on the K/S is proposed.

The Joint Metric is given by

$$J = K / S \tag{5}$$

where K is the Kurtosis, S is the Skewness.

Threshold Selection Based on J

In order to use the joint metric in threshold selection, a function that can describe the relationship between J and normalized threshold value is required. Then, the threshold value can be set by calculating the joint metric of the received signal. As the relationship of J and SNR, as well as MAE and SNR is easy to study, thereby we can find the relationship between J and MAE through SNR. In addition, the normalized threshold (ξ_{norm}) is the best threshold (ξ_{best}) when MAE takes the minimum value. So in order to determine the best threshold (ξ_{best}) based on J, 1000 IEEE802.15.3c channel realizations are simulated. Taking ξ as the threshold, then comparing to the energy blocks to find the first threshold crossing value, and the relationship between ξ and ξ_{norm} is defined in Eq. 3. The relationship of J and SNR is showed in Fig.2, while the relationship of MAE and SNR is showed in Fig.3. Through Curve Fitting, the function for CM1.1 $T_b = 4ns$ is given in Eq. 4.

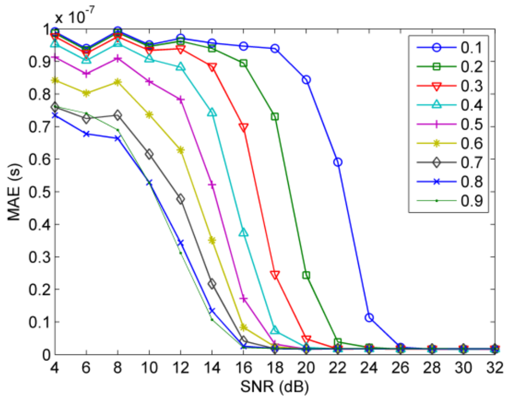

Fig.2. MAE with SNR (CM1.1, $T_b = 4ns$)

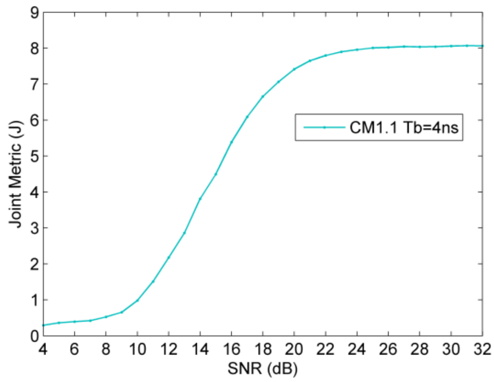

Fig.3. J with SNR (CM1.1, $T_b = 4ns$)

$$\xi_{best}^{(4ns)}(J) = \begin{cases} 0.8, J < 0.53 \\ -0.001118J^4 + 0.01345J^3 - 0.06393J^2 + 0.1543J + 0.7464, 0.53 \le J \le 8.01 \\ 0.1, J > 8.01 \end{cases} \tag{6}$$

Performance Analysis

The MAE is examined for different TOA estimation algorithms based on ED in the IEEE 802.15.3c CM1.1 channel with T_b=4ns. The MES refers to the Maximum Energy Selection algorithm, and the Joint Metric refers to the proposed algorithm based on the Joint Metric J.

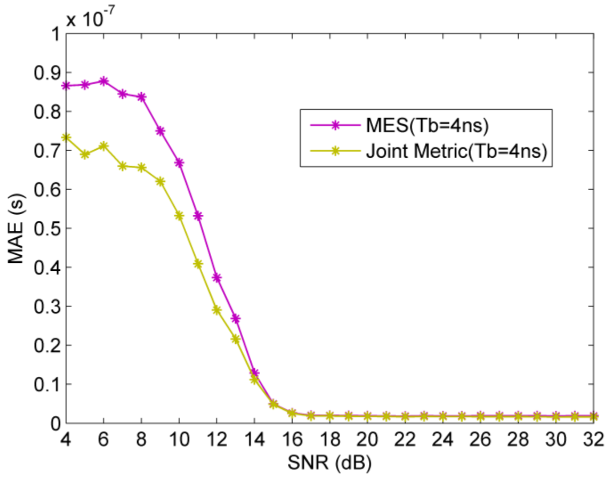

Fig.4 MAE for Different Algorithms with CM1.1

For each algorithm, 1000 channel realizations are simulated. Figs.4 presents that the MAE with Joint Metric algorithm is lower than MES, particularly at low or moderate SNR. For example, when

SNR is between 4dB to 14dB, the MAE of the proposed algorithm is better by 8ns~18ns than MES. Therefore, the positioning precision is optimized by 2.4 meter~5.4 meter. When SNR>16dB, the MAE with Joint Metric algorithm is about 1.5ns. Thus, the positioning precision can reach to 0.45 meter.

Conclusions

In this paper, a new threshold selection for TOA estimation based on a joint metric of Kurtosis and Skewness in IR-60GHz networks is proposed. The best normalized threshold was determined using simulation with IEEE 802.15.3c CM1.1 channel and a function based on the threshold algorithm is built through curve fitting. In order to analyze the performance of the proposed algorithm, the MAE is used to describe the differences between the proposed algorithm to a traditional algorithm MES. The result shows that the proposed algorithm increases the positioning precision and has higher robustness, especially under the situations with low or moderate SNR.

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