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Performance of Channel Estimation in Two-Dimensional Modulation System

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Abstract

Orthogonal time frequency space (OTFS) modulation is considered as one of the solutions to cope with high mobility channel environments. It converts the time-varying channel to the near-constant channel response in the delay-Doppler domain. This modulation scheme also benefits from the diversity in two-dimensional modulation. According to recent researches, this method outperforms the conventional OFDM modulation, especially in high-speed channel conditions. In this paper, to investigate the performance of OTFS in a practical system, channel estimation in the delay-Doppler domain is compared with the conventional method in the time-frequency domain at different mobile speeds. Simulation results confirm that the delay-Doppler domain channel estimation brings a better performance compared to the conventional one under the same overhead rate.

Keywords: *Channel estimation, Two-dimensional modulation, Time-varying channel, OTFS, OFDM*

1. Introduction

Orthogonal time frequency space (OTFS) is known as a novel modulation method to deal with the high-speed mobile user. In OTFS, each symbol in the time-frequency (T-F) domain is spread into two dimensions in the delay-Doppler (D-D) domain [1]. In D-D channel representation, each user is defined by its distance (delay) and speed (Doppler) [2]. This approach helps to transform the time-varying channel into a stable and condensed one in the D-D domain. With this method, the equalization process can be done with relatively lower complexity compared to T-F domain. Therefore, channel estimation in D-D domain plays an important role in designing an OTFS system. It is worth noticing that T-F domain channel estimation can be applied in the OTFS system. The channel response in T-F domain can be estimated based on the pilot-aided algorithm in which pilots are distributed in time and frequency domains [3]. However, under a very high mobility system, these structures require a high pilot overhead rate to prevent performance degradation in the channel estimation stage. On the other hand, D-D domain channel estimation can be applied in a simpler and

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more efficient way under the same channel condition because of the condensed channel profile in the D-D domain. In this paper, the performance of a channel estimation method is evaluated in OTFS system which is based on the method introduced in [4]. Also, the zero-padding interpolation method is applied to the channel reconstruction process at the receiver side [5]. In the following section, the system model for the two-dimensional modulation system is discussed and followed by the simulation results.

2. System Model

OTFS transforms the symbol in the T-F into D-D domain to benefit from the two-dimensional diversity and the stability of the channel [6]. The dimension of the symplectic finite Fourier transform (SFFT) modulation is equal to the size of the T-F domain which is assumed to be $M \times N$ in our system model. In the two-dimensional modulation, an OTFS symbol is expanded in a larger region of the T-F plane. By spreading across time and frequency domains, this method helps to utilize the diversity in time and frequency domains of the channel. In D-D domain, the received signal can be represented as a 2D circular convolution between the transmitted signal and the channel [1]:

$$y[k,l] = \sum_{k'=0}^{M-1} \sum_{l'=0}^{N-1} h[k-k', l-l']\, x[k', l'] + w[k,l] \tag{1}$$

where $w[k,l]$ is the Gaussian noise, $x[k,l]$ is transmitted symbol, and $h[k,l]$ is channel response in D-D domain. In D-D domain, the channel impulse response is condensed in a limited area, which is an advantage for using the pilot-aided channel estimation.

Based on the idea in [4, 5], we investigate a pilot structure for the channel estimation in the D-D domain. This approach requires a smaller number of pilot and guard symbols to estimate the channel impulse response since it is condensed in a smaller area in D-D domain. As illustrated in figure 1(a), one pilot is surrounded by guard symbols which are utilized as a buffer area to exclude the adjacent interference to the pilot and also help to detect the data symbols. The dimension of the guard symbols area is equal to the delay spread of the channel to maintain the accuracy of the estimation. The size of the pilot block is $(2M_p + 1) \times N_p$ and the position of the pilot is determined by the index k_p and l_p. At the receiver, we use the received symbols $y[k,l]$ with $k_p \leq k \leq k_p + M_p$, $0 \leq l \leq N-1$ for channel estimation as:

$$y[k,l] = \sum_{k'=k_p}^{k_p+M_p} \sum_{l'=0}^{N-1} h[k-k', l-l']\, x[k', l'] + w[k,l] \tag{2}$$

In this area, since $x[k,l] = 0$ if $k \neq k_p$ and $l \neq l_p$, (2) can be expressed as:

$$y[k,l] = h\left[k-k_p, l-l_p\right] x\left[k_p, l_p\right] + w[k,l] \tag{3}$$

The channel impulse response can be estimated as:

$$\hat{h}\left[k-k_p, l-l_p\right] = \frac{y[k,l]}{x[k_p, l_p]}. \tag{4}$$

In our system, the channel delay spread in the D-D domain must be covered by the pilot block. Therefore, M_p and N_p should be greater than the number of significant channel taps in D-D domain.

3. Simulation Results

In this section, the pilot-aided channel estimation in D-D domain is investigated and compared with the conventional block-type T-F domain channel estimation whose pilot structure is illustrated in figure 1(b). In figure 2, the performance of the D-D and T-F domain channel estimations are also compared with the ideal case in Urban Micro (Umi) channel model. We select $M_p = 10$ and $N_p = 13$ and the overhead rate is equal to 15% for both channel estimation methods. In non-ideal cases, at the speed of 30 km/h, the performance gap between channel estimations in T-F and D-D is not so significant. However, when the speed increases to 300 km/h, T-F domain channel estimation performs with a very high error floor while D-D channel estimation maintains good performance. In case of the estimation in the D-D domain, at the user equipment (UE) speeds of 30 and 300 km/h, the gaps of the non-ideal channel estimation compared with the ideal channel estimation are 0.2 and 2.3 dB, respectively while the gaps increases from 0.8 dB to unmeasurably big for the T-F case. It is worth noticing that the robustness of the estimation method in D-D domain comes from the condensed and stable channel impulse response as shown in the simulation results.

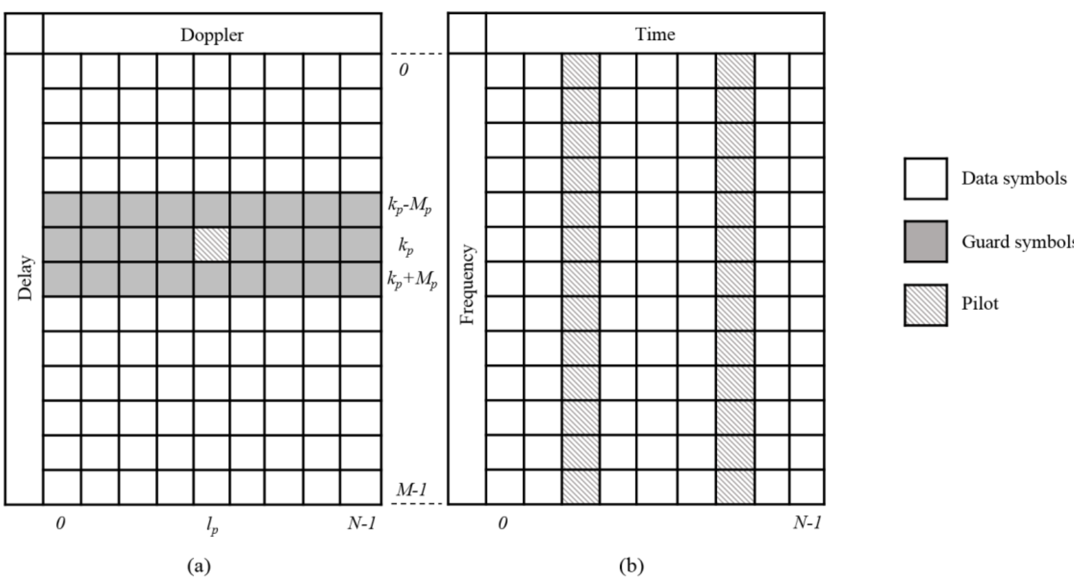

Figure 1. Pilot structure (a) in time-frequency and (b) in delay-Doppler domain

4. Conclusion

In this paper, the performance of channel estimation in the D-D domain is evaluated and compared with the conventional approach on the two-dimensional modulation based system. The D-D domain channel estimation benefits from the condensed channel response. Due to this channel profile characteristic, the performance of the channel estimation in the D-D domain is better, especially in the time-varying channel. Also, the performance gap becomes bigger when the user speed gets higher with the same overhead rate. Packet error simulation results confirm that D-D channel estimation performs much better than T-F channel estimation at higher user speed. Therefore, this pilot-aided channel estimation method is a potential candidate to be implemented in the practical two-dimensional modulation system.

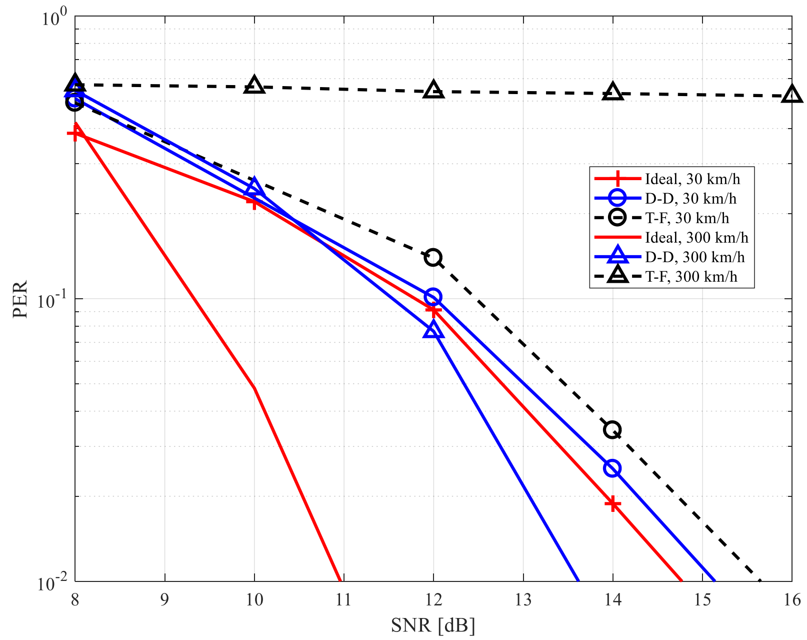

Figure 2. Performance of channel estimation on the Urban Micro channel

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