# Research on Pilot Pattern Design of Channel Estimation

Qun Yu and Ronglin Li
School of Electronic and Information Engineering, South China University of Technology, Guangzhou, China
Email: yu_qun2007@163.com, lirl@scut.edu.cn

***Abstract*— Channel estimation is a crucial technique in wireless communication, and pilot pattern design is an essential procedure to realize PSA-OFDM (pilot symbol assisted orthogonal frequency division multiplexing). In this paper, we researched on the constrained conditions of pilot pattern such as the number and the interval of pilot symbols. Then, all kinds of the pilot patterns and usage scenarios are summarized roundly. Finally, we put forward some problems which are significant but have not been solved well up to now.**

***Index Terms*—pilot patterns, channel estimation, constrained conditions, PSA-OFDM**

## I. INTRODUCTION

In wideband wireless communication, the goal is to achieve credible and high-speed data transmission. There are two severe challenges to realize the goal: the service efficiency enhancement of bandwidth and the multipath fading of the channel. Orthogonal frequency division multiplexing (OFDM) can meet the requirements. In order to realize the effects of OFDM, the estimation of the channel frequency response is invariably required. Pilot symbol assisted modulation (PSAM) is one of the hot issues of channel estimation, and pilot pattern design is the first step in PSAM. The selection and insertion of pilot is the basis of PSAM, viz. pilot pattern design plays a key role to the estimation performance of channel.

## II. THE REQUIREMENTS OF PILOT PATTERN DESIGN

Pilot pattern design refers to the decision of where to place pilot symbols and how many pilot symbols should be used. On one hand, the interval of pilot should be as small as possible, so that it can track the frequency selection and the time-varying of the channel, on the other hand, considering reducing the system overhead, the interval of pilot should be as big as possible. So we should make a compromise in the design of practical system. Commonly, we can make judgments by Bit-Error -Rate (BER).

How to design the pilot pattern? The relevant requirements are as following.

### A. The Interval of Pilot

Two important parameters are involved in the pilot pattern design, one of them is the maximum Doppler frequency offset $f_m$ (it is related with the minimum coherence time), and the other is maximum multipath delay $\tau_m$ (it is related with the minimum coherence bandwidth). According to Nyquist's theory, the frequency interval and the time interval should respectively meet the following formulas [1] and [2].

$$N_f \approx \frac{1}{2\Delta f\,\tau_{\max}} \tag{1-1}$$

and

$$N_t \approx \frac{1}{2f_m T_s} \tag{1-2}$$

The $T_s$ is the OFDM symbol length and the $\Delta f$ is the frequency interval of subcarrier.

In the practical engineering, in order to achieve the more correct estimation, (1-1) and (1-2) should be respectively modified to

$$N_f \approx \frac{1}{2}\bullet\frac{1}{2\Delta f\,\tau_{\max}} \tag{1-3}$$

and

$$N_t \approx \frac{1}{2}\bullet\frac{1}{2f_m T_s} \tag{1-4}$$

Besides, we should also take the hardware variation (i.e. the phase noise and oscillating frequency drift) into consideration.

### B. Pilot selection and Insertion

In this part, it already had some theoretical conclusions.

- It will cost a waste of resources when inserts the pilot, the loss can be expressed as [3].

$$\Lambda = \frac{N_{grid}}{N_c N_s} \tag{1-5}$$

Thereinto, $N_{grid}$ is the number of pilot symbols, $N_c$ is the number of carriers, $N_s$ is the number of OFDM symbols in every frame.

The loss of signal noise ratio (SNR) is

$$V_{pilot} = 10\lg\left(\frac{1}{1-\Lambda}\right) \tag{1-6}$$

- If no noise, choosing any L signals of N subcarriers in OFDM system as the training

Manuscript received October 25, 2012; revised December 23, 2012.


doi: 10.12720/joace.1.2.160-163

symbols, we can recover the channel information perfectly. And L is maximum length of channel.

- The location of optimum pilot. Under the condition of additive white Gaussian noise (AWGN), when L pilot location is $\{i, i+\frac{N}{L}, \dots, i+\frac{(L-1)N}{L}\}, i = 1,1,\dots,\frac{N}{L-1}$, we will achieve the minimum mean square error (MMSE) [4].

Moreover, we should try to insert pilot symbols in the first and the last OFDM signal in every frame, meanwhile, we should also insert pilot symbols in the first and the last subchannel. Then, we can ensure estimation accuracy on the edge of every frame.

### *C. The Number of Pilot*

To obtain a tradeoff between the channel estimation accuracy and the bandwidth efficiency, how many pilot symbols are needed? There is no exact formula yet; however, we only know that the more pilot symbols, the better of the performance, but the lower of the bandwidth efficiency. Wei et al. had proposed a solution, at a given SNR, it can find the minimal number of pilot symbols by plotting those different BER curses with respect to the pilot spacing L [5].

## III. Existing Pilot Pattern

For different channels, we should choose different pilot patterns. As depicted in Fig. 1, a regular pilot arrangement can be illustrated with two basis vectors $v_1 = [x_1, y_1]^T$ and $v_2 = [x_2, y_2]^T$ .Where the vectors are represented in Cartesian coordinates: the time axis by the abscissa and the frequency axis by the ordinate. Then, all the pilot patterns with a regular structure can be represented by the two basis vectors [6].

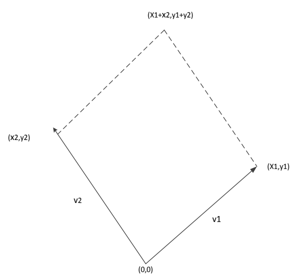


Figure 1. Pilot pattern in Cartesian coordinates

- Comb-type pilot [7].

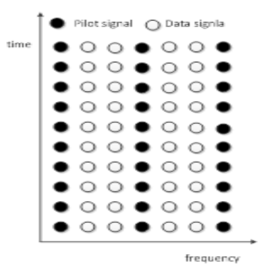


Figure 2. comb pilot structure

It is uniformly distributed in every OFDM signal. It is greatly affected by the frequency selective fading, but it is insensitive to slow fading in time. So it is fitted very well to the fast fading channel. Its structure is shown as Fig. 2.

- Block-type pilot [8].

Pilot sequence is systematically and periodically transmitted, the whole OFDM signal is pilot signal, which is shown in Fig. 3, so the operation is very simple. With this characteristic, it is insensitive to the frequency selective fading and it is commonly used in the slow fading channel.

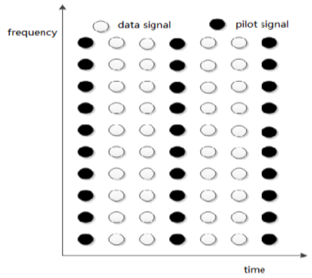


Figure 3. Block pilot structure

- Hybrid-type pilot [9]

Just because comb pilot pattern and block pilot pattern possesses different characteristics, it is very natural to combine this two kinds of pilot patterns into a hybrid pilot structure, as shown in Fig. 4, The hybrid pilot structure retains the merits of the comb pilot and block pilot and discards their shortages. It can enhance the capability of channel tracking and the frequency efficiency. But the algorithm may cause more computer complexity.

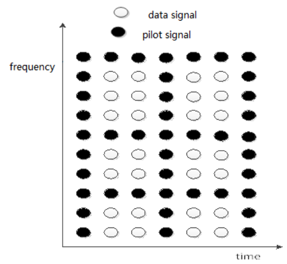


Figure 4. hybrid pilot structure

In every frame of OFDM system, it should insert hybrid pilot symbols, the interval should meet the Nyquist sampling theorem, and the weighting coefficient is solved by the Lagrange conditions. During transmitting pilot signals, every frame should have multiple OFDM symbols and pilot symbols should be inserted in every subchannel.

- Scattered-type pilot [10]

Under the reciprocal of the twice bandwidth is greater than the sample interval, namely, according to Nyquist law, we respectively insert pilot signals from the frequency domain and the time domain, just as Fig. 5 shown. The merit of this pilot pattern is that it needs a small number of pilot symbols, so its spectral utilization is very high. However，due to its computer complexity, it is difficult to be realized.

If the intervals of pilot from the frequency and the time are equivalent, the pilot pattern will transform into the square pilot pattern. If the pilots are inserted in parallel, it will transform into diamond pilot pattern (namely hexagonal pilot pattern). These two pilot patterns can estimate the channel state instantaneity and they are always used in fast fading channel, but they have more complex structure, resulting in increasing the system complexity. M.J.et al first proposed the hexagonal pilot pattern and proved that it was optimum in terms of sampling efficiency [11].

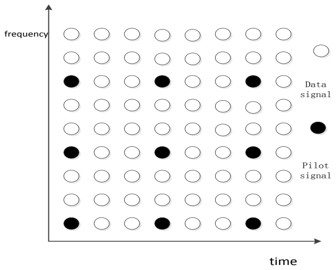


Figure 5. scattered pilot structure

- Trellis-type pilot [12]

In order to meet the sample theorem, the pilots are inserted evenly on frequency domain and time domain.

This pilot pattern has simple structure, which won't increase the system complexity and can reduce the system redundancy at the same time, so it can increase the system transmission speed. But it will bring many estimation errors. Fig. 6 shows the trellis pilot structure.

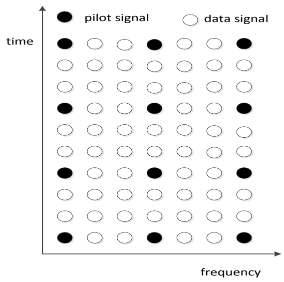


Figure 6. Trellis pilot structure

- Diagonal-type pilot [13]

Because pilot symbols are inserted linearly into the signal, it makes full use of the information of the frequency domain and the time domain. It can reduce the computer complexity and tend to reduce the difficulty of the calculation compared with the traditional Wiener filtering algorithm. Dai et al. simplify its structure and algorithm so as to reduce the arithmetic complexity [14]. The structure is shown in Fig. 7.

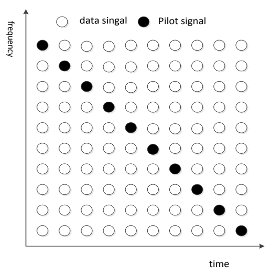


Figure 7. Slash pilot structure

- Clustered-type pilot [5]

In DVB-T standard, an equal-spaced pilot pattern is adopted, in [5], every two neighboring pilots are grouped as one cluster, and these clustered pilot groups are equal-spaced as shown in Fig. 8.The merit of this pilot pattern is that it can reduce half of the noise power in the pilot subchannel estimation, thereby leading to more accurate data subchannel estimation.

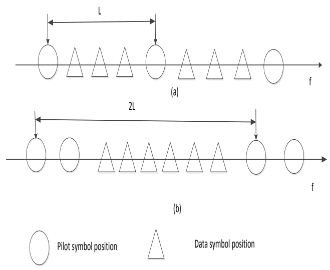


Figure 8. (a) equi-spaced pilots, (b) clustered pilots

## IV. CONCLUSION

By synthetically analyzing the constrained conditions of pilot patterns and existing pilot patterns, we can see that there are some important issues in the design of pilot patterns:

Further improvement has been made on the pilot pattern design to obtain higher efficiency, higher precision and lower computation complexity to the channel estimation.

There still hasn't an exact formula to directly compute the numbers of pilot in terms of actual channel state.

Compressed sensing (CS) is a very popular technology now, if we can combine it with pilot pattern design, we will achieve the same performance with less pilots, or gain the better performance with the same number of pilots. There already has a few literatures on this issue, it still need further research.

## REFERENCES

[1] H. B. Zhang, "The Basic Principles and Key Technologies of Orthogonal Frequency Division Multiplexed," National Defence Industry Press, 2006

[2] J. K. Cavers, "An analysis of pilot symbol assisted modulation for Rayleigh fading channels," *IEEE Trans. Vehicle Tech.*, vol. 40, no. 4, pp. 686-693, 1991.

[3] Y. M. Wang, "Key technology and application of OFDM," Machinery Industry Press, 2007.

[4] R. Negi and J. Cioffi, "Pilot tone selection for channel estimation in a mobile OFDM system," *IEEE Trans. on Consumer Electronics*, vol. 44, pp. 1122-1128, 1998.

[5] W. Zhang, X. G. Xia, and P. C. Ching, "Optimal Training and Pilot Pattern Design for OFDM Systems in Rayleigh Fading," *IEEE Trans, Broadcasting*, vol. 52, no. 4, pp. 505-514, December 2006.

[6] J. W. Choi and Y. H. Lee, "Optimum pilot pattern for channel estimation in OFDM system," *IEEE Trans. Wireless Com*, vol. 4, no. 5, pp. 2083-2088, September 2005.

[7] S. Coleri, M. Ergen, A. Puri, and A. Bahai, "Channel Estimation Techniques Based on Pilot Arrangement in OFDM system," *IEEE Transactions on Broadcasting*, vol. 8, no. 3, pp.223-229, 2002.

[8] J. X. Ding, K. R.Wang, and X. B. Chen, "OFDM channel estimation based on block-type pilots," *Information Technology*, vol. 7, pp. 81-87, 2011.

[9] Y. Zhang, “Study on Mixed Pilot-Aided Channel Estimation of OFDM Systems,” M.S. thesis, Jilin University, June 2011.

[10] S. Haykin, *Adaptive Filter Theory*, 3rd ed. Englewood Cliff: prentice Hall, 1996.

[11] M. J. F. -G. Garcia, S. Zazo and J. M. Paez-Borrallo, “Pilot patterns for channel estimation in OFDM,” *Electronics Letters*, vol. 36, no. 12, pp. 1049-1050, June 2000.

[12] W. Gu, “Design of High-Speed Power-line communication based on OFDM Technology,” M.S. thesis. Tsinghua University, 2005.

[13] Y. F. Tian, H. P. Wang, and W. H. Tong. “A New Algorithm for OFDM Channel Estimation Based on Diagonal pilots.” [Online]. Available: http://www.paper.edu.cn.

[14] X. Y. Dai and L. Wang, “The Algorithm Research in Channel Estimation Based on Diagonal Pilot Structure,” *Journal of Jishou University (Natural Science Edition)*, vol. 28, no. 4, pp. 79-81, Jul. 2007.


**Y.Qun** born in GuangDong province of China, received the B.S. degree in electrical engineering from Jimei University, China, in 1995, and the M.S. degrees in System of Information and Telecommunication from the South China University of Technology (SCUT), in 2003. She is currently doing her PhD degree in SCUT. Her research interests include LTE Physical Layer.

**R.L. Li**, in Ph.D, Professor of the South China University of Technology. He has published more than 100 papers in refereed Journals and Conference Proceedings, and 3 book chapters. His current research interests include new design techniques for antennas in mobile and satellite communication systems, phased arrays and smart antennas for radar applications, wireless sensors and RFID technology, electromagnetics and information theory.