Pilot-assisted channel estimation in MC-CDMA for future mobile cellular systems

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Abstract

The effect of two different pilot-assisted channel estimation techniques on BER in Multi-Carrier CDMA (MC-CDMA) is considered. The first technique involves sending both data and pilot symbols in the same OFDM symbol. The second technique involves sending data and pilot symbols in separate OFDM symbols. In both cases multi-access interference is present. Simulations of both systems in a UMTS multipath channel are presented. The results of this investigation conclude that the second technique outperforms the first technique, however both systems suffer a reduction in throughput.

Introduction

The deployment of 3rd Generation (3G) mobile cellular systems in Japan in late 2001 and the anticipated deployment of such systems in Europe in late 2002 has focussed attention in the research community on the requirements of future mobile cellular systems. These future systems have been termed ‘beyond 3G’ or ‘4G’ systems [1, 2]. The main features of such a system will be greater capacity and access speed in the downlink. Multi-carrier CDMA (MC-CDMA) [3, 4] is a promising candidate for the air interface of such systems. This paper will focus on channel estimation techniques in MC-CDMA using pilot symbols.

1 MC-CDMA basics

MC-CDMA is a modulation / multiple access scheme which is a combination of Orthogonal Frequency Division Multiplex (OFDM) and Code Division Multiple Access (CDMA). In OFDM systems data is transmitted over multiple subcarriers instead of a single carrier. CDMA is a multiple access scheme where different users in a system are identified by a unique spreading code. In a MC-CDMA transmitter with N subcarriers the data symbol from user u is replicated N times and multiplied by a chip from a user specific spreading code, $c(n, u)$, where $n = 0..N\text{-}1$. The n th spread symbol from each user is combined and then modulated onto one of the N subcarriers. In effect spreading is performed in the frequency domain. In discrete-time MC-CDMA each of the spread symbols in the transmitter is modulated onto N subcarriers using an N-point inverse fast Fourier transform (IFFT). This creates an N–sample OFDM symbol at the output of the IFFT. In the receiver an N-point FFT is used to demodulate the OFDM symbol. The signal at each subcarrier is multiplied by a channel equalising coefficient, $a(n)$, and then despread using the user specific spreading code. The despread symbols are combined to form an estimate of the original data symbol for user u. A single user MC-CDMA transmitter and receiver is illustrated in Figure 1.

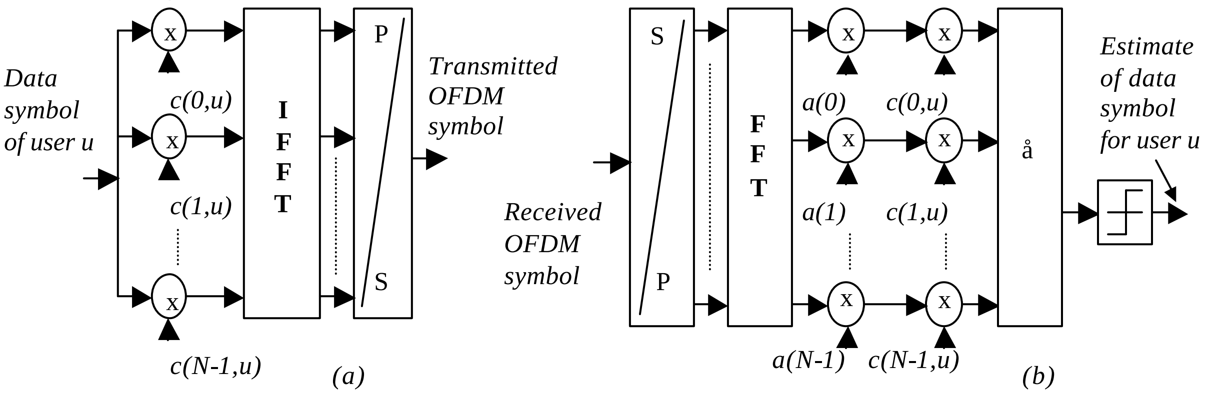


Figure 1: Digital MC-CDMA transmitter (a) and receiver (b).

2 Channel estimation

Channel estimation will permit the channel equalisation coefficients $a(n)$ to be derived. The most popular method of performing channel estimation in wireless channels is to use pilot symbols. Pilot symbols are interspersed in time with data symbols in the downlink of the 3G UMTS standard [5]. In terrestrial Digital Video

Broadcasting (DVB-T) [6], which is OFDM based, pilots are transmitted both continuously on dedicated pilot subcarriers and also time multiplexed with data symbols on other subcarriers. In WLAN 802.11a [7], which is also OFDM based, pilot symbols are transmitted on each subcarrier at the beginning of each data burst.

The location of pilot symbols in the frequency-time domain can be represented as $p_{n,r}$ where n is the subcarrier index and r is the OFDM symbol index. The location of these pilot symbols are fixed reference points which are known in the receiver. The channel estimate at the pilot locations can be calculated as follows,

$$\hat{h}_{n,r} = \frac{y_{n,r}}{p_{n,r}} \tag{1}$$

where $y_{n,r}$ is the corresponding received signal. Channel estimates from different pilot locations can then be interpolated to obtain channel estimates at all values of n and r. The performance of a multiuser MC-CDMA system is simulated in the UMTS vehicular channel B model [8] with the maximum Doppler frequency set to 200 Hz. The channel model is constructed using Jakes method [9]. The MC-CDMA system uses 128 subcarriers – hence a 128 point IFFT is used in the transmitter and a 128 point FFT is used in the receiver. Each OFDM symbol will consist of 128 complex samples and the output sample rate is 3.84 Msamples/s. The data symbol rate of each user is therefore 30,000 symbols per second.

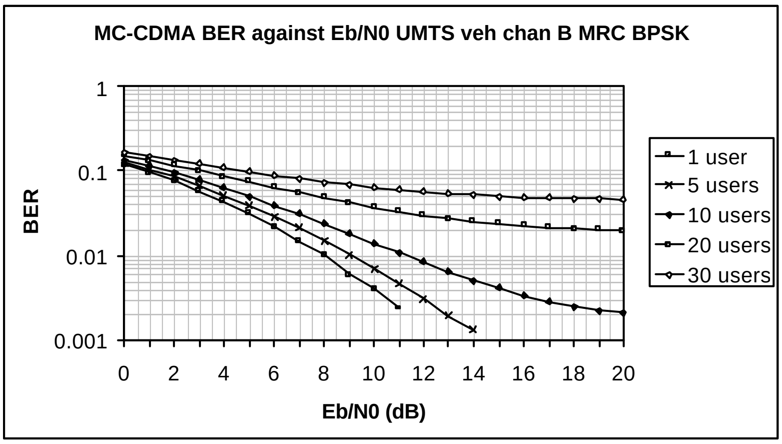


Figure 2: MC-CDMA in UMTS vehicular channel B with perfect channel knowledge in the receiver.

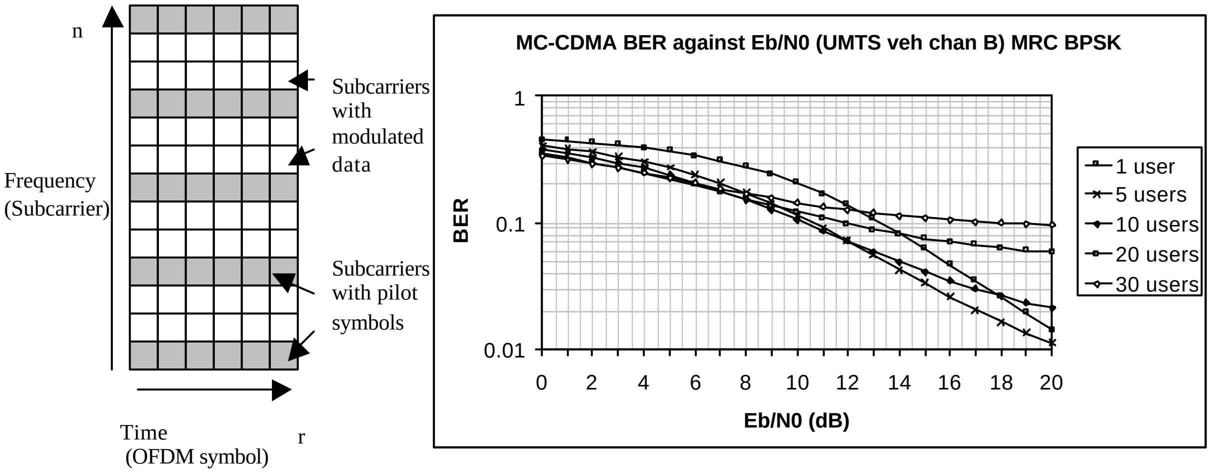
The data symbol from each user is spread with a randomly generated length 128 spreading code. BPSK modulation is used to modulate the spread values onto the subcarriers. Figure 2 illustrates the performance of this system in this channel. The receiver is perfectly synchronised with the incoming OFDM symbols and has perfect knowledge of the channel. In effect these results will represent a lower bound on the performance of channel estimation in the system. Maximal ratio combining (MRC) equalisation i.e. $a(n) = h(n)^*$, is performed in the receiver. Two techniques of pilot-assisted channel estimation will now be examined.

2.1 Technique 1: Pilot and data symbols transmitted in same OFDM symbol

Pilot symbols are now arranged among data symbols at the transmitter similar to the pattern illustrated in Figure 3 (a). At the receiver channel estimates are formed at each pilot symbol location and linear interpolation is now applied on the I and Q values of each channel estimate to form a channel estimate at the intervening subcarriers. The maximum frequency separation, s_f, of pilot symbols is set by [10],

$$s_f < \frac{1}{t_{\max}} \tag{2}$$

where t_{max} is the maximum delay spread of the multipath channel. For the UMTS vehicular channel B model t_{max} is 20 μs and hence s_f must be less than 50 kHz. The subcarrier separation in this system is determined by the output bandwidth of the system divided by the number of subcarriers. The output sample rate of the system is 3.84 Msamples/s, hence the minimum output bandwidth is 1.92 MHz. With 128 subcarriers this gives a subcarrier separation of 15 kHz. Therefore the pilot symbols must be placed on every third subcarrier to give a subcarrier separation of 45 kHz and hence obey equation 2. This system, therefore, has 44 subcarriers allocated to carry pilot symbols and 84 subcarriers allocated to carry spread data. Figure 3 (b) illustrates the performance of this system. Each user specific pilot symbol has the same power as a spread data symbol from a single user and pilot power is proportional to the number of users.



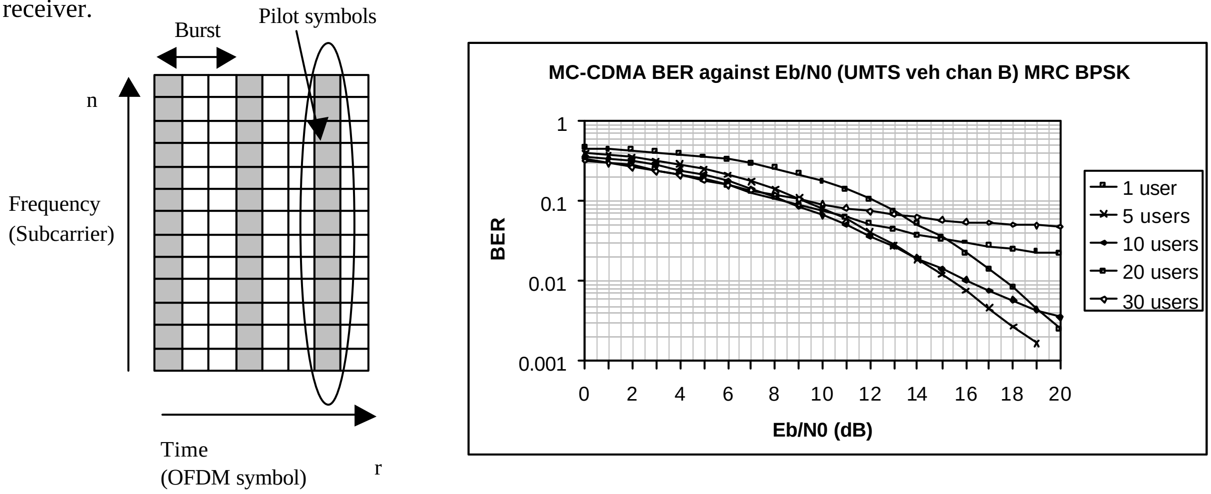
(a) *(b)*

Figure 3: Arrangement of pilot symbols in channel estimation technique 1 (a) and associated BER performance (b).

The loss in performance of this system compared to that with perfect channel knowledge in the receiver is apparent. A receiver with a perfect channel estimate, with a system load of 10 users, attains a BER of 3×10^{-2} at Eb/N0 7 dB, see Figure 2. However in a system with identical load and using this technique of channel estimation in the receiver a BER of 3×10^{-2} is now attained at Eb/N0 17 dB, a performance degradation of 10 dB.

2.2 Technique 2: Pilot and data symbols transmitted in separate OFDM symbols

An OFDM symbol which only consists of pilot symbols is transmitted at the start of each data burst as shown in Figure 4 (a). The channel equalising coefficients derived from that channel estimate and are reused throughout that burst. A data burst consists of one OFDM symbol which carries exclusively pilot symbols followed by two data carrying OFDM symbols. The performance of this method is illustrated in Figure 4 (b). The channel is assumed to be essentially invariant over the data burst as the duration of the burst is less than the coherence time of the channel. Each user specific pilot symbol has the same power as a spread data symbol from a single user and pilot power is proportional to the number of users. At a system load of 10 users a BER of 3×10^{-2} is attained at Eb/N0 12.5 dB, a performance degradation of 5.5 dB over the system with perfect channel knowledge in the receiver.

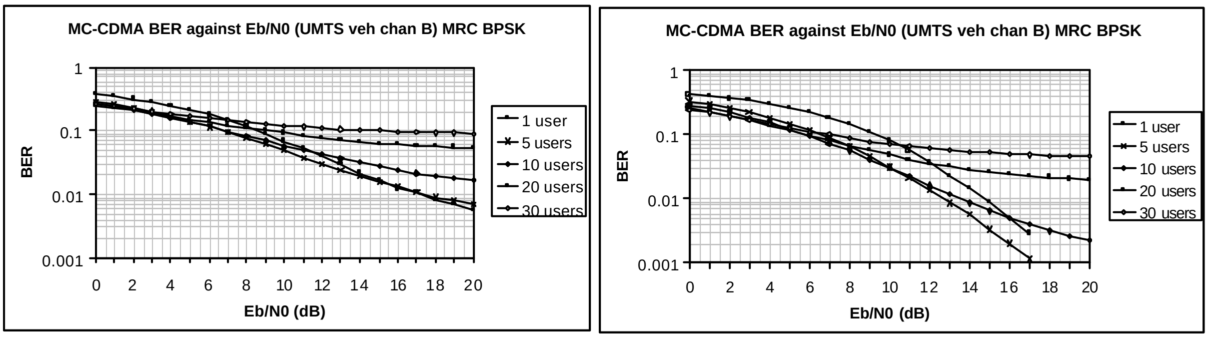


(a) *(b)*

Figure 4: Arrangement of pilot symbols in channel estimation technique 2 (a) and associated BER performance (b).

3 Performance of averaging

The performance of both channel estimation techniques may be improved by time-averaging the channel estimates in the receiver. Averaging will mitigate the effects of AWGN. The averaging window must be less than the coherence time of the channel so that the channel can be assumed stationary during the window. The duration of the averaging window selected for both techniques is the same and is 10 OFDM symbol periods long. The effect of averaging on BER performance in technique 1 and technique 2 is shown Figure 5 (a) and (b) respectively. Both systems show improvement in BER performance especially at low Eb/N0 values where AWGN dominates. At higher Eb/N0 values and at high system loads there is little improvement in performance.



(a) *(b)*

Figure 5: Effect of time averaging on BER performance in technique 1(a) and technique 2 (b).

4 Conclusion

In a mobile cellular channel it is essential that regular channel estimates are performed as the multipath channel may change rapidly. The use of pilot symbols, suitably situated in the time and frequency domain, supports channel estimation. In a MC-CDMA system transmitting over a standard UMTS channel model two channel estimation techniques are compared. Technique 1 involved transmitting pilot and data symbols in the same OFDM symbol and performing interpolation in frequency between pilot symbols. Technique 2 involved transmitting pilot and data symbols in separate OFDM symbols and interpolating in time. Both techniques have identical power and spectral efficiency. Techniques 1 and 2 both suffer considerable performance loss compared to a receiver which has perfect channel knowledge. However across the range of Eb/N0 values and system loads technique 2 outperforms technique 1. At a BER of 3×10^{-2} with a system load of 10 users technique 2 has a 4.5 dB performance advantage over technique 1. The effect of time averaging is to improve the performance of both systems, especially at low Eb/N0 values. At the operating point mentioned above technique 2 only suffers a performance degradation of 3 dB compared to the perfect channel estimate. Both techniques suffer a loss in data throughput as OFDM time-frequency slots are sacrificed to transmit pilot symbols.

5 References

[1] Evans, B. G. and Baughan, K.: ‘Visions of 4G’, IEE Electronics & Communication Engineering Journal, December 2000, pp. 293-303

[2] Pereira, J. M.: ‘Fourth Generation: Now, it is Personal!’, The 11th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), 2000, vol. 2, pp. 1009-1016

[3] Hara, S. and Prasad, R.: ‘Overview of Multicarrier CDMA’, IEEE Communications Magazine, December 1997, ISBN 0163-6804, pp 126-133

[4] Atarashi, Hiroyuki, Abeta, Sadayuki and Sawahashi, M.: ‘Broadband Packet Wireless Access Appropriate for High-speed and High-capacity Throughput’, VTC Proceedings 2001, vol. 1, pp. 566-570

[5] ‘Physical channels and mapping of transport channels onto physical channels (FDD)’, 3rd Generation Partnership Project (3GPP), July 2001, 3GPP TS 25.211 v4.1.0

[6] ‘Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television’, ETSI, January 2001, ETSI EN 300 744 v1.4.1

[7] ‘Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, High-speed Physical Layer in the 5 GHz Band’, IEEE, IEEE Std 802.11a -1999

[8] ‘Universal Mobile Telecommunications System (UMTS); Selection procedures for the choice of radio transmission technologies of the UMTS’, ETSI, April 1998, TR 101 112 v3.2.0

[9] Jakes, W. C.: ‘Microwave Mobile Communications’, John Wiley & Sons, 1974, ISBN 0-471-43720-4, pp. 70-76

[10] van Nee, R. and Prasad, R.: ‘OFDM for Wireless Multimedia Communications’, Artech House, 2000, ISBN 0-89006-530-6, pp. 96-97