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Transmission Systems

A spectrally efficient frequency diversity technique for single-carrier modulations with frequency division multiplexing

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SUMMARY

When the number of relevant propagation paths between the transmitter and the receiver is small and/or when they are not separable (i.e. the difference between the corresponding delays is smaller than the symbol duration), we can have deep fading effects and poor performance, especially for slow-varying channels. In this case, the use of diversity techniques is strongly recommendable.

In this paper, we consider an single-carrier-based (SC) block transmission, employing frequency domain equalisation (FDE) receivers and we present a frequency diversity technique that allows high spectral efficiencies. As with conventional frequency diversity techniques, L replicas of a given signal are transmitted at L different frequencies. However, contrarily to conventional frequency diversity schemes, up to L users can share this set of L frequency bands. Since this leads to strong interference levels, we propose an iterative, frequency-domain receiver where all the users sharing the L frequencies are jointly detected.

Our performance results show that the proposed frequency diversity scheme allows high diversity gains, while keeping the spectral efficiency of conventional SC schemes. Moreover, we can cope with channels that can be severely time-dispersive and/or can have deep fading effects. Copyright © 2009 John Wiley & Sons, Ltd.

1. INTRODUCTION

It is widely recognised that cyclic prefix-assisted (CP) block transmission schemes, combined with frequency domain equalisation (FDE) techniques, are suitable for broadband wireless systems. Due to the reduced envelope fluctuations of the transmitted signals, block transmission techniques employing single-carrier (SC) modulations are promising candidates for broadband wireless systems, especially at the mobile terminals [1, 2]. As with orthogonal frequency division multiplexing (OFDM) modulations [3], a CP, longer than the maximum channel impulse response length, is added to each block and an FDE is employed at the receiver [4].

Both OFDM and SC-FDE modulations can effectively take advantage of the multipath diversity that is implicit in frequency selectivity of the channel. However, for OFDM schemes we need to employ suitable channel coding schemes, combined with intra-block interleaving, since each data symbol is transmitted by a given subcarrier, while for SC-FDE schemes each symbol uses all the available bandwidth, allowing good uncoded performances [1, 5]. In fact, when the number of separable propagation paths between the transmitter and the receiver is high, the performances of SC-FDE schemes can be very good, even without the use of powerful error correction codes, since almost all the energy of the separable paths can be effectively used for detection purposes. If the

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conventional linear FDE receiver is replaced by the more powerful iterative block-decision feedback equaliser (IB-DFE) receiver [6, 7] there is a further improvement, with performances that can be very close to the matched filter bound (MFB), even for severely time-dispersive channels.

However, when we have a small number of relevant propagation paths and/or when they are not separable (i.e. the difference between the corresponding delays is smaller than the symbol duration), we can have deep fading effects and poor performance, especially for slow-varying channels. In this case, the use of diversity techniques is strongly recommendable [8].

The most popular diversity technique is space diversity, where several antennas are used at the receiver (and, more recently, at the transmitter [9]). Since the propagation channels should be almost uncorrelated, the different antennas need to be separated by several wavelengths. For terminals with small dimensions, this leads to implementation difficulties, namely when a large diversity order is intended and/or when a mobile terminal is communicating directly with another.

As an alternative, we could employ frequency diversity techniques [10, 11], where different replicas of the intended signal are transmitted at different frequency bands. With these techniques it is easy to have a large diversity order, with almost uncorrelated channels, provided that their frequency separation is much higher than the coherence bandwidth of the propagation channel (for broadband wireless systems, the channel is usually strongly frequency selective and the coherence bandwidth can be a small fraction of the symbol rate). This means that the different antennas can be very close; alternatively, we could employ a single, wideband antenna for transmitting/receiving the multiband signal.

The major drawback of these diversity techniques is that the spectral efficiency of the system is reduced by a factor L, for L-order diversity. The simplest way of achieving frequency diversity without decreasing the spectral efficiency is to employ orthogonal frequency-hopping schemes [12]. When combined with suitable interleaving and channel coding techniques, these schemes allow good performance gains, without decreasing the overall spectral efficiency of the system. However, the achievable performances are not as good as the ones with conventional frequency diversity schemes, where the same signal is transmitted simultaneously at several frequency bands [13]. Moreover, when frequency-hopping techniques are adopted within SC-FDE schemes, the carrier frequency should remain constant over a block, at least, which means that the performance gains can be very poor when just intraburst interleaving is employed (the desirable situation for block transmission schemes) and/or when an interburst interleaving spanning over a number of blocks shorter than the number of used frequency bands is employed. As an alternative, we could employ multi-carrier-code division multiple access (MC-CDMA) schemes [14], where the diversity order can be equal to the spreading factor and, since the number of users sharing the band can also be equal to the spreading factor, theoretically there is no degradation in the spectral efficiency (although complex multi-user detection techniques might be required). However, as with OFDM schemes, the transmitted signals have high envelope fluctuations, which might lead to amplification difficulties. For this reason, it is preferable to employ SC/FDE schemes, especially when we want very low cost transmitters [1, 2].

In this paper, we consider the use of SC modulations in wireless uplink systems where the length of the channel impulse response can be sometimes very long (spanning over several 10s of symbols), but can also be very short (leading to almost flat fading conditions). To cope with long channel impulse responses, we consider an SC-based block transmission, employing FDE receivers; to cope with the fading inherent to short channel impulse responses[†] we consider a frequency diversity technique that enables high spectral efficiencies, since bandwidth efficiency is increased by a factor of L (this compensates the L factor reduction caused by frequency diversity). As with conventional frequency diversity techniques, L replicas of a given signal are transmitted at L different frequencies. However, contrarily to conventional frequency diversity schemes, up to L users can share this set of L frequency bands. Since this leads to strong interference levels, we propose an iterative, frequency-domain receiver structure where all the users sharing the L frequencies are jointly detected.

This paper is organised as follows. The system considered in this paper is introduced in Section 2 and Section 3 describes the proposed receiver structure. A set of performance results is presented in Section 4 and Section 5 is concerned with the conclusions and final remarks of this paper.

[†] It should be noted that we can have channel impulse responses that are very long (requiring FDE), but where the 'diversity effect' inherent to the multipath is very small (leading to significant fading effects): for instance, a two-path channel where we have Rayleigh fading on each path and the second path is weaker that the first (leading to small 'multipath diversity'), but not too weak to be negligible (leading to significant time distortion levels when the first is in a deep fade).