Loosely synchronised spreading code aided network performance of quasi-synchronous UTRA-like TDD and FDD CDMA systems

S. Ni, H. Wei and L. Hanzo

It is demonstrated that loosely synchronised (LS) spreading codes exhibit a so-called interference-free window, where both the autocorrelation and cross-correlation of the codes become zero. Therefore LS codes have the promise of mitigating the effects of both inter-symbol-interference and multiple-access-interference in time dispersive channels. Hence, LS codes have the potential of increasing the capacity of CDMA networks. The work reported has studied the achievable network performance and compared it to that of a UTRA-like time division duplex (TDD) and frequency division duplex (FDD) CDMA system using orthogonal variable rate spreading factor codes.

Introduction: In our previous research [1], we quantified the UTRA frequency division duplex (FDD) system's performance using both adaptive beamforming and adaptive modulation. The system employed orthogonal variable rate spreading factor (OVSF) codes, which offer the benefit of perfect orthogonality in an ideal channel. Hence in a non-dispersive channel, all intra-cell users' signals are perfectly orthogonal. However, upon propagating through a dispersive multipath channel this orthogonality is eroded, hence all other users will interfere with the desired signal. Therefore, in practice the intra-cell interference is always nonzero.

Network performance evaluation of loosely synchronised spreading codes: The novel contribution of this Letter is the network performance evaluation of loosely synchronised (LS) spreading codes [2]. These codes exhibit a so-called interference-free window (IFW), where the off-peak aperiodic autocorrelation values as well as the aperiodic cross-correlation values become zero, resulting in zero inter-symbol-interference (ISI) and zero multiple-access-interference (MAI), provided that the delayed asynchronous transmissions arrive within the code's IFW. More specifically, interference-free CDMA communications become possible even without a multiuser detector, when the total time offset expressed in terms of the number of chip intervals, which is the sum of the time-offset of the mobiles plus the maximum channel-induced delay spread is within the code's IFW [3]. By employing this specific family of codes, we are capable of reducing both the ISI and MAI, since users in the same cell do not interfere with each other, as a benefit of the IFW provided by the LS codes used.

System model: There exists a specific family of LS codes [2], which exhibits an IFW, where both the autocorrelation and cross-correlation of the codes become zero. Specifically, LS codes exploit the properties of the so-called orthogonal complementary sets [2]. An example of the design of LS spreading codes can be found in [4]. The cell radius was 78 m, which was the maximum affordable cell radius for the IFW duration of ± 1 chip intervals at a chip rate of 3.84 Mchip/s. The mobiles were capable of moving freely, at a speed of 3 mph, in random directions, selected at the start of the simulation from a uniform distribution, within the infinite simulation area of 49 wrapped-around traffic cells [1]. Furthermore, the post-despreading signal-to-interference plus noise ratios (SINRs) required for obtaining the target bit error rates (BERs) were determined with the aid of physical-layer simulations using a 4-QAM modulation scheme, in conjunction with 1/2-rate turbo coding for transmission over a COST 207 seven-path bad urban (BU) channel [5]. Using this turbo-coded transceiver and LS codes having a spreading factor (SF) of 16, the post-despreading SINR required for maintaining the target BER of 1×10^{-3} was 6.2 dB. The BER, which was deemed to correspond to low-quality access, was stipulated at 5×10^{-3}. This BER was exceeded for SINRs falling below 5.2 dB. Furthermore, a low-quality outage was declared, when the BER of 1×10^{-2} was exceeded, which was encountered for SINRs below 4.8 dB. These values can be seen along with other system parameters in Table 1. All other experimental conditions were identical to those in [1].

Table 1: Simulation parameters

Parameter	Value
Cell radius	78 m
Signal bandwidth	5 MHz
Modulation scheme	4-QAM/QPSK
Spreading factor	16
Maximum BS MS TX power	17 dBm
Minimum BS MS TX power	−44 dBm
Pedestrian speed	3 mph
Target SINR	6.2 dB

Simulation results: The BER performance of OVSF codes and LS codes was compared, which was determined with the aid of physical-layer simulations using a 4-QAM modulation scheme, 1/2-rate turbo coding and a minimum mean squared error block decision feedback equaliser (MMSE-BDFE) based multi-user detector (MUD) for transmission over a COST 207 seven-path bad urban channel. The achievable BER performance of LS codes is better than that of OVSF codes. For a spreading factor of 16, the post-despreading SINR required for maintaining a BER of 1×10^{-3} was 6.2 dB in the case of LS codes, which is almost 2 dB lower than that necessitated by the OVSF codes. Fig. 1 shows the UTRA-like TDD/CDMA system's forced termination probability associated with a variety of traffic loads quantified in terms of the mean normalised carried traffic expressed in Erlangs/km^2/MHz, when subjected to 0.5 Hz frequency shadowing having a standard deviation of 3 dB. As can be observed from Fig. 1, nearly an order of magnitude reduction of the forced termination probability has been achieved by employing LS spreading codes compared to those of using OVSF spreading codes. In conjunction with OVSF codes, the 'no beamforming' scenario suffered from the highest forced termination probability of the four traffic scenarios characterised in the Figure at a given load. Specifically, the network capacity was limited to 50 users, or to a teletraffic density of approximately 0.55 Erlangs/km^2/MHz. With the advent of employing four-element adaptive antenna arrays [1] at the base stations the number of users supported by the TDD system increased to 178 users, or to a teletraffic density of 2.03 Erlangs/km^2/MHz. However, in conjunction with LS codes, and even without employing antenna arrays at the base stations, the TDD system was capable of supporting 306 users, or an equivalent traffic density of 3.45 Erlangs/km^2/MHz.

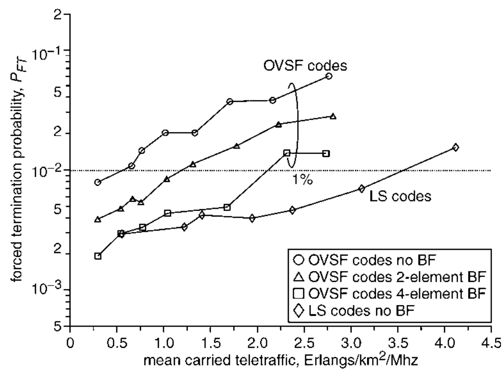

Fig. 1 *Forced termination probability against mean carried traffic of UTRA-like TDD cellular network using LS codes and OVSF codes both with as well as without beamforming in conjunction with shadowing having frequency of 0.5 Hz and standard deviation of 3 dB for spreading factor of SF = 16*

Fig. 2 portrays the UTRA-like FDD/CDMA system's forced termination probability against various traffic loads. The Figure illustrates that the network's performance was significantly improved using LS codes. As can be observed from the Figure, nearly an order of magnitude forced termination probability (P_{FT}) reduction has been achieved employing LS codes compared to the scenario using OVSF codes. Specifically, the network capacity was limited to 152 users, or to a teletraffic load of approximately 2.65 Erlangs/km^2/MHz. With the advent of employing four-element adaptive antenna arrays [1] at the base stations the number of users supported by the network increased to

428 users, or almost to 7.23 Erlangs/km^2/MHz. However, in conjunction with LS codes, and even without employing antenna arrays at the base stations, the network capacity was dramatically increased to 581 users, or 10.10 Erlangs/km^2/MHz. When the four-element adaptive antenna array was employed in the LS code aided scenario, the system was capable of supporting 800 users, which corresponded to a teletraffic load of 13.39 Erlangs/km^2/MHz. This is because the LS codes' autocorrelation and cross-correlation functions exhibit an IFW, which essentially eliminated the intra-cell interference.

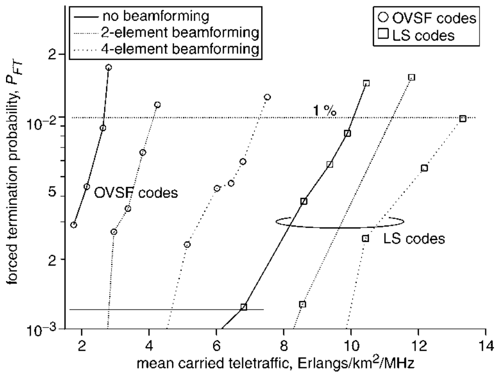

Fig. 2 *Forced termination probability against mean carried traffic of UTRA-like FDD cellular network using LS codes and OVSF codes both with as well as without beamforming in conjunction with shadowing having frequency of 0.5 Hz and standard deviation of 3 dB for spreading factor of SF = 16*

Conclusion: The network performance of a UTRA-like system employing LS spreading codes was substantially better than that of the system using OVSF codes. In the context of the interference limited 3G CDMA system LS codes might hold the promise of increased network capacity without dramatic changes of the 3G standards. However, LS codes exhibit two impediments. First, the number of spreading codes exhibiting a certain IFW is limited and hence under high user-loads the system may become code-limited, rather than interference-limited. The number of LS codes may be increased using the procedure proposed in [6], but further research is required for increasing the number of codes. A particularly attractive solution is to invoke both DS-CDMA time-domain (TD) and frequency-domain (FD) spreading [7] to multiple carriers in MC-CDMA. This can be achieved for example by using LS and OVSF codes in the TD and FD, respectively. Then no MUD is required in the TD and the MUD employed in the FD has a low complexity owing to using an OVSF code having a low SF. The total number of users supported becomes the product of the number of LS and OVSF codes.

The second deficiency of LS codes is that they tend to exhibit a short IFW duration. However, this deficiency is also eliminated with the aid of the above-mentioned joint TD and FD spreading regime, because upon spreading the information to multiple carriers the TD chip-duration may be commensurately extended by a factor corresponding to the number of carriers.

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