39 Subspace Techniques in CDMA Reception

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The explosive growth in wireless communications, in conjunction with emerging new applications, has increased the demand for developing more efficient mobile radio systems. Analog mobile phone systems, such as NMT (Nordic Mobile Telephone) are called first generation systems. They were accompanied by digital second generation systems, for example GSM (Global System for Mobile communications). Those systems are primarily voice oriented; however, especially second generation systems also support low data rate services. Due to the high acceptance of cellular mobile radio systems, capacity limits have already emerged in highly populated areas. For capacity reasons and offering new services and system features, third generation mobile radio systems are under development. These systems emphasize the importance of coverage and access throughout the world. Trends towards multimedia applications and video transmission in mobile environment require high rate data transmission capability over radio interface. A potential practical system must provide reliable data transmission with very small bit error ratio. Third generation system should be able to adapt quickly to different user requirements and to build up solutions tailored to customers.

All these requirements increase the demand for more bandwith efficient multiple access schemes. There are several ways to allocate the frequency spectrum to users. The most widely known multiple access schemes are FDMA (Frequency Division Multiple Access; e.g. NMT) and TDMA (Time Division Multiple Access; e.g. GSM). Both methods rely on user partitioning in the time-frequency plane. The number of users that can be served is determined by the available frequency slots in FDMA (Figure 73 left), and by the available time slots in TDMA (Figure 73 middle). CDMA (Code Division Multiple Access) is considered as a promising solution for mobile communications. In CDMA all users are using the same frequency band at all times (Figure 73 right), as opposed to FDMA and TDMA. In CDMA, the separation of users is carried out by assigning each user with a unique code sequence (Figure 74).

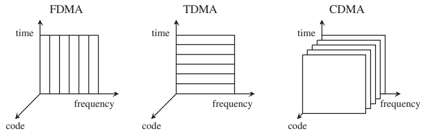

Figure 73: Different multiple access schemes.

Standard receiver structure for CDMA is simply a bank of matched filters (MF), kinds of keys, each matched to a particular user code. MF is optimum when only one mobile phone is in use, or when the codes of all the users appear to be orthogonal. In mobile environment orthogonality cannot in general be guaranteed because transmitted signal propagates through several paths (Figure 75).

In such a multipath environment standard receiver fails, especially when the different powers of different users received by the base station are very dissimilar due to their dissimilar distances to the base station. This is called near-far problem. Therefore,

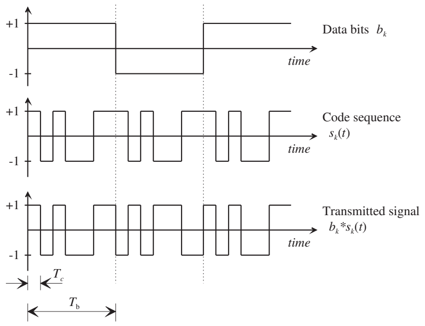

Figure 74: Illustration of the signal formulation.

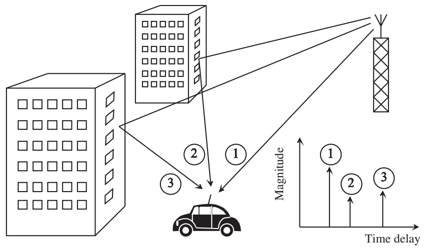

Figure 75: Urban multipath environment and channel impulse response.

more sophisticated receivers have been proposed. Common to all of these receivers is that they require knowledge of one or several parameters, such as propagation delay, carrier phase, and received power level. Frequently, the propagation delay estimate is a necessary prerequisite to the estimation of other parameters.
Conventional delay estimators are based on MF, correlator and delay-locked loop structures, but they suffer from the same performance degradation as standard receivers. More efficient methods have been introduced to overcome these problems. Theoretically optimal maximum likelihood method (MLM) requires multidimensional optimization, and thus is computationally too demanding in practice. Therefore, algorithms providing a trade-off between achieved performance and computational complexity are of primary interest. Subspace-based methods offer a potential solution for the delay estimation problem. Many of these methods are based on the projection matrix estimation via eigenanalysis. They use the knowledge of users' code sequences to form a parametric model for communication system. The observation space of the received signal is separated into the hyperplanes, called signal and noise subspaces (Figure 76).

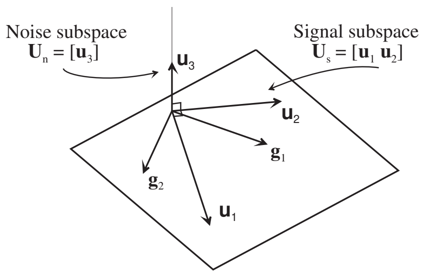

Figure 76: Illustration of signal and noise subspaces.

The power of the subspace methods lies in that under some mild conditions, signal and noise subspaces uniquely determine the unknown delays, even if the codes are not orthogonal. Code sequences are the only information needed on users. Moreover, multi-dimensional optimization problem is reduced to a series of one-dimensional problems, which decreases the computational requirements considerably. The best known subspace method called MUSIC (MUltiple SIgnal Classification) produces delay spectrum, from which one can estimate the delays by selecting those test delays producing the largest values to the spectrum (Figure 77).

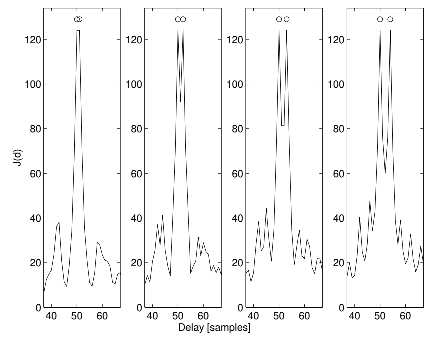

Figure 77: Resolvability of delays using MUSIC when spacing is 1, 2, 3, and 4 samples. Correct delays are indicated as circles.

This research project has been carried out in co-operation with Nokia Research Center. During the project, Mr. Petteri Luukkanen from Nokia Research Center finished his Master's Thesis *Subspace Delay Estimators for CDMA Systems* under the instruction of Dr. Jyrki Joutsensalo. The research project focused on the propagation delay estimation in asynchronous CDMA communication system. Performances of several novel and "classical" subspace methods have been evaluated in the multiuser multipath environment by Monte Carlo simulations. The estimators were compared to the conventional MF delay estimator. Subspace methods have earlier been studied in the Laboratory of Computer and Information Science in context with sinusoidal frequency estimation and array signal processing, leading to development of several new, computationally efficient variants of standard eigenvector-based MUSIC.
The main contributions of this project were:

- Development of hierarchic algorithms for implementing MLM as well as ACM-MUSIC type method. ACM-MUSIC has been introduced by the authors in 1990. Especially hierarchic MLM is computationally very attractive compared to the brute-force version of the MLM. The performance of the new algorithm HMLM (Hierarchic MLM) is based on the following fact: if the data can be modeled as linear combinations of some basis functions and noise, then the largest peak given by a simple linear transfrom based method, e.g. matched filter or sliding correlator, is usually close the true value. The value corresponding to the largest peak can be removed, and the next parameter can be estimated in similar manner. Under suitable conditions maximum likelihood estimator can be constructed hierarchically by estimating the parameters sequentially. This approach do not usually lead to the true values. However, it yields a very good initial estimate, so that one can finally perform a search

Algorithm	N	SNRs	4	3	2
HMLM	10	10,20,10,25	25 %	65 %	10 %
MUSIC	10	10,20,10,25	0 %	35 %	65 %
HMLM	10	20,30,20,35	45 %	50 %	5 %
MUSIC	10	20,30,20,35	5 %	45 %	50 %
HMLM	20	20,30,20,35	65 %	30 %	5 %
MUSIC	20	20,30,20,35	45 %	50 %	5 %
HMLM	50	0,10,0,15	65 %	20 %	15 %
MUSIC	50	0,10,0,15	0 %	55 %	45 %

Table 12: Comparing HMLM to MUSIC. Percentage of the number of correct delay estimates when two users and two paths exist. The total number of delays is four. N is number of observed symbols, and SNR:s are signal-to-noise ratios of different signals with respect to the noise.

Algorithm	SNR= 15 dB	SNR= 20 dB
MF	20.00%	31.00 %
MUSIC	28.00 %	69.25 %
ACM-MUSIC	99.50 %	100.00 %

Table 13: Comparison of different algorithms in nonstationary environments. The delays are changing, and users and paths are suddenly appearing or disappearing. Percentage of the number of correct delay estimates.

only in the vicinity of the estimated values, or use a gradient algorithm for fine tuning the estimates. Table 12 shows that HMLM works clearly better than MUSIC. The algorithm for hierarchic ACM-MUSIC is quite similar. See references [1,3,5,6].

- Modification of the ACM-MUSIC for tracking the changing delays. The performance of the algorithm is based on the assumption that the delays are changed sufficiently slowly so that one can detect the changes only near an "operating point", which is the point defined by previous estimates. In Table 13, the ACM-MUSIC has been compared to MF and MUSIC. See references [5,6].

- Introduction of criteria for estimating the model order. These criteria, on the contrary to the minimum description method based on the information theory, exploit efficiently the parametric form of the data, being still as simple as minimum description length (Figure 78). See references [2,3,5,6]. The new criteria have also been applied to sinusoidal frequency estimation and array signal processing [4].

- Introduction of simple methods for blind delay estimation and source separation in the mobile phone environment have led to the patent application.

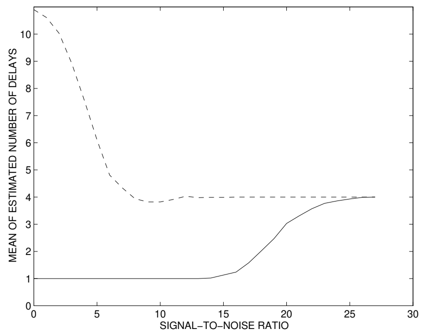

Figure 78: Comparing model order estimators in CDMA. The correct model order is four (two users with two paths). Solid: minimum description length; dashed: new method.

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