The MAI performance of orthogonal codes for channel cover in Asynchronous CDMA system

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Abstract: *It is widely believed that the walsh code is the best to provide covering for a CDMA channel due to its orthogonality. However, it exhibits a severe aperiodic ACF and variation of its aperiodic ACF pattern for each code. Hence, the comparison of MAI performances of walsh sequences with other three orthogonal sequences as a channel cover code in DS-CDMA was established. The aperiodic ACF and CCF that are directly correspondent with average system performance are examined. It is shown that walsh codes have the worst among the others in term of aperiodic ACF and CCF. The average system performance is assessed by AIP-based computation and simulation based on the gaussian approximation method. However, the result shows that the other orthogonal codes provide slightly lower BER performance in the simulation. The computation shows both Luke type I and Cubic polyphase codes produce strongest resistance to MAI with significant margin compared with walsh codes, while OCPS codes generate the weakest resistance to MAI. It is due to that the aperiodic auto correlation of both polyphase codes which directly influence the AIP is better than walsh and OCPS code. In contrast, the simulation shows walsh code outperform the polyphase codes and OCPS for Eb/No > 4 dB, due to the effect of filtering and complex modulation that are not taken into account in AIP-based computation.*

1. Introduction.

In CDMA systems, the code covering is intended to separate the transmission of data streams from users at different or the same rates and to separate logical channels into purposes such as signaling and traffic bearing.

The problems in CDMA are that a bank of users share the same frequency bandwidth and access at the same time. As a result, the mutual interference between coded channels used by active users arises due to un-ideal correlation characteristic of the code. An ideal criterion for the sets of codes are having uncorrelated correlation properties. That is each code is totally unique with the other codes as well as with its own time shifted version. However it seems very difficult to have this sort of code with a large family size suitable for high bit rate and multirate transmission.

The walsh code as commonly used in CDMA exhibits a severe aperiodic auto correlation value. It significantly contributes to multipath interference and also to code synchronisation, especially in asynchronous CDMA systems. In addition, it is also evident that the pattern of aperiodic ACF value for each code and aperiodic CCF value for any pair of codes in the walsh family is not the same in many cases. As a result, variation of amount of MAI might arise in one or subsequent times, depending on which codes used by other active users are interfering the channel used by the intended user in the demodulation process.

Since the resistance of a code to the MAI is the key to enhance the capacity of a CDMA channel, we try to compare walsh codes with other orthogonal codes to attain a clear picture which code better fulfills to that criterion. Initially we set three critera to select the candidate code. That is Orthogonality at zero shift, Family size (M) in accordance with the length N, and complexity in terms of the number of phase levels. After an exhaustive literature searches , it were identified with three candidate codes, namely 2nd set of OCPS, Luke type I polyphase sequence, and Cubic polyphase sequence.

2. Property of code.

2.1 Sequence Generation.

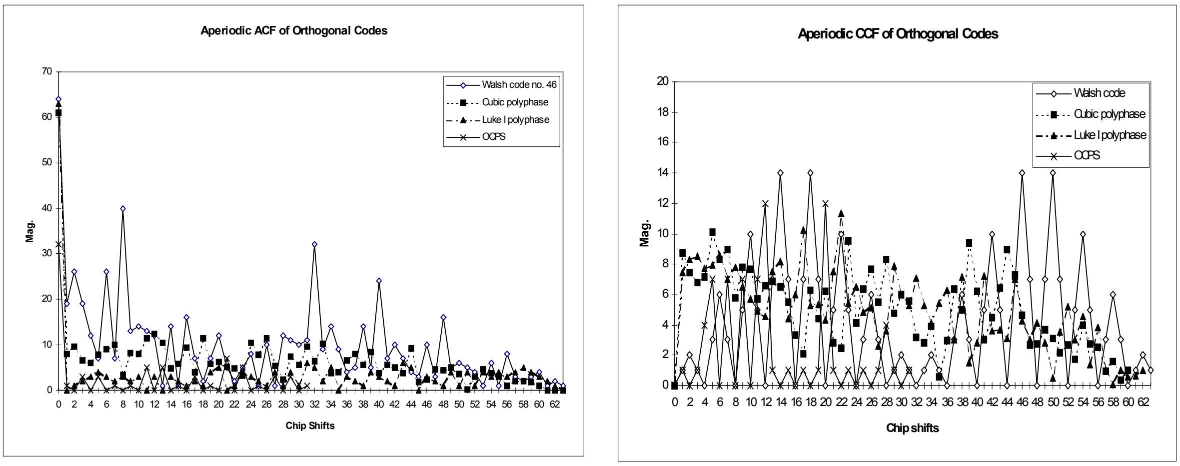
Sequence generation with the length as well as the size in the vicinity of 64 is defined in [1]. Each of those is used to generate a database of Luke I polyphase code for length N = 63, cubic polyphase for N = 61, OCPS for N = 64, and walsh codes with N = 64.

2.2 Correlation Property.

If sequence $\hat{a}_n$ and $\hat{b}_n$ are complex sequences with length N, then complex aperiodic correlation function is defined as:

$$C_{a,b} = \begin{cases} \sum_{n=0}^{N-\tau-1} \hat{a}_n \cdot \hat{b}^*_{n+\tau} & ;0 \le \tau \le N-1 \\ \sum_{n=0}^{N+\tau-1} \hat{a}_{n-\tau} \cdot \hat{b}^*_n & ;1-N \le \tau < 0 \\ 0 \quad ; \quad |\tau| \ge N \end{cases} \qquad (1)$$

if $\hat{a}_n = \hat{b}_n$, then $C_{a,b}$ is the aperiodic ACF, while $\hat{a}_n \neq \hat{b}_n$, then $C_{a,b}$ is the aperiodic CCF. For a given code's length as above, the absolute aperiodic correlation value of the selected codes are as depicted in fig.1 for positive symbol shifts, due to its symmetrical property, i.e. $C_{a,b}(-\tau) = [C_{a,b}(\tau)]^*$.



(a) (b)

Fig.1. Aperiodic ACF (a) and CCF (b) for given length of code, N.

It is evident that most codes in walsh family have different aperiodic ACF values. The merit factor, defined as the ratio between energy of ACF mainlobe with energy of ACF sidelobes, also varies between 0.024 to 0.259. Code no. 0 and 1 give the lowest merit factor, and code no. 62 has the highest one. While the other family selected here exhibit constant pattern of aperiodic ACF and fixed merit factor for every code. It is important to note that different values of aperiodic ACF will cause difficulties in code synchronisation due to its varying pattern. Walsh codes exhibit the worst sidelobes as can be seen in fig.1(a), whereas Luke type I polyphase and OCPS code have very favourable sidelobes. Cubic polyphase have significantly high sidelobes and low merit factor.

The aperiodic cross correlation values for any pair of codes within the family are not the same in many cases. As a result, variation of the amount of MAI might arise in one or subsequent times, depending on which codes being used by other active users are interfering with the channel used by the intended user in the demodulation process. To get a complete aperiodic CCF value of a Family of codes, we need to compute 1/2 M(M-1) for M number of codes in the family. Obviously it requires a huge amount of computation much of which is unnecessary. However, an approximation is used here to compute its effect to MAI. Fig.1 (b) gives a rough comparison of aperiodic CCF values of a pair of codes selected randomly from each family.

3. Analysis of performance and numerical results.

A basic model used in [4] is reused in this analysis. The performance of an asynchronous CDMA system is determined by its AIP and system SNR which depend upon the aperiodic CCF of the code. MAI can be measured by the sum of the AIP of K simultaneous and interfering users. The AIP value depends on the aperiodic CCF between the desired *j-th* user and *k-th* interfering user, as can be seen in the relation below :

$$r_{k,j} = 2\left(\sum_{l=1-N}^{N-1} C_{k,j}^2(l)\right) + \sum_{l=1-N}^{N-1} C_{k,j}(l)C_{k,j}(l+1) \qquad (2)$$

The SNR for the *j-th* user at the output of the receiver is:

$$SNR_j = \left\{\frac{N_0}{2E_b} + \frac{1}{6N^3}\sum_{k=1,k\neq j}^{K} r_{k,j}\right\}^{-1} \qquad (3)$$

and for K>1, by gaussian approximation, the probability of error can be estimated, [3], [5]:

$$P_{e,j} = Q(\sqrt{SNR_j}) \qquad (4)$$

To compare BER performance of orthogonal codes, two approaches have been adopted. Firstly, computation of BER is done based on AIP as analyzed above. Secondly, Monte Carlo simulation is done to compare the resistance against MAI of asynchronous CDMA systems employing orthogonal codes. A baseband system model is used, assuming each user transmits an equal power, and the system has a perfect power control. In addition, code synchronisation is successfully done in the receiver. The channel model consists of AWGN and asynchronous MAI. The delays of each interferer relative to the intended user is assigned randomly reflecting the asynchronous condition. The receiver employ a cross corellator followed by a decision circuit. A square root raised cosine filter with roll of factor of 0.35, as defined by IS-95 standard, is used in both transmitter and receiver.

Table. BER performance for Number of User K = 20.

Eb/No (dB)	Walsh		OCPS		Luke type I Poly.		Cubic Poly.	
	Computed	Simulation	Computed	Simulation	Computed	Simulation	Computed	Simulation
0	$8.5x10^{-2}$	$1.5x10^{-1}$	$9.8x10^{-2}$	$1.8x10^{-1}$	$8.2x10^{-2}$	$1.6x10^{-1}$	$8.2x10^{-2}$	$1.6x10^{-1}$
2	$4.5x10^{-2}$	$1.05x10^{-1}$	$6.0x10^{-2}$	$1.3x10^{-1}$	$4.1x10^{-2}$	$1.0x10^{-1}$	$4.1x10^{-2}$	$1.1x10^{-1}$
4	$1.9x10^{-2}$	$5.5x10^{-2}$	$3.3x10^{-2}$	$6.8x10^{-2}$	$1.5x10^{-2}$	$5.2x10^{-2}$	$1.5x10^{-2}$	$5.5x10^{-2}$
6	$5.7x10^{-3}$	$1.3x10^{-2}$	$1.7x10^{-2}$	$3.3x10^{-2}$	$3.8x10^{-3}$	$1.9x10^{-2}$	$3.8x10^{-3}$	$2.3x10^{-2}$
8	$1.3x10^{-3}$	$2.2x10^{-4}$	$8.8x10^{-3}$	$8.7x10^{-3}$	$5.6x10^{-4}$	$3.1x10^{-3}$	$4.5x10^{-4}$	$6.0x10^{-3}$

Simulation results, however, give different figures than the AIP-based computation results as can be seen in the table. The computation shows both Luke type I and Cubic polyphase codes produce strongest resistance to MAI with significant margin than walsh code, while OCPS code generates the weakest resistance to MAI. It is due to this aperiodic auto correlation of both polyphase code which directly influence the AIP is better than the walsh and OCPS codes. In contrast, the simulation shows the Walsh codes outperform the polyphase codes and OCPS for Eb/No > 4 dB.

4. Conclusion

The MAI performances of Orthogonal sequences being used as channel cover codes in CDMA applications are examined, firstly by assessing its aperiodic ACF and CCF properties which determine the resistance from multipath interference and multiple access interference, respectively. Secondly the average system performance which is closely related to system implementation is assessed by AIP-based computation and montecarlo simulation. The former only considers correlation properties of the code as fundamental parameters. However, the latter incorporated both correlation properties and the effect of filtering that have impact in producing different results.

This research provides the idea of alternative channel cover codes, instead of only walsh codes for DS-CDMA application. However it needs further investigation in order to compromise between the advantages of having better aperiodic correlation properties and the high complexity it has to overcome.

Acknowledgments

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Acronym:

ACF : Auto Correlation Function
CCF : Cross Correlation Function
AIP : Average Interference Parameter
MAI : Multiple Access Interference
OCPS : Orthogonal Complementary Pair of Sequence