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The Use of Walsh Codes for Source Coding in Uplink IS-95

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Abstract – Jitter results in significant degradation in the performance of CDMA systems. This paper presents a novel source encoding method that makes the text messages using CDMA systems more resistant to timing jitter. By appropriate assigning Walsh functions to messages in the IS-95 uplink for orthogonal modulation, the resulting performance can be doubled that of systems using conventional source coding method.

I Introduction

Out of several possible multiple access methods, the code division multiple access is the favored multiple access technique for the third generation cellular system. The CDMA technique was first introduced in public cellular mobile telecommunication system in the form of IS-95. The CDMA system works on the principle of spread spectrum where a narrow band information signal is spread to a much wider transmission bandwidth. In the IS-95, the highest information rate of 9600 bits/sec is spread over a bandwidth of 1.28 MHz.

The use of spread spectrum technique is preferred over FDMA or TDMA because of several desirable properties of CDMA. Interference rejection and a very little need for spread management are the two most important attributes of spread spectrum systems. However, maintenance of synchronism between the transmitter and the receiver is a major design requirement in CDMA. In order to maximize the received signal to noise ratio, the two ends of a link must be in perfect synchronism. Any deviation from perfect synchronism results in loss of correlation or signal to noise ratio, increase in the multiple access as well as in the self- interference. Thus, both the performance and the capacity of the system suffer. It has been shown that any deviation from the correct timing reduces the quality of the received signal [1, 2] and may even render the system totally unusable [2, 3].

One of the difficulties in designing CDMA systems is that of maintaining synchronism between the base station (BS) and the mobile station (MS). It has been shown that even an error as small as tenth of a chip interval (T_c) causes a significant degradation in performance [3]. Furthermore, for timing errors of more than 10% of T_c, the BER degrades dramatically. For synchronization errors of half a chip or more, the ambiguities present in the timing recovery makes the retrieval of timing information extremely difficult.

The IS-95 system derives the timing information from the GPS in order to track the timing of the spreading codes. However, the movement of one of the ends of the mobile link causes random timing jitter as the geometry of the environment surrounding the terminal changes rapidly. The random Doppler thus produced is not easy to compensate. Since the performance is related to the error in synchronization, the goal of the designer is to minimize the timing jitter.

Walsh symbols are used in the IS-95 over the both up link and down link channels, though with different purposes. Over the downlink channels, the Walsh codes are used for scrambling the information whereas in the up link for orthogonal modulation of the user data, as they are ideal in identifying the correct data under perfect conditions. However, the presence of timing errors undermines their usefulness. Thus, a complex timing synchronization algorithm is required when timing error is in the form of jitter, especially in fading conditions e.g. multi-path Rayleigh.

The remainder of the paper is organized as follows. In Section II, the correlation properties are studied in the presence of timing errors. In Section III, a method is proposed to assign Walsh codes to represent text messages. In Section IV, a simulation model is presented. Section V discusses the simulation results while Section VI presents conclusions drawn from the work.

II. Effect of Timing Errors on the Correlation Properties of Walsh Functions

In CDMA receiver, the incoming spread spectrum signal is multiplied with locally generated spreading sequence. In other words, the received signal is correlated with the locally generated sequence. Even if the two sequences are the same, the correlator output is inversely related to the time shift between them. The output completely disappears (in some cases it may be equal to $1/N$, N being the length of the sequence) for an offset of 1 chip.

The auto-correlation of any Walsh code W_i with period T_b, and an offset τ_ε, can be expressed as

$$R_{i,i}(\tau) = R_{i,i}(k,\tau_{\varepsilon})$$
$$= \left(1 - \frac{\tau_{\varepsilon}}{T_c}\right)\theta_{i,i}(k) + \frac{\tau_{\varepsilon}}{T_c}\theta_{i,i}(k+1)$$

where

$$\theta_{i,i}(k,\tau_{\varepsilon}) = \frac{1}{M}\sum_{n=1}^{M} w_{i,n} w_{i,n+k} \qquad (2)$$

and

$$\tau = kT_c, 0 \le \tau \le T_c \qquad (3)$$

M is the number of chip in the sequence and T_c is the chip interval. If $R_{i,\,i}\,(k, \tau_{\varepsilon})$ is oversampled $T_{sm}=T_c/L$ times, so that τ_{ε} can be quantized as αT_{sm}, then

$$R_{i,i}(k,\alpha) = (1 - \frac{\alpha}{L})\theta_{i,i}(k) + \frac{\alpha}{L}\theta_{i,i}(k+1) \qquad (4)$$

The autocorrelation, $\{|R_{i,\,i}\,(\tau)|\}$, of Walsh for three Walsh codes, W_0, W_3, and W_5 are plotted in Figure 1. The maximum autocorrelation occurs, at $\tau = 0$ as expected. The autocorrelation, $|R_{i,\,i}\,(\tau)|$ decreases as $|\tau|$ increases. It goes through a minimum. For some Walsh functions, $|R_{i,\,i}\,(\tau)|$ goes through a broader minima while for others the minimum may be quite sharp, W_5 and W3 respectively in the figure. A rapid decrease in the auto-correlation, R_{xx}, of a code with τ, indicates its sensitivity to errors in synchronization. For example, Walsh codes with rapidly decreasing R_{xx} are less likely to be affected by timing errors. Thus, the characteristics of $\{R_{xx}\}$ for the Walsh codes can be utilized to encode correlated data such as text for use in CDMA systems. In addition to using Walsh functions for spreading or scrambling we could use them to encode user information data. In this paper, we propose a novel encoding scheme that may be used in maintaining acceptable error probability in the presence of timing errors.

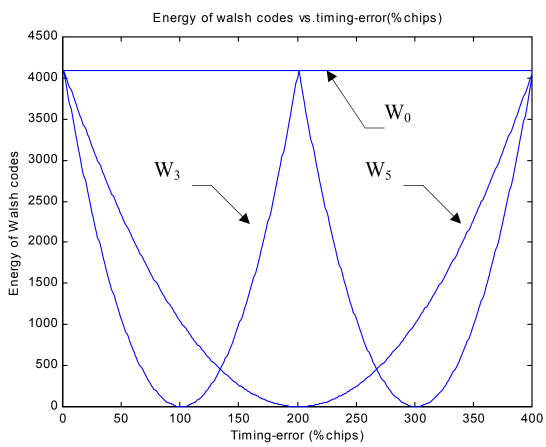

Fig.1 Examples of $|R_{i,\,i}\,(\tau)|$ *for Walsh Codes* W_0*, W3, W5*

In this regard, the data selected is English text, which is transmitted from a mobile terminal to the base station. In the following section, a simulation model is presented.

III. Simulation Model

A long sequence of English text is assembled as the data for simulation. The data is transmitted over the uplink, from the MS to BS, channel. The input text data consists of 64 characters (a to z, A to Z and some punctuations symbols), and each character is assigned on of the 64 Walsh codes. The assignment of codes is according to the occurrence probabilities of the characters and sensitivity to the timing error. The best mapping is to assign a code least susceptible to the timing errors to the most probable of the character. Figure 2 illustrates the mapping process for best coding assignment.

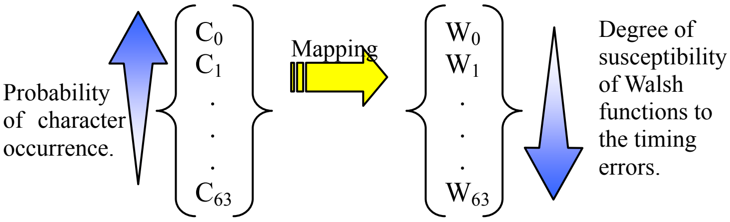

Fig. 2 Best Mapping of the Walsh Codes

Figure 3 shows the block diagram of the simulation experiments. The characters are first mapped onto the Walsh codes according to the procedure shown in Figure 2.

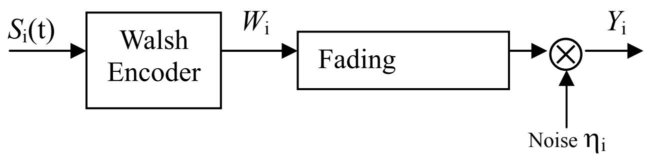

Fig. 3 Block Diagram of the Walsh Encoder

The encoded data is spread using a scrambling code and the spread spectrum signal is transmitted over an uplink at 8000bits/s. The channel is a 3-path Rayleigh fading channel having a maximum Doppler of 90Hz. The received signal is divided into intervals containing N_v Walsh modulation symbols. During this interval, the data is assumed to have a constant timing shift of $\sigma_t T_c$. For each Walsh code, the timing error is related to the output correlation; that is the correlation is regarded as a function of the timing jitter. The direction of the timing shift is randomly set.

At the receiver, the signal is a to a block of 64 matched filters, one for every Walsh code. The output of the matched filter is used in conjunction with a look up table with an aim of identifying the transmitted character. In the case of perfect timing or zero off set, the matched filter that gives the maximum output identifies the transmitted character.

Figure 4 shows the block diagram of the decoder.

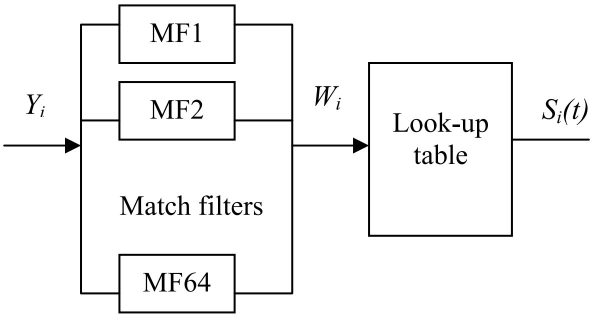

Fig.4 Block Diagram of Decoder

The simulation experiments were conducted on three possible encoding processes. In the first encoding process, the Walsh code with the least susceptibility is assigned to the most frequently occurring character. The second encoding process does not take into consideration the occurrence probabilities of the characters; the Walsh codes are assigned randomly to the characters. In the third assignment method, the most probable character is assigned a Walsh code that is most susceptible to the timing errors.

IV. Simulation Results

The three methods of code assignment to characters are simulated under noiseless conditions. It is seen that for timing errors of less than $0.4\tau_c$, the three schemes perform equally well i.e. the symbol error rate is better than 10^{-4}. However, when the timing error increases beyond $0.6\tau_c$, the symbol error rate is quite poor. Between $0.4\tau_c$ and $0.6\tau_c$ timing errors, the SER degrades sharply. The slope of SER degradation is worst for the worst allocation. It is followed by the performance of the random code assignment. The best allocation shows the best results. The results are shown in Figure 5. From the results, we see that under ideal (noiseless) conditions, SER improvement of approximately 60 times results when the correct encoding scheme is choosing.

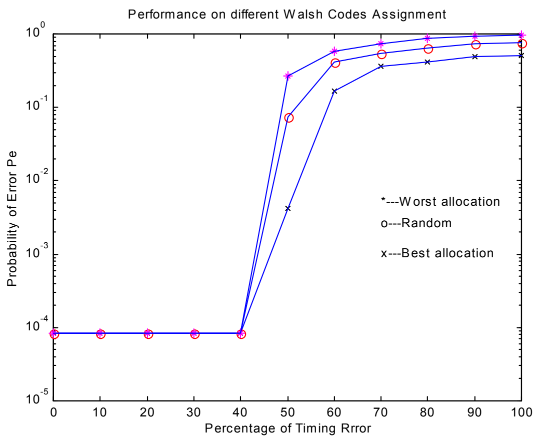

Fig.5 SER for perfect noiseless channel

In practice, perfect noiseless channels are not found. The mobile channels are impaired by noise, fading and multiuser interference. The worst encoding is evaluated under Rayleigh fading channel. In this case for no timing error, the SER varies between 2.5×10^{-4} to 3.8×10^{-6} when the average signal to noise ratio increases from 0 to 12 dB. The results are shown in Fig.6. When the timing error is increased to $0.4\tau_c$ the SER degrades from 2×10^{-4} to 5×10^{-3} over this range of average signal to noise. This represents an increase in the SER of 20 to 52 times when the timing error is increased from 0 to $0.4\tau_c$. It is also observed that when the timing error is around 50%, there is no improvement in the SER even with an increase in the signal to noise ratio.

The best encoding scheme where the code least sensitive to timing error code is assigned to the most probable character is also simulated for different signal to noise ratios and timing errors. The results are shown in Fig.7. The performance for the limiting error of 50% of the chip is quite poor and it does not seem to improve much with an increase in the average signal to noise ratio. For timing errors up to 40% of the chip duration, the SER improves with an increase in the average signal to noise ratio.

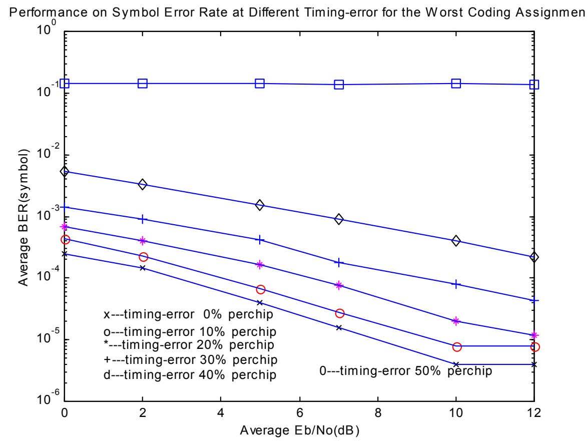

Fig.6 SER v SNR for the worst coding assignment

For the similar range of signal to noise ratios, the best coding scheme (Fig.7) results in SERs between 2.1×10^{-4} and 4×10^{-6} for the timing error of $0\%T_c$, and between 4×10^{-4} and 8×10^{-6} for timing error of $40\%T_c$. This is degradation in SER of a factor of 2.

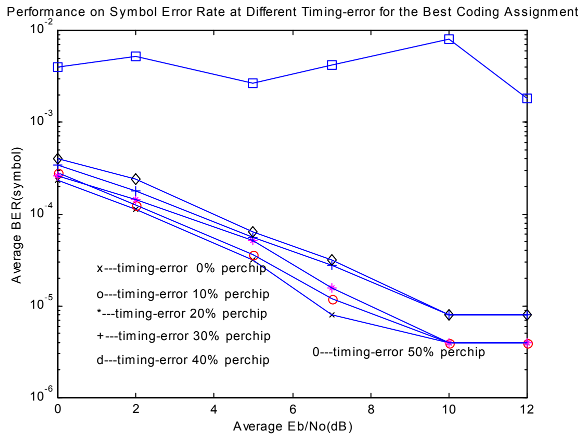

Fig.7 SER v SNR for the best coding assignment

From the simulation results shown in Figures 6 and 7, it is seen that the improvement in SER of 25 to 84 times is obtained for timing error of 0.4 T_c when Walsh codes are appropriately assigned. The improvement of up to 8 times is obtained in the absence of any timing error. At low signal to noise ratios, a greater improvement in the SER is realized.

In Fig. 8, the best and the worst assignment schemes are compared for a timing error of $0.4T_c$. This timing error is chosen as it was seen to be at the threshold of degradation that is the SER deteriorates very sharply when the timing error exceeds this value. In the case of the worst code assignment, the log of symbol error rate improves linearly with the increase in the signal to noise ratio expressed in dB. The best code assignment maintains the superiority over the range of the signal to noise ratio tested. It is seen that the improvement in the case of best code allocation, improvement is slightly faster with the increase in the signal to noise ratio. In any case, it can be stated that the order of improvement in the SER can be obtained with choosing encoding scheme appropriately.

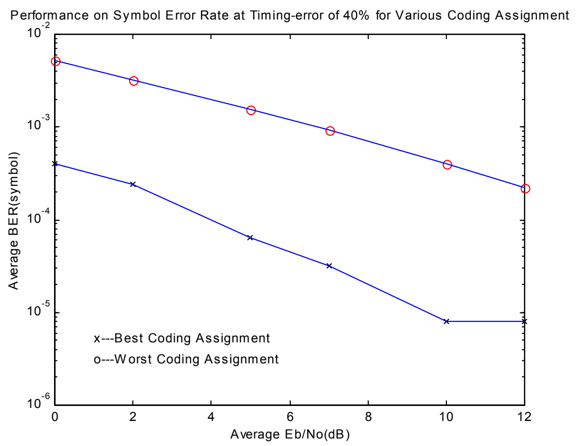

Fig 8: SER performance for the best and the worst coding schemes for timing error of $0.4T_c$

Conclusions

The Walsh codes are used in the uplink of IS-95 system to encode the user data. How these codes should be assigned is addressed in this paper. It is shown that if we assign codes on the basis of their susceptibility to timing errors and the occurrence probability of the user symbols, substantial improvement in the performance can result. We have used test data comprising of 64 characters and shown that the SER improves by many folds. This improvement can be as high as 84 times in the case of text messages transmitted over fading channels. The improvement is even greater in the case of perfect channels.

The performance of the worst and the best assignments is similar for small timing errors of less than 0.1 T_c. However, the best coding assignment scheme maintains symbol error at a low level even when the timing error is increased to 40%T_c. Although the proposed assignment technique is tested for correlated text, it is expected that it can also be applied to other information sources such as voice and image or even multimedia sources. The method here requires very little overhead in the design but is likely to significantly increase the capacity of the system.

Acknowledgement

The authors acknowledge the support of the Hong Kong Polytechnic University in carrying out this work

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