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TITLE:

Proposal for RACH Preambles

SOURCE:

Motorola, Texas Instruments

1.0 Introduction

Several problems with the originally proposed RACH preambles based on Gold codes [1] were presented in [2]. These included 1) Large crosscorrelations between signature sequences at offsets greater than 255 chips, 2) Large crosscorrelations between signature sequences at all offsets when, due to Doppler shifts and differences between mobile TX and base RX oscillator frequencies, channel phase rotation is present, and 3) Poor estimation of the offset frequency due to this channel phase rotation caused by multiple access interference. Consequently, Nokia’s proposal of using a section of a real-valued version of the uplink scrambling code as the spreading code was, in principle, accepted. This eliminates the problem of large crosscorrelations at offsets greater than 255 chips. The resulting preambles therefore consist of length 16 signature sequences formed from a set of orthogonal Gold codes spread by a 4096 chip segment section of a $2^{25} - 1$ length Gold code. *The problem of large crosscorrelations in the presence of frequency offset is still however present*. This is illustrated in Fig. 1 where, for one particular long spreading code, a histogram of the maximum absolute crosscorrelations over a 2048 chip window is shown for the case of a 400 Hz frequency offset. Each point in the histogram represents one of the $\binom{16}{2}$ crosscorrelations. This contribution presents a set of preambles which eliminates this problem and, in addition, facilitates simple and accurate estimation of offset frequency as required for AFC initialization. Accurate AFC initialization based only on the received preamble is important for reliable detection of the message.

The proposed preambles have the following characteristics:

1. Low crosscorrelations at all offsets with and without the presence of channel phase rotation
2. Flexibility in detection schemes. Coherent accumulation, noncoherent accumulation, or differential detection can be used without increased crosscorrelation. *Consequently, there is no need to include a second set of preambles in the standard to facilitate differential detection.* Mobile and base station complexity as well as broadcast channel signaling is reduced.
3. Detection schemes with complexity no greater that possible needed with the present preambles.

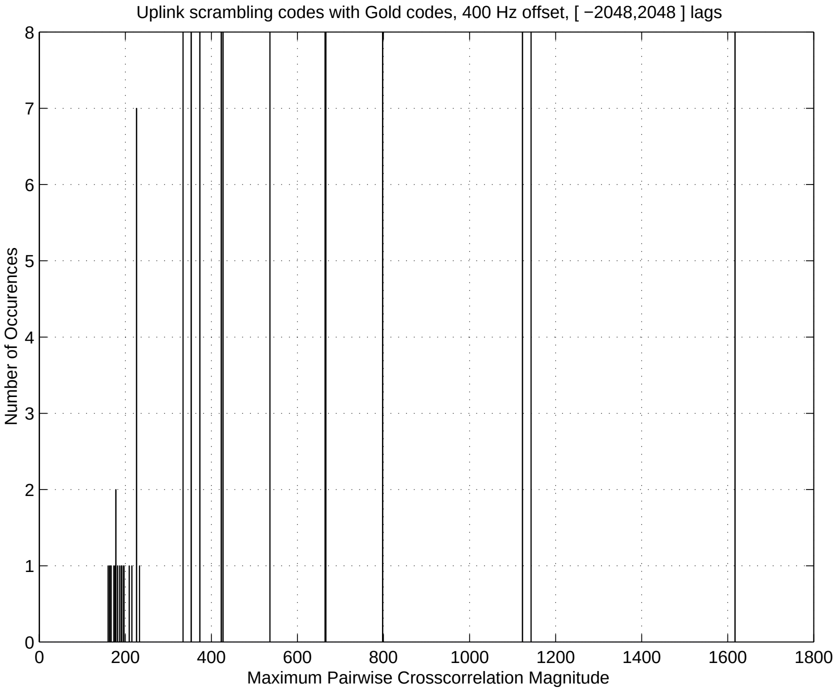

Figure 1: Maximum absolute crosscorrelations for the present preambles when a channel phase rotation of 400 Hz is present.

4. Improvement in detection performance relative to that possible with the present preambles

5. Simple offset frequency estimation without susceptibility to multiple access interference. These characteristics are discussed in detail in the following sections.

2.0 Proposed Preambles

The proposed preambles are formed from 256 repetitions of length 16 Hadamard codes multiplied by a cell-specific scrambling code consisting of a 4096 chip segment of a $2^{25} - 1$ length, real-valued Gold code. Each of the sixteen preambles associated with a cell-specific scrambling code uses a different Hadamard code. The scrambling codes are formed in the same manner as the in-phase dedicated channel uplink scrambling code. The 256 different codes correspond to different initial shift register contents of one of the shift registers.

If h_m, $m = 0, 1, \cdots, 15$, is the set of length 16 Hadamard codes and c_n, $n = 0, 1, \cdots, 255$,is the set of 256 length 4096 scrambling codes, then the mth preamble, s_{mn}, corresponding to the nth scrambling code is

$$s_{mn}(k) = c_n(k) \sum_{i=0}^{255} h_m(k - 16i)\,. \qquad (1)$$

This is illustrated in Fig. 2.

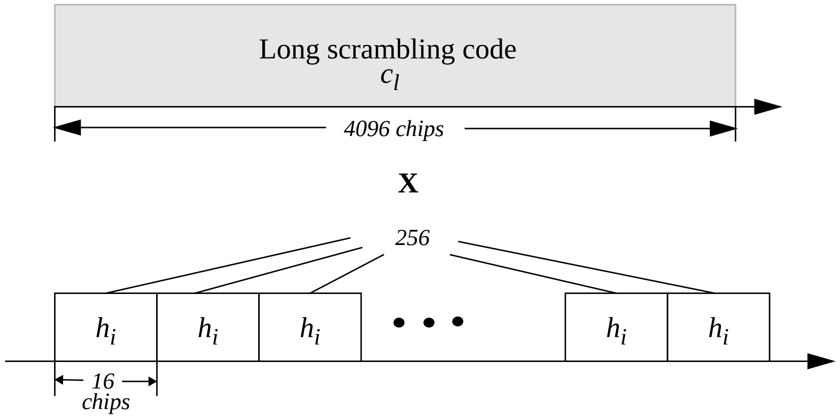

Figure 2: Structure of proposed preambles.

This structure can be viewed as a modification of the current preambles. The main difference is that in the proposed codes, the 256 chips corresponding to one symbol are interleaved at intervals of 16 across the preamble while in the current proposal all 256 chips are transmitted consecutively. In addition the 16 symbols are derived from Hadamard codes in the proposed structure instead of Orthogonal Gold codes.

3.0 Advantages of the Proposed Preambles

The proposed preambles offer three advantages over the current preambles.

3.1 Flexibility

The proposed structure allows a great deal of flexibility in the design of preamble detectors. Coherent accumulation over the entire 1ms, differential detection over some number of symbols, and noncoherent detection are all possible while specifying only one set of preambles. *The latter two methods are possible without adding an additional set of preambles* because the received preamble can be broken into segments without loss of orthogonality. For example, with the present preambles if two preambles arrive at the base within a chip and the received preamble is broken into four segments and correlations are performed over these segments, the resulting correlator outputs will contain signal energy from both users since the preambles are not orthogonal over 0.25ms segments. The noncoherent addition over the correlator outputs for the four segments will therefore contain signal energy from both users and thus a strong preamble could bias the decision statistics of weaker users. The proposed preambles however are orthogonal over 16 chip segments and therefore the correlator outputs will contain signal energy from only one user.

This flexibility has several advantages. First, because it is not necessary to have two sets of preamble codes, mobile station complexity is reduced and less signaling is required on the broadcast channel. Second, multiple detection schemes can be applied in the same sector. Noncoherent or differential detection could be used to detect high speed users while coherent detection could be used for slow speed users.

The following notation will be used in describing three possible detection schemes. Let the received preamble be denoted by $r(k)$ which is assumed to be sampled at the chip rate. This signal is multiplied by the scrambling code of the nth sector and matched filtered against the mth user's Hadamard code:

$$y_m(l) = \sum_{k=0}^{15} c_n(k+16l)r(k+16l)h_m(k), \qquad l = 0, 1, \cdots, 255 \tag{2}$$

to yield a sequence of 256 matched filtered outputs.

Coherent Accumulation

Detection by coherent accumulation can be performed by summing the matched filter outputs and squaring the result to give the decision statistic:

$$\gamma_m^c = \left|\sum_{l=0}^{255} y_m(l)\right|^2 . \tag{3}$$

Noncoherent Accumulation

Alternatively, matched filter outputs can be accumulated within some number of segments of the preamble, the results squared and then accumulated. For example if the 1 ms preamble is divided into four segments, the decision statistic would be:

$$\gamma_m^n = \sum_{i=0}^{3}\left|\sum_{l=0}^{63} y_m(l+64i)\right|^2 . \tag{4}$$

Differential

Differential detection may be performed by accumulating within a segment and then taking the conjugate product of consecutive sums. With four segments the decision statistic would be

$$\gamma_m^d = \left|\sum_{i=1}^{3}\left[\left(\sum_{l=0}^{63} y_m(l+64i)\right)\left(\sum_{k=0}^{63} y_m(k+64(i-1))\right)^*\right]\right| . \tag{5}$$

Note that this statistic is somewhat different from what is usually considered with differential detection. Namely, the absolute value of the consecutive products is taken instead of the real part. As will be discussed shortly this was found to give better performance when large frequency offsets are present.

3.2 Reduction in Crosscorrelation

As illustrated in Fig. 1, the current preamble codes can have large crosscorrelations when a frequency offset is present. With coherent accumulation detection, crosscorrelation causes the decision statistics of preamble codes which are not present to take nonzero values. When the transmitted preamble is received with large signal power, these decision statistics could cross the detection threshold and cause false detections. This may occur for example when the power control error is such that the mobile overestimates the amount of power required to reach the base. A distribution of power control error which is log-normal with standard deviation of 9 dB and limited at 12 dB is suggested in [3]. To insure a low rate of false detections, a large degree of “isolation” between the decision statistics of the transmitted and non-transmitted preambles is required. This false detection phenomenon is described in more detail in Section 6 for a case where the undesired decision statistics are only 9 dB down from the desired.

The large crosscorrelations seen in Fig. 1 were found to occur at zero lag. and are investigated further in the following section.

3.2.1 Zero Lag Crosscorrelations

The decision statistics for the three detection methods discussed above are presented in Figs. 3 through 5 for frequency offsets from 0 to 1200 Hz. These plots show the 16 decision statistics when the first preamble is transmitted and the correct timing offset is being processed. In Fig. 3 the 16 decision statistics for coherent detection of the present and proposed preambles are plotted. From Fig. 3a we see that for the current preambles the decision statistic corresponding to the 14th preamble is less than 10 dB below that of the transmitted preamble at an offset of only 400 Hz. On the other hand, the decision statistics are greater than 40 dB below that of the transmitted preamble for the proposed codes for offsets up to 1200 Hz. In either case however, the decision statistic of the transmitted preamble drops off rapidly between 400 and 800 Hz. This reduction does not occur when noncoherent accumulation is used as shown in Fig. 4 where the noncoherent decision statistics of (4) are plotted. From Fig. 4a we see that noncoherent accumulation over four segments is not viable with the current preamble codes due to the low isolation between decision statistics at even 0 Hz. This is expected in that the present preamble codes are not orthogonal over.25ms. Greater than 40 dB of isolation between decision statistics is however seen with the proposed codes, Fig. 4b. Note that the decision statistic of the transmitted preamble does not drop with large frequency offsets. The case of differential detection is shown in Fig. 5. A uniform isolation of approximately 12 dB is seen for the current preambles and more than 40 dB with the proposed preambles.

3.2.2 Crosscorrelation of Proposed Signatures at Nonzero Lags

The above section described the crosscorrelation properties of the proposed codes at zero-lag. At other lags, the random property of the long code keeps the crosscorrelations small. Figure 6 shows a histogram of the maximum absolute crosscorrelations over a 2048 chip window with a 400 Hz frequency offset for the proposed preambles. Crosscorrelations are seen to be clustered at about -26 dB relative to the main peak. Comparison with the corresponding plot for the present

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