ACQUISITION FOR SATELLITE UMTS WITH LARGE FREQUENCY OFFSETS

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Abstract- **This paper discusses the implementation of signal acquisition for Satellite UMTS, where the frequency offset is of similar size to that of the symbol rate. The entire frequency compensation and signal acquisition process is explained before an explanation of the correlating acquisition process is detailed. The resultant method provides low complexity while providing a very efficient implementation.**

INTRODUCTON

In the acquisition of direct-sequence code-division multiple-access signals it is well known that frequency offset has an impact on signal acquisition performance, for example, a 4dB loss occurs when the frequency offset is half the symbol rate [GauGia98ETT]. The problem is primarily due to oscillator crystals with poor accuracy, and the Doppler frequency offset. Our acquisition method was applied to Satellite UMTS receivers at the gateway, where fast acquisition procedures of bursty messages are needed. For the system in question the frequency offset can be as large as the pilot symbol frequency of the system.

In [SpiSpa98ISSSTA] [CheHur90TC] a FFT correlator for PN code acquisition from LEO satellites is considered. This method is computationally complex and not as flexible in terms of frequency bin selection, compared to our method. In [GliTal96JSAC] a design study for CDMA-based LEO satellites is discussed. Here the authors assume the use of a continuous wave pilot carrier for Doppler estimation and compensation. In this proposal such assumptions are not used. In [SusKau90GC] a similar low complexity approach to ours is used, however the frequency resolution of this method is less than ours and the loss greater.

We assume the receiver knows the spreading code transmitted by the DS/CDMA transmitter and because we acquiring a preamble signal the modulation is also known. We assume an unknown phase and frequency of the received signal.. Finally we assume that the technique has to function in an additive white Gaussian noise (AWGN) channel with or without the presence of Rician fading (K=10) with vehicle speeds up to 70 km/hr.

SYSTEM MODEL

Transmitter Preamble Configuration

The transmitter preamble is shown in
Figure 1. This consists of a number of unmodulated symbols with a spreading factor of 256, followed by a unique word also spread with the same code. The code repeats for each symbol. In Stage 1 of the preamble the receiver's task is to reduce the frequency error from +/-15kHz to +/-5kHz, in the second stage the receivers task is to reduce the frequency error from +/-5kHz to +/-500 Hz, ready for the frequency tracking loop (AFC). A differentially encoded Unique Word (UW) is included at the end of the preamble to determine the start of the data sequence and also to identify the data type.

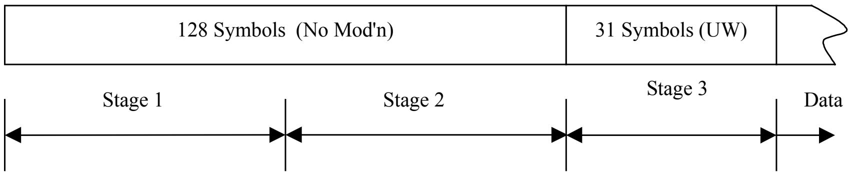

Figure 1 Transmitter Preamble

Although we show results only for preamble acquisition the method has also been successfully used to acquire on the control channel (pilot).

Channel Model

In the Satellite-UMTS low earth orbit (LEO) system considered the frequency offset that a Gateway receiver needs to deal with after centre of beam (COB) compensation can be as high as 15kHz. Up to +/-6kHz of this offset is due to the mobile terminal clock and the rest is due to the frequency difference between the COB and the edge of the beam. Closed loop timing control is not possible as in terrestrial systems due to the inherent delay in the system.

ACQUISITION DESIGN

The acquisition strategy is performed in three stages. Initially a correlating acquisition unit is used to reduce the determine the timing and frequency error to within +/-5kHz. Following this a feed-forward frequency estimator is used to reduce the frequency offset from +/-5kHz to +/-500Hz. Finally a unique word (UW) detection unit detects the end of the preamble and therefore the start of the data frame.

Correlation Acquisition Unit

This task is performed with five parallel correlators each covering part of the +/-15kHz frequency offset. The correlator spacing is designed such that the loss never exceeds 1dB as shown in Figure 2.

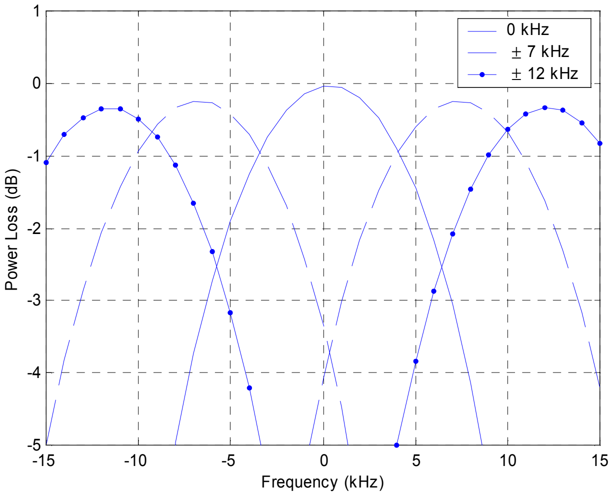

Figure 2 Correlator Performance over Frequency

The correlator implementation method is unique in the fact that to achieve the frequency offset correlators rotations of the spreading code are limited to eight positions, the corners of the unit square and the axis crossings. This is illustrated in Figure 3 where the eight points on the unit square are shown. This makes the correlation process very efficient as the rotation consists of a sign change and at most one addition. An DFT on the other hand requires a complex multiplication for each rotation amount.

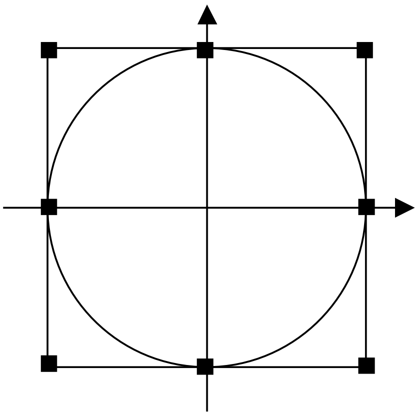

Figure 3 Rotating points used for correlation (squares)

This method has a loss of less than 0.2 dB, as seen by the reduced peaks in Figure 2.

Feed-Forward Frequency Estimation Unit

The 2^{nd} phase of acquisition was performed with a feed-forward estimation circuit as shown in Figure 4.

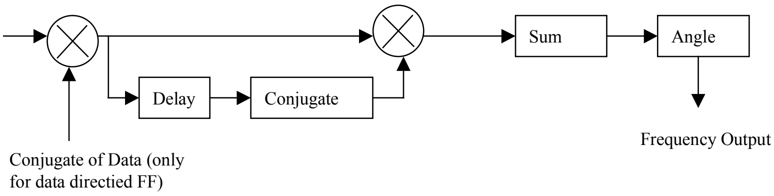

Figure 4 Feed-forward Frequency Estimation Circuit

This technique determines the average angle between each symbol and averages this over a number of symbols, to determine the frequency offset.

Unique Word Detection

The third stage of the preamble is the transmission of a unique word (UW). This detection is used to

- verify that correct correlation detection actually took place
- check that frequency and timing drift has been acquired to within 500 Hz and 0.25us/sec respectively (ie. rough tracking of both frequency and timing is working)
- determine if the oncoming data frame is a RACH or a DCH transmission

Figure 5 shows the UW correlator output. Here the correct timing is found at about symbol 190, prior to that are cross correlation terms. The UW is a 32 symbol M sequence with good correlation properties to the other UW sent. The UW threshold point is set after careful testing with and without noise. Because the UW detection unit input uses a signal with amplitude controlled by an AGC the amplitude of the correlation peak is relatively stable.

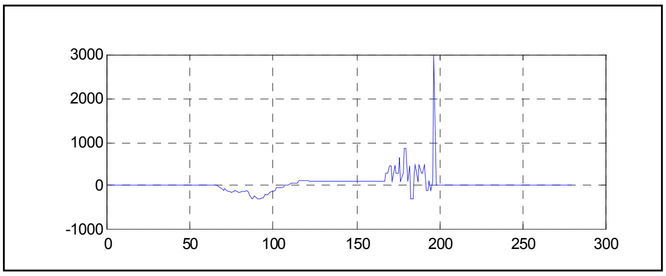

Figure 5 Unique Word Correlation Profile

The UW is 32 symbols long to guarantee good performance at the required operating point. The UW's are a preferred set of m-sequences taken from [PetZie95].

RESULTS

Correlator Acquisition Unit

In Figure 6 the performance of the correlator is shown over frequency offset for a realistic channel with Rician Fading (K=10, 70 km/hr) at Es/No=1dB, 30 experiments at each frequency between –15 kHz and +15 kHz with 1 kHz steps. The result shows that the detection of each frequency bin occurs as expected with approximately an 80% success rate. Each line type represents a different frequency bin correlator.

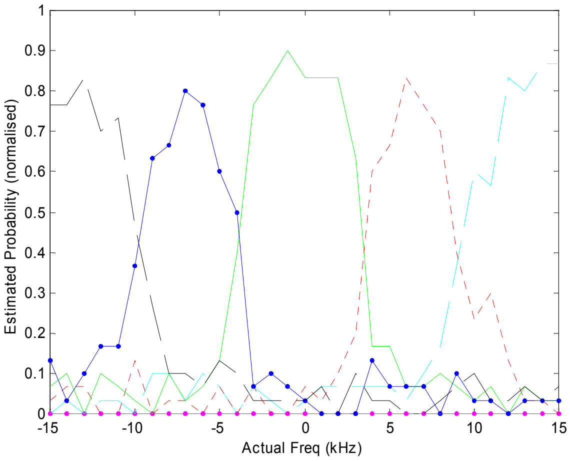

Figure 6 : Frequency Bin Acquisition vs. Actual Frequency Offset

In the next result we perform tests at 0Hz to test for the probability of false alarm and missed detection. To study the worst conditions we perform the tests at Es/No= 0dB which is 1dB under the expected operating point. This is to take account of the worst case correlator performance between frequency bins as shown in Figure 2.

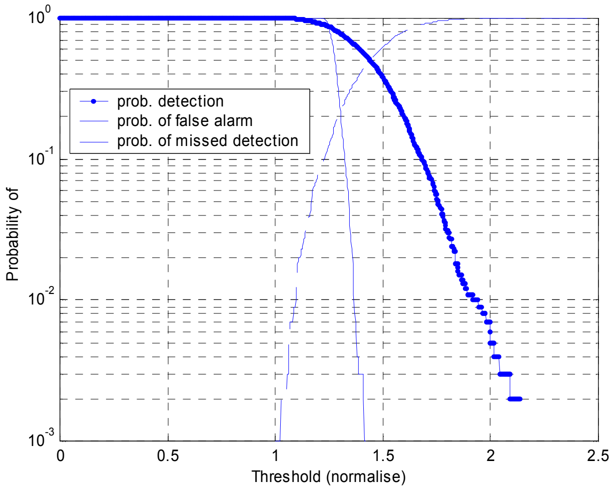

Figure 7 Pfa, Pd, and Pmd for Acquisition Unit vs. Threshold (Rician Fading, K=10, 70km/hr at Es/No=0dB, 0Hz freq. offset)

Another important thing to note from Figure 7 is that these results are for only one demodulator unit. As the receiver is actually running five simultaneous demodulator units the probability of false alarm will be approximately five times greater.

Feed Forward Frequency Estimation Unit

In Figure 8 we show the performance of the feed forward frequency estimation unit at Es/No=1dB.

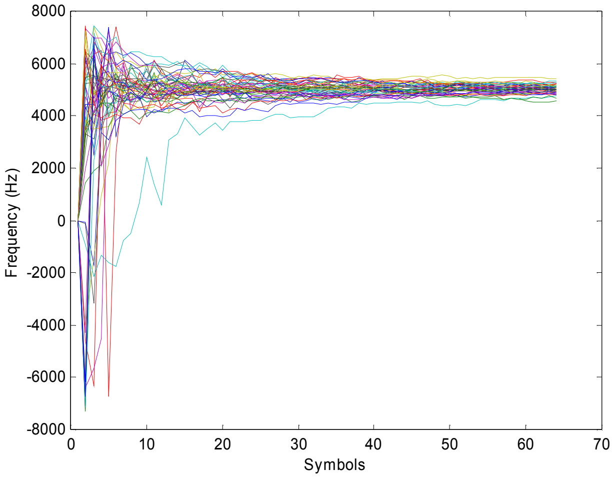

Figure 8 Feed Forward Frequency Estimator Performance

As can be seen for different experiments after approximately 50 symbols the estimation error has been reduced to +/-500Hz. This method provided fast reliable improvement in the frequency acquisition.

Unique Word Detection

Figure 9 shows the performance results for 15 symbols, 16 symbols and 32 Symbols at an Es/No = 1 dB. For comparison, the result from [Cor99] is also shown for a symbol length of 16 at Es/No= 1dB. All tests were performed over 10000 experiments, assuming perfect timing and frequency knowledge. There was no fading present in the simulation. Figure 9 shows the summary of these results in terms of probability of missed detection (P_{md}) and Probability of false alarm (P_{fa}).

Figure 9 shows that satisfactory levels of missed detection and false alarm can be determined, these are significantly improved for the length 32 correlator, as expected.

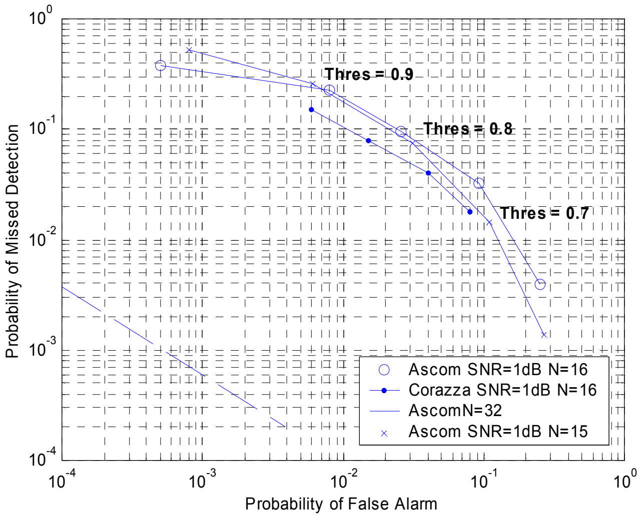

Figure 9 : Performance of Unique Word Correlator for different word lengths at Es/No = 1 dB

IMPLEMENTATION

The Stage 1 technique discussed was implemented in VHDL and has been validated and tested on Xilinx FPGA technology.

The Stage 2 feed forward frequency estimator and the Stage 3 Unique Word detection was written in C and is performed on a fixed point SHARC Analog Devices DSP.

CONCLUSIONS

This paper has shown a particular implementation of Satellite-UMTS burst acquisition for large frequency offset using a multistage approach on a known preamble signal. This task is very challenging due to the large frequency offset and a corresponding equivalent timing drift that is present. As a large proportion of the

This type of technique is important for efficient receiver operation and will be important in up-coming receiver systems such as the GALILEO navigation system. Techniques related to the correlator acquisition unit have been patented [ReeEgl00Pat].

ACKNOWLEGMENT

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