DS Spread Spectrum Link Based on 63 Tap Matched Filter

Fabio De Ferrari, Steve Allpress
Networks and Communications Laboratory
HP Laboratories Bristol
HPL-93-50
June, 1993

DS-CDMA, spread spectrum, matched filter, filtering

In this paper we present a simple simulation of a Direct Sequence Spread Spectrum link. The simulation was carried out using SPW and FDS Comdisco software.

A model of a simple spread spectrum link based on a 63 tap (PN sequence) matched filter receiver has been developed and used to optimize the link's channel filtering and receiver synchronization.

Signal analysis of waveforms at various points in the receiver has been used to verify the SNR improvement due to processing gain.

Using FDS, the effect of filter bandwidths and group delay characteristics on the BER performance has been assessed and a suitable choice of filtering determined.

The time domain output of the receivers matched filter has been investigated and methods of synchronizing the sampling of the demodulator input (based on a detect pulse generated by the matched filter itself) have been evaluated.

DS Spread Spectrum Link Based on 63 tap Matched Filter

Fabio De Ferrari
Mobile Communications Department
Hewlett-Packard Laboratories
Filton Rd., Stoke Gifford,
Bristol BS12 6QZ

Steve A. Allpress
Centre for Communications Research
University of Bristol
Queen's Building, University Walk
Bristol BS8 1TR

ABSTRACT

In this paper we present a simple simulation of a Direct Sequence Spread Spectrum link. The simulation was carried out using SPW and FDS Comdisco software.

A model of a simple spread spectrum link based on a 63 tap (PN sequence) matched filter receiver has been developed and used to optimise the link's channel filtering and receiver synchronisation.

Signal analysis of waveforms at various points in the receiver has been used to verify the SNR improvement due to processing gain.

Using FDS, the effect of filter bandwidths and group delay characteristics on the BER performance has been assessed and a suitable choice of filtering determined.

The time domain output of the receiver's matched filter has been investigated and methods of synchronising the sampling of the demodulator input (based on a detect pulse generated by the matched filter itself) have been evaluated.

1 INTRODUCTION

Direct Sequence Spread Spectrum has gained considerable credibility in the last few years as a suitable technology for mobile radio applications. The use of a set of orthogonal spreading codes allows multiple access, i.e. simultaneous access by different users to the same radio channel. This is called CDMA (Code Division Multiple Access).

The primary reasons for the interest in CDMA are [1,2,3,4]:

- high capacity
- flexible services
- no need for frequency planning
- lower transmitter powers

It has been analytically argued [1,2] that the spreading of the transmitted data achieves the end result of optimising the performance of the radio link. However, little is known about the trade-offs concerning the design of the different parts of the receiver.

2 THE GENERAL MODEL

Our simulation is based on a simple model: the transmitter consists of the data source modulated by a PN code. The spread sequence is then used to modulate a BPSK carrier. At the receiver, after the AWGN channel, the received signal is sampled at one sample per chip and enters the digital matched filter. The output of the matched filter is then sampled, once for each symbol, and then demodulated by means of a hold block followed by a decision element.

The first use of the model is to gain an understanding of the waveforms at different points in the system.

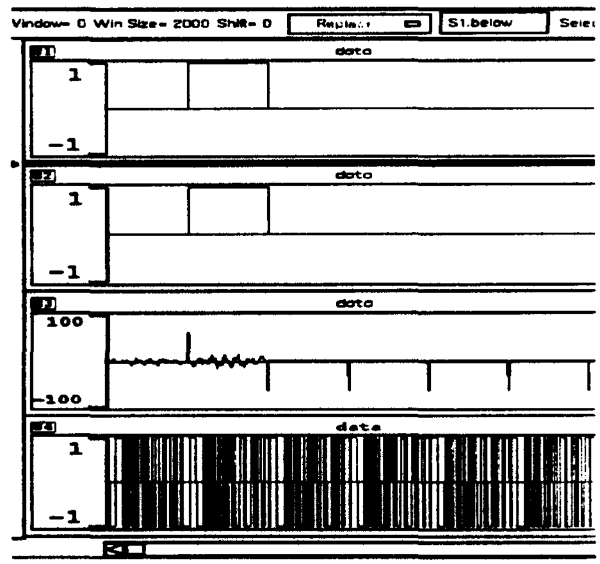

Figure 1
Time Domain Waveforms

In Figure 1, we see the transmitted data, recovered data, matched filter output and the spread sequence respectively, in the time domain.

Similarly, we can view the signals in the frequency domain.

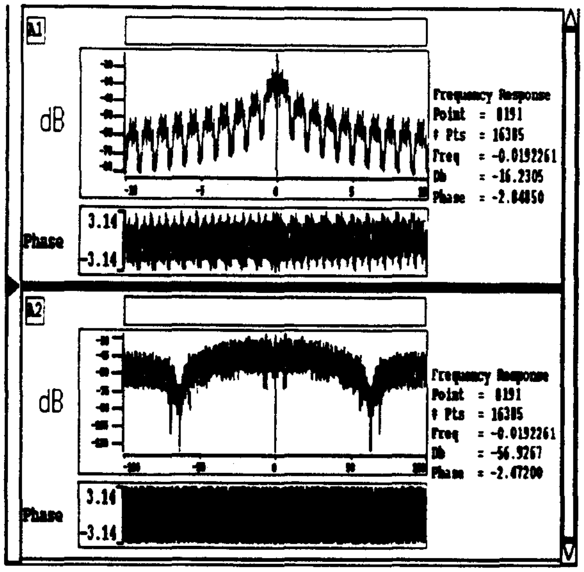

Figure 2
Frequency Domain Waveforms

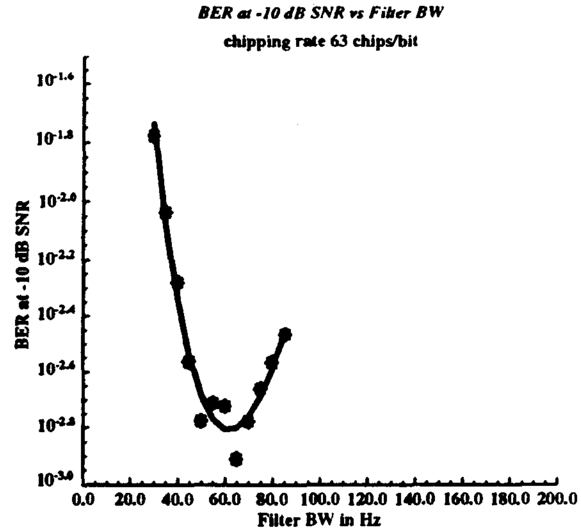

Figure 3
BER at fixed SNR vs. Channel BW

In Figure 2 the upper signal is the frequency spectrum of the original data, while the lower one is the frequency spectrum of the spread data. Note the spreading factor corresponding to the length of the code, 63 in this case.

3 CRITICAL FACTORS

3.1 Channel filtering

The drive of this work has been to gain an understanding of the trade-offs in choosing the channel filtering.

The issues that one should consider are:

- bandwidth of the filter
- group delay characteristics
- attenuation in the stop band
- width of the transition band
- practical issues

3.1.1 Filter Bandwidth

The first result we achieved through simulation was to identify an optimal bandwidth, in terms of SNR, for the channel filtering.

In Figure 3 we see the actual simulation points and a regression to highlight the regression behaviour. The glitches in the original line can be explained as statistical variation of the measured BER.

We show that for a certain Signal to Noise Ratio (SNR), increasing of the channel bandwidth first improves and then degrades the BER performance of the receiver.

In a practical CDMA system the transmitter should always transmit the minimum possible power to achieve the required BER at the receiver. This is done in order to minimise the interference to other users sharing the same channel, thus maximising system capacity. This means that each user will work at the minimum possible SNR.

Figure 3 keeps fixed the SNR and investigates the relation between BER and channel bandwidth. It can be used as well to understand the relation between SNR and channel bandwidth for a fixed BER.

The simulation shows that there is an optimal bandwidth of the filter in terms of SNR, which maximises the performance of the demodulator: this bandwidth corresponds to the main lobe of the signal.

However, if the system is optimised for capacity, the number of users which can share the same is given by [1]:

$$\frac{E_b}{N_0} = \frac{S/R}{\dfrac{(N-1)S + \alpha NS}{W}} \qquad (1)$$

where:

E_b is the energy per information bit;

N_0 the interference+noise spectral density

N the number of users per cell or per sector

S the received power

R the information transfer rate

α the ratio of out-of-cell to intra-cell interference

W the spreading bandwidth

Now suppose that there is a certain amount of bandwidth and that given a certain spreading factor we want to assess the most efficient channel width. We use a system with a CDMA/FDMA arrangement: different CDMA channels share the available bandwidth with an FDMA subdivision.

We can define the *spectral efficiency* as the maximum number of users divided by the channel bandwidth:

$$\sigma = \frac{N}{B} \tag{2}$$

where B is the channel bandwidth, not necessarily equal to the spreading bandwidth.

Firstly we observe that in (1) the quantity E_b/N_0 is directly proportional to the SNR. We can then rearrange equation (1) in order to obtain a relation between σ and the channel width. While rearranging (1), the total interference has been approximated with a term directly proportional to the number N of users per channel.

$$\sigma = \frac{N}{B} \propto \frac{W}{R} \times \frac{1}{SNR} \times \frac{1}{B} \tag{3}$$

It is then possible to plot (3) for different values of B.

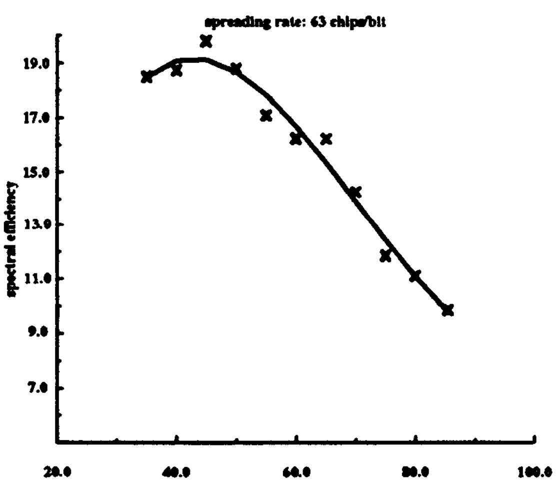

Figure 4
System Spectral Efficiency vs. Channel BW

Figure 4 is obtained for a BER of 10^{-2}. The units on the Y scale only serve the purpose of highlighting the trend. Looking at (3) we understand that narrowing the channel filter will have two interdependent effects on the spectral efficiency σ:

- changing the required E_b/N_0
- changing the width of the channel itself

This is well captured by Figure 4, where it is shown that:

- at large values of B the spectral efficiency is lower because of the width of the channel
- at small values of B the spectral efficiency is lower because the SNR to achieve the required BER is higher.

Despite the optimal bandwidth from the demodulator performance viewpoint being equal to the main lobe of the code, the spectral efficiency of the CDMA/FDMA system will actually be maximised with a channel width of about 2/3 of the main lobe of the signal.

3.1.2 Group delay

Concerning the group delay characteristics, we ran different simulations with different filter types. One of the worst filters, in terms of group delay, is the elliptic, which conversely presents the steepest possible transition band.

Figure 5 compares the result of a simulation with an FIR filter with ideal linear phase to a simulation that uses an elliptic IIR, with the same frequency response but the worst possible group delay characteristics.

It is shown that if we filter at the main lobe of the signal, the non linearity in the phase of the filter does degrade the BER.

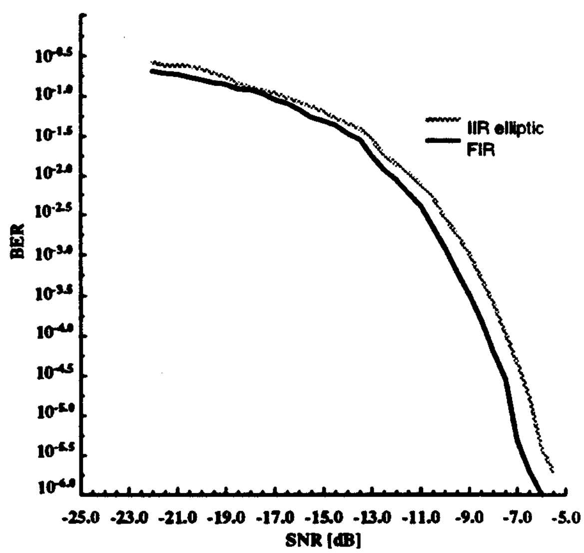

Figure 5
Effect of Non Linear Phase Channel Filtering

3.1.3 Practical implementation issues

The other important aspect is how practical the implementation of the filter is.
The following choices were considered:

- *Butterworth*, good group delay but poor transition band
- *Elliptic*, steepest transition band but poor group delay
- *Chebyshev*, a compromise between the previous two.

The simulation of Figure 5 used a steep "brick wall" type elliptic filter, in order to examine the extremes of this non linearity.

In practice it would be difficult to achieve a system channel filter with such characteristics, so a more realistic filter has been considered to examine the effect of adjacent channel interference.

Figure 6 shows the BER performance of the receiver with no adjacent channel interference compared to the case where an adjacent channel is present *and* filtered as in the main channel. No transition band was inserted between adjacent channels. The filter, in this case, is a possible practical implementation, i.e. the characteristics were relaxed compared to the filter of Figure 5.

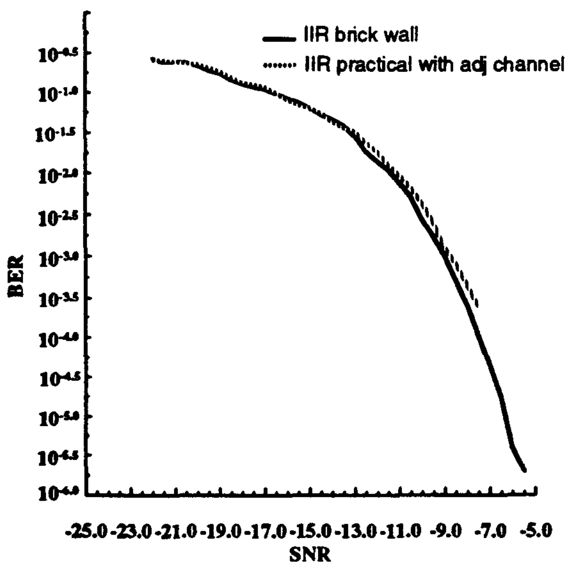

Figure 6
Effect of Adjacent Channel Interference

It is clear form Figure 6 that adjacent channel interference does not seem to be a major issue in limiting the performance of the receiver, given that a normal practical channel filter is used.

3.2 Sampling at the input of the matched filter

This section examines the effect of imperfect synchronisation when one sample per chip is used at the input of the digital matched filter.

Figure 7 shows the degradation in performance with only slight changes in the sampling synchronisation. From a system viewpoint this might indicate that it is preferable to use two samples per chip at the input of the matched filter

The sampling time I is the ideal one, at the centre of the bit period, while sampling time II is at 1/5 of the bit period offset from the previous one.

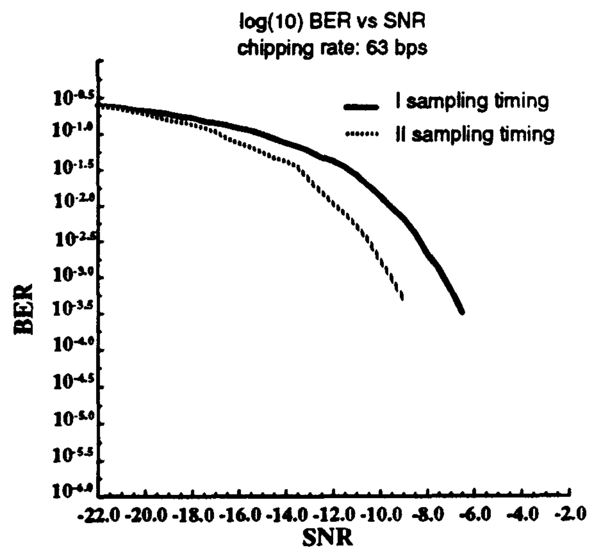

Figure 7
Effect of Incorrect Sampling Time

3.3 Sampling at the output of the matched filter

Figure 8 shows, top to bottom, the time domain output of the matched filter for ideal SNR and for an SNR more typical of a fully loaded system.

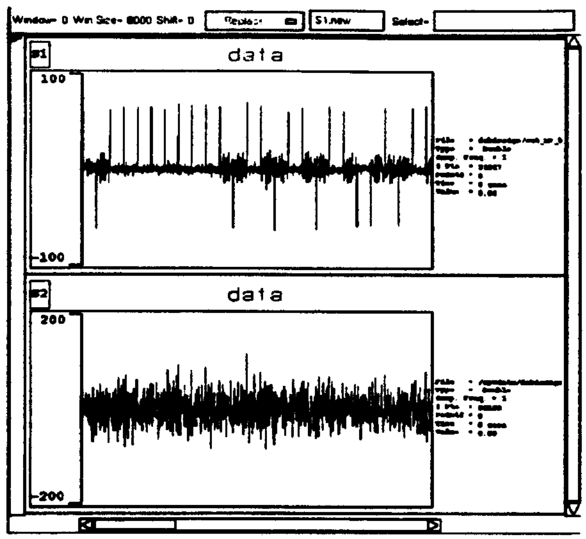

Figure 8
Outputs of the Matched Filter

The simulation results for different SNR values have been used to investigate the feasibility of synchronising the sampling at the output of the matched filter by mean of a detect signal.

This detect signal would be generated every time the output of the matched filter raises above a fixed threshold level.

Figure 9, ideal, shows that setting the threshold level anywhere between 16 and 62 will ensure that all of the expected detect signals are generated correctly, and that there are no spurious detect signals. For threshold levels below 16, the detect signal is spuriously generated by the correlation noise. For threshold levels above 62 all the correlation peaks are below the threshold, so no detect signal is generated.

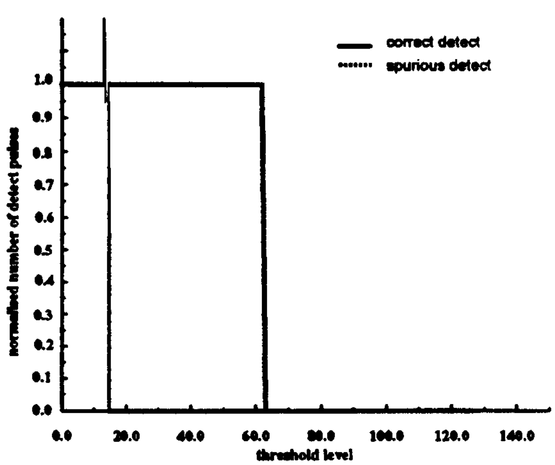

Figure 9
Correct and Spurious Detect at ideal SNR

Figure 10 shows that at high SNR it is not possible to set a threshold level such that all the expected detect signals are correctly generated, and that there are no spuriously generated detect signals.

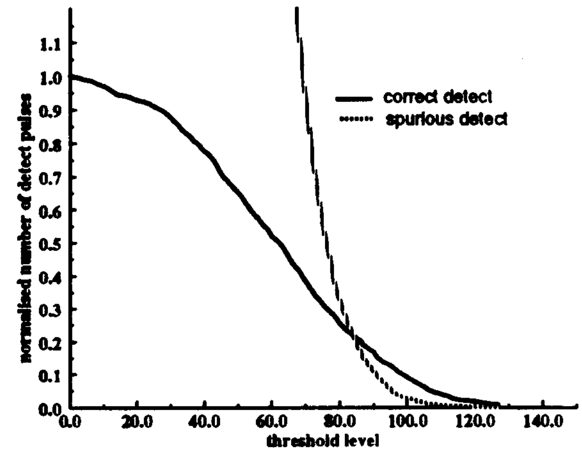

Figure 10
Correct and Spurious Detect at Low SNR

Other means of synchronising the output of the matched filter are:

- inserting a pilot code with high SNR
- further signal processing on the output of the detect output.

In the second case, the testing of such an algorithm was done using C programs and Comdisco simulations.

An algorithm based on a "flywheel" concept has been devised, and Figure 11 shows the improvements in the quantities of spurious and undetected pulses.

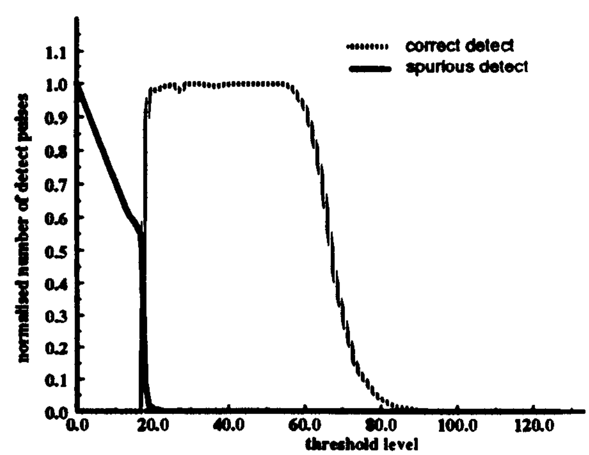

Figure 11
"Flywheel" Algorithm Results

Thus the use of the "flywheel algorithm" allows us to optimise the generation of detect pulses at low SNR.

Simulations can also be easily be run to assess the performance of different type of codes used in the spreading process.

4 CONCLUSIONS

This work shows some simulation results of a simple Direct Sequence system based on a Matched Filter receiver.

It is shown how simulation is a powerful tool to visualise the signal at different point in the system, to assess the importance of certain parameters, and to explore issues that would be difficult or impossible to tackle with analytical means.

In particular, we showed:

- general waveforms in the system
- trade-offs in the choice of the channel filtering and importance of the sampling instant at the input of the matched filter, if one sample per chip is used.
- relevance of the channel filtering from the demodulator performance and from the system spectral efficiency points of view.
- use of simulations to examine how to synchronise the sampling at the output of the matched filter, and to test the performance of different spreading codes

5 Acknowledgements

Thanks to Tom Gardner for kindly letting us use his results of the "flywheel" algorithm.

REFERENCES

[1] K.S.Gilhousen et al. *"On the Capacity of a CDMA Cellular System"*. IEEE VT May 1991.

[2] A.Salmasi, K.S.Gilhousen *"On the System Design Aspect of Code Division Multiple Access (CDMA) Applied to Digital Cellular Personal Communications Networks"*, 1991 IEEE ch2944-7/91.

[3] L.Shilling at al. *"Broadband CDMA for Personal Communications Systems"*, IEEE Comm. Mag. November 1991.

[4] *"CTIA Technology Forum: CDMA Trial"*, CTIA Technology Forum NYNEX Mobile Communications Company 5th Dec. 1991

[5] G.L.Turin *"An Introduction to Digital Matched Filters"*, IEEE Proc. vol.64 n.7 July 1976