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INTER-SYMBOL INTERFERENCES PROTECTION IN SINGLE FREQUENCY NETWORKS

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In digital communication systems widely use an orthogonal frequency division multiplexing (OFDM) modulation of signal. In OFDM signal the amplitude and phase of the subcarrier must remain constant over the period of the symbol in order for the subcarriers to maintain orthogonality. If they are not constant it means that the spectral shape of the subcarriers will not have the correct *sinc* shape, and thus the nulls will not be at the correct frequencies, resulting in Inter-Carrier Interference (ICI). At the symbol boundary the amplitude and phase change suddenly to the new value required for the next data symbol. In multipath environments inter-symbol interference (ISI) causes spreading of the energy between the symbols, resulting in transient changes in the amplitude and phase of the subcarrier at the start of the symbol. Therefore, one of the most important tasks is the task of countering the negative effects caused by inter-symbol interferences due to multiple reflections of the signal in the radio channel.

The length of these transient effects corresponds to the delay spread of the radio channel. The transient signal is a result of each multipath component arriving at slightly different times, changing the received subcarrier vector. Figure 1 shows this effect [1]. Adding a guard period allows time for the transient part of the signal to decay, so that the fast Fourier transform (FFT) is taken from a steady state portion of the symbol. This eliminates the effect of ISI provided that the guard period is longer than the delay spread of the radio channel. The remaining effects caused by the multipath, such as amplitude scaling and phase rotation are corrected for by channel equalization [2].

The addition of guard period removes most of the effects of ISI; however in practice, multipath components tend to decay slowly with time, resulting in some ISI even when a relatively long guard period is used. Figure 1 shows the simulated performance of an OFDM system in the presence of static multipath. In this case the multipath impulse response followed an exponential decay with a time constant of 8 samples, resulting in root mean square (RMS) delay spread of 3.5 samples. Each sample in the impulse response was complex and Gaussian distributed. The RMS delay spread is a common parameter to estimate the spread of the multipath energy in time, and used to estimate the level of ISI in single carrier communications. A more appropriate measure is the time over which 99% of the total accumulated impulse energy arrived, which in this simulation was 16 samples. The results shown in Figure 1 plot the effective signal to noise ratio (SNR) of the demodulated OFDM signal as a function of the channel SNR. Effective SNR is used extensively though out this thesis as a measure of the performance of the communications link. It is a measure of the signal to noise ratio as seen by the OFDM receiver after demodulation, where the signal power is the magnitude of the wanted signal, and the noise is the combined error in the received signal due to all the detrimental effects in the system including channel noise, filtering, ISI, ICI, frequency errors, time offset errors, channel equalization errors, etc. The effective SNR provides a measure of the OFDM performance, independent of the modulation scheme. Traditionally the bit error rate (BER) is used to measure the performance of a link, however in this thesis OFDM is considered the work with a large number of modulation schemes making BER a poor method of measurement. The BER of any particular modulation scheme can be estimated from the effective SNR by finding the BER of the modulation scheme in an additive white Gaussian noise channel with a SNR equal to the effective SNR.

Figure 2 shows the effect of multipath on the OFDM transmission. Ideally the effective SNR should follow the channel SNR, however detrimental effects such as ISI lead to degraded performance. We can see from the results that as the length of the guard period is increased the maximum effective SNR improves. For example, the effective SNR of the OFDM signal only reaches a maximum of 15 dB when the guard period length is 4 samples in length, but reaches 25 dB when a guard period of 16 samples is used.

This is a result of more of the ISI energy being removed by the guard period. This shows that having a guard period (16 samples) that is more than four times the multipath RMS delay spread (3.5 samples) still results in significant ISI.

The low effective SNR for when the guard period was a similar length to the channel RMS delay spread is fine for robust modulation schemes such as BPSK and QPSK, but is insufficient for higher spectral efficiency modulation schemes such as 64-QAM and 256-QAM. Traditionally the RMS delay spread has been used as a measure of ISI and the allowable symbol rate in a multipath environment [3]. However if a higher spectral efficiency is required a more appropriate measure is needed.

To achieve very high spectral efficiencies an effective SNR of greater than 35 dB must be able to be reached [1]. In this case it required a guard period of at least 64 samples in length. This length of the guard period corresponds to the time it took for the impulse energy to decay to –35 dB. Thus if we require a SNR of 25 dB then we have a guard period that is at least long enough to remove all impulse reflections that are stronger than –25 dB.

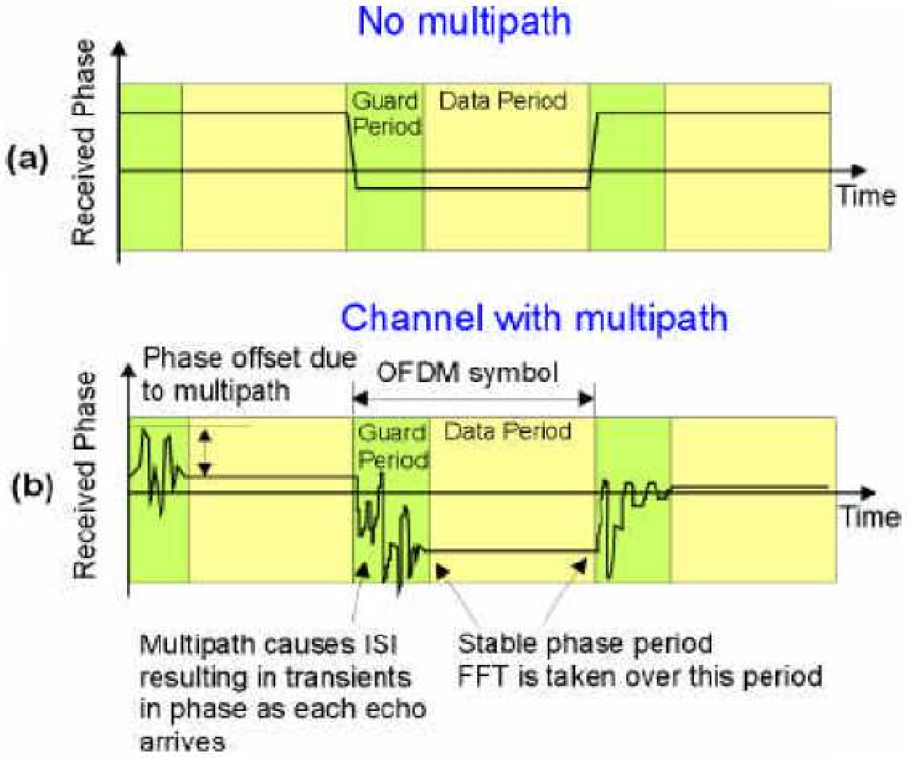

Figure 1. Function of the guard period for protecting against ISI.
The guard period protects against transient effects due to multipath, removing the effects of ISI, provided it is longer than the channel delay spread. This example shows the instantaneous phase of a single carrier for 3 symbols.

The last two results in the simulation show the performance when using a guard period of 64 samples, with an inverse fast Fourier transform (IFFT) size of 128, and 512. In the 128-point IFFT simulation, 80 subcarriers were used while in the 512-point simulation, 320 subcarriers were used, making the bandwidth of both systems the same. In order for the OFDM carriers to remain orthogonal to each other, the channel response must be approximately flat over the bandwidth of each subcarrier [1]. The simulation using 320 subcarriers divides the channel response using finer subcarriers, and hence the variation of the channel fading over their bandwidth of each subcarrier is more constant, improving the performance. The effective SNR for the 128 IFFT size is not limited by the guard period, but instead by poor channel equalization caused by an insufficient number of subcarriers. For OFDM to operate effectively, the frequency response must be approximately flat over the bandwidth of a subcarrier. If insufficient subcarriers are used then the frequency response changes too rapidly, leading to degraded performance.

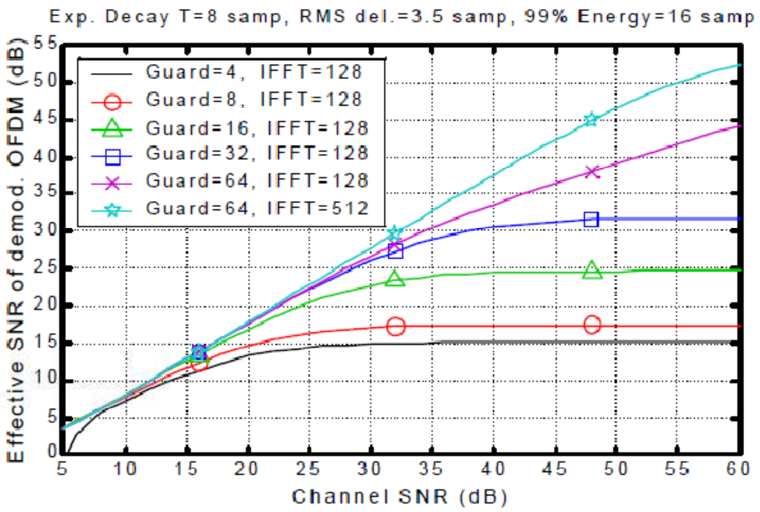

Figure 2. Effectiveness of adding a guard period for removal of ISI.

Adding a guard period lowers the symbol rate, however it does not affect the subcarrier spacing seen by the receiver. The subcarrier spacing is determined by the sample rate and the FFT size used to analyze the received signal [1].

$$\Delta f = \frac{F_s}{N_{FFT}}$$

In this equation Δf is the subcarrier spacing in Hz, F_s is the sample rate in Hz, and N_{FFT} is the size of the FFT. The guard period adds time overhead, decreasing the overall spectral efficiency of the system.

Thus, as shown by the results of the conducted computer simulation, the proposed options of using the guard periods in the structure of the OFDM channel signals enable you to effectively deal with the signal distortions caused by intersymbol interference in radio channels in multiple uncontrolled reflections. In general, it is possible to provide higher noise immunity and reliability of the transmission in terms of reflection of signals in radio channels.

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