Performance Comparison of OFDM and FOFDM Communication Systems in Typical GSM Multipath Environments

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ABSTRACT

Fast-OFDM (FOFDM) is a new scheme which offers twice the bandwidth efficiency when compared to OFDM. The performance of FOFDM though, is severely degraded when the received subcarriers are misaligned. This paper investigates the performance of FOFDM in typical GSM multipath environments. The results obtained are compared with those from a similar system using OFDM modulation.

I. INTRODUCTION

Increasing demand for wireless data communication and services has introduced new technologies capable of handling higher data rates. 3rd generation wireless mobile systems, like UMTS, are widely expected to cope with such demands [1]. Presently much research is being undertaken for future generations of wireless systems. One of the proposed modulation formats is Orthogonal Frequency Division Multiplexing (OFDM) [2]. OFDM has already been adopted in single frequency networks, such as DVB and DAB, as well as, in indoor wireless systems, such as IEEE 802.11 and Hiperlan2 [3].

OFDM is a promising technique because it alleviates most of the disadvantages encountered in other modulation formats when used for wireless systems. The division of the spectrum into many orthogonal sub-carriers, with the addition of a cyclic prefix guard interval, makes the signal robust to multipath delay spread allowing the use of more complex mapping techniques, thus higher data rates.

In the past year a new modulation format has been proposed which is actually a variation of OFDM. Fast-OFDM (FOFDM) is based on the OFDM principle with the advantage of having twice the bandwidth efficiency [4]. This is achieved by applying the Minimum Shift Keying principle to OFDM. In other words the spacing of the sub-carriers in FOFDM is twice as dense when compared to OFDM. A disadvantage of FOFDM is that it can only be used in conjunction with one dimensional modulation schemes. A more detailed background analysis of Fast-OFDM and its differences from OFDM is presented in [4]. In [5], FOFDM is further investigated in the presence of linear phase dispersion, showing that FOFDM may suffer from ICI and consequently, degradation in performance. To alleviate such a problem pre-equalisation was proposed. In [6] the performance of FOFDM is compared to an OFDM, under the effects of; frequency selective fading, frequency and timing offsets and IQ modulator gain/phase imbalance. In this work a more detailed analysis on the effect of multipath fading on the performance of Fast-OFDM is carried out. More specifically the system is tested under different types of GSM typical multipath fading environments, such as Rural Area, Urban Area and Hilly Terrain environments. The results are compared with a similar system using OFDM modulation. Both systems are designed to operate within the GSM spectrum bands.

The paper is organised as follows: The next section describes the principle of Fast-OFDM and defines multipath fading. Section III describes the simulation models of the FOFDM and OFDM systems. Section IV provides simulation results in the presence of the conditions outlined above. Finally, Section V concludes the results obtained.

II. BACKGROUND THEORY

a. FOFDM concept

OFDM stands for Orthogonal Frequency Division Multiplexing. Its basic concept is the division of the available bandwidth into a number of overlapping sub-carriers, orthogonal to each other. Thus, N low rate data streams modulate N orthogonal sub-carriers. In order for the sub-carriers to be orthogonal, their frequency separation must be $1/T\ Hz$, where T is the duration of the signalling interval in each sub-carrier. The orthogonality of the sub-carriers will ensure that the signal can be recovered at the receiver with no inter-carrier interference by using correlation techniques.

The complex envelope representation of an OFDM signal is given by:

$$S_{tx}(t) = \sum_{k=-\infty}^{\infty} \sum_{n=0}^{N-1} a_{n,k} g_n(t - kT) \tag{1}$$

$$g_n(t) = \begin{cases} \frac{1}{\sqrt{T - T_{CP}}} e^{\frac{2pnt}{T-T_{CP}}}, & t \in [0,T] \\ 0, & t \notin [0,T] \end{cases} \tag{2}$$

where, $a_{n,k}$ is the complex symbol transmitted on the n^{th} sub-carrier at the k^{th} signalling interval, N is the number of OFDM sub-carriers, $g_n(t-kT)$ represents the complex waveform (the complex sub-carrier) used to convey the complex data in the same time slot and sub-channel, T is the duration of the signalling interval and T_{CP} is the duration of the cyclic prefix.

FOFDM has similar properties to OFDM with the difference that in FOFDM the frequency separation of the sub-carriers is halved, that is $1/2T$ Hz.

The complex envelope representation of an FOFDM signal is expressed as:

$$S_{tx}(t) = \sum_{k=-\infty}^{\infty} \sum_{n=0}^{N-1} a_{n,k}\, g_n(t-kT) \tag{3}$$

$$g_n(t) = \begin{cases} \dfrac{1}{\sqrt{T-T_{CP}}} e^{j\frac{2pnt}{2(T-T_{CP})}}, & t \in [0,T] \\ 0, & t \notin [0,T] \end{cases} \tag{4}$$

where, $a_{n,k}$, represents the complex data conveyed in time slot k and sub-channel n and $g_n(t-kT)$ represents the complex waveform (the complex sub-carrier) used to convey the complex data in the same time slot and sub-channel, T is the duration of the signalling interval and T_{CP} is the duration of the cyclic prefix.

Figure 1, shows the constellation diagram for an 8 subcarrier OFDM/BPSK and FOFDM/BPSK signals. The figure shows that the real value of the data is received correctly, however, due to ICI, additional imaginary components are present. Thus, the transmitted data can be recovered by taking the real part of the received signal. On the other hand, when complex mapping is applied, for example QPSK, there is ICI in both real and imaginary part of the data, which make signal recovery difficult [4].

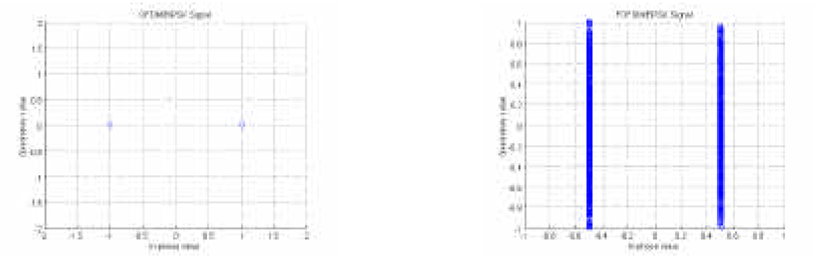

Figure 1 – Constellation diagrams: OFDM/BPSK (left) and FOFDM/BPSK (right) signals

b. *Multipath Fading*

In a multipath fading environment multiple delay versions of the OFDM/FOFDM frames under different power arrive at the receiver. The signal out of a multipath channel, r(t), is defined as:

$$r(t) = \left(a \sum_{i=1}^{M} b_i\, s(t-t_i) e^{-jt_i w_c} g_i(t) \right) \tag{5}$$

where a is the pathloss attenuation, b_i is the relative power of each echo, t_i is the relative delay of each echo, plus the direct path delay t_0, s(t) is the complex envelope input signal and $g_i(t)$ is a random gain function associated with each echo.

III. FOFDM AND OFDM SYSTEM MODELLING

The modelling of the systems is performed in Agilent Advanced Design System (ADS) simulation software.

The FOFDM system can either be modelled in a *"continuous"* or *"discrete"* time model respectively [5]. In this paper the FOFDM system is constructed using FFTs as shown in Figure 2.

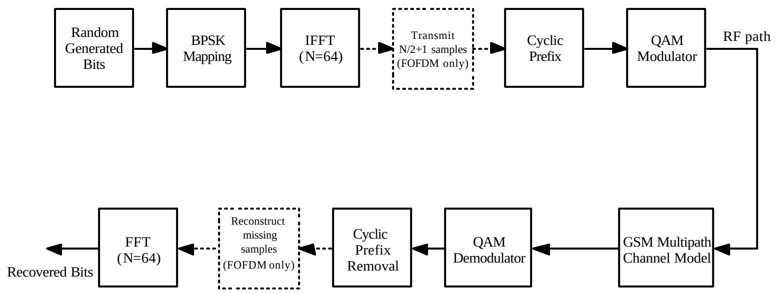

Figure 2 – FOFDM System Model

In this model the BPSK modulated data is converted from frequency to time-domain representation using a 64-sample IFFT. The FOFDM signal is created by discarding the last $N/2 - 1$ IFFT samples [5]. In this way eq. (3) and (4) are satisfied. An additional $N/2$ guard interval is then inserted into the FOFDM frame using the cyclic prefix property [7]. In this way the FOFDM system can withstand delay spreads of 160 µsec. The system is designed to have an effective data rate of 200 kbps. In ADS setting the sampling time to be 10 µsec will make the bandwidth of the FOFDM system 100 kHz [8].

Consequently, each of the 64 subcarriers will be separated by 1.5625 kHz. Finally, the signal is upconverted to RF using a QAM modulator. The RF signal is then fed into a channel model which introduces various effects such as multipath fading and Doppler spread. The FOFDM RF signal is then received through a QAM demodulator. After the removal of the guard interval the FOFDM signal is fed to a 64-sample FFT where the missing $N/2 - 1$ samples are replaced with zeros [5]. The output of the FFT, in the absence of any distortion factor, is the recovered BPSK data where its constellation resembles that of Figure 1 (right).

The OFDM system model follows the same design procedure of the FOFDM model. Once more, a 64-sample IFFT with an additional $N/2$ samples (for guard interval) are used. In order to have the same data rate as the considered FOFDM system, the sampling time is set to 5 µsec. The subcarriers will now be separated by 3.125 kHz, which gives a bandwidth of 200 kHz twice the bandwidth of the FOFDM system, but within the GSM spectrum band.

IV. RESULTS

a. GSM Typical Rural Area environment

Rural Area environments are defined from the small rms delay spread (maximum relative delay is 0.6 µsec). There are two GSM typical Rural Area environment modes. The first type has a 6-tap delay channel whereas the second one has a 4-tap delay channel.

Figure 3 shows the performance of FOFDM and OFDM channel in rural area environments under different E_b/N_0 values. The OFDM system has a 3dB advantage compared to the FOFDM one.

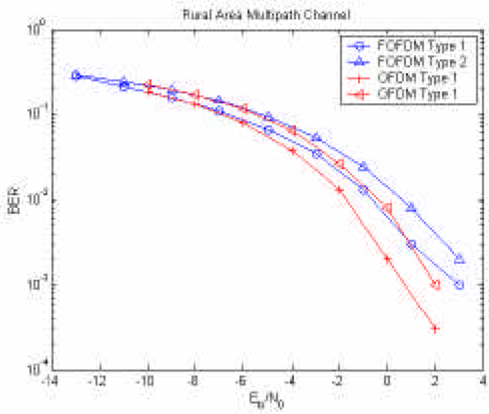

Figure 3 – GSM Typical Rural Area Environment

b. GSM Typical Hilly Terrain environment

Hilly Terrain environments are defined from a mixture of low rural area and very high delays (0.6 µsec for low and 20 µsec for high). The GSM multipath fading model has four different environments: two modes using 6-taps and two modes using 12 taps.

Figure 4 shows the performance of both systems under different Hilly Terrain environments over different E_b/N_0 values. The OFDM system has a significant advantage in terms of error rate over the FOFDM system.

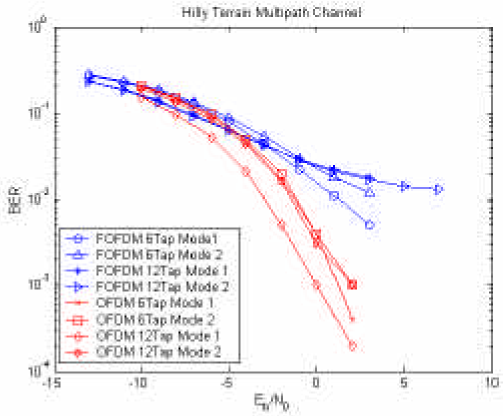

Figure 4 – GSM Hilly Terrain Environment

c. GSM Typical Urban Area environment

The tall buildings of urban areas obscure the generation of high relative delays. GSM typical urban area environments define a delay of 5 μsec, as the highest possible relative delay. Once more there four different urban area fading models are defined for GSM: two 6-tap and two 12-tap modes.

Figure 5 shows the performance of both systems under different Urban Area environments over different E_b/N_0 values. It is important to note that both systems have identical performance.

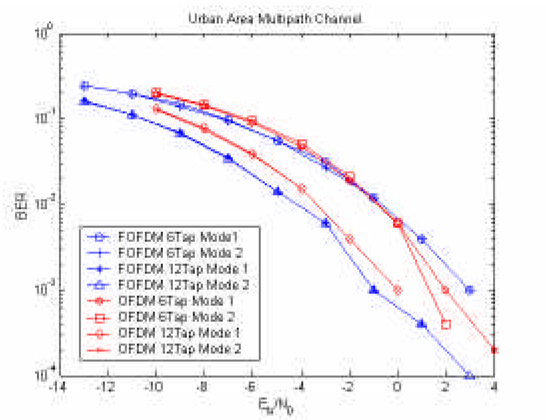

Figure 5 – GSM Typical Urban Environment

V. CONCLUSIONS

This paper is a continuation of the work presented in [6]. This work is concentrated on the performance of OFDM/BPSK and FOFDM/BPSK systems over multipath fading environments. The choice of GSM typical fading environments was due to the availability of the channel modes. For that reason, both systems were built to operate within the GSM band.

The results show that for high relative delays, as in Hilly Terrain environments, the FOFDM system is more susceptible to errors due to its smaller Intercarrier spacing. On the other hand when small-to-medium relative delays are considered, as in Urban area environments, the performance of both systems is identical.

ACKNOWLEDGEMENTS

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