Performance Evaluation of OFDMA in Frequency Selective Fading Channel in 3GPP LTE Downlink Interface Air

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Abstract
The paper evaluates the performance of orthogonal frequency division multiple access in mitigating the inherent attributes of multipath channels that is characterized by frequency selective fading. The performance of bandpass modulation in flat fading channel was investigated for different modulation schemes. The varying channel was simulated using 6 ray ITU Pedestrian frequency selective channel B model for 3GPP LTE downlink interface air. The performance of OFDM for different modulation scheme on the channel was compared to the results obtained for flat fading channel. The comparison results for different schemes show that OFDM transforms the characteristics of the frequency selective fading channel to flat fading channel. This shows that OFDMA is a suitable data access technique of transforming wideband frequency selective channel into flat fading narrow bands at high data rate.

Keywords: Wireless Mobile communication, OFDMA, Noise and Channels

1 INTRODUCTION

Wireless communication is enjoying a fast growth period in history which is supported by the technology advancement. Such is the cellular concept developed by Bell Laboratories [1]. Mobile communication offers a full duplex communication using a radio to connect portable device to a dedicated Base station, which is then connected to a switching network and hence providing facilities for voice call and data exchange. The first generation of mobile communication, known as Advanced Mobile Phone System (AMPS), which was deployed in 1983 [1]. The second generation (2G) of mobile communication is known as Global System for Mobile communication (GSM) was deployed in the 1990s [1] provides 9.6kbps data rate. The International Telecommunications Union (ITU) developed a plan in 1995 [2] called International Mobile Telecommunication 2000 (IMT-2000) to implement a global frequency band [1, 3]. The third Generation system (3G) standard was deployed in 21st century (2000s) with data rate of 64kbps to 2Mbps. Soon after the launch of 3G, a collaborative group of standards organisation and telecommunication companies called Third Generation Partnership Project (3GPP) was formed for enhanced versions to the standard. Evolved from 3GPP standards in 2004 [4], is the Release 8 version, which is known as Long Term Evolution (LTE). 3GPP-LTE targets to support high data rate of 100Mbps for the downlink and 50Mbps for the uplink with achievements of low delay, higher data rate, flexible bandwidth and optimised radio access and cell edge performance [5]. To achieve the above goals, data access and modulation technologies’ having the popular consideration is based on Frequency Division Multiple Access (FDMA). For the Downlink, Orthogonal Frequency Division Multiple Access (OFDMA) is considered while Single Carrier Frequency Division Multiple Access (SC-FDMA) is for the Uplink

2 CHARACTERISTICS of WIRELESS CHANNELS
Wireless channel is an unguided channel and signals not only contain the direct Line of Sight waves but also a number of signals as a result of diffraction, reflection and scattering. This propagation type is termed Multipath [2] degrades the performance of the channel.

2.1 Additive White Gaussian Noise Channel (AWGN)
The AWGN channel is a good model for the physical reality of channel, as long as the thermal noise at the receiver is the only source of disturbance [6]. The impairment this channel caused to signal is the addition of Gaussian distributed noise. Mathematically, it can be illustrated as:

\[ r(t) = s(t) + n(t) \]  

(1)

Where \( r(t) \) is the received signal, \( s(t) \) is the transmitted signal and \( n(t) \) is the noise.

2.2 Multi Path Fading Channels
An alternative class of channel used to model communication system is fading channels because mobile reception is harshly affected by multipath propagation which results in Fading or Inter-symbol Interference (ISI). This can be mathematically expressed as

\[ r(t) = s(t) * h(t) + n(t) \]  

(2)

In time disperse signals, if the delay spread is less than the symbol period \( T_s \) the signal channel is categorised as Flat fading which preserves the spectral characteristics of the signal at the receiver [2] but if signal bandwidth is more than the coherence bandwidth or delay spread is more than the symbol period, then the channel is categorised as Frequency Selective fading and leads to ISI.

3 CHANNEL MODELS
Andrea stated in [3] that deterministic channel models are rarely available. But to evaluate the performance of signals properly in fading channels, this work considered Flat and Frequency Selective fading channel and few of the models.

3.1 Rayleigh and Rician Fading Model
Rayleigh distribution model is often used for fading signal with infinite or large number of arrival paths at the same time whose gain are statistically independent and no dominant path[2]. The phase component of the channel gain is Gaussian distributed and equation 2.8 is its probability density function (PDF) as stated by Rappaport[1]:

\[ p(r) = \begin{cases} 
\frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} & 0 \leq r < \infty \\
0 & r < 0 
\end{cases} \]  

(3)

Where, \( \sigma \) is the RMS value of received signal before detection. And according to [2], the average channel power is given by:

\[ E[r] = 2\sigma^2 \]  

(4)

Similar to the distribution properties of Rayleigh is the Rician Distribution model except for the presence of a dominant path with numerous weak paths. Inclusive in its pdf (equation 5 [2]) is the peak amplitude \( A \) of dominant signal and zero-order Bessel function \( I_0 \), of the first kind

\[ p(r) = \begin{cases} 
\frac{r}{\sigma^2} e^{-\frac{r^2+A^2}{2\sigma^2}} I_0 \left( \frac{Ar}{\sigma^2} \right) & A \geq 0, r \geq 0 \\
0 & r < 0 
\end{cases} \]  

(5)

3.2 Clarke’s Fading Model
The model assumes all multipath signals arrive at the same time in horizontal direction and when the mobile user moves, each path will experience a different Doppler shift. Hence, a uniform probability density function (PDF) of the rays is assumed and a Doppler effect is introduced [7].
3.3 ITU Model

International Telecommunications Union published some generic test models that are commonly used in the communication industry. Depicted in [2] is the three common cases of the model: Indoor, Pedestrian and Vehicular. But in this work, the interest is in the Channel B type of the Pedestrian model with 6 rays, median delay spread (750 ns) and 55% probability of occurrence in an outdoor to indoor environment. Each tap is modelled using Rayleigh fading distribution characterised by Clarke’s outdoor to indoor environment. Each tap is modelled using Rayleigh distribution defined [8] as:

\[
S(f) \propto \frac{1}{1-(f/f_d)^2} \quad \text{for } f \epsilon -f_d, f_d \quad (6)
\]

Assuming all the paths arrives at the same time and are uniformly distributed, the PSD is modelled as [2]:

\[
\bar{a}(t) = \sum_{i=0}^{N-1} a_i e^{j2\pi f_i t + \theta_i} \quad f \text{ or } f_i = f_d \cos \theta_i \quad \text{for } 0 < f < f_d
\]

\[
S_b(f) = T(R_b(\Delta t; \tau)) = \begin{cases} 
\frac{P_m}{\sqrt{1-(f/f_d)^2}} & |f| < f_d \\
0 & |f| > f_d 
\end{cases} \quad (8)
\]

Where \(R_b\) is channel autocorrelation function, \(P_m\) is the average channel power, \(f_i\) is the Doppler shift in direction of travel for path \(\theta_i\), \(a_i\) is the channel response in relation to Doppler shift.

### Table 1

<table>
<thead>
<tr>
<th>Channel A</th>
<th>Channel B</th>
<th>Doppler Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap</td>
<td>Relative Delay (ns)</td>
<td>Average Power (dB)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>110</td>
<td>-9.7</td>
</tr>
<tr>
<td>3</td>
<td>190</td>
<td>-19.2</td>
</tr>
<tr>
<td>4</td>
<td>410</td>
<td>-22.8</td>
</tr>
<tr>
<td>5</td>
<td>2300</td>
<td>-7.8</td>
</tr>
<tr>
<td>6</td>
<td>3700</td>
<td>-23.9</td>
</tr>
</tbody>
</table>

4 BANDPASS MODULATION

Modulation is a process of transforming signal into waveforms that are compatible with the channel properties [9] and this is necessary in wireless communication where the antenna diameter must be at least equal to the wavelength of the carrier [10]. A digital data is usually in the sequence of 0s and 1s, regardless of their generic source, i.e either it is inherently digital or a result of analog-to-digital conversion [11]. To transmit such data over the channel, a signal that represents the data and matches the channel property is generated. Since, there is a limitation in antenna size that can meet efficient signal transmission, data signal are super imposed on carrier-wave by shifting the information bearing signal to the frequency band of the channel [12]. Baseband signals can be translated to higher frequency range. This technique is known as bandpass modulation and they are used in wireless and mobile communication. Three main parameters-amplitude, phase, frequency can be exploited to produce a modulated signal[10], which leads to three generic modulation scheme namely Amplitude Shift Keying (ASK), Phase Shift Keying (PSK) and Frequency Shift Keying (FSK). For a given digital data of finite bit sequence to be transmitted over a channel by a bandpass filtered signal \(s(t)\), a mapping process known as digital modulation is required between the bit sequence and possible signals [11, 6]. The mapping rule is also needed for proper demodulation and detection at the receiver. Also, signals can consider information bits in groups known as symbols and generate a wave form for each group. That is, transmitted data can have \(M\) numbers of symbols in a signal constellation or word length and \(k\) numbers of bit within each symbol.

\[
k = \log_2(M)
\]

5 ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS (OFDM)

The multiple access schemes are based on OFDM [13]. The multicarrier access is achieved by assigning a group of subcarriers to a particular user. OFDMA is inherently robust to time dispersion on the radio channel without recourse to complex receiver channel equalisation due to the combine use of narrow-band subcarrier transmission with cyclic prefix (CP) [14]. Therefore, data can be transmitted in large numbers of parallel, narrow-band subcarriers on the downlink interface and mitigate the effects of multipath propagation. OFDM signals can be generated by Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) implementation at Node B and UE. Thus, the basic OFDM signal \(x(t)\) can be expressed during the time interval \(0 \leq t < T\) as [2]:

\[
x(t) = \sum_{k=0}^{N-1} X_k e^{-j2\pi k \Delta f t}
\]
Where $X_k$ is the complex modulated symbol carried in $k$th subscriber in $N$ size subcarriers. $\Delta f$ is the subcarrier spacing and $T$ is the symbol period.

As the downlink access standard prescribes [12], $\Delta f = 15\text{kHz}$ This is made constant regardless of the transmission bandwidth simplify the implementation of 3G multimode terminal [2]. Hence, for an $N$ size FFT, the sampling rate $f_s$ is given by:

$$f_s = N \Delta f$$ (11)

Also the bandwidth is made scalable by controlling the size of $N$, keeping the subcarrier spacing constant. Thus, with FFT size varying from 128 to 2048, downlink bandwidth range up to 20 MHz can be supported [15].

Fig 2: LTE Downlink Frequency-domain structure

Similarly, two CPs, a short duration 4.69$\mu$s and long duration 16.67$\mu$s [16] are defined for flexibility of LTE system deployment. CP insertion means that the last part of the OFDM symbol is copied and attached to the beginning of the symbol. The CP length is chosen to be longer than the maximum delay spread and is carried out to retain the orthogonal properties between the subcarriers, in order to avoid inter-channel interference ICI. Similarly, two CPs, a short duration 4.69$\mu$s and long duration 16.67$\mu$s [16] are defined for flexibility of LTE system deployment. CP insertion means that the last part of the OFDM symbol is copied and attached to the beginning of the symbol. The CP length is chosen to be longer than the maximum delay spread and is carried out to retain the orthogonal properties between the subcarriers, in order to avoid inter-channel interference ICI. Part of OFDMA specification is the ability to reach high data rate. This is dependent on the delays in the system, premised on short sub-frame duration. As a result, sub-frame duration is made as short as 0.5$ms$, an extraction from 10$ms$ LTE transmission frame and corresponds to the minimum Transmission Time Interval (TTI)[21]. Fig. 3 below [5] depicts the time domain 10$ms$ frame structure consisting of ten equally sized sub-frames (1$ms$ frame is further splitted to two 0.5$ms$ subframes)

Fig. 3: LTE Subframe[2]

6 IMPLEMENTATION OF OFDMA FOR 3GPP DOWNLINK INTERFACE AIR

The implementation is to simulate the channel using the ITU model to determine the suitability of OFDM for the downlink air interface. It is expected that the selective fading channel is transformed to flat fading channel with OFDM. The description of OFDMA implementation is in time domain, but OFDMA transmission in Frequency
domain is exploited in this model making it relatively easier to implement frequency selective scheduling as 3GPP LTE standard prescribes. Therefore, OFDMA symbol implementation scheme can be described with the following analysis. Assume a Node transmits symbols \( s(t) \) which is passed through OFDM modulator yields OFDM symbols \( x \) as the output:

\[
x = \mathcal{F}^{-1} \{ s(t) \}
\]

in the presence of noise \( n \) produce the received signal \( r \) at the receiver before demodulation is

\[
r = h \otimes x + n
\]

Demodulating \( r \) yields \( S_n \)

\[
S_n = \mathcal{F} \{ r \} \tag{14}
\]

\[
S_n = \mathcal{F} \{ h \otimes x + n \} = \mathcal{F} \{ h \otimes x \} + \mathcal{F} \{ n \} \tag{15}
\]

\[
S_n = \mathcal{F} \{ h \} . \mathcal{F} \{ x \} + \mathcal{F} \{ n \} \tag{16}
\]

\[
S_n = \mathcal{F} \{ h \} . s(t) + \mathcal{F} \{ n \} \tag{17}
\]

Where \( S_n \) are the received OFDMA symbols of n size FFT.

### 6.1 Experimental Set-up

An initial model for all the modulation scheme is carried out in simple AWGN channel transmission, to test and evaluate the performance and detection of the modulated data as seen by the UE. Coherent detection is employed in the initial setup using Gray mapped signal constellation for all the modulation scheme and Maximum Likelihood Detection (MLD) at the receiver. Downlink transmission channel is characterised with multipath fading, dominance in frequency selectivity. A 6 ray ITU Pedestrian frequency selective channel B model (as shown in Table 2) is used to model the varying channel state. The signal arriving at the receiver is the sum of copies of the original signal with different delays and gains.

### TABLE 2

LTEOFDM Parameters [22]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Bandwidth (MHz)</td>
<td>14</td>
</tr>
<tr>
<td>Number of Resource Blocks</td>
<td>6</td>
</tr>
<tr>
<td>Number of occupied subcarriers</td>
<td>72</td>
</tr>
<tr>
<td>IDFT/FFT size</td>
<td>12</td>
</tr>
<tr>
<td>Subcarrier spacing ( \Delta f ) (kHz)</td>
<td>15(7.5)</td>
</tr>
<tr>
<td>Sampling Rate (MHz)</td>
<td>1.9</td>
</tr>
<tr>
<td>Samples/slot</td>
<td>960</td>
</tr>
<tr>
<td>CP sizes(( \mu s ))</td>
<td>Normal CP=15kHz</td>
</tr>
<tr>
<td></td>
<td>7 symbols/slot</td>
</tr>
<tr>
<td></td>
<td>Extended CP=15kHz</td>
</tr>
<tr>
<td></td>
<td>HZ</td>
</tr>
<tr>
<td></td>
<td>Extended CP=7.5kHz</td>
</tr>
<tr>
<td></td>
<td>HZ</td>
</tr>
</tbody>
</table>

In the downlink of OFDMA systems, modulated data is converted from serial to parallel and mapped to different subcarriers. IFFT of the mapped data is carried out to convert the data into their corresponding time domain and the output signal are converted back to serial data called OFDM symbols. CP is attached to the beginning of the symbols (as guard interval, elimination of ISI and to enable circular convolution) before transmitting across the channel. At this point, a convolution with the channel is performed and Gaussian distributed noise \( n \) added.
Subcarrier spacing in LTE is 15 kHz, CP length 4.69μs or 16.67μs and 1ms time unit sub-frame (see Figure 3)

6.1 Performance of in Fading Channel
Attribute of OFDMA is the inherent capability of combating interference by converting frequency selective channels into sets of flat fading channel. The considered frequency selective channel is of Rayleigh distribution.

OFDMA is expected to transform the channel from frequency selective Rayleigh fading to Flat fading. Provided below is the BER performance of simulated OFDMA in each modulation scheme as compared with a theoretical Rayleigh Flat fading.

![Fig. 5: Comparison of BER Performance of Simulated QPSK OFDM in Frequency Selective Channel and Theoretical QPSK in Flat Fading Channel](image-url)
Fig. 6: Comparison of BER Performance of Simulated 8PSK OFDM in Frequency Selective Channel and Theoretical 8PSK in Flat Fading Channel

Fig. 7: Comparison of BER Performance of Simulated 16QAM OFDM in Frequency Selective Channel and Theoretical 16QAM in Flat Fading Channel
7 RESULT DISCUSSION
The result shows the performances of different modulation techniques in flat fading channel. This result when compared to the performance of OFDMA for the various Band pass modulation techniques show that the selective fading channel is changed to flat fading channel. These performances are presented in Fig.5 to Fig.8. Data transmission can be done at a constant gain and linear phase over the signal bandwidth, while the spectral characteristic of the signals are preserved at the receiver. In addition, the results show that OFDM can be implemented in frequency domain. Channel dependent scheduling can thus be carried out in the frequency domain effectively.

8 CONCLUSION
The result sows that OFDM is suitable for addressing the channel impairments attributable to multipath channel by converting the selective fading channel to flat fading channel. This was established by the performance of OFDM baseband modulation in selective fading channel. The contributions of 3GPP are expressed in high data rate which is only attainable if the channel characteristics are mitigated. The result shows that for different modulation scheme that OFDMA is a suitable data access technique for 3GPP downlink interface air.

REFERENCES
