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System Performance Evaluation of Fixed and Adaptive Resource Allocation of 3GPPLTE Downlink Interface Air

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Abstract
The allocation strategies employed in assigning the subcarriers will affect the system performance in various ways such as data rate, power efficiency, spectrum efficiency and bandwidth flexibility. The study investigated the effect of two main assignment strategies which include fixed subcarrier allocation and dynamic subcarrier allocation on the performance of OFDM system. The objective of this study is to determine allocation algorithm that will optimise the available resources. Simulation results show that an adaptive subcarrier allocation based on user channel quality information perform better and optimise the network than fixed allocation.
Key words: OFDM, Spectrum efficiency,

1. Introduction

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 [1], is the Release 8 version, which is known as Long Term Evolution (LTE) and it has become increasingly difficult to ignore as the Next Generation Network (NGN). 3GPP-LTE targets to support high data rate of 100Mbps for the downlink and 50Mbps for the uplink using the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) with achievements of low delay, higher data rate when compared with previous 3G standard, flexible bandwidth and optimised radio access and cell edge performance[2]. 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 for transmitting from Base Station (BS) otherwise known as Node B to the mobile user which is known as User Equipment (UE) while Single Carrier Frequency Division Multiple Access (SC-FDMA) is for the Uplink, that is, UE to Node B. This work focuses on the Downlink access. OFDMA is an enabling technology for LTE. The multiple access scheme is based on Orthogonal Frequency Domain Multiplexing (OFDM)[3]. 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) [4]. Therefore, data can be mitigate the effects of multipath propagation that characterise wireless and mobile transmission channels. Among other benefits the radio access can offer in 3GPP LTE downlink is the degree of freedom for channel dependent scheduling[2] and multiuser diversity- by spreading the carriers over the spectrum and adaptivity of modulation based on user request. Basically, OFDMA is a suitable data access technique of transforming wideband frequency selective channel into flat fading narrow bands [5], allowing the UE to perform a less complex equalisation and offers a high data rate. 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];

$$x(t) = \sum_{K=0}^{N-1} X_k \, e^{-j2\pi k \Delta_f t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where x(t) is the complex modulated symbol carried in kth subcarrier in N size subcarriers. Δ_f is the subcarrier spacing and T is the symbol period.

1.1 Subcarrier Allocation

In OFDMA systems, resources are mapped to the available subcarriers. The allocation strategies employed in assigning the subcarriers will affect the system performance in various ways such as data rate, power efficiency, spectrum efficiency and bandwidth flexibility. Two main assignment strategies is exploited in this work and presented below.

1.2 Fixed Subcarrier allocation

Fixed allocation algorithm allocates a set of subcarriers to each UE and no other UE can use them even if they are not in use. This is often viewed as being fair to all users and ensures that all users have a dedicated channel when the need arise. But this method amounts to waste of resources if UEs are in deep fade or when UE is not in

need of the allocated subcarriers. Thus, the fixed allocation can be model as follows:
Assume Node B is scheduled to transmit *N* size subcarrier to *k* numbers of UEs, each user is allocated subcarrier sets M adjacent to each other. The algorithm is modelled as shown in equation 4.8 below:

$$S_k = n \,\epsilon\, [s_k : k : s_N] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$S_k = S_1, \ldots\ldots.. S_k \ldots \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where S_k is the set of subcarriers allocated to the k^{th} user, n is the number of allocated subcarriers, s_k is the subcarrier index of the first subcarrier allocated to the k^{th} user in the OFDM subcarrier stream of N size.

1.3 Dynamic Subcarrier allocation

Since, subcarriers are currently spread across the channel band with equal spacing at implementation of OFDM (equation 4.7 above), each OFDM symbol occupies a subcarrier (consisting of instantaneous subchannel *hn* for N size subcarriers). Recall that, 3GPP LTE specifies the use of CQI to estimate the UE performance per transmission subframe. Dynamic allocation relies on the knowledge of this estimate; hence the allocation scheme is modelled as follows:
Assume the CQI of independent UE is known at Node B, which comprise of the same channel characteristics of the transmission channel but varies per transmission time. The varying CQI *Hq* for the kth UE can be model as random instantaneous channel gain *Hq,k* by taking the frequency response of the randomly generated channel of the same delay profile as the transmission channel in *n* subcarrier transmission, which is expressed as:

$$H_{q,k.t} = \sum_{n=1}^{F} \left|h_{q,k,n}\right|^2_{\;t} \qquad f\ or\ 0 : t : T \ldots\ldots\ldots\ldots .4$$

Where $h_{q,k,n}$ is the instanteneous subchannel extracted from k^{th} UE's quality indication at the instant time t of subcarrier n over F=N subchannel of each UE (frequency response iteration of the randomly generated channel for each UE) within an OFDM data steam period T (T= tN)
To apply CDS, in allocating resources to the UE with best CQI-essentially the best channel condition. The k^{th} UE that get the nth subcarrier needs to maximize the following function:

$$n_k = arg\max\left(H_{q,k}\right) \qquad T; n\epsilon N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .5$$

Where n_k is the subcarrier to be allocated to the k^{th} user having $H_{q,k}$ that fulfils the condition above.
Using the known CQI from equation 20, Node B applies the n^{th} subcarrier to the corresponding UE. Let $S_{k,n}$ denote the set of *n* subcarriers assigned to the k^{th} UE, it follows that $S_{k,n}$ ε N. Thus, a KxN state matrix of subcarriers S and subchannels H is formed. If n is allocated to a *k* user, it returns a value and index the corresponding h_n in H, while returning false (0) for other users column-wise. Then, $S_{k,n}$ can easily be extracted row-wise.
The objective of this dynamic allocation algorithm is to find a good allocation that will optimise the available resources. More subcarriers are allocated to best UE for optimal performance and a subcarrier can only be used by at most one user. Each subcarrier *n* as perceived by user *k* is subject to flat fading. Therefore, user capacity C_k, can be formulated and simplified from the description in equation in accordance with Shannon equation [5] as:

$$C_k = max_{S_{k,n}} \sum_{n \subset S_{k,n}} \frac{BW}{N} \log_2\left(1 + \frac{SNR|h|_{k,n}{}^2}{\frac{BW}{N}}\right) \ldots\ldots\ldots\ldots\ldots\ldots .6$$

As also described for a power constrained system, C_k will be subject to [25]

$$\sum_{k=1}^{K} \sum_{n \subset S_{k,n}} SNR.N_0 \le P_{max} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...7$$

Where P_{max} is the maximum transmit power of the system, $|h|_{k,n}{}^2$ is the channel gain of subcarrier n of the kth UE. BW is the transmission channel bandwidth occupied by N size subcarriers (n=1…..N). SNR is the received Signal to noise power and N_0 is the noise power.

1.4 Implementation Of Subscarrier Allocation Scheme

This section describes the system model of the developed optimisation scheme and as implemented using a simulation package known as MATLAB. 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 1.1) 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.
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 4.69µ or 16.67µs and 1ms time unit sub-frame (see figure 1,

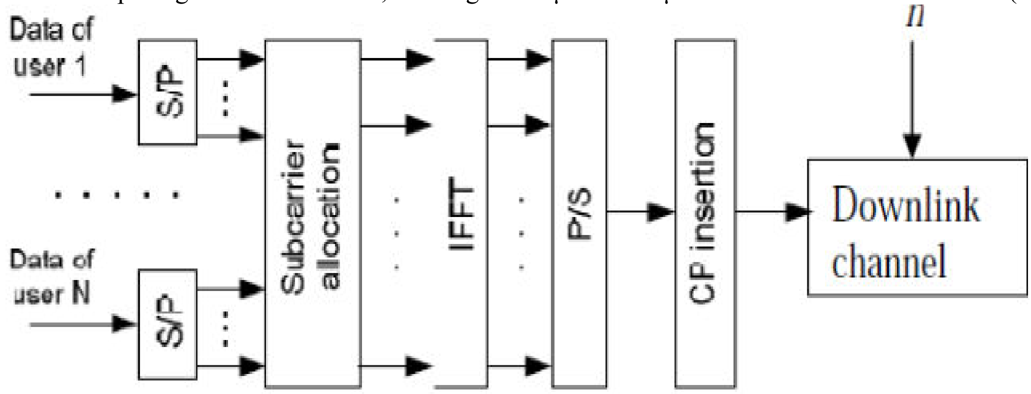

Fig. 1 OFDMA Downlink of 3GPP LTE [24]

The description of OFDMA implementation above 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 B transmits symbols *s(t)* which is passed through OFDM modulator yields OFDM symbols *x* as the output:

$$x = \mathcal{F}^{-1}\{s(t)\} \ldots\ldots 8$$

in the presence of noise n produce the received signal *r* at the receiver before demodulation is

$$r = h \otimes x + n \ldots\ldots 9$$

Demodulating r yields Sn

$$S_n = \mathcal{F}\{r\} \ldots\ldots 10$$

$$S_n = \mathcal{F}\{h \otimes x + n\} = \mathcal{F}\{h \otimes x\} + \mathcal{F}\{n\} \ldots\ldots 11$$

$$S_n = \mathcal{F}\{h\}.\mathcal{F}\{x\} + \mathcal{F}\{n\} \ldots\ldots 12$$

$$S_n = \mathcal{F}\{h\}.s(t) + \mathcal{F}\{n\} \ldots\ldots 13$$

Where Sn are the received OFDMA symbols of n size FFT.

1.5 Result Presentation

Subcarrier Allocation (Capacity)

Since the downlink broadcast channel is characterised with fading, the transmission channel have independent random subchannel . that changes over time [5]. Thus, the capacity of the downlink was estimated from h which is known at the Node B according to the allocated subcarriers per UE as expressed in equation 6. For frequency domain *n* numbers of subcarrier, ***h****n* is the *nth* subcarrier channel (subchannel) gain. Consideration was given to the set of subcarriers allocated to the users using the subchannel vectors **h, ∀h** d_(, h1,h2,h3……. ,hn). Capacity simulation results for 512 subcarriers adaptively allocated to 32 users over 5MHz bandwidth and compared with fixed allocation is shown below in Fig.3.

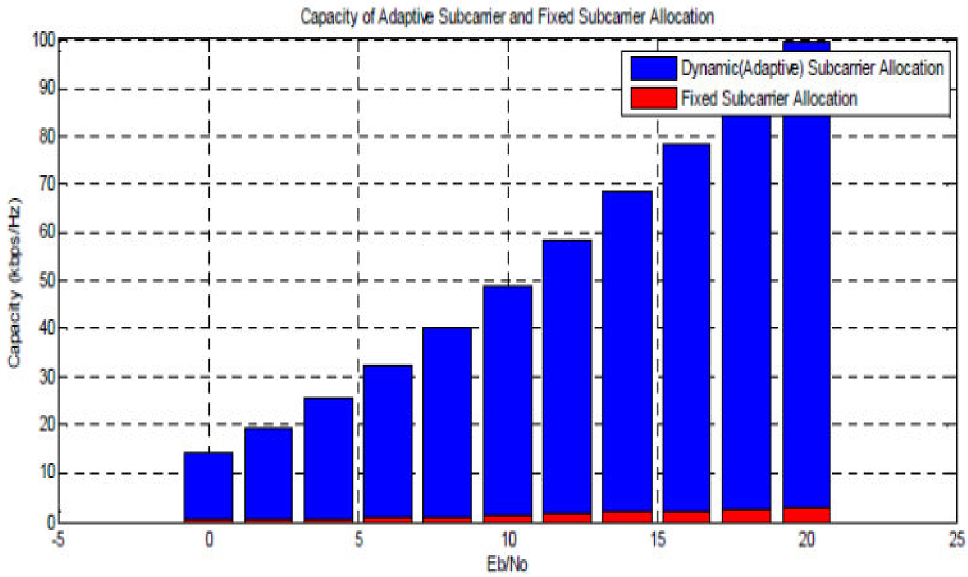

Fig. 3: Grouped Spectral efficiency of Adaptive and Fixed Subcarrier Allocation vs SNR

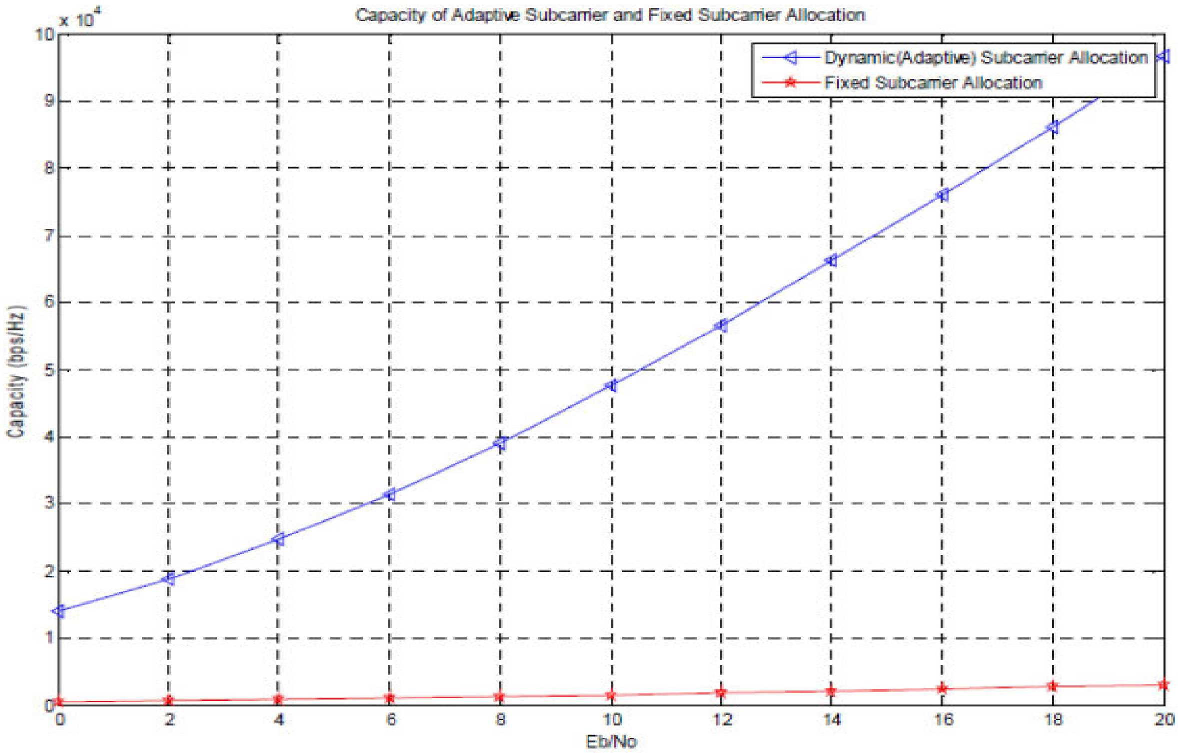

Fig. 4: Grouped Spectral efficiency of Adaptive and Fixed Subcarrier Allocation vs SNR

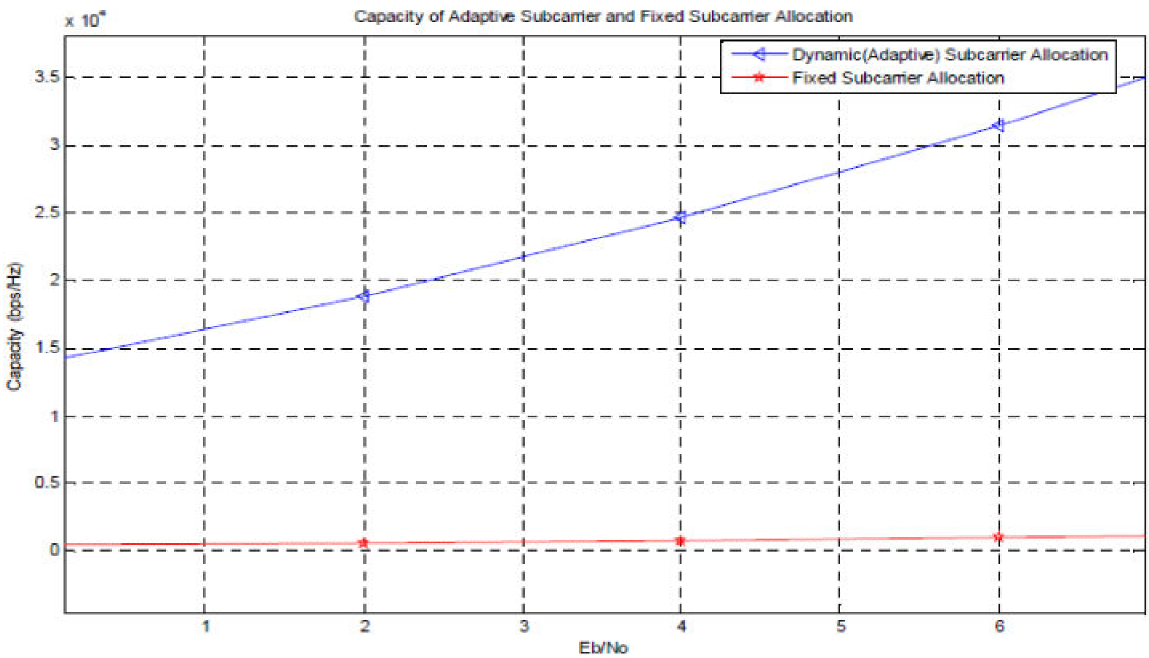

Fig. 5: Zoomed Spectral efficiency of Adaptive and Fixed Subcarrier Allocation vs SNR

RESULT DISCUSSION

Figure 5 shows the stacked spectrum efficiency of adaptive and fixed subcarrier allocation achieved over an average SNR. It can be observed that the average capacity adaptive subcarrier allocation can achieve compared to the fixed allocation over an average transmit signal to noise ratio is very wide. Figure 5.6 shows the spectrum efficiency achieved by Adaptive subcarrier allocation compared to the Fixed subcarrier allocation during a transmission of up to 20dB SNR. It can be observed that the spectral efficiency of adaptive subcarrier allocation increases rapidly with corresponding increase in SNR, while the fixed allocation scheme increases very slowly. Note that capacity is often limited by SNR and bandwidth [5], but the capacity achieved by the adaptive subcarrier scheme increases rapidly with increase in SNR, despite the fading channel performance. This is due to the capability of the Adaptive scheme to exploit multiuser diversity and frequency selectivity gain by allocating more resources to the users with best channel state that can maximise resources in any given fading condition. Also, observer that a very low signal level of 0 dB, it was able to achieve up to 14kbps/Hz while fixed allocation is at 1 kbps/Hz. This is as a result of the frequency scheduling the adaptive allocation scheme exploit to allocate the subcarrier to best UE. In the fixed allocation, most of the subcarriers are either in deep fade due to the low signal level while, the adaptive allocation would have allocated the subcarriers more to the UE with best condition. This is an indication that the adaptive allocation is spectrally efficient and could optimise the limited and available bandwidth than the fixed allocation.

CONCLUSION

The performance of the 3GPP system down link interface air is dependent on the subscriber allocation scheme adopted. It was established that the spectral efficiency of adaptive subcarrier allocation increases rapidly with corresponding increase in SNR. Though, capacity is often limited by SNR and bandwidth, but the capacity achieved by the adaptive subcarrier scheme increases rapidly with increase in SNR, despite the fading channel performance. This is due to the capability of the dynamic scheme to exploit multiuser diversity and frequency selectivity gain in any given fading condition.

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