The evaluation of the impact of Inter-Cell Interference Coordination on the performance of users in an LTE system

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Abstract**—**The Long-Term Evolution (LTE) mobile/wireless standard was introduced with the motivation that it would offer remarkable improvement to the previous communication standard – Evolved High Speed Packet Access (HSPA+). LTE systems, unlike the earlier standards, tend to utilize the available frequency spectrum in each cell of the network and hence promise to offer higher throughput to the users in the network, better system capacity, lower latency and delay, improved spectral efficiency etc.

In order for the standard to effectively meet up with these performance targets, it has to eliminate or minimize the interference on the network. LTE adopts the Orthogonal Frequency Division Multiple Access (OFDMA) method which successfully eliminates the presence of intra-cell interference by enabling the users in each cell to transmit orthogonally. However, the standard still suffers inter-cell interference which could be as a result of two cell-edge users located in two adjacent cells communicating at the same frequency or both causing interference to each other due to the high-power level at which they transmit. This leads to an overall reduction in the system performance in terms of signal to interference and noise ratio (SINR) values, system capacity, users' potential data rates.

This research studies the performance of cell-centre and cell-edge users in a 7-cell LTE cellular network model as simulated on MATLAB 7.11. This research evaluates the performance in terms of SINR, capacity and spectral efficiency of the users in the network with more focus on the users in the cell-edge region. A comparison was made of the performance of the users located in the reference cell in two conditions; when the interference from all the adjacent cells was not managed; and when inter-cell interference coordination (ICIC) was implemented. ICIC implementation was by shutting down one or more interfering cells. The comparison was to show the level of improvement as perceived by the users in the cell with the implementation of ICIC.

The outcome of the study showed improvement in the cell users' quality of experience (QoE) which includes higher SINR values, increased capacity and better spectral efficiency in the network as the number of sources of inter-cell interference reduces.

Keywords**—**Interference, Inter-Cell Interference Coordination (ICIC), Long-Term Evolution (LTE), MATLAB, Orthogonal Frequency Division Multiple Access (OFDMA), Signal to Noise Ratio(SINR).

I. Introduction

As the necessity for mobile broadband increases, improvement on existing mobile communications standards is imperative to provide the data and voice services required by mobile and wireless devices and the evolving data hungry applications.

Interference being the major challenge in LTE systems, has led to significant number of research works in this area of study. Inter-cell Interference (ICI) occurs when users in different neighbouring cells make attempts to use the same radio resource(s) at the same time or users in the neighbouring cells communicate at high power such that their signals act as interference on the users in the other cells [1]. Fig. 1 shows a graphical demonstration of ICI whereby a UE which moves further away from its serving eNodeB A experiences inter-cell interference from an adjacent eNodeB B which possibly allocates the same frequency channel f1 to UEs in its cell. This happens because each of the cells only knows what radio resources its UEs use and hence they independently schedule and allocate the same frequency resource to their UEs.

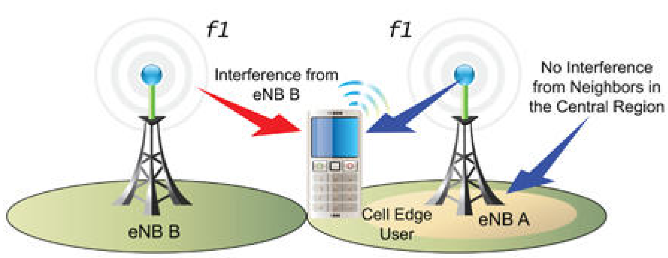

Fig. 1 A demonstration of Inter-cell interference in an LTE system [2]

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II. LITERATURE REVIEW

A. *Interference in LTE systems*

While LTE and later standards succeed in achieving their intended targets or specifications [3] by adopting tools such as the frequency reuse [4] of 1 (that is the use of the same frequency channel in all the cells in the network) and also creating multilayer heterogeneous networks (in which smaller cells are created within the coverage area of macro cells), they also bring about one of the most significant challenges in the mobile and wireless communications industry today– Interference, by increasing the portion of cell-edge users where two or more base stations compete for coverage and can transmit to and receive from the same user equipment (UE) device [2].

The effect of this interference results in a lower Signal to Interference and Noise Ratio (SINR), a degradation of network performance and user experience, and a diminished efficiency of use of network resources. Some of the interference however can be prevented by some careful Radio Frequency (RF) planning, but interference in networks cannot be completely eliminated [5].

In LTE networks, two different kinds of interference could be experienced by users and these are the intra-cell interference and inter-cell interference [6]. These two kinds of interference contribute to the degradation in the SINR experienced by the users in the cellular network. This can be seen in the equation shown below which is derived from a cellular network based on a Fractional Reuse Factor of n (FRF-n).

$$SINR, \quad Y^n = \frac{P_{desired}}{P_{intra-cell} + P_{inter-cell} + \frac{P_{noise}}{n}} \tag{1}$$

Where:
Y^n: Signal to Interference and Noise ratio (SINR)
P_desired: Power of the desired user's signal
P_(intra-cell): Power of the intra-cell interference
P_(inter-cell): Power of the inter-cell interference
P_noise: White noise power
n: Frequency Reuse Factor (FRF)

From equation (1), it can be seen that the SINR experienced by users in a cellular network is limited by the intra-cell interference, inter-cell interference and white noise. [7]

B. *Inter-cell Interference (ICI)*

In a cellular network layout, the cells are tessellated across the network with each cell having a transceiver which consists of either omni-directional or directional antennas covering each cell. This concept of splitting the network into cells brings about the idea of categorising users into cell-edge users (CEUs) and cell-centre users (CCUs) [8]. The CCUs are located well within the coverage of the cell's transceiver while on the other hand; the CEUs are located at a point where two or more cells on the same cellular network overlap or very close to each other.

When two cells overlap, a UE at the cell-edge could be receiving signals from two or more of these contiguous cells and thereby resulting in Inter-cell interference [8]. This kind of interference could also be experienced in a heterogeneous network whereby UEs receive signal from both the macro and small cells within the network [9]. Fig. 2 is an illustration of inter-cell interference when two cells overlap and when it occurs in a heterogeneous network.

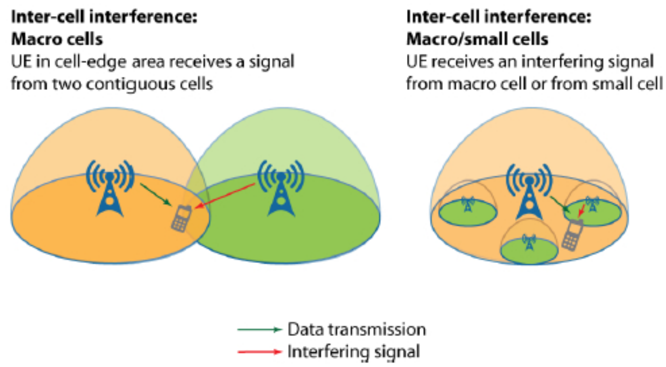

Fig. 2 Inter-cell interference between users in different but adjacent cells. [2]

Since there are limited spectrum resources, most mobile operators deploy in their LTE networks a frequency reuse = 1 configuration. This deployment scheme is known as a Single-Frequency Network (SFN) and it simply means that a single carrier frequency is reused in all cells of the network [10]. SFNs are commonly used in LTE networks to effectively utilize the limited radio spectrum and to also increase the coverage area. However, SFNs by nature are limited by inter-cell interference [10].

III. SPECIFICATION AND DESIGN (METHODOLOGY)

A. *Requirement Phase*

In order to show the impact of inter-cell interference from interfering cells on the users in a particular cell, a simulation model that consists of a seven hexagonal cell sites is considered. Each cell has an eNodeB assumed to be located at the centre of the cell; and each of these eNodeBs is equipped with an omni-directional antenna all transmitting at the same power level. The hexagonal cell layout has been adopted due to its conceptual and computational simplicity to approximate the cells which are irregular and complex in real life as a result of terrain features and artificial structures. The cellular network model is as shown in Fig 3.

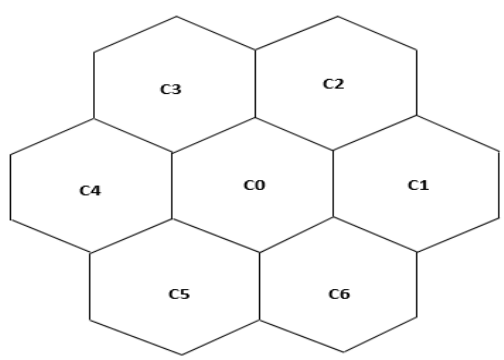

Fig. 3 Hexagonal Cellular Network Layout

The inter cell site distance has been chosen to be 100m and the UEs are randomly located between the eNodeB and the edge of the cell. The cell centre UEs are randomly located at a distance of about 10 – 15m from the eNodeB whereas the cell edge UEs are located at a randomly generated distance of about 80 – 85m from the eNodeB. A reference distance of 10m has been chosen and this forms a basis on which the path-loss gain for each UE is computed.

In this project, a free space signal propagation (which has a path-loss exponent of 2) has been assumed in which the signals tend to travel from the transmitter to the receivers without encountering any obstacles. However the users experience a distance dependent path-loss which impacts on the implementation of this project. The path-loss is defined as the loss in signal strength from the transmitter to the receivers as a result of a line-of-sight (LOS) path through free space. The path-loss gain has been employed in the computation of the received power for each of the receivers by subtracting its value from that of the transmitter power of the eNodeB.

The antennas of both the eNodeB and the UEs are both assumed to be omni-directional and since there is no potential danger of multipath effects in a free space propagation environment, the Single input, Single out, SISO antenna configuration has also been adopted. SISO refers to a wireless communications system in which one antenna is used at the source (transmitter) and one antenna is used at the destination (receiver).

For convenience, the system and simulation parameters used in this project are summarized in Table I;

TABLE I
SYSTEM AND SIMULATION PARAMETERS

PARAMETER	Value
Cellular Layout	Hexagonal
Cell Radius	100m
Path-loss exponent	2 (Free space propagation)
Antenna Configuration	SISO
Reference Distance d0	10m
eNodeB transmit power	1dBi
Noise figure	5e-16
Bandwidth of a RB	1e3
Cellular Layout	Hexagonal
Cell Radius	100m

B. *Chosen Approach and Simulation Scenarios*

The approach of this study shows how significantly the inter-cell interference in a cellular network affects the cell-edge and cell-centre located users in a particular cell. The approach also shows how avoiding or mitigating the inter-cell interference could impact on the performance of the users.

A cellular network may in real life consist of hundreds or even thousands of cells in a particular region of LTE deployment. However, this research considers only a few cells to keep it simple and manageable.

In order to show a good level of variation in the simulation results, different designs and scenarios are developed each of which depicts one of the following;

a) The users' experience when there is only one cell and hence no source of interference in the network.

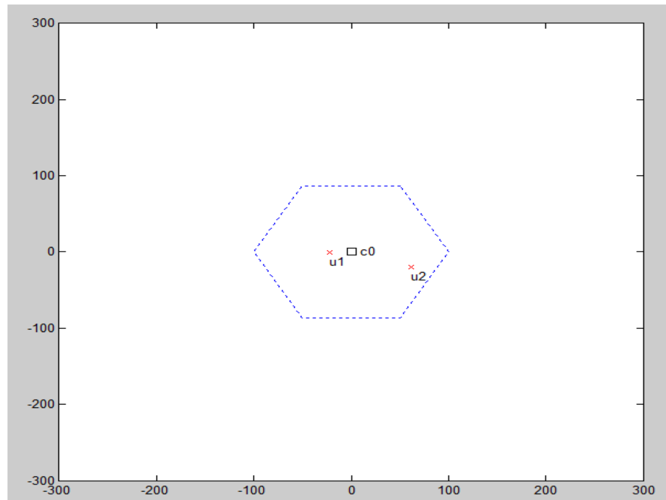

Fig. 4 Two (2) users in a single cell scenario

b) The users' experience when 5 UEs are randomly located in a single cell scenario

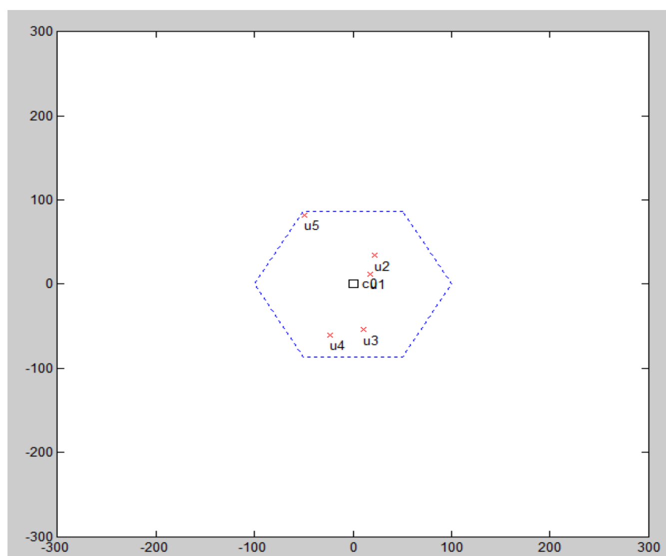

Fig. 5 Five (5) users in a single cell scenario

c) The degradation of the users' performance in (a) when two sources of interference are added to the network. This actually is close to a real-life case than (a) since no cell exists in isolation in practice.

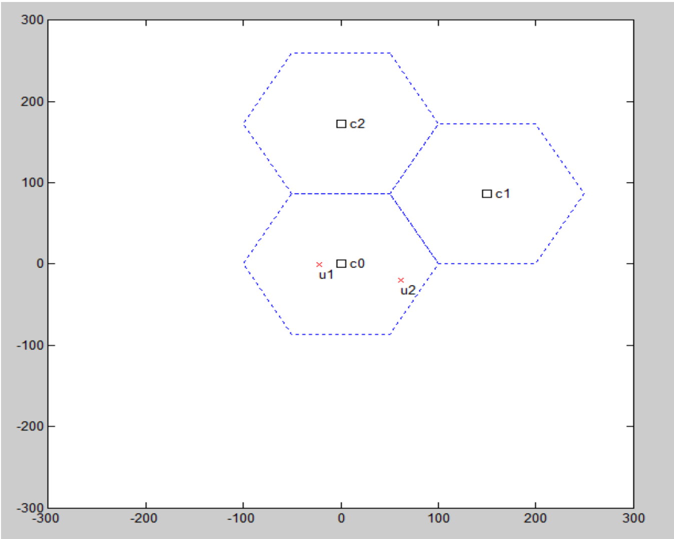

Fig. 6 Two (2) users in a multi-cell (3 cells) scenario

d) More sources of inter-cell interference (ie cells) are added to (b) so as to see how much more degradation in performance the users experience.

e) Finally, more UEs are added to our cell of interest at randomly generated positions between the eNodeB and the edge of the cell. The sources of interference are also increased to 6 cells. The output of this shows a very clear picture of users' performance based on their location in the cell.

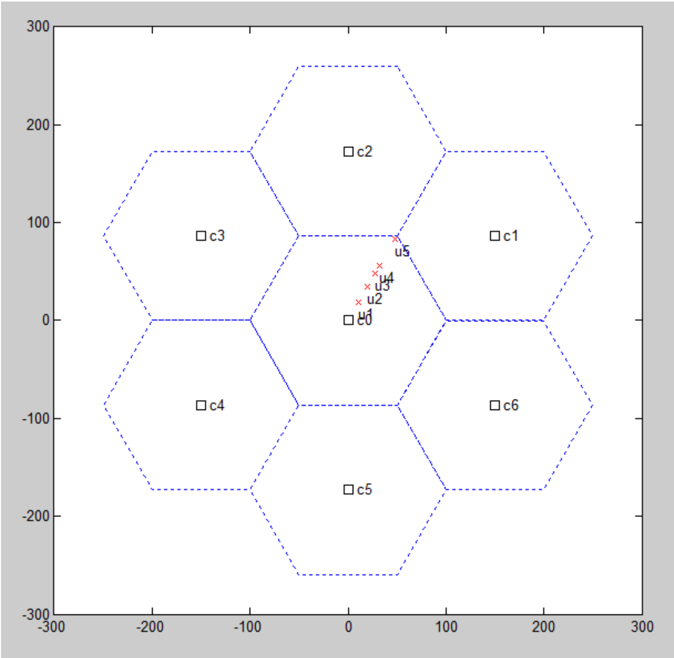

Fig. 7 Five (5) users in one cell of a multi-cell (7 cells) cellular network

IV. DEVELOPMENT AND IMPLEMENTATION

A. *MATLAB algorithm development*

The MATLAB algorithms developed in this study have been built in a modular fashion, with each module being responsible for the execution of a discrete aspect of the desired system functionality which is to study the performance of user equipment (UEs) in the cell-centre and cell edge regions. In this work, the following have been designed and implemented as a section of the algorithm but together they add to the overall success of this study.

a) Distance of the UEs from the eNodeB

In this study, the metrics measurements taken have been done only in the reference cell which is the middle cell in the cluster as defined in the model. The users whose performance metrics are measured have been designed to be located at a randomly generated distance between the eNodeB and the edge of the cell. For the first scenario, the distances of U1 (cell-centre user) and U2 (cell-edge user) from the eNodeB are calculated with the following section of the algorithm;

```
Ranges = sort (d0+(R-d0)*rand(U,1), 'ascend');
```

In this line of code, rand(U,1) generates the random variable which helps generate random positions for the UEs U1 and U2.

For the scenario with more than just the two UEs, the users' positions are also randomly generated using the line of section of the code;

```
Ranges = sort (d0+(R-d0)*rand(U,1), 'ascend');
```

The MATLAB function "sort" and "ascend" have been used to ensure that the smallest random distance is assigned to U1 which has been assumed to be closest to the eNodeB and the largest random distance assigned to U5 which is the supposed farthest UE from the eNodeB.

b) Angular position of UEs in the cell

While the UEs used in this simulation are distributed at random distances between the eNodeB and the edge of the cell, these UEs are also located at an angle from the eNodeB. Their angular positions however do not affect the signal transmission/reception since the antennas are omni-directional. The users' angular positions have been randomly generated with the following lines of codes;

```
Angles = 2*pi*rand(U,1); For the scenario with just 2 users

Angles = pi/3; For the scenario with more than 2 users
```

Combining the UEs' distances from the eNodeB and their angular position, their actual positions in the cell have been defined with the following line of code;

```
uPos = [Ranges.*cos(Angles),Ranges.*sin(Angles)];
```

c) Path-loss gain of the UEs

The path loss includes all the lossy effects associated with the signal propagation distance between a transmitter and a receiver. It is basically the reduction in power density of an electromagnetic wave from a line-of-sight (LOS) path as it propagates through free space. It does not include any loss associated with hardware imperfections and it assumes that the antenna gain is 1.0 or 0 dBi. In this work, the path loss gain for UEs in the cell has been computed using the following line of MATLAB code;

```
PL = @(d) 128.1+10.*n.*log10(d/d0);
```

Where
n = path-loss exponent for free space propagation.
d = the distance of the UE from the transmitting antenna
d0 = the reference distance
128.1 = a constant known as the path-loss constant

d) UEs' receive power

The receive power is the signal strength of the transmitted electromagnetic waves as measured at the receiver's antenna. It is equal to the transmitting antenna's output power minus the path loss (attenuation) as the signal propagates from the transmitter to the receiver. In short, RX input power (dBm) = TX output power – path-loss gain (field attenuation). This is executed for each UE's antenna using the MATLAB line of code;

```
uRxPow = P0.*10.^(-0.1*uPL);
```

e) SINR for each UE

The Signal to Interference and Noise Ratio (SINR) is a quantity used to give theoretical upper bounds on the rate of information transfer (channel capacity) in wireless communications networks. SINR is simply defined as the power of a certain signal of interest divided by the sum of the interference power from all other interfering signals and the power of the background/thermal noise. For the UEs, their SINR has been computed using the MATLAB code;

```
uSINR(:,i+1) = uRxPow(:,1) ./ (N0B + IPow);
```

The numerator on the RHS of the equality sign computes the power of the signal of interest (signal from the central cell's eNodeB); the denominator on the other hand sums up the power of the signals from the interfering cells and the system noise.

f) Channel Capacity for each UE

The channel capacity is the tightest upper bound on the rate of information that can be reliably transmitted over a wireless communications channel. The channel capacity is given in bits per second and has been calculated in this research in accordance with the Shannon-Hartley theorem using the MATLAB code;

```
uCap = B*log2(1+uSINR);
```

uSINR is the signal to interference and noise ratio as derived for each user above and B is the bandwidth of the channel in Hertz.

g) Spectral efficiency for each UE

Spectral efficiency refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. The spectral efficiency for each of the UEs is a function of their SINR and it has been implemented on MATLAB as follows;

```
uSpec = log2(1+uSINR);
```

The MATLAB algorithm showing how all the above components and other bits were merged to implement this design in this project is as shown in appendix A.

V. RESULT, DISCUSSION AND ANALYSIS

The users' performance has been measured using the metrics Signal to Interference (and Noise) Ratio (SNR/SINR), Capacity and Spectral Efficiency. These measurements have been taken only for users in the central cell which is this research point of focus.

A. The simulation scenarios and the results

The scenarios chosen to implement this project are presented here starting from the simplest one which is of a single cell and a 2 UEs. The size of the scenarios is increased in each step so as to present a view of the network performance when more users and cells are added to the network.

These scenarios, their results and discussions are as follows;

a) Single cell with 2 UEs at different positions

In this scenario, a single cell was modelled which has only two UEs, one located within the cell-centre distance range of the cell and the other located at a cell-edge distance range of the cell. Being the only cell in the network, it is assumed that there is no inter-cell interference coming from other cells and therefore the two UEs user experience are measured based on their position only. The results obtained in this scenario are as follows;

TABLE II
PERFORMANCE OF 2 USERS IN A SINGLE CELL CELLULAR NETWORK

	SNR (dB)	Capacity (b/s)	Spectral Efficiency (b/s/Hz)
UE1 (cell-centre)	66.28225	6072.154	4.208897
UE2 (cell-edge)	7.460729	3080.782	2.135435

From Table II, the two users UE1 and UE2 based on their distance from the eNodeB and hence path-loss gains, have different SNR, capacity and spectral efficiency. This shows that the distance of users from the centre of the cell is a determinant of their performance.

b) Single Cell with 5 UEs at different positions

In this scenario just like in the previous one, only one cell exists in the network but this time the number of users have been increased to 5 and each are place at random distances from the eNodeB. On implementation of this, the following results in Table III were obtained

TABLE III
PERFORMANCE OF 5 USERS IN A SINGLE CELL CELLULAR NETWORK

	SNR (dB)	Capacity (b/s)	Spectral Efficiency (b/s/Hz)
UE1(closest to eNodeB)	66.28225	6072.154	4.208897
UE2	19.06931	4326.919	2.999192
UE3	10.10888	3473.642	2.407745
UE4	7.460729	3080.782	2.135435
UE5 (closest to cell-edge)	3.393509	2135.374	1.480128

As shown in Table III, the UEs experience some level of degradation as their distances from the eNodeB (cell-centre) increases. This is clearly shown in the performances of UE1 and UE5 in which UE1 being the closest to the eNodeB has SINR, capacity and spectral efficiency values of approximately 66dB, 6072b/s and 4b/s/Hz respectively whereas UE5 which is the farthest from the eNodeB has SINR, capacity and spectral efficiency values of approximately 3dB, 2135b/s and 1b/s/Hz respectively.

c) Single cell with 2 UEs + 2 interfering cells

In this scenario, two cells which would be sources of inter-cell interference are added to the cellular network in scenario i. The two users are as usual placed randomly in the first cell with UE1 at the cell-centre region and UE2 at the cell edge region. On implementation, the result showing the performance of the UEs with respect to the number of interferers is as shown as follows in Table IV.

TABLE IV
PERFORMANCE OF 2 USERS IN A MULTI CELL (3 CELLS) CELLULAR NETWORK

	No of Interferer(s)	SNR (dB) (b/s)	Capacity	Spectral Efficiency (b/s/Hz)
UE1	0	66.28225	6072.154	4.208897
UE2	0	7.460729	3080.782	2.135435
UE1	1	36.09733	5213.244	3.613545
UE2	1	2.851968	1945.596	1.348584
UE1	2	23.28352	4601.906	3.189798
UE2	2	2.212733	1683.801	1.167122

d) Single cell with 5 UEs in cell C0 + 6 interfering cells

In this scenario, 4 more sources of inter-ell interference are introduced by adding 4 cells adjacent to cell c0. 3 more UEs are also placed in cell c0, making it a total of 5 UEs and all are placed at random distances from the eNodeB with UE1 being closest to the eNodeB and UE5 the farthest. The UEs are located on the same plane at an angle of pi/3 (180o/3) from the eNodeB, this has been done so that all the UEs are given a fair ground for the evaluation of their performances.

Graphically, the SINR of the 5 UEs in the scenario above changes with the distance of the UE from the eNodeB and the number of sources of inter-cell interference as shown in Fig. 8 below.

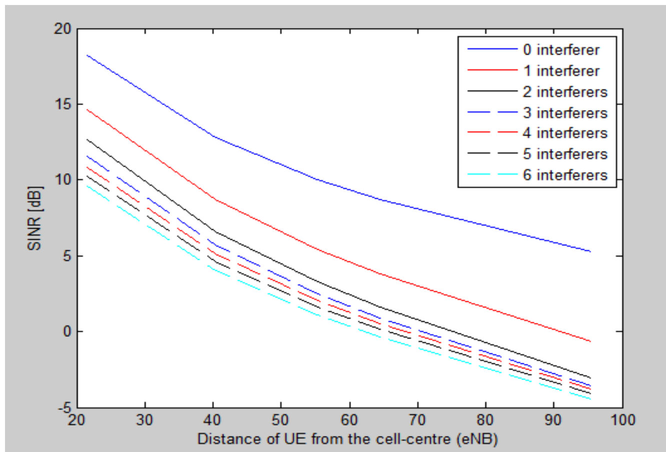

Fig. 8 The UEs' SINR values as influenced by their distance from the eNodeB and the number of interferers in the network.

From the Fig. 8, it can be clearly seen that the SINR values of the UEs suffers degradation as the number of sources of inter-cell interference increases. The long tail of the SINR distribution tends to the negative for users at a significantly long distance form the eNodeB and the tails tend even more to the negative when there are interferers in the network. This is noticed from the fact that the UEs have better SINR when there is no interferers in the network and then the values start dropping when the first interferer in introduced and continues almost at the same rate for each new source of interference added to the network. From the figure, it is also clear that the UE closest to the cell-centre (eNodeB) has better SINR values each time the number of interferers is increased than the UEs farther away from the eNodeB.

Fig. 9 is a graphical representation of how the spectral efficiency values of the UEs change with any change in their distance from the eNodeB and the number of sources of interferers.

The spectral efficiency which is in direct proportion to the SINR tends to exhibit the same behaviour as the SINR values of the UEs. As the distance between the UEs and the eNodeB increases, the spectral efficiency of the UEs drops at almost the same rate with the worst value observed in the UE farthest away from the eNodeB or closest to the cell edge. Similarly, the spectral efficiency of the users is best for each user when there is 0 interferer (as represented with a thick blue curve in the Fig.

9) in the network, but these values keep decreasing for each UE as the number of sources of interference increase.

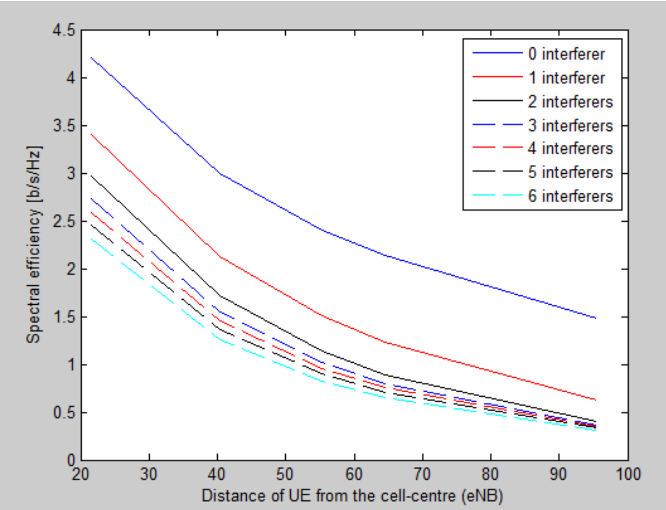

Fig. 9 The change in the spectral efficiency values of the UEs as their distance from the eNodeB changes and the number of interferers increase.

The results in this simulation have been obtained from the users in the reference cell – which is surrounded by other cells in a 1-cell, 3-cell and 7-cell cellular networks as implemented in this work. The results were obtained from an LTE system which uses a frequency reuse of N =1 whereby every cell is an interferer. The results explain the “Pilot Pollution” or “no dominant server” problem which describes a situation where power transmitted from many different cells appears in a location and none happens to be significantly better than the others. The UEs treat the best received power from one cell as “signal” and then power from other cells are treated as interference. For the cell-edge UEs therefore the composite signal is high but there is a very poor SINR from any single cell because the amount of the total signal treated as interference is too high.

B. Impact of shadowing effect on the performance of the users

In the course of propagation, a radio wave does not only attenuate through distance as is noticed in the case of path loss, but it does attenuate also through some physical phenomena such as scattering, reflection etc. depending on the type of environment observed. In this work, assumption has been made of a free space propagation which implies that there is a clear line of sight with no obstacles between the transmitter and the receivers. Aside the path loss attenuation, another propagation loss which could impact this project is shadowing – which is an effect of obstruction in the wave propagation. If shadowing had been considered in this work, the effect would lead to the fluctuation of the SINR values of the UEs as depicted in the Fig 10 below.

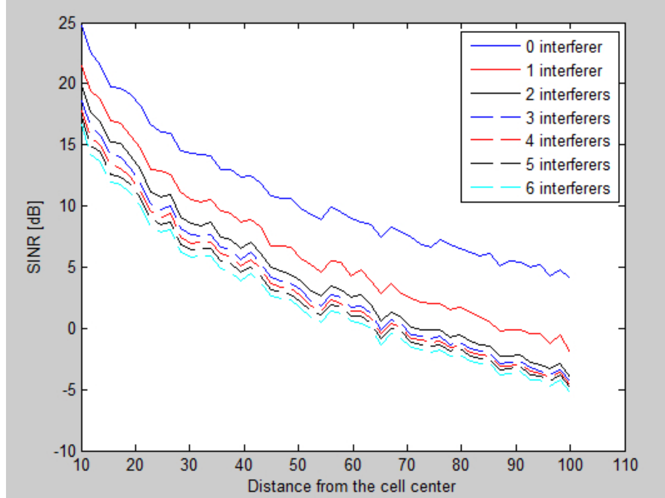

Fig. 10 Shadowing effect on the performance of the users with respect to their distances

C. LTE system performance in this model as perceived by the end-users and the system operators.

The network operators and the users both see the network differently depending on what roles/services each stands to play/receive. The system operators seek to provide efficient service to the users while at the same time keeping the system running. The users on the other hand look forward to receiving a certain level of quality of experience from the network.

a) The potential network capacity of this model

The network model in this project considered a maximum of 5 users randomly placed in the cell but in a real-life network, there is bound to be much more users in one cell at a time. Therefore, for this reason, attempt is made in this section of this work to find out how much UEs can exist in the cell as observed in this model.

In an attempt to achieve this, an assumption is made of the threshold SINR of 7dB with which the cell-edge UEs are distinguished from the cell-centre UEs. Assumption is also made of a threshold SINR value of 1dB below which the user is taken to have a zero performance in the network. When more UEs, precisely 100 are randomly added to the cell in the cellular network, it is noticed that about 25 of the UEs fall in the cell-centre region and the rest fall in the cell-edge region. And out of the 75 UEs in the cell-edge region, only about 45 show a good level of user performance by having SINR values greater than the SINR threshold which is 1dB. These measurements are taken from the reference cell when all the interferers are enabled. When the number of interferers is reduced, a drastic rise in the performance of the users is noticed. It should also be noted that there is also an increase in the number of users allocated to the cell-centre region as the number of interfering cells increase.

We can therefore conclude tentatively that given the assumption of the SINR values made in this model, the number of UEs likely to have a quality performance in the network when all the adjacent sources of interference are turned on would be within the range of 60-80 UEs.

b) The users’ potential data rates

This is a major factor to be considered in a communications network particularly from the users' perspective. From Table III where 5 users are considered in a multi-cell network, it is noticed that the users' performance is better when the interference is coordinated (that is when at least one interferer is shut down). With more users on the network, there is bound to be better performance for the users classified as cell-centre users. The UE classification therefore plays an important role in the performance of the system since more users (those at the cell-centre) are able to have a good level of quality of experience.

The SINR threshold configured and which is a criterion for the classification of the users in the cell is very sensitive to the performance of the network. If the SINR threshold is reduced from the assumed 7dB in the previous section to say 5dB, more users would fall in the cell-centre region and the more cell-edge users would also have better throughput. When this SINR threshold is configured, the data rates of the users in this model fall within the range 2 – 8Mbps and 0.8 – 4Mbps for the cell-centre and cell-edge users. This depends however on the level of interference on the cell and the exact position of the UE. These are practical data rates observed for the LTE system in this scale of the model and it is as expected quite lower than what LTE theoretically offers because some factors such as interference, fading (path loss, shadowing), signaling, terrain etc has not been put into consideration when coming up with the theoretical values.

The fluctuations in the SINR values (performance in general) of the users are as a result of Pilot Pollution whereby there are adjacent cells and all are transmitting at about the same level of signal power. The UEs in the reference cell see all the signals all at once and each signal acting as interferer to each other.
To solve this problem, engineers tend to make attempts to eliminate the unwanted or interfering signals, by setting power parameters or physical adjustments (tilt, azimuth) so as to make only the dominant signals visible to the UEs.

D. CRITICAL EVALUATION.

In this research, the focus has been on the performance of cell-edge and cell-centre located users in an LTE system based on the impact of the inevitable inter-cell interference in the system. With the results obtained from the study, it has been shown how the SINR, spectral efficiency and potential capacity of the users at each location change with their distances from the eNodeB and the number of sources of inter-cell interference in the system.

This research has shown comparatively similar results when compared with previous research works in this area. Similar to the work by Islam and Chowdry (2013), the performance of the users in this work was observed to degrade with an increase in the amount of interference from neighbouring cells. There is even further performance degradation for users farther away from their serving eNodeB due to a further reduction in the SINR.

This research shows as results the values of SINR, spectral efficiency and capacity which show the relationship between the performances of the users to their position in the cell. Even with the above results, there is no apt explanation of the users' performance based on the metrics such as Bit Error Rate (BER), delay, jitter and latency which are important in the quantitative measurements of Quality of Service (QoS) in a cellular network. These metrics were not retrieved in this work as there was no initiation of traffic flow, protocol definition and/or channel allocation for the users as modelled in this project.

The values of the SINR, spectral efficiency and capacity of the UEs' tend to show us a trend observed in LTE systems for users randomly located in a cell that is affected by inter-cell interference. These results might not be perfect to be relied on because in a large scale deployment of the system, the experience of the cell-edge users could be worse off owing to the irregularities from the real-life cellular networks. These irregularities could also result in better values of SINR, spectral efficiency and capacity for users in some regions and poor values for users in some other regions within the same cell.
Lastly, though not considered in this research, the result of this study could also have been influenced heavily by the difference in the antenna heights of the transmitters (eNodeBs) and receivers (UEs).

VI. CONCLUSION

This research focuses on the evaluation of the performance of both the cell-edge and cell-centre users in an LTE network relative to the impact of inter-cell interference from the neighbouring cells. This research successfully implemented an LTE cellular network model in which the neighbouring cells in the defined cluster act as sources of inter-cell interference to the users in the reference (centre) cell of the model. The results also have shown how much impediment the interference from other users in other cells could cause on the performance of users in an LTE system.

In conclusion this research was able to answer the following questions;

- How much impact does inter-cell interference have on the users based on their locations in the cell of the LTE network?

The users as used in the model were observed to react negatively to the impact of the interference with a reduction in the values of the performance metrics as measured in the reference cell. The effect of the interference was felt more by the UEs located close to the edge of the cell as compared to the UEs in the cell-centre region whose performance were somewhat better and acceptable within the LTE requirements.

- Does an ICIC LTE network perform any better than an LTE system in which ICIC is not implemented?

As depicted by the results of the simulations, the isolated cell in which there was no effect of inter-cell interference showed a remarkable level of quality of experience in the measurements taken. This scenario which represents a case where ICIC is wholly implemented, successfully showed how much better the users perform when ICIC is implemented as compared to when it is not.

- What is the impact of the inter-cell interference on system capacity of the LTE system modelled in this work?

This work has also shown that in LTE systems, the system capacity which is defined as the number of users the system can service, is inversely proportional to the level of inter-cell interference experienced in the system. This however depends on the SINR threshold value which determines what level of performance is acceptable in the system. With a choice of low SINR threshold, more users tend to show good performance in the network. The number of sources of inter-cell interference also impacts the system capacity as it was seen that with an increase in the number of interferers, the system capacity (number of UEs with acceptable performance) increases.

In this research, the strategies employed in inter-cell interference avoidance were also studied and the pros and cons of each technique were highlighted.

ACKNOWLEDGEMENT

The authors wish to appreciate the members of the telecommunication group at the University of Salford. We are also grateful to our friends and family for their support.

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