Performance evaluation of LTE and UMTS cellular networks in Iraq with multiple terrains

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Abstract. Cellular network planning is an essential stage that precedes implementation phase. The planning performance is widely dependent on the terrestrial features of the environment where a network is planned to be implemented in. This work involves the cellular planning of three networks applied in two cities, namely Baghdad and Shaqlawa, with different terrains. Two networks are planned in a flat terrain (Baghdad city) using universal mobile telecommunications system (UMTS) and long term evolution (LTE) technologies and one network is designed in a hilly terrain (Shaqlawa city) utilizing UMTS technology. In this study, several calculation themes are applied to evaluate the performance of the proposed planning such as coverage, power level, carrier to interference ratio, best server and elevation calculations. Also, some clients and points are positioned across networks to measure power levels, interference and coverage at different locations more precisely. The measurements show that the UMTS networks cover an area of 63.62 km² compared with 81 km² coverage area in the LTE network with different quality of service graduating from quadrature amplitude modulation (QAM16) and quadrature phase shift keying (QPSK) to voice services. In addition, comparisons between the networks are discussed and enhancement suggestions are presented in this paper.

1. Introduction
Wireless mobile communications have broadly spread worldwide for the period of the last two decades. It has progressed from being luxuriously utilized by some individuals to become ubiquitous technology used by most of people nowadays [1]. Although the 4th generation (4G) and 5th generation (5G) are widespread currently, the 3rd generation (3G) universal mobile telecommunications system (UMTS) is still widely operating in many countries [2]. The usage of wideband code division multiple access (WCDMA) and orthogonal frequency division multiple access (OFDMA) in UMTS and LTE networks respectively has enabled enhancements in spectral efficiency on radio links, capacity of systems and data rates [3]. On the other hand, wireless mobile networks are still facing essential challenges such as pathloss, shadowing and multipath. These factors have directly effects on the transmitted power (Pt) and received power (Pr) and they have to be taken into account when doing cellular planning. Figure 1 shows the how the Pr to Pt ratio is being degraded as the channel distance extends [4]. A channel with free space line of sight is represented in figure 1 as a thick-dashed line which declines steadily. However, when considering lognormal shadowing in wireless channel, the thin-dashed line varies unsteadily to indicate a change in loss. Furthermore, the addition of multipath effect to the channel would result in fluctuations as the solid line depicts in figure 1.
In order to estimate the total pathloss existent in a wireless channel between transmitter and receiver, many propagation models, either deterministic or empirical, can be applied in different terrains [5]. In this study, Erceg propagation model [6] is implemented to approximate the pathloss among base stations (sites) in the proposed networks using WiMAP-4G planning tool [7]. The Erceg model is employed when doing calculations and measurements since it allows to differentiate between various types of environments with diverse terrestrial features such as hills, mountains and tree density. The Erceg Type C model is used to plan UMTS and LTE networks in a flat terrain and light tree density in Baghdad city. On the other hand, a UMTS network with a hilly terrain and moderate tree density requires employing Erceg Type B model planned in Shaqlawa city in this paper. The three designs in this work have been planned with appropriate sites locations and pre-defined number of sites, heights of sites and antennae heights and transmitting power per site. Furthermore, the performance of the proposed cellular designs is evaluated using several calculations themes.

The organization of this paper is as follows. Section II presents the design of a flat-terrain UMTS network to explore the performance of such proposal. In the next section, another network is proposed with the same terrestrial features of the first design but now applied with LTE technology. Section IV describes the cellular design and measurements of a UMTS network planned in a hilly terrain. Later on, the main distinct differences of all designs are summarized in Section V along with discussing results. Section VI states the conclusions and suggests some possible enhancements.

2. UMTS cellular network design in flat terrain
The first scenario is to make a cellular plan with UMTS technology applied in Baghdad city as a sample of a flat terrain with light-tree density. The parameters of this design are as depicted in table 1. The complete geographic planning layout is shown in figure 2.

![Figure 1. Pathloss, multipath and shadow [4].](image)

| Parameter                | Value       |
|--------------------------|-------------|
| Network radius           | 4.5 km      |
| Number of sites          | 12          |
| Max. TX power in average | 95 W per site |
| Antenna height above ground | 45 m   |
| Frequency bands          | 1920 – 2170 MHz |
| Propagation model        | Erceg Type C |
The network shown in figure 2 consists of sites, antennae, clients and points placed reasonably to serve a coverage area of 63.62 km$^2$. The sites behave as base stations (BSs) which include 2-4 antennae depending on the coverage requirements. On the other hand, the placement of points and clients is necessary for measurements in terms of power levels and interference.

The propagation model that has been chosen to do the field strength measurements is Erceg Type C which is more suitable for Baghdad environment that is with light-tree density and flat terrain. To test the network cellular design, different calculations have been applied. Starting with coverage calculation that is tested at a height of 2 meters above ground level to simulate users as shown in figure 3. The coverage is displayed according to modulation/demodulation technique such that the nearer to the site served better. For example, QAM16 with 3/4 forward error correction (blue region) would provide higher data rate but the coverage will be limited. Also, as getting distant away from the site, the service is restricted to voice only.

In addition to checking the field strength of the network, examining the power levels served in the network is crucial when it comes to RF planning. Figure 3 shows the distribution of the signal power at 2 meters above the ground level. Five points have been spread across the network to test power levels at different places as shown in table 2. The power level at point (a) records as -98 dBm which is almost the same as its sensitivity, and hence it relatively does not receive signal. Furthermore, point (b) and point (d) receive limited signal powers at -85.8 and -80.8 dBm respectively. They are acceptable but not as good as those recorded by point (c) and point (e) at -77.7 and -62.7 dBm respectively. The best signal power is served to point (e) because of its location closest to the antennae of site (1).
Figure 4. Power calculation at 2m of flat-terrain UMTS network.

Table 2. Point power calculations of first design.

| Point name | Power (dBm) |
|------------|-------------|
| a          | -98.0       |
| b          | -85.8       |
| c          | -77.7       |
| d          | -80.8       |
| e          | -62.7       |

Another power level calculation has been applied at 20 meters above ground level, as depicted in figure 5, to study the case of serving users in buildings or communicating with other base stations at that height. As can be seen in figure 5 that power levels are extremely higher at 20m than those at 2m in figure 4 since the Fresnel zone is wider and obstacles and interference are less at higher heights.

Figure 5. Power calculation at 20m of flat-terrain UMTS network.

Even though extracting power level and coverage of a certain position directly from the map is possible, it is more precise and exact to do client calculations placed on real positions. Each client is associated with site to be served by. Several clients have been located on the network in order to measure coverage, received power and interference level as shown in table 3. The best received power at minimum interference level is achieved at client (c2) as -50.6 dB whereas client (c7) receives the weakest power level of -77.4 dB at carrier to interference ration of 10.9 dB. Moreover, although they are both related to site (5), client (c5/30) measures coverage, received power and interference better than those calculated by client (c5/10). That is because client (c5/30) has antenna height of 30m compared with that of client (c5/10) at 10m. Hence, increasing client height leads to improving QoS as the path loss is reduced.

Table 3. Client calculations of first design.

| Client Name | Coverage (dB) | Rx Power | C/I (dB) |
|-------------|---------------|----------|----------|
|             |               |          |          |
As can be seen in figure 5, client (c5-10) and client (c5-30) are associated with site (5) in spite of being positioned among site (9) and site (12). Hence, it might be one option to optimize those clients’ received power is to associate them with other sites (servers). By looking at the figure 6, it can be easily indicated which best site to connect each client to. In consequence, associating client (c5/10) and client (c5/30) to site (9) and site (12) respectively seems an effective optimization option in terms of received power and interference levels. The complete layout of interference of the network planning is shown in figure 7 in which the carrier of interference ratio is kept at better than 20 dB for the most of target design area.

|   | QAM16-3/4 | 50.6  | 51.33 |
|---|-----------|-------|-------|
| c2 | QAM16-3/4 | -50.6 | 51.33 |
| c3 | QAM16-3/4 | -55.43| 37.75 |
| c5/10 | QAM16-1/2 | -72.62| 9.81  |
| c5/30 | QAM16-3/4 | -63.20| 20.11 |
| c7 | QPSK-1/2  | -77.40| 10.90 |

3. LTE cellular network design in flat terrain

The second RF planning is to design a cellular network applied in the same terrestrial environment, i.e. Baghdad city, but with implementing LTE technology. The design parameters and the planning layout are presented in table 4 and figure 8 respectively. Traffic load has been taken into account when
planning the network in terms of base stations placement. For example, figure 8 shows the site (1) is located at area with less traffic load expected whereas the sites (4), (5) and (10) are positioned across a region with higher people density so that the sites can handle better capacity performance.

**Table 4.** Parameters of second design.

| Parameter                          | Value            |
|------------------------------------|------------------|
| Network radius                     | 4.5 km           |
| Number of sites                    | 11               |
| Max. TX Power in average           | 65 W per site    |
| Antenna height above ground        | 40 m             |
| Frequency bands                    | 2500 – 2690 MHz  |
| Propagation model                  | Erceg Type C     |

![Figure 8. Flat-terrain LTE network planning layout.](image)

The coverage of this network is planned to serve an area of 81 km². Moreover, the LTE design with is implemented with fewer number of sites, lower antenna height and less site transmit power than the UMTS design at 11, 40 meters and 40 watts respectively. That minimization in resources does not degrade the field strength (coverage) calculation as shown in figure 9. Also, it is explicitly noticeable from the figure that applying LTE in antennae has increased their directivity to provide an Excellent coverage (blue regions) for the areas closed to sites then a Good coverage (green regions) extend to further and wider zones across the network.
Similarly, the calculation of power levels provided in the network is shown in figure 10 in which the average power level of -70 dBm is presented at the zones beside the sites shaped to some extend of the antennas' directivity. For the purpose of recording the power more precisely, five points have been placed across the network to indicate the levels as in table 5. The point (b) senses the highest power level at -66.3 dBm since it is positioned close to site (9). On the other hand, the points (a) and (c) record the weakest powers at -93.7 and -86.3 dBm respectively as their locations are relatively distant from sites.

Table 5. Point power calculations of second design.

| Point name | Power (dBm) |
|------------|-------------|
| a          | -93.7       |
| b          | -66.3       |
| c          | -86.3       |
| d          | -82.0       |
| e          | -81.7       |

In order to calculations of coverage, received power and interference level at some real specific positions, some clients have been located on the network to reveal the values as exposed in table 6. The most potential location is where client (c25) positioned whose received power level and C/I hit the peak at -52.9 dB and 100 dB respectively along with an Excellent coverage. That is as an explicit result of associating that client with the nearest right-side antenna of site (3). In contrast, client (c10) receives the weakest power level of -81.9 dB but with a Good coverage.

Table 6. Client calculations of second design.
| Client Name | Coverage | Rx Power (dB) | C/I (dB) |
|------------|----------|---------------|---------|
| c10        | Good     | -81.9         | 27.7    |
| c15        | Excellent| -79.4         | 100     |
| c20        | Excellent| -75.8         | 26.7    |
| c25        | Excellent| -52.9         | 100     |
| c30        | Excellent| -71.6         | 35.2    |

The best signal offered to a specific zone by each particular antenna can be illustrated in figure 11. In some cases, the best service is unnecessarily offered to customer by the nearest antenna. For example, client (c15) served with an Excellent coverage and minimized level of interference in spite of being associated to site (5) which is apparently located farther in distance than site (1). Furthermore, figure 12 shows the received power of the modulated carrier in average to the power of co-channel interference (C/I) of the entire LTE network. Although, there are some spots shown in the figure with a high interference levels (yellow parts) between adjacent channel bands, the majority of network is served at a relatively acceptable level of C/I at better than 20 dB as shown in figure 12 (dark green areas).

**Figure 11.** Best server calculations of flat-terrain LTE network.

**Figure 12.** Carrier-to-interference calculations of flat-terrain LTE network.
4. UMTS cellular network design in hilly terrain

After presenting RF planning for a flat environment in the preceding two designs, it is important to explore another region with different terrestrial features. In this section, a third cellular planning of UMTS network is presented for a hilly terrain applied in Shaqlawa city in Iraq. The design parameters and the planning layout are presented in table 7. Since this chosen city is hilly with tree density, the Erceg Type B is implemented for the third design. Also, antenna height of sites is increased to be 60m above the ground in order to offer a better coverage in areas between hills and some valleys.

Table 7. Parameters of third design.

| Parameter                          | Value   |
|------------------------------------|---------|
| Network radius                     | 4.5 km  |
| Number of sites                    | 12      |
| Max. TX Power in average           | 100 W per site |
| Antenna height above ground        | 60 m    |
| Frequency bands                    | 1920 – 2170 MHz |
| Propagation model                  | Erceg Type B |

Unlike the first two flat-terrain designs presented earlier, the preliminary step to decide the sites placements is to do elevation calculation as shown in figure 13. This essential measurement reveals the peaks of terrains (bright white spots) are 1116m high to gradual lower heights (grey regions) at 489m. Moreover, the terrain profiler in figure 13 indicates a deeper view of terrestrial features of the selected area of design. For example, site (3) is placed at a geographical spot that is 750m high where there is a mountain of 900m high located at 920m far as going up. This scenario explicitly causes blockage by the mountain as can be seen from the Fresnel zone and pathloss showed at the terrain profiler in figure 13. To tackle this problematic issue, one possible suggestion is locating site (3) at the mountain peak or at another reasonable position with increasing antenna height.

Figure 13. Elevation calculations of hilly-terrain UMTS network.
The preceding elevation calculation has helped in terms of deciding where to place sites and their antenna azimuth and number. The design layout is shown in figure 14. There are 12 sites (each with 1 to 3 antennae) proposed to serve a coverage area of 63.62 km² (radius of 4.5 m). Each antenna is set to 60m high above the ground level with 60° downtilt to offer better quality of service.

![Figure 14. Hilly-terrain UMTS network planning layout.](image)

Terrain profilers among three sites are shown as samples in figure 15 to study the environment more deeply and estimate coverage. Figure 15a illustrates the elevation path starting from site (2) to site (4) whereas the path from site (2) ending to site (3) is depicted in figure 15b. The highest peak of antenna placement is that of site (3) at 1020m which is the sum of 960m and 60m as the ground level height and antenna height. That offers better line of sight, LOS, (Fresnel zone at figure 15b) between site (2) and site (3) compared with non-line of sight, NLOS, (Fresnel zone at figure 15a) caused by the mountain blockage between site (2) and site (4). In addition, site (2) is far away from site (4) by 3500m that clearly indicates higher pathloss levels estimated in such hilly elevation.

![Figure 15. Terrain profilers examples of Hilly-terrain UMTS network: (a) site (2) to site (4); (b) site (2) to site (3).](image)
The second calculation for this network planning is made to measure the coverage as shown in figure 16. It can be seen that the best coverage served at the regions with blue and green colors on map indicating for services with QAM and QPSK modulation schemes respectively. Those regions are restricted to the areas near site antennas. Although the majority of the design is served by voice service at minimum (shown in yellow on map), there are several zones have no coverage at all. Those reddish spots on map with no coverage are increasingly appeared compared with the preceding flat-terrain design since the environment at this planning is implemented with a tough hilly terrain. For example, there are some areas with no coverage appeared between site (2) and site (4) in figure 16 as a result of emerging mountains there as shown in figure 15a.

Figure 16. Coverage calculation of hilly-terrain UMTS network.

The power level of this hilly terrain is presented in figure 17 in which the overall power calculation is shown on map. It is noticeable that there are no better than -70 dBm of power level served around and close to sites. More precisely, some points are spread across the network to do measurement at specific real positions with the power values shown in table 8. Point (a) measures the weakest power level at -107.6 dBm because of its location placed far away from the nearest possible site, i.e. site (6). In contract, point (b) is served by the strongest power among other points at -72.7 dBm. Also, points (c) and (d) indicate the powers at -90.3 and -86.6 dBm respectively which are still reasonably acceptable. The exact location served with the best power level through the entire network can be indicated on figure 17 by the green ring close to site (4).

Figure 17. Power calculation of hilly-terrain UMTS network.
Table 8. Point power calculations of third design.

| Point name | Power (dBm) |
|------------|-------------|
| a          | -107.6      |
| b          | -72.7       |
| c          | -90.3       |
| d          | -86.6       |

In terms of interference measurements, the ratio of modulated carrier average power to interference average power of the entire network is shown in figure 18. Again as indicated in figure 17, the best location with the least amount of interference is shown as a green ring underneath site (4) in figure 18. Nevertheless, the rest of network shows high levels of co-channel interference because of the harsh environment chosen for this planning scenario. Also, the traffic load is set as maximum when doing the calculation to measure the most critical case, but another calculation is made in the following section in which a base traffic load is applied to explore the difference.

5. Discussion

In this section, some discussions and comparisons are made with regards the three cellular RF designs planned so far. Table 9 highlights a distinctive comparison of the networks planning. It can be apparently noticed that the second design with a flat-terrain LTE network is the best among the rest planning networks in terms of coverage area and required equipment. This distinct design is planned with minimized resources such as number of sites, total number of antennae, height of antennae, and maximum TX power per site at 11, 28, 40m and 65w respectively. That minimization in resources when planning the second design is a crucial factor in terms of budget management. On the other hand, although the two UMTS designs both cover 63.62 km² individually with the same number of sites, the sites' antennae height of the hilly-terrain network is 60m compared with 45m that of the flat-terrain design. That increase in height is necessary to mitigate the effect of mountains blockage and to compensate for the high pathloss in such environment.

Table 9. A comparative summary of all designs.

|                     | Flat-terrain UMTS Network | Flat-terrain LTE Network | Hilly-terrain UMTS Network |
|---------------------|---------------------------|--------------------------|---------------------------|
| Coverage area (km²) | 63.62                     | 81                       | 63.62                     |
| Number of BSs (sites) | 12                        | 11                       | 12                        |
| Total number of sectors | 39                       | 28                       | 32                        |
Compared with other networks, the UMTS design planned in a hilly terrain can be optimized in terms of quality of service. Increasing transmitting power by sites would certainly result in a raise in design budget and a probable higher interference in addition to possibly cause harm to humans [8][9]. Alternatively, one way to offer better service is by reduction in area coverage. That is achieved via shrinking the distances among base stations, i.e. sites, to guarantee an overall coverage area with a radius of 3.5 km as shown in figure 19. Obviously, figure 19 indicates the red spots with no coverage have been almost eliminated from the network compared with the design in figure 16. However, that better quality of services offered at the expense of a reduced coverage area. Hence, a trade-off is essentially existent. Interestingly, point (a) is still unserved and with no coverage even it is surrounded by some areas with voice service at minimum. That is a result the point's placement which lies behind a 625m high mountain that causes blockage as depicted in figure 20.

With regards to coverage and C/I calculations of the three designs planned earlier, two considerations are importantly highlighted. Firstly, the coverage calculation in all preceding designs are applied with 2m high above ground. That is the case for reasonable height of mobile stations (MSs) antennae considered in those planning designs. However, if another assumption is considered in which the height of coverage calculation is increased to 20m above ground to exploring how the network cover MSs standing at building's height or other BSs at that elevation is supposed to receive services. As can be seen in figure 21, the coverage calculation is done at 20m above ground for the hilly-terrain network, as an example, in which the quality of coverage service has been clearly improved compared with that depicted in figure 16. That enhancement is because the mountains and other obstacles have less effects when rising up the height of coverage calculation to 20m instead of 2m. Secondly, the carrier to interference ratio calculation of all the three designs is set to assume.
maximum traffic load. Even though considering maximum load reflects the extreme situations, it is also significant to measure the C/I with a base load to explore the difference. The C/I calculation with base traffic load of the hilly-terrain network is shown in figure 22 as a sample to compare with the same network calculation illustrated in figure 18 which is with maximum load.

![Figure 21](image1.png)

**Figure 21.** Coverage calculation of hilly-terrain UMTS network at 20m.

![Figure 22](image2.png)

**Figure 22.** C/I calculation of hilly-terrain UMTS network with base traffic load.

### 6. Conclusion

RF planning is a crucial step towards realizing wireless cellular networks. Three planning scenarios are presented in this work in which UMTS and LTE cellular networks are considered with different terrains. The design goals are to offer maximized signal coverage, better quality of service, minimized resources and cost budget and minimized level of interference. The design considerations are overlapping with each other. For example, raising the power level results in covering farther distances but that might increase interference and probably affect humans' health. Another apparent example is that adding more sites or lifting antennae height would sound great options to enhance services but that is offered at the expense of cost budget increase or even inapplicable. In consequence, trade-offs are permanent in cellular planning.

The calculation results of the three network planning designs can be further optimized by promoting to the professional edition of the WiMAP tool. That would help overcome the limitations of the community edition (utilized in this work) such as the number of sites is limited to 12 sites only and the calculations cannot be more precise than 50m with this license edition. Also, some calculation themes are disabled in the community edition like the field strength calculation which is a helpful theme to measure power density around antennae to make sure that the fields are not exceeding critical
values and not harming humans. In addition, the geodata that is used in this paper can be even improved to offer better environmental overview though importing more precise elevation models and cadastral information but those data have to be purchased. However, the networks planned in this work are aided by reasonably reliable calculations themes that are sufficient to have a good overview of planning at multiple terrains with different technologies.

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