QoS-Based Performance and Resource Management in 3G Wireless Networks in Realistic Environments

Aymen Issa Zreikat
Department of Information Technology, Mu'tah University, Jordan

Abstract: *The third generation networks like Universal Mobile Telecommunication Systems (UMTS) offers multimedia applications and services that meet end-to-end quality of service requirements. The load factor in the uplink is critical and it is one of the important parameters which has a direct impact on the resource management as well as on the cell performance. However, in this paper, the fractional load factor in the uplink and the total downlink power are derived taken into account the multi-path propagation in different environments. The analysis is based on changing new parameters that affect the Quality of Service (QoS) as well as the performance, such as: service activity factor, energy-to-noise ratio (Eb/N0), interference factor, and the non-orthogonality factor of the codes. The impact of these parameters on the performance and the capacity as well as the total throughput of the cell is also investigated. It is shown in this paper that in addition to the above parameters, the type of the environment has a major effect on the noise rise in the uplink as well as the total power in the downlink. The investigation is based on different types of services, i.e., voice (conversational: 12.2kbit/s), packet switched services with rates (streaming 64 and 128kbit/s) and (interactive 384kbit/s). Additionally, the obtained results in this paper are compared with some similar results in the literature*.

Keywords: *3G wireless networks, QoS, radio resource management, UMTS, load factor, noise rise.*

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1. Introduction

Third generation networks like Universal Mobile Telecommunication Systems (UMTS) in Europe will support multimedia services according to the 3rd Generation Partnership Project (3GPP) specification [1, 2, 3, 16], i.e., the supported bit rates will be at least 144 Kbps for rural areas, 384Kbps for urban/suburban area and 2 Mbps for indoor/low range outdoor environment.

UMTS is referred as Wideband Code Division Multiple Access (WCDMA) based, because Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are applied to paired and unpaired bandwidth respectively at 2GHz band. For Core Network (CN), the traditional circuit switched network will evolve to modern packet switched network e.g., IP-based network. As the Emerging of internet and mobile applications, UMTS users are capable of accessing both telecom and internet resources. Quality of Service (QoS) becomes a critical issue for the success of UMTS and to provide end users with perceptive QoS, the network resources at various nodes must be optimally utilized. Therefore, Radio Resource Management (RRM) plays an important role in the provision of UMTS services. W-CDMA access networks, such as the one considered in UTRA-FDD proposal [2], provide an inherent flexibility to handle the provision of future 3G mobile multimedia services. 3G will offer an optimization of capacity in the air interface by means of efficient algorithms for radio resource and QoS management. RRM entity is responsible for utilization of the air interface resources and covers power control, handover, admission control, congestion control and packet scheduling [3, 13, 18]. These functionalities are very important in the framework of 3G systems because the system relies on them to guarantee a certain target QoS, to maintain the planned coverage area and to offer high capacity. The QoS provisioning for multimedia traffic has gained interest in the literature in recent years, as the problem arises in the context of 2.5G and 3G systems and is not present in 2G systems. Thus, Das *et al*. [6] has developed a general framework for QoS provisioning by combining call admission control, channel reservation, bandwidth reservation and bandwidth compaction. Dixit *et al*. [8] among others have discussed the evolution scenarios from 2G to 3G networks and the QoS network architecture proposal by 3GPP for UMTS. In this respect, few studies aligned to the 3GPP specifications are available in the open literature [7, 17]. For the admission control, several old and recent schemes have been suggested for the uplink [4, 10, 15, 22, 23] under different conditions and at a lower extent for the downlink [12]. More recently, Ho *et al.* [9] have built mathematical models for various call admission schemes and have proposed an effective linear programming technique for searching a better admission control scheme. However, the presented investigation in this paper is innovative in the sense that the capacity analysis in both the uplink and downlink is derived and studied in more realistic environments where the multi-path propagation is included in the derivation of the fractional load factor as well as the noise rise. Moreover, the impact of the load factor on the system capacity is studied by changing new important performance parameters.

The rest of the paper is organised as follows. In section 2, the uplink fractional load factor is derived, whereas, the total downlink power is derived in section 3. The comparative results come in section 4 for both the uplink section 4.1 and the downlink section 4.2, whereas the comparison with other results comes in section 4.3, followed by the conclusions and the future work in section 5.

2. Uplink Load Factor Derivation

According to the cell breathing phenomenon in the third generation systems like UMTS, which is based on W-CDMA, when the load increases, the coverage area of the cell shrinks as the interference is increased. Therefore, the uplink interference margin (i.e., noise rise) is needed to estimate the coverage of the cell. The following requirement must be fulfilled by a user k:

$$PG \times \left(\frac{P_k}{I_{intra} - P_k + I_{inter} + I_0}\right) = PG \times \left(\frac{P_k}{I_{intra} - P_k + \varepsilon \times I_{intra} + I_0}\right) >= E_b/N_0 \quad (1)$$

Where,

$$\varepsilon = \frac{I\ inter}{I\ intra} = \frac{\sum_j p_j \ :where\ j \in users\ connected\ to\ other\ cells}{\sum_i p_i \ :\ where\ i \in users\ connected\ to\ own\ cell} :$$

is other cell-to-own cell interference factor.

PG=W/R: is the processing gain of the used service:

W: is the total bandwidth, *R* is the bit rate.

P_k: is the minimum received power of user *k*.

I_{intra}: is the own cell interference.

I_{inter}: is the other cell interference.

I_0: is the thermal or the background noise.

E_b/N_0: is the required energy per bit to noise to the user at Node B.

From equation 1, we get:

$$PG/\left(E_b/N_0\right) \geq \frac{I_{intra} - p_k + \varepsilon \cdot I_{intra} + I_0}{p_k}$$

$$P_k \cdot \left[PG/\left(E_b/N_0\right) + 1\right] \geq I_{intra} \cdot (1+\varepsilon) + I_0$$

Then, the minimum received power P_k of a user *k* can be reformulated as follows:

$$P_k \geq \frac{1}{\left[1 + PG/(E_0/N_0)\right]} \cdot (1+\varepsilon) \cdot I_{intra} + \frac{I_0}{\left[1 + PG/(E_0/N_0)\right]} \quad (2)$$

for a single cell case and assuming that all users are using the same service, then the total uplink power can be calculated as follows [11]:

$$I_{intra} = (1+\varepsilon) \sum_{k=1}^{N} P_k = \frac{I_0 \cdot \eta_{up}}{1 - \eta_{up}} \quad (3)$$

Where the uplink load equation (i.e., the uplink capacity utilized) is defined as:

$$\eta_{up} = \sum_{k=i}^{N} \frac{1}{1 + PG/\left(E_b/N_0\right)} \cdot (1+\varepsilon) \quad (4)$$

Assuming that all users have the same service and having the same E_b/N_0 then the load in equation 4 can be simplified further to:

$$\eta_{up} = N \cdot (1+\varepsilon) \cdot \left[\frac{1}{1 + PG/\left(E_b/N_0\right)}\right] \quad (5)$$

The voice activity factor, *v* has a clear impact on the uplink noise rise. This value is usually taken to be 0.50 plus 0.17 “capacity overhead” from control channels, which means that the voice activity factor is taken to be 0.67 (50% voice activity and DPCCH (Dedicated Physical Control Channel) overhead), whereas, this factor for data service is considered to be 100% [3, 11]. Therefore, the voice activity factor should be included in the load equation as follows:

$$\eta_{up} = N \cdot (1+\varepsilon) \cdot PL_{env}\left(d_i\right) \cdot \left[\frac{1}{1 + PG/\left(E_b/N_0\right) \cdot v}\right] \quad (6)$$

Recall from [24], where the capacity bounds are derived in different propagation environments using the extended version of Hata (i.e., Extended COST-231)[5]. $PL_{env}(d_i)$ is the path loss which is given in different propagation environments, *env* (i.e., urban, suburban, dense-urban or rural) as a function of the distance, *d* including the shadowing effects. In W-CDMA coverage and capacity are closely related. Therefore, satisfied user is the one who is able to transmit a power which is enough to cope with the (E_b/N_0) at the base station and less than the maximum transmission power, $P_{k,max}$, even if the user is located at the edge of the cell and it is possible to get the suitable value of η_{max} in order to maintain the coverage. Then by substituting equation 6 in equation 3 we get.

$$P_{k,\max} = PL_{env}\left(d_i\right) \cdot \frac{I_0 \cdot N \cdot (1+\varepsilon) \cdot \frac{1}{\left(1 - \eta_{\max}\right)}}{\left[1 + PG/\left(E_b/N_0\right)\right]} \quad (7)$$

where, $PL_{env}(d_i)$ is the path loss (including shadowing effects) at distance d_i , and η_{max} is the maximum allowable load factor for assuring the required coverage.

3. Downlink Load Factor Derivation

The load factor in the downlink follows the same steps and behavior in the uplink with small difference [11], where the orthogonal factor of the codes, α, must be included in this case as the codes in the downlink are not fully orthogonal. Therefore, the downlink fractional load can be estimated according to equation 5 above as follows:

$$\eta_{DL} = N \cdot ((1-\alpha)+\varepsilon) \cdot PL_{env}\left(d_i\right) \cdot \left[\frac{1}{1+PG/\left(E_b/N_0\right)\cdot v}\right] \qquad (8)$$

The capacity of the uplink is the critical one because in CDMA systems like UMTS, the scarce resource is the transmission power. However, given the frequency mode FDD of UMTS, the power budget of the uplink and the downlink is independent. The power of the uplink is limited by the User Equipment (UE), while in the downlink it is limited by the capabilities of Node B. In the downlink, all users share the same Node B and therefore, the total downlink power is shared between them, the more users, the less the power per user. According to the above and from equation 1, the DL power required for user *i* is given as follows:

$$PT_i = \frac{(I_0 + I_{intra} + I_{inter}) \cdot (E_b / N_0)_i \cdot v_i}{PG_i} \qquad (9)$$

Where:

$$I_{inter} = \frac{\alpha (PT - PT_i)}{PL_{env}(d)} \qquad (10)$$

and,

$$I_{intra} = \varepsilon \cdot \frac{PT}{PL_{env}(d)} \qquad (11)$$

Where:

PT_i: is the downlink power required for user *i*.
PT: is the total T_x power in the downlink.
α*:* is the non-orthogonal factor of the code in the downlink.

By substituting equations 10 and 11 in 9, the DL power required for user *i* can be reformulated as follows:

$$PT_i = \frac{(E_b/N_0)\cdot v_i}{PG_i} \cdot \left[\frac{I_0 \cdot L_p(d) + (\varepsilon+\alpha)\cdot PT - \alpha \cdot PT_i}{L_p(d)}\right] \qquad (12)$$

The total DL power represents the transport channels (i.e., the sum of the common channels and dedicated channels [14]. Hence,

$$PT = P_{CCH} + N \cdot PT_i \qquad (13)$$

Where P_{CCH} is the total power used for downlink common channels and *N* is the number of users, then from equation 13, PT_i can be redefined as follows:

$$PT_i = \frac{PT - P_{CCH}}{N} \qquad (14)$$

From equation 14:

$$PT = N \cdot PTi + P_{CCH} \qquad (15)$$

By substituting the value of PT_i in equation 12 into equation 15 in order to get the total power in the downlink in the left hand side, as follows:

$$PT = \frac{N \cdot I_0 \cdot PL_{env}(d_i)\cdot(E_b/N_0)\cdot v_i + PCCH \cdot (PG_i \cdot PL_{env}(d_i) + \alpha)}{(PG_i \cdot PL_{env}(d_i)+\alpha) - N\cdot(E_b/N_0)\cdot v_i \cdot(\varepsilon+\alpha)} \qquad (16)$$

4. Comparative Results

4.1. Single Cell Uplink Analysis

This section presents a set of results in the uplink for a conversational voice service (12.2kbps AMR). However, Figures 1 and 2 represent the uplink noise rise for data service (i.e., PS: 64kbit/s and 128kbit/sec). Figure 3 representing the path loss against the number of users in different propagation environments. Although there are large numbers of parameters that can be considered, the following results will concentrate on the influence of three main parameters: service activity factor, *v*, the uplink interference factor, *ε*, and energy-to-noise ratio, Eb/N0, Figures 4, 5 and 6 respectively. These results are generated using MATLAB package which is a very powerful tool for simulation and other mathematical computations. Table 1 show the parameters used in this study unless it is specified explicitly.

Table 1. Default system parameters [11, 21].

Parameters	Values
Required E_b/N_0	3, 4, 5, 6,7,8 dB (variable of study)
Mobile maximum transmission power	125 mW
Thermal noise	-103 dBm
Inter-cell interference to own cell power ratio, ε	0.50, 0.55, 0.67 (variable of study)
Service activity factor (*v*) of voice	0.67
Service activity factor (*v)* of data	1
Wave length	0.15
Height of the mobile	1.5 m
Height of the base station	50 m
WCDMA chip rate	(3.48 Mcps) or 3840000 Hz
Voice AMR (adaptive multi rate) service	12.2 kb/s
Packet switched (PS) data service	64, 128, 384 kb/s
Non-orthogonality factor in the DL	0.50, 0.70, 0.90 (variable of study)
Block Error Rate (BLER)	(for Data = 0.10, for Voice = 0.01)

4.1.1. Uplink Noise Rise for Packet Switched Data Service

Assuming E_b/N_0 of 1.5dB and ε (i.e., own cell to other cells interference) is assumed to be 0.50, and the data activity factor is taken to be 1 as assumed before. Figures 1 and 2 show two examples of the noise rise for packet switched data service. In Figure 1, the bit rate is assumed to be 64kbit/s whereas in Figure 2, it is assumed to be 128kbit/s. The noise rise of approximately 4dB is equivalent to 50% load factor and the noise rise of 7dB is equivalent to 75% load factor. Therefore, and according to Figure 1, the throughput of 1750kbit/s is supported by 4dB noise rise whereas the throughput of approximately 2750kbit/s is supported by 7dB noise rise. However, in Figure 2, the same parameters used in Figure 1 are used here except that the bit rate is taken here to be 128kbit/s. It can be noticed from Figure 2 that double value of throughput is supported by the same noise rise; the throughput of 3000kbit/s is supported by 4dB noise rise and the throughput of 5500kbit/s is supported by 7dB noise rise.

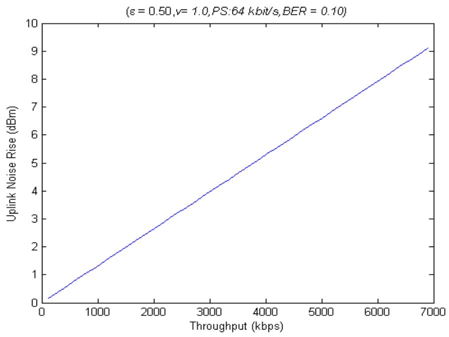

Figure 1. Uplink noise rise as a function of uplink data throughput (PS: 64kbit/s).

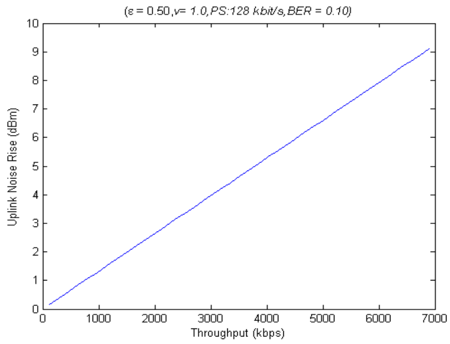

Figure 2. Uplink noise rise as a function of uplink data throughput (PS: 128kbit/s).

4.1.2. Uplink Path Loss in Different Propagation Environments

Figure 3 shows the path loss in different propagation environments. It visualizes the path loss against the number of users. It is clear that the loss in the free space environment is low compared with other environments as the Line-Of-Sight (LOS) between the transmitter and the receiver is clear with no obstacles. On the other hand, the loss is expected to be higher in other environments (i.e., urban, dense-urban) as the buildings are expected to be high and therefore, the LOS would not be clear. As the number of users increases, the path loss becomes higher, Figure 3 explains this situation.

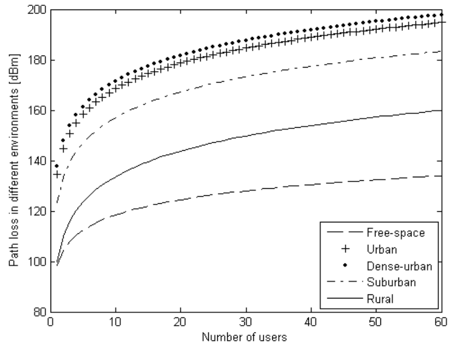

Figure 3. Path loss against distance in different propagation environments.

4.1.3. The Effect of the Service Activity Factor, *v* on the Noise Rise

Figure 4 demonstrates the effect of the service activity factor, *v* on the uplink noise rise as well as the system capacity. The rest of the parameters are kept fixed as mentioned in the title part of the Figure (i.e., *ε*=0.50, *Eb/N0*=4dB). It is clear from Figure 4 that the service activity factor has a clear impact on the uplink noise rise. When the service activity factor increased from 0.50 to 1.0 the uplink noise rise increases from approximately 6dBm to 12dBm noise rise, where the maximum number of active users (i.e., system capacity) achieved at this range is 60. This explains the direct impact of the service activity factor on the noise rise; the higher the activity service factor, the higher the noise rise and the better the capacity.

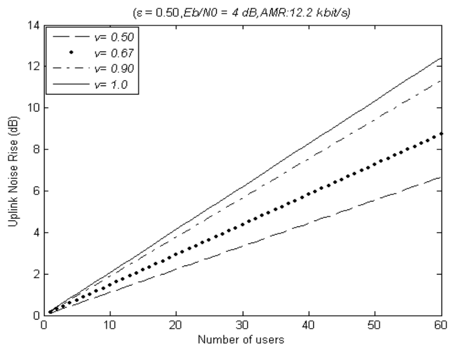

Figure 4. Uplink noise rise against number of users for different service activity factors.

4.1.4. The Effect of the Uplink Interference Factor, ε on the Noise Rise

Figure 5 demonstrate the effect of the interference factor, ε, on the uplink noise rise as well as the system capacity. Two parameters are kept fixed (i.e., *v*=0.67, *Eb/N0*=4dB). It is clear from Figure 5 that the higher the interference factor, the higher the noise rise. For example, at interference factor, ε =0.50, the maximum number of 60 users can be reached at noise rise of approximately 6.0dBm, while at higher interference (i.e., ε =1.0), the same number of users is reached at about 9.0dBm noise rise. This explains the fact that the interference factor in the uplink has also a direct impact on the noise rise. The higher the interference factor, the higher the noise rise, which means that the system reaches its maximum capacity.

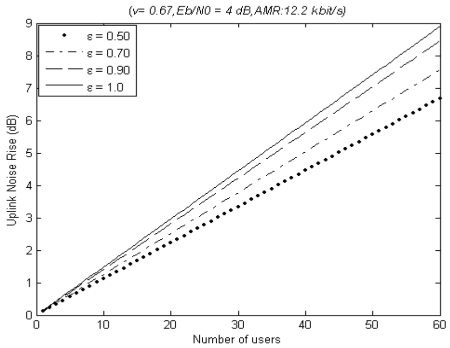

Figure 5. Uplink noise rise against number of users for different interference factors.

4.1.5. The Effect of Eb/N0 on the Noise Rise

It is clear from Figure 6 that *Eb/N0* has a clear impact on the noise rise. As *Eb/N0* increases, the noise rise is also increases. For example, 30 users can have service with 3dBm noise rise at *Eb/N0*=3dB. On the other hand, 30 users can have service with about 7dBm noise rise at *Eb/N0*=6dB. Of course, choosing *Eb/N0* is a planning issue and it has to be decided by UMTS specifications.

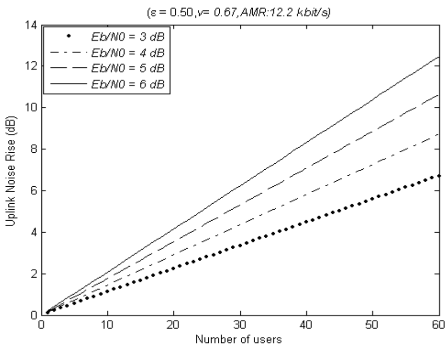

Figure 6. Uplink noise rise against number of users for different Eb/N0 values.

4.2. Downlink Analysis

The analysis in the downlink is based on Packet-Switched (PS) with rates: 64kbps, 128kbps and 384kbps. There are seven Figures in this analysis: Figures 7, 8, 9, 10, 11, 12 and 13. All Figures are generated for the total downlink power against the number of active users in different propagation environments (i.e., free space, urban, dense urban, suburban and rural) in Figures 7, 8 and 9.

However, in the rest of the Figures (i.e., Figures 10, 11, 12 and 13) urban environment is considered in the analysis and the service is taken to be PS with 384kbit/s.

4.2.1. Total Downlink Power in Different Propagation Environments

It is clear from Figures 7, 8 and 9 that not only the user received power and the capability of the base station has an effect on the quality of service, but also the type of environment and the propagation conditions have an impact. It is clear from Figures 7, 8 and 9 that as we have a clear environment (i.e., free space) the total received power at the base station will be high regardless of the bit rate. However, the maximum power is achieved when we have PS 384kbit/s. It is around 47.5dBm in the free space and 41dBm in the dense urban area. The following investigation is assumed only in urban environment.

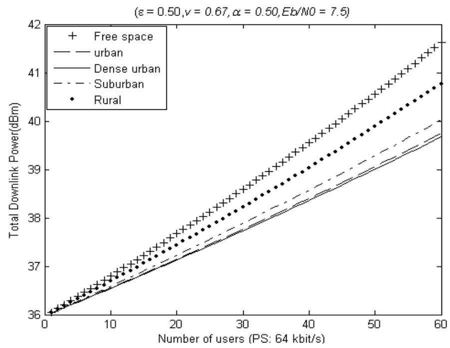

Figure 7. Total downlink power against the number of PS users in different environments.

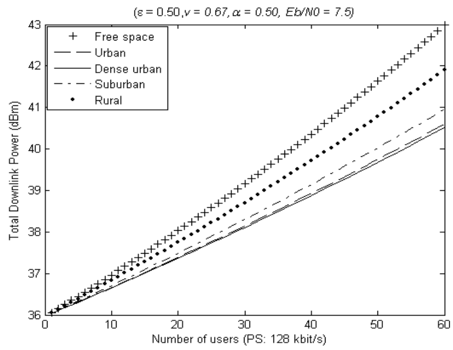

Figure 8. Total downlink power against the number of PS users in different environments.

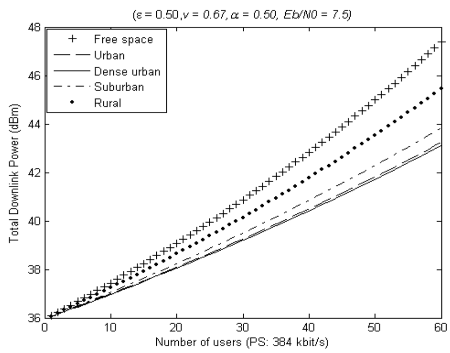

Figure 9. Total downlink power against the number of PS users in different environments.

4.2.2. The Effect of Interference Factor, ε

The effect of the interference factor is shown in Figure 10. It can be seen from Figure 10 that as the interference factor between users increased, the total downlink power will be higher as increasing the interference between users means that each user has to increase his power in order to achieve the required *Eb/N0* at Node B.

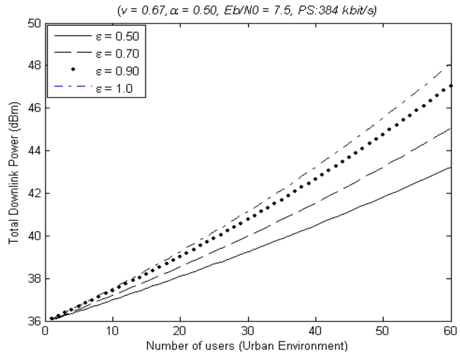

Figure 10. The effect of the interference factor, ε on the total downlink power in urban environment.

4.2.3. The Effect of Orthogonality Factor, α

It is clear from Figure 11 that the orthoganality factor between the users in the downlink has a clear impact on the total downlink power. This factor is very important as the codes in the downlink are not orthogonal. However, the perfect orthogonality beween the codes can be achieved when we have α=1, but this is not realistic assumption in real life. It can be seen from Figure 11 that when we have perfect orthogonality (α=1), the maximum received power is achieved (around 49dBm). While with realistic orthogonality factor (α=0.50) only around 41dBm total received power is achieved.

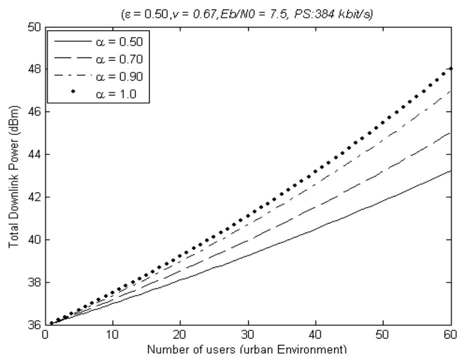

Figure 11. The effect of the orthogonality factor, α on the total downlink power in urban environment.

4.2.4. The Effect of the Service Activity Factor, *v*

Figure 12 shows the effect of the service activity factor, *v* on the total downlink power. When the service activity factor is high, the total received power reaches its maximum (i.e., 30 users are served), it is 48dBm when we have the value of *v*=1.0, and it is 41dBm when the value of *v*=0.50.

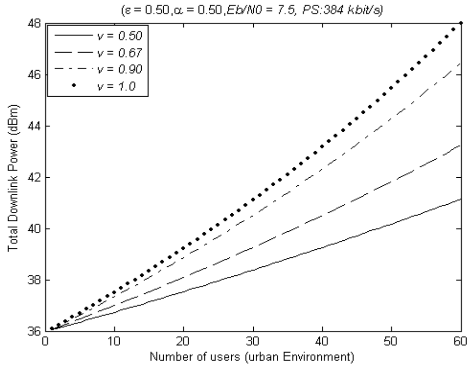

Figure 12. The effect of the voice activity factor, *v* on the total downlink power in urban environment.

4.2.5. The Effect of Eb/N0

The required *Eb/N0* has a clear impact on the total downlink power. This effect can be seen from Figure 13. As the required *Eb/N0* increases, the total received power is getting higher. For example, 40 users are served at power 39dBm when we have *Eb/N0*=5.5dB. On the other hand, 40 users are served at power 41dBm when we have *Eb/N0*=8.8dB.

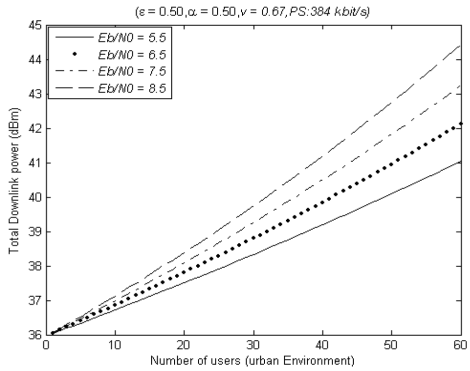

Figure 13. The effect of Eb/N0 on the total downlink power in urban environment.

4.3. Comparison with Existing Results

The results obtained in this paper are compared with some similar results in the literature [19, 20]. All presented results in [20] are assumed only an ideal space environment. Two Figures are used in this comparison (i.e., Figures 14 and 15). Figure 14, shows the uplink noise rise against the number of voice users.

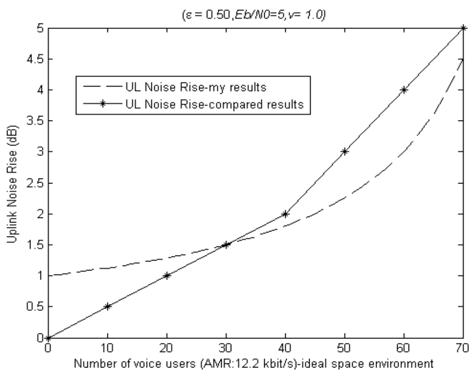

Figure 14. Uplink noise rise (dB).

The author assumed in this paper a value of 100% for the voice activity factor, *v* which is not realistic in a real network with AMR of 12.2kbit/s, whereas the other-to-own cell interference, ε is assumed to be 50%. It can be seen from Figure 14 that the uplink load is 2dB for 5 users in my results, whereas, it is 3dB for the same number of users in the compared results. The explanation of this is that when the uplink noise rise is low, the capacity of the cell will be better. My results become better when the number of users in the cell increases. The same parameters are used in Figure 15, however, the voice activity factor is assumed to be 0.67% (50% for voice activity + dedicated control channel overhead).

In Figure 15, the total downlink power is demonstrated. My curve shows better results than the compared one. It is clear that as the users reach the cell edge, the required received power by those users is increased which leads to degradation in the cell throughput. In [19], the investigation is presented based on the downlink pole capacity.

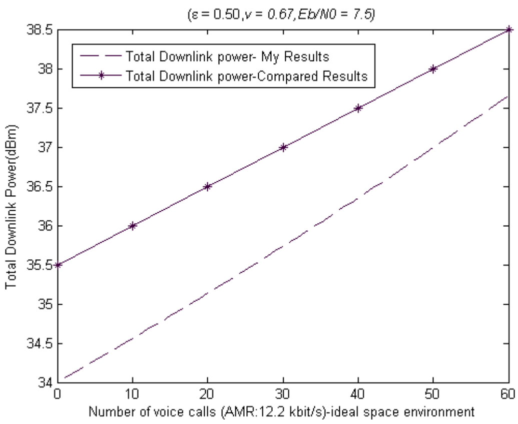

Figure 15. Total downlink bower (dBm) in free space.

Two Figures are presented in this comparison Figures 16 and 17. In Figure 16, the value of *Eb/N0* is assumed to be 8, whereas the orthogonality factor α is taken to be 50% and the other-to-own cell interference is assumed to be also 50%. Only macro cells environment is assumed here. It can be seen from Figure 16 that the curve for the total downlink power gives better results compared to my results only when the number of users is low. As the number of users increases, the total received power becomes better in my results than the compared results. This means that my model is able to maintain the downlink power to a lower level even when the number of users is large. Consequently, the total cell throughput is also maintained. Similar results are demonstrated in Figure 17, but in this time, the interference factor, ε is taken to be 0.80. When this factor is high, this means that more users are coming to the cell from outside, which leads to increase in the total downlink power required by those users.

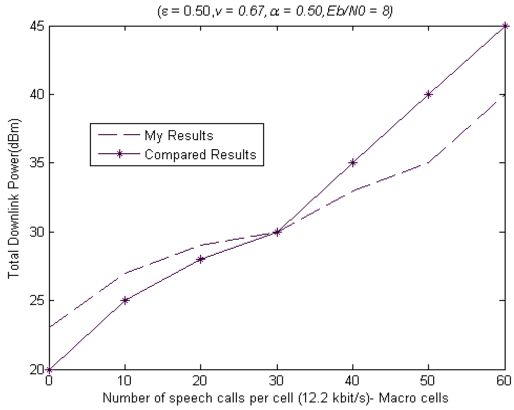

Figure 16. Total downlink power in macro cell environment.

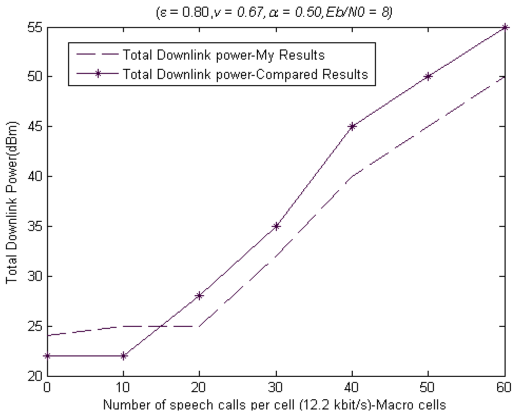

Figure 17. Total downlink power in macro cell environment.

5. Conclusions and Future Work

3G wireless networks offer different QoS guarantees and an optimization of the capacity in the air interface by means of efficient radio resource management algorithms. In this paper, the uplink and downlink load factor in addition to the total received power in the downlink are derived and analyzed by means of a set of important parameters that have an impact on 3G performance as well as the QoS; such as the path loss, the interference factor, the activity factor, the orthogonality factor, energy to noise ratio, as well as the capacity and the total throughput of the cell. The impact of these parameters on the performance is studied in different propagation environments with different types of services; conversational, streaming and interactive, in order to reflect the real life situation. These important parameters should be taken into consideration by the network designers in the planning issues of the future of 3G networks. The obtained results are compared with existing results in the literature. The above analysis was only done for one cell. In the future, this work could be extended to multi-cell analysis.

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Aymen Issa Zreikat is an Associate Professor at the Information Technology Department, Mu'tah University, Jordan. He has obtained his BSc in computer science from Yarmouk University, Jordan in 1990 and MSc in computational engineering from University of Erlangen, Germany in 2000. Additionally, he has obtained his PhD from Bradford University, UK in 2003. In January, 2001, he has joint the performance modelling and engineering research group at the Computing Department of Bradford University, UK. His area of research is in the performance evaluation and resource management of 3G wireless mobile networks and beyond. He has more than 35 international refereed journal and conference papers in this field and he is responsible for reviewing a set of papers in this area of research in a very reputable Journals. He has published two important books in LAMBERT publisher. He is a member of some national coordinating committees; (such as the coordinating committee for the management of Queen Rania Al-Abdullah center for Educational Technology, also Committee for Higher Education Accreditation Commission, and International Organizations. He has been appointed as an assistant professor at the Information Technology Department, Mutah University, Jordan. In 2009, he has been promoted to associate professor in the same University. He has been appointed as an assistant dean at the Faculty of Science. Recently, he has been appointed as the chairman of the Information Technology, Mu'tah University.