LTE Downlink Performance of Cigar-Shaped Highways Microcells with and Without Small Scale Fading

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Abstract: *In this paper, the performance of the downlink of the LTE systems for cigar-shaped microcells at highways is studied. The two-slope propagation loss model is used to calculate the signal to interference plus noise ratio taking into account the expected value and the variance of the cochannel and adjacent channel interference. Also, the effect of the inter-carriers interference due to the user movement is taken into account. A model of ten cigar-shaped microcells is used in the LTE performance analysis. For the frequency band of 2.6 GHz with a 10 MHz bandwidth, the base station transmitted power should be 2 W to get a sector range of 1356 m meanwhile it should be 3.1 W to get 1500 m sector range. For the 800 MHz frequency band, maximum range of 2909 can be got with a transmitted power 4 W when the break point distance R_b is maintained at 250 m. With a frequency reuse of 2, a sector mean bit rate up to 41.65 Mbps can be got with a 10 MHz bandwidth. Small scale fading affects the SINR of the LTE user and consequently the downlink bit rate.*

Keywords: *LTE, cigar-shaped microcell, cochannel interference, intercarrier interference, downlink bit rate, adjacent channel interference.*

1. INTRODUCTION

LTE (Long-Term Evolution) is a standard for wireless communication of high-speed data for mobile phones and data terminals. Its downlink bit rate that can reach 100 Mbps using 64QAM modulation with 20 MHz bandwidth.

Based on the GSM/EDGE and UMTS/HSPA network technologies, capacity and speed have been increased using a different radio interface together with core network improvements [1] [2]. The standard is developed by the 3GPP (3rd Generation Partnership Project) and is specified in its Release 8 document series, with minor enhancements described in Release 9.

Long Term Evolution (LTE) radio access technology is the fastest developing system in mobile communication. In mid-2012, LTE networks covered 455 million people in the world [3], and by 2018, it is expected to cover approximately 57% of the world's population. By 2018, the number of LTE base stations (BSs) is expected to increase to 2.43 million to achieve the population coverage target, which is expected to reach 1.3 billion LTE subscribers [4]. South Korea has a LTE penetration of 97%. Only multi-band phones will be able to use the different LTE frequencies that are used in different countries.

LTE as specified in the 3GPP Release 8 and 9 document series is marketed as a 4G wireless service in spite of their unsatisfaction of the technical requirements the 3GPP consortium has adopted for its new standard generation, and which were originally set forth by the ITU-R organization in its IMT-Advanced specification.

LTE uses OFDM in the downlink (DL) with a time division duplex (TDD) frame structure of duration 5 ms shared between the UL and DL. Adaptive modulation (QPSK, 16 QAM and 64 QAM) and coding is used in the downlink of the LTE system. In uplink, LTE uses the single-carrier frequency division multiple access (SC-FDMA).

Several papers have dealt with the capacity of LTE systems. In [2], the performance of the LTE downlink is investigated using 6 taps typical urban channel. In [5], the peak throughput for TDD and FDD 4 G LTE systems is calculated. For LTE system with 4*4 MIMO (Multi Input-Multi Output), using 20 MHz bandwidth, the peak throughput reaches 403.2 Mbps.

Work [6] shows a more comprehensive investigation of the maximum data throughput under different conditions and scenarios. The performance study includes TDD and FDD operational modes for uplink and downlink transmissions in different antenna diversity schemes, data modulation, and code rates. Results show that LTE (3GPP Release 8) supports downlink throughputs of up to 300 Mbps and for the uplink a throughput of up to 75 Mbps.

In this study, each cigar-shaped microcell has two sectors and a directional antenna is used in each one of them and that the typical separation between two successive base stations is 1.5 to 2.5 Km.

To the author's best knowledge, there isn't any literature that deals with the LTE in highways microcells.

The aim of this work is to investigate the performance (bit rate and range) of the LTE in highway's cigar shaped microcells.

The rest of the paper has been organized as follows. In Section 2, the propagation model used in the calculation of the interference statistics is given. In Section 3, the interference statistics (mean value and variance) are analyzed. Numerical results are presented in Section 4. Finally, in Section 5 conclusions are drawn.

2. PROPAGATION LOSS MODEL

In [7], it has been shown that the two slope model is the best propagation model that can be used to calculate the propagation loss in highways. We have used it in our previous work [8-12] to analyze the performance of the WCDMA systems. Thus, the two-slope propagation model with lognormal shadowing is used in the analysis of the LTE performance.

The two slope propagation model consists of a constant value which represents the propagation loss at a very short distance such as 1 m, a distance dependent term and extra terms representing shadowing, small scale fading and extra losses.

The exponent of the propagation is assumed to be n_1 until the break point (at a distance R_b) and then it changes to higher value of n_2. Small scale fading (if exists) is presented by Rice fading. In this way the path loss between the basestation and the mobile user at a distance r from it is given by:

$$L_p(dB) = L_{Rb} + 10 n_1 \log_{10}\left(\frac{r}{R_b}\right) + L_g + L_{extra} + \xi_1 + Rice \qquad r \le R_b \qquad (1)$$

$$L_p(dB) = L_{Rb} + 10 n_2 \log_{10}\left(\frac{r}{R_b}\right) + L_g + L_{extra} + \xi_2 + Rice \qquad r > R_b \qquad (2)$$

where L_g is the car window penetration loss, L_{extra} is an extra loss that depends on the direction of the arrival of the LTE signal (0 dB if the signal is received from the front side of the car and 10 dB if the signal is received from the back side of the car), r is the distance between the LTE basestation base and the mobile user , ξ_1 and ξ_2 are Gaussian random variables of zero-mean and a standard deviation of σ_1 and σ_2 respectively representing what is called the shadowing effect (in reality it is path loss deviation from the average value).

Without taking into account shadowing and small scale fading, L_b (propagation loss at the break point) is given as:

$$L_b(dB) = 20 \log_{10}\left(\frac{4\pi}{\lambda}\right) + 10 n_1 \log_{10}(R_b) \qquad (3)$$

The break-point distance R_b, where propagation exponent changes from n_1 to n_2 is given by [13]:

$$R_b = \frac{4 h_b h_m}{\lambda} \qquad (4)$$

Where

- h_b is the base station antenna height in m used to be 6 to 10 meters,

- h_m is the mobile antenna height in m that depends on the car in which users travel,

- λ is the operating wavelength in m.

Typical values of the above mentioned parameters are [8-12]:

- $n_1 = 2.0$,

- $n_2 = 4.0$,

- $\sigma_1 = 3.0$ dB,

- $\sigma_2 = 6.0$ dB,

- $R_b = 200$ to 400 m for the 2.6 GHz band,

- $L_g = 3$ dB for 2.6 GHz band,

- $K_{Rice} = 5$ to 10.

3. DOWNLINK INTERFERENCE ANALYSIS

We will calculate interference in the same way that has been given in our previous work [8-12] modifying some equations to apply it for our studied case. Here the cochannel interference and the adjacent channel interference will be calculated.

A- Cigar-shaped base stations model.

B- Coverage diagram of the two directional antennas used en each base station.
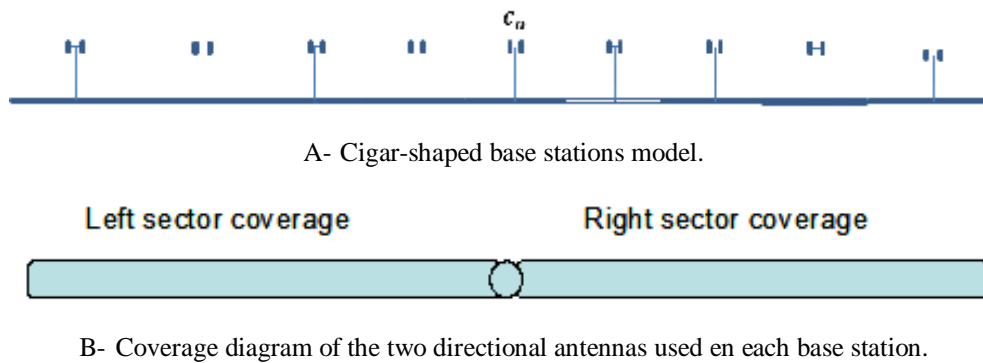
Fig1. *Base stations model and the base station coverage diagram.*

Using the two-slope model of propagation mentioned in Section 2, we will calculate the cochannel and adjacent channel interference statistics (mean value and variance) to find the LTE maximum sector range and bit rate. Fig. 1 shows the configuration of the base stations model accounted for in the analysis and the sector coverage of each one of the two sectors of the microcell. The base stations are assumed to be regularly spaced every 2R (in practice it is impossible to fulfil this assumption). The LTE performance will be studied considering the right sector of the base station C_0. If the user i is at a distance r_{io} from the base station under study (C_0) and at a distance r_{id} from the interfering base station d as shown in Fig. 2. Then the ratio of the interference signal ratio given by a loss like term $L(r_{id}, r_{io})$ due to the distance only is given as:
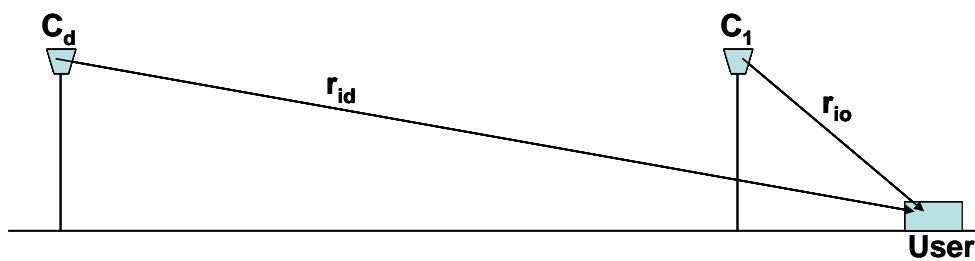

Fig2. *Schematic diagram of base stations and mobiles for highway microcells scenario.*

- For the impractical case when $(r_{id}$ and $r_{io} \leq R_b)$, then the loss like term $L(r_{id}, r_{io})$ is:

$$L(r_{id}, r_{io}) = \left(\frac{r_{io}}{r_{id}}\right)^{n_1} \tag{5}$$

- When $r_{id} > R_b$ and $r_{io} \leq R_b$ then $L(r_{id}, r_{io})$ is given as:

$$L(r_{id}, r_{io}) = \left(\frac{r_{io}}{R_b}\right)^{n_1} \left(\frac{R_b}{r_{id}}\right)^{n_2} \tag{6}$$

- When (r_{id} and $r_{io} > R_b$) then $L(r_{id},r_{io})$ is:

$$L(r_{id}, r_{io}) = \left(\frac{r_{io}}{r_{id}}\right)^{n_2} \tag{7}$$

Taking into account the effect of shadowing, the ratio of the interference signal $L_{shd}(r_{id},r_{io})$ is calculated as:

$$L_{shd}(r_{id}, r_{io}) = 10^{(\xi_{id} - \xi_{io})/10} L(r_{id}, r_{io}) \tag{8}$$

Where ξ_{id} and ξ_{im} are given as

- When (r_{id} and $r_{io} \leq R_b$), $\xi_{id} = \xi_1$ and $\xi_{io} = \xi_1$.
- If $r_{id} > R_b$ and $r_{io} \leq R_b$ then $\xi_{id} = \xi_2$ and $\xi_{io} = \xi_1$.
- When (r_{id} and $r_{io} > R_b$), $\xi_{id} = \xi_2$ and $\xi_{io} = \xi_2$.

The received power P_{rx} of the desired signal of the LTE user under study is given by:

$$P_{rx} = P_{tx} \, 10^{\,(-L_{or}(dB) + G_{TX}(dB) + G_{RX}(dB))/10} \tag{9}$$

where P_{tx} is the transmitted power of the LTE basestation toward the LTE mobile user, L_{or} is the path loss (measured in dB) between the basestation under study and the user at location r, G_{Tx} is the base station antenna gain measured in dB and G_{Rx} is the mobile antenna gain assumed to be 0 dB.

Equation (9) representing the desired signal received power can be rewritten as:

$$P_{rx} = \kappa \, P_{tx} \tag{10}$$

where κ is the propagation gain of the desired signal given as:

$$\kappa = 10^{\,(-L_{or}(dB) + G_{TX}(dB) + G_{RX}(dB))/10} \tag{11}$$

To calculate the received power of the desired signal, the propagation loss L_{or} of this signal should be calculated. Here the effect of both the distance and shadowing is included. For a given availability of α, L_{or} is given as:

$$L_{or}(dB) = L_{Rb} + 10 n_1 \log_{10}\left(\frac{r}{R_b}\right) + L_g + L_{extra} + \sigma_1 \, Q^{-1}(\alpha) + Rice \qquad r \leq R_b \tag{12}$$

$$L_{or}(dB) = L_{Rb} + 10 n_2 \log_{10}\left(\frac{r}{R_b}\right) + L_g + L_{extra} + \sigma_2 \, Q^{-1}(\alpha) + Rice \qquad r > R_b \tag{13}$$

Where $Q^{-1}(\ )$ is the inverse of the Gaussian Q function with a value of 2.05 for an availability of 98% while it is 2.33 for availability of 99%.

The expected value of the cochannel interference power due to N cochannel LTE base stations transmitting their interfering signal through the main lobe of the antenna and M cochannel LTE base stations transmitting their interfering signal through the back lobe of the antenna is given by:

$$E[I_{cc}] = \kappa \sum_{d \in N} P_{tx,d} \, e^{(\beta^2 \sigma^2/2)} \, L(r_{id}, r_{io}) \, Q\left[\beta \sigma + \frac{10 \log_{10}\{L(r_{id}, r_{io})\}}{\sigma}\right] U_d$$

$$+ \kappa \, Bll \sum_{d \in M} P_{tx,d} \, e^{(\beta^2 \sigma^2/2)} \, L(r_{id}, r_{io}) \, Q\left[\beta \sigma + \frac{10 \log_{10}\{Bll * L(r_{id}, r_{io})\}}{\sigma}\right] U_d \tag{15}$$

Where

- $\beta = (\ln 10)/10$,
- σ is standard deviation of shadowing term ($\xi_{id} - \xi_{io}$).

- Q is the Gaussian Q function given by:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-y^2/2} \, dy \tag{16}$$

- U_d is a number equal to 1 if the base station d is on line of sight (LOS) with the user and 0 for the non-line of sight (NLOS) case.
- Bll is the back lobe normalized gain of the transmitting antenna with a typical value of -25 dB to -30 dB.

The variance of shadowing σ^2 that depends on the location of the point under study is given as:

- When (r_{id} and $r_{io} \leq R_b$), $\sigma_{id} = \sigma_1$, also $\sigma_{io} = \sigma_1$ then

$$\sigma^2 = 2 \ (1 - C_{do}) \ \sigma_1^2 \tag{17}$$

Where C_{do} is the inter-sites correlation coefficient of the shadowing parameters ξ_{id} and ξ_{io}. It has a worst case value of 0 and a best case value of 1.

- If $r_{id} > R_b$ and $r_{id} \leq R_b$ then the value of σ^2 is given by:

$$\sigma^2 = (\sigma_1 - \sigma_2)^2 + 2(1 - C_{do})\sigma_1\sigma_2 \tag{18}$$

- When (r_{id} and $r_{io} > R_b$), $\sigma_{id} = \sigma_2$, also $\sigma_{io} = \sigma_2$ then

$$\sigma^2 = 2 \ (1 - C_{do}) \ \sigma_2^2 \tag{19}$$

Let us now calculate the interference variance.

The variance of the cochannel interference power is given by:

$$
\begin{aligned}
\text{var}[I_{cc}] = \kappa^2 \quad &\sum_{d \in N} P_{tx,d}^2 \ e^{2(\beta^2\sigma^2)} \ L(r_{id}, r_{io})^2 \left\{ g_1\left(\frac{r_{id}}{r_{io}}\right) - f_1^2\left(\frac{r_{id}}{r_{io}}\right) \right\} \quad U_d \\
+ \kappa^2 \quad Bll^2 \quad &\sum_{d \in M} P_{tx,d}^2 \ e^{2(\beta^2\sigma^2)} \ L(r_{id}, r_{io})^2 \left\{ g_2\left(\frac{r_{id}}{r_{io}}\right) - f_2^2\left(\frac{r_{id}}{r_{io}}\right) \right\} \quad U_d
\end{aligned} \tag{20}
$$

Where

$$g_1\left(\frac{r_{id}}{r_{io}}\right) = Q\left[2\beta\sigma + \frac{10\log_{10}\{L(r_{id}, r_{io})\}}{\sigma} \right] \tag{21}$$

$$f_1\left(\frac{r_{id}}{r_{io}}\right) = Q\left[\beta\sigma + \frac{10\log_{10}\{L(r_{id}, r_{io})\}}{\sigma} \right] \tag{22}$$

$$g_2\left(\frac{r_{id}}{r_{io}}\right) = Q\left[2\beta\sigma + \frac{10\log_{10}\{Bll * L(r_{id}, r_{io})\}}{\sigma} \right] \tag{23}$$

$$f_2\left(\frac{r_{id}}{r_{io}}\right) = Q\left[\beta\sigma + \frac{10\log_{10}\{Bll * L(r_{id}, r_{io})\}}{\sigma} \right] \tag{24}$$

The effect of the adjacent channel Interference (ACI) presented by ACIR (Adjacent Channel Interference Ratio) has been treated as follows:

If the leakage signal that reaches the user under consideration is transmitted via the main lobe of the base station antenna, Bll is changed by ACIR in equations (15, 20, 23 and 24).

If the leakage signal that reaches the user under consideration is transmitted via the back lobe of the base station antenna, Bll is changed by Bll*ACIR in equations (15, 20, 23 and 24).

The value of the total interference and total variance of the interference are given as:

$$E[I_t] = E[I_{cc}] + E[I_{ac}] \tag{25}$$

$$\text{var}[I_t] = \text{var}[I_{cc}] + \text{var}[I_{ac}] \tag{26}$$

Finally, for a given availability α (usually is 95% to 99%), the average Signal to Interference plus Noise ratio SINR per tone is given by:

$$SINR = \frac{\dfrac{P_{rx}}{N_{tones}}}{\dfrac{Noise}{N_{tones}} + \dfrac{Total \quad Interference}{N_{tones}}} \tag{27}$$

which can be written as:

$$SINR = \frac{P_{rx}}{P_N + ICI + E[I_t] + Q^{-1}(\alpha) \sqrt{\text{var}[I_t]}} \tag{28}$$

Where N_{tones} is the number of LTE subcarriers, P_N is the thermal noise of the entire channel band and ICI is the inter-carriers interference due to the movement of the user (Doppler effect causing frequency offset) and It is the total interference due to the cochannel and adjacent channel interference.

4. NUMERICAL RESULTS

Using the results of Section 3, some numerical results will be given. For our calculations we assume the following values. The inter-sites correlation coefficient $C_{do} = 0.5$, $n_1 = 2$, $n_2 = 4$, $\sigma_1 = 3$ dB, $\sigma_2 = 6$ dB, $R_b = 250$ m, $R = 1000$ m, and availability of 99% unless other values are mentioned. Also we assume that the base station transmitted power to each one of the two directions of the microcell is 2 W, the mobile receiver noise figure is 7 dB, and the frequency of operation is 2.6 GHz. The LTE bandwidth is assumed to be 10 MHz with 600 subcarriers. The inter-carrier interference (ICI) has been calculated assuming a user velocity of 120 Km/hr [14]. The antenna used in each sector is assumed to have a gain of 12 dB (with 3 dB beam width of 42°*42°) and a front to back level of 20 dB. ACIR of -30 dB is assumed.

Table 1 shows the modulations schemes considered and the SNIR necessary to support them. Each modulation scheme consists of the type of modulation (for example, 64QAM) and the code rate (for example, 0.64).

Table1. *Modulation schemes and their associated SINR.*

Order	Modulation scheme	SNIR (dB)
0	No service	< -3.4
1	QPSK 0.17	-3.4
2	QPSK 0.23	-2.3
3	QPSK 0.29	-1.4
4	QPSK 0.36	-0.4
5	QPSK 0.45	0.8
6	QPSK 0.55	2.7
7	QPSK 0.64	5.3
8	16QAM 0.5	6.8
9	16QAM 0.55	7.5
10	16QAM 0.62	8.5
11	16QAM 0.72	10.0
12	16QAM 0.80	11.4
13	64QAM 0.64	14.0
14	64QAM 0.68	14.5
15	64QAM 0.78	15.8
16	64QAM 0.82	17.1
17	64QAM 0.91	19.8

We will study the LTE performance assuming a frequency reuse factor of 2.

Firstly we will present the case when the car is moving toward the transmitting antenna (L_{extra} from left side = 0 dB, L_{extra} from right side = 10 dB).

Fig. 3 shows the SINR as a function of the distance between the base station and the LTE mobile users. It can be noticed that the SINR is 28.94 dB for the LTE user at 100 m from the base station. At the sector border it falls to 9.78 dB.
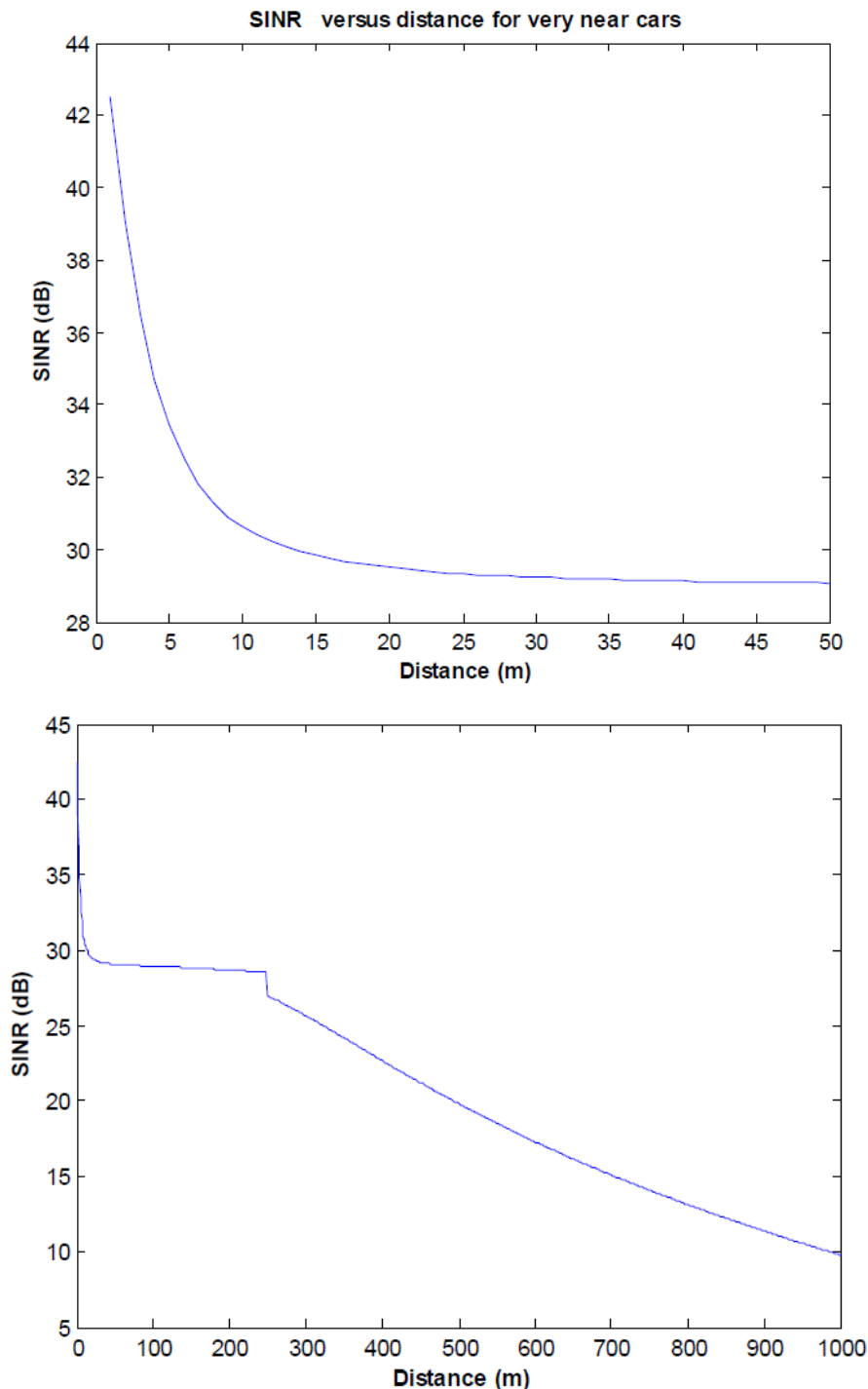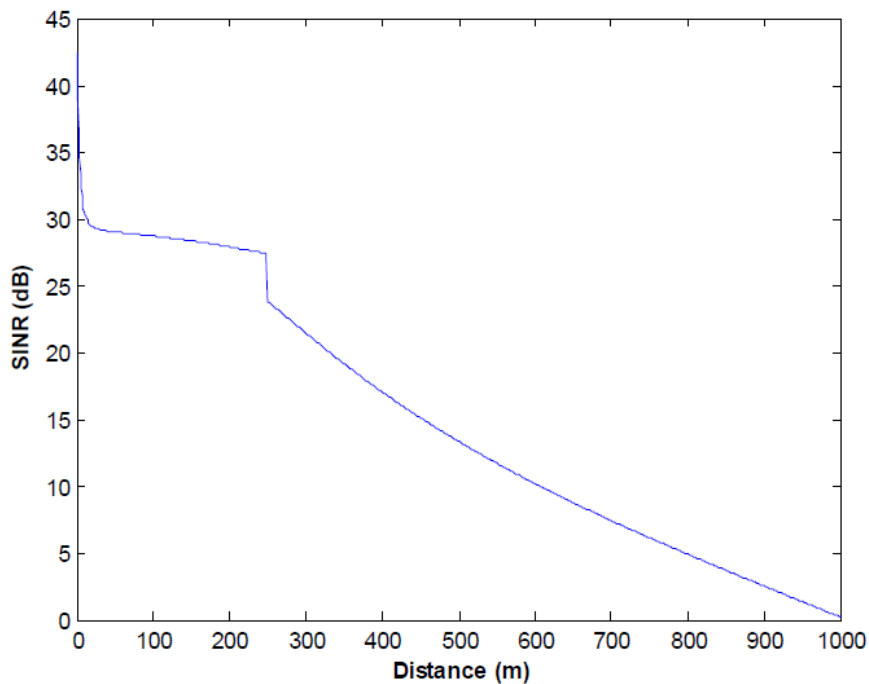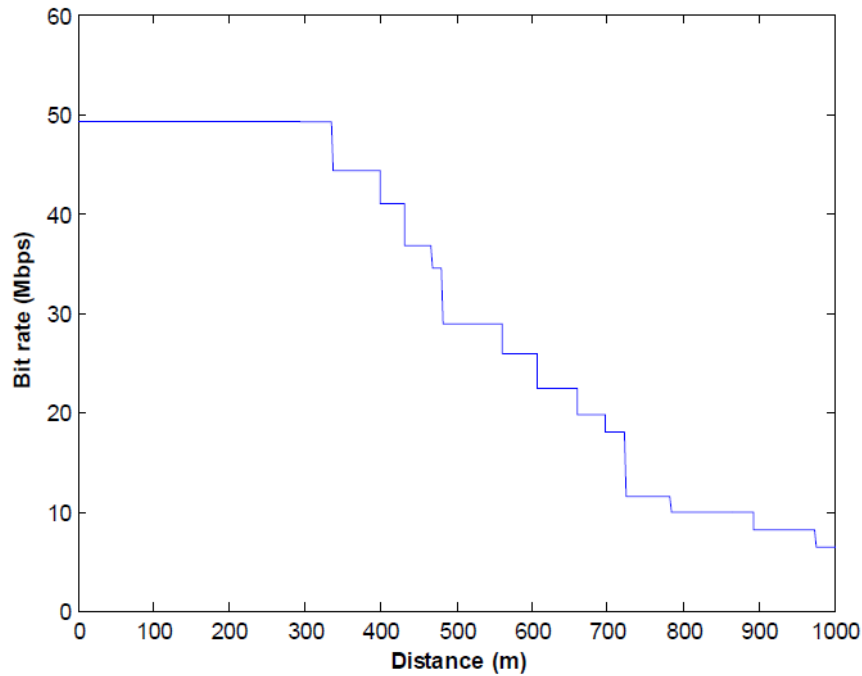

Fig3. *SINR as a function of the LTE user distance from the base station when the car is moving toward the transmitting antenna.*

The rapid change of SINR for users in cars very near to the base station is due to the rapid change of the Doppler frequency (due to the change of the angle between the base station antenna and velocity vector) and the effect of the vertical and horizontal radiation pattern of the base station directive antenna. We have to mention that, up to the R_b distance the most effective factor that limits the SINR is the inter-carrier interference. For a distance higher than R_b, the noise power and the co-channel interference will also affect the SINR value.

Fig. 4 shows the bit rate of the LTE user as a function of the distance between the base station and the LTE user. For a small distance between them, the bit rate reaches value of 49.14 Mbps. At the sector border, the bit rate falls to 22.32 Mbps. The average bit rate of this direction of the sector is 41.65 Mbps.
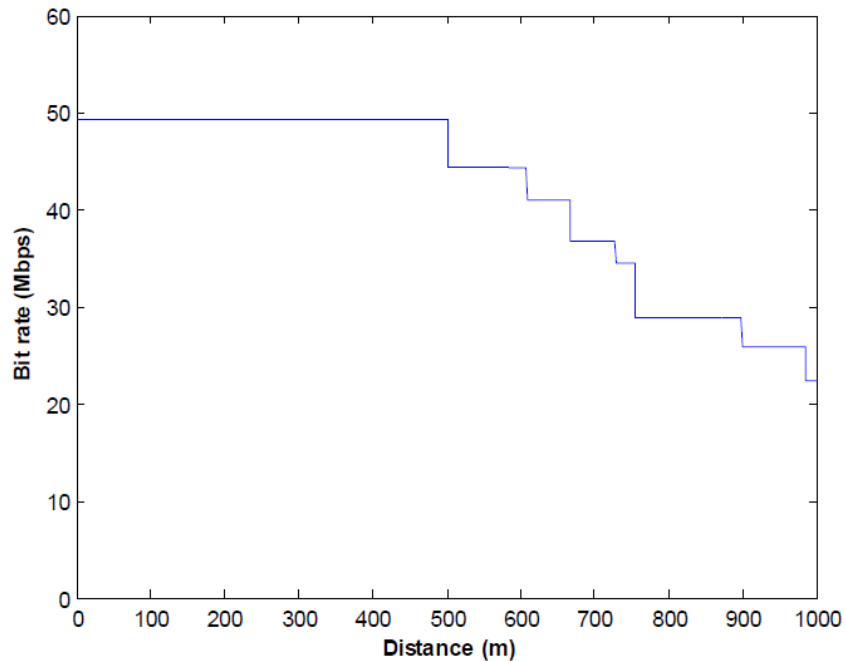
Fig4. *Data rate of the LTE user as a function of the distance from the base station when the car is moving toward the transmitting antenna.*

From Figures 3 and 4, it can be noticed that SINR near to the base station is high enough to support other higher modulations outside the standard.

Now we will present the case when the car is moving far away from the transmitting antenna (L_{extra} from left side = 10 dB, L_{extra} from right side = 0 dB).
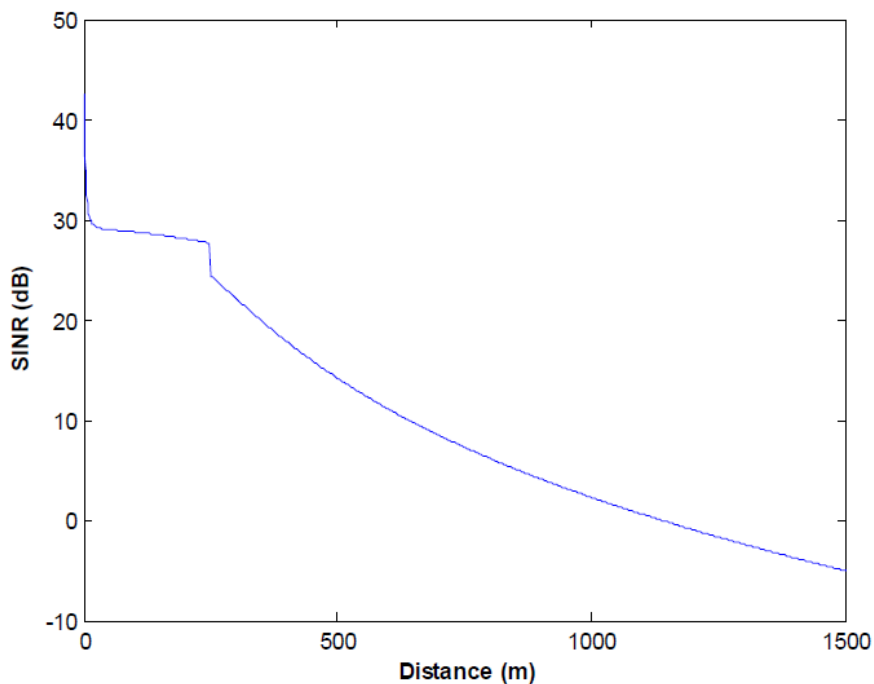

Fig5. *SINR as a function of the LTE user distance from the base station when the car is moving far away from the transmitting antenna.*

Fig. 5 shows the SINR as a function of the distance between the base station and the LTE mobile users. It can be noticed that the SINR is 28.73 dB for the LTE user at 100 m from the base station. At the sector border it falls to 0.22 dB.

Fig6. *Data rate of the LTE user as a function of the distance from the base station when the car is moving far away from the transmitting antenna.*

Fig. 6 shows the bit rate of the LTE user as a function of the distance between the base station and the LTE user. For a small distance between them, the bit rate reaches value of 49.14 Mbps. At the sector border, the bit rate falls to 6.48 Mbps. The average bit rate of this direction of the sector is 30.90 Mbps.

The average bit rate of the all of the sector is 36.27 Mbps.

Now we will present the case when the car is moving far away from the transmitting antenna for R = 1500 m.

Fig7. *SINR as a function of the LTE user distance from the base station when the car is moving far away from the transmitting antenna for R = 1500 m.*

Fig. 7 shows the SINR as a function of the distance between the base station and the LTE mobile users. At the sector border it falls to -5.03 dB.
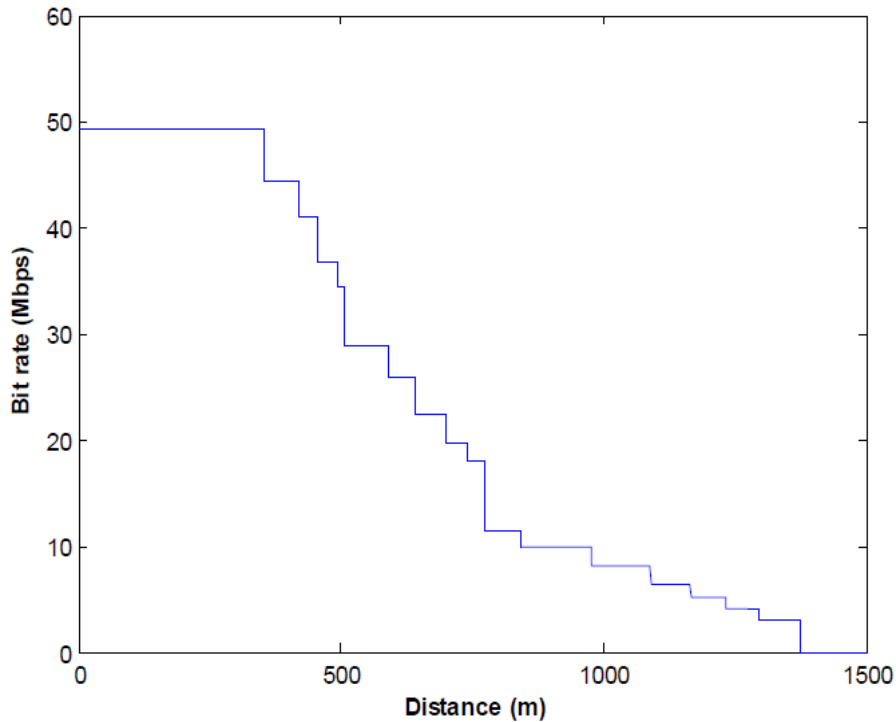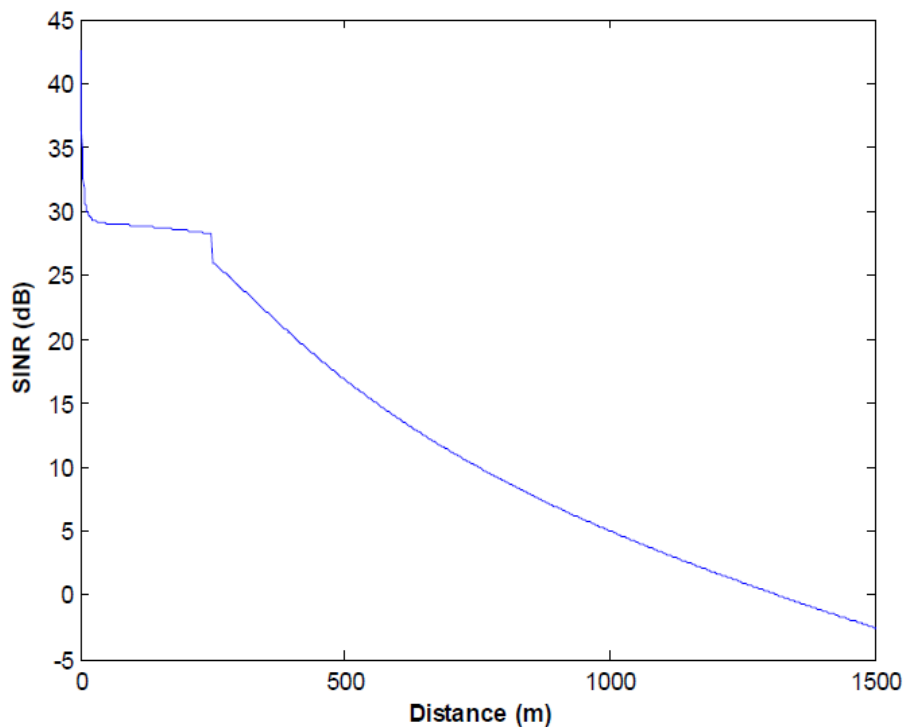
Fig8. *Data rate of the LTE user as a function of the distance from the base station when the car is moving far away from the transmitting antenna for R = 1500 m.*

Fig. 8 shows the bit rate of the LTE user as a function of the distance between the base station and the LTE user. For a small distance between them, the bit rate reaches value of 49.14 Mbps. At the sector border, the bit rate falls to 0 Mbps. For a distance of 1375 m, no service is supported. Thus it is not acceptable to have R = 1500 m when the transmitted power is 2 W.Now we will present the case when the car is moving far away from the transmitting antenna for R = 1500 m and a transmitted power of 4W.

Fig9. *SINR as a function of the LTE user distance from the base station when the car is moving far away from the transmitting antenna for R = 1500 m and a transmitted power of 4 W.*

Fig. 9 shows the SINR as a function of the distance between the base station and the LTE mobile users. At the sector border it falls to -2.54 dB.
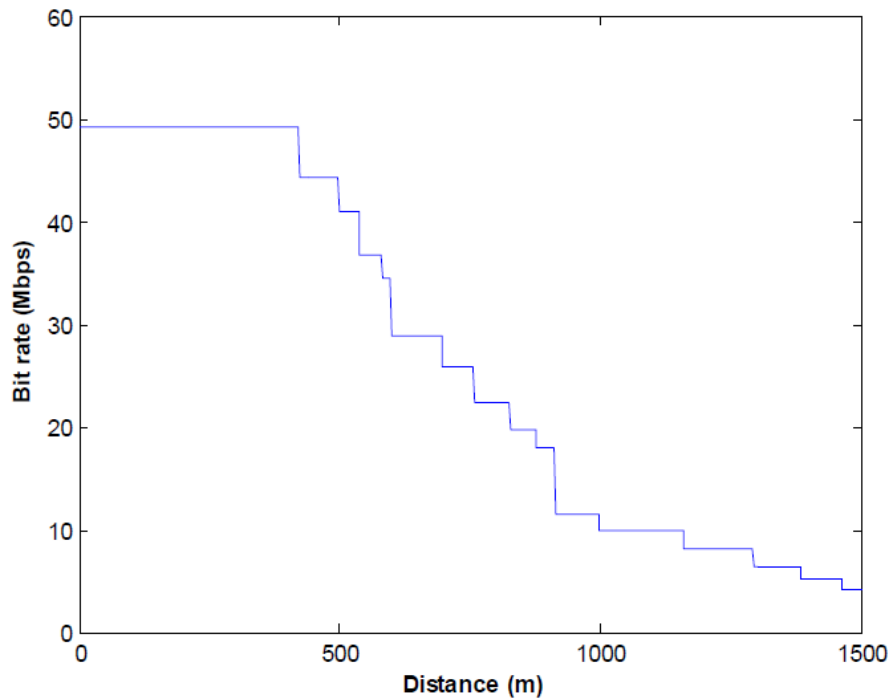
Fig10. *Data rate of the LTE user as a function of the distance from the base station when the car is moving far away from the transmitting antenna for R = 1500 m and a transmitted power of 4 W.*

Fig. 10 shows the bit rate of the LTE user as a function of the distance between the base station and the LTE user. For a small distance between them, the bit rate reaches value of 49.14 Mbps. At the sector border, the bit rate falls to 3.06 Mbps. The average bit rate of this direction of the sector is 26.58 Mbps.

The maximum sector range with a transmitted power of 4 W is 1637 m.

For a receiver noise figure of 6 dB, the maximum sector range that can be supported with a transmitting power of 4 W is 1716 m.

When 2*2 MIMO is applied, the bit rate can be doubled [5]. Fig. 11 shows the data rate of the LTE user as a function of the distance from the base station when the car is moving toward the transmitting antenna using a 2×2 MIMO. The maximum bit rate is 98.28 Mbps. At sector edge the bit rate reduced to 44.64 Mbps.
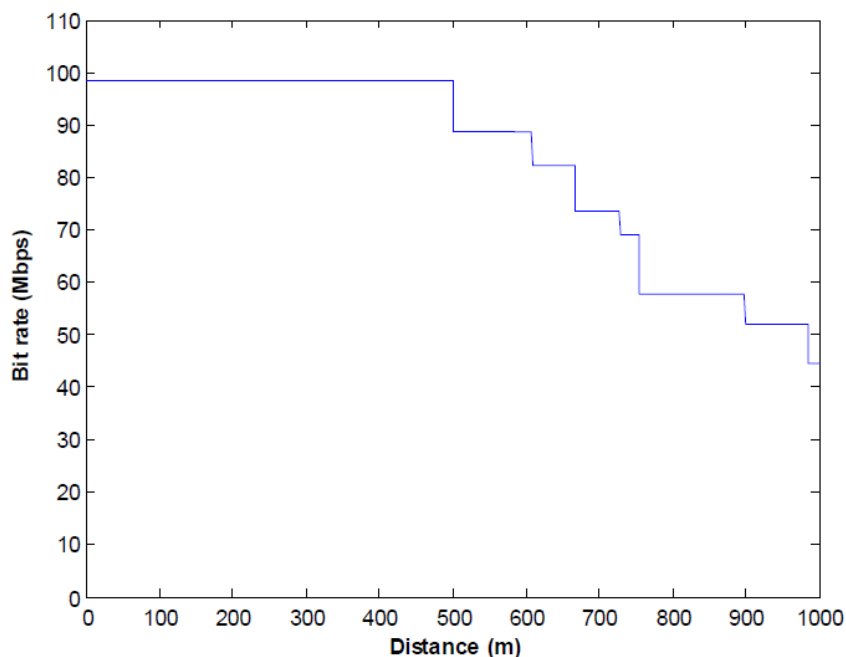

Fig11. *Data rate of the LTE user as a function of the distance from the base station when the car is moving toward the transmitting antenna when 2×2 MIMO is used.*

Table2. *Maximum sector range versus the transmitted power for the 2600 MHz working band and 10 MHz bandwidth for R_b = 250 m.*

Sector transmitted power (W)	Maximum sector range (m)
1	1145
2	1356
3	1488
4	1609

Table3. *Maximum sector range versus the transmitted power for the 800 MHz working band and 10 MHz bandwidth for R_b = 250 m.*

Sector transmitted power (W)	Maximum sector range (m)
1	2052
2	2428
3	2709
4	2883

Here base station antenna should be at a height of 30 meter. Comparing the results of Tables 2 and 3, it can be noticed that the maximum sector range in Table 3 is almost 80% higher than its value in Table 2.

Table 4: *Maximum sector range versus the transmitted power for the 800 MHz working band and 10 MHz bandwidth for R_b = 80 m.*

Sector transmitted power (W)	Maximum sector range (m)
1	1163
2	1377
3	1516
4	1631

Comparing the results of Tables 2 and 4, it can be noticed that the maximum sector range in Table 3 is little bit higher than its value in Table 2. With R_b of 77 meter, results will be almost equal.

If a channel bandwidth of 20 MHz is used, the peak download bit rate will be 98.28 Mbps.

For lower value of σ_2, the maximum supported range will be higher than the up given ranges. Also for lower availability α, the maximum supported range will be higher than the up given ranges. For lower R_b, the maximum supported range will be lower.

Since a directive antenna is used in the base station and an almost LOS ray also exists between the base station and LTE user then Rice fading from nearby objects (if they exists) is expected.

Let us now study the effect of small scale fading assuming that Rice fading takes place.

Firstly, let us study the case when K is 10. Fig. 12 shows the data rate of the LTE user as a function of the distance from the base station when the car is moving far away from the transmitting antenna with Rice fading when K = 10. It can be seen that there is a point at which there is not any LTE service.
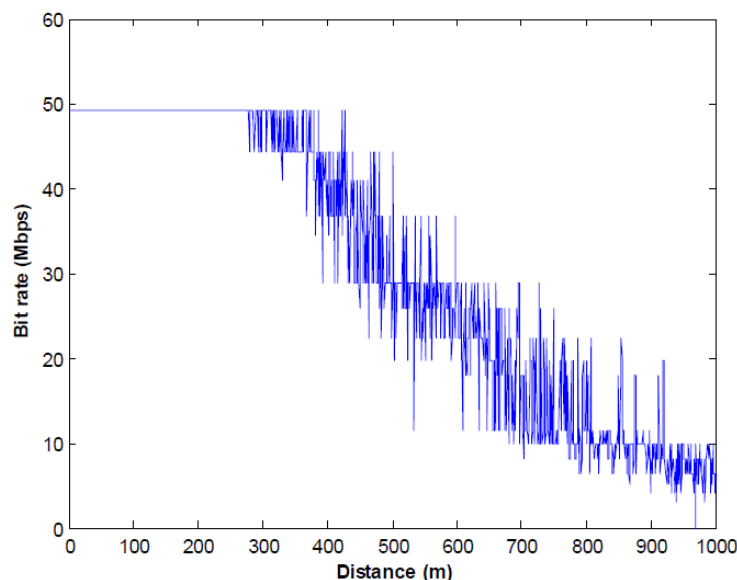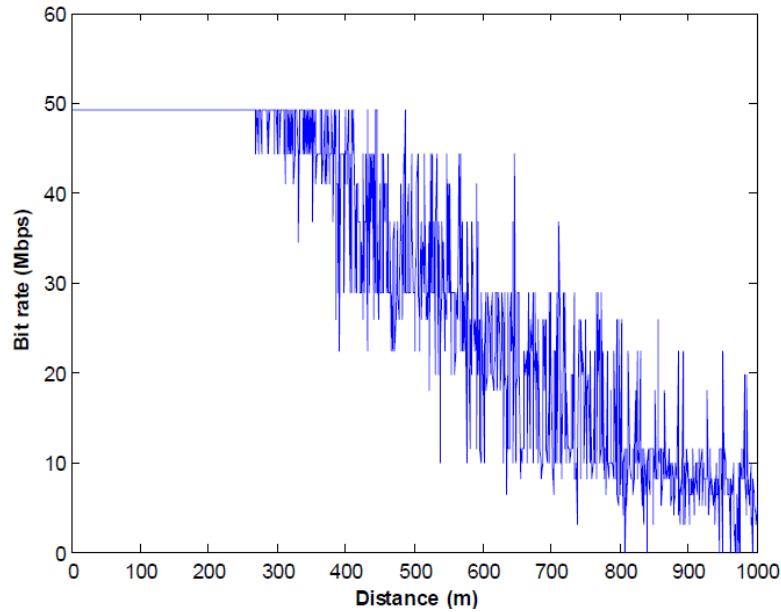

Fig12. *Data rate of the LTE user as a function of the distance from the base station when the car is moving far away from the transmitting antenna with Rice fading when K = 10.*

Secondly, let us study the case when K is 5. Fig. 13 shows the data rate of the LTE user as a function of the distance from the base station when the car is moving far away from the transmitting antenna with Rice fading when K = 5. It can be seen that there are many point at which there is not any LTE service.

Fig13. *Data rate of the LTE user as a function of the distance from the base station when the car is moving far away from the transmitting antenna with Rice fading when K = 5.*

To solve this, the transmitted power, the break point distance and the base station antenna gain should be increased. The break point distance can be increased increasing the base station antenna height.
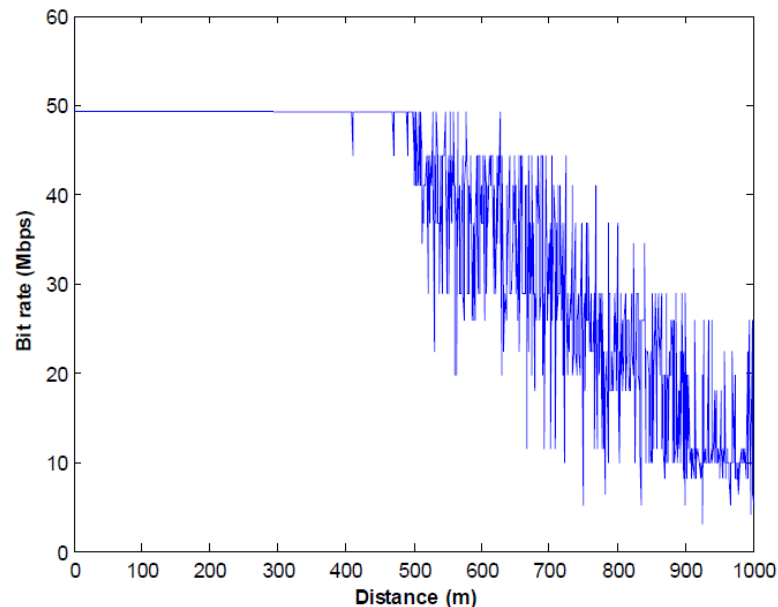
Fig. 14 shows the data rate of the LTE user as a function of the distance from the base station when the car is moving far away from the transmitting antenna with Rice fading when K = 5, R_b = 500 m, G_{tx} = 14 dB and P_{tx} = 4 W. Here the points without LTE service have been disappeared.

Fig14. *Data rate of the LTE user as a function of the distance from the base station when the car is moving far away from the transmitting antenna with Rice fading when K = 5, R_b = 500 m, G_{tx} = 14 dB and P_{tx} = 4 W.*

In Time Division Duplex (TDD) mode of operation, LTE use the same channel for uplink and downlink transmission. Possible Downlink time to (Downlink + Uplink) time could be 40% to 90%. To mitigate the effect of multipath, guard time is used. This will reduce the effective downlink bit rate. For the above given reasons, downlink effective bit rate could be 28% to 66% of the above given values of bit rate.

Using a frequency reuse of 3, the mean bit rate of the sector increases only 3% with the cost of using 150% bandwidth. Thus it is better to use the frequency reuse of 2.

In appendix A, the base station antenna gain as a function of the user distance from the base station is shown by Fig. A1. The Doppler frequency as a function of the user distance from the base station is depicted in Fig. A2. At a distance of 400 m form the base station, the base station antenna gain and the Doppler frequency almost reach their final values at very high distance.

5. CONCLUSIONS

In this work, the performance of LTE systems (SINR, modulation schemes and downlink bit rate) for cigar-shaped microcells at highways is studied. The two-slope propagation loss model has been used to calculate the signal to interference plus noise ratio taking into account the expected value and the variance of the interference. A model of ten cigar-shaped microcells is used in the LTE performance analysis. For the frequency band of 2.6 GHz with 10 MHz bandwidth, the base station transmitted power should be 2 W to get a sector range of 1356 m meanwhile it should be 3.1 W to get 1500 m sector range. For the 800 MHz frequency band, maximum range of 2909 can be got with a transmitted power 4W when the break point distance R_B is maintained at 250 m. With a frequency reuse of 2, a sector bit rate up to 41.65 Mbps can be got with a 10 MHz bandwidth meanwhile for a frequency reuse of 3, the mean bit rate of the sector will be 42.9 Mbps with the cost of using 150% bandwidth. Small scale fading affects the SINR of the LTE user and consequently the downlink bit rate.

Appendix A
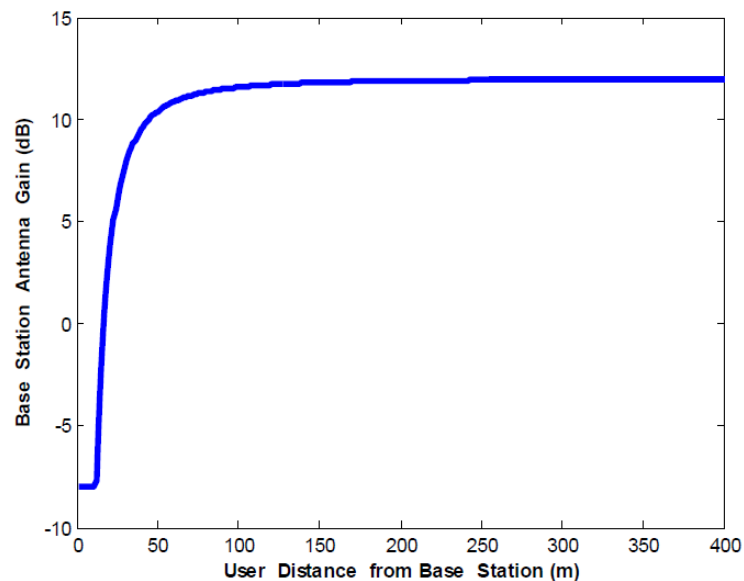
FigA1. *Base station antenna gain as a function of user distance from it.*
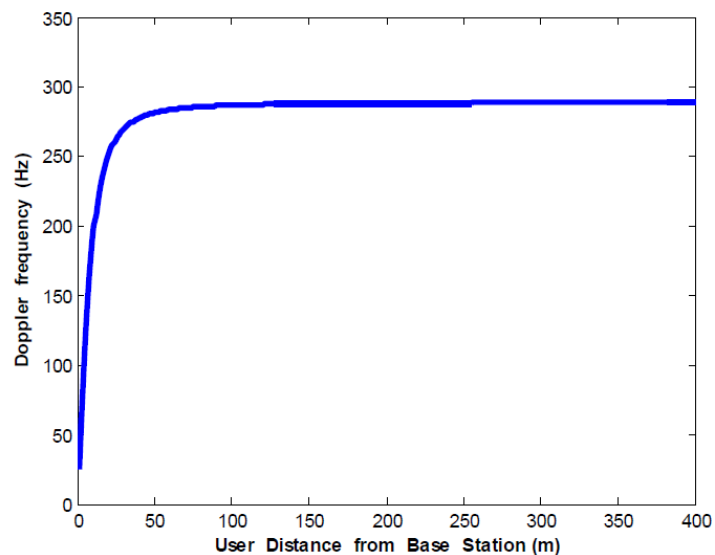
FigA2. *Doppler frequency as a function of user distance from the base station (v = 120 Km/hr).*

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