EE451 - Communication Systems II

Project: P13

Cell Coverage Area and Link Budget Calculation for LTE-based Cellular Networks

Final Project Report
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Group Members:

Elif Tansu Sunar #230206032
Emine Acar #220206025
Zeynep Aylanç #220206020

1. Introduction

Long Term Evolution or as known as LTE is a mobile communication standard. The name implies that thanks to this standard data could travel and be valid for a long time to come. Considering LTE cellular networks, mobile data could be transferred in the air with larger amounts and higher speeds in comparison to earlier wireless communication standards. The LTE standards are mostly defined in the 3rd Generation Partnership Project (3GPP) which is a global consortium of organizations that develop mobile telecommunication protocols [1].

The protocols and standards state the parameters and their optimal values for the most efficient and reliable communication network. The plan of the reliable communication network starts with the calculation of the Link Budget. Link Budget calculations generate an estimation of all of the gains and losses on the network which start from the transmitter through the medium/channel and receiver. Link budget calculation provides also the prediction of maximum allowed signal attenuation between the transmitter and receiver parts of the network. Additionally, these calculations give information about the number of subscribers who could get service from the communication system in a significant cell coverage area on an LTE system, Long Term Evolution is a 4G standard. It provides high-speed data and voice cellular services [2].

As it has been written link budget calculations with cell coverage area simulations indicate the reliability of any communication system. This project aims to determine the link budget calculations and simulate the cell coverage area with specified numbers of users to figure out the rate of reliable communication. The problem consists of one base station as a transmitter and 1000 users in given two different areas which are urban and rural.

2. System Model and Design

2.1 Path Loss

In a wireless communication system, fading can occur in two different ways as large-scale or small-scale fading in the channel. Large scale variations of the signal according to the distance are caused by large scale fading. The average of the signal at any distance from the transmitter to the receiver gives a straight line, the slope and the intercept of this line gives the expression for the path loss. Generally, the path loss can be expressed as a loss on the signal strength as a function of distance. Assuming that, the receiver and the transmitter are in free space and there are no obstacles between them, the free space path loss can be calculated by the formula:

$$Path\ loss = Pt(dB) - Pr(dB)$$

where $Pt(dB)$ is the transmitted power and $Pr(dB)$ is received power.

The path loss is generally a function of the terrain like urban or rural, frequency, and antenna height. A large number of measurements results from more different available frequencies and sites. Then, the empirical models become more popular. The examples of empirical models are the Okumura-Hata model and the Cost-231 model [3][4]. Also, there is another path loss model determined by the 3GPP.

2.1.1. Hata Model

For urban areas the path loss:

$$PL_u = 69.55 + 26.16 log_{10}(fc) - 13.82 * log_{10}(hb) - a(hm) + [44.9 - 6.55 * log_{10}(hb)] * log_{10}(d) \text{ [dB]}$$

where a(hm) is equal to for small and medium-sized cities:

$$a(hm) = 0.8 + (1.1 * log_{10}(fc) - 0.7) * hm - 1.56 * log_{10}(fc) \text{ [dB]}$$

For larger sized cities;

$$a(hm) = 8.29 * (log10(1.54 * hm))^2 - 1.1 \quad \text{[dB]}, \quad for\ fc \leq 400 \text{ [MHz]}$$
$$a(hm) = 3.2 * ((log10(11.75 * hm))^2 - 4.97 \text{ [dB]}, \quad for\ fc \geq 400 \text{ [MHz]}$$

For rural areas the path loss:

$$PL_r = PL_u - 4.78 * (\log_{10}(fc))^2 + 18.33 * log_{10}(fc) - 40.94 \text{ [dB]}$$

2.1.2. Cost-231 Model

$$PL = 46.3 + 33.9 * log_{10}(fc) - 13.82 * log_{10}(hb) - a(hm) + (44.9 + 6.55 * log_{10}(hb)) * log_{10}(d) + C \text{ [dB]}$$

$$a(hm) = 8.29 * (log10(1.54 * hm))^2 - 1.1 \quad \text{[dB]}, \quad for\ fc \leq 400 \text{ [MHz]}$$
$$a(hm) = 3.2 * ((log10(11.75 * hm))^2 - 4.97 \text{ [dB]}, \quad for\ fc \geq 400 \text{ [MHz]}$$

C = 0 , for medium cities and suburban areas
C = 3 dB , for large city centers.

2.1.3. 3GPP Model

For urban areas the path loss:

$$PL_u = 40 * (1 - (4.10^{-3}) * hb) * log_{10}(d) - 18 * log_{10}(hb) + 21 * log_{10}(fc) + 80 \text{ [dB]} \qquad [5]$$

For rural areas the path loss:

$$PL_r = 69.55 + 26.16 * log_{10}(fc) - 13.82 * log_{10}(hb) + [44.9 - 6.55 * log_{10}(hb)] * log_{10}(d) - 4.78 * (\log_{10}(fc))^2 + 18.33 * log_{10}(fc) - 40.94 \text{ [dB]} \qquad [6]$$

- hb is the height of the base station antenna
  - $0 \leq hb \leq 50$ [m] , for 3GPP Model for Urban Area[7]
  - $30 \leq hb \leq 200$ [m] , for Hata Model & 3GPP Model for Rural Area[8]
  - $30 \leq hb \leq 300$ [m] , for Cost-231 Model
- hm is the height of the mobile station antenna
  - $1 \leq hm \leq 10$ [m] , for Hata Model
  - $1 \leq hm \leq 10$ [m] , for Cost-231 Model
- fc is carrier frequency/ frequency of transmission
  - $150 \leq fc \leq 1500$ [MHz] , for Hata Model & 3GPP Models[9]
  - $1.5 \leq fc \leq 2$ [GHz] , for Cost-231 Model
- a(hm) is antenna height correction factor
- d is the distance between Base Station and Mobile Station [10]

2.2 Shadowing

In wireless communication systems, the signal which comes from the transmitter may be diffracted, reflected, or scattered due to obstacles (trees, buildings, etc.) between the transmitter and receiver. Hence, there are some fluctuations in the received power, and this fluctuation is called the shadowing effect. The shadowing effect may change depending on the geographical position and radio frequency [11]. Thus, it is modeled as a random process that has a distribution of log-normal distribution. The log-normal distribution of φ which represents the shadowing is:

$$p(\varphi) = \frac{1}{\sqrt{2\pi\sigma_{\varphi dB}}} \exp\left[-\frac{(\varphi_{dB} - \mu_{\varphi dB})^2}{2\sigma_{\varphi dB}^2}\right]$$

where $\mu_{\varphi dB}$ is the mean and $\sigma_{\varphi dB}$ is the variance of the φ_{dB} in dB. When the mean is equal to zero the distribution of the shadowing is becoming to have a normal distribution in dB model. Typical values for variance are for rural is 3dB, for suburban is 6dB and for urban it is 8dB [12].

The combination of shadowing and path loss which is generally called combined path loss and shadowing in the literature is in the linear model as follows:

$$\frac{P_r}{P_t} = K\left(\frac{d}{d_0}\right)^2 \varphi$$

and in dB:

$$\frac{P_r}{P_t}(dB) = 10log_{10}K - 10\gamma log_{10}\left(\frac{d}{d_0}\right) - \varphi_{dB}$$

In the wireless communication systems, with shadowing the received power that at any distance from the transmitter is log-normally distributed with some probability of falling below P_{min} which the target minimum is received power level. If the received power is below this value, the performance of the channel is not acceptable. The outage probability is defined for the probability that the received power $P_r(d)$ at a given distance d, falls below P_{min} under the condition of occurrence of combined path loss and shadowing. The outage probability can be shown as $P_{out}(P_{min}, d) = p(P_r(d) \leq P_{\min})$ which is:

$$p(P_r(d) \leq P_{\min}) = 1 - Q\left[\frac{P_{\min} - \left(P_t + 10logK - \frac{10\gamma \log d}{d_0}\right)}{\sigma_{\varphi dB}}\right]$$

where the Q-function is defined as the probability that a Gaussian random variable X with mean zero and variance 1 is greater than z.

2.3 Link Budget

In a communication system, the losses and the gains of the signal which travels from the transmitter to receiver will compose link calculation. With the help of the link calculations, cell Radius and the coverage area could also be found. In general, the following expression is used in link budget calculations;

Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) – Losses (dB) [13]

To calculate the link budget in radio systems, some specifications must be determined correctly. In radio communications, the omnidirectional antennas which are a real class of antenna and have uniform radiation in two dimensions on the contrary to isotropic antennas, are not commonly used so antenna gain must be considered during the calculation [14].

In radio applications between the transmitter and the receiver, the following application could be used;

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX}$$

- P_{RX} is for received power (dBm)
- P_{TX} is for transmitted power (dBm)
- G_{RX} is for antenna gain of the receiver (dBi)
- G_{TX} is for antenna gain of the transmitter (dBi)
- L_{TX} is for losses of the transmitter (dB)
- L_{FS} is for path loss, usually free space loss (dB)
- L_M is for miscellaneous losses (fading margin, body loss, polarization mismatch, etc.) (dB)
- L_{RX} is for receiver losses (coax, connecters, etc.) (dB)

2.4 Cell Coverage Area

A cell coverage area is a small part of the cellular network which is a wireless radio network that is distributed over small cells. Cellular networks provide services for many usages of mobile phones, pagers, etc. to communicate with each other. The cell coverage mainly depends on usual causes such as geographical conditions, propagation conditions, and on social causes such as the terrain type (urban, suburban and rural), etc. For this reason, it is sufficient to be able to estimate the propagation conditions accurately for a specified region. Propagation mainly depends on reflection, diffraction, and scattering.

Since the cell coverage area is defined as the expected percentage of area with received power higher than a given minimum, the calculation of cell coverage is can be investigated by firstly consideration of a base station inside a circular cell with radius R. As it is known that a minimum SNR

(Signal-to-noise ratio) value is an important parameter for a communication system for acceptable performance. This minimum acceptable SNR value can be translated to minimum received power P_{min} which is generally named as receiver sensitivity level under some noise and interference assumption. The average received power at the cell boundary $\bar{P}_R$ is designed according to path loss and averaged shadowing variations. But shadowing causes the occurrence of the received power below $\bar{P}_R$ at some locations and other locations the exceeding $\bar{P}_R$ [15].

As seen in Figure 1, the black contour is based on path loss and average shadowing. Constant power contours are for combined path loss and shadowing is seen in the figure, since the combined path loss and average shadowing is the same at a uniform distance from the base station. The path loss and random shadowing contours occur because of the random shadowing variations on the average power. It causes that all the users in the cell boundary are not received the same power.

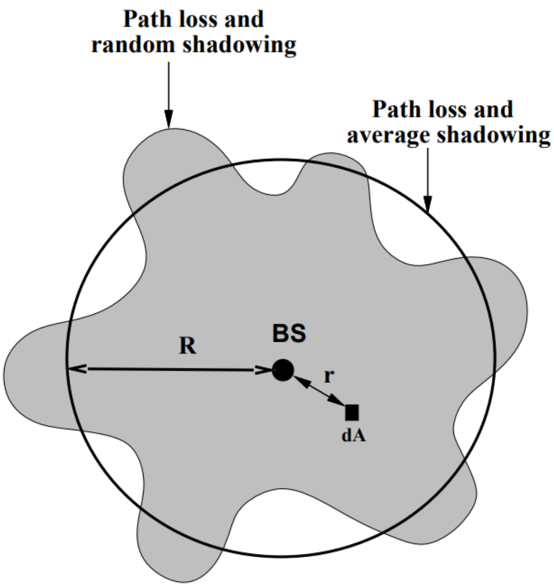

Figure 1: The Contours of Cell Coverage Area [16]

To get rid of this problem, the base station must transmit extra power to transmit the user minimum needed power P_{min}, but this might cause interference between neighbor cells. Also, the proximity to the base station does not change the fact that not receiving minimum power occurrence because of the nature of shadowing which is based on Gaussian distribution. Then, the computation of the cell coverage area is as follows:

$$C = \frac{1}{\pi R^2} \int_{cell\ area} P_A dA = \frac{1}{\pi R^2} \int_0^{2\pi} \int_0^R P_A r dr d\theta$$

where P_A is equal to p(Pr(r) > Pmin) in dA.

The outage probability of the cell is defined as the percentage of area in the cell that does not meet its receiver sensitivity reference level P_{min}. According to path loss and log-normal distribution of shadowing, the outage probability of the cell is:

$$p(P_r \geq P_{min}) = Q[(P_{min} - (P_t + 10logK - 10\gamma \log(\frac{r}{d_0}))/\sigma_{\varphi dB}] = 1 - p_{out}(P_{min}, r)$$

where p_{out} is the outage probability defined in d = r. The meaning of all these equations is the cell coverage area is determined based on the sensitivity reference level. The probability of the received power at any distance not falls below the P_{min} gives the cell coverage area. The result can be considered as to how much percentage of the users is in the cell coverage area. For example, if the result is 0.99, the 99% of the users are in the cell coverage area. If there are 500 users in this cell, only the 495 users are in the cell coverage area. When the minimum power requirement is increased, only the 88% of the users can be in the cell coverage area. This means that only 440 users are in the cell coverage area.

For the detection of the receiver sensitivity reference level P_{min}, there are some factors like:

- System bandwidth
- Noise figure
- Thermal noise
- SNR value according to the chosen modulation scheme and channel coding method [17]

The noise figure is generally represented as:

$$NF = SNR_{input} - SNR_{output}$$

where SNR_{input} is the SNR value at the input of the receiver and SNR_{output} is the SNR value at the output of the receiver. The SNR at the input depends on the input signal power P_i and the noise floor which is determined by the bandwidth BW and the thermal noise that is equal to -174dBm/Hz. Then, the SNR value at the input becomes:

$$SNR_{input}dB = P_i dBm - Nfloor\ dBm$$

The noise floor is equal to:

$$Nfloor\ dBm = -174dBm/Hz - 10logBW$$

Finally, the noise figure becomes:

$$NF = P_i + 174\ dBm/Hz - 10logBW - SNR_{output}$$

From the noise figure and the minimum SNR requirement, the receiver sensitivity level can be calculated with the following formula:

$$P_{min} = -174\ dBm/Hz + NF + 10log_{10}BW + SNR_{o,min}$$

In digital communication systems, the receiver sensitivity can be determined according to the specified bit error rate (BER) or probability of error (PER) value. The maximum BER has specified the minimum output SNR value. The relationship between SNR and BER is coming from the energy per bit to noise spectral density ratio E_b/N_0. BER is a function of the E_b/N_0 the ratio which can be seen in Figure 2 and, the BER can be determined from the constant value of this ratio based on the modulation scheme. Then, the relation of SNR and BER can be given as:

$$SNR_{o,min}dB = 10\log\,(E_b/N_0) + 10\log\,(R/BW),$$

where R represents the data rate [18].

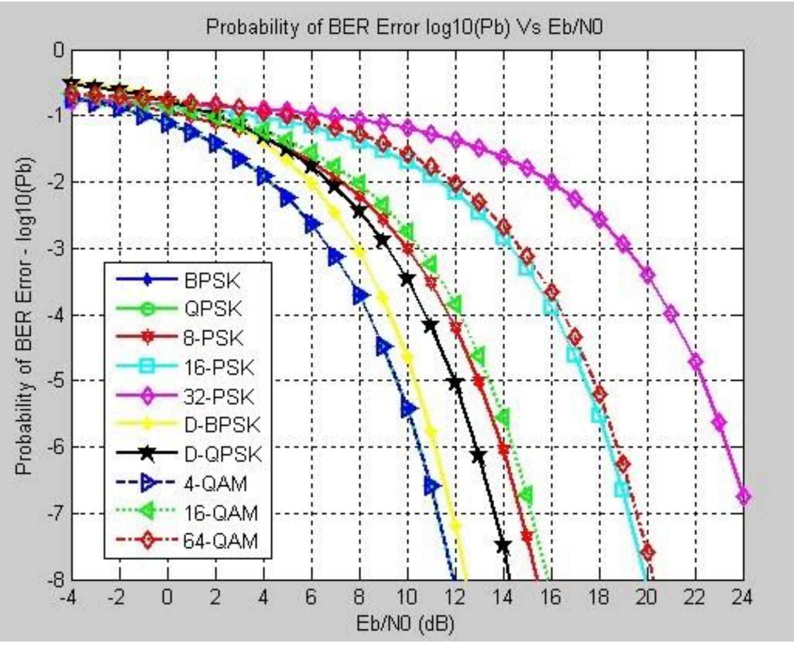

Figure 2: Theoretical BER versus E_b/N_0 Graph for Different Modulation Schemes [19].

According to the 3GPP standards, 16QAM modulation and 2/3 coding rate should be used in the LTE systems. The maximum BER should be equal to 10^{-3} for voice communication and 10^{-6} for video communication. Based on these standards, the E_b/N_0 the ratio is equal to 10dB for voice and 14dB for video communication.

In order to calculate the minimum output SNR, the corresponding data rate could be found according to the chosen transmission bandwidth and the number of resource block which corresponds to a single bandwidth. In LTE standards, there are two types of a frame structure which are the one that uses Frequency Division Duplexing (FDD) and the other one that uses Time Division Duplexing (TDD). FDD is more widely implemented because of prior frequency spectrum assignments and earlier technologies [20]. The illustration of the FDD frame can be seen in Figure 3.

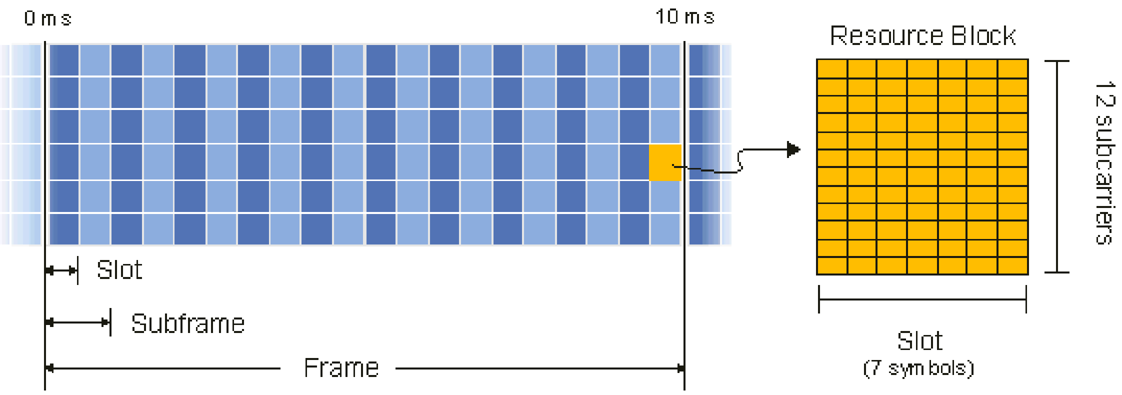

Figure 3: The FDD Frame Illustration [21]

A resource block is the smallest unit of the resources that can be allocated to users. One resource block is corresponding to 180 kHz in the frequency domain and one slot time which is equal to 0.5ms. There are 12 subcarriers for each resource block [22]. The standards of bandwidths, resource block, and according to subcarriers for LTE systems can be seen in the following table:

Bandwidths	**Number of Resource Block**	**Number of Subcarriers (downlink)**	**Number of Subcarriers (uplink)**
1.4 MHz	6	73	72
3 MHz	15	181	180
5 MHz	25	301	300
10 MHz	50	601	600
15 MHz	75	901	900
20 MHz	100	1201	1200

Table 1: The Standards of Bandwidths, Number of Resource Blocks, and Number of Subcarriers for Downlink and Uplink [23]

Considering a 10MHz FDD LTE system, the number of resource block will be 50. The data rate can be calculated as a symbol per second. Because the duration of the resource block is equal to 0.5 ms and there are 7 symbols in each subcarrier, each resource block has 2*7*12=168 symbol per ms. As the number of resource block is equal to 50 in 10MHz, there are 8400 symbols per ms. Since the used modulation scheme is 16QAM, 4 bits per symbol is sent. Then, the data rate will be 8.4*4=33.6 Mbps for a single antenna.

The minimum output SNR value becomes for this system:

$$SNR_{o,min}dB = 10\log(10) + 10\log\left(\frac{33.6Mbps}{10MHz}\right) = 15.2\ dB\ for\ voice\ communication$$
$$SNR_{o,min}dB = 10\log(14) + 10\log\left(\frac{33.6Mbps}{10MHz}\right) = 16.7\ dB\ for\ video\ communication$$

Then the receiver sensitivity level P_{min} becomes:

$$P_{min} = -174\ \text{dBm} + 5\ \text{dB} + 10log_{10}10MHz + 15.2\ dB = -53.8\ dBm\ for\ voice\ com.$$

$$P_{min} = -174\ \text{dBm} + 5\ \text{dB} + 10log_{10}10MHz + 16.7\ dB = -52.3\ dBm\ for\ video\ com.$$

3. Numerical Results

For the implementation of the problem, the MATLAB environment is used. Firstly, the change of the path loss based on the distance from the base station is implemented. The radiuses of the cell areas are taken 50 km for rural and 15 km for the urban area. The path loss model is chosen as the 3GPP model which is derived from the Hata model because of the simplicity and the accuracy of the 3GPP model. The most used LTE frequency bands which are used in Turkey are 800 MHz, 900 MHz, 1800MHz, and 2100 MHz[17]. The path loss versus distance graph urban terrain can be seen in Figure 4 and for the rural area, it can be seen in Figure 5 based on four different frequency bands.

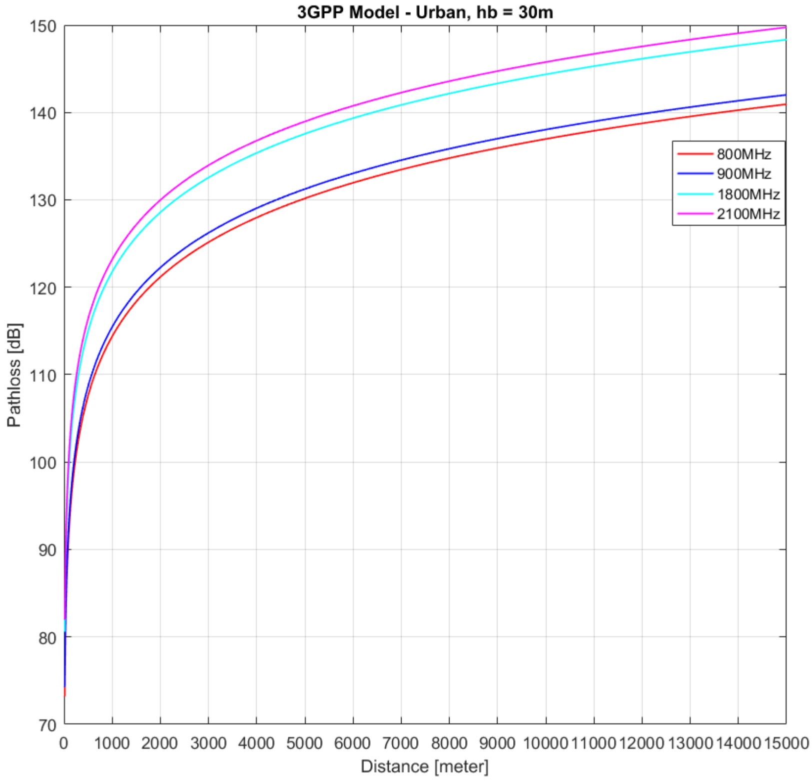

Figure 4: The Pathloss - Distance Graph for Urban Area

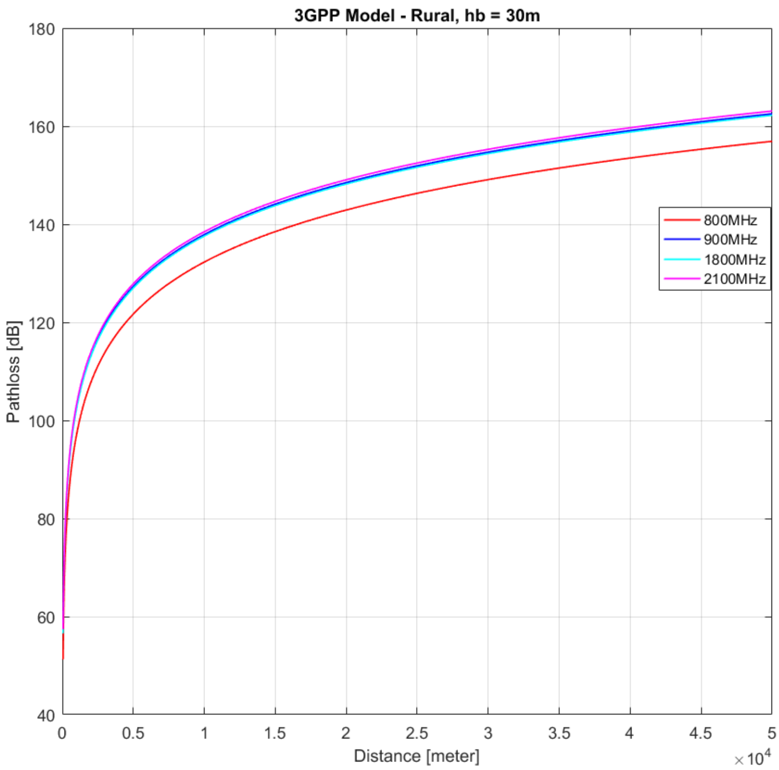

Figure 5: The Pathloss - Distance Graph for Rural Area

According to Figure 4 and Figure 5, path loss and distance have a logarithmic relationship for both two terrain types when the distance is increasing the path loss value is also increasing. Moreover, the path loss is much higher in the urban area as regards the rural area at the same base station antenna height and same frequency values. The frequency effect on the path loss in the urban area only depends on the $21 * log_{10} f_c$ the parameter in the 3GPP model formula. The difference between the effect of frequency at 800 MHz and 2100 MHz is approximately 9dB from the formula, and it is observed in Figure 4. Since, there are buildings, trees, vehicles, etc. in the urban area and they may cause reflection, diffraction, or scattering of the signal during the propagation. Besides, the shadowing fading is added two the system. Because of the nature of the shadowing fading which has a log-normal distribution, random values around the path loss values at each distance are obtained for urban and rural areas at 800 MHz and 2100 MHz. As seen in Figure 6, Figure 7, Figure 8, and Figure 9, the effect of the shadowing is randomly changing as expected. This randomness indicates that the user can be anywhere at any time instant.

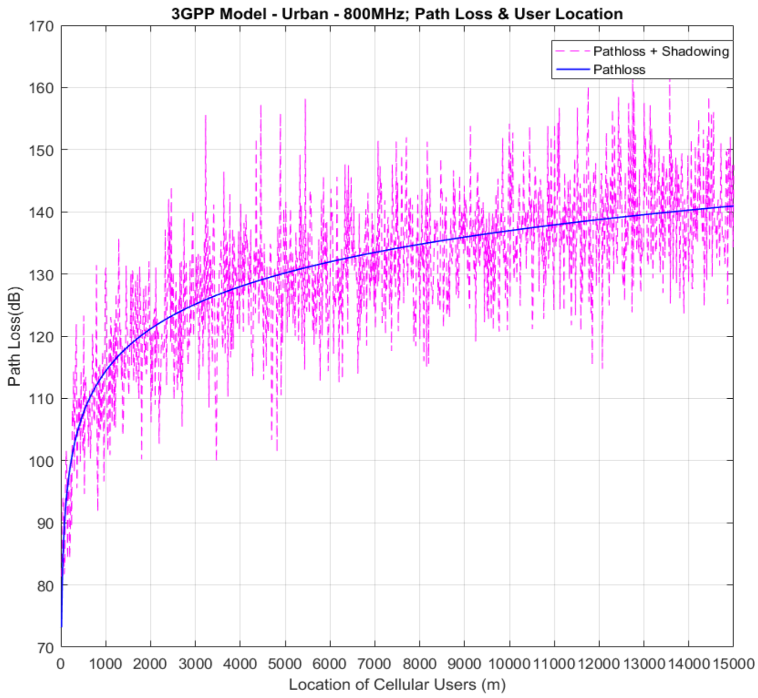

Figure 6: Combined Pathloss and Shadowing - Distance Graph at 800MHz in Urban Area

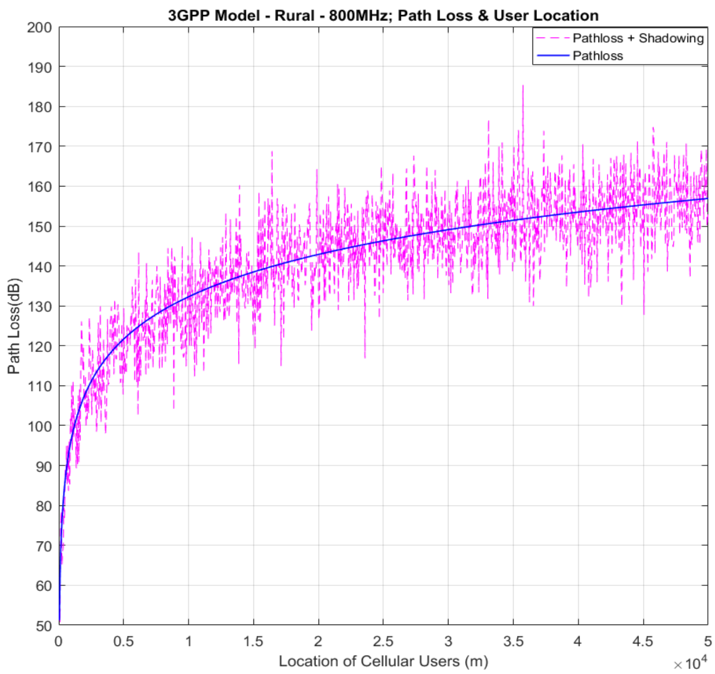

Figure 7: Combined Pathloss and Shadowing - Distance Graph at 800MHz in Rural Area

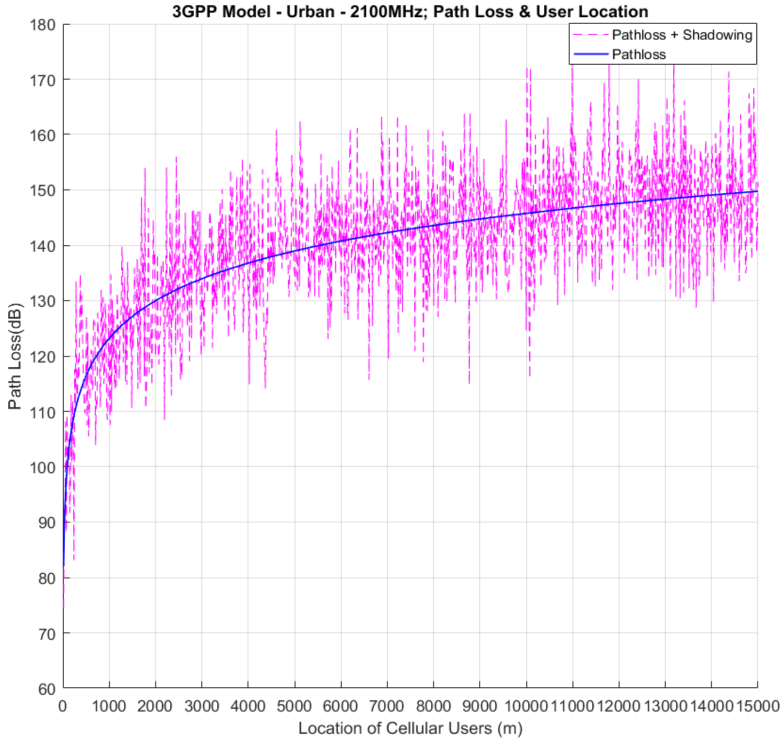

Figure 8: Combined Pathloss and Shadowing - Distance graph at 2100 MHz in Urban Area

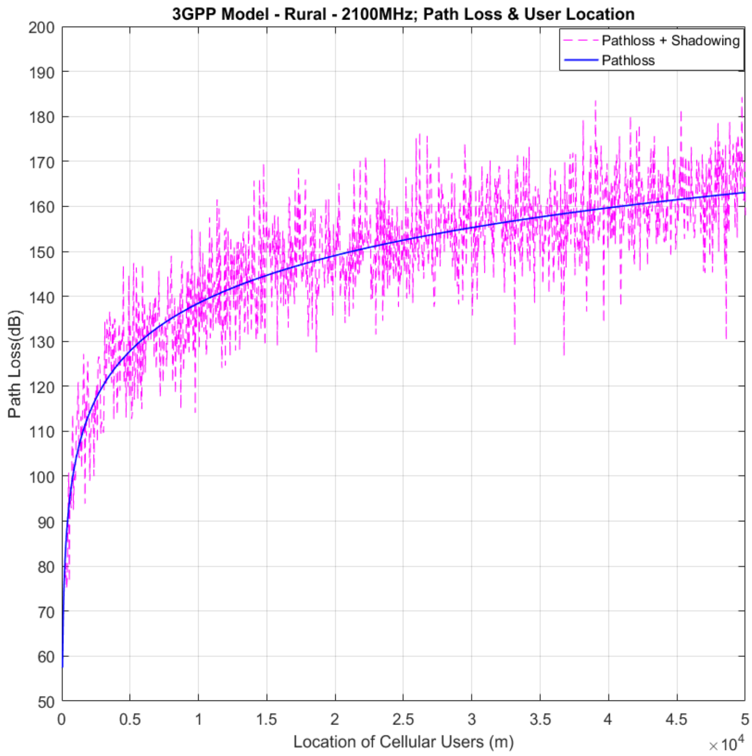

Figure 9: Combined Pathloss and Shadowing - Distance graph at 2100 MHz in Rural Area

Secondly, the cell coverage area is implemented for urban and rural areas and the system consists of 1000 users. The main point of the algorithm was the comparison between the calculated receiver sensitivity value and received a power which is calculated from the link budget formula for every user in the area. The base station antenna gain is taken 12 for frequencies less than 900 MHz and 15 for other frequencies, the receiver antenna gain is taken 0. The transmitted power from the base station is 43 dB and the path loss values at different distances are included to calculate the received power. If the received power is less than the receiver sensitivity value at any user which is at any distance, the user is marked as red in the implementation. When the received power is higher than the receiver sensitivity value, the users marked as green as seen in Figure 10 which is for the rural area, and in Figure 11 which is for the urban area.

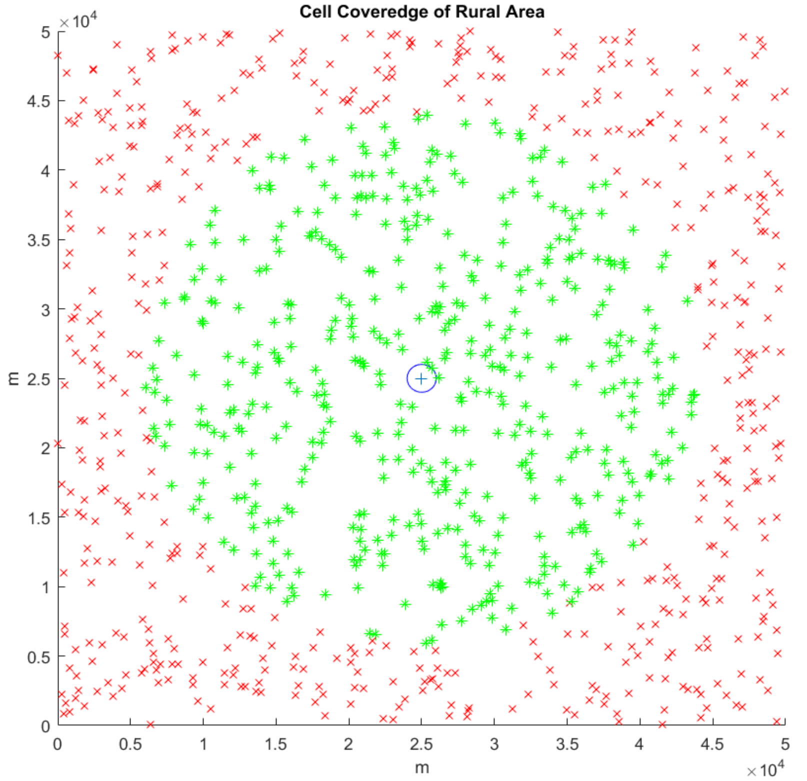

Figure 10: Cell Coverage Area for Rural Area, only Pathloss is Considered

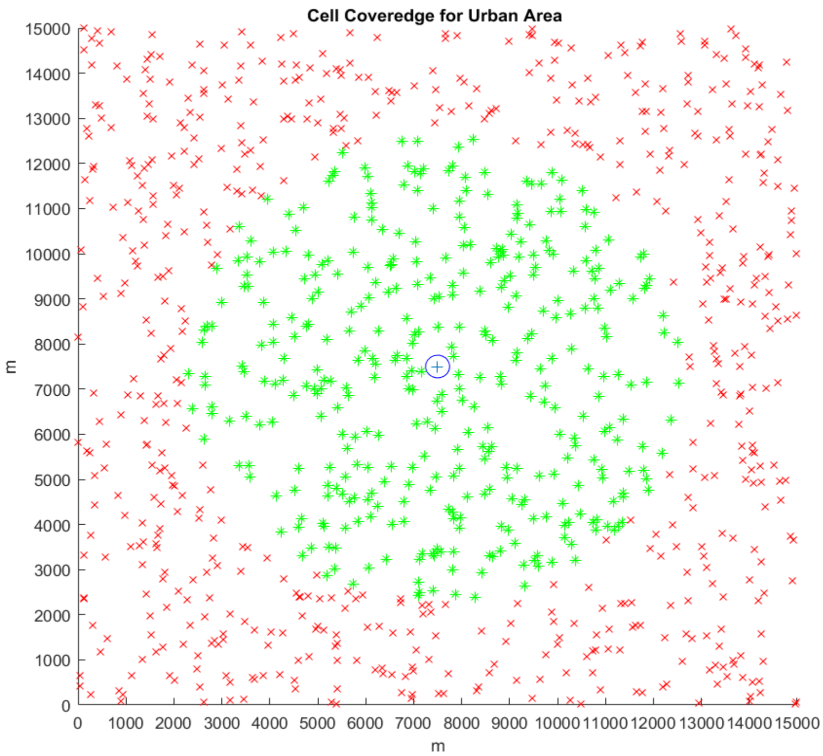

Figure 11: Cell Coverage Area for Urban Area, only Pathloss is Considered

In Figures 10 and 11, the contour of the cell coverage area based on the path loss is clearly observed. There is no randomness, the users are in the coverage from the base station to a certain distance. In the rural area graph, the certain distance approximately 20 km, and in the urban area it becomes 5 km. The distances will be investigated in order to have certain information.

When the shadowing fading is added to the systems, the certain contour of the coverage yields randomness as expected. Some users which were in the coverage based on only path loss become not in the coverage anymore because of the shadowing, and also some users which are normally not in the coverage according to the just path loss effect, are in the coverage in the effect of combined path loss and shadowing fading. The combined path loss and shadowing fading effect on the coverage can be seen in Figure 12 and Figure 13.

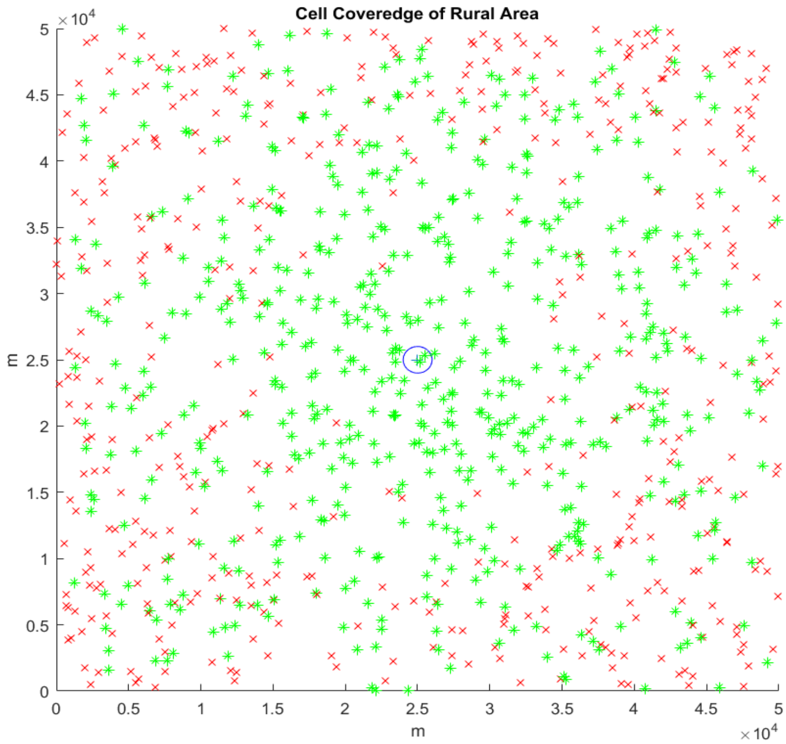

Figure 12: Cell Coverage Area of Rural Area for Combined Pathloss and Shadowing

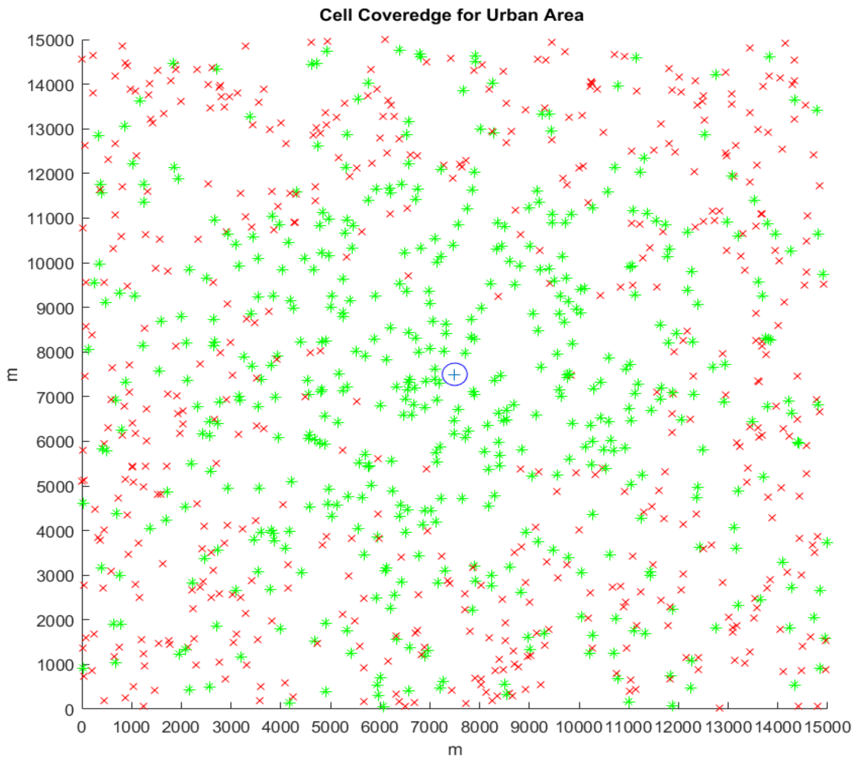

Figure 13: Cell Coverage Area of Urban Area for Combined Pathloss and Shadowing

Finally, the cell coverage area based on the distance change is investigated. As it is expected that when the distance from the base station increases, the number of users in the coverage becomes less. In Figure 14, around the base station which can be considered as the distance from the base station equal to at to 4 km, the 100% of the users are in the coverage for the rural area. There are some factors that are affected by the cell coverage area directly such as transmitter power, frequency band, or receiver sensitivity. These parameters' effects will be covered one by one. As it is seen in Figure 14, the graph consists of two curves, increased transmit power also increases the number of users that are in the coverage at more far distances. Since the goal is achieving 80% reliability which is defined as the distance we can achieve 80% coverage percentage, when the transmit power is increased to 63 dBm, the distance that we achieve 80% reliability is also increased to approximately 6.3 km from 1.7 km that is the distance gives 80% reliability when the transmitter power is 43 dBm.

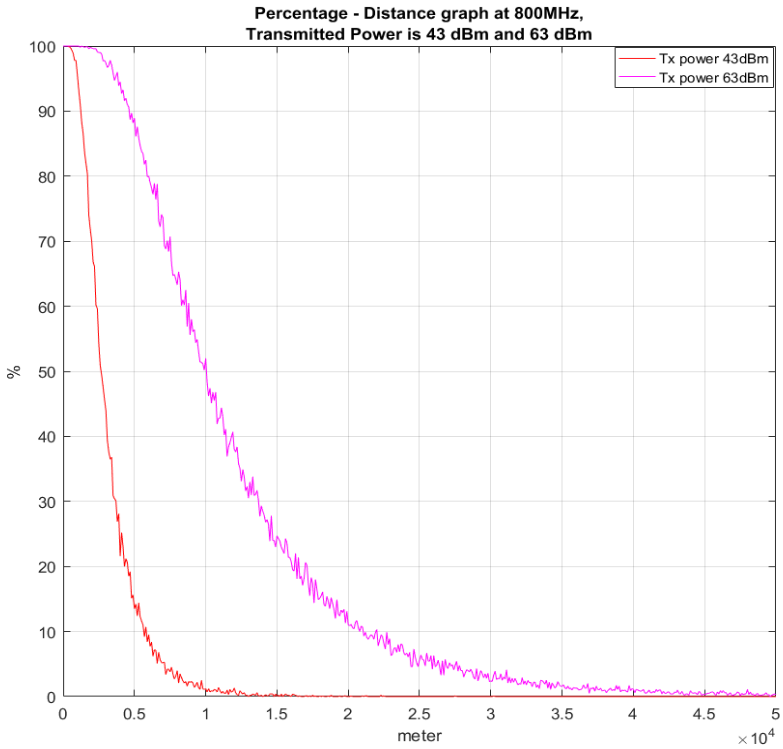

Figure 14: The Cell Coverage Percentage - Distance Graph at 800 MHz Transmitted Power is 43 dBm and 63 dBm for Rural Area.

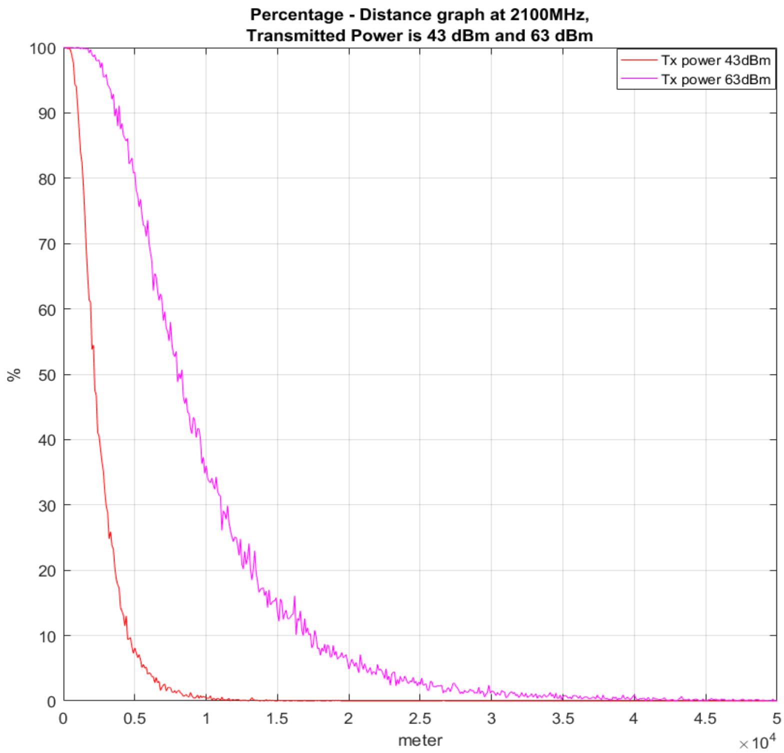

Figure 15: The Cell Coverage Percentage - Distance Graph at 2100 MHz Transmitted Power is 43 dBm and 63 dBm for Rural Area

The effect of the frequency band can be seen in Figure 15 which is the case that the frequency is increased to 2100 MHz. The distance that gives 80% reliability was 1.7 km at 800 MHz. Since the increased frequency value is also increased the path loss, the received power at that distance is decreased. At 2100 MHz frequency, the 80% reliability is achieved at 1.4 km. Finally, the receiver sensitivity value effect on the coverage percentage is investigated. As calculated in the System Model and Design part of the report, the receiver sensitivity value was found -53dBm. All the implementations and comparisons were done according to this value. Now, the receiver sensitivity value is decreased to -70dBm from -53dBm. Decreased receiver sensitivity value causes that increment of the number of users at far distances from the base station. When the transmitter power is 43 dBm, the distance that gives 80% reliability becomes 3.9 km instead of 1.7 km at 800 MHz. At 2100 MHz, it becomes 3.1 km instead of 1.4 km.

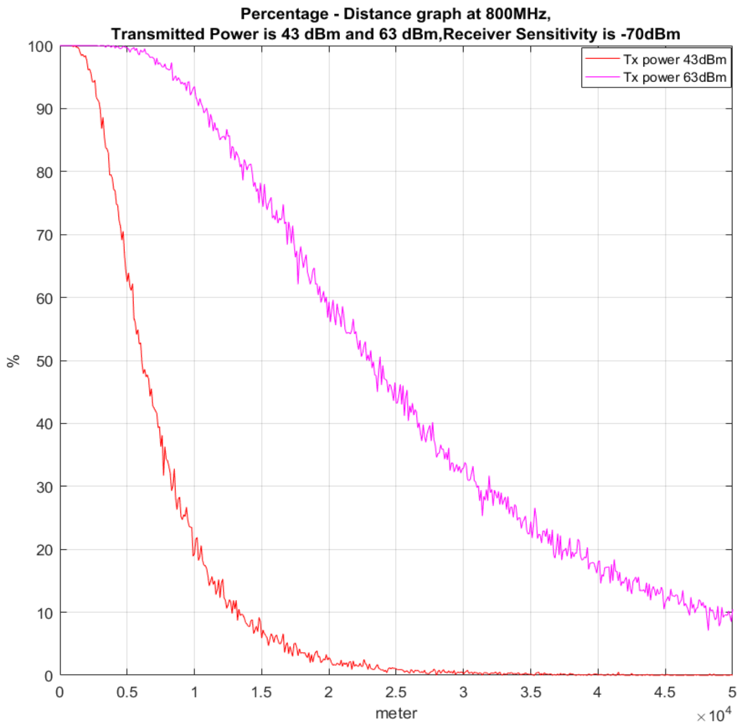

Figure 16: The Cell Coverage Percentage versus Distance graph at 800 MHz, Receiver Sensitivity -70dBm for Rural Area

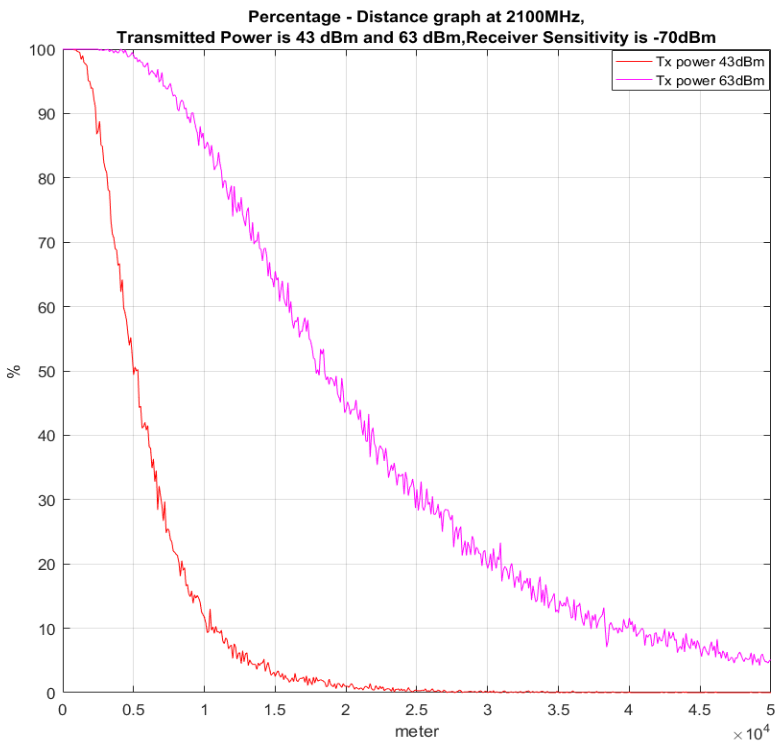

Figure 17: The Cell Coverage Percentage - Distance Graph at 2100 MHz Receiver Sensitivity is -70dBm for Rural Area

For the urban area, the effects of transmitter power, frequency band, and receiver sensitivity are the same as the rural area. In Figure 18 and Figure 19, the changing transmitter power and frequency effect can be seen. At 800 MHz, the 80% reliability can be achieved at maximum 400 m from the base station, but at 2100 MHz, the maximum distance becomes 300 m at 43 dBm transmit power. When the transmitter power is increased to 63 dBm, the maximum distance that gives the 80% reliability becomes 1.5 km at 800 MHz.

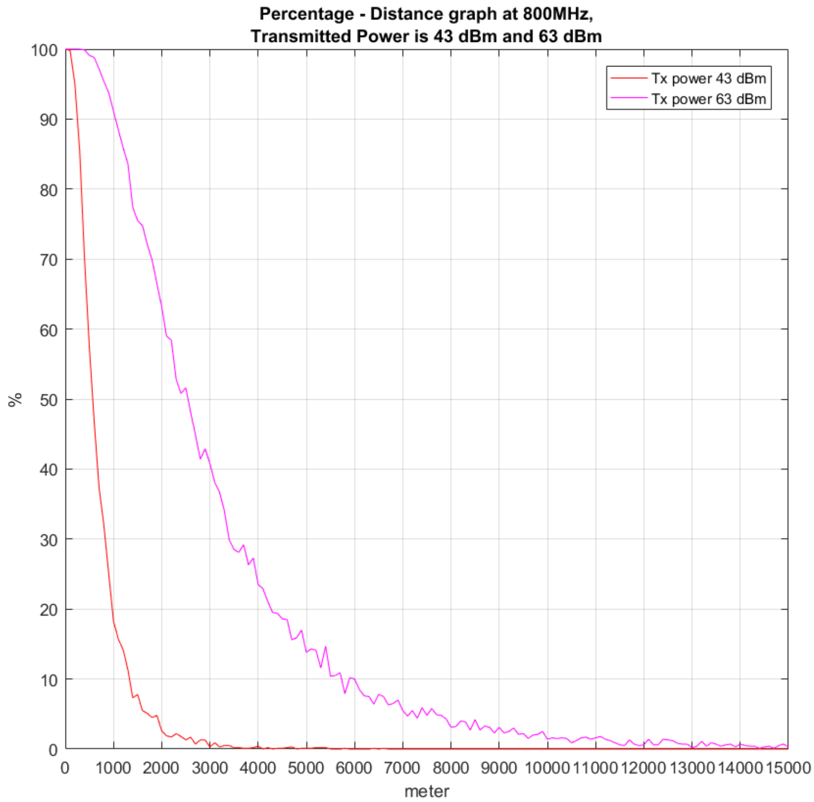

Figure 18: The Cell Coverage Percentage - Distance Graph at 800 MHz Transmitted Power is 43 dBm and 63 dBm for Urban Area

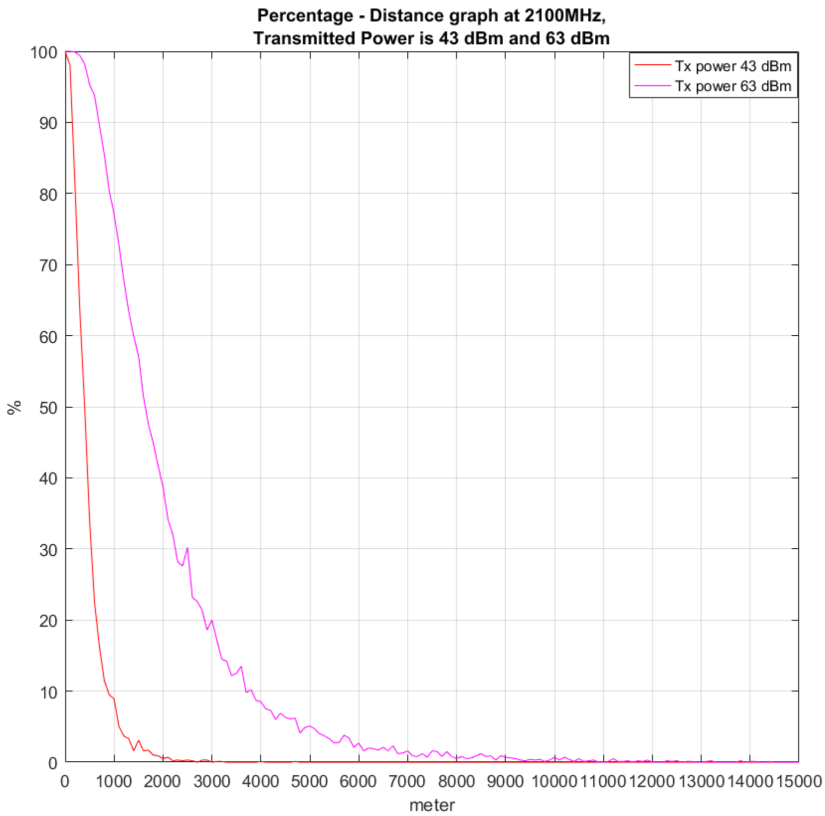

Figure 19: The Cell Coverage Percentage - Distance Graph at 2100 MHz Transmitted Power is 43 dBm and 63 dBm for Urban Area

In Figure 20 and Figure 21, the receiver sensitivity is decreased to -70 dBm. The maximum distance that gives 80% reliability is increased with the decreased receiver sensitivity value.

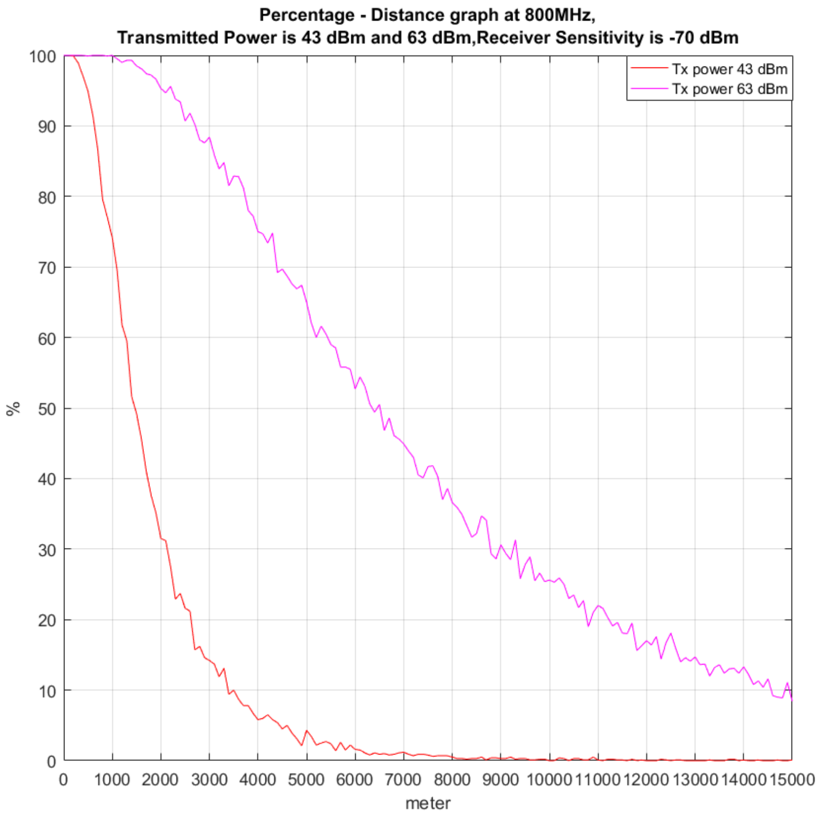

Figure 20: The Cell Coverage Percentage - Distance Graph at 800 MHz
Transmitted Power is 43 dBm and 63 dBm, Receiver Sensitivity is -70dBm for Urban Area

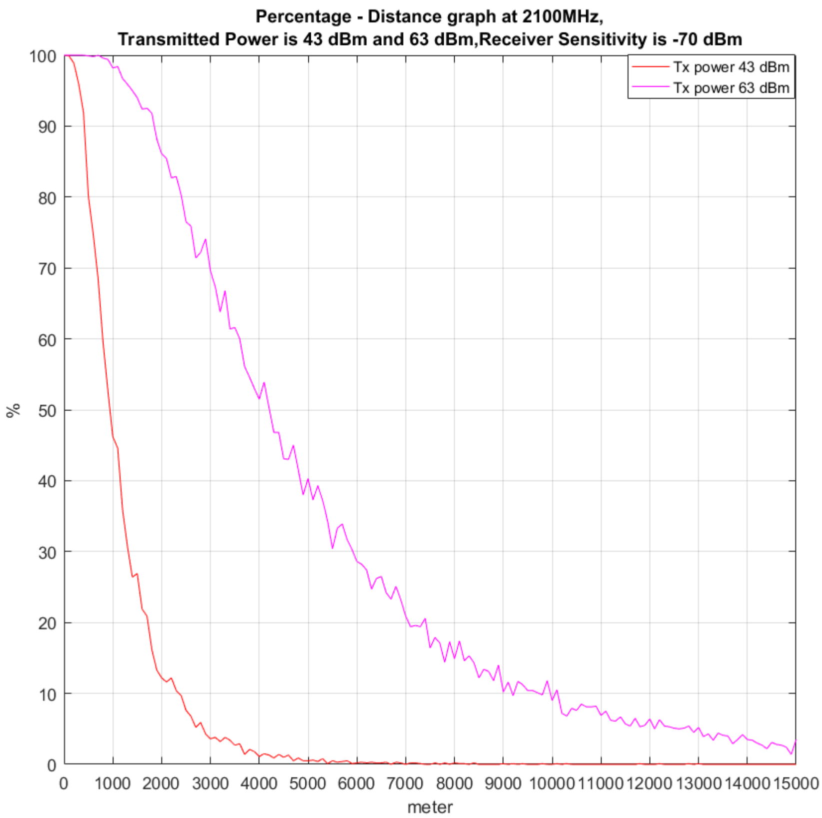

Figure 21: The Cell Coverage Percentage - Distance graph at 2100 MHz
Transmitted Power is 43 dBm and 63 dBm, Receiver Sensitivity is -70dBm for Urban Area

4. Conclusion

The main aim of the project was calculating the link budget for a communication system and determining the cell coverage area of this system, at the beginning of the project, the needed researches are investigated. To be able to find the reliability of the system, the received power of each user at different distances should be found. According to link budget calculations, firstly the path loss and shadowing fading concepts are analyzed. The path loss models are given for different terrain types and heights of receiver and transmitter antennas. 3GPP path loss model is chosen for the implementation of path loss on MATLAB because of the accuracy and simplicity of the model. The parameters that affect the path loss value are investigated and the results are shown in the numerical results part. The impact of shadowing fading and combined path loss and shadowing fading on the coverage is explained with figures and outage probability. Since the cell coverage area is defined as the expected percentage of area with received power higher than a given minimum value, the important parameter receiver sensitivity value calculations are examined. The received power of each user at different distances is found by link budget calculations. The combined path loss and shadowing effect on each user is calculated, and the received power of each user is calculated. Then, based on the chosen modulation scheme which is 16-QAM and bandwidth 10 MHz, the data rate and output SNR value are found to calculate the receiver sensitivity value. The found received power of each user is compared with the receiver sensitivity level. When the received power for the user is higher than the receiver sensitivity, the user is marked as green in MATLAB simulation which means that the user in the coverage. Finally, the cell coverage area based on the distance from the base station relation is investigated. The transmitter power, frequency band, and receiver sensitivity value effects on the coverage and distance relationship are covered. Some improvements are done with these parameters to have 80% reliability at far distances. With higher transmitter power, and less receiver sensitivity value and frequency band, the number of users that are in coverage at far distances are increased which declares that the reliability is increased at far distances from the base station.

To sum up, the general relationship between the link budget calculation and the cell coverage area is observed. The effect of path loss and shadowing, and the terrain type, frequency band, and heights of the antennas on the received power is examined. The reliability of a communication system is investigated and the effected parameters on the reliability are observed.

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