IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 5, Issue 4, Aug - Sept, 2017
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

Performance Analysis Of MIMO In Urban And Rural Environments

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Abstract— Multiple inputs multiple outputs (MIMO) have emerged as an enabling technology to increase the data rate of wireless link. In this paper we discuss the performance of propagation models like HATA and OKUMURA in the MIMO 2x2, 4x4, 8x8 antenna configurations and also compared the MIMO results with SISO on the basis of throughput by simulating under different scenarios using MATLAB. The purpose of this work is to show the very nature of throughput and how it can be maximized by observing its response to signal to noise ratio in HATA and OKUMURA models under MIMO configurations.

Keywords: *MIMO; SISO; HATA; OKUMURA; Throughput; propagation models.*

1. Introduction

THIS paper takes a look at some of the radio propagation models used in designing radio channels, and gives a MATLAB simulation of Okumura model and the Hata model, which can be readily applied in MIMO system with different antenna configurations like 2x2, 4x4 and 8x8. And these results are compared with the SISO system. The simulation is done using three different environments; those are urban area, suburban area and the rural area. The results are discussed.

Wireless communication is a rapidly growing segment of communication system. The key objective of wireless system is to increase the data rate and improve the transmission reliability. MIMO technology constitutes the major breakthrough in wireless communication system by increasing the data rates without increasing the transmitted power of antenna. The Multiple Input multiple Output (MIMO) method can be divided into various forms depending on uses. MIMO is basically the combination of all the multiple antenna techniques such as SISO, SIMO and MISO. SISO refers to a wireless communication system in which one antenna is used at the source (transmitter) and one antenna is used at the destination. SISO requires no processing in terms of the various forms of diversity that may be used but it is limited in terms of performance. Interference and fading will impact the SISO more than a MIMO system. The SIMO or Single Input Multiple Output version of MIMO occurs when the transmitter has a single antenna and the receiver has multiple antennas. It is often used to enable a receiver system that receives signal from a number of fading signals. The receiver is then able to receive the optimum signal which it can then use to extract the required data. MIMO offers various advantages over SISO SIMO and MISO. The capacity of MIMO system is increased without increasing the transmitted power and better communication coverage and transmission quality is achieved. In radio, multiple-input and multiple-output, or MIMO (commonly pronounced my-moh or me-moh), is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. Here the terms input and output refer to the radio channel carrying the signal, not to the devices having antennas. As a result of the use of multiple antennas, MIMO wireless technology is able to considerably increase the capacity of a given channel. By increasing the number of receive and transmit antennas it is possible to linearly increase the throughput of the channel with every pair of antennas added to the system. This makes MIMO wireless technology one of the most important wireless techniques to be employed in recent years. As spectral bandwidth is becoming an ever more valuable commodity for radio communications systems, techniques are needed to use the available bandwidth more effectively. The MIMO technique supports enhanced data throughput even under conditions of interference, signal fading, and multipath.

MIMO thrives to achieve the following:

1. Higher data rates,
2. Improved reliability and coverage
3. Larger spectral efficiency
4. Larger number of users
5. Better interference suppression
6. Better quality of service (QoS),
7. Lower bit-error rate (BER)
8. Lower Tx power
9. And higher data throughputs.

Throughput is a key measure of the quality of a wireless data link. It is defined as the number of information bits received without error per second and we would naturally like this quantity as to be high as possible.

Maximizing throughput in a wireless channel is a very important aspect in the quality of a voice or data transmission. MIMO system can be used to find the optimum signal to noise ratio that the system should be operated at to achieve the maximum throughput. At low SNR, the throughput is maximized by adapting the symbol rate while using the smallest constellation size and some fixed packet length.

For the MIMO system deployment, an understanding of the radio channel is paramount, and modeling of this channel using the most appropriate propagation model is very important. The radio propagation models are very significant while planning for any wireless communication system. The radio propagation model describes the behavior of the signal while it is transmitted from the transmitter towards the receiver, and the path loss .It gives a relation between the distances of the transmitter. The Propagation models are important for predicting coverage area, interference analysis, frequency assignments and cell parameters which are basic elements for network planning process in mobile radio. The radio wave propagation model plays a very important role in planning of any wireless communication system.

2. Propagation Models

A radio propagation model, also known as the radio frequency propagation model, is an empirical mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance and other conditions. A single model is usually developed to predict the behavior of propagation for all similar links under similar constraints. Created with the goal of formalizing the way radio waves are propagated from one place to another, such models typically predict the path loss along a link or the effective coverage area of a transmitter.

There are three main types of propagation models. Those are

1) Empirical Model

2) Stochastic Model/ Statistical model also known as Semi deterministic model

3) Deterministic Model

The empirical models are derived from measurement and observations while the deterministic model starts from the electromagnetic wave equation to determine the received signal power at a particular location. Deterministic model provides a reliable and thorough estimation of the path losses and the channel characteristics, but often require a complete three-dimensional map of the propagation environment.

2.1 Okumura Model

Okumura Model is the most widely used radio frequency propagation model for predicting the behavior of cellular transmission in urban area. This is based on measurement carried out by Y. Okumura in 1960.It is used for a frequency range of 150MHz to 1500MHz. But it can be extended up to 3000MHz. Distances range from 1km-100km and antenna height range from 30-1000m. This model is perfect for using in the cities having dense and tall structure, like Tokyo. The Okumura model takes note of three terrains /environment: **Open area:** defined as Open space, no tall trees or building in path. **Suburban area:** defined as Villages, highway scattered with trees and houses, some obstacles near the mobile **urban area:** defined as large settlement with high building having two or more storeys, or big villages having buildings close to each other and huge trees (Built up city or large town with large buildings and houses)

Okumura used the urban area as a standard model and introduced correction factors for application of the model to other categories. By using Okumura model we can predict path loss in urban, suburban and rural area up to 3 GHz. The empirical path loss formula devised by Okumura, expressed in terms of dB at carrier frequency and distance is given by

$$L_m(dB) = L_F(d) + A_{mu}(f,d) - G(h_M) - G(h_B) - G_{AREA} \quad (1)$$

Where

PL = Median path loss [dB]

L_F = Free space path loss [dB]

$A_{mu}(f,d)$ = Median attenuation relative to free space [dB]

G (h_B) = Base station antenna height gain factor [dB]

G (h_M) = Mobile station antenna height gain factor [dB]

G_{AREA}= Gain due to the type of environment and parameters [dB]

F = Frequency [MHz]

h_{te}= Transmitter antenna height [m]

h_{re}= Receiver antenna height [m]

d = Distance between transmitter and receiver antenna [km]

$$G(h_b) = 20\log(h_b/200) \quad 1000m > h_b > 30m \quad (2)$$

$$G(h_m) = 10\log(h_m/3) \quad h_m <= 3m \quad (3)$$

$$G(h_m) = 20\log(h_m/3) \quad 10m > h_m > 3m \quad (4)$$

Major disadvantage with this OKUMURA model is its slow response to rapid changes in terrain; therefore the model is fairly good in urban areas, but not as good in rural and suburban areas.

2.2 Hata Model

It is an empirical formulation of graphical path loss data provided by Okumura and is valid from 150MHz-1500MHz. Hata established empirical mathematical relationships to describe the graphical information given by Okumura. Hata's formulation is limited to certain ranges of input parameters and is applicable only over quasi-smooth terrain. Hata model is also 150 to 1500MHz, provides three separate formulae for each type of environment, namely: Urban area, Suburban areas and open area.

Carrier Frequency (f_c): 150 MHz ≤ f_c ≤1500 MHz

Base Station (BS) Antenna Height: 30 m ≤h_b ≤200 m

Mobile Station (MS) Antenna Height:1m ≤h_m ≤10 m

Transmission Distance: 1 km ≤d ≤20 km

The mathematical expression and their ranges of applicability are as follows:

For urban area:

$$L_p \text{ (dB)} = A + B\, log_{10}\text{ (d)} \quad (5)$$

For suburban area:

$$L_p \text{ (dB)} = A + B\, log_{10}\text{ (d)} - C \quad (6)$$

For open area:

$$L_p \text{ (dB)} = A + B\, log_{10}\text{ (d)} - D \quad (7)$$

Where:

$$A = 69.55 + 26.161 log_{10}(f_c) - 13.82\, 1log_{10}(h_b) - a(h_m) \quad (8)$$

$$B = 44.9 - 6.55\, log_{10}(h_b) \quad (9)$$

$$C = 5.4 + 2\,[log_{10}(\tfrac{f_c}{28})]^2 \quad (10)$$

$$D = 40.94 + 4.78[log_{10}(f_c)]^2 - 18.33\, log_{10}(f_c) \quad (11)$$

These expressions have considerably enhanced the practical value of the Okumura method, although Hata's formulations do not include any of the path specific corrections available in the original model.

Later in this paper we have analyzed the performance of MIMO, by plotting throughput versus signal-to-noise-ratio graph for various antenna configurations in different propagation models. These results are also compared with SISO technology.

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3. Performance Analysis

In this paper we have presented performance analysis of MIMO system by using OKUMURA and HATA in comparison to other technology i.e. SISO. We have compared these technologies by plotting throughput versus signal to noise ratio. We have explored the above technologies for various antenna configurations: 2x2, 4x4 and 8x8. And the value of SNR ranges between 0 to 25dB.

A simulation was done in MATLAB to compare the throughput at different SNR values between the Okumura and Hata models for three different base station antenna heights (30m, 100m and 200m) in MIMO system for different antenna configurations (2x2, 4x4 and 8x8) and the following results were obtained.

Throughput is an important measurement for characterizing system performance. The vertical axis represents the Throughput in bps; the horizontal axis represents the SNR in dB.

The throughput of a wireless data communications system depends on a number of variables. I've examined several of them including: packet size, transmission rate, the number of overhead bits in each packet, received signal power, received noise power spectral density, modulation technique, and channel conditions. And the SNR has given as:

SNR = signal power / noise power

And the SNR in dB has given as:

SNR (dB) = 10*log10 (signal power / noise power)

So the throughput depends on signal power and the noise power and the SNR also given in terms of signal power and noise power. So there is a relation between throughput and SNR.

3.1 Okumura and Hata Model in the SISO Configurations

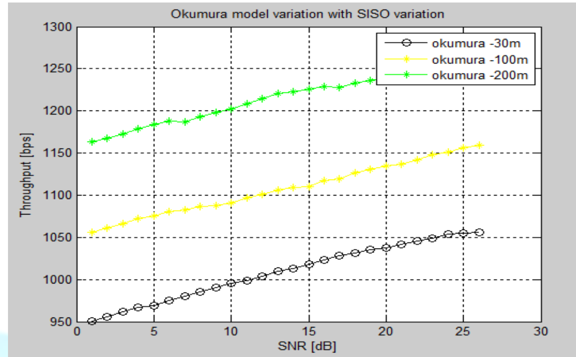

Fig. 1 Throughput v/s SNR for SISO Antenna System for OKUMURA Model

The fig.1 describes the OKUMURA model results when that model performed in the SISO system. The graph drawn between the SNR (dB) and the throughput (bps), the range of SNR taken here is 0 to25 dB. The graph drawn for different antenna heights i.e.30m, 100m and 200m. From this plot we can see that increasing SNR and the antenna height gives us a higher throughput.

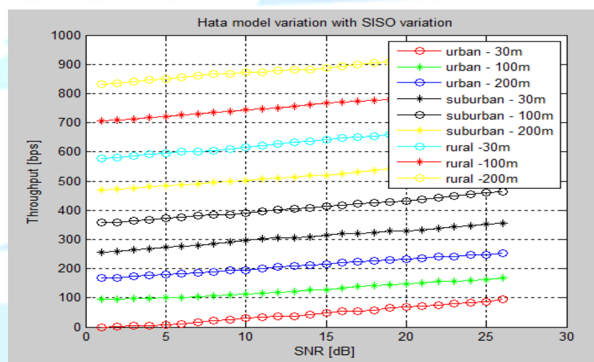

Fig. 2 Throughput v/s SNR for SISO Antenna System for Hata Model

The figure 2 describes the HATA model results when that model performed in the SISO system. The plot drawn between the SNR (dB) and the throughput (bps), the range of SNR taken here is 0 to 25dB. The graph drawn for different antenna heights i.e. 30m, 100m and 200m HATA model can be classified into 3 regions i.e. urban, suburban and rural areas. From the above plot we can observed that HATA gives better result in urban area than the suburban and rural areas. From this plot we can see that increasing the SNR and the antenna height gives us a higher throughput.

Table 1: Comparison table for both Okumura Model and Hata Model using SISO Antenna System

Throuput values for SISO configuration												
	OKAMURA MODEL			HATAMODEL								
SNR(dB)	URBAN			URBAN			SUBURBAN			RURAL		
	30m	100m	200m	30m	100m	200m	30m	100m	200m	30m	100m	200m
1	9.5030e+02	1.0558e+03	1.1634e+03	0	93.7100	167.7553	254.9195	356.9733	469.5827	576.6950	704.7675	832.1708
5	9.6935e+02	1.0753e+03	1.1834e+03	8.3055	100.9263	179.5824	272.7457	372.4057	482.8841	594.9925	719.0629	850.8758
10	9.9514e+02	1.0906e+03	1.2012e+03	29.5407	113.2246	195.7813	296.8854	390.7307	502.3300	614.9281	743.7198	873.0985
15	1.0184e+03	1.1102e+03	1.2259e+03	47.8707	128.5720	216.3496	312.9254	412.3421	518.8850	641.5197	767.6176	887.3791
20	1.0374e+03	1.1343e+03	1.2404e+03	69.8689	149.0399	233.8089	329.4610	431.6766	544.7280	664.2833	788.0565	915.4124
25	1.0562e+02	1.1558e+03	1.2532e+03	87.0268	162.9045	247.0318	350.8956	459.8974	566.0253	694.4392	817.9823	941.3668

Table 1 gives the performance comparison of HATA and OKUMURA models in SISO system at different antenna heights. In which the comparison can be done on urban, sub urban and rural environments.

3.2 OKUMURA and HATA model in the MIMO 2x2 Configurations

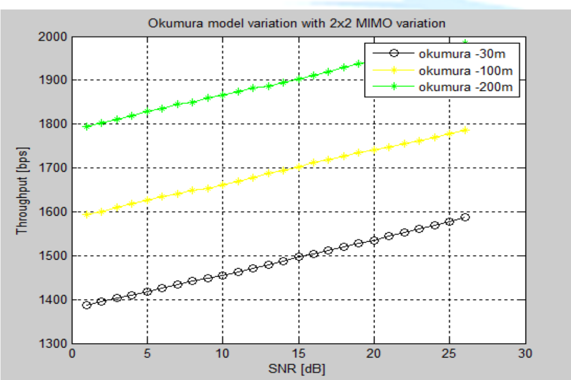

Fig. 3 Throughput v/s SNR for MIMO 2x2 Antenna System for Okumura Model

The figure 3 describes the OKUMURA model results when that model performed in the MIMO 2x2 systems. Compared to SISO, MIMO 2x2system gives better performance. From this graph we can see that increasing the SNR and the antenna height gives us a higher throughput.

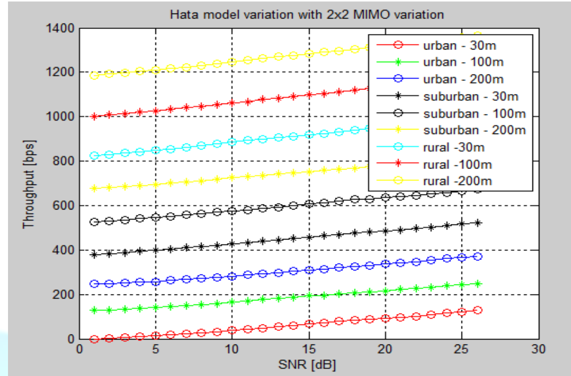

Fig. 4 Throughput v/s SNR for MIMO 2x2 Antenna System for Hata Model

The figure 4 describes the HATA model results when that model performed in the MIMO 2x2 systems. From the above plot we can observed that HATA gives better result in rural area than the urban sub urban areas. Compared to SISO system, the MIMO 2x2 system gives the better performance.

Table 2: Comparison table for both Okumura Model and Hata Model using MIMO 2x2 Antenna System

Throuput values for MIMO (2X2) configuration												
	OKAMURA			HATAMODEL								
SNR(dB)	URBAN			URBAN			SUBURBAN			RURAL		
	30m	100m	200m	30m	100m	200m	30m	100m	200m	30m	100m	200m
1	1.3716e+03	1.5758e+03	1.772e+03	0	128.1645	245.9576	366.6061	524.0359	676.8509	823.2215	1.0067e+03	1.1900e+03
5	1.4013e+03	1.6051e+03	1.8017e+03	13.5399	141.8164	256.1334	385.4021	542.8084	694.6072	848.4366	1.0341e+03	1.2147e+03
10	1.4395e+03	1.6480e+03	1.8407e+03	38.8761	166.2573	277.4269	415.7025	572.2342	717.8048	887.1358	1.0662e+03	1.2482e+03
15	1.4771e+03	1.6871e+03	1.8762e+03	66.5385	189.2056	303.5578	445.6640	600.3648	749.9384	925.7547	1.1032e+03	1.2845e+03
20	1.5151e+03	1.7239e+03	1.9174e+03	92.8942	214.1980	328.8538	476.3988	631.9064	780.8181	956.9823	1.1362e+03	1.3182e+03
25	1.5583e+03	1.7615e+03	1.9570e+03	121.2194	240.6136	356.1153	509.6677	666.8089	810.1986	994.6323	1.1747e+03	1.3553e+03

Table 2 gives the performance comparison of HATA and OKUMURA models in MIMO 2x2 systems at different antenna heights. In which the comparison can be done on urban, sub urban and rural environments. Increasing the SNR and antenna height it can be inferred that the throughput can be increased under MIMO 2x2 configurations.

3.3 Okumura and Hata model in the MIMO 4x4 Configurations

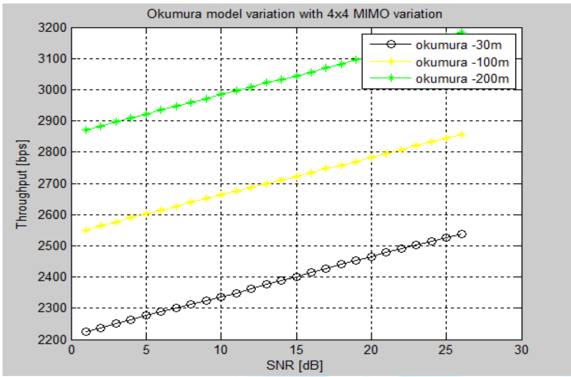

Fig. 5 Throughput v/s SNR for MIMO 4x4 Antenna System for Okumura Model

The figure 5 describes the OKUMURA model results when that model performed in the MIMO 4x4 systems. Compared to MIMO 2x2, MIMO 4x4 system gives better performance. From this graph we can see that increasing the SNR and the antenna height gives us a higher throughput.

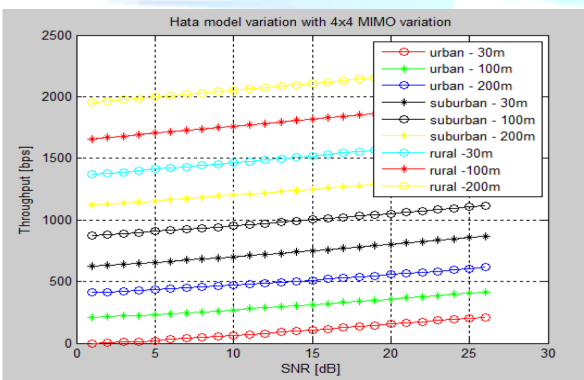

Fig. 6 Throughput v/s SNR for MIMO 4x4 Antenna System for Hata Model

The figure 6 describes the HATA model results when that model performed in the MIMO 4x4 systems. From the above plot we can observed that HATA gives better result in rural area than the urban sub urban areas. Compared to MIMO 2x2 systems, the MIMO 4x4 system gives the better performance.

Table 3: Comparison table for both Okumura Model and Hata Model using MIMO 4x4 Antenna System

Throuput values for MIMO (4X4) configuration												
	OKAMURA			HATAMODEL								
SNR(dB)	URBAN			URBAN			SUBURBAN			RURAL		
	30m	100m	200m	30m	100m	200m	30m	100m	200m	30m	100m	200m
1	2.2135e+03	2.5416e+03	2.8668e+03	0	211.2121	409.1642	606.0668	856.4856	1.1064e+03	1.3488e+03	1.6470e+03	1.9391e+03
5	2.2613e+03	2.5920e+03	2.9167e+03	23..6110	233.4744	427.3196	634.8080	890.6728	1.1362e+03	1.3931e+03	1.6898e+03	1.9774e+03
10	2.3238e+03	2.6523e+03	2.9795e+03	62.2095	270.0062	463.2129	681.3537	936.2460	1.1816e+03	1.4512e+03	1.7461e+03	2.0311e+03
15	2.3877e+03	2.7160e+03	3.0434e+03	106.1180	310.8238	505.3769	734.8729	985.3038	1.2287e+03	1.5097e+03	1.8063e+03	2.0893e+03
20	2.4545e+03	2.7783e+03	3.1066e 03	151.0770	354.3696	547.0323	787.4328	1.0364e+03	1.2778e+03	1.5690e+03	1.8619e+03	2.1477e+03
25	2.5165e+03	2.8436e+03	3.1700e+03	202.0082	400.1642	590.7701	838.8172	1.0883e+03	1.3265e+03	1.6263e+03	1.9188e+03	2.2049e+03

Table 3 gives the performance comparison of HATA and OKUMURA models in MIMO 4x4 systems at different antenna heights. In which the comparison can be done on urban, sub urban and rural environments. Increasing the SNR and antenna height it can be inferred that the throughput can be increased under MIMO 4x4 configurations.

3.4 Okumura and Hata Model in the MIMO 8x8 Configurations

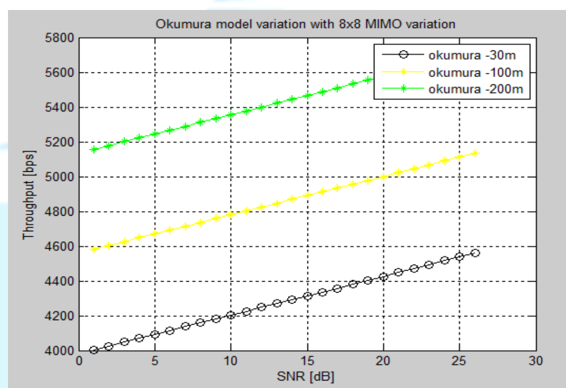

Fig. 7 Throughput v/s SNR for MIMO 4x4 Antenna System for Okumura Model

The figure 7 describes the OKUMURA model results when that model performed in the MIMO 4x4 systems. Compared to MIMO 4x4, MIMO 8x8 system gives better performance. From this graph we can see that increasing the antenna height gives us a higher throughput.

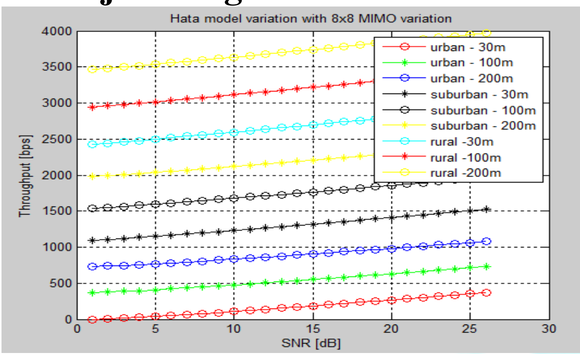

Fig. 8 Throughput v/s SNR for MIMO 8x8 Antenna System for Hata Model

The figure 8 describes the HATA model results when that model performed in the MIMO 8x8 systems. From the above plot we can observed that HATA gives better result in rural area than the urban sub urban areas. Compared to MIMO 4x4 systems, the MIMO 8x8 system given the better performance.

Table 4: Comparison table for both Okumura Model and Hata Model using MIMO 8x8 Antenna System

Throuput values for MIMO (8X8) configurations												
	OKAMURA			HATAMODEL								
SNR(dB)	URBAN			URBAN			SUBURBAN			RURAL		
	30m	100m	200m	30m	100m	200m	30m	100m	200m	30m	100m	200m
1	4.0063e+03	4.5790e+03	5.1497e+03	0	367.7602	724.1567	1.0846e+03	1.5337e+03	1.9760e+03	2.4161e+03	2.9419e+03	3.4653e+03
5	4.0944e+03	4.6653e+03	5.2386e+03	37.5536	406.1160	761.8945	1.1436e+03	1.5918e+03	2.0338e+03	2.4898e+03	3.0163e+03	3.5395e+03
10	4.2008e+03	4.7759e+03	5.3489e+03	106.3724	471.3198	827.3810	1.2254e+03	1.6721e+03	2.1126e+03	2.5878e+03	3.1167e+03	3.6389e+03
15	4.3120e+20	4.8876e+03	5.4577e+03	184.0420	546.2784	900.0805	1.3135e+03	1.7585e+03	2.1993e+03	2..6901e+03	3.2177e+03	3.7399e+03
20	4.4246e+02	4.9980e+03	5.5670e+03	266.1437	624.7468	977.0341	1.4060e+03	1.8495e+03	2.2891e+03	2.7950e+03	3.3207e+03	3.8408e+03
25	4.5352e+03	5.1056e+03	5.6781e+03	351.7602	707.7743	1.0561e+03	1.5015e+03	1.9447e+03	2.3811e+03	2.9026e+03	3.4260e+03	3.9476e+03

Table 4 gives the performance comparison of HATA and OKUMURA models in MIMO 8x8 systems at different antenna heights. In which the comparison can be done on urban, sub urban and rural environments. In this table red colour indicates the increased values than the other regions and the other antenna configurations. Here okumura model at 200m antenna height given the higher throughput in urban region.

In figures 1, 2, 3, 4, 5, 6, 7 and 8, graphs of throughput vs. SNR are presented, with varied antenna heights for SISO and MIMO (2x2, 4x4, and 8x8) systems by using the HATA and OKUMURA models. Where antenna height is lower, As observed from these graphs, the throughput increases with SNR, such that the antenna heights, the higher the throughput. This shows that throughput can be jointly optimized with the SNR and antenna heights.

4. Conclusion and Future scope

In the present work, an idea about performance of the MIMO system using the outdoor propagation models and for different antenna configurations is presented. Generally, this work was focused for predicting the Throughput in different areas and also in different systems i.e. SISO and MIMO. However, most propagation models aimed to predict the median path loss. But, here throughput can be predicted for MIMO systems with the different antenna configurations (2x2, 4x4 and 8x8) by using the OKUMARA and HATA models. These results can be compared with the SISO system results. It is been observed that OKUMURA model under different antenna configurations has given better results compared to HATA model, and also observed that the throughput increases with SNR and base station antenna heights. It may be concluded that MIMO configuration improves the link reliability and throughput. This is the formal ending of never ending process. In future, our simulated results can be tested and verified in practical field. We may also derive a suitable propagation models for all terrains. Future study can be made for finding more suitable parameters for HATA and OKUMURA models and also other models in rural, suburban and urban area.

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