Heterogeneous modelling framework for 5G urban macro ultra dense networks

Fayad Ghawbar[1], Faiz A. Saparudin[2], Jumadi A. S.[3], Aimi S. A Ghafar[4], N. Katiran[5]
[1,2,3,4]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia Pagoh Campus, Malaysia
[5]Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia Pagoh Campus, Malaysia

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ABSTRACT

The explosive growth of mobile devices is the main engine to continue evolution in the communications field. The amount of traffic generated by today's users in applications such as high definition videos, cloud computing, and wearable devices, require a drastic change in mobile telecommunications. 5G Ultra Dense Network (UDN) is one of the key components leading in achieving the high capacity for all users. In UDN, the number of base stations or access nodes equals or exceeds the number of active users by unit area. In this paper, different modeling techniques of UDN are studied. Moreover, a heterogeneous framework modeling was proposed. This framework illustrated a system model for UDN based on Urban Macro (UMa) Scenario. The distance dependent path loss model for UMa was presented and analyzed. The Simulation results of path loss model indicated an increase in the path loss with increasing the distance range from 10m to 500m. The received power simulation results of User Terminal (UT) displayed the power is approaching zero when the distance between the BS and UT goes beyond 250m. Therefore, it is assumed that UTs located 250m away from the BS can reuse the subchannel of AN in another sector with negligible interference.

Corresponding Author:

Faiz A. Saparudin,
Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia Pagoh Campus,
Johor, Malaysia.
Email: faizs@uthm.edu.my

1. INTRODUCTION

The explosive growth in mobile devices leads to starving users for high data rate with potential capacity and high throughput [1, 2]. Watching the evolution of mobile wireless technology starting with 2G till 4G LTE, make us reconsider our current key Technologies for improving the quality and the same time facing the quantity. The annual growth of mobile data traffic from 2013 to 2018 reached 61% as indexed by Cisco Visual Networking [3]. The significant increase in the mobile data traffic is highly expected to continue through several coming years based on the academia and wireless industry researchers. It is challenging to watch a huge growth of mobile data traffic expected to reach 1000-fold in the throughput of 5G by 2020. In Mobile wireless communication, Mobile Internet and Internet of Things are becoming the main driving forces for such growth into 5G [4]. Therefore, 5G is an ongoing research for establishing a very promising background for making a breakthrough in mobile technology. 5G is expected to provide high demand data rate with extensive capacity that would satisfy the User need.

However, it has never been easy as it seems to come out with a finalized standard for 5G. So many challenges and drawbacks need to be tackled. During the evolution of 4G LTE, a nonstop advancement in wireless technology is undergoing. However, not to the extent that allows and provide a full coverage and enough capacity with significant needs satisfaction especially with high data traffic. Therefore, it comes the urgent need for 5G to allow for unnegotiable speed allied with enough coverage and high capacity [5]. Those changes require an epic shift in the key enabling technologies areas of developing 5G can be divided into three sectors, spectrum efficiency, spectrum expansion, and small cells network densification. Network densification is one of the key enabler technologies to address the mobile data traffic challenge [6-8]. It can be realized by installing a huge number of small access points with low transmission power and small coverage areas. Section 2 discusses the 5G UDN densifications with its features and challenges.

2. 5G ULTRA DENSE NETWORKS (UDNs)

The UDNs can be defined as those networks where the base stations (BS) density equals or exceed the density of the active users [9], and that is suitable for characterizing the traffic per user rate increasing scenario while the number of users maintains the same quantity [10]. These inter-site distances range from a few meters in indoor densification to almost 50 meters in outdoor densification. In general, the classification of small cells in UDN can be divided into two categories, the first category is the full working base stations (BSs) such as Picocells and femtocells. The second category is the macro-extension access nodes such as relays and Remote Radio Heads (RRH) [11]. The difference is that the fully active BSs perform all the tasks of a macrocell, more specifically, do all the jobs of whole protocol stack while the extension-macro BSs do some or all the tasks of the physical layer [12].

The following section discusses the feature of these small cells as follows [13]:

1) Picocells are operator installed small cells with low power having a backhauling from Fiber and Microwave links just the same as macrocells. They are installed in centralized form in indoor and outdoor areas for hotspots to serve a few tens of active users ranging not more than 300 m or less. They are mainly deployed for improving the capacity and the coverage in hotspots (indoor and outdoor). They have a transmission power range from 23 to 30 dBm.
2) Femtocells are small cells which are recognized as home BSs since they are installed in indoor areas such as offices, homes and enterprises. They are typically low power and low cost access nodes serving dozens of users within a distance less than 50 m and within a power less than 23 dBm. Their connection to the main network via cable, fiber, or using Digital Subscriber Line (DSL). Picocells can be operating either in open or regulated (closed Subscriber Group (CSG) access points [14].
3) Relays are installed mainly for the coverage purpose where the signal strength are weak as well as improving the coverage in dead areas such as tunnels and cell edges. Relays are deployed by the operators and can be routed from the both sides of the macro BS and users. Relays and Picocells share some feature in terms of having low transmission power with the same coverage. However their purpose of deployment are different as Picocells are installed to improve the capacity while Relayed are deployed to improve the coverage. Furthermore, Picocells are considered as fully functioning access nodes while relays are macro-extension. Moreover, they both have different backhauling in which Picocells have an ideal backhauling differ from relays with wireless backhaul in and out of band.
4) RRHs are lower power and low complexity access points that are synchronized by central processor [15]. The RRHs could be either a BS same as the conventional networks or relay access nodes but not able to encode or decode [16]. They are mainly installed to increase the coverage of a central BS to remote geographical locations. RRHS are connected to a central BS using an optic fiber cable, hence it generates a distributed BS [13]. Besides, they can be deployed as an extension for the macrocells BS as they are considered as a centralized densification opposing the distributed densification of both picocells and femtocells. As shown in table 1 that femtocells are deployed in indoor spots in three different access cases: open, closed and hybrid. All subscribers for each service operator can have a full access to the node while in closed mode, the access only possible for Closed Subscriber Group (CSG). However, in hybrid mode, the femtocells are accessible by all subscribers with a priority to the CSG subscribers. as part of these drivers, mobile internet and Internet of things are promising drivers for such applications in the coming ten years [17, 18].

Figure 1 displays a UDN with various densifications scenarios. Figure 1 displays UDN with deployed small cells in UMa and UMi Scenarios for outdoor and indoor densification. The question is what makes the UDNs different from the traditional UDNs and what makes it more challenging. The answer to this question lays beneath the complex architecture of UDN which results in challenging features such as, the need for advanced techniques for frequency reuse in UDNs. The architecture of UDNs allows for an extreme spatial reuse and that will enhance potentially the capacity of the network [10, 19]. Therefore, the frequency reuse techniques in UDN need a new innovative paradigm shift to be considered to offer the expected significant capacity [20]. Moreover, excessive interference among neighboring small cells is a significant small limiting factor [21]. The large deployment number of small cells with small coverage areas generate contribute in high interference ratio. Therefore, an innovative strict interference management techniques are required to mitigate the interference among the neighboring small cells. In addition, backhauling is another due to the environment of UDN which has a large number of small cells, hence deployment cost, equipment, and operating maintenance has to be low. Different deployment scenarios of interest for UDN is presented in section 3.

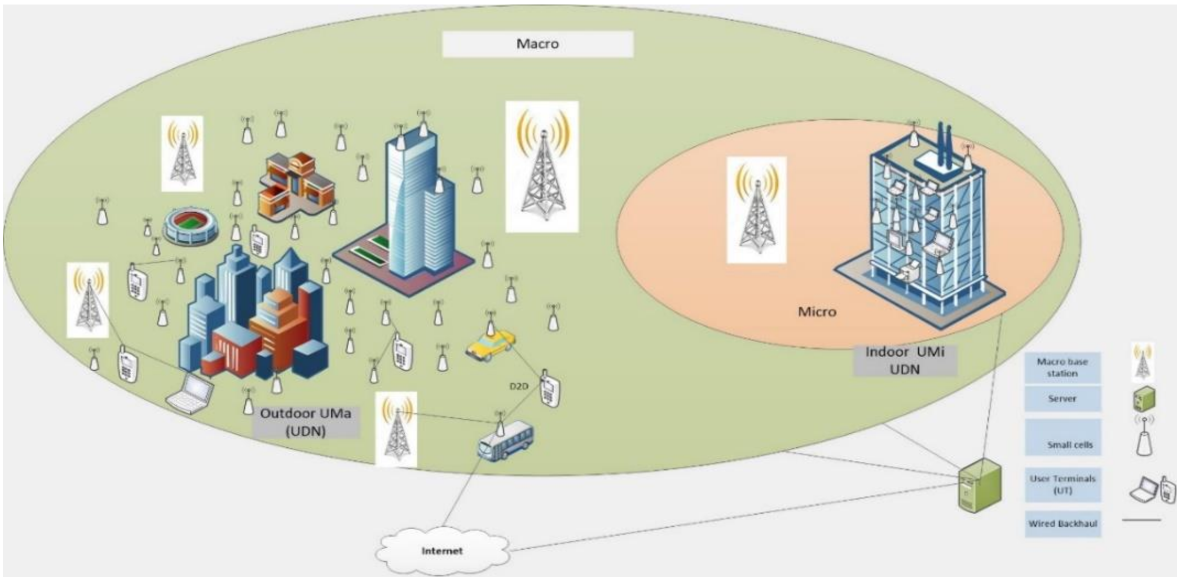


Figure 1. UDN with deployed small cells in UMa and UMi Scenarios for outdoor and indoor densification

3. 5G UDN SCENARIOS OF INTEREST

3.1. Urban Micro (UMi)

UMi with Outdoor-to-Outdoor and Outdoor-to-Indoor such as open area and street Canyon. In UMi, the Base Stations (BSs) are installed under the rooftop level of the nearby buildings and it is considered the same as 3 Dimensional (3D) UMi, as indicated in Figure 1. Describing the open area scenario in UMi to show the real picture in real life situation such as station or city square. An example of this Scenario is a transmitter height (Tx) of 10 m, receiver height (Rx) of 1.6-2.5 m and inter-site distance (ISD) of 5oo m [22].

3.2. Urban Macro (UMa)

UMa includes Outdoor-to-Outdoor and Outdoor-to-Indoor. In this Scenario, the BSs are installed on the rooftop of nearby buildings which is considered the same as 3D Scenario of UMa [23]. An example of this Scenario is a transmitter height of 25 m, receiver of 1.5-2.5m and inter-site-distance of 500m. Table 1 displays the parameters for both UMa and UMi.

Table 1. Evaluation Parameters of UMa and UMi [22]

Parameters	UMa	UMi (street canyon)
Cell layout	Hexagonal	Hexagonal
No. of Sectors	3 Sectors per site	3 Sectors per site
ISD	500	200
BS Antenna Height	25m	10m
User height	1.5-22.5 m	1.5-22.5 m
Minimum Distance (User-BS)	35m	10m
Carrier Frequency	6GHZ,30GHZ	30GHZ
Bandwidth	20MHZ for 6GHZ,100MHZ for 30GHZ	100MHZ for 30GHZ
Tx Power	49dBm at 6 GHz,35dBm at 30GHZ	35dBm at 30GHZ

3.3. Indoor

In this Scenario, it describes the typical environment scenarios such as office, apartments, and shopping malls. In indoor office scenario, it captures the open areas, cubicles, offices with full walls, corridors etc. as shown in Figure 1. The installment of BSs in the office is done either on the walls or ceilings at height of 2-3 m. In a shopping mall scenario about 1-5 stories, the BSs are installed on the ceilings, walls or shops at a height of 3 m. An example of this Scenario is a transmitter height of 2-3 m, receiver of 1.5 m and inter-site-distance of 500 square meters [22].

3.4. Device-to-Device (D2D)/Vehicle-to-Vehicle (V2V)

The access of D2D is through open area, indoor, and street canyon while V2V is considered as a special due to its high mobility.

4. UDN MODELLING TECHNIQUES

There are different techniques are used to model UDNs with different Performance metrics. Stochastic Geometry, Game Theory, and Markov chain are one of these techniques. Game Theory is a study based on applied mathematical models consists of conflicts and cooperation among intelligent decision makers. It contains a variety of techniques and tools used to provide a reasonable solution to the conflicts of interest between groups of rational entities. A theoretic game can be classified into three main components called, players, actions, and payoffs [24]. In UDN, a wide research area for Game theory approaches can be exploited such as interference management, small cells discovery, users association, resource allocation and handover of user subscribers. However, there is a questioning about the scalability of game theory with a large number of access nodes or players at UDNs in which there is a limitation in optimization this number of nodes [9].

In addition, the impact of the stochastic modelling on small cells UDNs in spatial distribution has shown significant results compared to the traditional modelling techniques as shown in the literature [7]. In UDN, the unplanned random deployment of the small cells makes the stochastic geometry as a crucial modelling technique to fit the random environment [25]. The position of UND access nodes can be modelled in two-or-three dimensional Euclidean space point process (PP) which is considered as a sub-field of stochastic geometry. Besides, the Markov process is defined as a stochastic process which matches the Markov properties where the conditional dependence is on the present state while both future and past are independent [26]. In cellular networks, Markov chain has been applied as a modelling technique used for optimization. The unplanned and random environment structure of UDN, makes Markov chain a significant technique for modelling such environment [27]. From the reviews above of these different modelling techniques, it can be seen that the stochastic Geometry are the main potential technique for modelling the UDNs because of the randomness and irregularity of UDNs. The irregularity of UDN Access nodes deployment is due to the infrastructure deployment practical limitation and also the availability of mobile devices as content providers. Section 5 below proposed a model for UDN using a single cell in UMa scenario with a hexagonal layout. Stochastic geometry can be used as well to model the single cell using Poisson Point Process layout (PPP).

5. PROPOSED UDN SYSTEM MODEL

We consider a downlink Multi-Input Multi-Output (MIMO) single cell heterogeneous UMa network. The coordinates of the Access Nodes (ANs) and the User Terminals (UTs) follow the hexagonal cell layout with the density of ANs per sector denoted as λ_b and the density of UTs per sector denoted as $\lambda_u$where, $\lambda_b \geq \lambda_u$for UDN . The network cell is referred as *m* which is divided into 3 sectors with base station (BS) at the center. The 3 sectors are referred as sector *i* where *i* ∈ {1, 2, 3}. Each AN is referred as *n* and the cell *m* has $\boldsymbol{N_m}$ sets of ANs where *n* = {1, 2, 3,…, ‖$\boldsymbol{N_m}$‖}. In addition, each sector *i* has $\boldsymbol{N_{m,i}}$ where $\boldsymbol{N_{m,i}} \subset \boldsymbol{N_m}$. Each user UT is referred as *u* and the cell has $\boldsymbol{U_m}$ sets of UTs where *u* = {1, 2, 3,…, ‖$\boldsymbol{U_m}$‖}. Besides each sector has $\boldsymbol{U_{m,i}}$ UTs where $\boldsymbol{U_{m,i}} \subset \boldsymbol{U_m}$. The BS of cell *m* serves $\boldsymbol{U_m}$ sets of UTs with different traffic demands. The total bandwidth of this network *WT* is divided into *K* number of sets of subchannels, *K*= {*K1*, *K2*, *K3* } in which each sector is assigned to one subchannel. All ANs and UTs consist of two antennas where the BS has two antennas per sector. Figure 2 displays the cell layout of single cell UDN in UMa.

Assume the transmitter and receiver antennas are isolated to avoid any interference at UT. Therefore, UT can receive and transmit simultaneously. Besides, every small cell AN serves linked users with equal power allocation and zero forcing beamforming to reduce the network complexity [9]. The power received in UT from the BS is denoted as $E_{BS,u}$which depends on the distance measured. The received power is a function of the power of transmission from the UT to the BS which is denoted as $P_{BS,u}$, the attenuation gain $A^{"}(\theta^{"},\phi^{"})$ and the Gain of of the UT from the BS $G_{BS,u}$.

Assuming the long normal shadowing χ in dB. The gain pattern follows the one specified in [22] as

$$A''_{\mathrm{dB}}(\theta'' = 90^\circ, \phi'') = -\min\left\{12\left(\frac{\phi''}{\phi_{3\mathrm{dB}}}\right), A_{\max}\right\} \quad (1)$$

where $\phi_{3\mathrm{dB}} = 65^\circ$, $A_{\max} = 30\mathrm{dB}$ and $\phi'' \in [-180^\circ, 180^\circ]$.
The received power at UT can be calculated as

$$E_{BS,u} = P_{BS,u} \times A''(\theta'', \phi'') \times G_{BS,u} \quad (2)$$

$$G_{BS,u} = 10^{-(PL_{BS,u\,LOS} + \chi)/10} \quad (3)$$

The Gain of BS and UT depends on the path loss model of the distance between BS and UT as discussed in section 6.

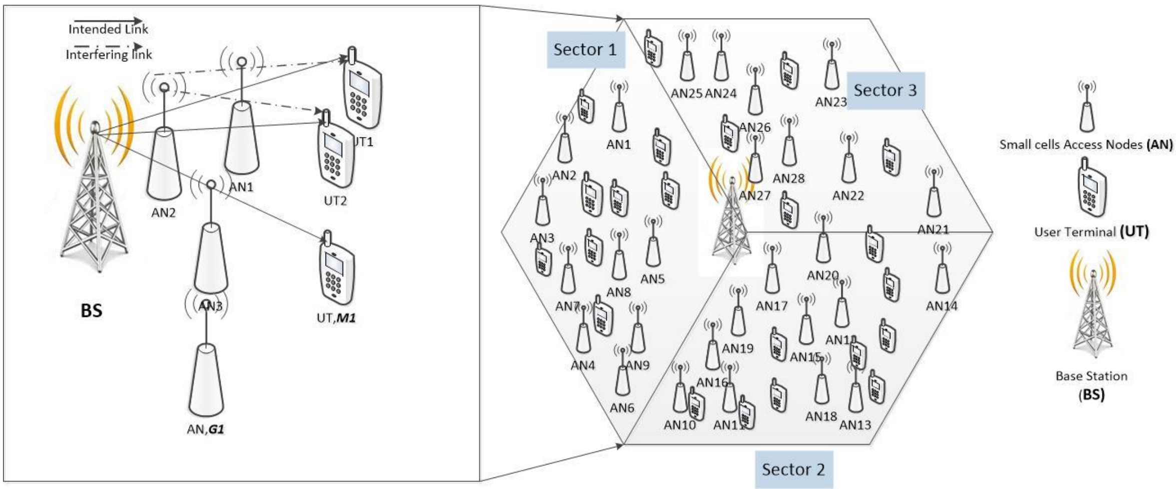


Figure 2. Network Layout for single cell

6. PATH LOSS MODEL FOR UMa

In this section, the path loss of Uma is modelled based on the modelling equations in Table 2. This model is measured on a distance from 10m to 500m in outdoor for 2D and 3D distance. In addition, it includes the path loss modelling for LOS and NLOS. The distance definitions for 2D and 3D indoor and outdoor are indicated in Figure 3. The parameters needed for path loss model are listed as well in Table 1.

Table 2. Distance Path loss for UMa Scenario [22]

LOS	$PL_{LOS} = \begin{Bmatrix} PL_{d1} & 10m \le d2D \le d'_b \\ PL_{d2} & d'_b \le d2D \le 500m \end{Bmatrix}$ $PL_{d1} = 28 + 22\log(d3D) + 20\log(fc)$ $PL_{d2} = 28 + 40\log(d3D) + 20\log(fc) - 9\log((d'_b)^2 + (h_{BS} - h_{UT})^2)$	σ =4 $1.5m \le h_{UT} \le 22.5m$ $h_{BS} = 25$m
NLOS	$PL_{NLOS} = \max(PL_{LOS}, PL'_{NLOS})$ for $10m \le d2D \le 500m$ $PL'_{NLOS} = 13.54 + 39.08\log(d3D) + 20\log(fc) - 0.6(h_{UT} - 1.5)$	σ =6 $1.5m \le h_{UT} \le 22.5m$ $h_{BS} = 25$m

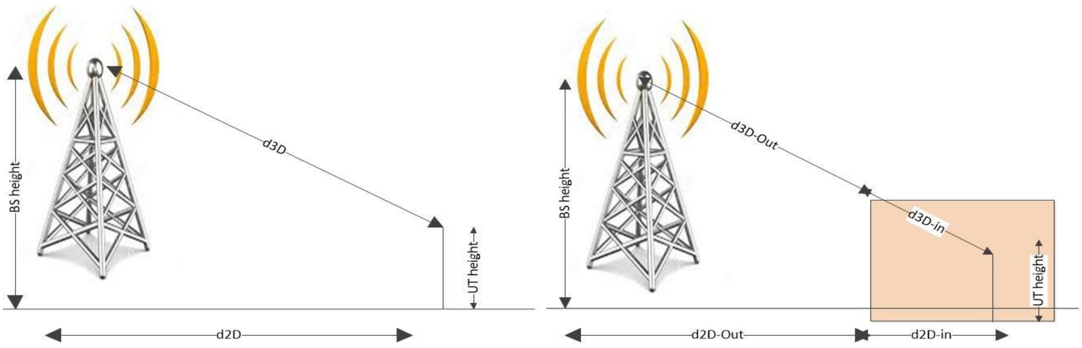


Figure 3. Description of d2D and d3D for outdoor (a) and indoor (b) (UTs)

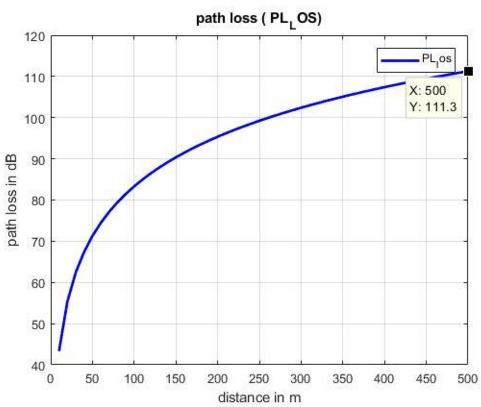
Equation 4 is to calculate the 3D distance for both outdoor and indoor considering the antenna and user height.

$$.d_{3D-o} + d_{3D-i} = \sqrt{(d_{2D-o} + d_{2D-i})^2 + (h_{BS} - h_{UT})^2} \quad (4)$$

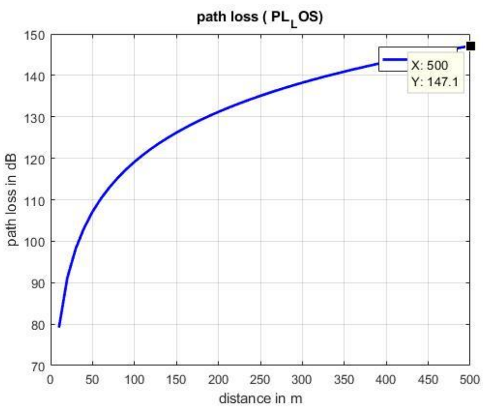
From the UMa path loss model, the break distance $d'_b = 4h'_{BS}\, h'_{UT} f_c$, where $h'_{BS}\, h'_{UT}$ are the effective heights for BS and UT,f_c in Hz is the center frequency which is normalized by 1GHz while $c = 3 * 10^8$m/s which is the propagation velocity. $h'_{BS} = h_{BS} - h_V$, where h_{BS} is the actual base station height while $h_V = 1m$ is the environment effective height. $h'_{UT} = h_{UT} - h_V$.

7. RESULTS AND DISCUSSION

Figure 4 shows the path loss when line of sight for UMa dense network. The distance measured according to the equations in Table 2 which reflects the 2D and 3D distance considering the heights of base stations and the UTs as shown in Figure 3. The line of sight path loss shows the 2 distances d1 and d2 starting from 10m to 500m. The distance is measured between the BS and UT. Figure 4(a) shows an increase in the path loss in dB with increasing the distance at $1GHz$. At 10m, path loss was 44dB then it keeps increasing till it reaches 111.3 dB at 500m. Figure 4(b) below shows the path loss when the $fc = 6GHz$. It indicates an increase in the path loss about 35.1 dB compared to path loss at Figure 4(a).



(a)



(b)

Figure 4. Path loss of LOS (a) fc=1GHz and (b) fc=6GHz

Figure 5 illustrates the path loss of Non-line of sight (Non-LOS) for UMa UDN network. The distance measured for both the 2D distance and the 3D considering the heights of BSs and the UTs as shown in Figure 3. The non-line of sight path loss demonstrates d1 and d2 starting from 10m to 500m. The resulting path loss displays an increase in the path loss in dB with increasing the distance at fc =1GHz. At 500m the path loss reaches 119dB compared to 111.3dB at LOS.

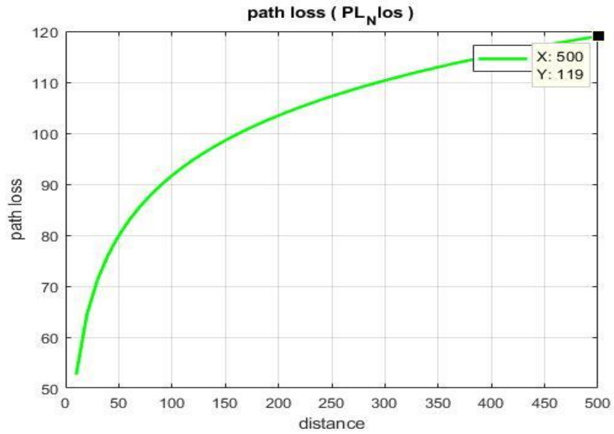


Figure 5. Path loss of Non LOS (PL_NLOS)

In order for the network to accommodate more users, a spatial reuse technique is required whenever the channels are occupied. Thus, the analysis is done to define the interference range occurred by the transmission of the AN. Based on equation (2), the UT received power from the BS as a function of the distance between the BS and the UT is plotted in Figure 6. It indicates that, as the distance between BS and UT goes beyond 250m, the received power is approaching zero. Therefore, based on this observation, it is assumed that a user located more than 250m away from the BS of another sector can reuse the subchannels of the AN with negligible interference.

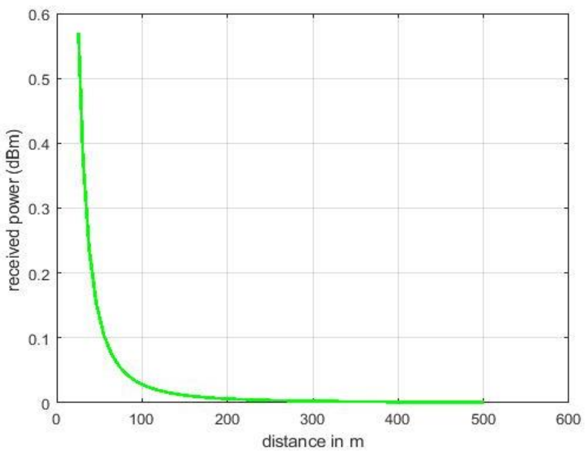


Figure 6. Received power of UT from the BS

8. CONCLUSION

5G networks ultimate race is intensely fostered by the amount of generated traffic by the current users due to the significant increase in mobile devices. Ultra dense networks are considered as a leading enabling technology that will provide an efficient capacity and performance for future networks. In this paper, an introduction to 5G UDN networks and its Challenges were presented. Further researches are needed to indicate the differences between the fundamentals of traditional Heterogeneous networks and that of UDNs. Besides, various scenarios for modeling the heterogeneous 5G UDN were discussed such as UMa, UMi, D2D, and indoor. Furthermore, different modeling techniques were studied in terms of its impact on the performance of 5G UDNs including. Moreover, the system model of a single heterogeneous UDN model was proposed in UMa scenario based on 5G parameters for various distances. Stochastic Geometry showed a significant performance in UDN due to the randomness and the irregularity of small cells.

The differences in the fundamentals of UDN emphasize the need for an efficient and appropriate propagation modeling techniques. Furthermore, UMa path loss model for 5G UDN was proposed and analyzed for distances from 10m to 500m. The simulation results of the received power of UT distance dependent indicated that a user 250m away from the BS in another sector can reuse the subchannel of the BS as the received power approaches zero at 250m distance from the BS. For further discussion on 5G UDN channel Modelling, the outdoor-to-indoor for RMa should be considered. Besides, complexity in terms of generating channel coefficents, description and simulation should be considered as well. The prposed model should be consistant in time, space and frequency. Furthermore, the channel model should cover a wide range of coupling loss using typical cell size up to range of km for macrocells. On the other hand, the UT mobility need to be accommodated for a speed up to 500 km/h. For future development, a methodology for model extensions to D2D and V2V should be considered with large antenna arrays.

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BIOGRAPHIES OF AUTHORS

Currently Fayad Ghawbar is an electrical engineering PHD candidate at University Tun Hussein Onn Malaysia, Batu Pahat, Malaysia. He has received the Master of electrical engineering in 2015 from University Tun Hussein Onn Malaysia. Previously, he has obtained his first degree from University Malaysia Pahang, Malaysia, with honors, in electrical & electronics engineering in 2013.

Faiz Asraf Saparudin received his Bachelor B.Sc. in Electrical Engineering (Telecommunication) with First Class Honours from Universiti Teknologi Malaysia in 2010 and received WAMY Academic Excellence Award in the same year. Ph.D. degree in Electrical Engineering (Telecommunication) from the Universiti Teknologi Malaysia in 2015. He is currently a Faculty Member in Fakulti Teknologi Kejuruteraan, Universiti Tun Hussein Onn Malaysia. Member of Institue of Electrical and Electronic Engineers (IEEE) and IEEE Communication Society (ComSoc). His current research interests include radio resource management, distributed algorithms, nature-inspired techniques, multiagent system and game theoretic approach for next-generation mobile network.

Jumadi Abd Sukor received both his B.Eng. in Optical Communication from Tokushima University. Masters Degree in Electric-Electronic and Telecommunication from Universiti Teknologi Malaysia and PhD in Biomedical Engineering from University of New South Wales. Currently he is holding Associate Professor position in Universiti Tun Hussein Onn Malaysia His research interests are Bioinformatics Tools, Telehealth technologies and decision support systems.

Aimi Syamimi Ab Ghafar received both her B.Eng. in Electrical - Telecommunications and PhD in Electrical Engineering from Universiti Teknologi Malaysia Johor. She is currently serving as a lecturer in Department of Electrical Engineering Technology, Faculty of Engineering Technology in Universiti Tun Hussein Onn Malaysia. Her current research interests are cooperative relay communications, resource allocation in wireless communication networks, and Internet of Things (IoT).

Norshidah Katiran received her Ph.D in Electrical Engineering from Universiti Teknologi Malaysia, in 2015, her M.Eng. degree in Communication and Computer Engineering from Universiti Kebangsaan Malaysia, in 2004, and her B.Eng. degree in Electrical Engineering (Telecommunications) from Universiti Teknologi Malaysia, in 2001. Currently, she is a Senior Lecturer in the Department of Communication Engineering at Universiti Tun Hussein Onn Malaysia. Her major research interests include optimization of resource allocation in cooperative networks and multiple input multiple output (MIMO) transmissions.