Performance Characterization of randomly moving users in a Stochastic Heterogeneous Network

Submitted By – Ashish Puri

Email – puri1@ualberta.ca

Supervisor & Mentor – Dr. Sachitha Kusaladharma

Email - kusaladh@ualberta.ca

Submitted To – Dr. Mike Macgregor

Director MINT

University of Alberta

Edmonton, AB, CA

Index

Abstract

Wireless Communication has seen an exponential growth during the last few years and is expected to grow further in the coming years. From the planned base station deployment of yesteryear, the industry has come to a stage where the locations and numbers of base stations are increasingly random, and heterogeneous where different classes of base stations exist. This randomness will be exemplified by the addition of small cells and pico-cells whose locations and activities are sometimes out of the operator's control.

As such, random modeling of wireless networks is essential to analyze the performance. The random base station modeling can also work when the base stations follow a planned distribution. In contrast to the base stations, the user locations are almost always completely random, and sometimes the users are mobile. Here we study how the mobility affects the performance of the user in terms of the coverage, throughput, and multiple hand-offs.

Acknowledgment

I would like to thank Dr. Sachitha Kusaladharma for being an excellent supervisor and guiding me to complete the project. I also wish to thank all my family and friends and other teachers who have helped me come to this stage.

1 Introduction

We have witnessed the evolution of cellular networks into a vast area of applications. Wireless communications have enabled people to communicate in remote parts of the world. The evolution of wireless communication is characterized by generations with major shifts in technology between generations. During the past decades, wireless communication has benefitted from substantial advances and is considered as the key enabling technique of innovative future consumer products. In the near future, the large scale operation of wireless devices and the necessities of high-bandwidth applications are estimated to lead to incredible new challenges in terms of the efficient utilization of the spectral resources. The convenience of wireless allows us to use cellular telephones and wirelessly connected computers almost everywhere in towns and cities and along major transportation corridors.

1.1 History

The first international cellular networks were deployed in the 1980s. The Nordic mobile telephony (NMT) system was the first cellular network used in the Nordic countries and it is based on analog cellular technology, as well as the systems deployed shortly after NMT in North America and Japan. The first Generation (1G) network focused on mobilizing landline telephony [21]. 1G is circuit switched that aided analog voice transmission over the air. It employed Frequency Division Multiple Access (FDMA). The major drawback of 1G is its high sensitivity in a dynamic environment and tarnished quality [22].

The second generations (2G) dealt with digital transmission technology. The digital cellular technology supports larger subscribers within the specified frequency band and supports higher user capacity, better voice quality as well as security. Second Generation networks supported data transmission along with enhancement in voice transmission. The second generation (2G) cellular systems were pioneered by the Groupe Spécial Mobile (GSM) with a European cellular standard now known globally as the Global Systems for Mobile Communications and Interim Standard 95 (IS- 95), which is known as (CDMA one) commercially [23]. General packet radio services (GPRS) were incorporated into the GSM standard where each mobile network is assigned an IP address, which possibly will be static, determined by the cellular operator or dynamic, dependent on per connection basis. The data transfer and the operating bandwidth were tripled with the opening of the enhanced data-rates for global evolution (EDGE).

The third generation (3G) mobile communication standards were first being developed by the International Telecommunication Union (ITU) and they were based on wideband code division multiple access (WCDMA). The 3G network was first launched in Japan and shortly after that in Europe, and is known as Universal Mobile Telecommunications Services (UMTS). The 3GPP (3rd Generation Partnership Project) 3G system was later further improved with high-speed packet access (HSPA) and multiple antennas.

Increasing escalation of user demand and also the emergence of latest technologies in the mobile communications have prompted researchers and industries to approach up with extensive manifestations of the forthcoming fourth generation (4G) wireless communications in mobile technology [18]. Compared to 3G, the 4G brings about new levels of user experience and multi service capacity by integrating all the mobile technologies that exist (e.g. GSM, GPRS, IMT-2000, Wi-Fi, Bluetooth, ZigBee). 4G technology data transfer is much faster and less expensive. 4G provides flexibility and any desired service with the reasonable quality of services (QoS) anytime, anywhere. 4G is considered as Long Term Evolution (LTE) and gives the additional features of 3G, like wireless broadband access, Multimedia Messaging Service (MMS), Video chart, Mobile TV, HDTV content, Digital Video Broadcasting (DVB) [19]. IMT-Advanced 4G standards will steer us in a new era of mobile broadband communications that provide a global platform to build next generations of interactive mobile services including enhanced roaming capabilities, faster data access, broadband multimedia and unified messaging.

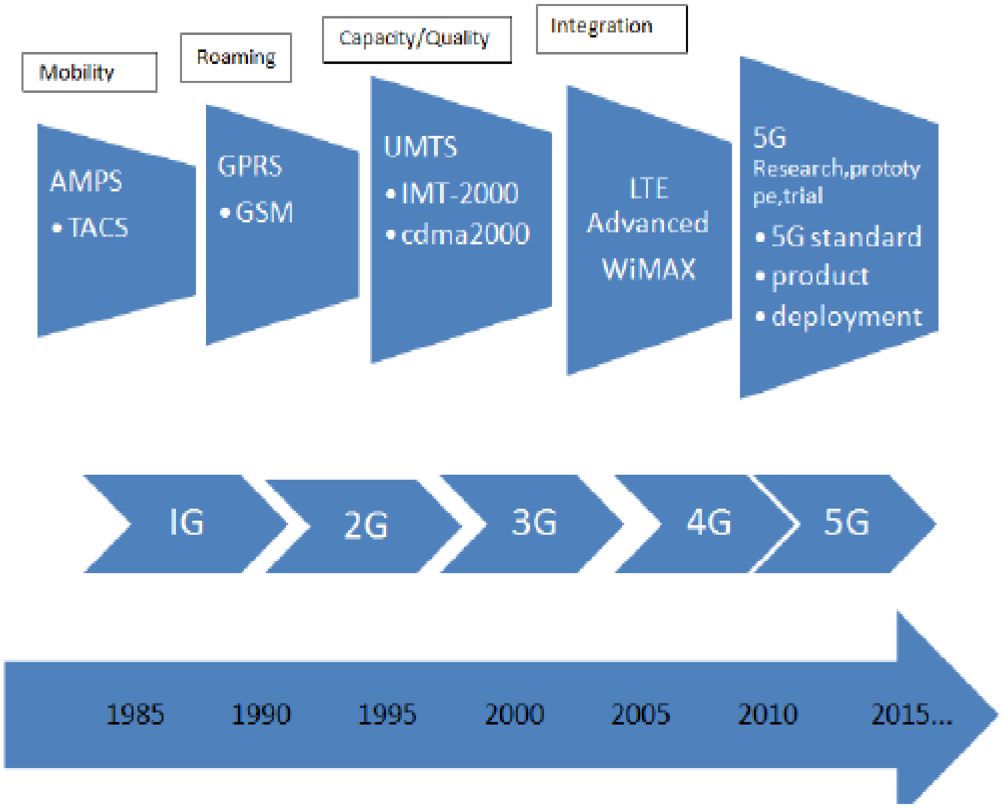

Fig 1: Evolution of mobile communication systems

Fifth generation technology will be very fast and reliable and the services of the networks and applications are to be accessed by the single IP, as telephony and worldwide cellular technology come under one umbrella. Fifth generation mobile with Nanocore is a convergence with Nanotechnology, Cloud Computing, and the entire IP platform. The link of communications from end to end between the client and server using internet protocol is necessary to raise the appropriate internet socket uniquely determined by the application of the client and server [20]. This means that in case of interoperability between heterogeneous networks and for the vertical handover between the respective radio technologies, the local IP address and destination IP address will be fixed and unchanged.

1.2 Current Issues

The increased demand for the capacity, service, and coverage requires a carefully planned deployment to transition into a more irregular, heterogeneous deployments of Macro, Pico and Femto-BSs along with new design approaches [1]. The location of the users and base stations are not predetermined. The location of users is always random in nature assuming a mobile user connects to the nearest base station. Hexagonal models are unrealistic in nature. Cellular network capacity is fundamentally limited by the intensity of the received power and interference. Both are highly dependent on the spatial locations of the base stations (BSs). By far, the most popular approach used in modeling the BSs topology is the hexagonal grid model adopted by standard bodies such as the 3rd Generation Partnership Project (3GPP). Grid models are highly idealized models which do not accurately capture the actual BSs topology. The received signal is the composition of the several signals with the different phases and time delay [10]. Variation in time of the channel is described as the Doppler Effect which occurs due to the frequency shift between the transmitted signal and the received signal.

Due to this, the stochastic geometry has got attention in the research community [2]-[7]. Stochastic geometry based models – random spatial models- are able to model a realistic network scenario [8]. The Binomial point process and the Poisson point process (PPP) are thus used for analytical tractability [9]. In reality, cell radii differ from one cell to another due to differences in the transmitted powers and the user density as shown for a real deployment. Stochastic geometry allows us to study the average behavior over many spatial realizations of a network where the nodes locations are derived from a point process. Most of the stochastic geometry work on cellular networks focuses on the case where the BS deployment follows a PPP [9]. The points derived from a PPP are independent which significantly simplifies the analysis. However, this is far from reality since the BSs locations in real cellular networks are not totally independent. Instead, they have planned deployments with a degree of randomness due to irregular terrains and hot-spots. The coverage analysis of a PPP by using a stationary point process does not capture the repulsion between BS.

User mobility is one factor which all networks should deal with. A network which supports static users may not be able to provide the same performance to mobile users. For example, a user having to move from one location to another may experience multiple handovers, coverage holes, and busy base stations which significantly hinder its performance. To this end, mobility models are important building blocks in simulation–based studies of wireless networks. Researchers in this area can choose from a variety of models that have been developed. Random walk, Brownian motion, and models from transportation theory are well-known motion models from physics and chemistry which are used in simulations of mobile networks in the wireless communications and mobile computing communities during the last decades.

1.3 Motivation and Contribution

The performance of a receiver with respect to the overall coverage when it is moving randomly from one place to another for different mobility models in a stochastic heterogeneous wireless network is an open research issue. The user's performance is affected by three factors. First, interference from other co-channel base stations affects the reception of signals. Second, due to the load factors of base stations, there may not be any slots available for a user to connect with a base station once it has moved to that particular base station's coverage area. Third, constant hand-offs affect the QoS (quality of service).

There are different stochastic models to represent random node distributions, and the PPP has been the most popular among researchers. Therefore, we will use this model to represent base station and user locations. For modeling the random motion, we will be using the Random Waypoint Model. For modeling the channel impairment, we will use Rayleigh fading model for small scale fading, the simplified path loss model for path loss and the lognormal model for shadowing. The performance will be obtained for metrics such as coverage and the number of hand-offs required.

1.4 Outline

The remaining chapters are organized as follows:

Chapter 2: Introducing background concepts.

Chapter 3: Modelling the wireless network heterogeneously and introducing the system model.

Chapter 4: Assessing the performance of the user in terms of coverage, throughput, and the number of hand-offs for static users

Chapter 5: Assessing the performance of the user in terms of coverage, throughput, and the number of hand-offs for mobile users

2. Background

The interference that is experienced by the user is the combination of interference from all active co channel devices. The individual interference is the combination of the activity of the interfering device, the transmit power, shadowing gain, small scale fading gain, the distance between the interfering node and the user, and the path loss exponent. The moment generating function is generally used approach for the aggregate interference [17]. The modeling of the aggregate interference with well-known distributions is popular due to the intractability of exact analysis. This aggregate interference, in turn, affects the outage performance of a user, which I will characterize in the later chapters. I will now go through some of the background concepts which affect the outage.

2.1 Poisson Point Process

The locations of the user terminals and the base stations are not usually static. It is random in nature [4]. User terminals are almost always random. To this end, stochastic models can be used to model the network scenario. Point processes are such models which are randomly generated through some mechanism. Mathematical models for point processes include the binomial point process and the PPP. Users can associate themselves with the closest base station. Such a cellular model is termed as the voronoi tessellation and the cell is termed as the voronoi cell.

When the total number of nodes is uniformly distributed and fixed in an area such type of model is described as binomial point process [15]. In a geographical area, the node distribution is accurate in the binomial point process.

Another stochastic geometry based analysis model is the PPP. In PPPs, the node dependencies are not there. The node is distributed randomly over a geographical area [16]. It has widely been used to exemplify the location of the nodes in prior research. If the PPP is homogeneous, then the number of the points in disjoint are independent [24]. The process has convenient mathematical properties which have led to it being frequently defined in Euclidean space and used as a mathematical model for seemingly random processes in numerous disciplines such as astronomy, physics, image processing and telecommunications [25]. In all settings, the Poisson point process has the property that each point is stochastically independent of all the other points in the process, which is why it is sometimes called a purely or completely random process [26]. The following is the equation for spatial poisson point process.

$$P\{N(B) = n\} = \frac{(\lambda|B|)^n}{n!} e^{-\lambda|B|}$$

here |B| is the area of B.

2.2 Fading

The fundamental phenomenon which makes transmission unreliable is fading. Deep fades that may occur at particular time or frequency or in space. This results in severe degradation of the quality of the signal at the receiver making it impossible to decode or detect. Multipath fading arises due to the non-coherent combination of signals arriving at the receiver antenna. The transmission impairments cause information to be lost in a signal. If the transmission medium is ideal, then the receiver will get the same data, but practically it is not possible. The phenomenon is described as the constructive/destructive interference between signals arriving at the same antenna via different paths, and hence with different delays and phases, resulting in random fluctuations of the signal level at the receiver. When destructive interference occurs, the signal power can be significantly reduced and the phenomenon is called as Fading.

One of the most common fading models that is used to represent the wireless channel is the Rayleigh fading. This is valid only when transmitters and receivers are not at the line of sight. With Rayleigh fading, the Rayleigh distribution specifies the amplitude while the power is specified by an exponential distribution. When the transmitter and receiver are at the line of sight, Rician fading is considered. One of the empirical fading models of the wireless channel is Nakagami-m fading model in which ‘m’ is a parameter representing the severity of fading [10].

2.3 Rayleigh Fading

With Rayleigh fading, the received signal at the receiver is the sum of all the reflected and scattered waves. Many objects in the environment cause the radio signal to be scattered before reaching to the receiver [27]. According to the central limit theorem, if there is sufficient scatter, the channel impulse response will be well modeled as a Gaussian process irrespective of the distribution of individual components. The probability density function of Rayleigh random process is expressed as:

$$P_R(r) = \left(\frac{2r}{\Omega}\right) e^{\frac{-r^2}{\Omega}}, \ r \geq 0 \qquad \text{---- (1)}$$

Where, $\Omega = E(R^2)$, and R is a random variable.

2.4 Log Normal Shadow Fading

The random variation of the amplitude of signal due to the large obstacles in the path is called shadowing. The dimension of the obstacle depends on the shadowing effect. The common model used for shadowing is the log-normal shadowing model.

The free-space propagation model is used for predicting the received signal strength in the line-of-sight (LOS) environment where there is no obstacle between the transmitter and receiver. The power radiated by an isotropic antenna is spread uniformly and without loss over the surface of a sphere surrounding the antenna. In fact, a more generalized form of the path loss model can be constructed by modifying the free-space path loss with the path loss exponent n that varies with the environments. This is known as the log-distance path loss model. If the distance between the transmitter and receiver is equal to each other, every path may have different path loss since the surrounding environments may vary with the location of the receiver in practice. A log- normal shadowing model is useful when dealing with a more realistic situation. Thus the received signal strength at a distance d taking in consideration the shadow effect is

$$PL(d) = PL(d_0) + 10n_p \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \qquad \text{---- (2)}$$

Where X_σ is a random variable. The random variable X_σ is modeled as log normal with zero mean and variable.

2.5 Path Loss

Path loss, which represents signal attenuation as a positive quantity measured in dB, is defined as the difference (in dB) between the effective transmitted power and the received power. It is due to the reduction in the signal amplitude between the transmitter and receiver over a distance. The simplest path loss model is the free space path loss model. In the free space model, variable factors such as hills, buildings, and houses are not included [10].

$$PL(dB) = 10 \log_{10} \left(\frac{P_t}{P_r}\right)$$

Some empirical models such as Hata model, Wofisch Ikegami model, and Okumura model are developed using real world experimental data to account for the limitations in analytical models.

2.6 Random Way Point Model

The Random Waypoint (RWP) model is an elementary model which describes the movement pattern of independent nodes by simple terms. Each node moves along a zigzag line from one waypoint to the next point. The spatial distribution of network nodes moving according to this model is not uniform. The non uniformity of the RWP node distribution has important practical consequences. First, it reduces the applicability of existing analytical results concerning ad hoc networks, which are typically based on the uniformity assumption [28]. Second, the non uniform distribution implies that the representativeness of the huge amount of simulation results obtained by using the RWP model could be impaired [29].

The exact model is given as follows. A user will decide to move to a new location which is at a certain distance and angle. Then, the user will move at a certain velocity to the new location. Once there, a user may stay there for a certain time. This process is repeated further until the user decides to stop.

2.7 Handover and Outage

At the receiver, the handover rate, quality of service and the outage are the affecting factors. Of these, the probability of outage is the most critical performance measure. It is defined as the probability that the received signal to interference and noise ratio (SINR) is lower than a fixed threshold. In a general system scenario, with a central cluster and interfering base stations, the average outage probability is computed along a trip of the mobile terminal that involves crossing the boundary between adjacent cells. The effects of correlated co-channel interferers are accounted for in the computation of outage probability, as well as in the dynamics of a relative signal strength handover.

On another note, handover rate affects the performance by constantly having the user switching to different base stations. If a user goes out of the coverage area of a particular cell, it will have to complete a handover to a different cell in order to be covered. However, even if a successful handover takes place, the number of handovers is inherently detrimental and should be reduced if possible.

2.8 Power Control Schemes

Transmit power control schemes are classified as fixed power, distance based, and measurement based methods [33]. Such schemes are widely used in modern mobile communication networks [34]. A mobile unit aims to obtain a predefined SINR level in the transmission from a base station (BS) with the least power consumption. It is desired to get this objective sensitivity level by allocating the network’s resources in the most efficient way [30]. Transmission powers signify a key amount of freedom in the design of wireless networks. Thus, power control is the way to set the transmitted power to perform the communication successfully. The power of every transmitter is adjusted to the level required to meet the requested QoS. Determining the transmitter power level is a very sophisticated task due to dynamic variation of the radio channel. Power control in 1st generation wireless networks was a relatively simple problem because of the enforced separation in resources [31]. There are two basic types of power control. One is open

Loop power control and another is closed Loop power control. The open loop power control techniques require the transmitter to measure the channel interference and adjust its transmission power consequently. The closed-loop power control technique requires the quality measurements to be done on the other end of the connection, and the outcomes are then sent to the transmitter so that it can adjust its transmitted power.

2.9 Receiver Association Schemes

Receiver association schemes can be based on the transmitter-receiver distance or the signal to noise ratio (SNR) of the transmitter receiver channel [32]. Each transmitter attempts to connect with the nearest available receiver. If it is not available, the transmitter attempts to connect with the next closest one. This process continues until the M-th closest receiver nodes are scanned. If no receiver node is available, the transmitter node remains silent.

3. System Model

To meet the increasing mobile traffic demand, mobile operators typically employ more resources, which results in the use of more energy. Consider a wireless network with multiple base stations. These base stations are to be deployed over a fixed geographical area. The users are randomly positioned and users always have data to transmit. The channel gain includes the path loss attenuation, shadow fading, and multi-path fading components.

In real time the base station and user terminals are in an irregular pattern. To create such scenario stochastic models are used. A stochastic model is a part of the mathematical area to analyze the point patterns. The point process is a set of the points which is generated randomly. Some of the mathematical models for the point process are Binomial point process (BPP) Poisson point process, the Beta-Ginibre point process, the Matern Hardcore point process and the cluster process. BPP is of use when the nodes are uniformly distributed and fixed. Poisson point process is a popularly used model. In this model, there are no dependences between the location of nodes and the nodes are random.

In the mobile model scenario, each base station can handle a certain number of users. For each user, the nearest base station is evaluated based upon the distance. For example, if there are fourteen users then all ten users can connect. Then there are four drop out base stations. For each of these connected users, base station would transmit data and the power.

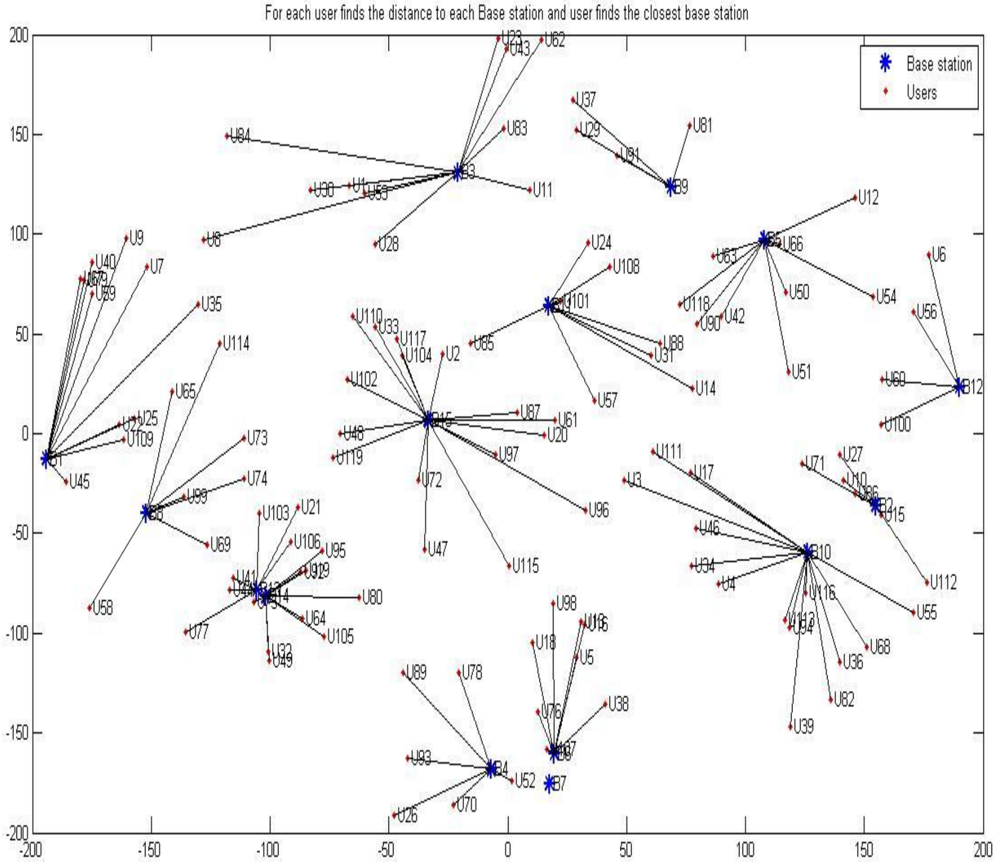

Fig 2: Base station nearer to the corresponding user based on minimum distance calculations

The figure 2 shows that for each user, it finds the distance to each Base station. Then find the base station nearer to the corresponding user based on minimum distance calculations.

This figure 3 below shows for each base station listed out the users which are within the base station coverage. Here we considered a constraint that the maximum number of users that can be served by a base station is 10. If the number of users is less than 10, then all the users can connect to that base station. If number of users is greater than 10, then only first 10 users can connect to the base station.

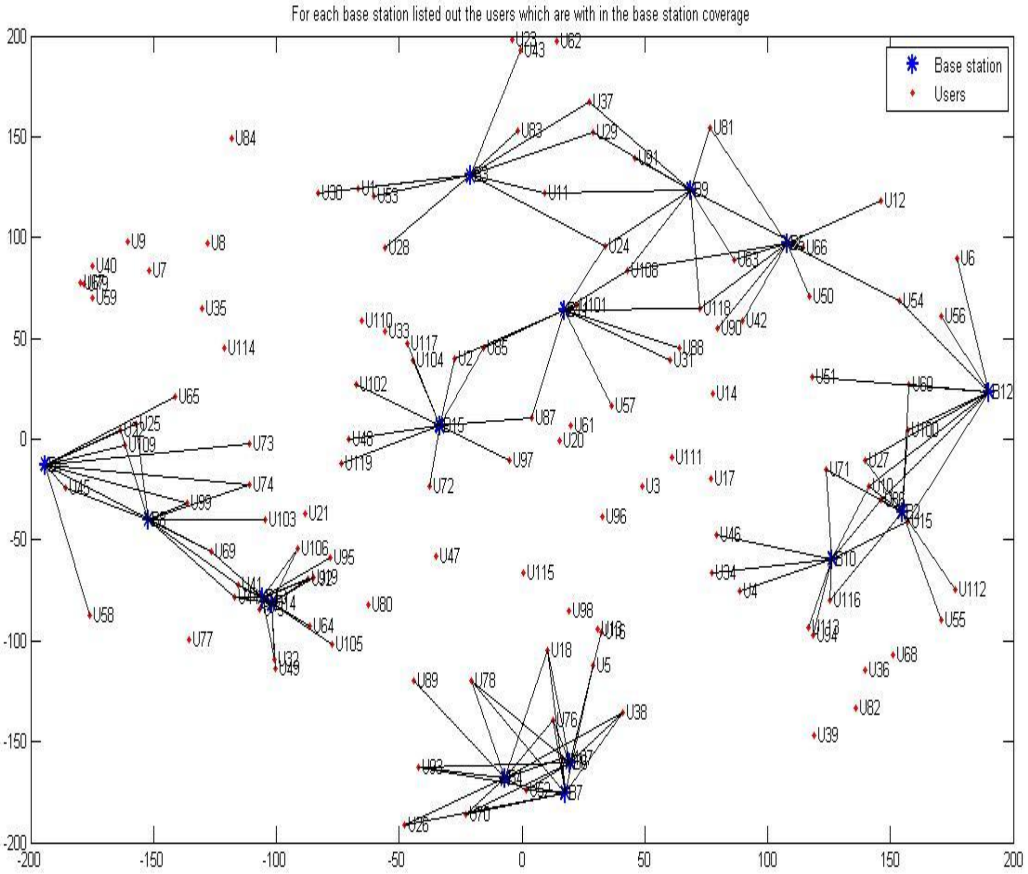

Fig 3: Maximum number of users that can be served by a base station is 10.

The transmitted power is calculated based on the transmitted power from the base station to the particular user asρd^{α}. Where ρ is the transmitted power, d is the distance between the base station and user and α is the path loss exponent.

The signal to interference ratio is evaluated as the received power at the user at the origin from base station to the interference. There will be interference from all the base stations.

Let user at U (0, 0) be connected to the nearest base station 'B' is always connected to first sub band. Interference will only occur if another base station has the user at the first sub band. Even if there are some users, the interference only occur from the user from the first sub band.

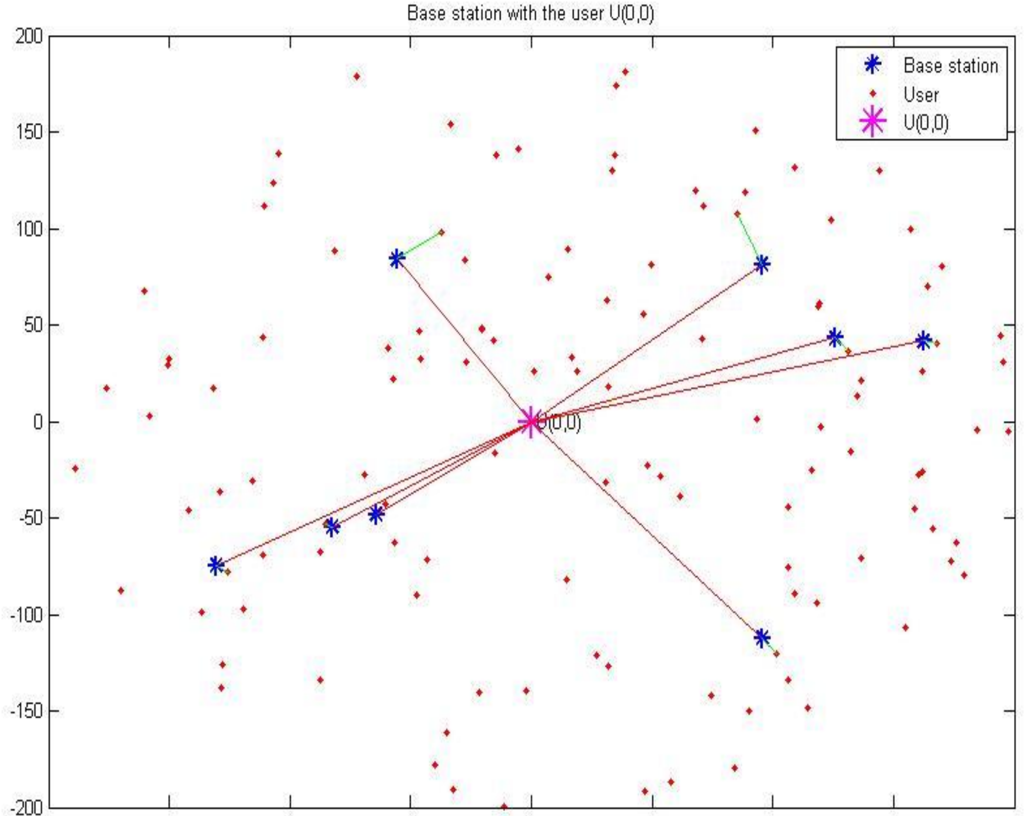

Fig 4: User at U(0,0) with base station and respective interference of the corresponding base stations.

Here figure 4 shows the user at U(0,0) with the base station and the respective interference of the corresponding base stations. The green line shows the user at band 1. Here the user U(0,0) is assumed in band 1 of the nearest base station. As that there is a lot of interference that any user will face from the corresponding base stations. These all things are kept in mind while placing the base stations so that the effect is minimised. We will take all these considerations in our simulations. Generally the closest base station usually connects to the user unless other interference parameters are taken into consideration.

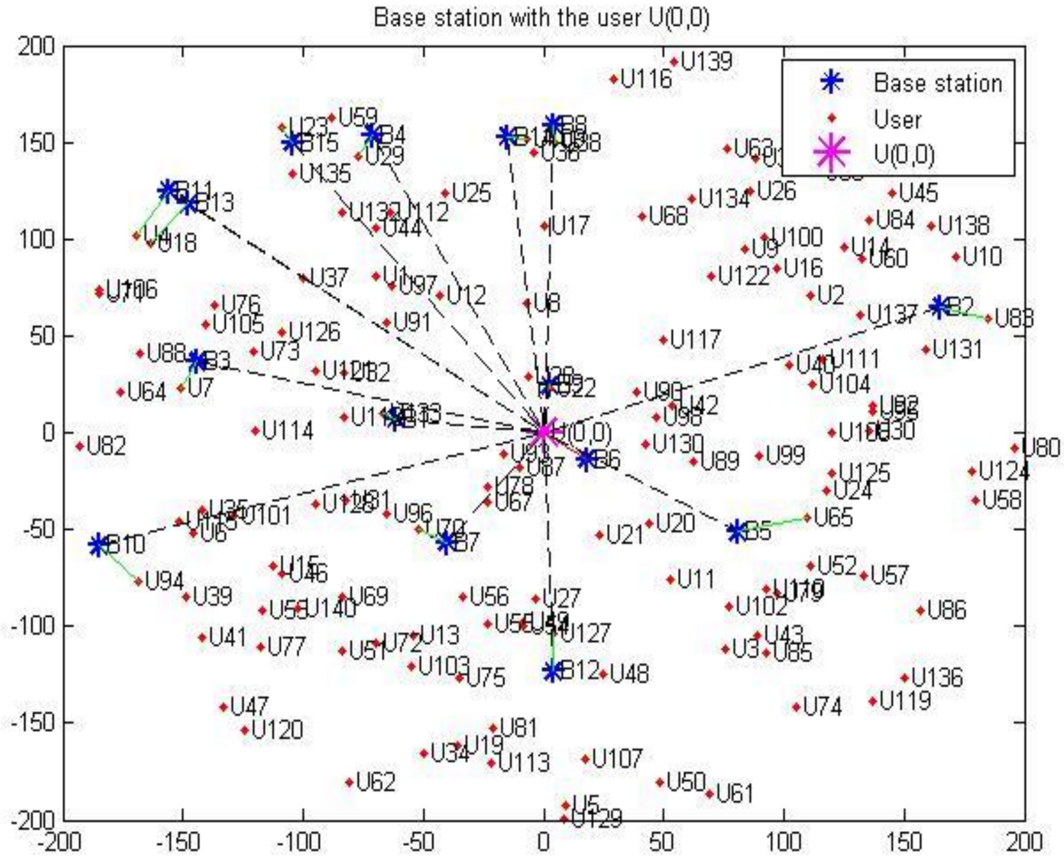

Fig 5: User at U(0,0) with 10 base stations and interference of the corresponding base station

The figure 5 is like the figure 4 but here all the base stations and users are numbered so that we can differentiate between them while conducting our simulations. We can see the principal user at (0,0) with 10 base stations and it is receiving interference from the nearby base stations.

4. Performance Analysis of the Wireless Network when the user is Stationary

In order to communicate with a user, one needs to know their location. The network thus faces a problem of continuously keeping track of the location of every user. An important issue in mobile wireless networks is the design and analysis of location management schemes. Before diving into a mobile network, we will consider a static network which comprises of fixed hosts and communication links between them.

To assess the performance of a static user during a complete transmission let us assume that a typical call lasts T time slots. Let T=15 for now. Then the SIR is calculated for each time slot. If the SIR is less than the required threshold in any of the time slots, there will be an outage (call drop). SIR represents threshold in here as an assumption. Check if there is an outage during the duration of the call. During the call time, even if one outage occurs, the call will be dropped, and thus an outage would occur.

Average outage probability - calculate the number of outages and divide it by the number of iterations.

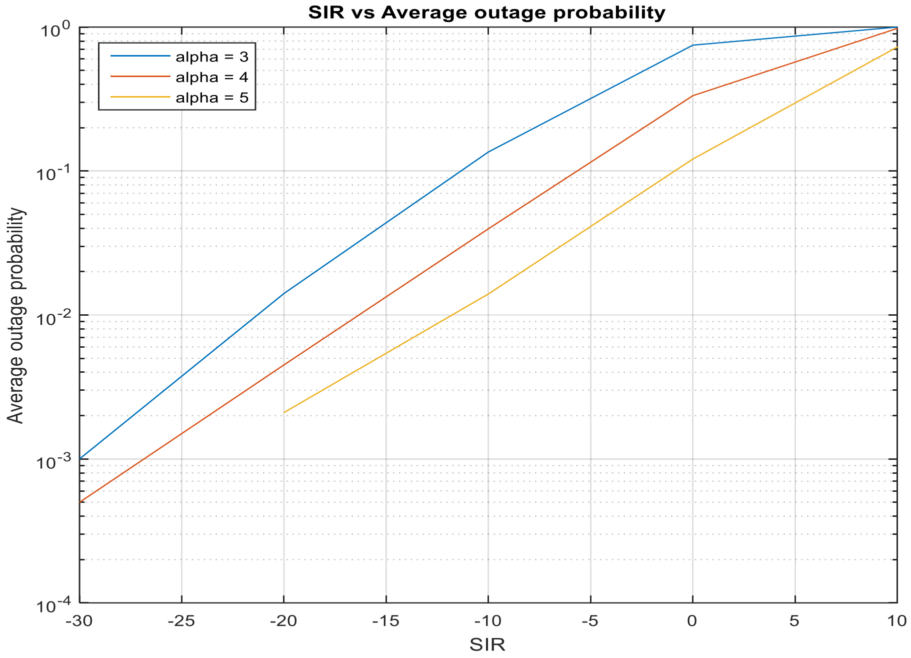

Fig 6: SIR versus Outage probability for path loss exponent at 3, 4, 5 user at U (0, 0)

The average outage probability vs the SIR for path loss exponent with 3, 4, 5 are plotted in figure 6. Outage probability is more at the path loss exponent with value 5. Outage value is increased initially then it flattens. At the higher levels, the transmitted power will fall below the threshold level. The rate of outage increases before flattening and depends on transmitted signal strength. The received power from an interfering node doesn't depend on the angular position but on its distance to the receiver. As the path loss exponent increases the performance decreases. At higher path loss exponent attenuate the interfering signals. The received primary power level is also low. When the path loss exponent is high then the transmitted power of the transmitter also increases to ensure a constant average received power at the receiver.

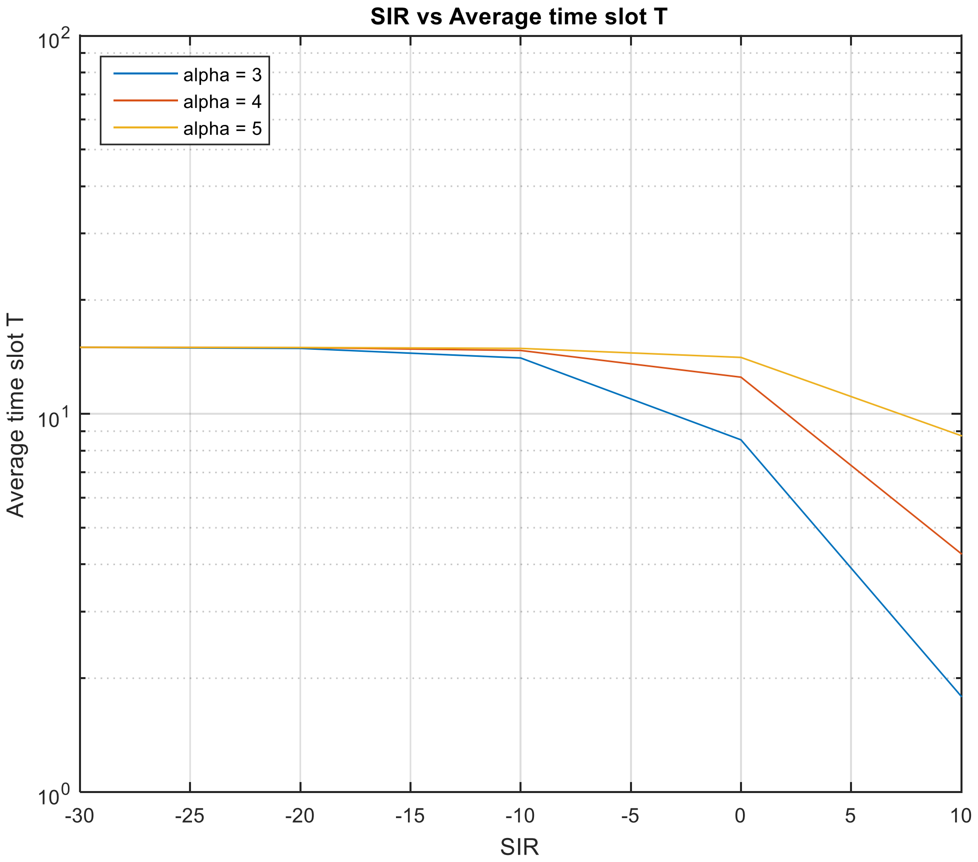

Fig 7: SIR versus average time slot for path loss exponent at 3, 4, 5 user at U(0,0)

In figure 7 above, the average time slot versus SIR for path loss exponent with 3, 4, and 5 are plotted. The average time slot is more at the path loss exponent with value 5. At the higher levels, the transmit power will fall below the threshold level.

The average outage probability versus the SIR with changing rho (10^{-8}, 10^{-9}, 10^{-10}), and keeping the path loss exponent at 3 is plotted in figure 8. At high SIR the outage probability is flattened for all rho values.

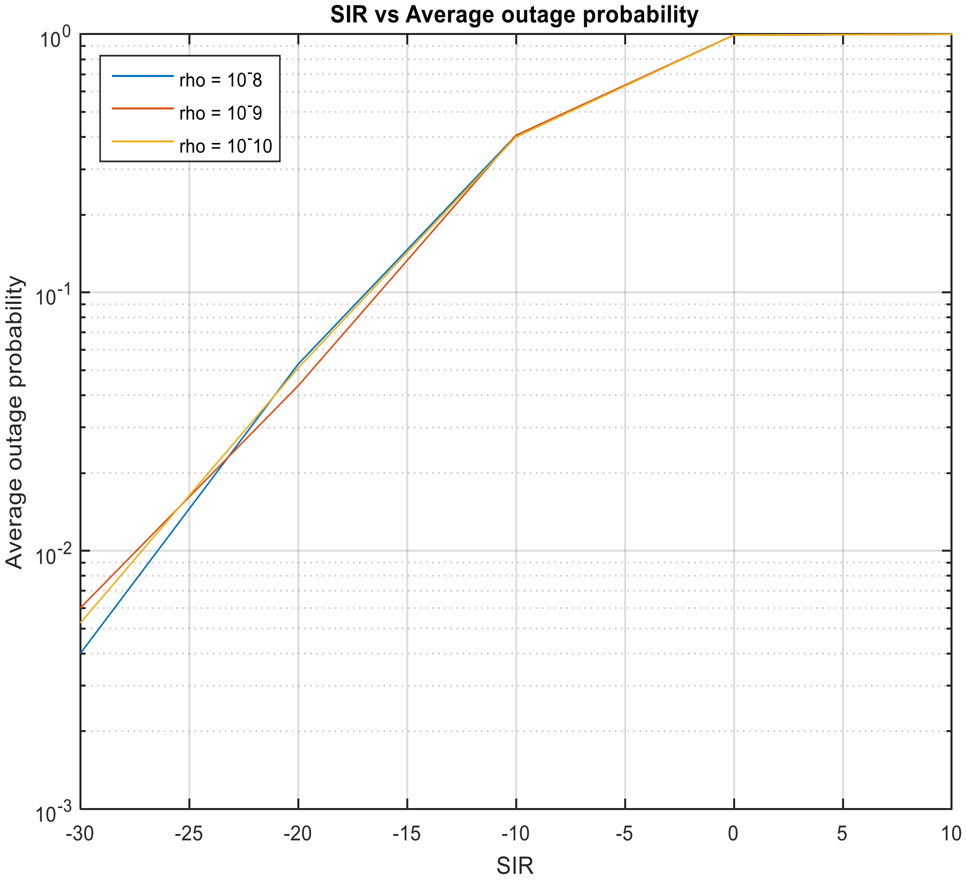

Fig 8: SIR versus outage probability for transmitted power at 10^{-8}, 10^{-9}, 10^{-10} at path loss exponent of 3

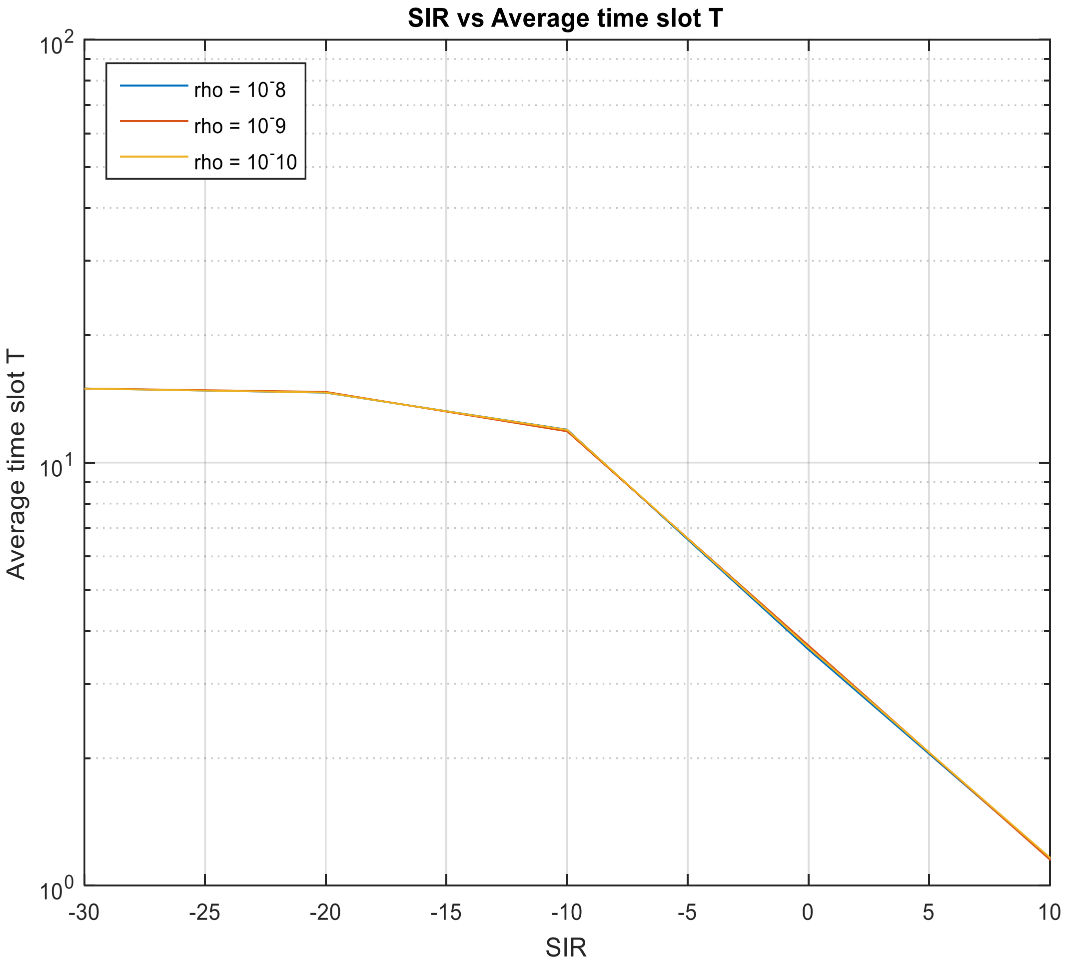

Fig 9: SIR versus average time slot for transmitted power at 10^{-8}, 10^{-9}, 10^{-10} at path loss exponent of 3

The average time slot versus the SIR with changing rho (10^{-8}, 10^{-9}, 10^{-10}), and keeping the path loss exponent at 3 is plotted in figure 9. For all rho values, the pattern is same at path loss exponent 5.

Outage probability and average time slot while changing the user density (have 0.01, 0.001, 0.0001) by keeping rho at 10^{-10} and path loss exponent at 3 is plotted in figure 10. It shows that as the user density increases computation time increases as well as the outage probability is increased as SIR increases.

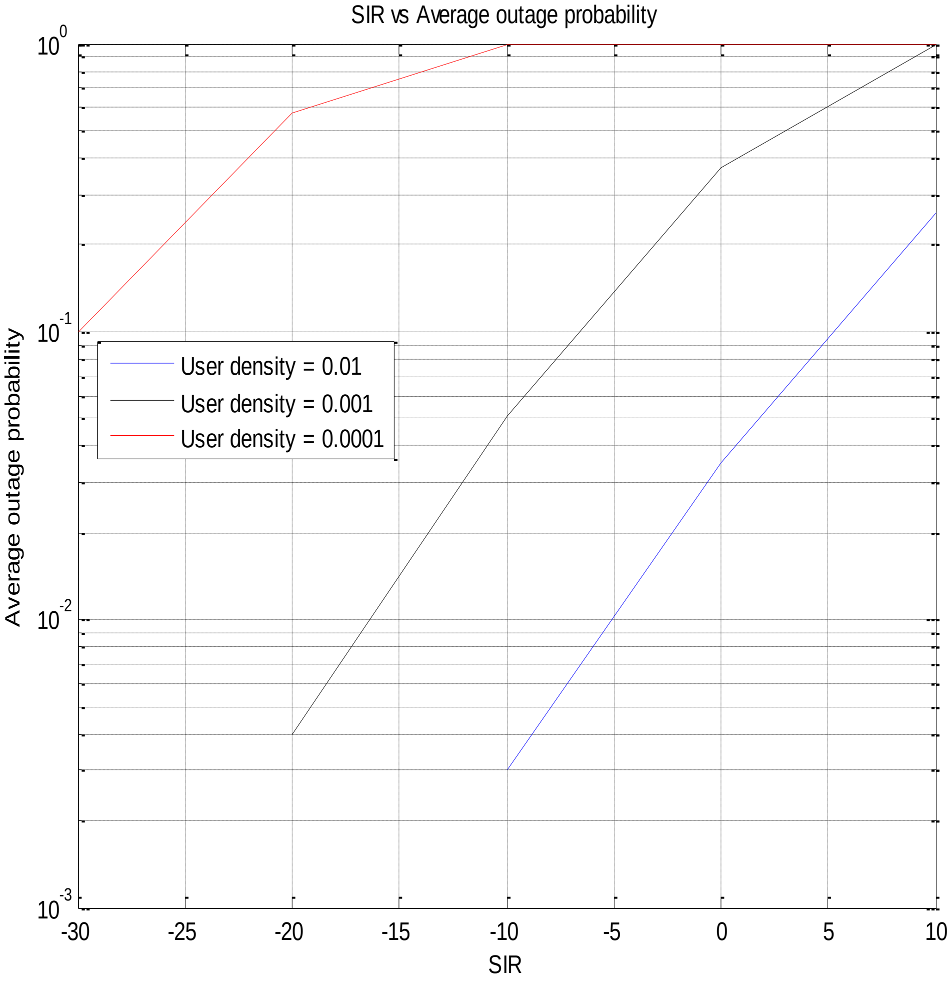

Fig 10: SIR versus outage probability for user density 0.01, 0.001, 0.0001 at path loss exponent of 3 and transmitted power 10^{-10}

Average time slot versus SIR with changing the user density (have 0.01, 0.001, 0.0001) by keeping rho at 10^{-10} and path loss exponent at 3 is plotted in figure 11. At lower SIR values with more user density 0.01the average time slot variation is less while user density at 0.0001 the average time slot variation is more.

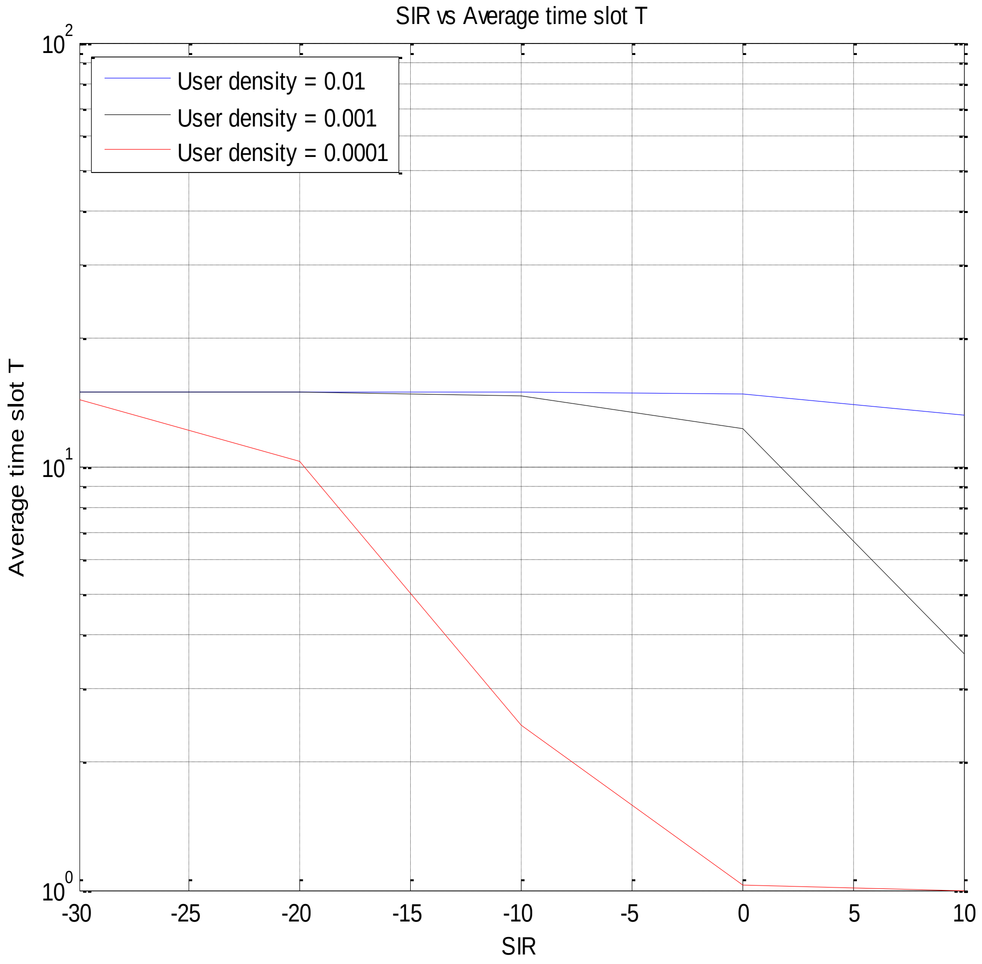

Fig 11: SIR versus average time slot for user density 0.01, 0.001, and 0.0001 at path loss exponent of 3 and transmitted power 10^{-10}

Here investigated the outage probability vs SIR and average time slot versus SIR for the user at U(0,0) with three variations. Variation with the path loss exponent 3, 4 and 5 is performed, then variation of transmitted power 10^{-8}, 10^{-9}, 10^{-10} with path loss exponent 3. Finally by varying the user density 0.01, 0.001, and 0.0001 at path loss exponent of 3 and transmitted power 10^{-10} is performed.

5. Performance Analysis of the Wireless Network when the user is in Motion

The motion of a mobile terminal is considered along with a path which involves crossing the border between two adjacent cells. In order to achieve effective elements for system design. Dynamic mobile wireless networks consist of mobile hosts which can communicate with each other over the wireless links (direct or indirect) without any static network interaction. In such networks, the mobile host has the capability to communicate directly with another mobile host in its vicinity.

In this model, after each time slot, the user selects a random location and moves. For example, the user is at the origin (0,0) before the first time slot. Before the second time slot, the user is at another location, say L1 (lx1,ly1). Similarly, before the third time slot, the user is at a different location L2 (lx2,ly2). This goes on for the duration of the call. The user selects to move a random distance (d) and a random angle (beta) from the current location.

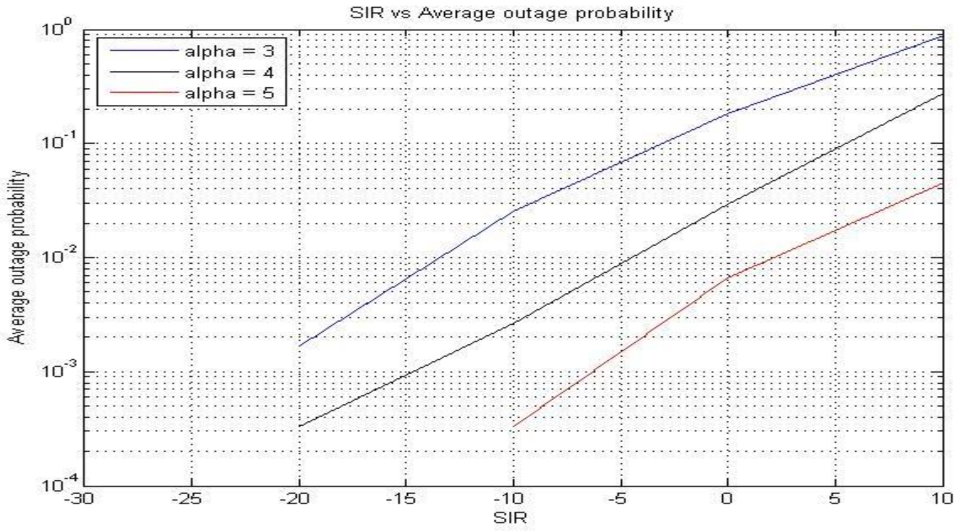

Fig 12: SIR versus Outage probability for path loss exponent at 3, 4, 5 for random way model

The average outage probability vs the SIR for path loss exponent with 3, 4, 5 for random way are plotted in figure 12. Outage probability is more at high SIR value with the path loss exponent with value 3. Outage value is increased initially then it flattens. At the higher levels, the transmitted power will fall below the threshold level. The rate of outage increases before flattening depends on transmitted signal strength. The received power from an interfering node doesn't depend on the angular position but on its distance to the receiver.

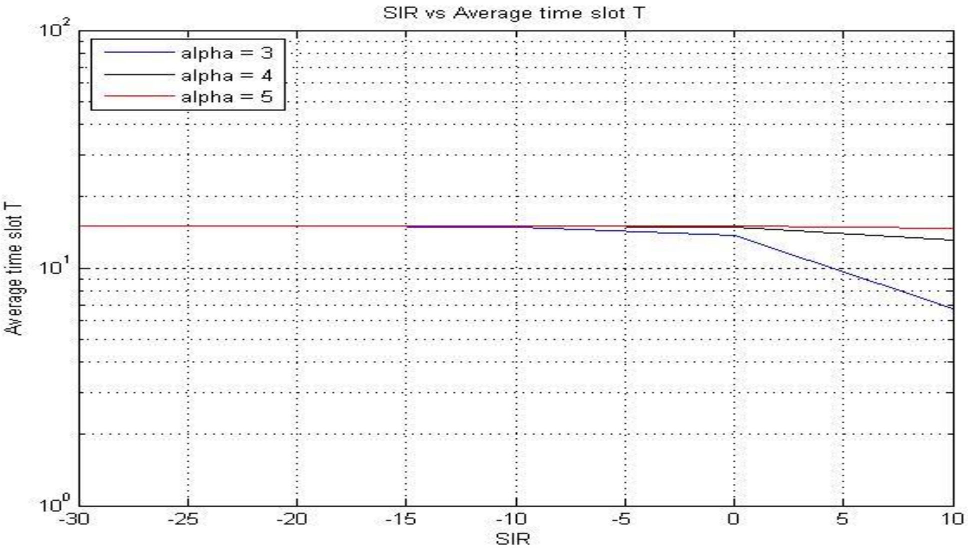

Fig 13: SIR versus average time slot for path loss exponent at 3, 4, 5 for random way model

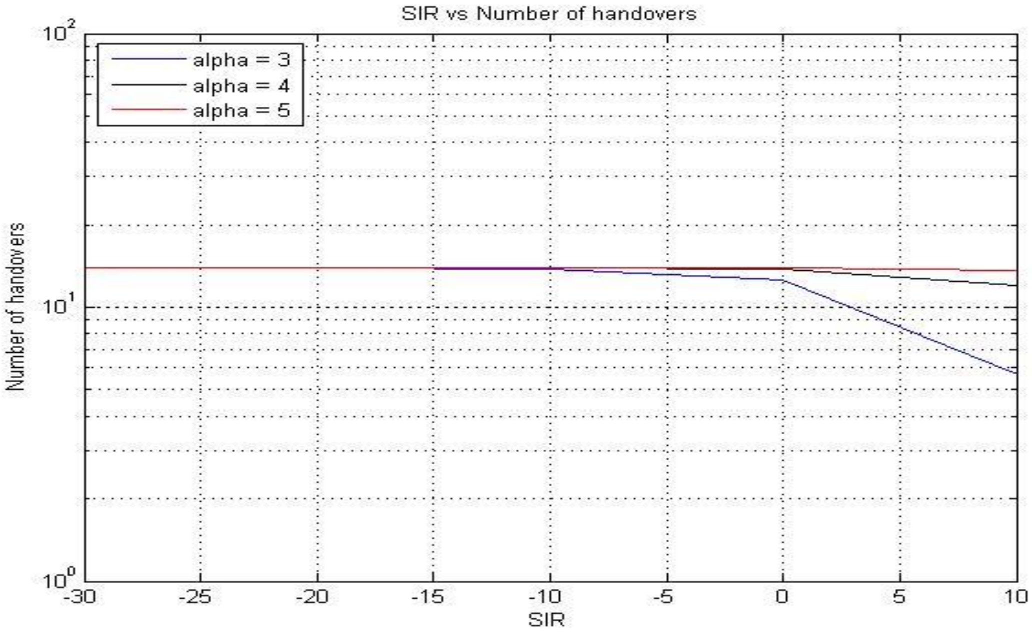

Fig 14: SIR versus handovers for path loss exponent at 3, 4, 5 for random way model

In figure 13, the average time slot versus SIR for path loss exponent with 3, 4, and 5 are plotted. The average time slot is more at the path loss exponent with value 5. At the higher levels, the transmit power will fall below the threshold level. Similarly, in figure 14, the SIR versus handovers for path loss exponent with 3, 4, and 5 are plotted.

The average outage probability versus the SIR with changing rho (10^{-8}, 10^{-9}, 10^{-10}) with random way model and keeping the path loss exponent at 3 is plotted in figure 15. At high SIR the outage probability is flattened for all rho values. As the path loss exponent increases the performance decreases. At higher path loss exponent attenuate the interfering signals. The received primary power level is also low.

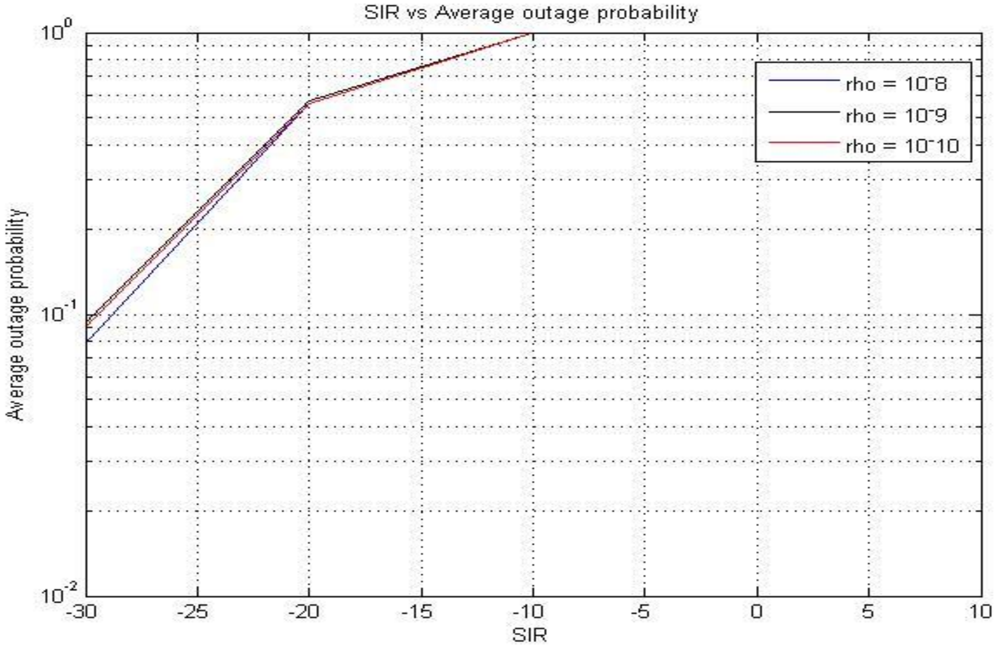

Fig 15: SIR versus outage probability for transmitted power at 10^{-8}, 10^{-9}, 10^{-10} at path loss exponent of 3

The average time slot versus the SIR with changing rho (10^{-8}, 10^{-9}, 10^{-10}) for random way model and keeping the path loss exponent at 3 is plotted in figure 15. For all rho values, the pattern is same at path loss exponent 5. Similarly, in figure 17, the SIR versus handovers for path loss exponent with 3, 4, and 5 are plotted. When the path loss exponent is high then the transit power of transmitter also increase to ensure a constant average received power at the receiver.

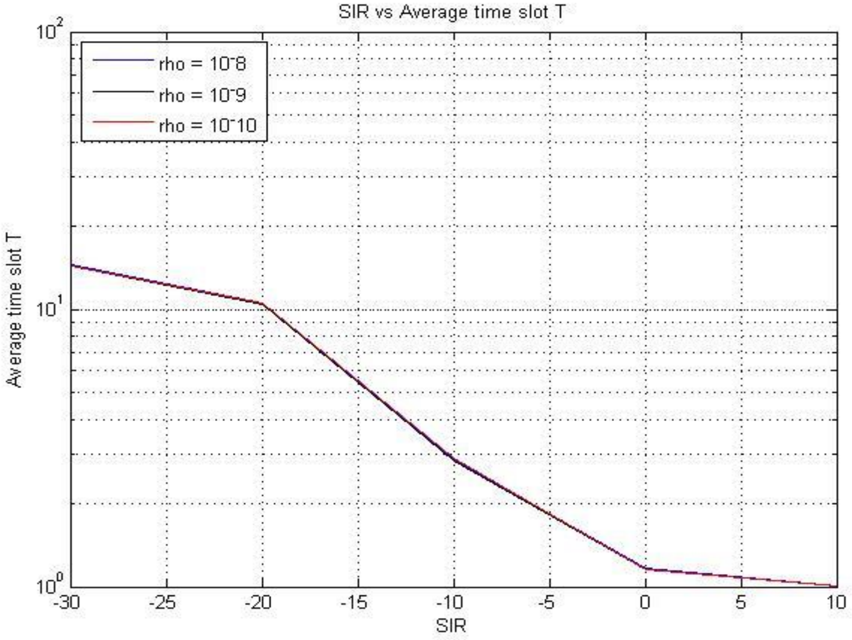

Fig 16: SIR versus average time slot for transmitted power at 10^{-8}, 10^{-9}, 10^{-10} at path loss exponent of 3

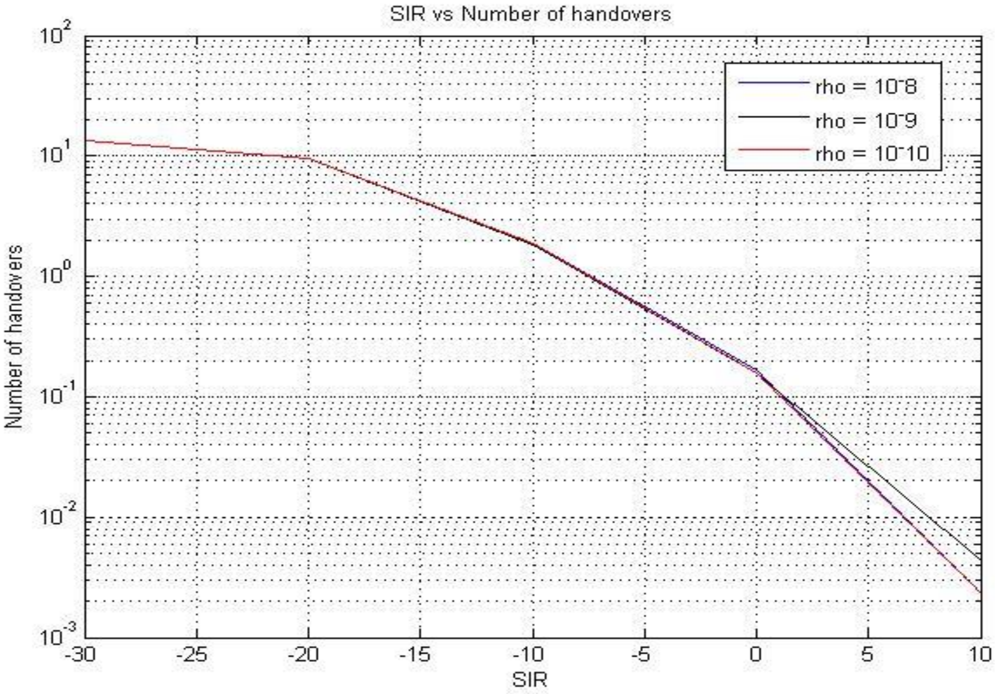

Fig 17: SIR versus handovers for transmitted power at 10^{-8}, 10^{-9}, 10^{-10} at path loss exponent of 3

Outage probability and average time slot for random way model is with changing the user density (have 0.01, 0.001, 0.0001) by keeping rho at 10^{-10} and path loss exponent at 3 is plotted in figure 18. It shows that as the user density increases computation time increases as well as the outage probability is increased as SIR increases.

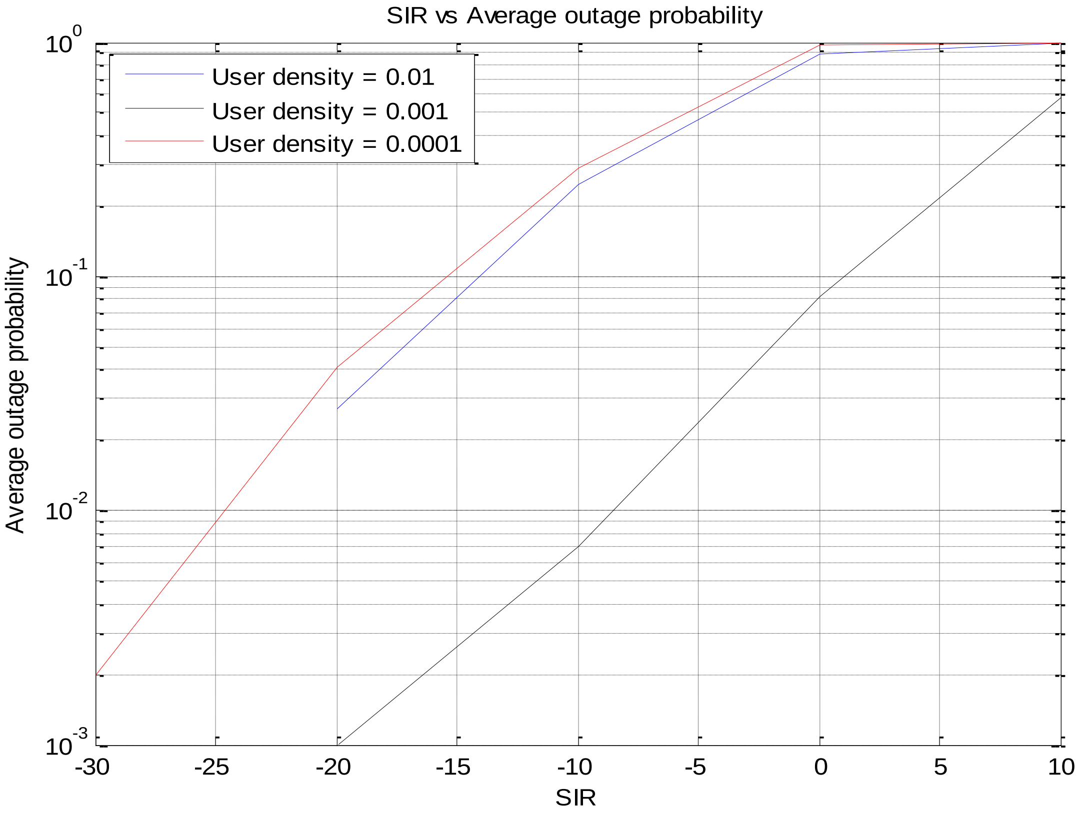

Fig 18: SIR versus outage probability for user density 0.01, 0.001, 0.0001 at path loss exponent of 3 and transmitted power 10^{-10}

Fig 19: SIR versus average time slot for user density 0.01, 0.001, and 0.0001 at path loss exponent of 3 and transmitted power 10^{-10}

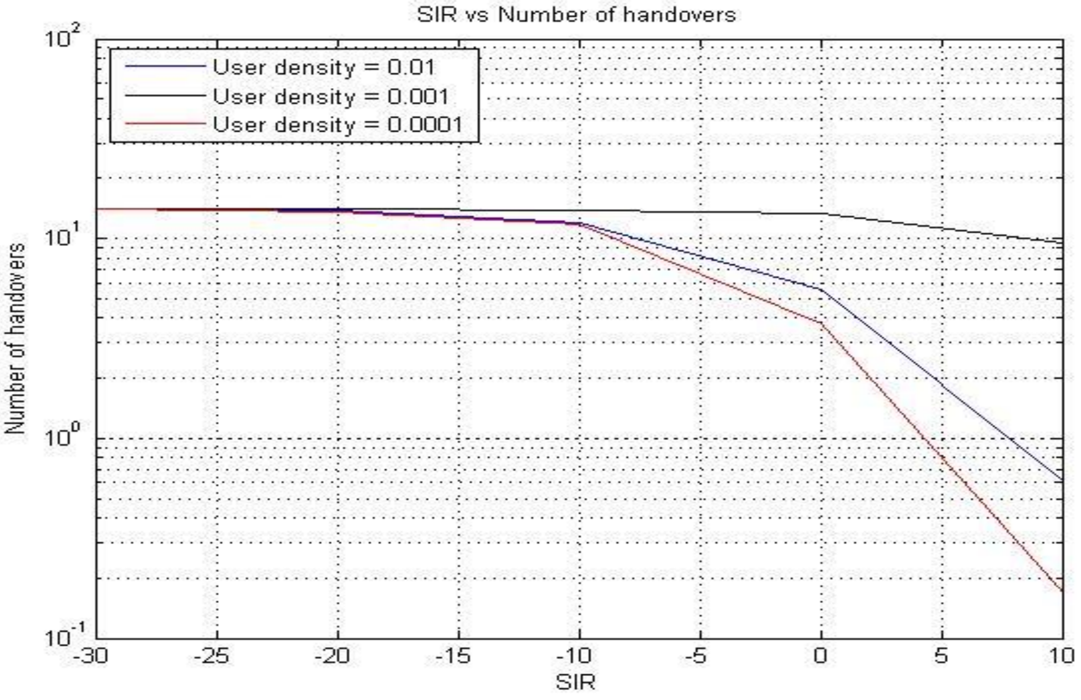

Fig 20: SIR versus handover for user density 0.01, 0.001, and 0.0001 at path loss exponent of 3 and transmitted power 10^{-10}

Average time slot versus SIR with changing the user density (have 0.01, 0.001, 0.0001) by keeping rho at 10^{-10} and path loss exponent at 3 is plotted in figure 19. At lower SIR values with more user density 0.01the average time slot variation is less while user density at 0.0001 the average time slot variation is more. Similarly, in figure 20 the SIR versus handovers with changing the user density (have 0.01, 0.001, 0.0001) by keeping rho at 10^{-10} and path loss exponent at 3 for random way model is plotted.

Here we investigated the outage probability vs SIR, average time slot versus SIR and hand off for the user in random way model with three variations. Variation with the path loss exponent 3, 4 and 5 is performed, then variation of transmitted power 10^{-8}, 10^{-9}, 10^{-10} with path loss exponent 3. Finally by varying the user density 0.01, 0.001, and 0.0001 at path loss exponent of 3 and transmitted power 10^{-10} is performed.

Standard Error

The Standard Error is an indication of the reliability of the mean. The standard error is a statistical indicator of the reliability of a descriptive statistic estimated from a sample. The standard error represents the typical amount of error that can be expected from an estimator.

Matlab code: 1000 iterations , alpha = 3, rho = 10^-10, SIR (-30dB to 10dB) user density (0.01, 0.001, 0.0001)

Pathloss /SIR	-30	-20	-10	0	10
3	0	0.0028	0.0086	0.0160	0.0170
4	0	0.0004	0.0023	0.0227	0.1686
5	0.0009	0.0120	0.0808	0.2805	0.2888

Matlab code: 3000 iterations , alpha = 3, rho = [10^-8, 10^-9,10^-10], SIR (-30dB to 10dB)

Pathloss /SIR	-30	-20	-10	0	10
3	0.0028	0.0073	0.0098	0.0098	0.0098
4	0.0275	0.1657	0.2880	0.2887	0.2887
5	0.0262	0.1613	0.2880	0.2887	0.2887

MODIFIED RANDOM WAYPOINT MODEL - Matlab code: 3000 iterations - pathloss exponent = 3,4,5 - SIR (-30dB to 10dB)

Pathloss /SIR	-30	-20	-10	0	10
3	0	0.0004	0.0015	0.0042	0.0092
4	0	0.0001	0.0007	0.0088	0.0775
5	0	0	0.	0.0020	0.0132

6. Conclusion:

In the mobile model scenario, each base station can handle a certain number of users. In real time, the base station and user terminals are in an irregular pattern. A stochastic model is a part of the mathematical area to analyze the point patterns. A prominent approach is to use random spatial models from stochastic geometry to capture the real deployment as accurately as possible. Stochastic geometry allows us to study the average behavior over many spatial realizations of a network where the nodes locations are derived from a point process (PP).

The performance of a receiver with respect to the overall coverage when it is moving randomly from one place to another for different mobility models in a stochastic heterogeneous wireless network. The location of the user terminal and the base station are not usually static. It is random in nature. User terminals are almost random in nature. For each user based on distance we evaluate the nearest base station.

Here we studied mobility affect the performance of the user in terms of the coverage, throughput, and multiple hand-offs. We investigated the outage probability vs SIR, average time slot versus SIR and hand off for the user at U(0,0) and in random way model.

The handoff procedure is just one feature in general mobility structure, to provide ubiquitous access to mobile station moving in a heterogeneous wireless environment. The proposed work can be collective with other resource schemes such as channel assignments to provide unrelenting and guaranteed quality of service. Such an integrated system may provide a largely optimal performance with user’s satisfaction.

Furthermore, these networks have to deal with the adverse effects from uncertain and dynamic physical environments.

Furthermore, tests in simulation situation are for limited scenarios. An extensive simulative evaluation and optimization of the algorithm and a subsequent test in real nodes can be done in order to prove its utility.

References:

[1] S. Kusaladharma, P. Herath, and C. Tellambura, “An overview of cognitive radio networks,” in *To appear in Wiley Encyclopedia of Electrical and Electronics Engineering*.

[2]M. Di Renzo, “Stochastic geometry modeling and analysis of multi-tier millimeter wave cellular networks,”*Wireless Communications, IEEE Transactions on*, vol. 14, no. 9, pp. 5038–5057, Sept 2015.

[3]M. Haenggi, J. Andrews, F. Baccelli, O. Dousse, and M. Franceschetti, “Stochastic geometry and random graphs for the analysis and design of wireless networks,” *Selected Areas in Communications, IEEE Journal on*, vol. 27, no. 7, pp. 1029–1046, September 2009.

[4]H. Dhillon, R. Ganti, F. Baccelli, and J. Andrews, “Modeling and analysis of k-tier downlink heterogeneous cellular networks,” *IEEE J. Sel. Areas Commun.*, vol. 30, no. 3, pp. 550–560, April 2012.

[5]P. C. Pinto and M. Z. Win, “Communication in a Poisson field of interferers–part I: Interference distribution and error probability,” *IEEE Trans. Wireless Commun.*, vol. 9, no. 7, pp. 2176–2186, Jul. 2010.

[6]E. Salbaroli and A. Zanella, “Interference analysis in a Poisson field of nodes of finite area,” *IEEE Trans. Veh.Technol.*, vol. 58, no. 4, pp. 1776–1783, May 2009.

[7]Y. Dhungana and C. Tellambura, “Outage probability of underlay cognitive relay networks with spatially random nodes,” in *2014 IEEE Global Communications Conference*, Dec 2014, pp. 3597–3602.

[8]H. Dhillon, R. Ganti, F. Baccelli, and J. Andrews, “Modeling and analysis of k-tier downlink heterogeneous cellular networks,” *IEEE J. Sel. Areas Commun.*, vol. 30, no. 3, pp. 550–560, April 2012.

[9]J. Chen, M. Ding, and Q. Zhang, “Interference statistics and performance analysis of mimo ad hoc networks in binomial fields,” *IEEE Trans. Veh. Technol.*, vol. 61, no. 5, pp. 2033–2043, Jun. 2012

[10] A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.

[11] Christian Bettstetter and Christian Wagner, “The Spatial Node Distribution of the Random Waypoint Mobility Model” Technische Universit¨at M¨ unchen Institute of Communication Networks D–80290 Munich, Germany.

[12] Amr Reza Momen, Jahangir Dadkhah Chime', “A new analytical method in user mobility modelling in wireless network” Islamic Azad University-Rey Branch, Iran Telecommunication Research Center

[13] Abdelrahman M. Ibrahim, Tamer ElBatt , Amr El-Keyi, “Coverage Probability Analysis for Wireless Networks Using Repulsive Point Processes” Wireless Intelligent Networks Center (WINC), Nile University, Giza, Egypt

[14] Christian Bettstetter “Stochastic Properties of the Random Waypoint Mobility Model” Technische Universit¨at M¨ unchen, Institute of Communication Networks, 80290 Munich, Germany

[15] J. Chen, M. Ding, and Q. Zhang, “Interference statistics and performance analysis of mimo ad hoc networks in binomial fields,” *IEEE Trans. Veh. Technol.*, vol. 61, no. 5, pp. 2033–2043, Jun. 2012.

[16]A. Baddeley, I. Barany, R. Schneider, and W. Weil, *Spatial Point Processes and their Applications*. Springer, 2007.

[17] Sachitha Kusaladharma, Chintha Tellambura “Aggregate interference analysis for underlay cognitive radio networks,” *IEEE Wireless Commun. Lett.*, vol. 1, no. 6, pp. 641–644, 2012.

[18] Nenavath Ravikumar, and J.Ravi Sankar, “Current and Future Trends In Wireless Mobile Communication Systems,” *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE.*, vol. 10, Issue no. 2, pp. 16–22, Ver. II (Mar - Apr.2015).

[19] B.F. Gessler, O. Queseth, R. Stridth, M.Unbehaun, J.Zendler, “4th Generation wireless infrastructures: Scenarios and Research Challenges”, IEEE Personal Communications, 8(2), 2010

[20] Mohd. Maroof siddiqui “Vision of 5G Communications” , A. Mantri et al. (Eds.): HPAGC 2011, CCIS 169, Springer-Verlag Berlin Heidelberg, pp:252-256, 2011.

[21] W. R. Young, “Advanced Mobile Phone System: Introduction, Back-ground, Objectives,”Bell Syst. Tech. J., vol. 58, no. 1, pp. 1–14,Jan.1979.

[22] D. L. Huff, “Advanced Mobile Phone System: The Developmental System,”Bell Syst. Tech. J., vol. 58, no. 1, pp. 249–269, Jan. 1979.

[23] A. K. Merhotra, GSM System Engineering. Norwood, MA, USA: Artech House, 1997.

[24] D. Stoyan, W. S. Kendall, and J. Mecke. Stochastic geometry and its applications, volume 2. Wiley Chichester, 1995

[25] F. Baccelli and B. Błaszczyszyn. Stochastic Geometry and Wireless Networks, Volume II- Applications, volume 4, No 1-2 of Foundations and Trends in Networking. NoW Publishers, 2009.

[26] D. J. Daley and D. Vere-Jones. An introduction to the theory of point processes. Vol. I. Probability and its Applications (New York). Springer, New York, second edition, 2003.

[27] T. S. Rappaport, “Wireless communications: Principles and Practices”, Second Edition, Prentice Hall Inc., New Jersey, USA, (2004).

[28] C. Bettstetter, “Mobility Modeling in Wireless Networks: Categorization, Smooth Movement, and Border Effects,” ACM Mobile Comp. and Comm. Rev., vol. 5, no. 3, 2001.

[29] C. Bettstetter and O. Krause, “On Border Effects in Modeling and Simulation of Wireless Ad Hoc Networks,” Proc. IEEE Int’l Conf. Mobile and Wireless Comm. Networking (MWCN), 2001.

[30] B. Da and C. C. Ko, “Dynamic resource allocation in relay-assisted OFDMA cellular system,” European Transactions on Telecommunications, vol. 23, no. 1, pp. 96–103, 2012.

[31] GrandhiS.A.;Vijayan,R.;GoodmanD.J.;Zander,J.Vehicular Technology “Centralized Power Control in Cellular Radio Systems” IEEE Transa ctions on Volume 42, Issue 4, Nov 1993 Page(s):466 – 468

[32] Y. Qu, J. Fang, and S. Zhang, “Nearest neighbor nodes and connectivity of three-dimensional wireless sensor networks with poisson point field,” in Proc. IEEE ICCSIT, vol. 2, July 2010, pp. 269–272.

[33] P. Mach and Z. Becvar, “QoS-guaranteed power control mechanism based on the

frame utilization for femtocells," EURASIP Journal on Wireless Communications and Networking, vol. 2011, 2011.

[34] A. Molisch, Wireless Communications. Wiley-IEEE Press, 2011

Appendix

MODIFIED RANDOM WAYPOINT MODEL - Matlab code: 3000 iterations - pathloss exponent = 3,4,5 - SIR (-30dB to 10dB)

```
clc; clear all; close all;
R = 200;
fprintf('\n Radius of simulation area is %d \n',R);
sizeW = pi*(R^2);
fprintf('\n Size of simulation area is %f \n',sizeW);
lambda1= 0.001;
lambda = 0.0001;
N = poissrnd(lambda*sizeW);
r = sqrt((R^2)*rand(1,N));
th = 2*pi*rand(1,N);
X = r.*cos(th); Y = r.*sin(th);
B1 = length(X);
fprintf('\n Number of base stations: %d \n', B1)
Nusers = poissrnd(lambda1*sizeW);
r1 = sqrt((R^2)*rand(1,Nusers));
th1 = 2*pi*rand(1,Nusers);
X1 = r1.*cos(th1); Y1= r1.*sin(th1);
U1 = length(X1);
fprintf('\n Number of users: %d \n', U1)
a_o_alp = []; a_t_alp = []; v_o_alp = []; h_o_alp = [];
sir = [0.001 0.01 0.1 1 10];
```

```
alp = [3 4 5];
h = waitbar(0,'Please wait...');
for kk = 1:1:length(alp)
a_o = []; a_t = []; v_o = []; h_o = [];
for jj = 1:1:length(sir)
T_out = 0; T1 = []; T2 = []; H2 = [];
step = 3000;
for ii = 1:1:step
    H_O = 0;
    waitbar((ii)/(step),h,sprintf('Path loss exponent = %d, SIR = %d dB, Iteration = %d ',alp(kk),10*log10(sir(jj)),ii))
for T = 1:15
rho = 10^-10;       % rho
alpha = alp(kk);         % path loss
TT = [];
for j = 1:B1
    B =[];
    for k = 1:U1
        d1 = sqrt((X(j)-X1(k))^2 + (Y(j)-Y1(k))^2);
        B = [B; [d1 k X(j) Y(j) X1(k) Y1(k)]];
    end
    A = sortrows(B,1);
    Tx = rho*A(1,1)^alpha;
    TT = [TT; [Tx j A(1,2) A(1,3) A(1,4) A(1,5) A(1,6)]];
```

```
end
    X2 = randi([0,5],1)*cosd(randi([0,360],1)); Y2 = randi([0,5],1)*cosd(randi([0,360],1));


    B = [];
    for k = 1:B1
        d1 = sqrt((X2-X(k))^2 + (Y2-Y(k))^2);
        Tx = rho*d1^alpha;
        B = [B; [d1 k Tx X(k) Y(k)]];
    end
    A2 = sortrows(B,1);
    if T ~= 1
        if H1 ~= A2(1,1)
            H_O = H_O + 1;
            H1 = A2(1,1);
        end
    else
        H1 = A2(1,1);
    end
    Rx = A2(1,3)*A2(1,1)^(-alpha)*exprnd(1);
    R1 = [];
    Ip = 0;
    for j = 1:B1
        if A2(1,2) ~= j
            if TT(j,2) == j
```

```
                Rxi = TT(j,1)*A2(j,1)^(-alpha)*exprnd(1);

                Ip = Ip + Rxi;

                R1 = [R1; [Rxi j TT(j,3) A2(j,1) TT(j,4) TT(j,5) TT(j,6) TT(j,7)]];

              end

          end

      end

    SIR = Rx/Ip;

    if SIR < sir(jj)

        T_outage = T;

        T_out = T_out+1;

%       fprintf ('\n  >> SIR      : %d \t at  T_outage = %d iteration = %d \n', SIR,T_outage,ii);

        break;

    end

end

T1 = [T1 T];

T2 = [T2 T_out];

H2 = [H2 H_O];

end

avg_o_p = T_out/ii; var_o_p = var(T2);

avg_t_slot = mean(T1);

avg_h_slot = mean(H2);

a_o = [a_o avg_o_p]; v_o = [v_o var_o_p];

a_t = [a_t avg_t_slot];

h_o = [h_o avg_h_slot];
```

```
end

a_o_alp = [a_o_alp; a_o]; v_o_alp = [v_o_alp; v_o];

a_t_alp = [a_t_alp; a_t];

h_o_alp = [h_o_alp; h_o];

end

semilogy(10*log10(sir),a_o_alp(1,:),'-b'); hold on;

semilogy(10*log10(sir),a_o_alp(2,:),'-k'); hold on;

semilogy(10*log10(sir),a_o_alp(3,:),'-r');

title('SIR vs Average outage probability');grid on;

xlabel('SIR'); ylabel('Average outage probability');

legend('alpha = 3','alpha = 4','alpha = 5','Location','NorthWest')

figure;

semilogy(10*log10(sir),a_t_alp(1,:),'-b'); hold on;

semilogy(10*log10(sir),a_t_alp(2,:),'-k'); hold on;

semilogy(10*log10(sir),a_t_alp(3,:),'-r');

title('SIR vs Average time slot T'); grid on;

xlabel('SIR'); ylabel('Average time slot T');

legend('alpha = 3','alpha = 4','alpha = 5','Location','NorthWest')

figure;

semilogy(10*log10(sir),h_o_alp(1,:),'-b'); hold on;

semilogy(10*log10(sir),h_o_alp(2,:),'-k'); hold on;

semilogy(10*log10(sir),h_o_alp(3,:),'-r');

title('SIR vs Number of handovers'); grid on;

xlabel('SIR'); ylabel('Number of handovers');
```

```
legend('alpha = 3','alpha = 4','alpha = 5','Location','NorthWest')
```

Matlab code: 3000 iterations , alpha = 3, rho = [10^-8, 10^-9,10^-10], SIR (-30dB to 10dB)

```
clc; clear all; close all;
R = 200;
  fprintf('\n Radius of simulation area is %d \n',R);
sizeW = pi*(R^2);
fprintf('\n Size of simulation area is %f \n',sizeW);
lambda1= 0.001;
lambda = 0.0001;
meters
N = poissrnd(lambda*sizeW);
r = sqrt((R^2)*rand(1,N));
th = 2*pi*rand(1,N);
X = r.*cos(th); Y = r.*sin(th);
B1 = length(X);
fprintf('\n Number of base stations: %d \n', B1)
Nusers = poissrnd(lambda1*sizeW);
r1 = sqrt((R^2)*rand(1,Nusers));
th1 = 2*pi*rand(1,Nusers);
```

```
X1 = r1.*cos(th1); Y1= r1.*sin(th1);
U1 = length(X1);
fprintf('\n Number of users: %d \n', U1)
a_o_alp = []; a_t_alp = []; v_o_alp = []; h_o_alp = [];
sir = [0.001 0.01 0.1 1 10];
rh = [10^-8 10^-9 10^-10];
h = waitbar(0,'Please wait...');
for kk = 1:1:length(rh)
a_o = []; a_t = []; v_o = []; h_o = [];
for jj = 1:1:length(sir)
T_out = 0; T1 = []; T2 = []; H2 = [];
step = 3000;
for ii = 1:1:step
    H_O = 0;
    waitbar((ii)/(step),h,sprintf('rho = %d, SIR = %d dB, Iteration = %d
',rh(kk),10*log10(sir(jj)),ii))
for T = 1:15
rho = rh(kk);       % rho
alpha = 3;          % path loss
TT = [];
for j = 1:B1
    B =[];
```

```
    for k = 1:U1
        d1 = sqrt((X(j)-X1(k))^2 + (Y(j)-Y1(k))^2);
        B = [B; [d1 k X(j) Y(j) X1(k) Y1(k)]];
    end
    A = sortrows(B,1);
    Tx = rho*A(1,1)^alpha;
    TT = [TT; [Tx j A(1,2) A(1,3) A(1,4) A(1,5) A(1,6)]];
end
    X2 = randi([0,5],1)*cosd(randi([0,360],1)); Y2 =
randi([0,5],1)*cosd(randi([0,360],1));
    B = [];
    for k = 1:B1
        d1 = sqrt((X2-X(k))^2 + (Y2-Y(k))^2);
        Tx = rho*d1^alpha;
        B = [B; [d1 k Tx X(k) Y(k)]];
    end
    A2 = sortrows(B,1);
    if T ~= 1
        if H1 ~= A2(1,1)
            H_O = H_O + 1;
            H1 = A2(1,1);
        end
```

```
    else
        H1 = A2(1,1);
    end
    Rx = A2(1,3)*A2(1,1)^(-alpha)*exprnd(1);                    U(0,0) from nearest base
station


    R1 = [];
    Ip = 0;
    for j = 1:B1
        if A2(1,2) ~= j
            if TT(j,2) == j
                Rxi = TT(j,1)*A2(j,1)^(-alpha)*exprnd(1);
                Ip = Ip + Rxi;
                R1 = [R1; [Rxi j TT(j,3) A2(j,1) TT(j,4) TT(j,5) TT(j,6) TT(j,7)]];
            end
        end
    end
   SIR = Rx/Ip;
   if SIR < sir(jj)
       T_outage = T;
       T_out = T_out+1;
```

```
%	fprintf ('\n  >> SIR	: %d \t at  T_outage = %d iteration = %d \n',
SIR,T_outage,ii);

      break;

   end

end

T1 = [T1 T];

T2 = [T2 T_out];

H2 = [H2 H_O];

end

avg_o_p = T_out/ii; var_o_p = var(T2);

avg_t_slot = mean(T1);

avg_h_slot = mean(H2);

a_o = [a_o avg_o_p]; v_o = [v_o var_o_p];

a_t = [a_t avg_t_slot];

h_o = [h_o avg_h_slot];

end

a_o_alp = [a_o_alp; a_o]; v_o_alp = [v_o_alp; v_o];

a_t_alp = [a_t_alp; a_t];

h_o_alp = [h_o_alp; h_o];

end

semilogy(10*log10(sir),a_o_alp(1,:),'-b'); hold on;

semilogy(10*log10(sir),a_o_alp(2,:),'-k'); hold on;
```

```
semilogy(10*log10(sir),a_o_alp(3,:),'-r');
title('SIR vs Average outage probability');grid on;
xlabel('SIR'); ylabel('Average outage probability');
legend('rho = 10^-8','rho = 10^-9','rho = 10^-10','Location','NorthWest')
figure;
semilogy(10*log10(sir),a_t_alp(1,:),'-b'); hold on;
semilogy(10*log10(sir),a_t_alp(2,:),'-k'); hold on;
semilogy(10*log10(sir),a_t_alp(3,:),'-r');
title('SIR vs Average time slot T'); grid on;
xlabel('SIR'); ylabel('Average time slot T');
legend('rho = 10^-8','rho = 10^-9','rho = 10^-10','Location','NorthWest')
figure;
semilogy(10*log10(sir),h_o_alp(1,:),'-b'); hold on;
semilogy(10*log10(sir),h_o_alp(2,:),'-k'); hold on;
semilogy(10*log10(sir),h_o_alp(3,:),'-r');
title('SIR vs Number of handovers'); grid on;
xlabel('SIR'); ylabel('Number of handovers');
legend('rho = 10^-8','rho = 10^-9','rho = 10^-10','Location','NorthWest')
```

Matlab code: 1000 iterations , alpha = 3, rho = 10^-10, SIR (-30dB to 10dB) user density (0.01, 0.001, 0.0001)

```
clc; clear all; close all;
R = 200;
fprintf('\n Radius of simulation area is %d \n',R);
sizeW = pi*(R^2);
fprintf('\n Size of simulation area is %f \n',sizeW);
a_o_alp = []; a_t_alp = []; v_o_alp = []; h_o_alp = [];
h = waitbar(0,'Please wait...');
lam = [0.01 0.001 0.0001];
for kk = 1:1:length(lam)
lambda = 0.0001;
N = poissrnd(lambda*sizeW);
r = sqrt((R^2)*rand(1,N));
th = 2*pi*rand(1,N);
X = r.*cos(th); Y = r.*sin(th);
B1 = length(X);
fprintf('\n Number of base stations: %d \n', B1)
Nusers = poissrnd(lam(kk)*sizeW);
r1 = sqrt((R^2)*rand(1,Nusers)); th1 = 2*pi*rand(1,Nusers);
X1 = r1.*cos(th1); Y1= r1.*sin(th1);
U1 = length(X1);
```

```
fprintf('\n Number of users: %d \n', U1)
sir = [0.001 0.01 0.1 1 10];
a_o = []; a_t = []; v_o = []; h_o = [];
for jj = 1:1:length(sir)
T_out = 0; T1 = []; T2 = []; H2 = [];
step = 1000;
for ii = 1:1:step
   H_O = 0;
   waitbar((ii)/(step),h,sprintf('Users density = %d, SIR = %d dB, Iteration = %d
',lam(kk),10*log10(sir(jj)),ii))
for T = 1:15
rho = 10^-10;
alpha = 3;
TT = [];
for j = 1:B1
   B =[];
   for k = 1:U1
      d1 = sqrt((X(j)-X1(k))^2 + (Y(j)-Y1(k))^2);
      B = [B; [d1 k X(j) Y(j) X1(k) Y1(k)]];
   end
   A = sortrows(B,1);
   Tx = rho*A(1,1)^alpha;
```

```
    TT = [TT; [Tx j A(1,2) A(1,3) A(1,4) A(1,5) A(1,6)]];
end
    X2 = randi([0,5],1)*cosd(randi([0,360],1)); Y2 = randi([0,5],1)*cosd(randi([0,360],1));


    B = [];
    for k = 1:B1
        d1 = sqrt((X2-X(k))^2 + (Y2-Y(k))^2);
        Tx = rho*d1^alpha;
        B = [B; [d1 k Tx X(k) Y(k)]];
    end
    A2 = sortrows(B,1);
    if T ~= 1
        if H1 ~= A2(1,1)
            H_O = H_O + 1;
            H1 = A2(1,1);
        end
    else
        H1 = A2(1,1);
    end
    Rx = A2(1,3)*A2(1,1)^(-alpha)*exprnd(1);
    R1 = [];
```

```
    Ip = 0;
    for j = 1:B1
        if A2(1,2) ~= j
            if TT(j,2) == j
                Rxi = TT(j,1)*A2(j,1)^(-alpha)*exprnd(1);
                Ip = Ip + Rxi;
                R1 = [R1; [Rxi j TT(j,3) A2(j,1) TT(j,4) TT(j,5) TT(j,6) TT(j,7)]];
            end
        end
    end
   SIR = Rx/Ip;
   if SIR < sir(jj)
       T_outage = T;
       T_out = T_out+1;
%       fprintf ('\n  >> SIR      : %d \t at  T_outage = %d iteration = %d \n', SIR,T_outage,ii);
       break;
   end
end
T1 = [T1 T];
T2 = [T2 T_out];
H2 = [H2 H_O];
```

```
end
avg_o_p = T_out/ii; var_o_p = var(T2);
avg_t_slot = mean(T1);
avg_h_slot = mean(H2);
a_o = [a_o avg_o_p]; v_o = [v_o var_o_p];
a_t = [a_t avg_t_slot];
h_o = [h_o avg_h_slot];
end
a_o_alp = [a_o_alp; a_o]; v_o_alp = [v_o_alp; v_o];
a_t_alp = [a_t_alp; a_t];
h_o_alp = [h_o_alp; h_o];
end
semilogy(10*log10(sir),a_o_alp(1,:),'-b'); hold on;
semilogy(10*log10(sir),a_o_alp(2,:),'-k'); hold on;
semilogy(10*log10(sir),a_o_alp(3,:),'-r');
title('SIR vs Average outage probability');grid on;
xlabel('SIR'); ylabel('Average outage probability');
legend('User density = 0.01','User density = 0.001','User density = 0.0001','Location','NorthWest')
figure;
semilogy(10*log10(sir),a_t_alp(1,:),'-b'); hold on;
semilogy(10*log10(sir),a_t_alp(2,:),'-k'); hold on;
```

```
semilogy(10*log10(sir),a_t_alp(3,:),'-r');
title('SIR vs Average time slot T'); grid on;
xlabel('SIR'); ylabel('Average time slot T');
legend('User density = 0.01','User density = 0.001','User density = 0.0001','Location','NorthWest')
figure;
semilogy(10*log10(sir),h_o_alp(1,:),'-b'); hold on;
semilogy(10*log10(sir),h_o_alp(2,:),'-k'); hold on;
semilogy(10*log10(sir),h_o_alp(3,:),'-r');
title('SIR vs Number of handovers'); grid on;
xlabel('SIR'); ylabel('Number of handovers');
legend('User density = 0.01','User density = 0.001','User density = 0.0001','Location','NorthWest')
```