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Handoff mechanisms in LTE networks

Preeti Lal, Vidhu Yamini, Noor Mohammed V

School of Electronics Engineering, VIT University, Vellore 632 014, Tamil Nadu, India

E-mail: vnoormohammed@vit.ac.in

Abstract. In this paper, we have analysed and studied the handoff mechanism in Long Term Evaluation (LTE) network. A LTE network has been defined with a set number of macro-cells, micro-cells and mobile devices. In this handoff mechanism distance and speed has been considered as an important parameters. The speed has been detected using the Gauss Markov Mobility Model, and from that distances have been predicted at different instances. In the handover process, Received Signal Power (RSP) for various users has been calculated with respect to base stations at various time intervals and the path loss between transmitter and receiver. A comparative study between path loss models is done in order to improve the signal power. A detailed study has been done on unnecessary handoff probability and handoff failure probability. Simulation results shows that there is an improvement in performance of the above mentioned parameters in the defined network.

1. Introduction

In the recent age of technology, wireless communication has become the requirement in every sector. With Analog transmissions, we had the First Generation Communications. The Second Generation witnessed the development of GSM standards. Packet switching followed by Enhanced Data Rate for GSM evolution further added to the technology. By the end of the 20th Century, we had UMTS and wide band CDMA with faster data rates (3G). In the past year, the Fourth Generation has rooted itself in India, to even smallest villages due to its affordability and extremely high data rates.

For a communication network to be efficient, various parameters have to be monitored and kept in mind while designing the network itself. One of those major governing factors is the handover mechanism. In any network, when an ongoing call or data session is transferred to a different station than its current one, it is termed as a handover. A handover might be initiated when a user is moving from one cell to another. Handovers occur after consideration of various parameters such as signal power, signal quality, interference and so on. When a mobile user is on the move, at some point it will be at a distance from its base station such that the signal will fall below a required threshold to keep the call going. At this moment, the call will be dropped. But as we use soft handovers, before dropping the call, handoff requests are sent to various nearby base stations. The entire handover process works in three steps: Handoff Initiation, Handoff Decision and Handoff Execution. The channel change due to handoff may be through a time slot, frequency band, code word, or combination of these for time-division multiple access (TDMA), frequency-division multiple access (FDMA), code-division multiple access (CDMA), or a hybrid scheme. In this paper the handoff decision making phase has been analyzed.

Every network has some basic requirement for handover schemes, such simple requirements



as follows:

- Service quality to be maintained not only before and after the handover, but during the process as well.

- Services to be continued as normally after the handover as they were done before.

- There must be seamless handover between 2G/3G/CDMA/LTE technologies.

Handoffs can be classified in various ways. There are:

- ★ Hard/ Soft handovers

- ★ Inter cell/ Intra cell handovers

- ★ Vertical /Horizontal handovers

Horizontal handovers are not feasible in today's communication system as there are varied sorts of technologies used. Vertical handovers with optimizations to improve handover qualities are used. Generally in LTE systems, a traditional way of handover schemes is followed by following signal strength as the key parameter for decision making. Like we have Received Signal Strength (RSS) based algorithms, Bandwidth based algorithms, Cost function based algorithms, such algorithms base their results on one specific factor.

The algorithms that use single parameters have lesser reliability- because of fluctuations and variable parameters. While MADM algorithms give an overall result. This is more reliable in non-ideal conditions.

For a network, handover would be occurred in between cells at any time. But, considering the mobility of the users, an Umbrella Cell approach is taken. Here, there are set number of microcells which are covered by a macrocell. The power level of the central cell (i.e. Macrocell) is higher than that of the microcells. When a high speed user is present in a normal cell approached network, there would be continuous handoffs which might be unnecessary handoff. In this technique, the high speed user would be under the Macrocell which covers a larger area, and low speed users are under micro cells. This way, unnecessary handovers has been reduced. These days networks have to handle dense user bases. For this, the Umbrella techniques works out well as micro cells can handle small bunches and make a more effective network. Similarly, Pico cells and Femtocells have also been implemented to make sure quality of service is maintained. Pico cells can handle about hundred users at a time. Femtocells are the smallest, and handle a few users only at a time. These might be used to improve situations in retail spaces or offices.

In this paper, handoff process in a hierarchical LTE network has been analysed in terms speed and position. It works in two phases- initial phase, and decision making phase of handoff. For the initial phase, a mobility theorem has been used and further two- Gauss Markov Mobility theorem and Random Waypoint has been analyzed. In section 2 a brief literature review has been done. In section 3, hierarchical network model based handover procedure is analysed. In section 4 performance evaluation has been done and in section 5 is the conclusion.

2. Literature Review

In the advancement of communication, LTE has broadened the bounds of cellular communication. New approaches are taken for better QoS like the one mentioned previously. Mixed cell architectures are introduced to make sure the demands of dense user capacity are met along with maintaining system integrity. Differently sized cells co-exist in a two-layer structure comprising of micro cells at the lower layer and macro cell at the upper layer. Issues faced in these pertaining to handover are mainly due to delay caused before handover execution. Also, it is quite a task to smoothly integrate the small cells into the high powered macrocells[1,2]. Microcells are a boon for they off load the traffic from the macrocell, but they also cause inter cell interference, cause unnecessary handoffs and force termination of ongoing calls if priorities aren't fixed [1]. Studies pertaining to handoffs in hierarchical systems have been done using micro cells [1,3], femto cells[7], pico cells [4]and relay networks[5,6]. Mobility models are used for these networks

for predicting speeds and positions of users. Random waypoint Theorem generates a random set of speed and direction for each user. Next set of values are calculated considering pause times. But this model doesn't work its best in urban areas. To overcome this, Gauss Markov Mobility theorem is used. An adaptive vertical handoff algorithm is developed which uses predictive RSS[14]. This reduces unnecessary handoff while increasing utilization and lowering call drop rates[11]. To increase the utility, the handoff hysteresis can be adjusted according to the distance between the macrocell base station and the femtocell base station[15]. Apart from these models, using prediction techniques ensured comparatively lesser handoff latency. In [10,12], a prediction handoff trigger scheme is used to reduce handoff latency in hierarchical femtocell networks. Gauss Markov Mobility model in [8,9] shows a vast range of user mobility patterns and the constant velocity fluid-flow model as two extreme cases along with considering the correlation of a user speed. After a detailed study of all these, the Gauss Markov mobility turned out to be the best for our work using an urban area network. In[1], an algorithm was proposed for efficient handover using Gauss Mobility Model. The speed of the users are detected along with their directions, for a period T. Future speeds are predicted by the theorem. From these values, RSPs and RSQs (received signal power and received signal quality) are calculated. These values are compared to threshold values which are system defined. The speeds of the users are classified into High speed, Medium Speed, Low speed [13]. The low speed users are handed over to the micro cell, the high speed users are also handed over to the Macro cells. The users with medium speed having real time sessions are handed over to the same. The rest go to microcells. For users that approach the microcells, the highest signal quality is selected. The decision phase of the Handover process ends here.

3. Hierarchical Network Model and Handover Procedure

The network model comprises of a macro cell and four microcells. The macrocell has a larger coverage than the microcells. Their coverage areas are assumed to be circles with defined radius. They have been allocated their own resource blocks and hence do not interfere with each other. Orthogonal frequency division multiplexing (OFDM) has been used in the system. The mobile station velocities are divided into fast, medium and slow and these values are assumed to be uniform during a call. The slow and medium speed mobile users are handed over to the micro-cells while the fast speed mobile users are handed over to the macro cell. So, the cells will have newly generated traffics as well as those that are handed over. The total new traffic generated in the system [1] can be calculated as

$$\lambda_a = \lambda_{f_0} + \lambda_{m_0} + \lambda_{s_0} + N(\lambda_{s_1} + \lambda_{m_1}) \quad (1)$$

Here, λ_{f_0} , λ_{s_0} and λ_{m_0} are the rate of new traffic generated by high speed, slow and medium speed mobile users in macrocell. Where λ_{s_1} , λ_{m_1} are rate of new traffic generated by low speed and medium speed users in microcells and N is the number of microcells.

A generalised handover mechanism has several phases namely initiation, decision and execution phase. Our work revolves around the initiation and decision phase i.e the pre handover stage. To achieve efficient and better handover results, the future location and velocities of the mobile users has been predicted using the Gauss Markov mobility model[1]. This prediction helps in deciding the right time for initiation of the handover procedure so as to avoid any kind of failures. According to the model we can calculate the speed and direction as follows

$$V_n = \alpha V_{n-1} + (1 - \alpha)V' + \sqrt{(1 - \alpha^2)}\delta_{n-1} \quad (2)$$

$$\theta = \alpha\theta_{n-1} + (1 - \alpha)\theta' + \sqrt{(1 - \alpha^2)}\gamma_{n-1} \quad (3)$$

Here, n is the time instant, α is a tuning parameter, V_n and θ_n are the speed and direction at time n , V' and θ' are the mean speed and direction when time tends to infinity, δ and γ are uncorrelated Gaussian processes with zero mean and unit variance. The system parameters are detected at constant intervals of time. A detecting period equal to the handoff delay is preferred for prediction accuracy and resource utilization[1].

Using (2) and (3) position is predicted as

$$X_n = X_{n-1} + V_{n-1} \times T \cos \theta_{n-1} \quad (4)$$

$$Y_n = Y_{n-1} + V_{n-1} \times T \sin \theta_{n-1} \quad (5)$$

Here, X_n and Y_n are coordinates of users at time instants n and T is the detecting period. Based on the coordinates, the distance between the mobile users and the several base stations is predicted and is given by

$$d_{in} = \sqrt{(Y_n - Y_i)^2 + (X_n - X_i)^2} \quad (6)$$

The received signal power is the foremost and basic requirement for a good call quality. For LTE networks $RSP > -80dB$ is considered excellent for users near the base station and $RSP > -100dB$ is accepted for those near the cell edge. The received signal power is affected by the path loss, transmission power of the base station antennas and the shadow fading effects. Therefore, its very important to choose the path loss model aptly according to the network environment and requirement so as to get a desirable RSP.

3.1. Path loss models

The path loss models examined in this section are suitable for application in mainly urban areas

3.1.1. Model 1

$$L[dB] = 128.1 + 37.6 \log[d(km)] \quad (7)$$

$$L[dB] = 39 + 20 \log[d(m)] \quad 10m < d < 45m \quad (8)$$

$$L[dB] = -39 + 67 \log[d(m)], \quad d > 45m \quad (9)$$

In the above model, (7) is used for macrocell while (8) and (9) are used for computation of path loss in micro cells. Here, d refers to the distance between mobile users and base stations.

3.1.2. Model 2 This model is referred as cost 231 Hata model and is applicable for a frequency range of 500 – 2000 MHz.

$$L[dB] = 46.3 + 33.9 \log(f) - 13.82 \log(h_t) - \alpha(h_r) + (44.9 - 6.55 \log(h_t)) \log(d) \quad (10)$$

Here, f is the working frequency in MHz, h_t is the transmitting antenna height, h_r is the receiving antenna height, d is the distance between these two antennas in km and cm depends on type of environment and is selected as 3dB for urban surrounding.

3.1.3. Model 3 This model was developed by Stanford University and is referred as SUI model.

$$PL[dB] = A + 10\log\left(\frac{d}{d_0}\right) + X_f + X_h + s \quad (11)$$

$$A = 20\log\left(\frac{4\pi d_0}{\lambda}\right) \quad (12)$$

$$X_f = 6\log\left(\frac{f}{2000}\right) \quad (13)$$

$$X_h = 20\log\left(\frac{h_r}{2000}\right) \quad (14)$$

Here, d_0 is taken as $100m$ and h_r is the height of receiving antenna. The factor s accounts for shadow fading and has a value between 8.2 and 10.6.

All the above pathloss models are examined and compared to finally select the best option for calculating Received signal strengths and subsequently received signal quality. Any of them can be chosen based on our system environment .

3.2. Received signal strength and signal quality

The received signal strength from a cell can be predicted based upon the distance calculated between base stations and mobile user s using (6).

$$RSP_i = P_{tx} - P_{loss} - f(\mu\sigma) \quad (15)$$

Here, P_{tx} is the transmission power of the base station, $f(\mu, \sigma)$ accounts for shadow fading effect. From this we can calculate the received signal quality of mobile user in any cell.

$$RSQ_i = \frac{M \times RSP_i}{\sum_{j \neq 1}^{max} RSP_i + N_0} \quad (16)$$

Where M refers to the number of channels for macro cell, and N_0 is the ground white noise. When the RSQ of a mobile user is goes below the threshold level the handover algorithm is initialized. It is followed by inspecting the class of speed of the mobile user. The upper and lower limit for speed are calculated based on the probability of unnecessary handoffs , probability of handover failure and handoff delays as given in[1].

$$v_1^u = \frac{2R}{t_1 + t_2} \sin(\pi P_{nmax}) \quad (17)$$

$$v_2^u = \frac{2R}{t_1} \sin(\pi P_{fmax}) \quad (18)$$

Here, R is radius of the cell, P_{fmax} and P_{nmax} are the maximum values for probability of handover failure and unnecessary handover respectively, and t_1, t_2 denote the handover delays.

The users whose speed lie below lower limit or between the limits are handed over to the microcells while those with the speed equal to or greater than upper limit are handed over to the macro cell.

Using the fluid flow mobility model, the cell boundary crossing rate for users with different class of speed can be calculated as given in [1].

$$\eta_0 = \frac{2v}{\pi r_0} \quad (19)$$

Here, v is the speed of the mobile station and r is the radius of the concerned cell. Zero in subscript refers to the parameters for macrocell and one in the subscript refers the same for microcells. One can calculate the corresponding parameters for microcell in a similar way.

The handoff probability of the mobile units can be calculated as per [1] in the following way.

$$Ph_0 = \frac{\eta_0}{\eta_0 + \mu} \quad (20)$$

The unencumbered call duration follows an exponential distribution with μ . Based on (19) and (20) the session duration can be calculated as

$$\frac{1}{\mu_0} = \frac{1}{\eta_0 + \mu} \quad (21)$$

The aggregation traffic rate into microcell due to slow and medium speed mobile stations can be obtained as described in [1].

$$\lambda_{t_1} = \lambda_{s_1} + \lambda_{sh_1} + \lambda_{sh_0} \quad (22)$$

$$\lambda'_{t_1} = \lambda_{m_0} + \lambda_{mh_0} + N\lambda_{mh_1} \quad (23)$$

Where λ_{s_1} and λ_{m_1} are the new traffic generated by the slow and medium speed mobile users in the microcells, λ_{sh_1} and λ_{mh_1} refer to the handover rate of slow and medium mobile users from microcell to macrocell while λ_{sh_0} and λ_{mh_0} are the handover rate of slow and medium speed mobile users from macro cell to micro cell respectively.

In a similar way the traffic aggregation rate into macrocell due to slow, medium speed and fast mobile stations can be calculated as [1]

$$\lambda_{t_0} = \lambda_{s_0} + \lambda_{sh_0} + N\lambda_{sh_1} \quad (24)$$

$$\lambda'_{t_0} = \lambda_{m_0} + \lambda_{mh_0} + N\lambda_{mh_1} \quad (25)$$

$$\lambda''_{t_0} = \lambda_{f_0} + \lambda_{fh_0} \quad (26)$$

Where λ_{s_0} , λ_{m_0} and λ_{f_0} represent rate of new traffic generated by slow, medium speed and fast moving mobile stations in macrocell. λ_{sh_0} , λ_{mh_0} and λ_{fh_0} represent handover rates of different speed class mobile users from other macro cells to current macrocell. λ_{sh_1} , λ_{mh_1} refer to the handover rates from a microcell to a macro cell. The offered loads of the macrocell and microcell can now be calculated as

$$\rho_0 = \frac{\lambda_{t_0}}{\mu_0} + \frac{\lambda'_{t_0}}{\mu_0} + \frac{\lambda''_{t_0}}{\mu_0} \quad (27)$$

$$\rho_1 = \frac{\lambda_{t_1}}{\mu_1} + \frac{\lambda'_{t_1}}{\mu_1} + \frac{\lambda_{t_0}}{\mu_0} \quad (28)$$

Using the Erlang loss formula the blocking probability of a cell can be derived as given in [1].

$$P_{b_i} = \frac{\frac{p_i^{k_i}}{k_i!}}{\sum_{l=0}^{k_i} \frac{p_i^l}{l!}} \quad i = 0, 1 \quad (29)$$

The forced termination probability calculation as follows

$$P_{F_i} = \frac{P_{h_i} + P_{B_0} + P_{B_1}}{1 - P_{h_i}(1 - P_{B_i})} \quad i = 0, 1 \quad (30)$$

The channel utilization can be calculated as

$$C = \frac{\rho_0}{M} \quad (31)$$

4. Performance evaluation

The simulation consists of one macrocell and four micro cells with 10 users spread randomly. The initial position, velocity and direction of users is specified and then we use (2), (3), (4) and (5) to predict the same in the future time instants. Parameters have been evaluated at ten different time instants. Number of channels allotted to macrocell is set as 30 and that to microcell is set as 8. Where μ is set to $0.01s^{-1}$. The call arrival rate, λ , varies from 0.01 to 0.16 with a step of 0.01. λ_{f_0} and λ_{m_0} are taken as half of λ_a while λ_{s_0} is set to 0 as no new traffic is generated by slow mobile users in macro cell.

Fig.1 shows that call blocking probability increases with call arrival rate so as to accommodate the handed over calls. From fig.2 it is evident that as the velocity increases the probability of handover increases. When the speed of the mobile users increases beyond the upper limit set in the system model, they are handed over to the macro cell. Fig.3 showcases an increase in the channel utilization with increasing call arrival rate for 10 users at 10 different time instants.

In fig.4, we can observe the forced termination probability increases with an increase in the call arrival rate and then stabilizes after a certain value. There is a trade-off between the forced termination and call blocking probability. It is desirable to maintain the ongoing call instead of providing resources for a new call. But if the forced termination probability is reduced it would lead to increase in the number of new calls being blocked. However, the forced termination probability obtained here is much lower than the traditional RSS handoff model.

Fig.5 shows that the handover failure probability increases slightly with increasing speed but then stays constant. Moreover the value for handover failure probability is very low. This is because as the speed crosses the specified upper limit of speed, the mobile user is successfully handed over to the macro cell.

From fig. 6 we can see that the unnecessary handover probability increases for high speed mobile stations but still has considerably low value when compared to other traditional algorithms. This can further be reduced by setting the detecting period equal to the handover delay. Fig.7 compares the different path loss models available for urban environment. We can clearly observe that for our environment and requirements SUI model provides the best results.

5. Conclusion

In this paper speed sensitive algorithm with multiple users in a hierarchical LTE network has been analyzed. Gauss Markov Mobility model was useful for location and speed predictions in an urban area. Various Path loss models were studied and implemented for best results. The RSPs of the mobile stations were improved during this process. Probabilities of various parameters such as call blocking, handovers, forced termination, unnecessary handover has been calculated. Along with these, Call arrival rates, channel utilization and Path loss values which we have also calculated. These helped us in determining the performance of hierarchical network. It is concluded that SUI Path loss model gave the best results in terms of received signal power. Also, as the speed of the users increases, there is a higher probability of handover to the Macrocell.

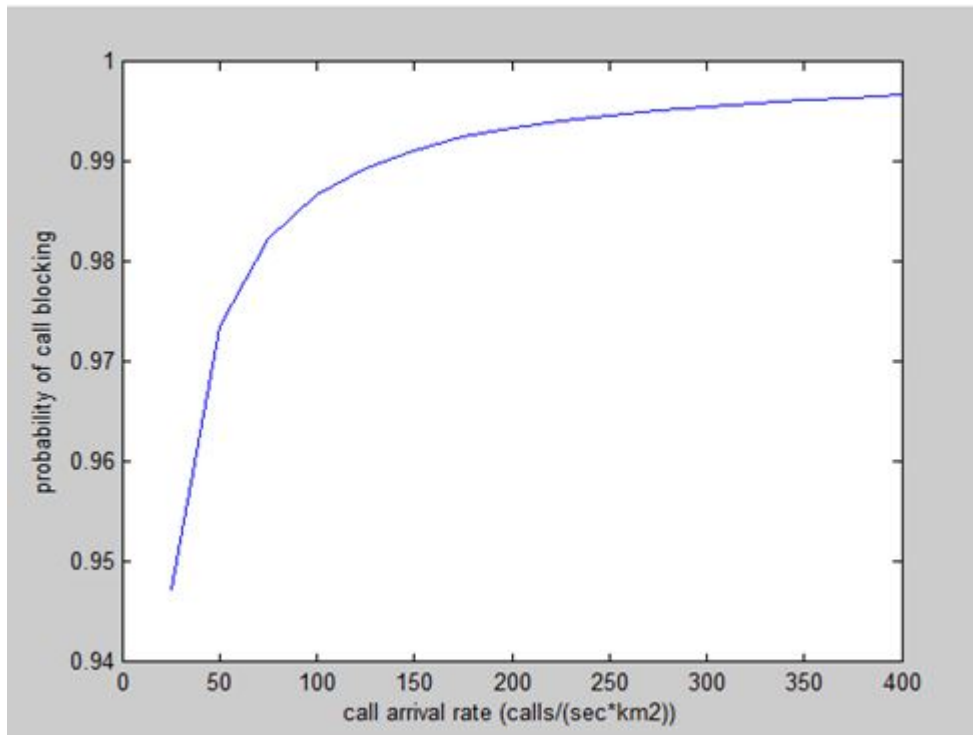


Figure 1. Probability of call blocking versus call arrival rate

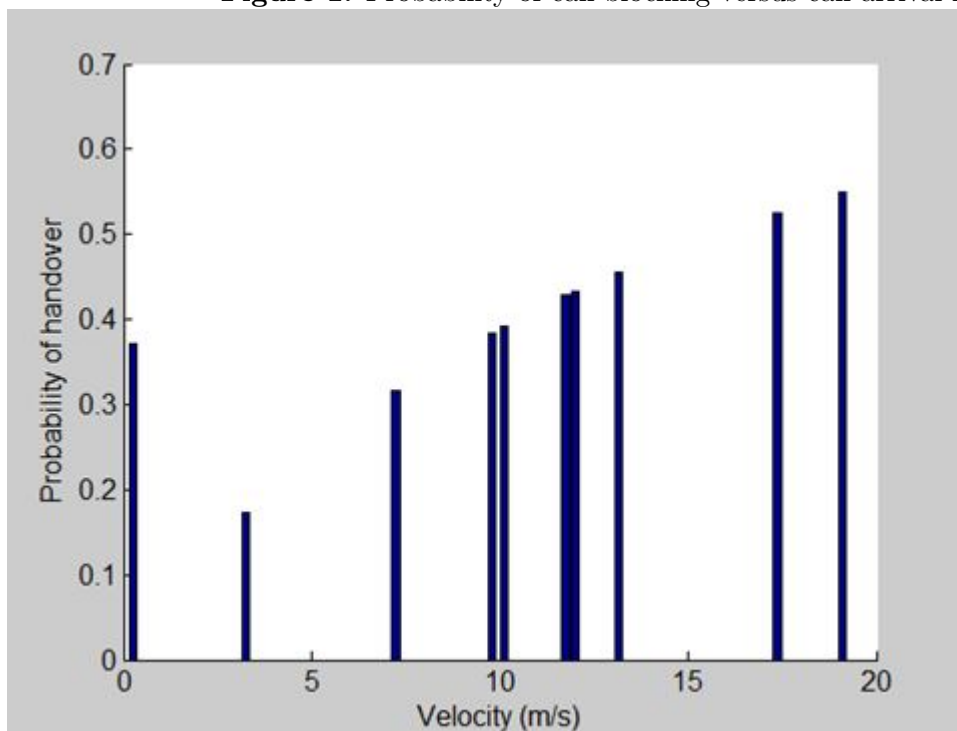


Figure 2. Probability of handover versus velocity

We also had a trade off between forced termination probability and call arrival rate. The further

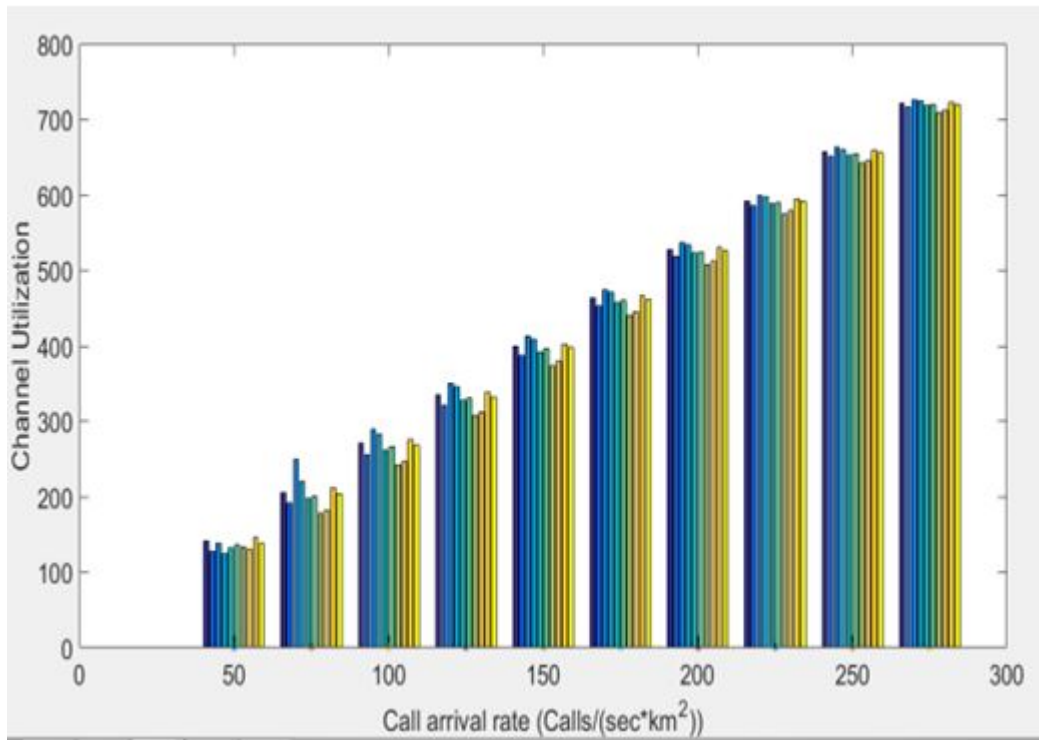


Figure 3. Channel utilization versus call arrival rate

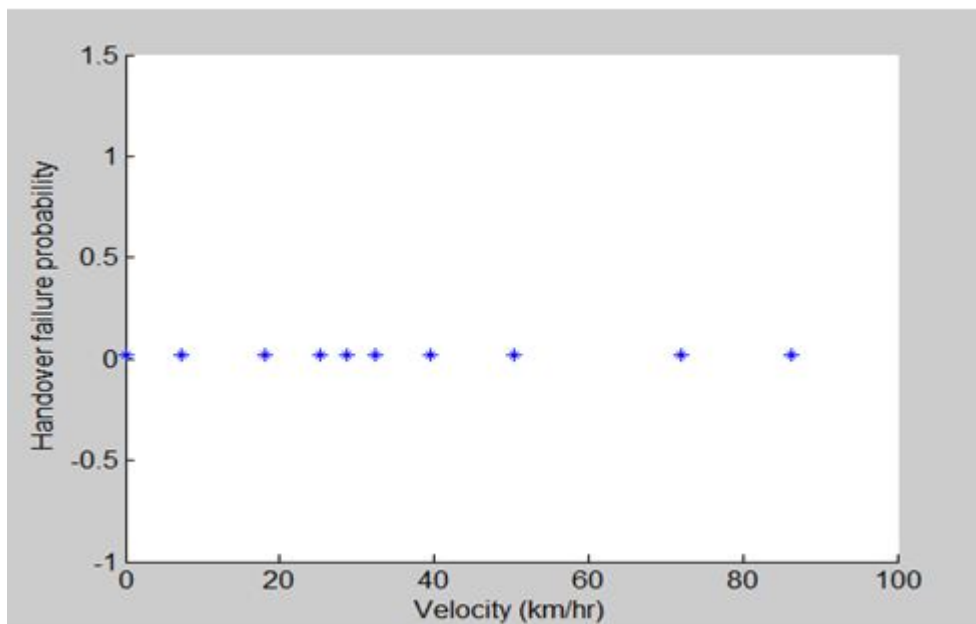


Figure 4. Forced termination probability versus call arrival rate

work in this area would be to develop on this trade off and derive an optimal result.

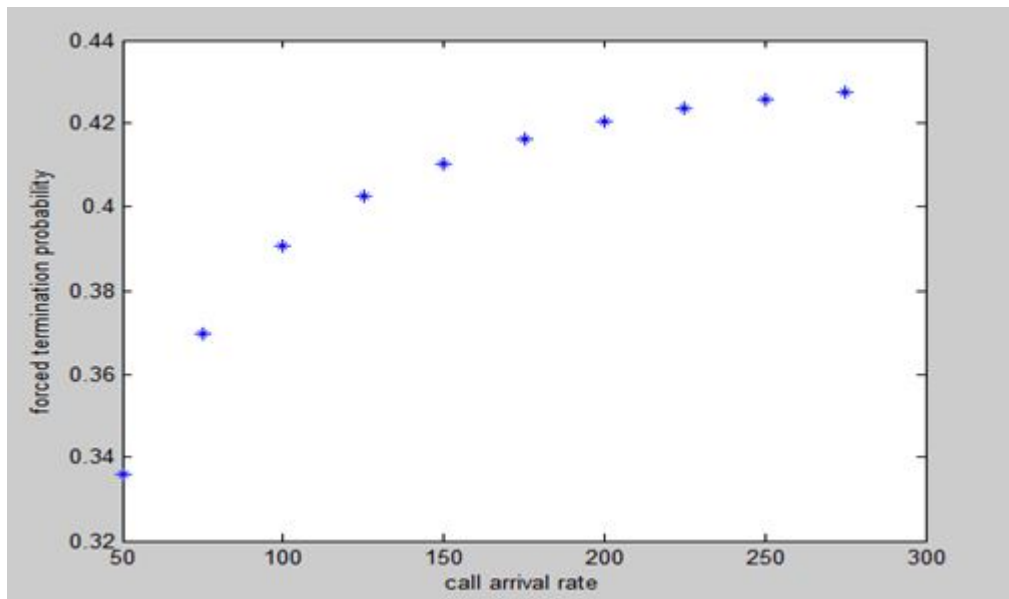


Figure 5. Handover failure probability versus velocity

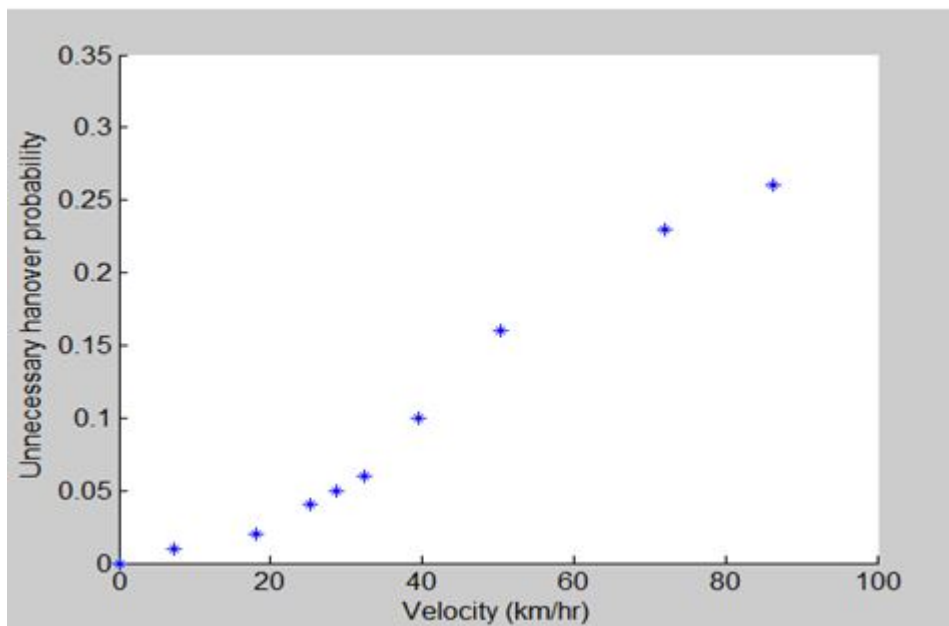


Figure 6. Unnecessary handover probability versus velocity

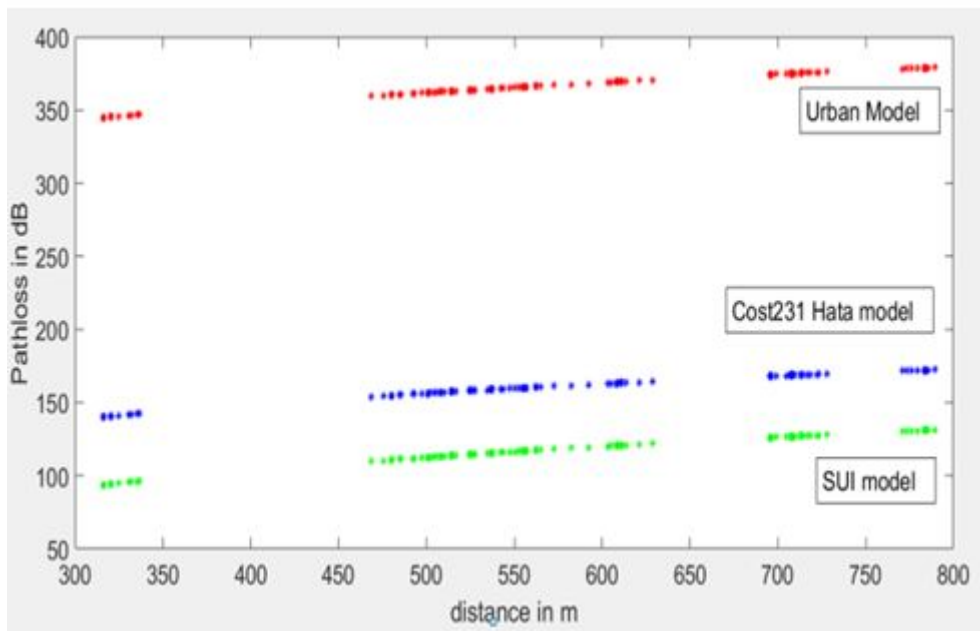


Figure 7. Path loss versus distance

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