# A Proposed Solution to Enhance Mobile Telecommunication Infrastructure in Kuching, Sarawak

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*Abstract*— **Wireless communication systems must be able to provide an optimum, distortion-free link regardless of the obstructions and irregularities in the propagation environment. The Telecommunication industry in East Malaysia (Sarawak) is still developing, under limitations due to terrain, tropical rainforest conditions and scattered population. Therefore, the service level figures are poorer in Sarawak, even as the demand for mobile networks in Sarawak is comparatively higher. In this paper, we are proposing and simulating solutions to overcome the mobile telecommunication connectivity problems in Kuching, Sarawak. The study shows that an optimum handoff performance can be achieved by using a stable handoff algorithm and coverage can be improved by adding microcells. This study focuses on a static mobile node handoff and lower antenna height problems.**

*Index Terms*— **Telecommunication, Handoff, Mobile Network, Propagation Modle, Signal**

## I. INTRODUCTION

THE wireless medium is extremely unpredictable and hostile. However the mobile networks are expected to perform with similar efficiency as wired networks. A wireless channel is expected to provide a distortion free link. In a competitive market, service providers who are unable to satisfy this, may lose customers. Service providers therefore realize the importance of evaluating the performance of a network and the impact of geographical and man-made obstacles on its performance before actually deploying it. Unfortunately, even the simple wireless scenario is too complex to be traced and analyzed accurately, as there are many parameters to be evaluated. Users within the coverage area of certain base station experience issues like poor signal strength and frequent call drops even while stationary, which can be due to shadowing attenuation, insufficient coverage due to antenna height or power, or poor handoff performance etc. [1]. Therefore, in this paper, we have proposed and simulated some solutions to enhance the current mobile telecommunication infrastructure in Kuching.

In this paper, we have used MATLAB as a simulation tool to simulate the poor handoff and problematic scenarios in order to study the cause of poor coverage performance. The solutions were proposed and simulated to observe the performance results.

## II. LITERATURE REVIEW

A mobile phone network provides a wireless extension to the wired Public Switched Telephone Network (PSTN). The main elements involved are Mobile Station (MS), Base Transceiver Station (BTS) and Mobile Switching Centre (MSC) [2, 4]. Mobile networks are currently capable of handling many value added services that have been integrated with mobile networks [5, 6].

### A. *Wireless Propagation Basics*

The simplest and most desired propagation scenarios are to have a direct line of sight between sender and receiver. In most cases, the signal path will have obstructions in the form of buildings, foliage, hills, etc. Wireless applications that use the Very High Frequency (VHF) and Ultra High Frequency (UHF), bands are ideal for coverage in areas where issues like Reflection, Diffraction, and scattering dominate [4], [7], [8]. Due to this, the MS usually receives many different versions of the same signal. The signal strength at the MS is the vector sum of all received signals, and can have either a destructive or constructive result. A wireless channel should be able to provide a distortion free link, with a frequency response of constant amplitude & linear phase i.e. [9, 10]:

$$|H(f)| = constant\ and\ \arg[H(f)] \propto f \qquad (1)$$

When analyzing the performance of a mobile network, usually two kinds of extreme scenarios are considered [3], [11], [13]. A strong Line Of Sight (LOS) signal is available, together with weaker versions of the same signal and modelled using Rice Distribution. Weaker versions of the

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signal are received with no LOS component and known as the Non Line of Sight (NLOS), usually in environments where buildings and other obstacles may block-out/ reflect direct signals from the base station. The propagation characteristics of Radio Frequency (RF) signals (reflection, diffraction and scattering) make communication feasible in such environments and can be modelled using the Rayleigh Distribution [10], [12], [14].

### B. *The Cellular Concept*

While base stations for mobile communications may be capable of transmitting signals with high power, the mobile stations are low powered. Also, many mobile stations need to share the limited available bandwidth. In order to achieve spectral and power efficiency, the coverage area is broken into many smaller cells. Each cell uses different frequency groups within the same band until the entire bandwidth is exhausted [4], [15], [16]. This approach allows a high capacity network design within a limited available spectrum. The frequency can be re-used many times by adding more low power base stations [4]. The size of cells can vary according to the location and height of the Base Station (BS). The most common sizes are Macro Cells, Micro Cells and Pico Cells [2], [4], [10]. Furthermore, the cellular design and Call handoff requires acute attention to power management to avoid interference from co-channels.

### C. *Call Handoff*

Call handoff facilitates an uninterrupted communication while the mobile station is travelling between cells, by transferring the mobile station to a different base station once the Received Signal Strength Indicator (RSSI) drops below a chosen threshold [4]. An issue identified in this area is for mobile stations moving within areas having similar RSSI levels from different BS, will cause the MS to keep switching between base stations, leading to performance issues and call drops. New handoff strategies such as handoff margin method improve stability of the handoff performance for mobile stations in such regions [10]. Handoff strategies can generally be divided into two main classifications, a Hard Handoff, and a Soft Handoff [4], [10]. In hard handoff, mobile users will switch to a new BS once the old connection to BS is completely broken and requires the least processing power. In a soft handoff, the mobile user retains the connection to the original BS even when a connection to the target base station is made and requires mobile station's hardware to be capable of receiving two or more frequency channels at the same time. Soft handoff improves handoff process reliability, reducing chances of abnormal termination of calls.

### D. *Free Space Path Loss*

Very slow signal variations are experienced due to the increased travel distance. Those variations manifest as losses that will be referred to as path losses for the remainder of this paper. The Friis Free Space Model uses the following equation [9]:

$$l_{fs} = \frac{p_t}{p_r} = \frac{1}{g_t g_r}\left(\frac{4\pi d}{\lambda}\right)^2 \qquad (2)$$

$l_{fs}$ is free space path loss, $p_t$ is transmitted power, $p_r$ is received power, $g_t$ is transmitter antenna gain, $g_r$ is receiver antenna gain, $d$ is distance between transmitter and receiver and $\lambda$ is the propagation wavelength.

If we assume isotropic transmitter and receiver antennas, can define the *Effective Isotropic Radiated Power* EIRP as [4]:

$$EIRP = p_t g_t \qquad (3)$$

Therefore, for isotropic antennas, formula (2) can be presented in practical units as:

$$L_{fs}(dB) = -146 + 20\ \log f\ (MHz) + 20 \log d\ (km) \qquad (4)$$

Equations (2) and (4) are only valid for large distances compared to the wavelength. The minimum distance, where both equations apply is known as the Fraunhofer distance and is defined as [9]:

$$d_f = \frac{2D^2}{\lambda} \qquad (5)$$

$d_f$: Fraunhofer distance and D is the antenna largest dimension

And

$$d_f >> D,\ d_f >> \lambda$$

### E. *Log-distance Path Loss*

If the received power at a reference distance $d_o$ is measured as $p_o$, the power at distance $d > d_0$ can be calculated using the following equation [9]:

$$p_r(d) = p_0 \left[\frac{d_0}{d}\right]^n \qquad (6)$$

Or in practical units

$$P_r(d)\ dB = P_0(dB) + 10\ log\left[\frac{d_0}{d}\right]^n \qquad (7)$$

It can be seen that the free space path loss follows an inverse power law with exponent n=2. In terms of path loss, an equation (7) can be written as [9]:

$$L(d)\ dB = L_0(d_0)dB + 10\ log\left[\frac{d}{d_0}\right]^n \qquad (8)$$

$L(d)$ is the path loss at distance $d$, $L_o$ path loss at a reference distance $d_o$, $n$ is the path loss exponent.

### F. *Log-normal Shadowing*

Very slow variations of signals were found to follow the inverse power law ($1/d^n$). The slow or long term variations occur mainly due to shadowing. It was experimentally proved that the path loss at a particular location is log-normally distributed with a local mean that depends on the MS-BS separation distance. Therefore, equation (8) needs an extra parameter that takes into account the different environmental clutter for different locations [9]:

$$L(d)\ dB = L_0(d_0)dB + 10\ log\left[\frac{d}{d_0}\right]^n + X(0,\sigma) \qquad (9)$$

$X$ is a Gaussian random variable of zero mean, $\sigma$ is a standard deviation(location variability).

Although the shadowing effect is considered as random, it was found that the rate of change of the shadowing effect may have values ranging from a few meters to several tens of meters depending on the obstacles' size found along the propagation path. The spatial correlation of shadowing can be modelled using the following equation [17], [18].

$$R(\Delta r) = e^{-\ln 2 \frac{\Delta r}{d_{corr}}} = e^{\frac{-\Delta r}{L_{corr}}} \qquad (10)$$

Where: $R$ is the special correlation, $\Delta r$ is the change in position, $L_{corr}$: is the correlation distance.

Equation (10) models the spatial correlation only in one dimension. It is necessary to modify the equation to work in two dimensions since maps are in two dimensions. For (x, y) Cartesian co-ordinates, $\Delta r$ can be expressed as [17]:

$$\Delta r = \sqrt{\Delta x^2 + \Delta y^2} \qquad (11)$$

$\Delta x$ *and* $\Delta y$ are shifts in positions in horizontal and vertical directions.

So the equation (10) can be written in two dimensions as [17]:

$$R(\Delta x, \Delta y) = e^{-\ln 2 \frac{\sqrt{\Delta x^2 + \Delta y^2}}{L_{corr}}} = e^{\frac{-\sqrt{\Delta x^2 + \Delta y^2}}{L_{corr}}} \quad (12)$$

### G. *Small-scale Fading*

When there is no clear LOS from BS to MS, multiple weaker echoes of the signal may be received, each with a different propagation path. The final received signal will be a vector sum having either a destructive or constructive result, usually with rapid signal variations. Mobile stations may experience fading in highly built up urban areas or in areas where environmental features (trees, foliage, etc.) completely block the line of sight. Multipath propagation, frequency shifts (*Doppler Effect*) etc., are the reasons for this kind of fading [2], [4].

### H. *Link Budget*

A mathematical formula that accounts for all gains and losses of wireless signal propagation, whether they were induced by the transmitter or receiver antennas or by the wireless channel is a link budget formula and it takes the form [13], [19]:

$$P_r(dBm) = P_t(dBm) + Gains(dB) - Losses(dB) \quad (13)$$

where: $P_r$: power received, $P_t$: power transmitted

Equation (13) can be further expanded:

$$P_r(dBm) = P_t(dBm) + G_t + G_r - L_r - L_t - L_{fs} - L_{excess} \quad (14)$$

$G_t$: transmitter antenna gain (dB), $G_r$: receiver antenna gain (dB), $L_r$: receiver antenna loss (dB), $L_t$: transmitter antenna loss (dB), $L_{fs}$: free space loss (dB), $L_{excess}$: excess loss (dB).

The excess loss is calculated using the following equation[13]:

$$L_{excess} = 20 \log\left[\frac{\emptyset_0}{\emptyset}\right] \quad (15)$$

$\emptyset_o$ is field strength at the receiver antenna under free-space conditions, $\emptyset$ is actual field strength both in linear units (V/m).

The link budget formula is not used only to evaluate the desired signal, it is often used for interference and noise evaluation as well.

### I. *Coverage Probability Calculation*

The shadowing variations follow a normal distribution, explained using the Central Limit Theorem [8]. The presence of several shadowing processes in a wireless link leads to a Gaussian distribution. Fringe coverage is usually used to evaluate coverage, quality [4], [6], [10]. To evaluate the coverage mathematically, we assume a desired threshold $\gamma$ and $R$ is the radius of the coverage area. The fraction of the total area where the probability that a signal equals or exceeds the threshold $\gamma$, needs to be calculated [10]. For a circular coverage area, the coverage area probability is calculated using the following equation [10]:

$$U(\gamma) = \frac{1}{\pi R^2} \int Prob(P_r \geq \gamma) dA \quad (16)$$

*dA:* is an infinitesimally small fraction of the area.

Using the cumulative distribution and error functions & equations (6), (7), (8), equation (19) can be written as [13]:

$$U(\gamma) = \frac{1}{2}\left[1 - \operatorname{erf}(a) + e^{\left(\frac{1-2ab}{b^2}\right)}\left(1 - \operatorname{erf}\left(\frac{1-ab}{b}\right)\right)\right] \quad (17)$$

where:

$$a = \frac{\gamma - P_t + \overline{L(d_0)} + 10n \log(R/d_0)}{\sigma\sqrt{2}} \quad (18)$$

and:

$$b = \frac{10n \log(e)}{\sigma\sqrt{2}} \quad (19)$$

### J. *Propagation Models*

The average power value for shadowing is typically predicted using propagation models. Okumura Model is a large-scale propagation model, which is used for signal power prediction in the presence of the very slow distance dependent variations and the slow shadowing variations in urban areas. It was developed from extensive measurements that were collected in Tokyo-Japan, and it can be used given that [4], [10]; Frequency range: 150 – 1920 MHz, MS antenna height: 1 – 10 m, BS antenna height: 30 – 1000 m, Distance: 1 – 100 km. The model evaluates the path loss with the following equation [9], [13]:

$$L_{50}(dB) = L_{fs} + A_{mu}(f, d) - G(h_t) - G(h_r) - G_{AREA} \quad (20)$$

where: $L_{50}$ is the median value of the path loss, Lfs is the free space path loss, $A_{mu}$ is the median attenuation relative to free space, $G(h_t)$ is the base station antenna height gain factor, $G(h_r)$ is the mobile station antenna height gain factor, $G_{AREA}$ is the gain due to the environment type.

$A_{mu}$ and $G_{AREA}$ are predetermined using the measurements collected for Okumura model, while $G(h_t)$ are $G(h_r)$ determined as follows [9], [13]:

$$G(h_t) = 20 \log\left(\frac{h_t}{200}\right) \quad (21)$$

$$G(h_r) = \begin{cases} 10 \log\left(\frac{h_r}{3}\right), & h_r \leq 3\,m \\ 20 \log\left(\frac{h_r}{3}\right), & 10\,m > h_r > 3\,m \end{cases} \quad (22)$$

*Hata Model*: The Okumura model does not provide an analytical explanation. An empirical formulation of this was done by Hata. The mathematical representation of the median path loss in urban areas using Hata model is given as follows [9], [10]:

$$L_{50}(dB) = 69.55 + 26.16 \log(f_c) - 13.82 \log(h_t) - a(h_r) + (44.9 - 6.55 \log(h_t)) \log(d) \quad (23)$$

$f_c$ is the carrier frequency between 150 – 1500 MHz, $h_t$ is transmitter antenna height between 30 – 200 m, *hr* is receiver antenna height between 1 – 10 m, *d* is BS-MS separation distance and $a(h_r)$ is mobile antenna height correction factor.

Determined as follows [4], [10]:

For small to medium size cities:

$$a(h_r)dB = (1.1 \log f_c - 0.7)h_r - (1.56 \log f_c - 0.8) \quad (24)$$

For large cities [4, 10]:

$$a(h_r)dB = \begin{cases} 8.29(\log 1.54\, h_r)^2 - 1.1 & for\ f \leq 300\,MHz \\ 3.2(\log 11.75\, h_r)^2 - 4.97 & for\ f \geq 300\,MHz \end{cases} \quad (25)$$

*Hata COST-231 model*: To accommodate mobile communications that typically use the 1800 MHz band, the Cooperative for Scientific and Technical research (COST) developed a COST-231 extension to Hata model which is valid for the following [4], [10]; The proposed model was:

$$L_{50} = 46.3 + 33.9 \log f - 13.82 \log h_t - a(h_r) + (44.9 - 6.55 \log h_t) \log d + C_m \quad (26)$$

$a(h_r)$ *is the* same as defined in equations (27) and (28), and $C_m$ is 0 dB for medium sized cities and urban areas, and 3 dB for metropolitan areas. $f$ is 500 – 2000 MHz, $h_t$ is 30 – 200 m, $h_r$ is 1 – 10 m and *d* is 1 – 20 km

Other models for signal strength predictions were not taken into considerations as our study only needed models for large-scale propagation.

## III. Methodology And Simulation

In our experiments, the Mobile stations were frequently handed off between base stations. A bad handoff threshold could be a result of a bad power management scheme, poorly chosen threshold, less stable handoff algorithms, etc. Coverage issues can be a result of several sub-factors such as, BS and MS antenna heights, propagation frequency, BS transmission power, and path loss. Small scale fading is unlikely, since MS has LOS to the base station. Therefore, only distance dependent large-scale path loss is considered. It was not possible to gain access to the actual service providers' sites for protection of sensitive information, so we have proposed a model using estimated values. We have varied the values of the estimates to observe the effect.

### A. *Simulation of the Hata Model*

The most widely used propagation model to predict losses in urban areas, Hata model was adopted as the propagation model of choice for our study. The original Hata model has a maximum frequency restriction of 1500 MHz, which is not sufficient for 3G or 4G signals operating at 1800 MHz band. So the COST-231 extension of Hata model is also included. In this simulation, we have used equations (23, 24, 25 and 26). Depending on the obtained frequency value, the simulation will either choose Hata or COST-231 extension (150 - 1500 MHz for Hata, 1500 - 2000 MHz for COST-231). A plot for path loss as a function of travelled distance is produced for Urban, big city, Urban, small to medium city, Suburban and Rural environments. Fig. 1 shows the results for a transmission frequency of 1800 MHz, MS height of 2 m, and BS antenna height of 32 m.

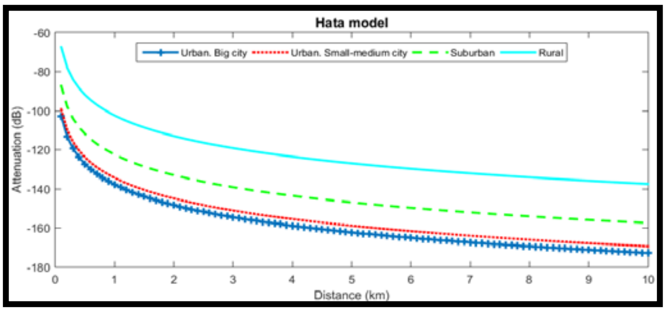


Fig. 1. Hata Model

### B. *Generating a Realistic Signal*

Our simulated signal included shadowing and distance dependent losses only. It is needed to synthesize realistic signal so that the outcome resembles an actual measured signal. We have assumed that a mobile station is travelling along a circular path at a constant distance from the BS in order to visualize the shadowing effect alone. The signal variation rate of the shadowing effect is characterized by the correlation distance, which varies widely for different obstacles' sizes. Variation due to shadowing is random; therefore, we have produced random Gaussian samples of zero mean and unit standard deviation. The random samples are uncorrelated, to introduce the autocorrelation distance; we used MATLAB interpolation functions "interp1" and "spline". The values for frequency, correlation distance, samples mean, samples standard deviation, fringe coverage threshold, number of samples, and sample spacing are obtained from the user input. We assumed that distance dependent variations occur along a radial path from the BS. We have used Hata model to simulate the path loss. For the same parameters entered before, we get Fig. 2.

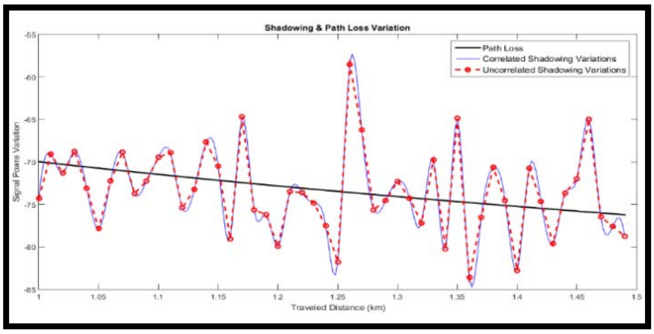


Fig. 2. Path Loss Added to Shadowing Variations

### C. *Simulating Handoff Behavior*

We assumed a scenario, where a mobile station is travelling between two base stations. When the received signal strength indication from both the base stations reached a similar level about halfway between them. The MS will be handed off only once the received signal strength drops below the threshold. Otherwise a threshold margin is defined such that the MS only switches to other BS, if the difference in received signal levels is higher than the margin. This approach allows for more stable handoff, whereas the former approach caused frequent switching between base stations. To visualize the procedure in either approach, we have generated a second identical signal to the one created earlier. Fig. 3 shows the handoff behavior between two base stations 5 Km apart, both of them transmit 3G signals. The number of samples are set according to the separation distance between the two base stations. The handoff threshold is chosen at -90 dB, and the handoff margin at 15 dB.

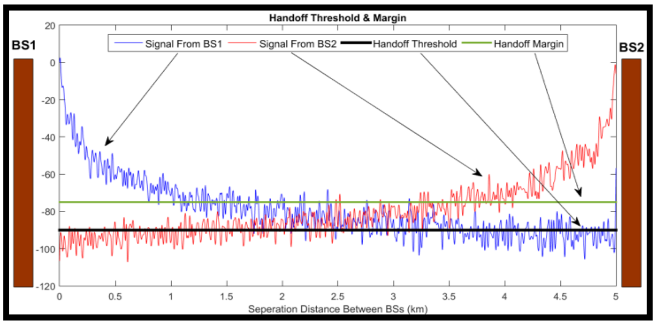


Fig. 3. Handoff Simulation

### D. *Base Station Coverage Simulation*

We need to assume a correlation distance, which is valid in two dimensions to produce the base station coverage map. We have used MATLAB function "interp2" for interpolation in two dimensions to introduce the correlation distance. After interpolation, the path loss is added using values from Hata model. We assumed an isotropic BS antenna with unit gain. We start by producing a map for the average power using Hata model. We assumed a reference loss at 1 Km to be 137 dB (obtained from a Hata model in an urban area), the map will be 1 x 1 Km with the base

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station at its center. Next, we produced a map for the correlated shadowing samples.

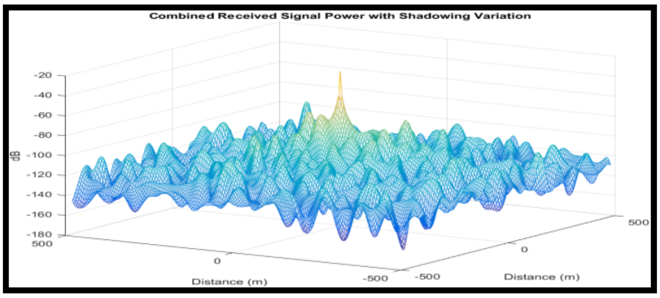


Fig. 4. Average Power with Shadowing Variation

The values of the correlation distance, sampling standard deviation, and the samples spacing is 30 m, 10 dB, and 5 m respectively. Shadowing variation, when superimposed on a signal strength plot, will produce the combined shadowing variation with the average signal power as shown in fig. 4. A coverage contour map is generated assuming a coverage threshold of -110 dB below; where the area is considered out of coverage using the MATLAB function “contour” with fig. 4 will produce the map (fig. 5.).

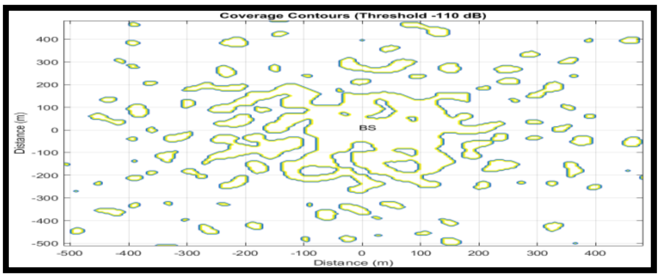


Fig. 5. Coverage Contours

## IV. RESULTS AND DISCUSSIONS

In the following section, we have implemented the proposed methods in a problematic base station area, and model required BS performance. Our simulation methods were capable of modelling the shadowing behavior for all signals propagating using a Hata-like model.

### A. *Modelling the handoff behavior*

In our tests, we have observed that mobile stations are being handed off as soon as the received signal strength hits -95 dB. In rare situations, the RSSI dropped as low as -99 dB before the handoff. Therefore, we can safely assume that a handoff threshold of -95 dB was implemented by the provider in consideration. Kuching Central is a problematic area, which we have noticed. We located two base stations, each about 35m high, and 8 km apart. The area is classified as an urban with a path loss exponent no more than 3.5 dB. These factors allowed us to assume a correlation distance of at least 30m.

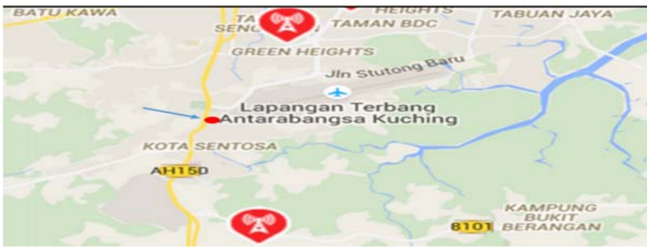


Fig. 6. Base Station Location at Kuching Central

The signals received from base stations were 3G signals at 1800 MHz. We assumed an isotropic base station antenna with 0 dB gain to simulate the worst case scenario. The reference path loss was calculated using Hata model, at -137 dB for an urban small city. Fig. 6 shows the location of the base stations and the spot the location of observed issue. As we can see, the area of interest is almost halfway between the two base stations. Mobile stations in that area can experience handoff issues, if a robust handoff algorithm is not implemented. Fig. 7 shows a handoff threshold of -95 dB. The rest of the parameters chosen are; Frequency 1800 MHz, Correlation distance 30 m, Antenna Gain 0 dB, Reference loss -137 dB, Path loss exponent 3.5, Separation distance between base stations 4 km, Handoff Threshold -95 dB. Fig. 8 shows that a mobile station located 2 to 6 km from either base station experiencing numerous handoffs between the two base stations, which cause hindering network performance in that area.

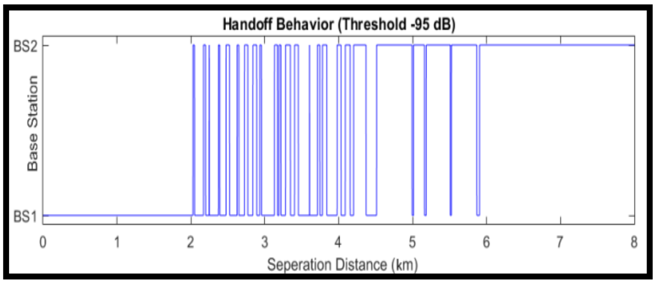


Fig. 7. Handoff with Threshold of -95 dB

### B. *Modelling Base Station Coverage Area*

For this simulation, we used the same values as for the handoff simulation. The coverage threshold was kept to be -115 dB because any lower value is unusable. The simulated coverage area have a diameter of 4 km, since the nearest base station for the same provider is about 8 km away. Using the same approach as in section 3.4 & same values in section 4.1, we produced a coverage contours for the base station.

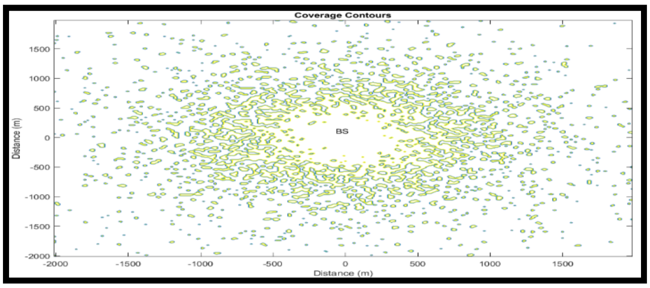


Fig. 8. Base Station Coverage Contours

This is also the worst case scenario because of the 0 dB antenna gain. It is also important to note that 8 km diameter is actually good enough for 3G implementation. For such an area size, there are small Microcell areas that cannot be properly covered by the main base station. By keeping this in mind, the coverage map (Fig. 8.) was produced for the main base station alone. Evidently, with our current configuration, the base station is not capable of covering the area. Most mobile stations located beyond 1 km from the base station will experience coverage issues.

## V. RESULTS ANALYSIS AND DISCUSSION

The results showed in the previous section involved assumptions about the values of some parameters. Some assumptions were made due to lack of information available from the service providers and others were inferred from the geographical and man-made features in the area of study. The latter assumptions are a good representation of the scenario under consideration. The service providers can adjust parameters like base station height, transmission power, handoff mechanisms, etc., to better adapt to the contours of the area to be serviced.

### A. *Handoff Issues*

In our simulation, we assumed a handoff threshold of -95 dB. The handoff performance can be improved by changing the threshold, or better still, by defining a handoff margin whereby the mobile station does not switch to a different base station until the difference in RSSI from both base stations is above the margin. By decreasing the threshold to -100 dB, we expect less switching frequency between the base stations.

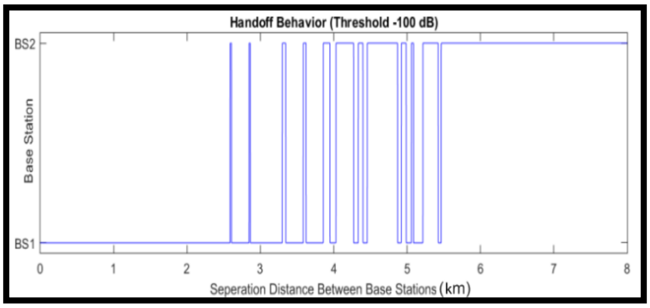


Fig. 9. Handoff behaviour Threshold -100 dB

Fig. 9 shows the simulation results of -100 dB threshold. The remaining parameters have the same values to fig. 7. As we can analyze, decreasing the threshold value improves performance of network. Fig. 9 shows a lower switching frequency as compared to fig. 7. However, we still observed that when a mobile station moving within the area from 2.5 to 5.5 km from any base stations, experience several handoffs; -100 dB RSSI is too low for call quality. Therefore, it does improve the handoff performance marginally, reducing the threshold as low as -100 dB is not recommended. If we keep the threshold at -95 dB and define a handoff margin to 15 dB, the mobile station will measure the RSSI from both base stations and will only do the switch if the difference in the received RSSI is higher than 15 dB. Fig. 10 shows the simulation results of the handoff procedure involving a handoff margin, with the rest of the parameter unchanged. Using the margin technique improves the handoff performance, as seen clearly in fig. 10. We see a mobile station travelling from BS1 to BS2 will only be handed-off three times between the two base stations compared to the previous result seen in fig. 7 and fig. 9.

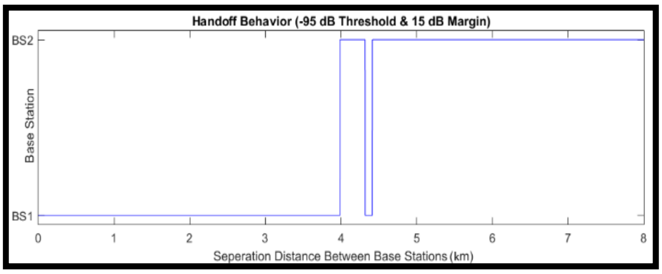


Fig. 10. Handoff Behaviour Using -95 dB Threshold & 15 dB Margin

Running the simulation several times will produce different results for the same parameter values due to the randomness of the shadowing effect. However, the results will be comparable and not change drastically. More sophisticated handoff mechanisms exist, but it is not included in this paper as they employ complex algorithms and require detailed research. The key conclusion of these experiments is that a handoff issue can be improved using more efficient mechanisms rather than simply adjusting the threshold.

### B. *Coverage Issues*

We have suggested earlier in fig. 8 that a single base station with 0 dB antenna gain is not sufficient to cover an area with a radius of 2 km. Improving coverage involves several measures like Base station antenna height, Mobile station antenna height, Base station transmission power, Base station antenna gain, and Transmission frequency.

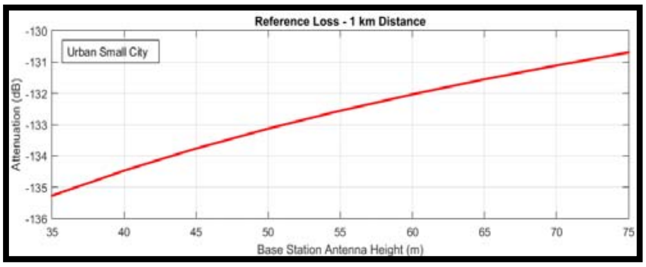


Fig. 11. Reference Loss at 1 km

In this section we have experiment with some of these parameters. Mobile station antenna height has been fixed since the area, we are studying consists mostly of low rise houses and transmission frequency is fixed in 1.5m and 1800 MHz respectively since it is the required frequency for 3G signals. 4G and 2G also propagate at the 1800 MHz frequency band. We start by observing the effect of changing the height of the antenna on the base station coverage performance. Since we are using Hata model, we tabulate the reference loss for base station antenna heights ranging from 35 m to 75 m in a 5 m increments.

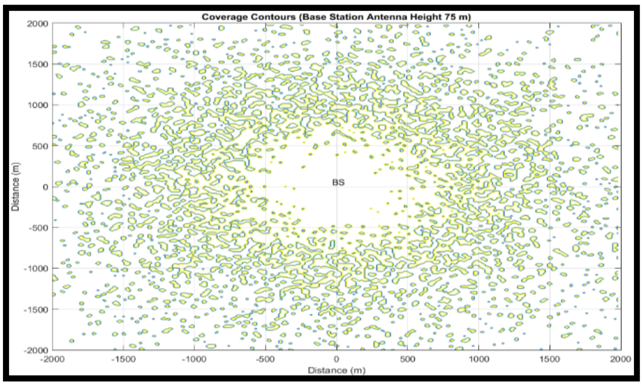


Fig. 12: Coverage Contours for 75 m Base Station Antenna Height

By applying equation 26, we have computed losses at a reference distance of 1 km for the desired height. Fig. 11 shows that improvement can be achieved by increasing the base station height. The improvement will be marginal as only a 5 dB increase in signal power will be observed by increasing the tower height from 35 m to 75 m. We will first produce a contour map for a base station height of 75 m and compare it with the map of fig. 9, which was about 35 m. The coverage achieved with 75 m base station antenna height is much better than that achieved with 35 m (fig. 13.). Yet, doubling the antenna height may not be a practical or economical solution.

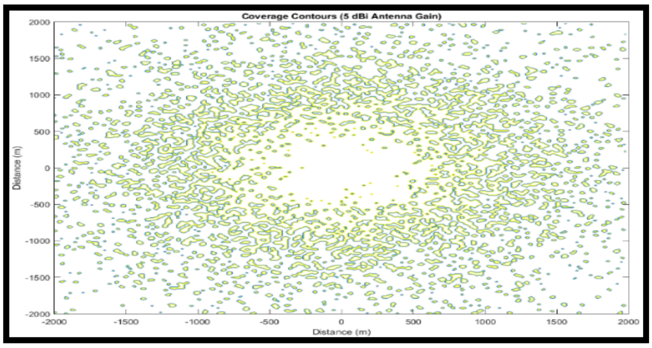


Fig. 13: Coverage Contours (35m Antenna Height & 5 dBi Gain)

We examined the effect of increasing the base station antenna gain on its coverage capabilities. The height was fixed to the original 35 m. The results are compared to fig. 9, where a 0 dB antenna gain was used. Fig. 14 shows a map of a 5 dB antenna gain. Compared to fig. 9, the coverage results with 5 dB antenna gain are significantly better. The base station still cannot cover the 2 km radius. Finally, we generated coverage contours for 10 dB antenna gain, which is shown in fig. 15, and clearly has the best result obtained so far. We also can increase the EIRP (Equation 3), which can produce similar effect as well. It must also be noted that increasing the power or antenna gain should done very carefully to avoid interference from co-channel cells and to ensure optimum handoff performance.

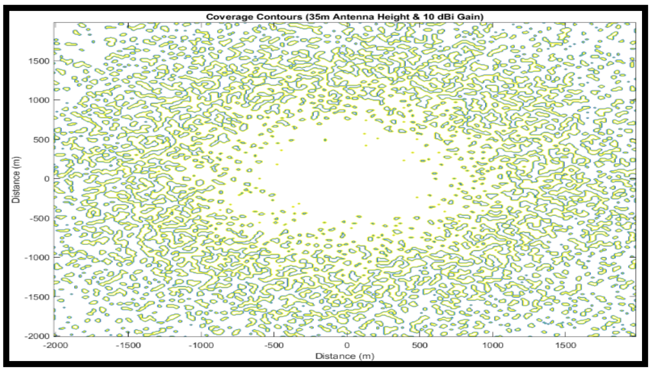


Fig. 15: Coverage Contours (35m Antenna Height & 10 dBi Gain)

## VI. Conclusion

Our handoff simulation showed that an optimum handoff performance can be achieved using a stable handoff algorithm. Our experiments with a simple handoff margin method showed major improvement in the implemented scenarios. Adopting one of the many sophisticated handoff algorithms is highly recommended since handoff issues can seriously impact the performance and quality of calls, and render mobile internet unusable. Our coverage simulation also showed that coverage can be improved in many different ways. The ideal solution would be adding microcells (low power base stations) as needed. If such a solution cannot be economically justified, the base station antenna height or transmission power (or gain) can be increased. The detected issues could be solved in some cases, even completely eliminated using one of the methods we have proposed and tested. The simulation approach proves to be precise since it gives more interpretable results than actual implementation. In future work, actual values can be used to run the simulation, in order to actual more realistic results.

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