Investigation of Handoff Algorithms for GSM Mobile Cellular Networks

S. A. MAWJOUD **H. A. Al-TAYYAR**

Electrical Eng. Dept.

University of Mosul

Abstract

One of the main feature of wireless cellular network is to achieve continuous (uninterrupted) services using handoff when mobile subscribers cross the boundaries of cells in the coverage area. Handoff calls are usually given higher priority than new calls initiated.

Various algorithms are investigated using simulation and the results obtained show that the received signal strength with hysteresis and threshold in the serving cell (RSS-HT$_{ser.}$) and the received signal strength with hysteresis and threshold in the new cell (RSS-HT$_{new.}$) are the two methods which are closely representing the cellular system environment since they contain additional constrains in Handoff (HO) execution. Simulation are carried out by varying the governing parameters including the effects of fading on the received signal strength, averaging of signal strength, hysteresis and threshold, window size on average signal strength, and the standard deviation which represent worsening signal fading.

Keywords: Cellular networks, Signal strength, Hysteresis, Handoff algorithms.

استقصاء خوارزميات المناقلة لشبكات النظام الخلوي نوع GSM

الدكتور سامي عبد الموجود **هدى عقيل الطيار**

قسم الهندسة الكهربائية

جامعة الموصل

إحدى أهم مميزات الشبكة الخلوية اللاسلكية هو توفير خدمات اتصالات مستمرة (غير متقطعة) باستخدام عملية المناقلة عندما تعبر المحطة المتنقلة حدود الخلايا في منطقة التغطية. عادة تعطى عملية المناقلة للمكالمات المستمرة أولوية مقارنة بالمكالمات الجديدة. تم استقصاء عدة خوارزميات باستخدام المحاكاة ، وأن النتائج المحصل عليها تبين أن خوارزمية قدرة الإشارة المستلمة مع التخلفية وحد العتبة في الخلية الخادمة (RSS-HT$_{ser}$) وكذلك خوارزمية الإشارة المستلمة مع التخلفية وحد العتبة في الخلية الجديدة (RSS-HT$_{new}$) هما الطريقتان اللتان تمثلان أقرب ما يكون للحالة الفعلية لظروف النظام الخلوي.

إن عملية المحاكاة وبتغيير متغيرات التحكم مثل تأثير الخفوت على قدرة الإشارة ، ومعدل قدرة الإشارة ، والتغيير في التخلفية وحد العتبة ، وتأثير حجم النافذة على شدة الإشارة ، وكذلك زيادة الانحراف المعياري والذي يمثل الحالة الأسوأ لخفوت الإشارة.

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1. Introduction:

The challenging needs in a wireless cellular system is good performance in diverse environments. Efficient methods to execute handoff (HO), when mobile stations (MSs) are moving between adjacent cells or in the intended coverage area, otherwise loading increases on the network resulting in calls terminations.

Handoff is the process of changing the channel (frequency, time slot, spreading code, or combination of them) when a mobile station (MS) crosses the boundary of the serving cell and enters a neighboring cell. Handoff is classified in broad categories to: hard handoff (HHO) and soft handoff (SHO). HHO in characterized by "break before make", for which serving channels are released from the serving cell and new channels are allocated from the neighboring cell, SHO is characterized by "make before break" (i.e. two or more cells communicate with a MS) before handoff is executed. HHO is implemented in Global System for Mobile Communication (GSM) , while soft handoff is used in Code Division Multiple Access (CDMA) [1].

In this paper, HHO is investigated.

2. The Mobile Radio Channel:

The mobile channel places fundamental limitation on the performance of wireless communication systems. The radio channels are extremely random and do not offer easy analysis. Modeling the radio channel is the most difficult part of the radio system design and is characterized in a statistical fashion. The channel experiences two effects[1][3]:

- **Short-term Fading:**

This fading is mainly caused by the multipath propagation of radio waves that are reflected or diffracted on obstacles such as buildings, vehicles etc. The transmitted signal reaches the receives with time delay signals and on paths with different lengths. Depending on the phase position of the signals of the individual paths, this results in interference of the received signal at the receiver.

Fades are more or less at fixed locations in a given environment. The distances of fading minima are frequency-dependent at about half a wavelength, thus in GSM 900 at approximately 15 an and GSM 1800 at approximately 8 cm.

- **Long-term Fading:**

This fading is caused by shadowing, such as by buildings, therefore it has a greater distance of occurring in build-up urban areas. In GSM this type of fading occurs at about 12-60 m.

3. Reasons For Handoff (HO):

There are many reasons for HO execution. Usually every MS tries to utilize the radio channel with the best carrier to interference ratio (CIR) by monitoring the signal strength using the MS and the BS of the radio channel. Handoff execution is performed using the BS or the MS by the followings:

- **Radio Link-type HO:**

This handoff occurs due to the mobility of the MS in the coverage area and depends on:

  - Number of MSs in the cell.

- Number of new calls in the cell.
- Number of calls transferred from a serving cell to a neighboring cell due to handoff.
- Number of terminated calls.
- Number of calls transferred to adjacent cells.
- Dwell time in the cell.

- **Network Management HO:**

The network executes handoff in case of imbalance in traffic intensity between neighboring cells and try to achieve the best balance of channels and other resources required between these cells.

- **Service-Related HO:**

It occurs due to degradation in the quality of service (QoS).

4. Problems Encountered With Handoff:

Handoff does not always occurs in the correct and successful way due to the limitations facing this process.

4.1 Ping-Pong Handoff:

It occurs when an MS reaches the boundary of the serving cell and entering the neighboring cell and then returns back to the serving cell [4] [5]. Hysteressis margin (the difference in signal strength level in the neighboring cell and the serving cell at which handoff is initiated), and the average window length are the two basic factors used to avoid ping-pong HO to happen. The effect of ping-pong can be reduced by increasing the hysteresis level to overcome signal fading in shadow region, or using appropriate average window length of the signal to overcome the time the MS spend in a shadow region. Certain limitations must be taken into account:

- The value of high hysteresis will limit the ping-pong happening also the number of handoff executions, but it will increase delay in HO at cells boundaries which is not accepted practically.
- The increase in average window length of signal strength causes handoff to be slow and not executed in the appropriate time resulting in lost call.

It is important to known the averaging window (either rectangular or exponential of variable weights). The ping-pong cannot be avoided completely even when using appropriate variables (average signal strength and hysteresis), but can be reduced to acceptable level.

4.2 Number of Handoff:

Usually microcell radius is about 1 km radius or less is appropriate in urban areas in order to increase system capacity [1] [2]. In such a case the mobile station may cross cell boundaries (depending on MS speed) and therefore many handoff's are needed. Each handoff requires the provision of channels for the MS from the BS the mobile is entering its boundary. This will add an extra burden on the network [5][6] and cause call dropping or handoff failure, also increased number of handoff's requires modified handoff algorithms for a required quality of service (GoS).

4.3 Corner Effect on Handoff:

Mobile stations moving in microcells experience handoff in line of sight (LOS-HO) and non line of sight handoff (NLOS-HO). In the latter case the handoff will be difficult. The problem of MS's moving in microcells is when there is a sudden change at street corners or streets junction. A sudden large drop in signal level (20 to 30 dB) occurs. The corner effect is due to the loss of LOS component from the serving BS to the MS, which demands a faster handoff to a new BS otherwise call dropping occurs.

5. Types of Handoff [8] [6]:

- Network controlled handoff (NCHO): In this type of handoff, the network will decide the handoff by measuring the signal strength at the MS and is performed by the mobile switching center (MSC). This type is used in the 1st generation advance mobile phone service (AMPS).
- Mobile Assisted handoff (MAHO): In this method, the MS perform the signal strength measurements and the mobile switching center (MSC) or the base station controller (BSC) control the handoff.
- Mobile Controlled Handoff (MCHO): The MS completely control and execute the handoff. This method is suitable for microcell system. The method is of the highest degree of decentralization and the benefits of decentralized handoff is the fast decision making. It is used in Digital European Cordless Telephone (DECT).

6. Detection of the Necessity of Handoff:

The need of handoff is specified by the measurement of signal strength or the measurement of carrier to interference ratio (CIR) which is considered as an important value in a cell and at a certain location. Low value of CIR will force to change the use of the present channel between a mobile station and a base station [1]. The mobile radio channel is a fading channel and this makes the initiation of handoff decision difficult. This effect may cause many unnecessary handoff's (e.g. ping-pong), therefore the need of effective, adaptive and fast method for handoff to deal with fast and temporal (i.e. change of radio channel environment) [9]. To deal with such channel environments, the average signal strength is adopted in order to reduce the effect of short term signal fading [3].

Figure (1) illustrates the signal variation of the MS from BS_1, to BS_2. The average signal strength received by the MS from BS1 decay as the MS moves further away from BS1, at the same time the average signal strength received by the MS from BS_2 increases as the MS moves toward BS_2.

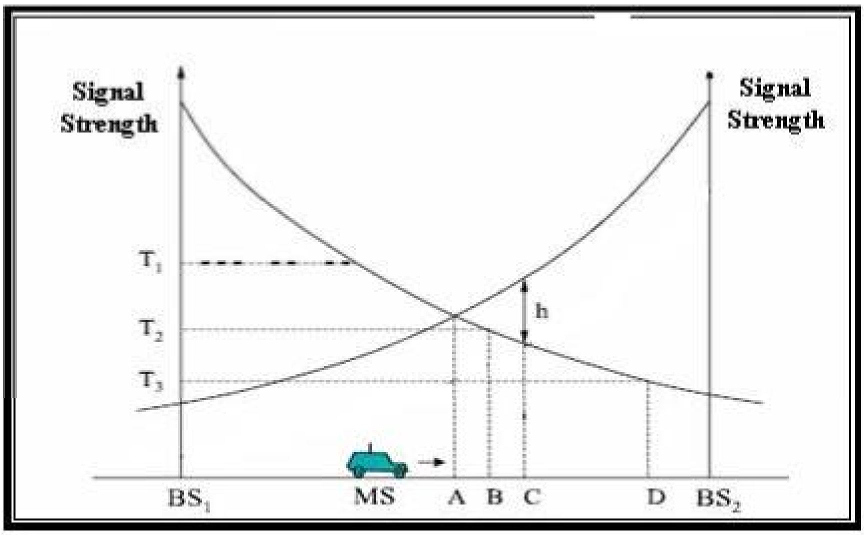

Fig. 1 Received signal strength from two neighboring base stations [Ref. 13].

6.1 Received Signal Strength (RSS):

Handoff occurs when the signal strength of a neighboring base station received by the MS exceeds that from the serving base station [1].

6.2 Received Signal Strength with Threshold (RSS-T):

Handoff occurs when the signal strength of the serving base station is at a level below threshold and the signal strength of the neighboring base station is higher than the signal strength of the serving base station [10].

If the threshold is relatively large as at point T1 in figure 1, the case will be exactly similar to the RSS in section (6.1), and handoff will occur at point A in figure 1. If the threshold is less than that for example at T2 in figure 1, the handoff is delayed until the curve of signal strength intersects the threshold level at point B. If handoff is executed at T3 the delay will be more so the MS will travel large distance in the neighboring cell and MS connection is till with the serving base station, which results in degradation in the quality of connection with BS1 and results in call failure.

6.3 Received Signal Strength with Hysteresis (RSS-H):

Handoff occurs when the signal strength of the neighboring base station is higher than that of the serving base station by a hysteresis value (h) as in figure 1 at point C. This method reduces multiple HO (ping-pong HO), and handoff occurs even when the signal strength of the serving base station is strong enough to serve the MS in that cell, so RSS-H results in unnecessary handoff. To avoid unnecessary handoff the received signal strength with hysteresis and threshold of the serving base station is used.

6.4 Received Signal Strength with Hysteresis and Threshold of Serving BS (RSS-HT_{ser}):

In this case handoff to a new cell occurs only when the level of the received signal by the MS from the serving base station (BS_1) decreases to a level lower than the threshold and the received signal from the new base station BS_2 is higher that from BS_1 by a certain hysteresis as in figure 1 at point D.

6.5 Received Signal Strength with Hysteresis and Threshold of the New BS (RSS-HT_{new}):

An unintentional handoff to the wrong cell may sometimes occurs. To reduce such wrong handoff, handoff is delayed until the received signal strength received by the MS from a neighboring station is of enough value, to achieve the threshold of the intended new base station with the RSS-H algorithm, and this enhances system performance according to the following:

- When choosing a correct threshold for the new BS, this will reduce the number of unnecessary handoffs to the new cell when the cell signal strength is inadequate.
- When threshold value is high and appropriate, the number of unintended handoff, (wrong cell) is lowered.

7. Handoff Performance Parameters:

Handoff is classified into:

- Hard Handoff (HHO) is employed in GSM [1].
- Soft Handoff (SHO) is used in Code Division Multiple Access (CDMA).

In HHO, communication between the serving BS and the MS is disconnected by the serving BS cell before communication between the MS and the neighboring cell BS starts (i.e. communication of the MS is with one BS at a time).

To evaluates the efficiency of handoff operation, it is necessary to define the performance of the measuring parameters of the HHO method [11] which are:

- The number of unnecessary handoff's which occur when the previous connection is of satisfactory performance (no need of handoff).
- The number of unsuccessful handoff that occur in the cell of which the MS receives inadequate signal strength.
- Expected number of handoff: is the number of handoff's which occur when the MS is traveling from serving cell to a neighboring cell.
- Crossover point: is the distance between the MS and the BS of the serving cell at which the probability of connection between the MS and the serving BS becomes 0.5, and at the same time the probability of connection of the MS with the neighboring cell BS reaches 0.5. The crossover point is considered to be an important measure of delay in handoff operation.
- Expected Average Signal Strength (EASS): is the average signal strength of the serving base station and at which the handoff operation is initiated when the MS travel from one cell to another. This parameter is considered as an indication of delayed handoff.
- The effect of window size on the expected average signal strength (EASS).

8. Simulation of Handoff Algorithms:

A two cell mode have been considered in [12] [13].

Considering a three cells model [14] shown in figure 2.

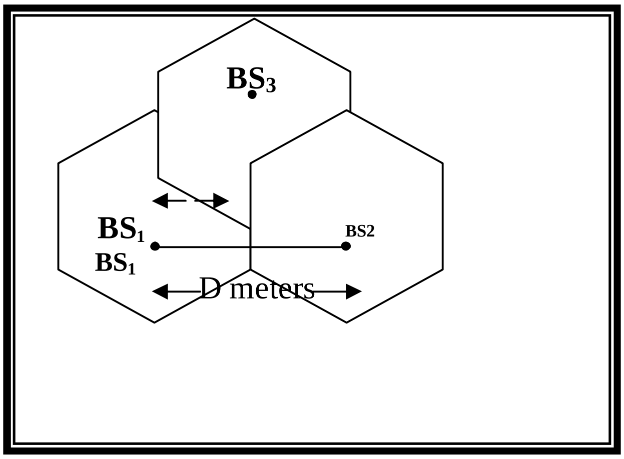

Fig. 2 Three neighboring cells model

The model network has three base stations BS_1, BS_2 and BS_3, the distance between any two cell centers is D meter with the mobile moving at constant speed along the straight line path.

The signal strength received by the MS from the three base stations can be written as:

$$a(d) = k_1 - k_2 \ \mathrm{Log}(d) + u(d) \qquad \ldots (1)$$

$$b(d) = k_1 - k_2 \ \mathrm{Log}(D-d) + v(d) \qquad \ldots (2)$$

$$c(d) = k_1 - k_2 \ \mathrm{Log}\left[\sqrt{\left(\frac{D}{2}-d\right)^2 + \left(\frac{3}{\sqrt{3}}-\frac{D}{2}\right)^2}\right] + w(d) \qquad \ldots (3)$$

Where: a(d), b(d) and c(d) are the received signal strength by the MS (in dB) from BS_1, BS_2 and BS_3 respectively.

D: is the distance between any two cells centers in meters.

d: is the distance moved by the MS from BS_1 towards BS_2 in meters.

k_1: is the signal strength of BS_1 and is taken as 1W (0 dB).

k_2: represent the path loss and is equivalent to ten times the path loss exponent (n) which depends on the propagation environment and take a value ≈ (3 – 4) in urban area.

u(d), v(d) and w(d) represent shadow fading, which follows Log-normal distribution is represented by zero mean, stationary Gaussian random process and of a standard deviation (σ) in dB.

The values of the parameters used in the simulation are assumed as follows:

k_1 = 0 dB, k_2 = 30, D = 2000 m, correlation distance = 20, averaging constant = 30 and a standard deviation representing shadow fading.

The terms u(d), v(d), and w(d) can be generated using white Gaussian noise generator, then passing it to first degree filter [11].

The final equations representing shadow fading terms:

$$u(d) = \sqrt{1/10}\ g_1(d) + \exp(-1/20)\ u(d-1) \qquad \dots (4)$$

$$v(d) = \sqrt{1/10}\ g_2(d) + \exp(-1/20)\ v(d-1) \qquad \dots (5)$$

$$w(d) = \sqrt{1/10}\ g_3(d) + \exp(-1/20)\ w(d-1) \qquad \dots (6)$$

Where g_1 (d), g_2 (d) and g_3 (d) are the signals resulting from the noise generators used for the serving, new wrong cells (BS_1, BS_2 and BS_3) respectively.

Figure 3 represents the received signal strength from BS_1 and BS_2 given by equations 1 and 2.

Figure 4 represents the received signal strength received from BS_3.

Which is given by equation 3.

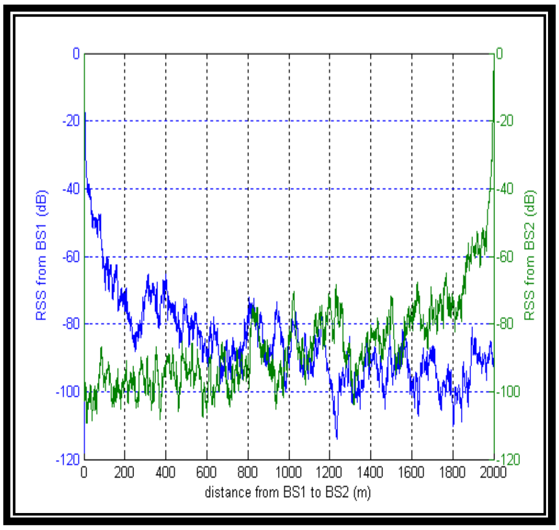

Fig. 3 Received signal from BS_1, and BS_2 with shadow fading.

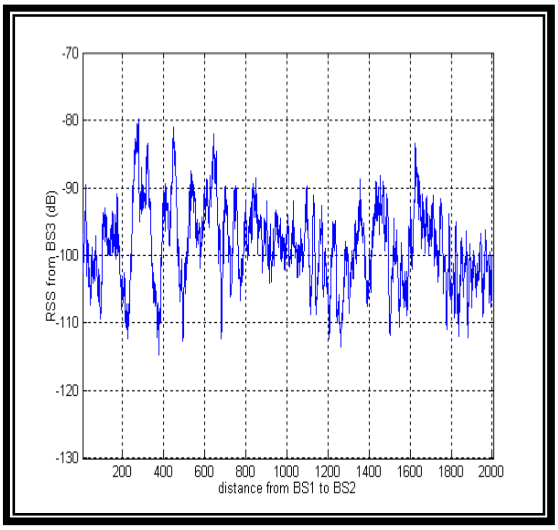

Fig. 4 Received signal strength from BS_3 with shadow fading.

When dealing with random numbers in system's simulation (e.g. generation of random numbers of log-normal distribution as path loss, or exponential distribution to represent duration of a cell … etc.) requires executions of simulation for many times (1000 to 2000) which means increasing the number of iterations and taking the average results to reach the stable state.

Assuming that there is no direct radio waves between the BS and the MS, the probability distribution of the envelop of the composite signals is a Rayleigh distribution, and its probability density function is given by:

$$P(r) = \frac{r}{\sigma^2} e^{\frac{-r^2}{2\sigma^2}} \qquad r > 0 \qquad \ldots (7)$$

Where r is the envelop of the fading signal and σ is the standard deviation. By increasing the value of σ indicates the worsening environment (increased fading) as shown in figure 5.

9. Averaging Process of Signal Strength:

It is well known that taking the average signal strength is an important operation in simulation models in various mobile cellular system. The two fundamental indications in the execution of handoff are the average number of handoff and the delay in handoff [12] and both are affected by taking the average signal strength.

In the handoff algorithm used in this paper, the average signal strength is calculated in accordance with the simulation program from the two basic cells in the RSS-HT_{ser} model (or from the three neighboring cells in the RSS-HT_{new} model) for one meter distance during the movement of the MS from BS_1 location to BS_2 location. The results of this model depends on the distance and not on the MS speed [23].

In the case of practical window, the average signal strength was taken as exponential window representing the process of taking the average signal strength from BS_1, BS_2 and BS_3 as follows [11]:

$$\bar{a}(d) = f(d) \otimes a(d) \qquad \ldots (8)$$

$$\bar{b}(d) = f(d) \otimes b(d) \qquad \ldots (9)$$

$$\bar{c}(d) = f(d) \otimes c(d) \qquad \ldots (10)$$

$$f(d) = \frac{1}{dav} \exp(-d/dav) \qquad \ldots (11)$$

Where $\bar{a}(d), \bar{b}(d), \bar{c}(d)$ are the average signal strength from BS_1, BS_2 and BS_3 respectively. f(d) is the impulse response of the filter used in calculating the average signal strength. dav is the distance constant for the windowing process when taking the average signal strength, it is also called the window size of taking the average signal strength, it is value is taken to be 30 meter and is considered an appropriate value in the simulation model [11-14].

$$\bar{a}(d) = \frac{1}{dav} \int_0^\infty \exp(-x/dav)\ a(d-x)\ dx \qquad \ldots (12)$$

$$\bar{b}(d) = \frac{1}{dav} \int_0^\infty \exp(-x/dav)\ b(d-x)\ dx \qquad \ldots (13)$$

$$\bar{c}(d) = \frac{1}{dav} \int_0^\infty \exp(-x/dav)\ c(d-x)\ dx \qquad \ldots (14)$$

The final equations representing the average signal strength received by BS_1, BS_2 and BS_3 are:

$$\bar{a}(d) = \exp(-1/dav)\ \bar{a}(d-1) + (1-\exp(-1/dav))\ a(d) \qquad \ldots (15)$$

$$\bar{b}(d) = \exp(-1/dav)\ \bar{b}(d-1) + (1-\exp(-1/dav))\ b(d) \qquad \ldots (16)$$

$$\bar{c}(d) = \exp(-1/dav)\ \bar{c}(d-1) + (1-\exp(-1/dav))\ c(d) \qquad \ldots (17)$$

Figure 5 represents the average signal strength from BS_1, BS_2, while figure 6 is the average signal strength received for BS_3.

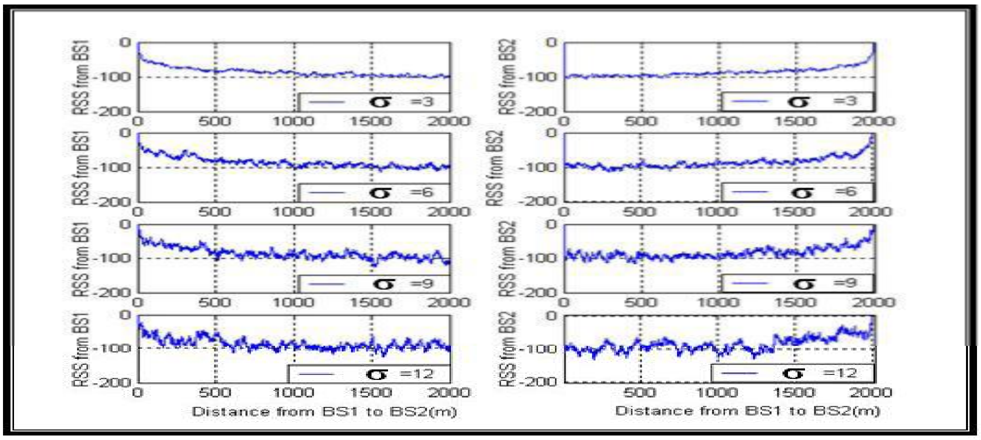

Fig. 5 Received signal strength from BS_1, and BS_2 at different standard deviation (σ) representing shadow fading.

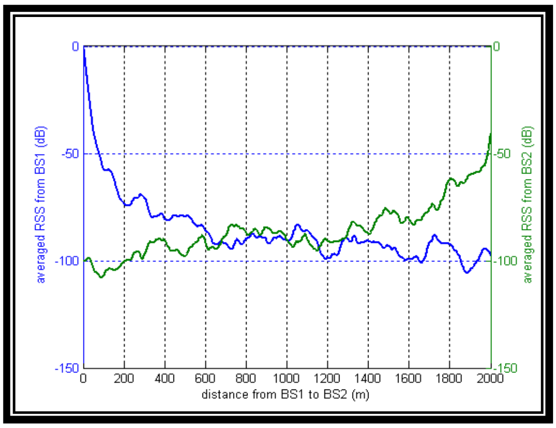

Fig. 6 Average received signal strength from BS_1 and BS_2.

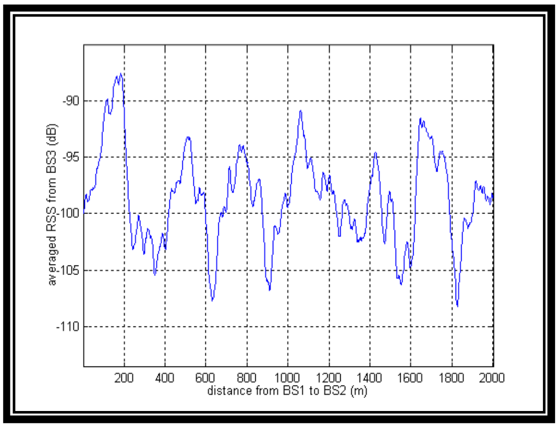

Fig. 7 Average received signal strength from BS_3.

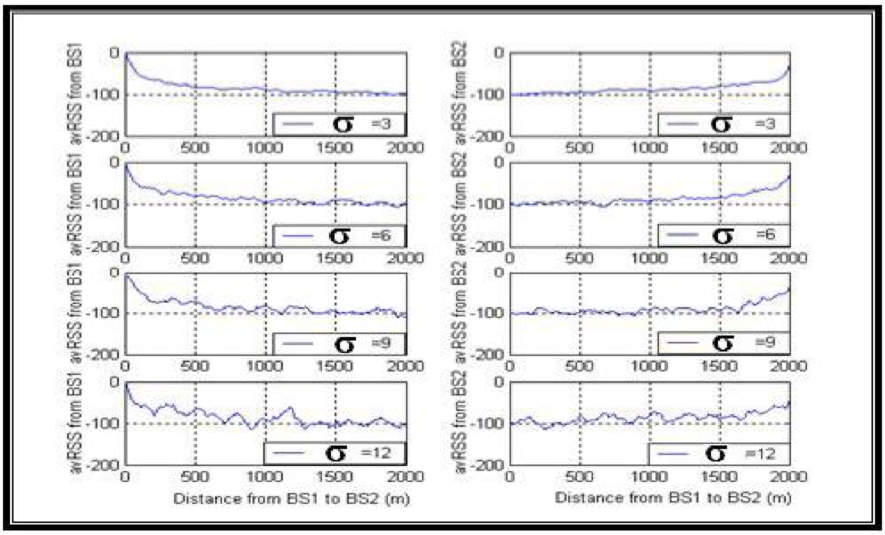

Fig. 8 Average received signal strength from BS_1 and BS_2 at different standard deviation representing shadow fading.

Figure 3 and 6, 4 and 7 show the difference between the average signal strength from BS_1, BS_2 and BS_3 before and after taking the average signal strength also in figures 5 and 8.

10. Simulation Models for Handoff Process:

The methods mentioned in section 6 which are: RSS, RSS-T, RSS-H, RSS-HT_{ser}, RSS-HT_{new} of which the last two [RSS-HT_{ser} and RSS-HT_{new}] are considered in the simulation due to resembling the mobile cellular environment and contain extra constrains in HO.

10.1 RSS-HT_{ser} Model:

This model is explained in section 6.4 and the two cells model (figure 2 without BS_3) is used in the simulation. The signal strength received by the MS for a certain location when moving from BS_1 cell towards BS_2 cell is calculated using equations 1 and 2.

The signals are filtered to calculate the average signal strength in order to reduce the effect of shadow fading on the signal strength. Then comparison is drawn and if the handoff constrains are met the handoff is executed. The operation is repeated as the MS moves to the next location (1 meter distance) from BS_1 to BS_2.

Finally the number of handoff occurrence are calculated from the simulation and then re-executed for large number of times and calculating the number of handoff to exclude the effect of the random variables on the results.

10.2 RSS-HT_{new} Model:

This method assures the reduction of unintentional handoff to the wrong cell. Using the model of three cells instead of two cells model used in RSS-HT_{new} as in figure 2. In this model ping-pong handoff is taken into consideration when HO occurs between BS_1 to BS_2 and BS_3 to BS_1.

11. Comparisons of the RSS-HT_{ser} and RSS-HT_{new} Models:

The comparative performance of the RSS-HT_{ser} and RSS-HT_{new} models in the handoff process some results are presented [11].

Figure 8 represents the variations in average number handoff's versus hysteresis level for the two models. The average number of handoff in the RSS-HT_{new} is less than that in the RSS-HT_{ser}. for the same threshold level of – 85 dB.

Figures 9 to 12 are for constant threshold level of – 85 dB for comparison purpose.
Figure 9 shows the average crossover point versus hysteresis level in the RSS-HT model is higher (longer time delay of HO) than that of RSS-HT_{ser}. Figure 10 represents the relation between crossover point with hysteresis level for RSS-HT_{ser} and RSS-HT_{new}, it shows that the values of crossover periods of RSS-HT_{new} is higher than RSS-HT_{ser} but it is acceptable due to large decrease of the average number of handoff.

Fig. 11 shows comparison between average number of handoff when using exponential and rectangular average signal window, while Fig. 12 shows comparison between call dropping probability when using exponential and rectangular average signal window (dav explained in section 9) and cell dropping probability when using exponential and rectangular window size, which clearly indicate the improved results of the average signal strength using exponential window. In addition, the rectangular window size deals with the signal strength when taking its average with equal weights, while the exponential window deals with the signal strength with different weights. It is clear that the received signal strength versus in level by large amount due to shadow fading and that is why exponential window is used.

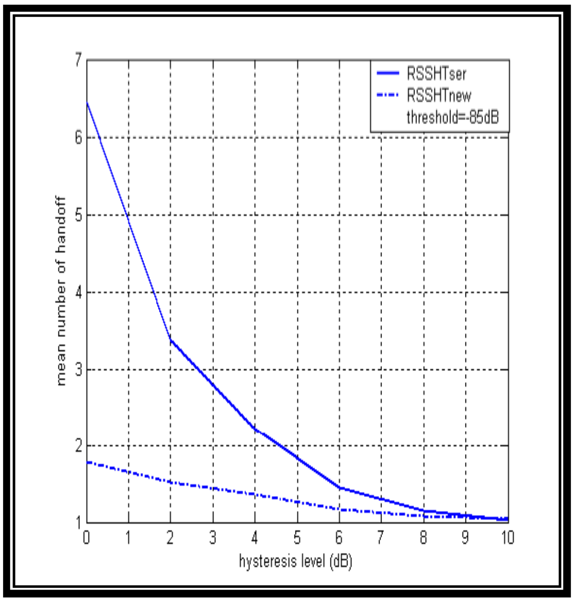

Fig. 9 Average number of handoff versus hysteresis level in the RSS-HT$_{ser}$ and RSS-HT$_{new}$ models.

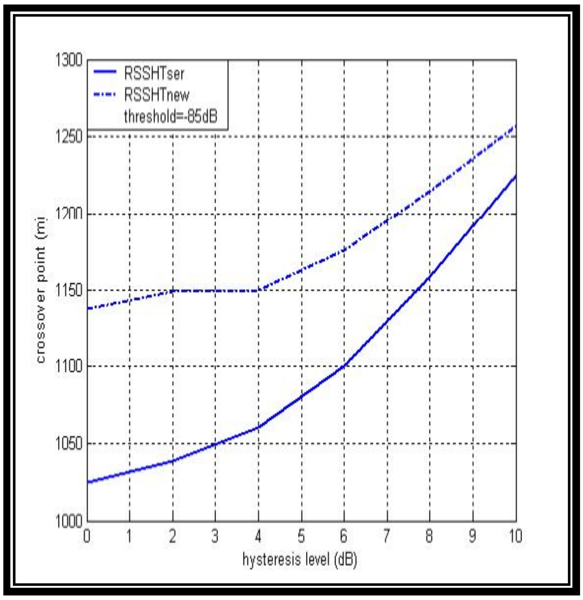

Fig. 10 Crossover point versus hysteresis level in the RSS-HT$_{ser}$ and RSS-HT$_{new}$ models.

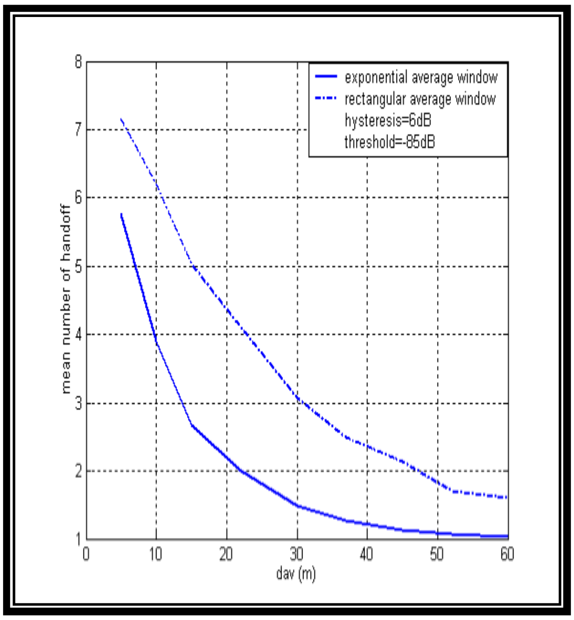

Fig. 11 Comparison between average number of handoff when using exponential and rectangular average signal window.

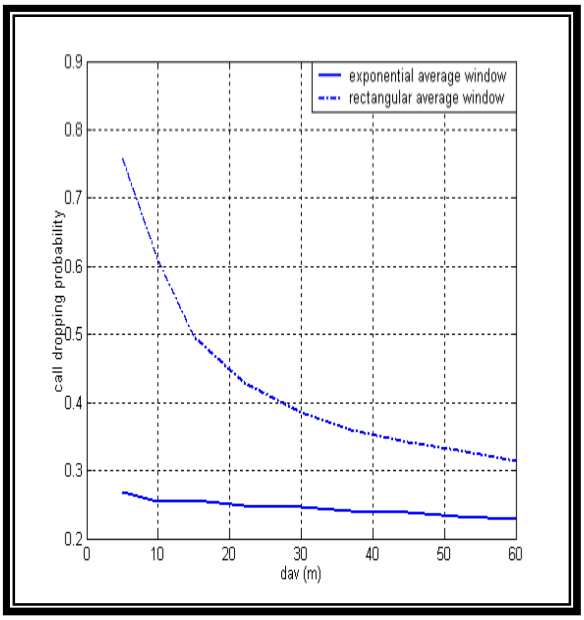

Fig. 12 Compassion between the probability of lost call when using exponential and rectangular average signal window.

12. Conclusions:

From the results obtained the following conclusions can be drawn.

- From the methods of detection of necessary handoff, the use of threshold level for the new cell (RSS-HT$_{new}$ gives less number of handoff for the same hysteresis level and of a constant threshold level but it presents an acceptable delay in the execution of handoff.

- The hysteresis levels used in the simulation model decrease the average number of handoff but on the account of increased delay in handoff.
- The process of taking the average received signal strength from the base stations will decrease the number of handoff by decreasing the effect of shadow fading on signal strength.
- When taking the average signal strength, it is clear that the exponential window gives improved results over rectangular window. Increasing window size results in decrease in the average number of handoff's and decrease in the probability of lost calls (probability of decrease in the received signal level 10 dB below threshold level) and increased delay (increase in crossover points and decrease in EASS values).
- Increasing the values of standard deviation of the shadow fading (worsening of propagation environment will increase the average numbers of handoff and increase the probability of lost calls also causes handoff to occur at crossover points near the boundary of the cells concerned.

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