A Comparative Study on Handoff Algorithms for GSM and CDMA Cellular Networks

S. Neeraja[1], G. Sasibhushana Rao[2]
[1]Department of Electronics and Communication Engineering, Gitam University, India
[2]Department of Electronics and Communication Engineering, Andhra University, India

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ABSTRACT

The GSM, CDMA cellular systems are most trendy 2G and 3G digital cellular telecommunications systems, which is widely used throughout the world. These systems have many advantages such as high security, higher quality of call transmission over the long distances, low transmitted power, and enhanced capacity with more efficient utilization of the frequency spectrum. With these advantages these cellular systems have attracted more subscribers with more attention in the field of mobile communications. One of the most attractive features of cellular system is handoff which is a continuation of an active call when the mobile is moving from one cell to another without disconnecting the call. Usually, continuous service is achieved by efficiently designed handoff algorithms. So, efficient handoff algorithms are necessary for enhancing the capacity and QoS of cellular system. In this paper, the handoff analysis for GSM, CDMA cellular networks are done under various propagation models. Various handoff algorithms of GSM are described and also a novel received signal strength (R_{SS}) based GSM handoff algorithm with adaptive hysteresis is analyzed. CDMA Soft handoff algorithm is analyzed and effective soft handoff parameters are estimated for better performance. The Comparison of handoff algorithms is studied based on results.

Corresponding Author:

S. Neeraja,
Department of Electronics and Communication Engineering,
Gitam University, India.
Email: neeraja413@yahoo.co.in

1. INTRODUCTION

Mobility is the most important feature of a cellular network. In a cellular network, the total geographical area is divided into small cells in order to achieve high system capacity due to limited spectrum. The frequency band is separated without interfering with each other into smaller bands called cells. When the mobile station (MS) is moving, it crosses more number of cells during ongoing call conversations. The active call should be transferred from one cell to another without disconnection. This can be achieved by the handoff.

Handoff is a process of transferring an ongoing active call from one cell to another or from one base station (BS) to another or one channel to another as a user moves through the coverage area of a cellular system. The transfer of current communication channel could be in terms of a time, frequency, code, or combination of these for time-division multiple access (TDMA), frequency-division multiple access (FDMA), code-division multiple access (CDMA), or a hybrid scheme, respectively [1]. Handoff depends on base station’s signal strength with which communication is being made, along with the signal strengths of the surrounding base stations and the availability of channels. The purpose of handoff as follows. Handoff enhances the QoS, reduces traffic, Improves the capacity and also improves the cellular network performance by reducing factors such as the call drop rate and the congestion rate. Tripathi N. D., et al. [1] presented various handoff algorithms. Akhila S. et al.[2] explained handoff decision in GSM and Viterbi A. J., et al. [3] explained soft handoff mechanisum but in the literature comparisions of the adaptive hysteresis based handoff algorithm for GSM and CDMA Soft handoff algorithmare not available. So, in this paper, handoff mechanisums of GSM and CDMA cellular Systems are described and Comparisons of adaptive hysteresis based GSM handoff algorithm and CDMA Soft handoff algorithm are presented and analyzed based on the results.

2. HANDOFF MECHANISM IN GSM AND CDMA

Handoff Mechanisms are two types. They are Hard handoff and Soft handoff.

2.1. Hard Handoff in GSM

A hard handoff in GSM is a "break-before make approach". Hard handoff is the process that breaks connection with source cell and then makes the new connection to the target cell, i.e. the link to the prior BS is terminated, as user is transferred to a new cell's BS [2]. The MS is linked to not more than one BS at any given time. Hard handoff can be seamless or non-seamless. Seamless hard handoff means that the handoff is not perceptible to the user.

2.2. Soft Handoff in CDMA

CDMA came into existence in the telecom world with the inception of 2G IS-95 systems in the mid-nineties [4]. 3G systems such as WCDMA, CDMA 2000 are based on CDMA principle. 2G and 3G CDMA based cellular systems support soft handoff which is "make before break approach". The soft handoff is a mechanism in which the new connection is made first to the next cell and then breaks the old connection i.e. the connection to the target is established before the connection to source is broken [3].

Compared to the traditional hard handoff, soft handoff shows more advantages, such as eliminating the "ping – pong" effect, and smoothening the transmission (there is no break point in soft handoff). No "ping – pong" effect implies lower switching load on the network signaling and with soft handoff, there is no data loss due to the momentary transmission break that happens in hard handoff.

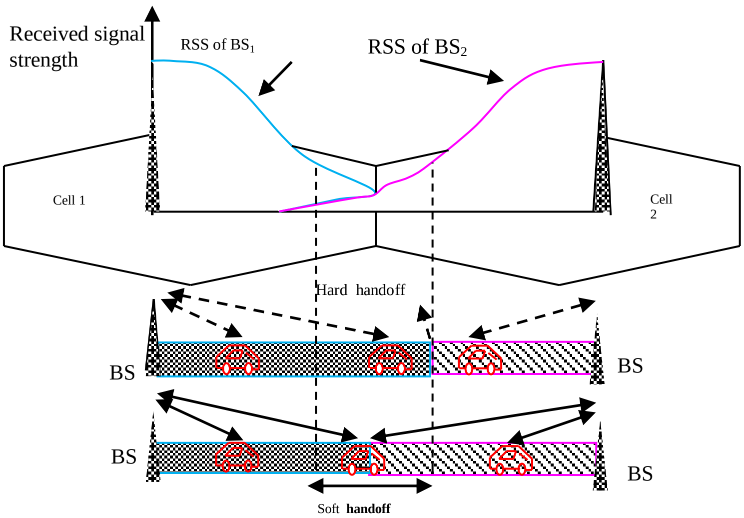

Figure 1. Comparison of Hard Handoff and Soft Handoff

A comparison of both hard handoff and soft handoff is illustrated in the Figure 1. In hard handoff, the mobile station is connected to only one BS at any time based on highest signal strength. Whereas, in soft handoff more than one BS is connected to MS for a certain period of time in soft handoff region and selects the strongest signal among those BSs. Fig. 1 shows that in soft handoff mechanism, the mobile is connected to two BSs where as hard handoff the mobile is connected to only one BS. CDMA cellular systems such as IS-95 use soft handoff, while TDMA cellular systems such as GSM and D-AMPS typically use hard handoff [5].

The comparisons of GSM and CDMA cellular systems are presented in Table 1.

Table 1. Comparisons of GSM and CDMA cellular system

Parameter	GSM	CDMA
handoff	Hard handoff	Soft handoff
Multiple Access Technique	TDMA	CDMA
Type of the System	Band limited	Power limited
Frequency Reuse	Maximum 3,	Maximum1
Frequency Planning	Complicated	Simple
Carrier Frequency	200KHz	1.25MHZ
Multipath Errors	Appears	Eliminated
Spread Spectrum	Not applicable	Applicable
System Capacity	Less	4 to5 times more than GSM

3. HANDOFF ALGORITHMS IN GSM AND CDMA CELLULAR SYSTEMS

Inadequately designed handoff schemes are tend to generate very heavy signaling traffic thereby, a significant decrease in quality of service (QoS). A well-organized handoff algorithm is needed to improve the QoS. Received Signal Strength (R_{SS}) is the most commonly used criteria for handoff analysis.

Hard Handoff algorithms used in GSM are:

a. R_{SS} based handoff algorithm
b. R_{SS} based handoff algorithm with Threshold
c. R_{SS} based handoff algorithm with hysteresis
d. A novel R_{SS} based GSM handoff algorithm with Adaptive hysteresis

In cellularand mobile systems the obstacles between the BS and the MS significantly influences the strength of the mobile signal. The attenuation of the radio signal is referred as path loss [6]. Received signal strength at user terminal is varied by the pathloss. In GSM cellular systems, path loss is the evaluated using Okumura-Hata model.

Pathloss for Okumura-Hata model is given [7] as,

For mobile to BS_1:

$$L1(dB) = 69.55 + 26.16\log(f) - 13.82\log(h_{b1}) - a(h_m) + (44.9 - 6.55\log(h_{b1}))\log(d) \quad (1)$$

For mobile to BS_2:

$$L2(dB) = 69.55 + 26.16\log(f) - 13.82\log(h_{b2}) - a(h_m) + (44.9 - 6.55\log(h_{b2}))\log(D_c - d) \quad (2)$$

L1, L2 = total path loss in dB using HATA‘s model for BS_1 and BS_2 respectively,
f = frequency of the carrier, 900 MHz
h_{b1}, h_{b2} = 35m =Transmitter antenna heights for BS_1 and BS_2
h_m = 1.5m=Effective Receiver (Mobile) antenna height
D_c = =2000 m=.distance between BS_1 and BS_2
d = distance of BS_1 to MS in Km
D_c-d = distance of MS to BS_2 in Km
a (h_m)= correction factor in dB for effective receiver (mobile) antenna height and it is given by

$$a(h_m) = [1.1\log(f) - 0.7]h_m - [1.56\log(f) - 0.8] \quad (3)$$

For the Okumura - Hata model, the received signal strength due to BS_1 located at a distance of d from the mobile station is,

$$R_{SS}1 = Pt - L1 \quad (4)$$

And the received power due to BS_2 located at a distance of D_c-d from the Mobile Station is,

$$R_{SS}2 = Pt - L2 \quad (5)$$

where,

Pt= Transmitted power from BS_1 and BS_2=43 dBm =13 dB
$R_{SS}1$ and $R_{SS}2$ are the Received Signal Strengths of mobile from BS_1 and BS_2.

3.1. GSM Handoff Algorithms

Figure 2 shows the two cell model.

a. R_{SS} bBsed Handoff Algorithm

In this, the received signal strengths of two base stations are compared and when the R_{SS} of BS_1 is less than the R_{SS} of BS_2 then the call is handover to BS_2 otherwise the mobile station is in connection with the BS_1.

A main problem with this approach is that the R_{SS} of both base stations are equal at the boundary then if the mobile is moving and cause the mobile to rapidly switch links with either base station. The base stations bounce the link with the mobile back and forth. This event is called ping- ponging [8]. Due to this effect, several handoffs can be requested while BS_1's R_{SS} is still sufficient to serve mobile unit to cause unnecessary handoffs. To avoid unnecessary handoffs, a better method is to use the averaged signal levels relative to a threshold and hysteresis margin for handoff initiation.

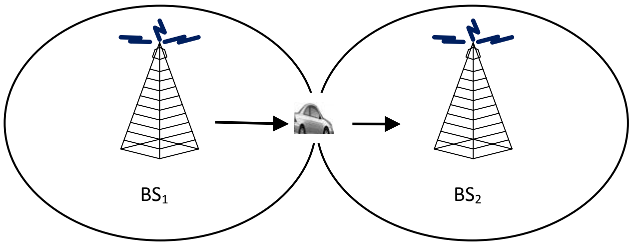

Figure 2. Cellular System Model

b. R_{SS} Based Handoff with Threshold

In this, R_{SS} of BS_1 is less than the threshold value and R_{SS} of BS_1 is less than the BS_2 the handoff is made to BS_2 otherwise there is no handoff and MS still in connection with the BS_1. In this technique the "ping – pong effect" avoided but still unnecessary handoffs are presented because BS_1's signal strengths still satisfactory for continuing the call [9].

c. R_{SS} Based Handoff Algorithm with Hysteresis

In this, when the R_{SS} of BS_2 more the BS_1 with hysteresis then call handoff to the BS_2 otherwise it is connected to BS_1. It minimizes the unnecessary handoffs [10]. This method hysteresis is fixed that means the hysteresis value is either small or large. If hysteresis is large causes more burden on the network and delay increases. Otherwise, with smaller hysteresis, more unnecessary handoffs are occurred. To avoid this adaptive hysteresis based handoff algorithm is proposed.

d. R_{SS} Based GSM Handoff Algorithm with Adaptive Hysteresis

In fixed hysteresis method, if hysteresis (H) is too small, numerous unnecessary handoffs may be processed, increasing the network burden. However, if H is too large, the long handoff delay may result in a dropped-call or low QoS. A tradeoff exists between these two conflicting performance measures. For optimizing handoff performance adaptive hysteresis is used. As a result, the main objectives of adaptive handoff algorithm are to: preventing unnecessary handoffs, handoff delay minimized, reducing the system interference level, improves call quality during handoff.

For this model the adaptive hysteresis is given by,

$$Adaptive\ h = \max\left\{20\left(1-\left(\frac{d}{R}\right)^4\right),0\right\} \tag{6}$$

Where, the distance between the MS and serving BS is d, and radius of the cell is R [11].

For a hexagonal cell $R = \frac{D_c}{\sqrt{3}}$, where the distance between two base stations is D_c. The coefficient 20 determines the range of h and the exponent 4 determines its shape. The coefficient is chosen to be 20 to enable the handoff algorithm to control unnecessary handoffs and react to the deep fading simultaneously, resulting in sudden drop (20–30 dB) of R_{SS}. Adaptive h decreases from 20 to 0 dB that is the MS moves away from the serving BS. In setting the above adaptive hysteresis value h, the number of unnecessary handoff is decreased. Because of a large h, if the MS is near the serving BS and the MS are encouraged to hand over to adjacent cells and because of a small h if it is near the boundary of the current cell. In this way, the handoff area is optimized. Figure 3 shows the R_{SS} based handoff algorithm with adaptive hysteresis.

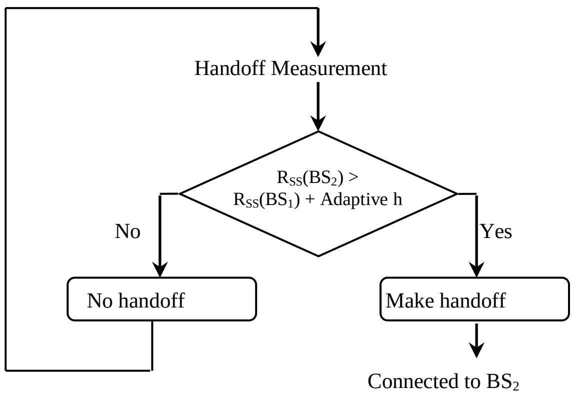

Figure 3. R_{SS} based GSM handoff algorithm with Adaptive Hysteresis

In this when the R_{SS} of BS2 is higher than R_{SS} of BS_1 with adaptive hysteresis value h, the call is handover to BS_2 otherwise it maintains the current connection with BS_1. This adaptive handoff algorithm is developed by dynamically determining the hysteresis value as a function of the distance between the MS and the serving BS. Since the handoff hysteresis value is varied based on MS's location, it can intelligently reduce the probability of unnecessary handoffs and maintain the QoS.

3.2. R_{SS} Based Soft Handoff Algorithm in CDMA

CDMA systems support the soft handoff process. Active set is defined as the set of base stations to which the Mobile Station (MS) is simultaneously connected. In soft handoff region, MS is connected with more than one base station. Initially when MS is very near to BS, the active set consists of only one BS but as distance from BS1 increases and when soft handoff region starts then active set size changes with distance.

The primary objective of a soft handoff algorithm is to provide good signal quality. Signal quality can be improved by including more base stations in the active set, but this comes at the cost of increased use of system resources. For minimizing the active set size, one alternative is to frequently update the active set at each time instant, to maintain the smallest active set with sufficient signal quality. However, frequent updates or handoffs bring switching costs with them. A soft handover algorithm is implemented to maintain the user's active set. The following parameters are needed to describe the soft handoff algorithm which is shown in Figure 4.

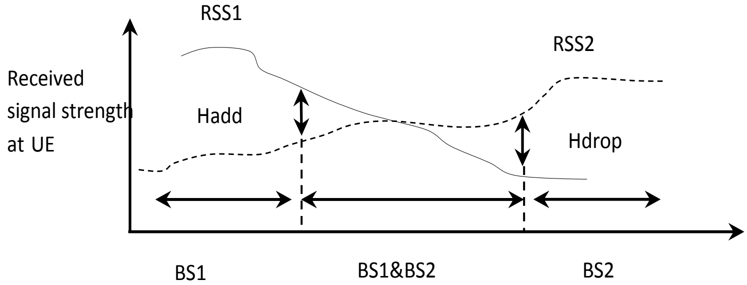

Figure 4. R_{SS} Based Soft Handoff Algorithm

a. Hadd: Hysteresis for adding
   Hdrop: Hysteresis for dropping
b. $R_{SS}1$: Received Signal Strength from BS1
   $R_{SS}2$: Received Signal Strength from BS2

Hysteresis add, determines the received signal strength level for which qualifying BSs are added to the active set, whereas a hysteresis drop, determines when the weak BSs are dropped from the active set.

R_{SS} based CDMA Handoff Algorithm:
Active set is reorganized in following manner,

a. If active set consists of BS_1 and $R_{SS}1>R_{SS}2$ and $|R_{SS}1-R_{SS}2|$ is greater than Hadd
b. then active set consists of BS_1 itself.
c. If $\left|(R_{SS}1-R_{SS}2)\right|<Hadd$, active set consist of BS1 and BS2.
d. If active set consists of BS_1 and BS_2 and $|(R_{SS}1-R_{SS}2|$ becomes greater than or equal to Hdrop, active set consist of that base station whose average signal strength is higher. Base station with smaller signal strength will be dropped from the active set.

The soft handoff distance is the difference between the distance at which Hadd started and the distance at which Hdrop assigned. The soft handoff distance is a pointer of how long a soft handoff will take place. The soft handoff distance and Hadd and Hdrop are very important parameters in determining system performance and need to be carefully optimized for a given situation.
Received signal strength at Mobile station is calculated based on the path loss. In CDMA cellular systems, path loss is the evaluated using Cost 231 Hata model [12].
COST-231 Hata Model
For CDMA and WCDMA cellular systems, the Cost 231 model is most suitable for estimating the path loss and R_{SS}. According to this model, the path loss in urban areas is given by,
Path loss for MS to BS_1:

$$L1(dB)=46.33+33.9\log(f)-13.82\log(h_{b1})-a(h_m)+[44.9-6.55\log(h_{b1})]\log(d) \quad (7)$$

$$L2(dB)=46.33+33.9\log(f)-13.82\log(h_{b2})-a(h_m)+[44.9-6.55\log(h_{b2})]\log(D_c-d) \quad (8)$$

$$a(h_m)\text{in dB}=[1.1\log(f)-0.7]h_m-[1.56\log(f)-0.8] \quad (9)$$

L1, L2 = total path loss in dB using Cost 231 model for BS_1 and BS_2 respectively
h_{b1}, h_{b2}= Height of the base station in meters, 30m to 200m
h_m= Height of the mobile station in meters, 1m to 10m
f= 1800 MHz= frequency of the carrier in MHz
d = Distance between base station and mobile station in kilometers, 1Km to 2Km
D_c=2000m= distance between two base stations
Pt= Transmitter Power =43 dBm =13 dB
The R_{SS} from BS_1

$$R_{SS}1=Pt-L1 \quad (10)$$

Received signal strength from BS_2

$$R_{SS}2=Pt-L2 \quad (11)$$

4. RESULTS AND ANALYSIS

Figure 5 shows the received signal strength variations with adaptive hysteresis values. In this method, the hysteresis values are not fixed for call handling instead dynamic hysteresis values are obtained depending upon the distance of the MS from the current BS. It avoids the ping – pong effect and delay is nearly 120 m and the cross over point is also observed at a distance of less than 1200 m. The corresponding values are tabulated in Table 2.

In adaptive hysteresis method, the cross over point occurs at 1188m. That means the actual handoff is delayed and occurred 188m far than the BS_1. At that point the signal strength is -115dB.The signal strength of BS_1 is utilized maximum extent even the mobile is BS_2.That means it avoids unnecessary handoff meanwhile the BS_2 is free for activating any new mobile. In the R_{SS} based handoff algorithm, the handoff occurs exactly at 1000m. At this point BS1 signal strength is -112.478. At this point “Ping-Pong effect” occurs. Even though by adding threshold and fixed hysteresis values, the unnecessary handoffs are more. So, R_{SS} based GSM handoff algorithm with adaptive hysteresis is the best method because there is no need to select the hysteresis value but those are dynamically assigned based on the MS distance.

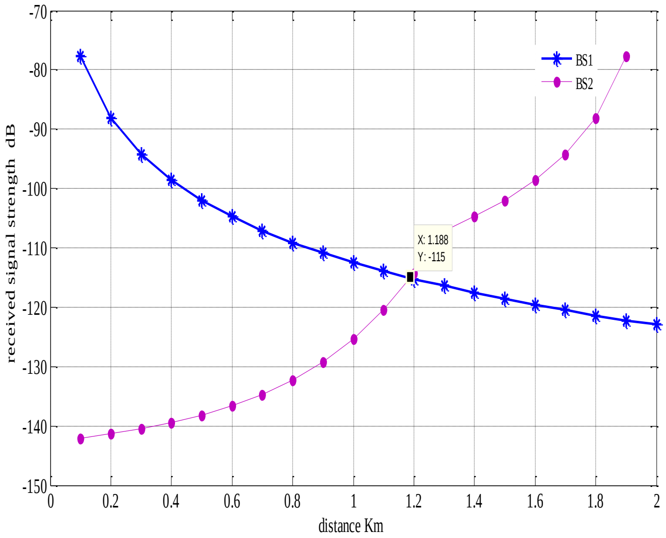

Figure 5. R_{SS} based GSM Handoff Algorithm with Adaptive Hysteresis Method

Table 2. Variation of R_{SS} of BS1 and BS2 with adaptive hysteresis

S.No	BS_1 to MS distance ,d(m)	MS to BS_2 distannce,D_c-d(m)	Adaptive Hysteresis(h)	$R_{SS}1$(dB)	$R_{SS}2$(dB)
1	100	1900	19.999	-77.691	-142.174
2	200	1800	19.988	-88.163	-141.346
4	400	1600	19.816	-98.635	-139.395
6	600	1400	19.072	-104.760	-136.633
8	800	1200	17.067	-109.106	-132.300
10	1000	1000	12.840	-112.478	-125.318
11	1100	900	9.518	-113.917	-120.404
12	1200	800	5.154	-115.232	-114.261
13	1300	700	0	-116.441	-107.089
14	1400	600	0	-117.561	-104.760
16	1600	400	0	-119.578	-98.635
18	1800	200	0	-121.358	-88.163
19	1900	100	0	-122.174	-77.691

4.1. R_{SS} Based CDMA Soft Handoff Algorithm

Figure 6 shows various Hadd and Hdrop values which are indicated by different colours. From the figure it is observed that if Hadd and Hdrop are at 12 dB, the soft handoff distance is more and if Hadd and Hdrop values are at 2 dB the soft handoff distance is less. As Hadd and Hdrop are increased, SHD increases rapidly. Large SHD increases forward interference and hence capacity decreases. Very small SHD may increase probability of outage. Therefore Hdrop should neither be very large nor very small. The Table indicates how the soft handoff distance (SHD) varies with different Hadd and Hdrop values and the R_{SS} at handoff.

Table 3 represents that the received signal strengths, call quality observations for different values of soft handoff parameters (Hadd, Hdrop). If Hadd and Hdrop are at 12dB, the R_{SS} during handoff is found to be -85 dBm and handoff distance is very large which 740 m is. The signal strength is still sufficient to maintain the call. Also for a fixed hysteresis add and variable hysteresis drop also the soft handoff distance increases and vice versa. Large hysteresis add and drop values create large SHD which results in increase of downlink interference. As the soft handoff distance decreases, the uplink interference increases because uplink interference properties of soft handoff reduce. So, the design of soft handoff parameters is very important for improving the quality of service. From this Table 3 it is observed that the hysteresis and, hysteresis drop values from 3dB to 5dB range can give optimum performance with moderate soft handoff distance.

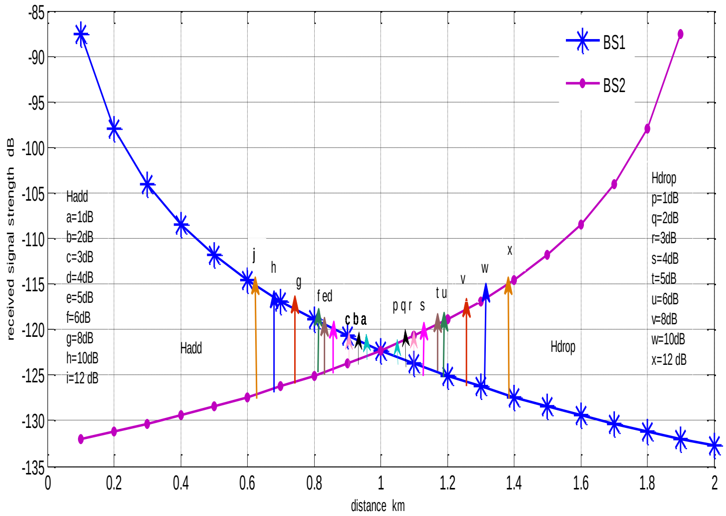

Figure 6. R_{SS} based Soft handoff algorithm at different Hadd and Hdrop values

Table 3. Soft handoff algorithm at different Hadd and Hdrop and its observations

Hadd (dB)	Hdrop (dB)	SHD (m)	R_{SS} at handoff (dBm)	Result
12	12	740	-85	QOS very good but very large SHD
10	10	640	-86.5	QOS very good but very large SHD
8	8	520	-87.8	QOS good but large SHD
6	6	390	-89	QOS good but large SHD
5	5	320	-89.6	QOS good but moderate SHD
4	4	270	-90	QOS good but medium SHD
3	3	200	-90.7	QOS better but medium SHD
2	2	140	-91.1	QOS degrading but minimum SHD
1	1	70	-91.7	QOS degrading but very less SHD
6	4	335	-90.2	QOS good but large SHD
4	6	335	-90.2	QOS good but large SHD

4.2. Comparison of GSM and CDMA Algorithms

In GSM the carrier frequency is considered as 900MHz and using adaptive hysteresis method handoff is observed at -115dB. Whereas CDMA is operated at 1800MHz and based on R_{SS} based CDMA soft handoff algorithm the soft handoff parameters Hadd and Hdrop are in the range 3dB to 5dB and R_{SS} at handoff in the range of -119.6dB to -120.7dB that is equal to -89.6dBm to -90.7dBm. The signal strength of BS1 is efficiently utilized in CDMA compared to GSM which avoids unnecessary handoffs and system capacity also increases with QoS.

5. CONCLUSIONS

The GSM and CDMA technologies are popular 2G/3G digital cellular system technologies. In this paper, the R_{SS} based GSM handoff algorithm with adaptive hysteresis and R_{SS} based CDMA handoff algorithm performance are compared with the results. In adaptive hysteresis method, the cross over point occurs at 1188m. At that point the signal strength is -115dB. The GSM adaptive hysteresis based handoff algorithm minimizes the unnecessary handoffs and also optimizes the handoff area by reducing handoff delay. Due to this, the call quality improves which increases the performance of the GSM cellular system. Based on R_{SS} based CDMA soft handoff algorithm the optimum Hadd and Hdrop are in the range of 3 dB to 5dB for obtaining the best QoS which improves the performance of CDMA cellular system. By comparing GSM and CDMA handoff algorithms, soft handoff in CDMA is the best technique which reduces the unnecessary handoffs because of maximum utilization of available BS power i.e handadoff occurs at the received signal strength -119.6dB to -120.7dB. Due to this, soft handoff CDMA cellular systems capacity 4 to 5 times more than GSM and also provides best QoS.

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BIOGRAPHY OF AUTHORS

S. Neeraja is currently working as a Assistant Professor in the Department of Electronics and Communications Engineering, Gitam University. She received her Ph.D degree from Andhra University in the year 2013. She has over 10 years of Teaching Experience.She has published more than 30 research papers in various reputed International/National journals/Conferences. Her area of Intereset is Cellular and Mobile communications, Wireless Sensor Networks.

Gottapu Sasi Bhushana Rao is presently working as a Professor in the Department of Electronics and Communication Engineering, Andhra University, College of Engineering, Visakhapatnam. He has over 29 years of experience in Industry, R&D and Teaching. He has published more than 335 research papers in various reputed International/National journals/Conferences. He is Senior member of IEEE, FIETE, I EEE com Society, IGU and International Global Navigation Satellite System (IGNSS), Austalia. He is also the Chartered Engineer for IETE. His area of research includes GPS/INS Signal Processing, Cellular/mobile communications, RADAR, SONAR and Acoustic signal modeling. He Received "Dr.Survepalli Radha Krishna Award for Best Academician" in the year 2008 and Best Researcher Award"from Andhra University,Visakhapatnam during 75th Convocation Platinum Jubilee Celebrations-2008. He has Completed 5 research projects and 2 under progress. He is also Chief Editor of the Journal of Commmunications, Navigation and Signal processing, Andhra university, College of Engg., Editor of the Journal of Positiong (PoS), USA.