Soft Handoff Parameters Evaluation in Downlink WCDMA System

A. A. AL-DOURI
Electrical Engineering Department
Tikrit University

S. A. MAWJOUD
Electrical Engineering Department
Mosul University

Abstract

Mobility is an essential feature of mobile wireless communication systems. Handoff is a feature that deals with the mobility of the user in order to provide seamless phone call when the user cross the cell borders to another one. WCDMA system is the third generation system, implements soft handoff (SHO) technique while hard handoff (HHO) which is used in GSM system. Soft handoff is a technique which allows the user equipment in the overlap region to link with two or more base stations. The effect of soft handoff on the downlink direction of WCDMA will be studied because the downlink is considered as the limiting parameter in CDMA systems. The effect of soft handoff on the most important parameters of the downlink in WCDMA is investigated using simulation. Other related parameters of WCDMA system optimization such as load factor, noise rise, and parameters related to the quality of service like bit error rate (BER) are investigated. The results reveal that a user in soft handoff consumes less power from its serving base station. This reduction in the power leads to reducing the total interference in the cell and hence improving the performance of WCDMA system by reducing the load factor (loading) and noise rise, and increasing the capacity and enhancing the quality of service. Furthermore , the results assure why 2-way soft handoff is commonly used in CDMA system.

Keywords: Mobile System, WCDMA, Handoff, Soft Handoff, Load Factor, BER

تقويم تأثير المتغيرات في المناقلة السلسة في الاتصال النازل لنظام WCDMA

عبد المطلب عبد الوهاب الدوري
قسم الهندسة الكهربائية
جامعة تكريت

قسم الهندسة الكهربائية

المستخلص:

من مميزات نظم الاتصالات المتنقلة هي قابلية الحركة مع ادامة الاتصال. عملية المناقلة هي خاصية ادامة الاتصال عند انتقال المحطة المتنقلة من خلية الى خلية اخرى مجاورة وهكذا لكل منطقة التغطية المعنية. ان نظام الـ WCDMA هو نظام الجيل الثالث ويستخدم تقنية المناقلة السلسة (SHO) بينما نظام الجيل الثاني الـ GSM يستخدم تقنية المناقلة غير السلسة (HHO). في تقنية المناقلة غير السلسة يتم اتصال المستخدم(MS) في منطقة التراكب overlap بمحطتين اساسيتين(BSs) متجاورتين في نفس الوقت. ان تاثير المناقلة السلسة على الاتصال النازل (من المحطة الاساس الى المحطة المتنقلة) لنظام الـ WCDMA يعتبر عامل محدد في نظام CDMA. ان تاثير المناقلة السلسة على اهم العوامل المؤثرة على الاتصال النازل في نظام الـ WCDMA تم دراستها باستخدام المحاكاة. ان العوامل التي تؤثر على امثلية النظام كعامل الحمل، ارتفاع الضوضاء وكذلك العوامل التي لها علاقة بجودة الخدمة مثل معدل الخطأ في البتات. ان النتائج التي تم الحصول عليها تشير بان المستخدم في المناقلة السلسة يستهلك قدرة اقل من المحطة الاساسية الخادمة. ان تقليل القدرة المستخدمة يؤدي الى تقليل التداخل الكلي داخل الخلية ومن ثم يحسن اداء نظام الـ WCDMA وذلك بتقليل عامل الحمل وارتفاع الضوضاء وزيادة السعة وتحسين جودة الخدمة. ان النتائج قد اكدت اسباب الاستخدام المعتاد للمناقلة السلسة بين محطتين اساسيتين فقط في نظام الـ CDMA.

1. Introduction:

The last two decades has encountered enormous development in mobile radio communication. The developments started from the first generation (1G) analog system to the second generation (2G) digital system. While 1G can support voice service only, 2G provides voice service as well as low bit rate data service. The demand for multimedia and high data rate services has led to the development of the third generation (3G) system, which uses the wideband code division multiple access (WCDMA), a technique which allows to support high data rate services. One of the attractions of cellular systems is the handoff technique. It means that a mobile station (MS) can maintain its connection in cellular networks when it moves from one cell to another adjacent cell. Soft handoff (SHO) is a unique feature in WCDMA system, which is a smooth transition from one cell to another. Frequency reuse of one in CDMA makes it possible for a user at the cell borders to communicate simultaneously with two or more base stations. A user in the soft handoff zone establishes a new link before dropping the old link with the serving base station (BS). The MS combines the received signals from all base stations involved in the soft handoff operation in order to strengthen the received signal and consequently enhancing the performance of the system[1][2][3]. The bit error rate (BER), which is a parameter related to the quality of service (QoS), refers to the information bit error rate i.e. for user bits after decoding, the BER is given as a function of the measured signal-to-interference ratio(E_b/I_o)[4]. For voice the target value is 10^{-4}-10^{-3}[5]

In [6], the effect of soft and softer handoff on the CDMA system capacity was evaluated according to the average bit energy to interference power spectral density (Eb/Io) which corresponds to bit error rate (BER) of 10^{-3}. While in [7]Soft handoff gain in WCDMA was estimated and the results revealed that soft handoff improves the capacity of the system while keeping the same quality of service. Downlink soft handoff performance in WCDMA was studied in [8] and the results led to that 2-way soft handoff reduces the required dedicated transmission power up to 3dB, moreover, soft handoff gain has better value at soft handoff overhead equal to 30% . In [9] the impact of soft handoff on the UMTS system performance is investigated, and the results approved that in downlink, soft handoff improves not only the quality of service but also the overall system capacity.

2. Mobile Radio Environment and Propagation Model:

The propagation model used is introduced in [10] is modeled as a product of two components, the path loss and the shadowing attenuation.

Equation (1) represents the path loss as a function of the distance (r) and shadow fading ( ):

$$L(r,) = r^a . 10^{/10} \tag{1}$$

Where "a" is the path loss exponent (2< a <6) with typical value of 4 in urban area[2], " " is the attention in decibel due to shadowing which is a log-normal random variable with zero mean and standard deviation " " with typical value of 8 dB [3].

$$L(r,) = 10\ a\ \log(r) + \qquad (dB) \tag{2}$$

3. System Scenario

The system scenario used consists of seven-cell hexagonal grid, as shown in figure(1). There is one serving BS at the center and surrounded by six interfering BSs (first tire). The shaded area represents the soft handoff region and the remaining is known as the non-soft handoff region.
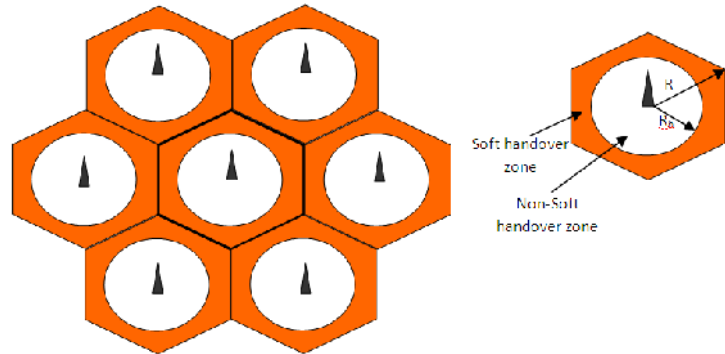

Figure (1) System scenario

4. Downlink Mathematical Analysis in WCDMA:

4.1 Analysis without SHO:

The downlink analysis starts from the common following equation [3]:

$$\left(\frac{E_b}{I_o}\right)_i = Processing\ gain\ of\ user\ i\ \frac{signal\ of\ user\ i}{Total\ received\ power\ (excl.\ own\ signal)} \tag{3}$$

$$\left(\frac{E_b}{I_o}\right)_i = \frac{W}{vR_b} \frac{\frac{P_{i1}}{L_{i1}}}{\frac{Pt_1(1-\alpha)}{L_{i1}} + \sum_{j=2}^{7} \frac{Pt_j}{L_{ij}} + P_N} \tag{4}$$

Where $\left(\frac{E_b}{I_o}\right)_i$ is the bit energy to interference power spectral density for user i , W is the chip rate = 3.84 Mcps , R_b is the bit rate for user i. It depends on the type of service, v is the activity factor, P_{i1} is the required transmit power at BS_1 allocated for user i, Pt_1 is the total transmits power of the serving base station (BS_1), Pt_j is the total transmit power of interfering base stations (BS_j) and 2 ≤ j ≤ 7, L_{i1} is the propagation loss between BS_1 and user i, L_{ij} is the propagation loss between BS_j and user i, is the orthogonality factor, and P_N is the background noise power at the receiver.

The noise power P_N is assumed negligible compared with the total interference power[3] and P_{i1} can be resolved as follows:

$$P_{i1} = \frac{vR_b}{W}\left(\frac{E_b}{I_o}\right)_i \left| Pt_i(1-\alpha) + \sum_{j=2}^{7} Pt_j \frac{L_{i1}}{L_{ij}} \right| \tag{5}$$

Assuming that all users have the same bit rate and all base stations transmit the same power level ($Pt_1 = Pt_j = Pt$), then

$$P_{i1} = \frac{vR_b}{W}\left(\frac{E_b}{I_o}\right)_i Pt\left[(1-\alpha) + \sum_{j=2}^{7}\frac{L_{i1}}{L_{ij}}\right] \tag{6}$$

A part of the total power of the base station is dedicated for the common pilot channel P_{CPICH} and the other part is dedicated for all users in the cell[3].

$$\sum_{i=1}^{I} P_{i1} + P_{CPICH} = \frac{vR_b}{W}\left(\frac{E_b}{I_o}\right)Pt\sum_{i=1}^{I}\left[1-\alpha+\sum_{j=2}^{7}\frac{L_{i1}}{L_{ij}}\right] + P_{CPICH}$$
$$= Pt \tag{7}$$

$$P_{CPICH} = Pt\left(1 - \frac{vR_b}{W}\left(\frac{E_b}{I_o}\right)\sum_{i=1}^{I}\left[1-\alpha+\sum_{j=2}^{7}\frac{L_{i1}}{L_{ij}}\right]\right) \tag{8}$$

where I is the number of users (connections) in the cell. The power(noise) rise over the common pilot channels can be solved as follows:

$$NR = \frac{Pt}{P_{CPICH}} = \frac{1}{1 - \frac{vR_b}{W}\left(\frac{E_b}{I_o}\right)\sum_{i=1}^{I}\left[1-\alpha+\sum_{j=2}^{7}\frac{L_{i1}}{L_{ij}}\right]} = \frac{1}{1-\eta_{DL}} \tag{9}$$

$$\eta_{DL\_noSHO} = \frac{vR_b}{W}\left(\frac{E_b}{I_o}\right)\sum_{i=1}^{I}\left[1-\alpha+\sum_{j=2}^{7}\frac{L_{i1}}{L_{ij}}\right] \tag{10}$$

$$NR\ (dB) = -10\log(1-\eta_{DL}) \tag{11}$$

4.2. Analysis with SHO:

When a mobile is located in the overlapping region of two cell as shown in figure (2) , the mobile will communicate with the two cells (2-way SHO)[11]:

$$\left(\frac{E_b}{I_o}\right) = \left(\frac{E_b}{I_o}\right)_1 + \left(\frac{E_b}{I_o}\right)_2 \tag{12}$$

$$\left(\frac{E_b}{I_o}\right) = \frac{W}{vR_b}\left[\frac{P_{i1}/L_{i1}}{Pt_1(1-\alpha)/L_{i1} + \sum_{j=2}^{7}\frac{Pt_j}{L_{ij}}} + \frac{P_{i2}/L_{i2}}{Pt_2(1-\alpha)/L_{i2} + \sum_{\substack{k=1\\k\neq 2}}^{7}\frac{Pt_k}{L_{ik}}}\right] \tag{13}$$
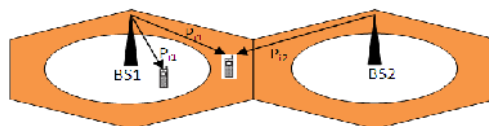
Figure (2) Soft handoff analysis

A balance power control is used for balancing the downlink power among active set cells during soft handoff [12], this means:

$P_{i1} = P_{i2}$

The transmit power for each downlink channel can be expressed as:

$$P_{i1} = P_{i2} = \frac{vR_b}{W}\left(\frac{E_b}{I_o}\right)Pt\left[\frac{1}{\frac{1}{1-\alpha+\sum_{j=2}^{7}\frac{L_{i1}}{L_{ij}}}+\frac{1}{1-\alpha+\sum_{\substack{k=1\\k\neq2}}^{7}\frac{L_{i2}}{L_{ik}}}}\right] \tag{14}$$

And from [9]: $\sum_{j=2}^{7}\frac{L_{i1}}{L_{ij}}$ $\quad$ $\sum_{\substack{k=1\\k\neq2}}^{7}\frac{L_{i2}}{L_{ik}}$

The same procedure can be followed for the 3-way SHO (three base stations are involved in SHO):

$$\left(\frac{E_b}{I_o}\right) = \left(\frac{E_b}{I_o}\right)_1 + \left(\frac{E_b}{I_o}\right)_2 + \left(\frac{E_b}{I_o}\right)_3 \tag{15}$$

and

$$\begin{aligned} P_{i1} = P_{i2} &= P_{i3} \\ &= \frac{vR_b}{W}\left(\frac{E_b}{I_o}\right)Pt\left[\frac{1}{\frac{1}{1-\alpha+\sum_{j=2}^{7}\frac{L_{i1}}{L_{ij}}}+\frac{1}{1-\alpha+\sum_{\substack{k=1\\k\neq2}}^{7}\frac{L_{i2}}{L_{ik}}}+\frac{1}{1-\alpha+\sum_{\substack{m=1\\m\neq3}}^{7}\frac{L_{i3}}{L_{im}}}}\right] \end{aligned} \tag{16}$$

The total load factor in the cell is the sum of the load factor due to users in the non soft handoff region and due to users in soft handoff region as follows:

$$\eta_{DL\_Total} = \eta_{DL\_noSHO} + \eta_{DL\_SHO} \tag{17}$$

$$\eta_{DL_{Total}} = \frac{vR_b}{W}\left(\frac{E_b}{I_o}\right)\left\{\sum_{i=1}^{I}\left[1-\alpha+\sum_{j=2}^{7}\frac{L_{i1}}{L_{ij}}\right]\right.$$

$$\left. +\sum_{n=1}^{N}\left[\frac{1}{\frac{1}{1-\alpha+\sum_{j=2}^{7}\frac{L_{n1}}{L_{nj}}}+\frac{1}{1-\alpha+\sum_{\substack{k=1\\k\neq2}}^{7}\frac{L_{n2}}{L_{nk}}}}\right]\right\} \tag{18}$$

5. Simulation of WCDMA Parameters

MATLAB software (version 7.4) is used to perform the simulation programs. Tables (4.1) and (4.2) list the parameters used in the simulation [3].

Table (4.1) Parameters Used in the Simulation

Parameter	Value
Total power of the base station (Pt)	20 W
Chip rate (W)	3.84 Mcps
Orthogonality factor ( )	0.6
Path loss exponent (a)	4
Standard deviation of shadowing ( )	8 dB
Soft handoff window	6 dB
Cell radius (R)	1 km

Table (4.2) Types of Service and the Required E_b/I_o

Service type (R_b)	Required (E_b/I_o)	Activity factor (v)
Voice 12.2 kbps	5 dB	0.5
Data 64 kbps	3 dB	1
Data 144 kbps	1.5 dB	1
Data 384 kbps	1 dB	1

Two models will be considered as shown in figure (2 a, b) In the first model, the user moves away from its serving base station, BS₁, to cell boundary ($r_1 = \frac{\sqrt{3}}{2}R$, ₁=0). While in the second model, the user moves away to the cell corner (r₁ = R , ₁=$\frac{\pi}{6}$).

Figure (3) Mobility of the User
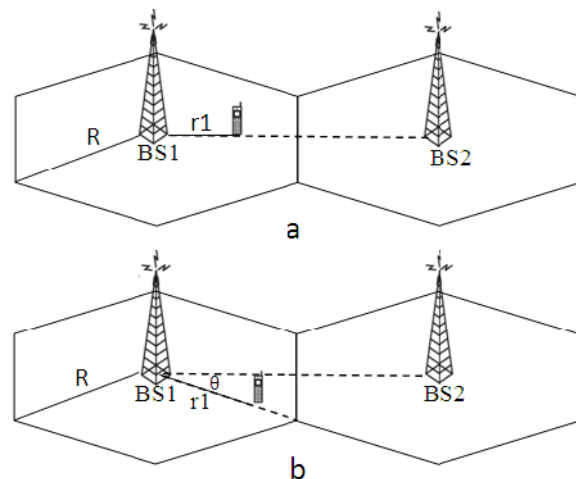
6. Results and Discussion

Figures (4), (5), (6), (7) show the power assigned for a user moving away from its serving BS to the cell boundary (₁=0) and figures (8), (9), (10), (11) for a user moving away towards cell corner (₁= /6) for different data rates (12.2kbps, 64kbps, 144kbps, 384kbps).
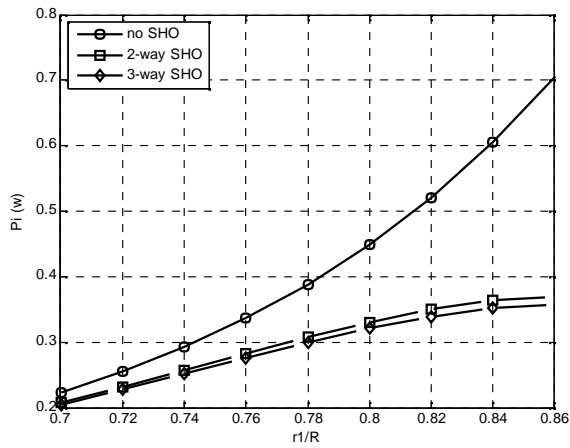
Figure (4) Power Assignment for User i (R_b=12.2 kbps, θ_1=0)
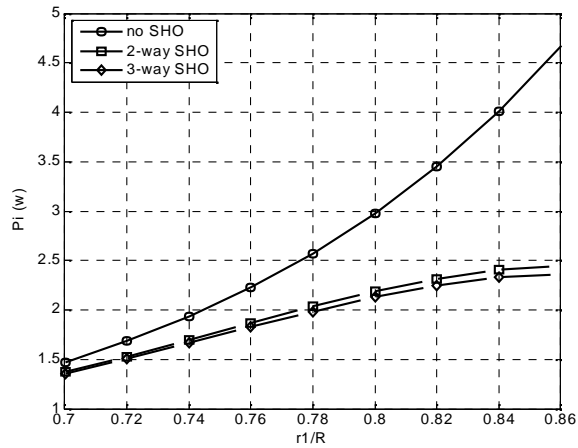
Figure (5) Power Assignment for User i (R_b=64 kbps, θ_1=π/6)
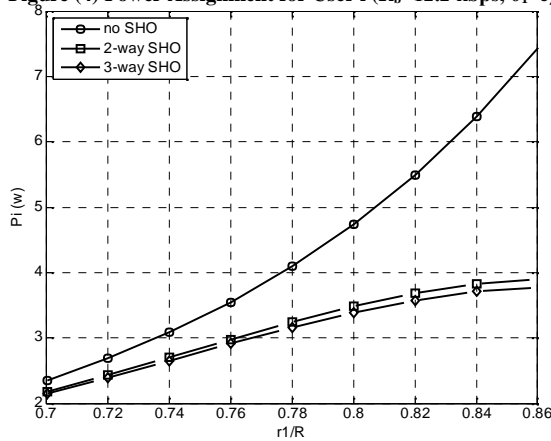
Figure (6) Power Assignment for User i (R_b=144 kbps, θ_1=0)
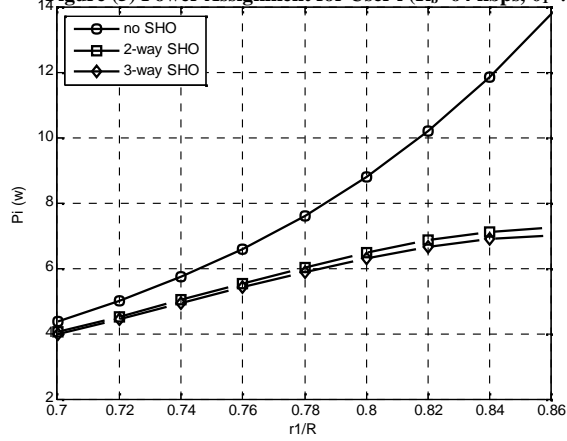
Figure (7) Power Assignment for User i (R_b=384 kbps, θ_1=π/6)
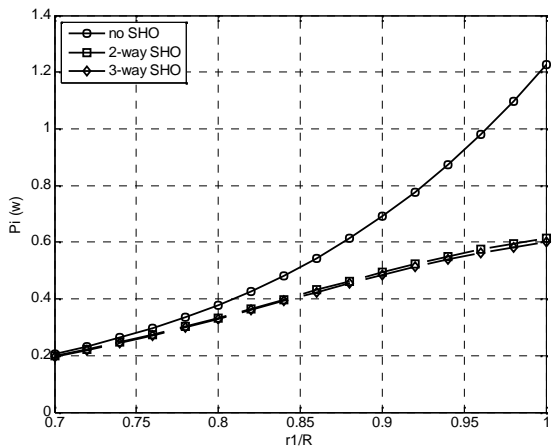
Figure (8) Power Assignment for User i (R_b=12.2 kbps, θ_1=π/6)
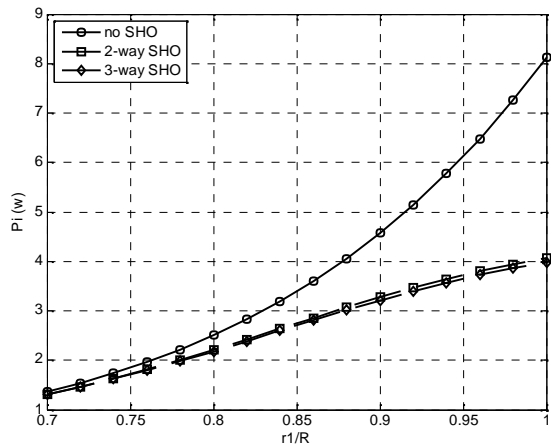
Figure (9) Power Assignment for User i (R_b=64 kbps, θ_1=π/6)
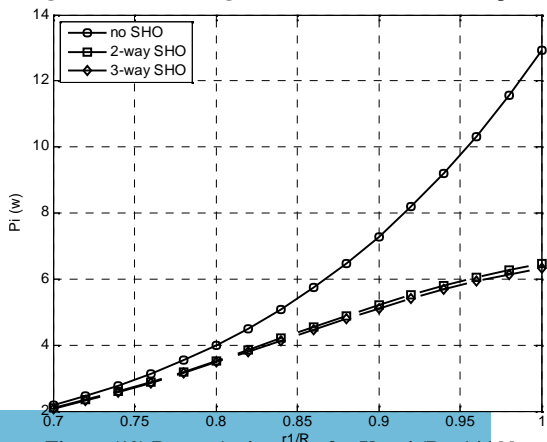
Figure (10) Power Assignment for User i (R_b=144 kbps, θ_1=π/6)
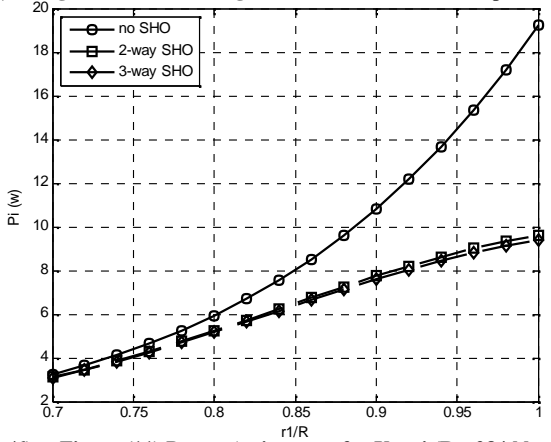
Figure (11) Power Assignment for User i (R_b=384 kbps, θ_1=π/6)

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The results show that soft handoff decreases the power at cell boundary and cell corner by approximately 50% (equation 15).

The value of E_b/I_o is increased by about 3dB at the cell boundary and cell corner due to implementing SHO, as shown in figures (12), (13), (14), (15) for $_1$=0, and figures (16), (17), (18), (19) for $_1$= /6. E_b/I_o is also plotted as a function the number of users, E_b/I_o is decreased as the number of users is increased as illustrated in figures (36), (37), (38), (39), and SHO increases the E_b/I_o resulting in enhancing the QoS of the system.

SHO also decreased the loading (load factor) and the noise rise in the cell as shown in figures (20), (21), (22), (23), (24), (25), (26), (27) leads to more users can be served by the cell, for voice service (12.2kbps) at 0.5 load factor (3dB noise rise) the number of users without SHO is 39, while with SHO is 56 resulting in soft handoff gain about 43.6%. Table (3) gives the capacity and soft handoff gain at 0.5 load factor for different data rates.

Table (3) Capacity and SHO Gain

Service type	Capacity		SHO Gain
	Without SHO	With SHO	
12.2 kbps	39	56	43.6%
64 kbps	6	8.5	43.3%
144 kbps	3.8	5.4	42.1%
384 kbps	1.6	2.2	37.5%

As the user which moves away from the serving BS, the BER is increased and hence the QoS is decreased. SHO decreases the BER leads to better QoS as shown in figures (28), (29), (30), (31), (32), (33), (34), (35). The BER is also increased as the number of users is increased, in the case of voice service as shown in figure (40), without SHO and in order to meet the target BER (10^{-4}-10^{-3}), the number of users is in the range 35-50. With SHO the number of users is 57-72 to satisfy the target BER. Figures (41), (42), (43) illustrates the BER for different data rates.
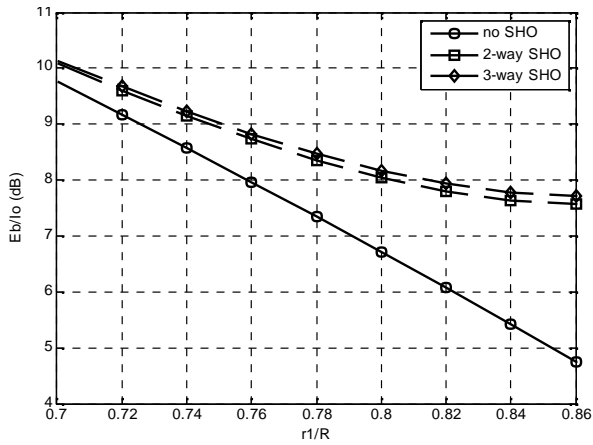
Figure (12) E_b/I_o for User i (R_b=12.2 kbps, θ_1=0)
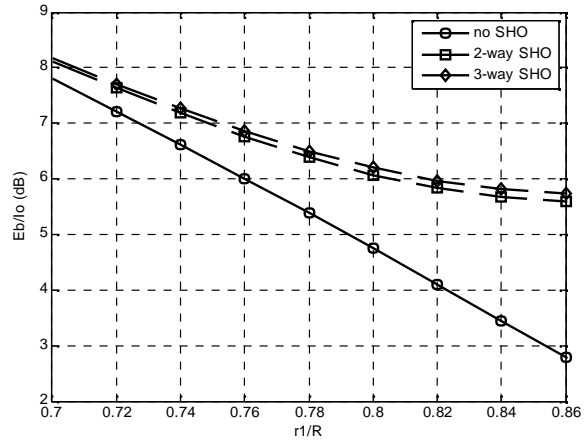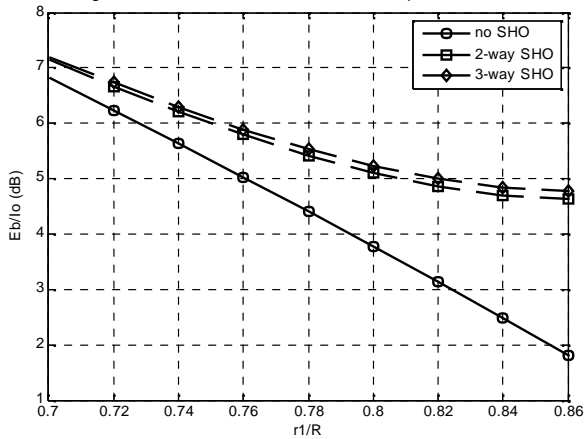
Figure (13) E_b/I_o for user i (R_b=64 kbps, θ_1=0)

Figure (14) E_b/I_o for User i (R_b=144 kbps, θ_1=0)

Figure (15) E_b/I_o for user i (R_b=384 kbps, θ_1=0)

Figure (16) E_b/I_o for User i (R_b=12.2 kbps, θ_1=π/6)

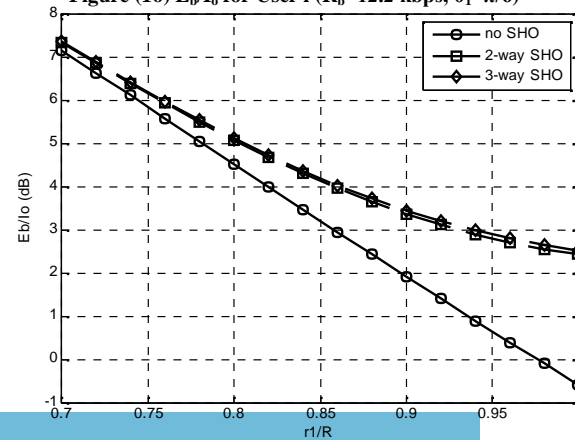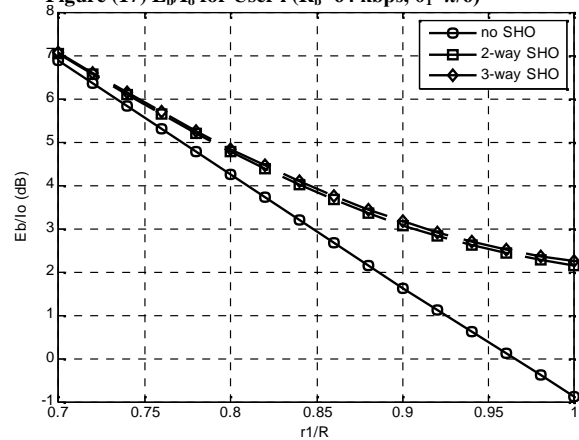**Figure (17) E_b/I_o for User i (R_b=64 kbps, θ_1=π/6)**

Figure (18) E_b/I_o for User i (R_b=144 kbps, θ_1=π/6)

Figure (19) E_b/I_o for User i (R_b=384 kbps, θ_1=π/6)

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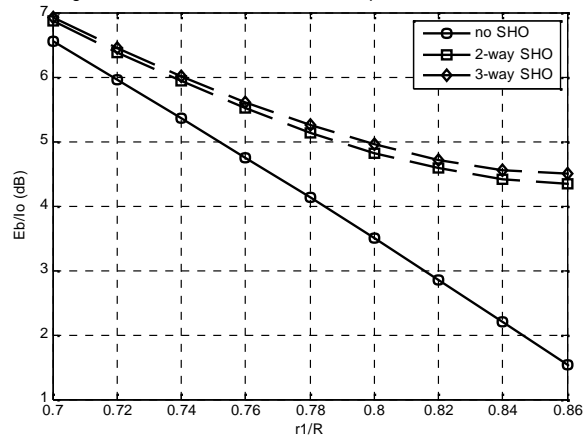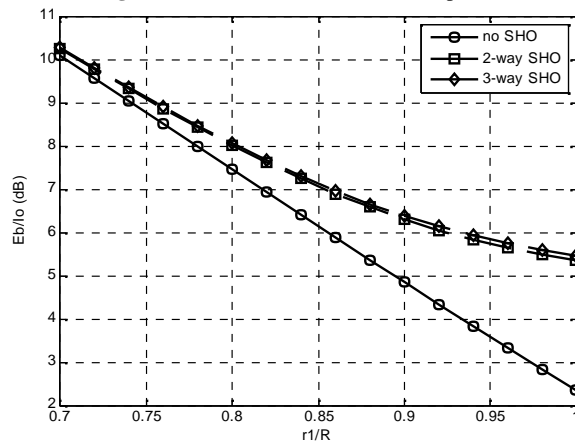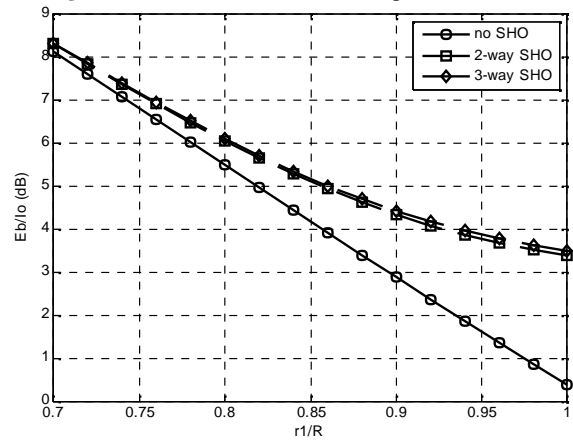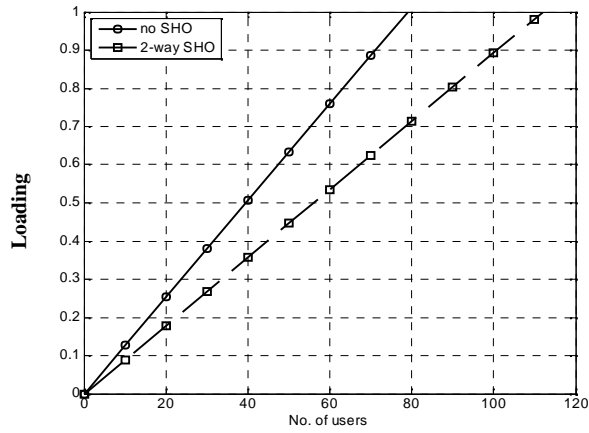
Figure (20) Downlink Load Factor (R$_b$=12.2 kbps)
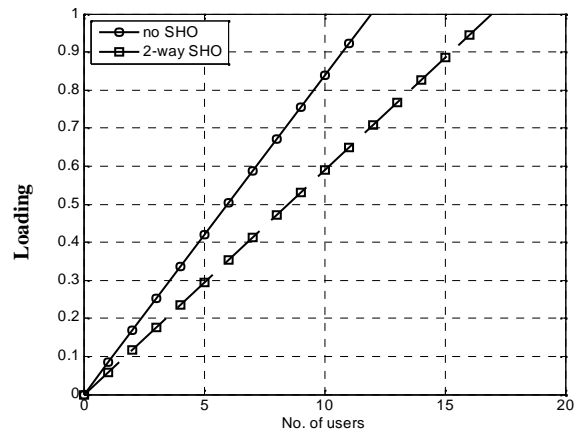
Figure (21) Downlink Load Factor (R$_b$=64 kbps)
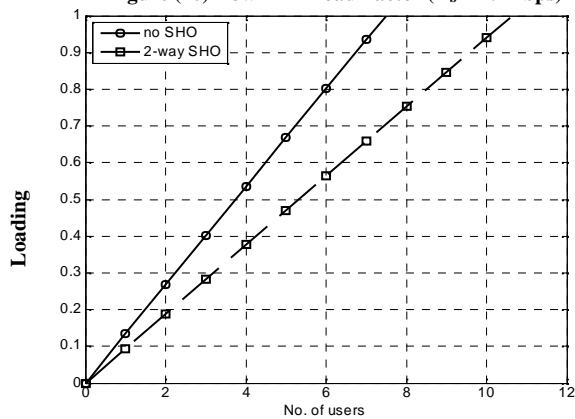
Figure (22) Downlink Load Factor (R$_b$=144 kbps)
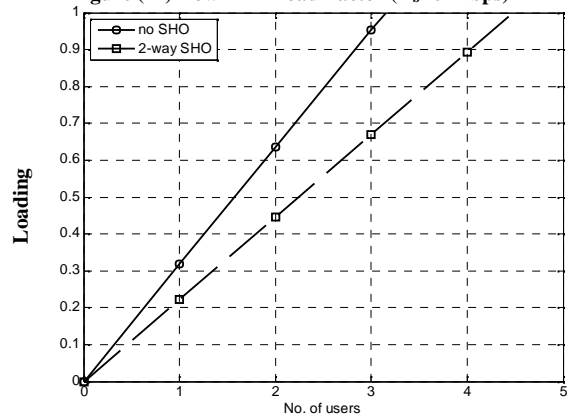
Figure (23) Downlink Load Factor (R$_b$=3844)
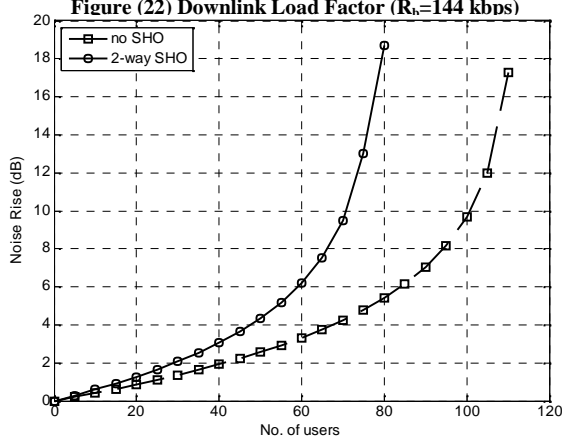
Figure (24) Downlink Noise Rise (R$_b$=12.2 kbps)
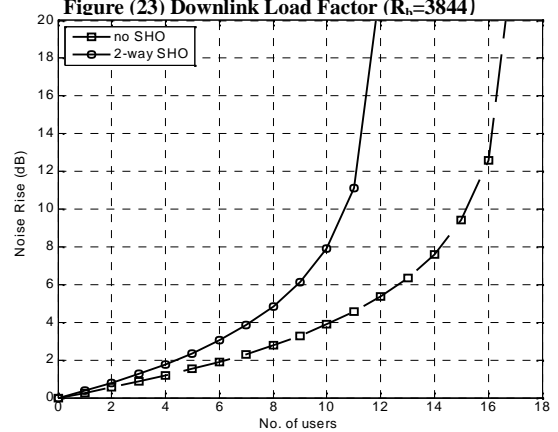
Figure (25) Downlink Noise Rise (R$_b$=64)
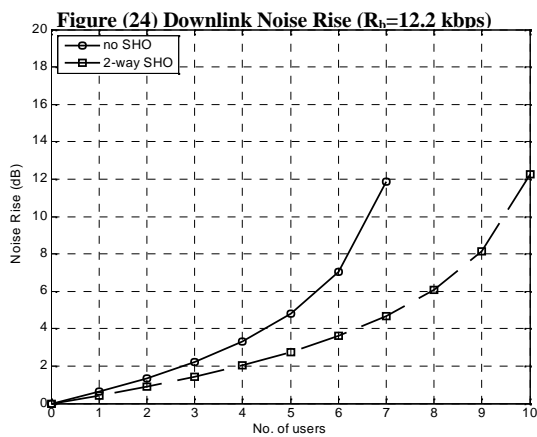
Figure (26) Downlink Noise Rise (R$_b$=144 kbps)
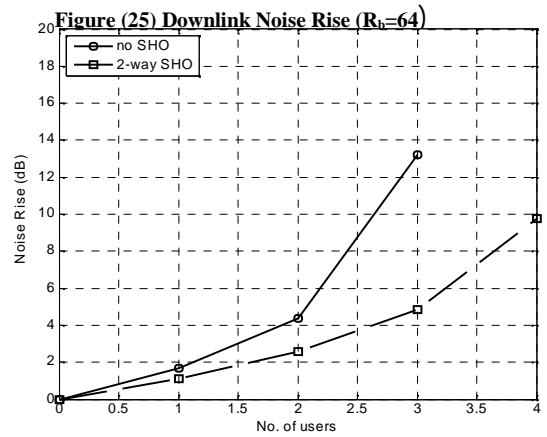
Figure (27) Downlink Noise Rise (R$_b$=384 kbps)

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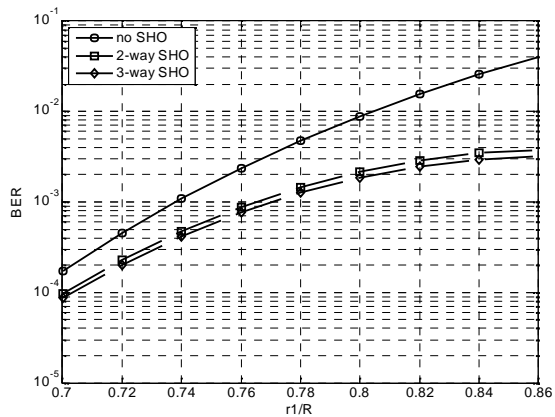
Figure (28) BER for Voice Service (R_b=12.2 kbps, θ_1=0)
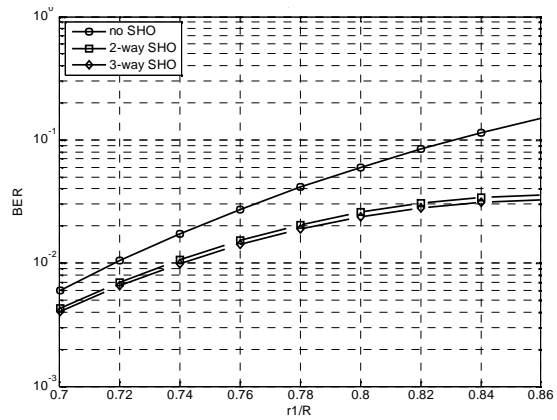
Figure (29) BER for Data Service (R_b=64 kbps, θ_1=0)
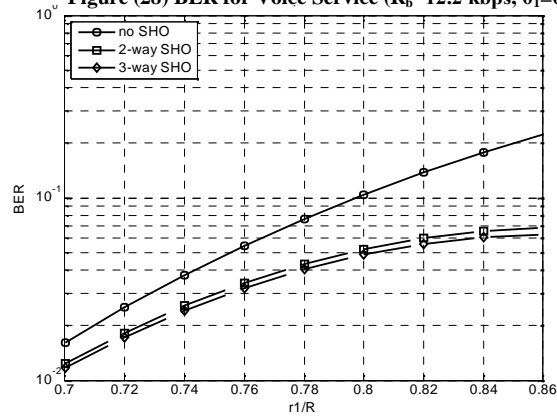
Figure (30) BER for Data Service (R_b=144 kbps, θ_1=0)
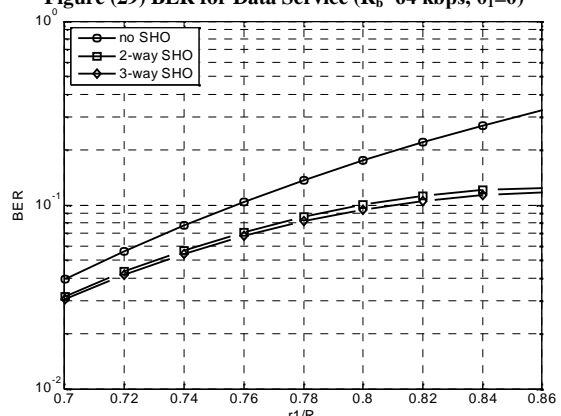
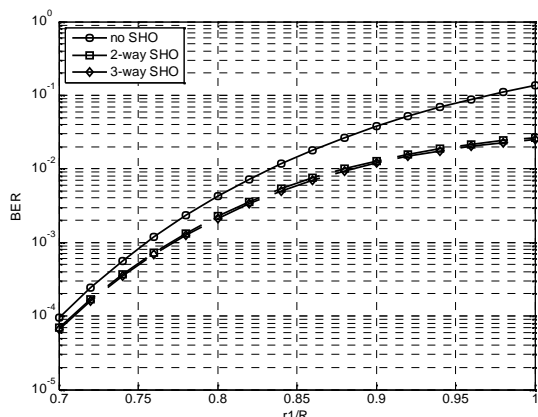**Figure (31) BER for Data Service (R_b=384 kbps, θ_1=0)**

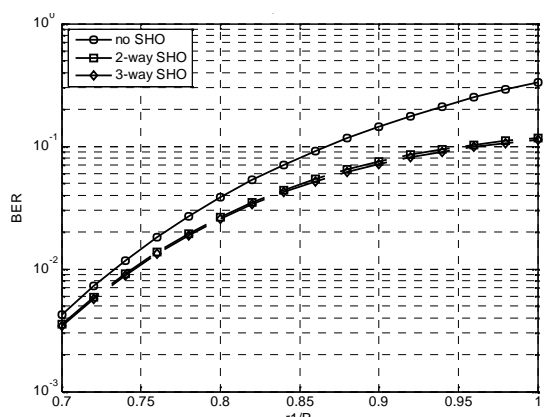**Figure (32) BER for Voice Service (R_b=12.2 kbps, θ_1=π/6)**

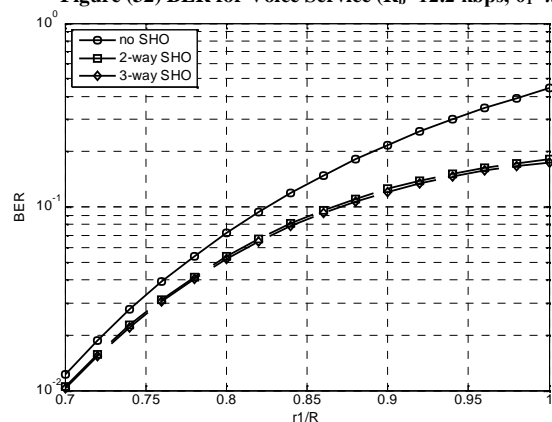**Figure (33) BER for Data Service (R_b=64 kbps, θ_1=π/6)**

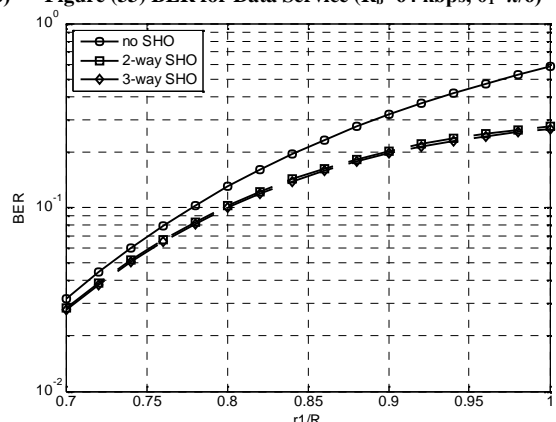**Figure (34) BER for Data Service (R_b=144 kbps, θ_1=π/6)**

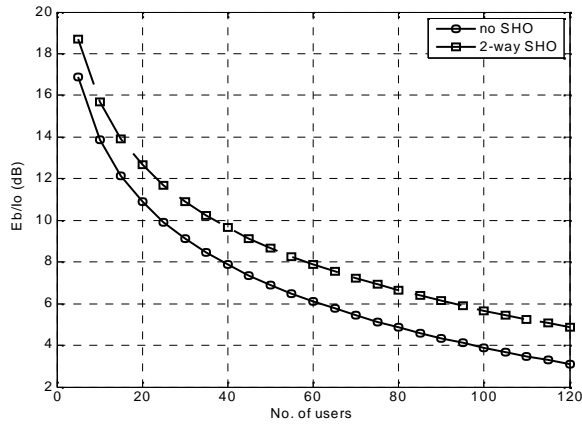**Figure (35) BER for Data Service (R_b=384 kbps, θ_1=π/6)**
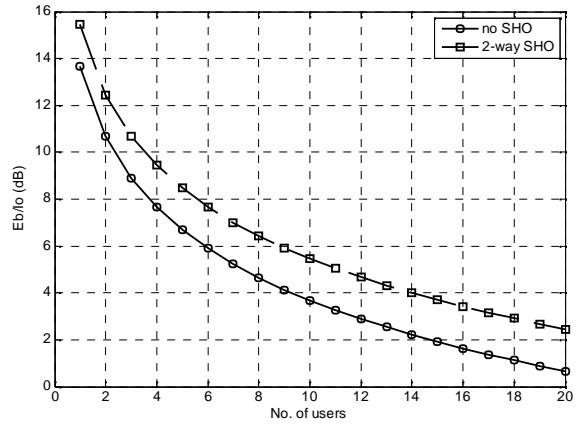
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Figure (36) E_b/I_o (R_b=12.2 kbps)

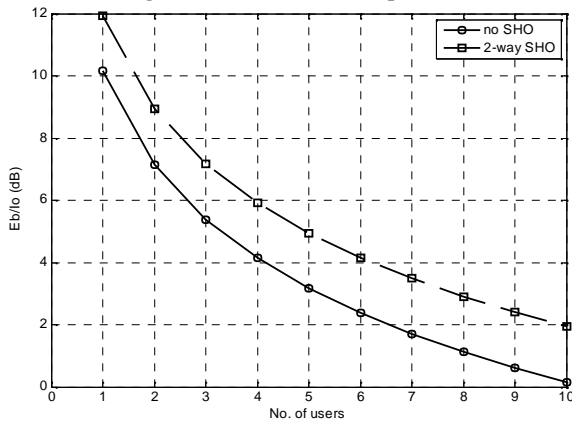**Figure (37) E_b/I_o (R_b=64 kbps)**
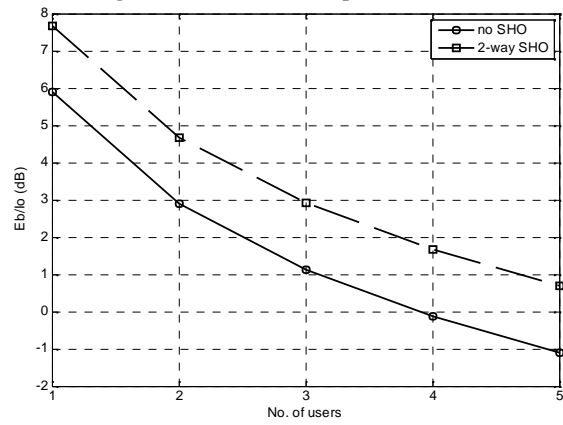
Figure (38) E_b/I_o (R_b=144 kbps)

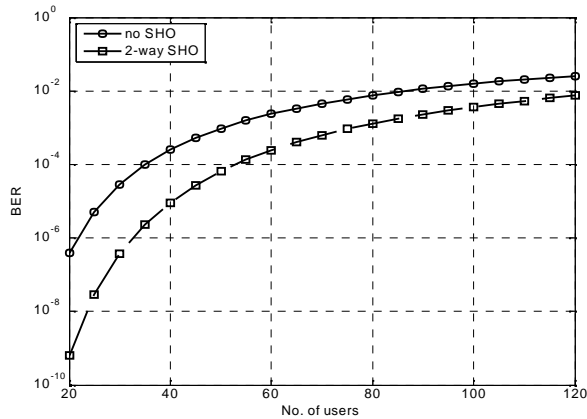**Figure (39) E_b/I_o (R_b=384 kbps)**
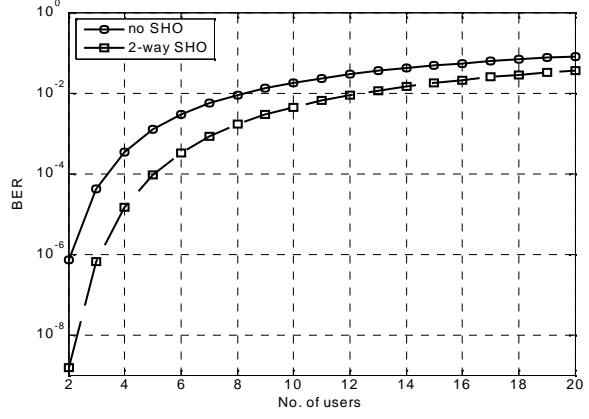
Figure (40) BER (R_b=12.2 kbps)
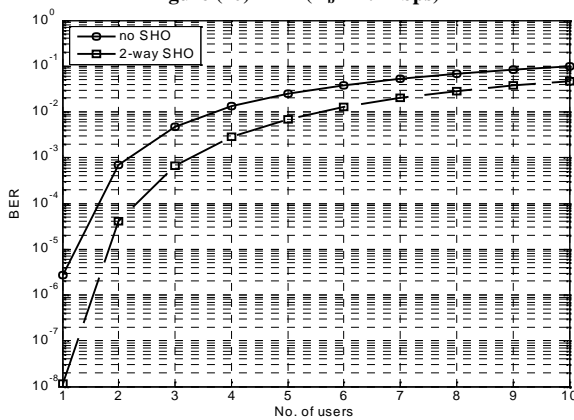
Figure (41) BER (R_b=64 kbps)

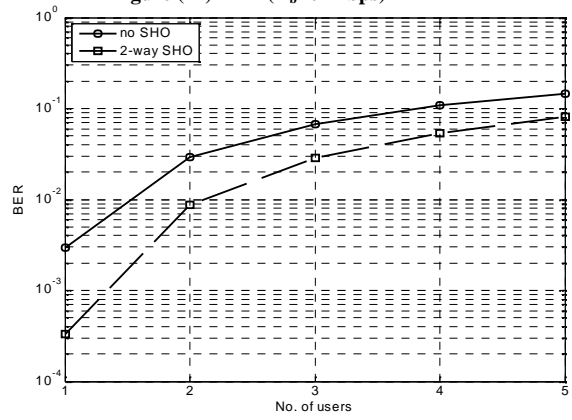**Figure (42) BER (R_b=144 kbps)**

Figure (43) BER (R_b=384 kbps)

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7. Conclusions

The SHO decreases the power assignment for a user from its serving BS by approximately 50% at cell boundary and cell corner. This reduction in the power leads to decreasing the overall interference in the cell, and hence increasing the signal to interference ratio (E_b/I_o). The load factor and the noise rise is also decreased when SHO is implemented resulting in increasing the number of users that can be served by the cell, this means the downlink capacity is increased. SHO gain has convergent values for different data rates. SHO improves the quality of service in terms of BER by decreasing it lower than the target value. Finally, results show a slight difference between 2-way and 3-way SHO, so 2-way SHO is used in CDMA systems.

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