Critical Analysis of Soft Handover Performance in UMTS Cellular Network

Muhammad Golam Kibria[1] Dr. Sati McKenzie[2] Al-Imtiaz[3]

Abstract: *Comparing to conventional hard handover (HHO) in 2G system soft handover (SHO) in Universal Mobile Telecommunication System (UMTS) supports more than one connection simultaneously where a new connection is established before the first one is released. In SHO mode user establishes an extra connection with neighboring cell which enables the user to use the first connection with lower quality leads to decrease in interference level and hence increases system capacity. In this research paper several functionalities and performance of SHO have been analyzed. The relation between traffic load and coverage area as well as capacity has been analyzed. Performance of the system in terms of load interference in both SHO and HHO mode has also been analyzed. According to the analysis of the performance gained due to SHO implies that SHO is an evolution in UMTS cellular system.*

Keywords: Cellular Network, Soft Handover, Soft Capacity

I. INTRODUCTION

UMTS is the third generation cellular network that supports data speed up to 14 Mbps and offers internet browsing, data and multimedia services, video conferencing, etc. [1]. User Equipments (UE) are connected to the Base Station while traveling using either SHO or HHO. Using multi-path propagation the base station receives two separated signals in SHO. Due to reflections on any physical structure or natural barriers the signal sent from the mobile stations reaches the base station from two different sectors. In SHO signals are treated as multi-path signals. Maximum ratio combining techniques are used in the uplink (UL) direction, but in the downlink (DL) direction the base station uses different scrambling codes to separate the different sectors it serves. So it is necessary for the different fingers of the rake receiver in the mobile terminal to apply the appropriate de-spreading code on the signals received from the different sectors before combining them together. Soft handover occurs in 5-10% of the connections [5].

[1] Assistant Profesor, UITS.
[2] Professor, University of Greenwich, UK.
[3] Information System Developer, UITS.

Several factors in SHO, such as Throughput, Transmission Power in uplink and downlink, Pathloss, Threshold value and Active Set Size have been analyzed. Soft Handover Algorithm, mechanism, window and probability also have been described for better understanding.

II. SOFT HANDOVER

In soft handover (SHO), the old connection is released after the new connection is established. SHO is performed between two cells which may or may not be under the same RNC. Most of the SHO in WCDMA is intra-frequency SHO where same frequency is used in both source and destination cells shown in Fig 1 [2]. UE is in overlapping coverage area belongs to two Node Bs. UE is connected to both Node B using two separate channels simultaneously where UE receives both signals by Rake processing [3].

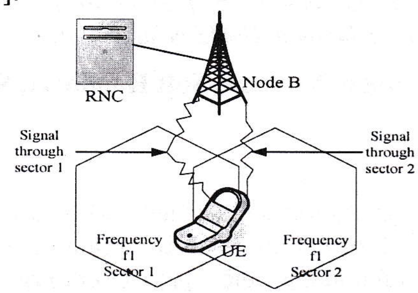

Fig 1. Intra-frequency SHO

The handover where UE is in overlapping area of two sectors belonging to single Node B is called softer handover. Two channels are used for two connections between UE and Node B as shown in Fig 2 which uses two different codes to separate the signal in UE for downlink [3].

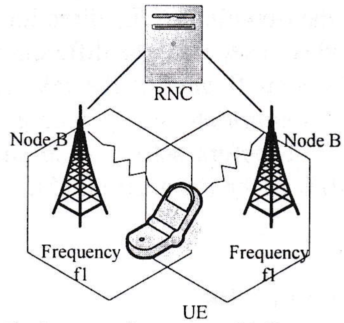

Fig 2. Intra-frequency Softer HO

The signals from two channels are received in UE by RAKE processing which can verify and combine the signals from radio path. In UL direction the signal is transmitted from UE to the same Node B via each sector and then RAKE receiver combines the received signals. [3]

A. SHO Algorithm

There are three reporting events such as 1A, 1B and 1C. The parameters used in the SHO algorithm are *AS_Th, AS_Th_Hyst, AS_Rep_Hyst,* ΔT and *AS_Max_Size*. *AS_Th* is Threshold for macro diversity which is the important design parameter that influence the system capacity and coverage, *AS_Th_Hyst* is Hysteresis for the Threshold value, *AS_Rep_Hyst* is replacement Hysteresis, ΔT is the time to trigger and *AS_Max_Size* is the maximum size of active set [7].

For better understanding of SHO procedure SHO algorithm is stated [3, 7]. Fig 3 shows the WCDMA SHO algorithm [4].

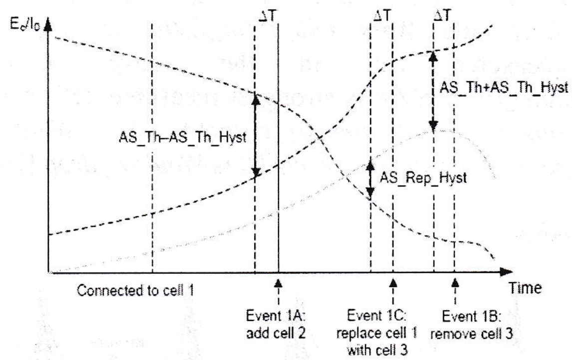

Fig 3. WCDMA SHO algorithm

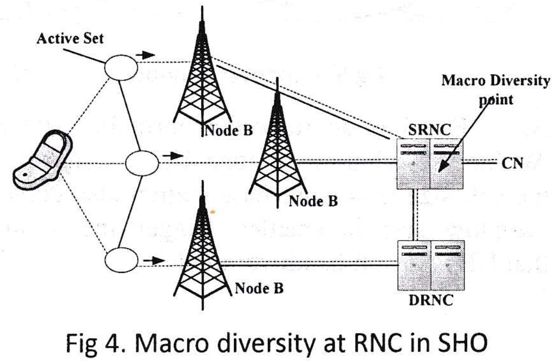

Fig 4. Macro diversity at RNC in SHO

WCDMA SHO algorithm is specified by 3GPP stated as follows:

1. "If *Pilot_E$_c$/Io* > *Best_Pilot_E$_c$/Io* – *Reporting_range* + *Hysteresis_event1A* for a period of ΔT and the active set is not full, the cell is added to the active set. This event is called Event 1A or Radio Link Addition.
2. If *Pilot_E$_c$/Io* < *Best_Pilot_E$_c$/Io* – *Reporting_range* - *Hysteresis_event1B* for a period of ΔT, then the cell is removed from the active set. This event is called Event 1B or Radio Link Removal.
3. If the active set is full and *Best_candidate_Pilot_E$_c$/Io* > *Worst_Old_Pilot_E$_c$/Io* + *Hysteresis_event1C* for a period of ΔT, then the weakest cell in the active set is replaced by the strongest candidate cell (i.e. strongest cell in the monitored set). This event is called Event 1C or Radio Link Addition and Removal. The maximum size of the active set is two in the above Fig 4 [2].

In the algorithm, *Pilot_E$_c$/Io* is the measured and filtered quantity, *Best_Pilot_E$_c$/Io* and *Worst_Old_Pilot_E$_c$/Io* are the strongest and weakest measured cell in the active set respectively, *Best_candidate_Pilot_E$_c$/Io* is strongest measured cell in monitored set, *Reporting_range* - *Hysteresis_event1A* is *Window_add* and *Reporting_range* + *Hysteresis_event1B* is *Window_drop* [20].

B. SHO Window

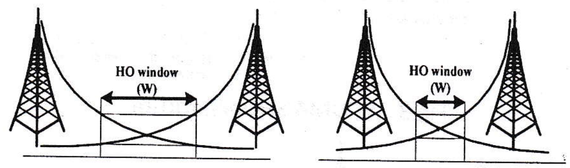

Fig 5. Handover window

SHO window in Fig 5 is an important term in SHO zone described earlier [8]. Within the window or zone UE is connected to both base stations, if the cell size is smaller base station also comes closer which means the window size is smaller. Bigger the window size more probability that UE is in soft handover mode.

C. SHO mechanism

As illustrated earlier during SHO two simultaneous radio links are connected between Node-Bs and UE. Simulation has been done on SHO mechanisms and the signals in physical layer are analyzed. Ten UEs have been set in the simulator to get the real scenario.

Different trajectories are assigned to different UEs to get the result of a real network as well as different signals and parameters are set, such as the ground speed of 10^{th} UE is set to 5.44 mi/hr, UL and DL bit rate is set to 12.2 kbps, threshold is set to 6.0 dB and active set size is set to 3. The signals of physical layer are changed as active set are updated while UE moves based on signal strength measurement reports.

Frequency reuse factor, Fe in Table 1 defines the UL interference of other cell. the ratio of same cell received power to total received power defines the Fe, Fe = $1/(1+f)$, where f is the ratio of interference of other cell to same cell. Vehicular model whose value is 0.75 is used in the simulation [6].

Different pathloss models are developed specified by ITU, such as Vehicular outdoor, pedestrian outdoor, indoor office. Throughout the research Vehicular Pathloss Model applicable to user speed and cell sizes has been used. The Vehicular pathloss model is defined in following equation 1[5]:

$$L_{pMax} = 40\,(1 - 4\,.\,10^{-3}\,\Delta h_b)\log_{10} R - 18\log_{10} R\,\Delta h_b + 21\log_{10} freq + 80 \qquad (1)$$

In equation 1 [5], Δh_b is the height of antenna of base station, R is the distance between UE and Node B in km and *freq* is the carrier frequency in MHz. If Δh_b is 40 meters and *freq* is 1940 MHz then the equation 1 becomes equation 2 [5].

$$L_{pMax} = 33.6\log_{10} R + 120.2 \qquad (2)$$

D. Transmission power (dBm)

The signal strength varies as UE moves away or towards the Node-B. in this Simulation the ground speed of UEs are set to 5 mi/hr in average, UL and DL bit rate is set to 15 kbps for better performance, threshold is set to 4.0 dB and active set size is set to 3.

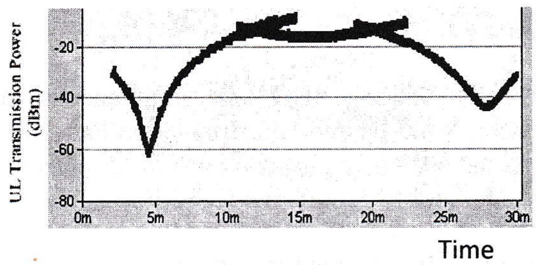

Fig 6. UL Transmission power

Vehicular Pathloss Model has been used in this simulation. Fig 6 shows the UL transmission power has been decreased as moving towards node-B and increased as moving away implies strength and weakness of the power. More the transmission power means more the noise will be generated.

Within the times lot 11m-15m and 19m-23m two simultaneous connections are established. The power in UL direction ranges almost 80dBm.

E. Reception power (dBm)

In the next Simulation ground speed of UEs are set to 7 mi/hr, UL and DL bit rate is set to 15 kbps, threshold is set to 6.0 dB and active set size is set to 3. The reception power shown in Fig 7 fluctuates due to combing of two separate signals coming from two different base stations in SHO. But the quality of signals in SHO is better as discussed in Soft capacity.

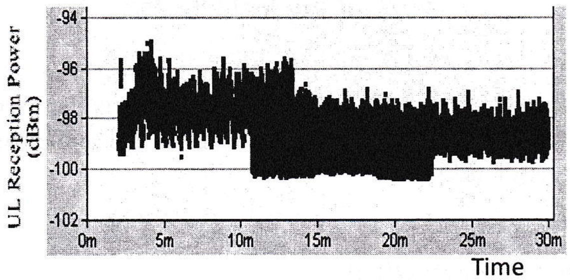

Fig. 7 UL Reception power (dBm)

Fig 7 shows the power received in Node-B in UL direction. Same two radio links are managed but the power ranges within 35 dBm compared to transmission power, this is due to power control mechanisms in RNC.

F. SHO probability and Threshold

SHO probability implies the amount of users connected to multiple radio links simultaneously compared to total number of users within the system. More the probability more the network resources used that increase the overall load of the system. That's why it is very important to set the parameters in such a way so that system resources are utilize. Different parameters affect SHO probability, such as threshold value, traffic types, user profiles.

Threshold value *AS_Th* in Fig 3 is an important parameter in SHO algorithm that determines the quality of signals for the cell to be added to active set. Larger the threshold means more cells are added to active set that increases the amount of user in SHO mode. Threshold is also known as handover margin, in OPNET threshold value can be edited by RNC node editor where it is known as Macro Diversity Threshold (dB).

Relation between SHO probability and threshold values is analysed using the analytical and mathematical model. The simulation is modelled using four Node-Bs and three UEs located at three Node-Bs. Main intension is given to *UE_3,* which moves between *Node_B_0* and *Node_B_1* at cell edge. The approximate distance from cell edge to Node_B is 1000 meters. The mathematical model, where handover window (*W*) and threshold affect the SHO probability is shown in Fig. 8 [5].

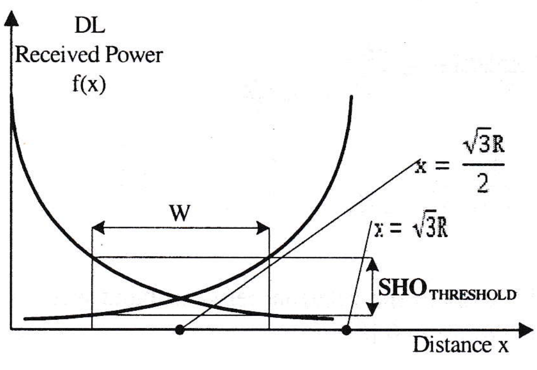

Fig. 8 Mathematical model: relation between HO window & SHO Threshold

Soft handover probability can be measured by dividing amount of time in SHO mode by the total time connected to the system. Equation 3 [5] defines SHO probability based on this method.

$$SHO_{PROBABILITY} = \frac{\Delta t_{SHO}}{\Delta t_{TOTAL}} = \frac{\frac{\Delta x_{SHO}}{v}}{\frac{\Delta x_{TOTAL}}{v}} = \frac{\Delta x_{SHO}}{\Delta x_{TOTAL}} \qquad (3)$$

In equation 3, Δt_{SHO} is the time user in SHO, Δt_{TOTAL} is the total simulated, Δx_{SHO} is the distance of the trajectory crossed in handover mode, Δt_{TOTAL} is the total length length of trajectory and v is the velocity of user.

Three locations have been pointed out at x=0, √3R and $x = \frac{\sqrt{3}R}{2}$ in Fig 8. If the UE moves through two Node-Bs located at x = 0 and x = √3R, the equation of SHO probability becomes

$$SHO_{PROBABILITY} = \frac{W}{\sqrt{3}R} \qquad (4)$$

In equation 4 [5], *W* is the SHO window and *R* is the cell radius.

If the UE moves between two Node-Bs at cell edge where $x = \frac{\sqrt{3}R}{2}$, the ratio between threshold and handover window becomes:

$$\frac{SHO_{THRESHOLD}}{W} \approx \left|\frac{df(x)}{dx}\right|_{x=\frac{\sqrt{3}R}{2}}$$

$$= \frac{33.6}{\ln 10} \cdot \frac{1}{x}\Big|_{x=\frac{\sqrt{3}R}{2}} = A.\frac{1}{R} \qquad (5)$$

Equation 5 [5] leads to the relation between handover window and SHO threshold as in equation 6 [5].

$$W \approx \frac{R}{A}\ SHO_{THRESHOLD} \qquad (6)$$

Substituting equation 6 into equation 4 generates relation between SHO probability and threshold stated in equation 7 [5].

$$SHO_{PROBABILITY} = \frac{\frac{R}{A} \cdot SHO_{THRESHOLD}}{\sqrt{3}R} = \frac{1}{\sqrt{3}A} SHO_{THRESHOLD} \quad (7)$$

Vehicular pathloss model (equation 2) is used in all simulations, for vehicular pathloss the equation 7 can be rewritten to generate the relation:

$$SHO_{PROBABILITY} = \frac{1}{29.2} SHO_{THRESHOLD} \quad (8)$$

In equation 7, *A* is the constant value determined by pathloss model's parameter, this equation is applied in the case where UE is located between Node-Bs which implies that SHO probability is independent of cell size. Equation 8 [5] also shows cell size that does not affect SHO probability. Higher the threshold values higher the SHO probability. If threshold values of 1 to 14 are applied in equation 8, relation between threshold and SHO probability can be drawn graphically as shown in Fig 9.

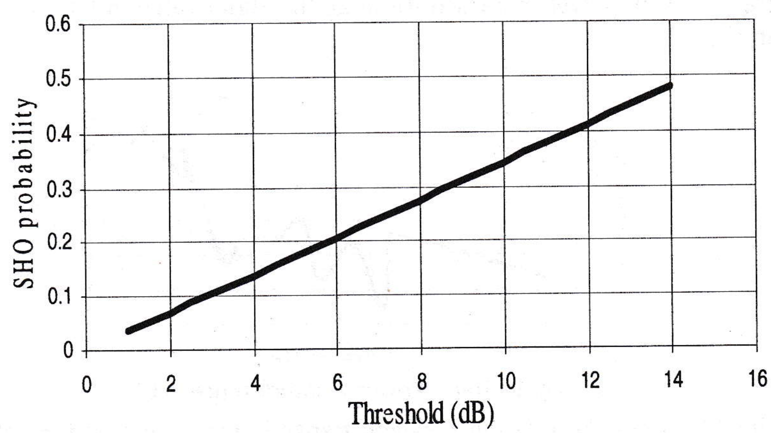

Fig. 9 Relation between probability & Threshold

III. INTERFERENCE

Each physical channel uses less power but the combination is high that

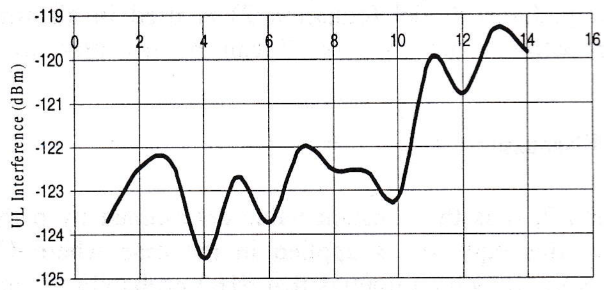

Fig. 10 UL Interference (dBm) according to Threshold

increases the interference (dBm) in UL direction as shown in Fig 10.

Interference level increases fast for threshold value > 6dB as transmission power increased for large threshold value in UL direction as in Fig 10.

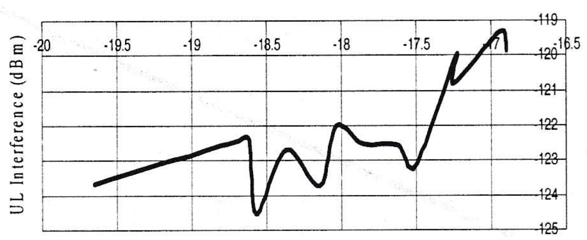

Fig. 11 Trans. Power vs Interference in UL

Fig 11 shows the relation between transmission power and interference in UL direction. Each system allows certain level of interference. Lower the transmission power gains macro diversity, but large transmission power generates additional interference higher than the gain which leads to loss in system capacity.

IV. CELL CAPACITY

A. Pathloss

The amount of traffic load depends on the number of users, which affects the usage of radio resources. Increase in user leads to increase the communication links results in increase in transmission power and hence interference in the system will be increased. UMTS services until the system is fully loaded due to increase in interference. In SHO, multiple connections are established with multiple base stations where UE at the cell edge are handed over to neighboring cell hence increase the capacity.

The user at the cell edge is affected more than those at the center due to increased noise thus increases power level by power control function to avoid the noise and communicates with the Node-B. As the transmission power is increased due to increase in load, the users at the cell edge also increases power which reaches its maximum level, at a certain level they loses connection with Node-B.

Due to increase in load, coverage is decreases. The coverage of a cell can be determined by maximum pathloss suported by the Node-B. Simulation has been done on traffic load comparing SHO and HHO, where number of users is incremented and Vehicular Pathloss model is used.
Pathloss for *UE_0* is calculated as moving away from the Node-B. User is able to communicate with Node-B up to the maximum pathloss supported by the Node-B. Pathloss decreases according to increase in load means coverage area is decreased due to higher traffic load.

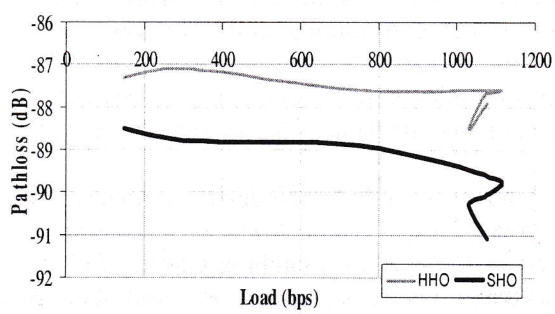

Fig. 12 Comparing pathloss in SHO & HHO

Fig 12 shows pathloss in SHO is lower than in HHO. Users in SHO are connected to multiple base stations, as more connections are increased more transmission power is increased, thus pathloss value is decreased, hence coverage area is decreased, means interference present in the cell in SHO will be reduced more than that of in HHO leads to improve in cell quality that enhances the cell capacity.

B. Soft Capacity

Amount of load in the system is more than in SHO than that of in HHO as users send same traffic to multiple Node-Bs using multiple connections, hence transmission power increases that results increased in interference. Soft Capacity enables loaded cell to share interference with neighboring lower loaded cell to reduce interference that increases capacity. The capacity gain for a loaded cell in both SHO and HHO mode has been simulated. In soft capacity maximum capacity is limited by interference. In case of real time data such as video streaming where high data rate is used, soft capacity is essential technique to reduce interference to increase capacity [3].

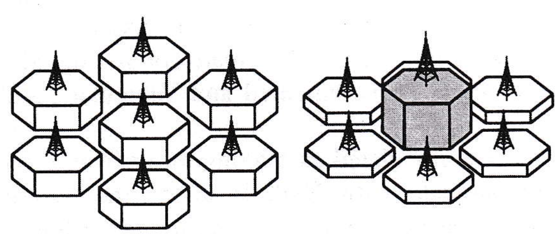

Fig. 12 Interference sharing among cells

Central loaded cell borrows capacity from surrounding cells as shown in Fig 12. Load of the surrounding cells are lower as less number of channels per cell are used for high data rate, thus usage of capacity is less. Soft capacity allows the loaded cell to borrow the unused capacity from the surrounding cells, hence sharing interference [3].

The simulated network includes Node-Bs, connected with single RNC where users under *Node_B_1* and *Node_B_2* move to *Node_B_0*, hence increasing load in *Node_B_0*. Switching Circuit (SC) allows *Node_B_0* to borrow available capacity from *Node_B_1* and *Node_B_2*.

In this Simulation the ground speed of UEs are set to 15 km/hr in average, Vahicular Pathloss model is used, Speech (VOIP -16kbps) and Video Conferencing (16kbps) are used as traffic type. Active set size is set to 3, Threshold is set to 8dB and Hysteresis is set to 1.5 dB in SHO. Generated result on the specified parameters is listed in Table 3.

Table 3. Capacity gain due to soft capacity

Traffic type	Data rate (kbps)	Load (kbps)		Increase in capacity (%)
		HHO	SHO	
Speech (Voice over IP (GSM quality))	16	86.79	94.53	8.92%
Real time (Video conferencing)	64	1.11	1.81	63.06%

Simulated result in Table 3 shows that load in SHO is higher than HHO in both traffic types. As multiple connections are used in SHO the transmission power is increased leads to higher throughput which increases the system load. Result also shows that gained capacity becomes higher in SHO due to higher data rate.

Erlang per cell and number of channels used define the gain in capacity which can be explained in terms of trunking efficiency [9]. Due to high data rate the number of channels becomes lower results in lower trunking efficiency means higher the amount of unused capacity in neighboring cells which can be borrowed by the higher loaded cell, hence soft capacity becomes higher [3].

Comparing load in terms of data rate in Table 3, load becomes lower with 64kbps than with 16kbps as trunking efficiency becomes lower both in HHO and SHO, hence soft capacity is higher. When comparing between SHO and HHO, the load is higher in SHO as users are connected to multiple Node-Bs where number of channels becomes higher, thus capacity is gained.

V. CONCLUSION

SHO transmission power is higher than HHO, thus pathloss is lower, implies coverage area in SHO is smaller than that in HHO. Lower the coverage area lower the interference, thus performance in SHO is higher than in HHO. Several simulated models have been analyzed, the results indicate that capacity is gained in SHO. Overall performance can be improved more in SHO if the parameters used in SHO algorithm are set to certain level that meet the required QoS to prefer SHO instead of HHO.

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