Performance Evaluation of Soft Handover in a Realistic UMTS Network

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***Abstract*— With the operation of multiple radio links simultaneously in a so-called soft handover situation, the link quality can significantly be improved. On the other hand, additional radio resources are necessary and distributed transmitters cause severe changes in a network's interference situation. This paper focuses on the effects of soft handover applied to a realistically planned UMTS network. As a result, the trade-off between interference mitigation and capacity loss is evaluated by means of dynamic simulation.**

I. Introduction

Universal Mobile Telecommunication System (UMTS) applies *Wideband Code Division Multiple Access* (WCDMA) at the radio air interface which offers improved connection maintenance during handover with the usage of transmit diversity techniques. If a *User Equipment* (UE) has to change the cell, an additional radio link to the new Node B will be established and the connection is transferred into *Soft Handover* (SHO). Up to six links can be in operation simultaneously by adding them to the active set. Dropping of links which do not significantly contribute to the overall link quality reduces the active set size and finally leads to a single link situation again [1].

Fig. 1 illustrates the *UMTS Terrestrial Radio Access Network* (UTRAN) topology and the management of UE being either in *soft* handover to three Ⓐ or two Ⓑ Node B, or in *softer* handover with only one Node B Ⓒ.

A detailed overview of SHO functionality, parameter settings and performance analysis can be found in [2–4]. This paper focuses on the parameterization and performance of SHO in a realistic network. Therefore, the *Radio Resource Management* (RRM) protocol functions concerning SHO are described in Sec. II. The simulation environment and parameters are presented in Sec. III and results are collected in Sec. IV.

II. Soft Handover Algorithm

Fig. 2–4 show the forms of soft and softer handover from the radio access networks point of view. The gray sectors and the dashed interfaces are involved in the SHO.

The softer or intra cell handover is illustrated in Fig. 2. The involved sectors in this SHO belong to one cell. Hence, the SHO can be handled by one Node B and only one Iub interface gets involved. This is the simplest form of SHO. Approximately 5–15 % of all connections can be expected to be in softer handover [5]. Micro diversity is entirely provided by the Node B. The *Radio Network Controller* (RNC) sends the data only once via the Iub interface. Data is split at the Node B and routed to the different antennas. The UE combines the signals in *Downlink* (DL) by means of Rake receiving. In *Uplink* (UL) the Node B can combine the signals by means of Rake receiving, too. This means maximum ratio combining is applied to the signal.

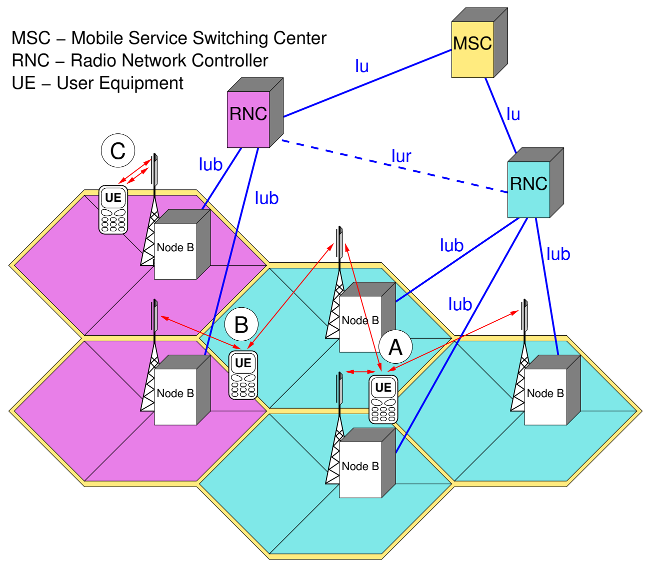

Fig. 1. UTRAN topology and SHO situations

The soft handover can either be an intra RNC handover (Fig. 3) or an inter RNC handover (Fig. 4). In both cases the involved sectors belong to different cells and macro diversity is provided by the RNC. The data has to be duplicated by the RNC and is then routed to the appropriate Node B. In intra RNC handover this can be done directly via the Iub interfaces. In inter RNC handover the *Serving RNC* (SRNC) has to send the data via the Iur interface to the *Drift RNC* (DRNC), which in turn sends it to the Node B via its Iub interface. In UL, selection combining on frame basis at the SRNC is performed, while in DL Rake reception at the UE is conducted.

A. Adding a Radio Link

In order to add another radio link to the active set, the so-called reporting event 1a has to be triggered. This is done if the

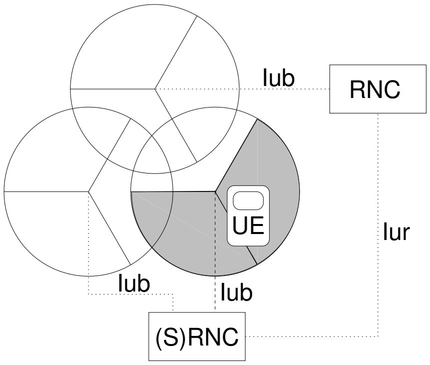

Fig. 2. Softer handover, intra cell handover

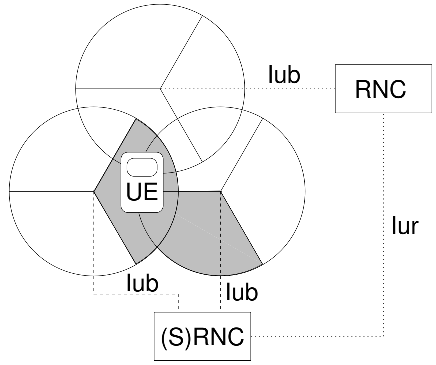

Fig. 3. Soft handover, intra RNC handover

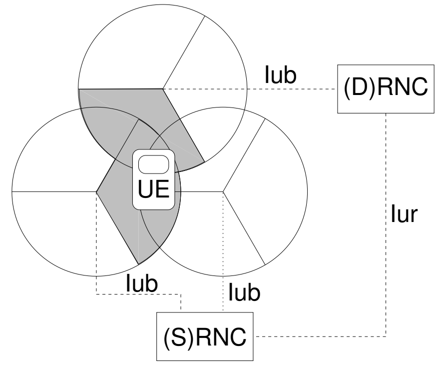

Fig. 4. Soft handover, inter RNC handover

triggering condition is fulfilled for the period *Time to Trigger* (TtT) ΔT_{1a}. During this time period the measurement have to be within a certain reporting range R_{1a} complemented by a hysteresis H_{1a} [6]. Fig. 5 illustrates the radio link addition if the *Common Pilot Channel* (CPICH) reception level is chosen as the decision measure. The timer is started if the second best CPICH level exceeds the upper border of the hysteresis around the reporting range, e.g. at time instant ①. The timer gets stopped if the measure drops below the lower border ②.

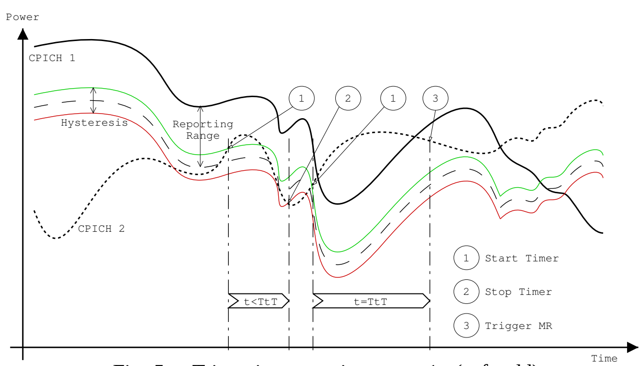

Fig. 5. Triggering reporting event 1a (soft add)

The radio link addition takes place if the UE has triggered reporting event 1a at time instant ③ and sent the respective measurement report to UTRAN. Suppose, the *Radio Resource Control* (RRC) in SRNC decides to add the suggested radio link which may be realized via a new cell that is controlled by another RNC. This is the most extensive form of a radio link addition and therefore presented as example here. Fig. 6 illustrates the separate steps for an inter-RNC soft add and the protocols involved [7].

The SRNC will request radio resources by sending the *Radio Network Subsystem Application Part* (RNSAP) message **Radio Link Setup Request** to the DRNC (1.). A new Iur signaling connection has to be established if this is the first radio link via this DRNC to this UE. After establishing the Iur signaling connection, it will be used for all further RNSAP signaling related to this UE. The radio bearer parameters and physical channel settings are signaled to the DRNC.

If radio resources are available, the DRNC sends the *Node B Application Part* (NBAP) message **Radio Link Setup Request** to the Node B with appropriate parameters (2.). The reception of UL transmission at the Node B is started immediately. If the resources have been allocated successfully at the Node B, the NBAP message **Radio Link Setup Response** is sent to the DRNC with parameters for *Asynchronous Transfer Mode* (ATM) data transport bearer(s) (3.). The DRNC sends the RNSAP message **Radio Link Setup Response** to the SRNC, which describes the established transport layer connection (4.).

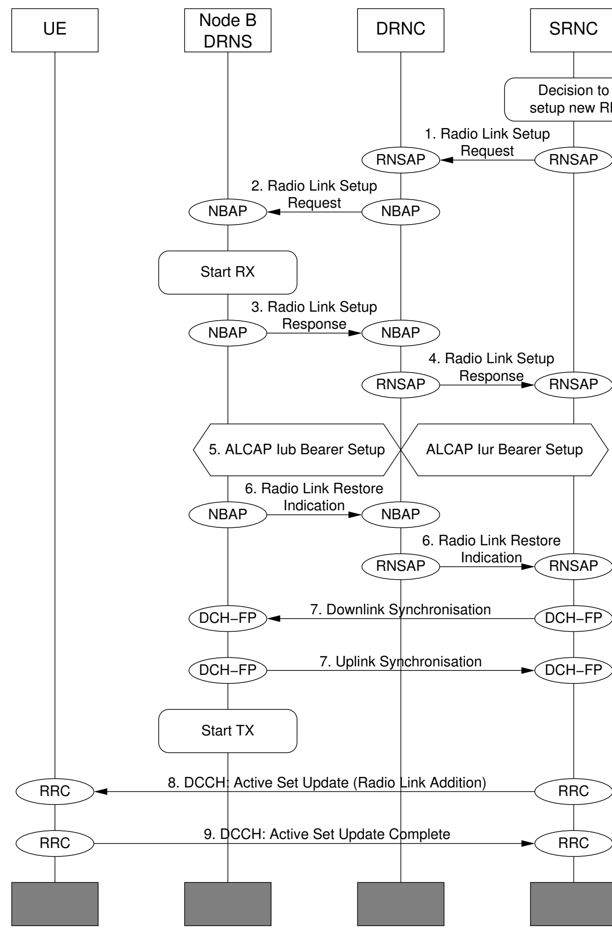

Fig. 6. Radio link addition [7]

The SRNC initiates the setup of the Iur/Iub data transport bearer using the *Access Link Control Application Protocol* (ALCAP) (5.). This request contains the ATM binding identity to bind the Iub data transport bearer to the *Dedicated Channel* (DCH). This may be repeated for each Iur/Iub data transport bearer to be setup.

When the Node B achieves UL synchronization on the Uu interface, it notifies the DRNC with a NBAP message **Radio Link Restore Indication**. In its turn the DRNC notifies the SRNC with an RNSAP message **Radio Link Restore Indication** (6.).

By exchanging the *DCH Frame Protocol* (DCH-FP) messages **Downlink Synchronization** and **Uplink Synchronization** the Node B and SRNC establish the synchronism for the data transport bearer(s) relative to already existing radio link(s) (7.). The Node B starts with the transmission in DL.

The RRC message **Active Set Update** (Radio Link Addition) is sent to the UE (8.). The SRNC sends this message on the *Dedicated Control Channel* (DCCH) with the appropriate connection information. After updating the active set, the UE confirms the update with the RRC message **Active Set Update Complete** (9.).

The radio link is now added to the active set and is used for transmission and reception of radio signals. Some of the above steps may be left out if the new Node B is connected to the same RNC as the currently involved Node B or if the Iur interface to the DRNC is already existing.

B. Deleting a Radio Link

Radio link deletion is triggered if the decision measure is outside the reporting range 1b R_{1b} with respect to hysteresis H_{1b} for the TtT period as illustrated in Fig. 7. The timer is started at ①, gets stopped again at ②, and finally triggers the measurement report at ③.

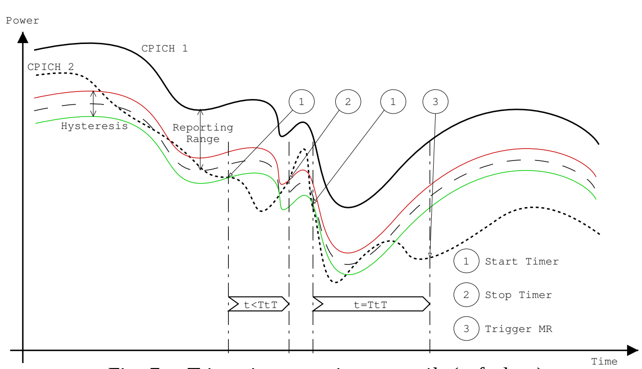

Fig. 7. Triggering reporting event 1b (soft drop)

When the UE has sent an appropriate measurement report, the SRNC decides to remove the link from the radio set. Once again, the case of an inter-RNC SHO is considered for explanation. The necessary steps are depicted in Fig. 8.

The SRNC sends the RRC message **Active Set Update** (Radio Link Deletion) to the UE on the DCCH (1.). The update type and cell ID parameters are transmitted. The UE deactivates the DL reception via the old branch, and acknowledges with the RRC message **Active Set Update Complete** (2.).

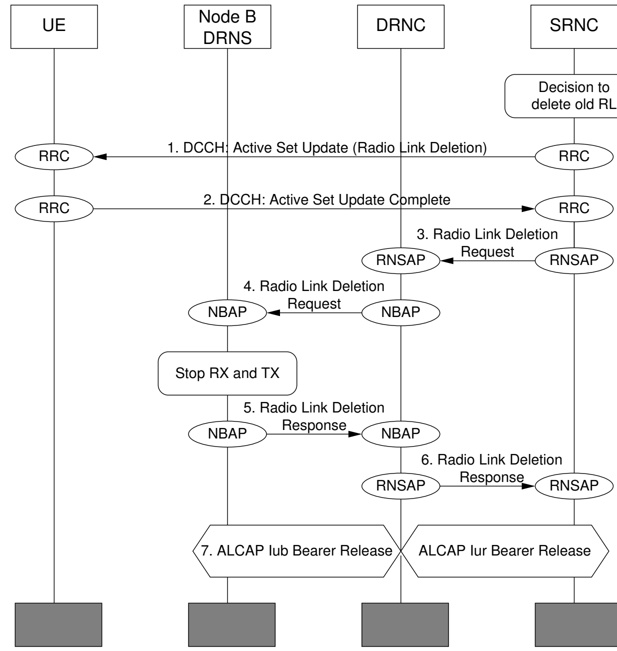

Fig. 8. Radio link deletion [7]

The SRNC requests the DRNC to deallocate the radio resources by sending the RNSAP message **Radio Link Deletion Request** (3.). In its turn the DRNC sends the NBAP message **Radio Link Deletion Request** to Node B (4.).

The Node B deallocates the radio resources. Successful outcome is reported in the NBAP message **Radio Link Deletion Response** (5.). The DRNC sends the RNSAP message **Radio Link Deletion Response** to the SRNC (6.).

The SRNC initiates the release of the Iur/Iub Data Transport Bearer using the ALCAP protocol (7.).

C. Replacing a Radio Link

If the maximum active set size $AS_{\max}$ is reached and a radio link that is not in the active set becomes better than the worst radio link in the active set, the worst radio link is replaced by the radio link that is currently not in the active set (Fig. 9). In this case, only the replace hysteresis H_{1c} and again the TtT are to be defined. Timer starts ① when entering the hysteresis range and timer stops ② when leaving this range are similar to soft add and soft drop. Only if the condition is fulfilled for the TtT interval, the measurement report is initiated ③.

The initial steps to perform the replacement are the same as in the case of radio link addition until the **Active Set Update** message. But in the case of replacing a radio link the RRC message **Active Set Update** (Radio Link Addition & Deletion) is send to the UE. The SRNC sends this message on the DCCH with the physical channel parameters needed for receiving the additional DL.

The reception of the old radio link is deactivated and the reception of the new radio link is activated. The UE acknowledges the active set update with the RRC message **Active Set Update complete**. Following are the same steps as for radio link deletion

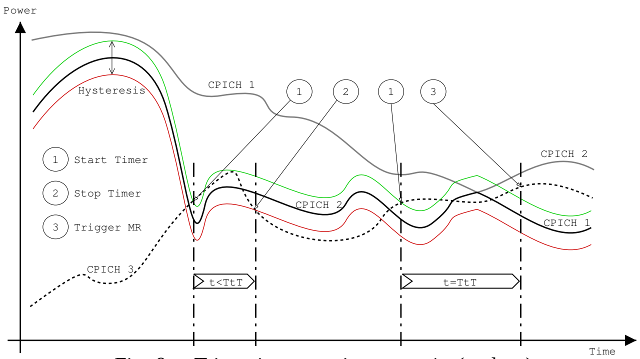

Fig. 9. Triggering reporting event 1c (replace)

III. Simulation Environment

The event-driven *Generic Object Oriented Simulation Environment* (GOOSE) is used for simulation purposes. Fig. 10 depicts the graphical user interface of the tool developed at ComNets. As simulation scenario, a real network deployment in a European metropolitan area is recreated considering 7 Node B positions, propagation characteristics, user's mobility along streets or railways, and antenna patterns [8].

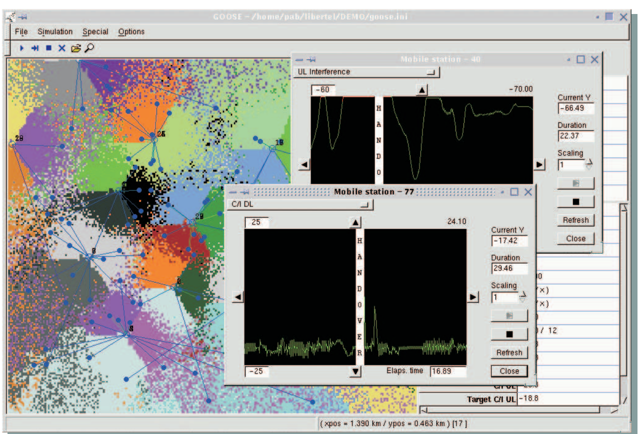

Fig. 10. GOOSE graphical user interface with the simulation scenario

Since SHO is rather a topic for circuit switched connections with longer call durations, speech service at 12.2 kbps is used. The traffic model is a two-state on-off model with a resulting activity of 50% [9].

Simulations are performed in a typical urban area representing the city of Amsterdam as depicted in Fig. 11. The network is configured according to the licensed UMTS frequencies

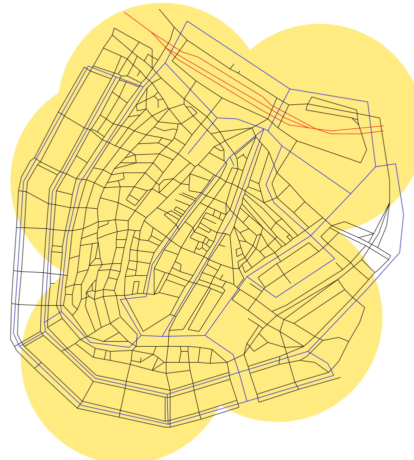

Fig. 11. Simulation area in Amsterdam, Netherlands

in the 2 GHz band. Radio propagation follows the vehicular test environment [9]. Correlated shadow fading with standard deviation 10 dB is considered. SHO parameters are set as follows: TtT ΔT for every SHO action is 2 s, reporting ranges $R_{1a/b}$ for radio link addition and deletion are varied from 1 to 5 dB with a hysteresis $H_{1a/b}$ of 1 dB. The replacement hysteresis H_{1c} is set to 3 dB in every case which means that a new signal has to be received with twice the level of the existing link for TtT before executing the handover (see Tab. I).

TABLE I SHO Parameters

Parameter		Value(s)
R_{1a}	Reporting range 1a (soft add)	1, 3, 5 dB
H_{1a}	Hysteresis 1a	1 dB
R_{1b}	Reporting range 1b (soft drop)	1, 3, 5 dB
H_{1b}	Hysteresis 1b	1 dB
H_{1c}	Hysteresis 1c (replace)	3 dB
$AS_{\max}$	Maximum active set size	1, 2, 3
ΔT	Time to Trigger (TtT)	2 s

IV. Simulation Results

In order to estimate the overhead introduced by SHO, the event rates (add, drop, replace), the average active set size $\overline{AS}$, and the fraction of connections being in SHO are collected in Tab. II. With decreasing $R_{1a/b}$, SHO transport network overhead can be reduced. In case of $R_{1a/b} = 5$ dB, UE are in SHO for about 55% of the time and $\overline{AS}$ is 1.7 whereas for $R_{1a/b} = 1$ dB, only 20% of the UE are in SHO and $\overline{AS}$ is 1.22. Signaling overhead can be estimated from the reporting event rate. Almost independent from SHO parameterization, the add and drop rate are 3–4 min^{-1} (per active connection). The replace rate is quite low if $AS_{\max} = 3$. For $AS_{\max} = 2$, we counted more than one replace event per minute. In case of disabled SHO ($AS_{\max} = 1$), replacements, i.e. hard handovers, are frequently performed with 3.84 min^{-1}.

The network operators intend to provide certain *Quality of Service* (QoS) to their customers. Therefore, criteria are defined in [9] to evaluate the satisfaction of the user which is related to call admittance (no blocking), connection quality (no

TABLE II SHO Event Rates and Performance Measures

Name	Add [min^{-1}]	Drop [min^{-1}]	Replace [min^{-1}]	Active set size	Time [%]
SHO_5dB_A3	3.93	3.66	0.37	1.72	55
SHO_3dB_A3	3.93	3.75	0.17	1.46	38
SHO_3dB_A2	3.01	2.86	1.01	1.38	38
SHO_3dB_A1	0.00	0.00	3.84	1.00	0
SHO_1dB_A3	3.36	3.30	0.02	1.22	20

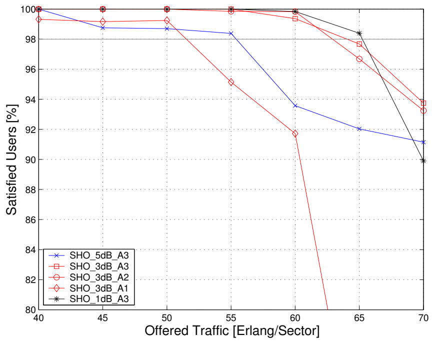

Fig. 12. Satisfied users in the network

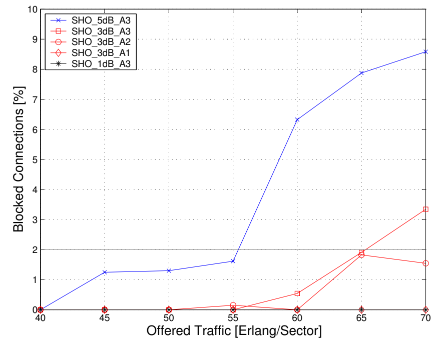

Fig. 13. Blocked connections

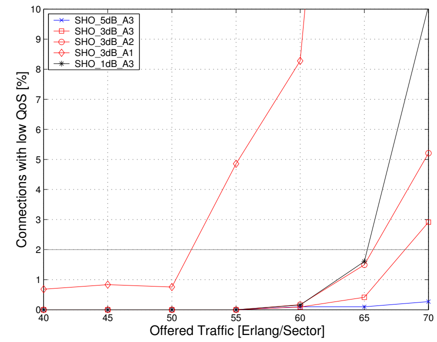

Fig. 14. Connections with insufficient QoS

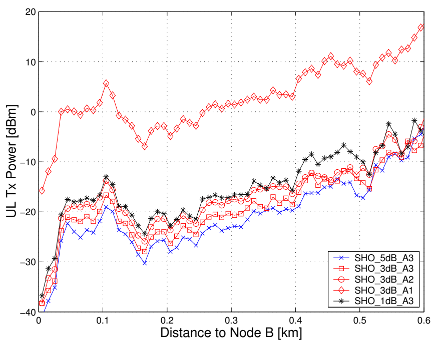

Fig. 15. Uplink Tx power at 60 Erlang/Sector

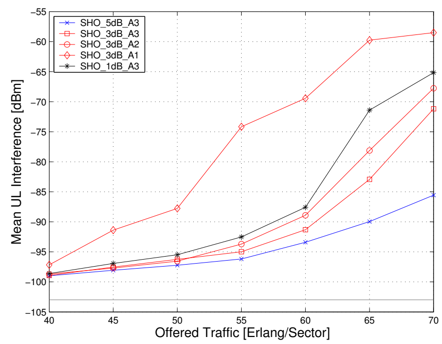

Fig. 16. Uplink interference (noise rise)

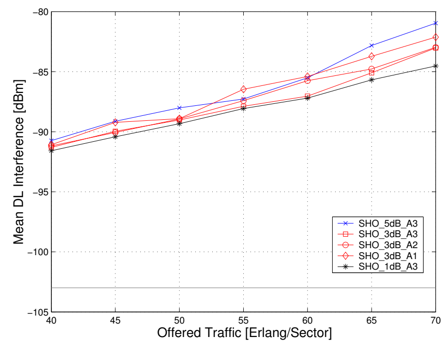

Fig. 17. Downlink interference (noise rise)

failure and sufficient voice quality) and handover success (no call abort). Satisfied users are taken into account to estimate the performance of different SHO parameters. Fig. 12 shows the fraction of satisfied users at different offered traffic.

On the one hand unsatisfied users are due to call blocking in the case of high $R_{1a/b}$ (Fig. 13) because SHO requires additional code resources in DL. On the other hand insufficient QoS is caused by restricted SHO functionality, i.e. small AS_{max} or a low $R_{1a/b}$, leading to small diversity gain (Fig. 14). This trade-off has to be taken into account for defining the optimal SHO parameters.

Carefully defined, SHO reduces UL transmission (Tx) power as illustrated in Fig. 15 and with this UL interference (Fig. 16). The higher the offered traffic, the clearer the advantage of SHO (keeping in mind that a lot of connections are already blocked for higher $R_{1a/b}$).

In DL, situation is different as presented in Fig. 17. Since code orthogonality is available, DL interference is generally lower. But with more users in SHO, increased transmission power is needed and interference rises. SHO offers still a little improvement compared to the hard handover but not for all the users. The network is running out of resources soon and with that serves less users.

V. Conclusion

It is presented that SHO significantly can improve the connection quality in UL. While benefiting from the diversity gain, transmission power and interference can be reduced and UE battery lifetime and network capacity is increased. On the other hand, SHO requires additional resources and transmission power in DL which leads to higher blocking probabilities. We therefore propose to parameterize small reporting ranges in DL and larger values in UL. As long as the standard supports only a common reporting range, a value between 1–3 dB is recommended with $AS_{\text{max}} = 3$.

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