I INTRODUCTION

Mobility is the main advantage of mobile cellular systems. Ability to communicate anywhere, at any time was the main reason for great success of wireless communications in 90’s. Handover is a key concept in providing mobility. Term handover stands for event when mobile station starts to communicate with another base station. It makes possible for a user to travel from one cell to another, with no interrupt - seamless connection.

In GSM system, handover was realized in a way that mobile station stops communication with serving base station and after short disconnection passes to another base station, so called "break before make" concept or hard handover. In UMTS we have soft handover, which is technique whereby mobile station – UE (user equipment in UMTS) in transition from one cell to another communicates with both base stations – (Node B in UMTS) simultaneously. Softer handover is very similar to soft handover; the difference is that in softer handover UE communicates with two sectors of the same Node B.

The Soft Handover procedure is composed of several functions: measurements, filtering of measurements, reporting of measurement results, the soft handover algorithm and execution of handover.

In UMTS system, UE measures level of CPICH (Common Pilot Channel) of neighbour cells, and handover decision is based on these measurements. Monitoring set can hold up to 32 inter-frequency cells. Cells from monitoring set are periodically checked against so called “triggering conditions” defined in soft handover algorithm. In order to understand the soft handover algorithm, it is necessary to introduce some new parameters:

- AS_Th: Threshold for macro diversity (reporting range)
- AS_Th_Hyst: Hysteresis for the above threshold
- AS_Rep_Hyst: Replacement Hysteresis
- \( \Delta T \): Time to Trigger
- AS_Max_Size: Maximum size of Active Set

Instead of serving base station, here we have term Active Set, which presents several base stations with whom UE communicates during soft handover. The soft handover algorithm is described on Figure 1. We can see that neighbour Node B can enter to Active Set in case that difference between level of CPICH from best serving Node B and candidate Node B is less than AS_Th - AS_Th_Hyst during \( \Delta T \). Condition for deleting Node B from Active Set is that difference between level of CPICH from best serving Node B and candidate Node B raise over AS_Th + AS_Th_Hyst during \( \Delta T \). Condition for replacing one Node B with another is that level of candidate Node B CPICH is larger then level of CPICH from replacing Node B for AS_Rep_Hyst during \( \Delta T \).

II SOFT HANDOVER AND COVERAGE

As it was described in previous chapter, in case of soft handover we have macro diversity. Signals from several Node B’s are combined in RNC (the best one is selected). We will analyse macro diversity gain in this chapter.

If one of conditions mentioned above is fulfilled, UE will report to UTRAN. Entire evaluation process – soft handover algorithm happens in UE. This type of handover is called mobile assisted handover. Report does not contain measurement results, only action proposal (f.e. Node B replacement) which might be approved or denied, by Call Admission Control in RNC.

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**Figure 1. Soft handover algorithm**
transmission power by some amount. The amount by which transmission power should be raised is fade margin. We will analyse fade margin in case of hard and soft handover.

We will start with standard model of propagation attenuation:

\[ \alpha(r, \zeta) = 10\mu \log r + \zeta \]  

(1)

The first component in equation 1 is loss due to propagation (\( \mu \) is path loss exponent and \( r \) is UE distance from Node B) and the second one is loss due to shadowing (\( \zeta \) is modelled as zero mean Gaussian variable with standard deviation \( \sigma \)). Desired performance is not achieved whenever propagation attenuation is greater than fade margin. In case of one serving Node B outage probability is:

\[ P_{\text{out}} = P(10\mu \log r + \zeta > \gamma) \]  

(2)

In case of two serving Node B's the desired performance is not achieved whenever the lesser of two attenuation is greater than the fade margin. Outage probability is in that case:

\[ P_{\text{out}} = P(\min[10\mu \log r_1 + \zeta_1, 10\mu \log r_2 + \zeta_2] > \gamma) \]  

(3)

It is obvious that fade margin will be smaller in case of soft handover. In [3] was shown that for outage probability of \( P_{\text{out}} = 0.1 \) and \( \sigma = 8\text{dB} \), fade margin is 10.3 dB for hard and 6.2 dB for soft handover. Fade margin reduction means cell area increase, so we can conclude that soft handover brings coverage improvement.

Soft handover impacts interference as well. Macro diversity gives possibility to transmit with lower power. Figure 2. taken from [4] shows soft handover gain at transmission power of UE as a function of signal difference from two Node B's, which are in Active Set.

**Figure 2.** Uplink soft handover gain

We can see that best results are achieved when signal levels from two Node B's has equal values. When the difference rises, gain decreases. For large signal value difference we can see that transmission power even raise, because of signalling errors on downlink (power control commands). At hard handover algorithm, handover occurs with delay because of hysteresis, which additionally enlarges interference.

### III SOFT HANDOVER AND DOWNLINK CAPACITY

Realization of soft handover on the downlink is different comparing uplink. The main difference is that without soft handover feature, only one Node B transmits signal to UE. Soft handover gain has to be paid by transmitting signals from several Node B's. It was shown in [2] that downlink system capacity is limited with Node B's transmission power. On the other hand, in order to maintain soft handover, additional signalisation on downlink is needed, which additionally raises power consumption of Node B. We will try to model impact of soft handover parameters on power consumption.

If we ignore thermal noise, SIR ratio in receiver in UE without soft handover can be expressed as:

\[ \frac{E_b}{I_0} = \frac{W}{\nu \cdot R \cdot P_{S} \cdot L_1} + \sum_{n} P_{T_n} \cdot L_n \]  

(4)

where \( W \) is chip rate, \( \nu \) is activity factor, \( R \) is bit rate, \( P_{S} \) is Node B transmission power dedicated to UE, \( P_{T_n} \) is total transmission power of n-th Node B, \( L_n \) is attenuation on propagation path from n-th Node B to UE. Required BS transmit power can be derived as:

\[ P_{S} = \left( \frac{E_b}{I_0} \right)_{\text{target}} \cdot \frac{\nu \cdot R}{W} \cdot P_{T_1} \cdot (1-a) + \sum_{n} \frac{L_n}{L_1} \]  

(5)

Last formula can be written as:

\[ P_{S} = \beta_1 \cdot \left( \frac{E_b}{I_0} \right)_{\text{target}} \cdot \frac{\nu \cdot R}{W} \cdot P_{T_1} \]  

(6)

where

\[ \beta_1 = \left[ (1-a) + \sum_{n} \frac{L_n}{L_1} \right] \]  

(7)

Factor \( \beta_1 \) depends on propagation conditions, and the rest in formula (7) depend on type of service.

Let's consider situation when UE communicates during soft handover with two Node B. We have maximum ratio combining in the receiver, so received SIR is:

\[ \left( \frac{E_b}{I_0} \right)_{\text{total}} = \left( \frac{E_b}{I_0} \right)_{1} + \left( \frac{E_b}{I_0} \right)_{2} \]  

(8)

\[ E_b = \frac{W}{\nu \cdot R} \left[ \frac{P_{S} \cdot L_1}{P_{T_1} (1-a) L_1 + \sum_{n} P_{T_n} \cdot L_n} + \frac{P_{S} \cdot L_2}{P_{T_2} (1-a) L_2 + \sum_{n} P_{T_n} \cdot L_n} \right] \]  

(9)
According to 3GPP recommendations [5], power control algorithm will try to avoid power drifting and maintain equal power on BS transceivers for UE in soft handover state, so we can assume $P_{s1} = P_{s2}$. Also, we will assume that users are uniformly distributed – we will assume same load for cells, which means same total transmitting power $P_{T1} = P_{T2} = P_{Tn}$. In such case:

$$P_{s1} = P_{s2} = \frac{\nu R \left( \frac{E_b}{I_0} \right)_{target} P_T}{1 + \frac{1}{1 - a} \sum_{n} \frac{L_n}{L_1} + \frac{1}{1 - a} \sum_{n} \frac{L_n}{L_2}} \quad (10)$$

Total transmission power dedicated to UE can be written, similar to (7) as:

$$P_s = \beta_2 \left( \frac{E_b}{I_0} \right)_{target} \frac{\nu \cdot R}{W} P_T \quad (11)$$

where:

$$\beta_2 = \frac{2}{1 + \frac{1}{1 - a} \sum_{n} \frac{L_n}{L_1} + \frac{1}{1 - a} \sum_{n} \frac{L_n}{L_2}} \quad (12)$$

In case of three Node B soft handover, factor $\beta_3$ is:

$$\beta_3 = \frac{3}{1 + \frac{1}{1 - a} \sum_{n} \frac{L_n}{L_1} + \frac{1}{1 - a} \sum_{n} \frac{L_n}{L_2} + \frac{1}{1 - a} \sum_{n} \frac{L_n}{L_3}} \quad (13)$$

Factors $\beta_1$, $\beta_2$ and $\beta_3$ indicate power consumption, and we can see in formulas (7), (12) and (13) that they depend on propagation – path loss from serving and neighbour base stations. In order to investigate connection between power consumption and soft handover parameters, we calculated $\beta_1$, $\beta_2$ and $\beta_3$ factors. Since UMTS base stations are going to be co-sited with GSM base stations, we decided to use drive test measurements of DCS signal (GSM on 1800 MHz) as input for calculations.

**IV RESULTS**

Figure 3. shows drive test route with base station sites and antenna azimuths. Soft handover zones are presented, for $AS_{Th} = 3 \text{ dB}$ and $AS_{Max\_Size} = 3$.

Table 1. presents overhead as function of $AS_{Th}$ parameter. We will notice at this point that Holma and Toskala in [4] recommend that overhead should not be more than 30% - 40%, which in case of Belgrade downtown and presented cell plan corresponds for to $AS_{Th}$ parameter values of 4 dB or 5 dB.

<table>
<thead>
<tr>
<th>$AS_{Th}$</th>
<th>1 dB</th>
<th>2 dB</th>
<th>3 dB</th>
<th>4 dB</th>
<th>5 dB</th>
<th>6 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead [%]</td>
<td>10.6</td>
<td>16.2</td>
<td>23.1</td>
<td>28.5</td>
<td>34.5</td>
<td>40.3</td>
</tr>
</tbody>
</table>

At the beginning, we compared power consumption in case of UE connected to best server only and UE in soft handover, for different soft handover parameters. If $n=1$ is best server Node B, then we have:

$$\sum_{n \neq 1} \frac{L_n}{L_1} \leq \sum_{n \neq 2} \frac{L_n}{L_2} \quad (14)$$

If we apply (14) in calculations of $\beta_1$ and $\beta_2$, it is not hard to prove that $\beta_2 > \beta_1$. Hence we have power consumption growth. Figure 4. shows power consumption growth as function of $AS_{Max\_Size}$ and $AS_{Th}$ parameters. We can see that power consumption growth is larger for $AS_{Max\_Size} = 3$ comparing $AS_{Max\_Size} = 2$, and it is larger for higher values of $AS_{Th}$ as well.
Power consumption growth presented in previous figure was derived comparing situation when UE is connected to best server. But in case of hard handover, UE will not always be connected to best server, because of several reasons:

- Measurements are passing through filter, which cause some delay of decision
- Handover procedure is not immediate procedure, it need some time
- When we set AS_Max_Size = 1, fact that neighbor cell signal is stronger is not enough for handover - difference must be higher than AS_Th. Similar in GSM, we had parameter ho_margin.

Problem of UE, which is not connected to best server, is not new. We encountered it even with GSM system with fractional load planning implemented as frequency planning technique (frequency hopping 1-1, see [7]).

If we focus on AS_Th, we can assume that in case of difference between serving cell signal level and best neighbour signal level is less than AS_Th, probability of UE is served by the best server is 50%, and in 50% of cases it is not served by the best server. With such assumption:

$$\beta_{\text{HARD}} = \frac{1}{2} \left( 1 - a \right) + \sum_{n=1}^{L_2} \frac{L_n}{L_2} \left( 1 - a \right) + \sum_{n=2}^{L_2} \frac{L_n}{L_2}$$

(15)

If we compare power consumption for AS_Max_Size = 2, 3 with hard handover (AS_Max_Size=1), we can see that soft handover brings benefit, since power consumption is smaller, and downlink capacity is improved. Capacity gain as function of AS_Th parameter is presented on figure 5.

V CONCLUSION

Soft handover improves coverage, which is uplink limited. On the other hand, soft handover may cause base station power consumption growth and decrease downlink capacity. We believe that soft handover should be encouraged immediately after UMTS network launch, since we can expect problems with coverage at the beginning. But, with traffic growth, soft handover parameters should be optimised from downlink capacity point of view. According results of investigation, parameter AS_Max_Size should be set to two Node’s B- AS_Max_Size = 2, since power consumption is higher for AS_Max_Size = 3, and improvement that soft handover brings comparing hard handover is achieved with soft handover with two Node’s B already. Parameter AS_Th should be 3dB or 4dB.

REFERENCES