SIMULATING SOFT HANDOVER AND POWER CONTROL FOR ENHANCED UMTS

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ABSTRACT

In this paper we present a soft handover algorithm for wide band CDMA based E-UMTS networks and the associated power control algorithm. The handover and power control algorithms have been developed and implemented in the framework of a system level E-UMTS simulator developed under the IST SEACORN project. The paper provides a background on handover design techniques and explains the handover implementation. The soft handover algorithm has been modeled using the guidelines provided in the standards and the literature for W-CDMA intra-frequency handovers. The combination of established handover techniques with Enhanced UMTS is a novelty feature of this paper and provides a reference for further performance comparison.

I. INTRODUCTION

The rapid growth of mobile and Internet users has led toward the development of the 3rd generation of mobile communication systems (3G). The Universal Mobile Telecommunication Systems (UMTS) is a family of 3G mobile networks designed to offer high bandwidth radio access [1][2].

Enhanced UMTS (E-UMTS) is a UMTS evolution step, which makes possible an effective high data rate end-to-end packet based transmission. IST-SEACORN has proposed a set of enhancements to UMTS, which include, among others, advanced modulation and radio transmission techniques, improved strategies for IP routing and QoS assurance [3][4].

The envisioned high-rate multimedia applications have a wide range of Quality of Service (QoS) requirements. Handling services with various QoS requirements, as well as multiplexing them in a multi-service environment is essential. Multimedia traffic puts heavy bandwidth demand on the cellular network. In order to increase the spectrum utilization, and effective system capacity, micro-cellular and pico-cellular networks are deployed. It has been shown in [5] that the number of cell boundary crossings is inversely proportional to the cell size. Since the mobile node has a certain probability of failure each time a handoff is attempted, it is clear that handoff algorithms must become more robust and reliable as the cell size decreases.

Handover algorithms are an integral part of the different radio resource management (RRM) techniques employed in E-UMTS [6]. Another RRM which is closely related to handovers is Power Control.

In this paper we present a soft handover algorithm for wide band CDMA based E-UMTS networks and the associated power control algorithm. The handover and power control algorithms have been developed and implemented in the framework of a system level E-UMTS simulator developed under the IST SEACORN project. The soft handover algorithm has been modeled using the guidelines provided in the standards and the literature [7][8][9][10] for W-CDMA intra-frequency handovers. This work is novel in that it investigates and presents results on the workings of a “traditional” handover technique in conjunction with Enhanced-UMTS. This provides the ability to researchers to have known reference in their investigation of the performance of E-UMTS.

The paper is organized as follows. In section II we discuss handover design issues and introduce the concept of power control. In section III we describe the proposed soft handover algorithm and its implementation. In section IV we present sample simulation results, and in section V we draw some conclusions for this work.

II. BACKGROUND

- *HANDOVER*

The handover process is one of the essential means that guarantees user mobility in a mobile communication network. The concept of mobility is simple. When a subscriber moves from the coverage area of one cell to another, a new connection with the target cell is set up and the connection with the previous cell is released.

A basic handover process consists of three main phases: (a) measurement phase, dealing with the mechanics of measuring important parameters, (b) decision phase, dealing with the algorithm parameters and handover criteria and (c) execution dealing with radio resource allocation and handover signaling.

1. Operating Environment

A handoff algorithm needs to be designed with the operating radio environment in mind in order to define the correct parameters needed in the decision phase. Operating environments are usually separated as:

- Indoor: low speeds and well-defined mobility paths
- Outdoor: variable speeds and mobility paths that depend on each environment separately.

A further classification of environments can be made according to their cell size:

- Pico-cellular and micro-cellular environments: characterized by small cells and low transmit powers. In pico-cellular both users and base stations are located indoors, whereas in micro-cellular only outdoor users are considered. The antenna height in a microcellular environment is typically at lamppost level (5m above ground).
- Macro-cellular environments have large cells (several kilometres) and transmit high output power with the antenna mounted on a high tower above all surrounding rooftops (15m+ above ground).

Because of the large coverage area the cell crossings in a macrocell are low and the transition area between two adjacent base stations is large. This feature requires handoff algorithms to allow some delay in changing cells to avoid a ping-pong effect. The handoff delay is important to be maintained small in order to prevent an increase in co-channel interference and degradation of the signal quality due to distortion of the cell boundaries when the mobile node penetrates into an adjacent cell.

Microcells are more sensitive to short-term traffic and interference variations than macrocells. Because of the low power and smaller range, handoffs are more frequent by an order of magnitude, and need to be performed at a faster time scale [10].

2. Handover Trigger Criteria

The basic reason behind a handover is that the air interface does not fulfil anymore the desired criteria set for it and thus either the UE or the UTRAN initiates actions in order to improve the connection.

There are a number of criteria that indicate the need for a handover operation to be performed. The handover execution criteria depend mainly upon the handover strategy implemented in the system. However, most criteria behind the handover activating rest in the signal quality, user mobility, traffic distribution, and bandwidth.

According to [11] most handover algorithms use the received signal strength power as the link quality measurement for handoff decisions. Different types of decisions can be taken:

- Execute a handoff to an alternate BS if the received signal measured over a time interval, exceeds that of the serving BS by a threshold H (hysteresis).
- Execute a handoff if the measured signal strength of the serving node drops below a threshold $T_L$while there is a higher signal from another base station
- Avoid a handoff if the measured signal strength of the serving BS is above a threshold T_h even if the alternate BS is stronger by the hysteresis threshold H.

One drawback of using the signal strength is the inability to distinguish between carrier strength (S) and interference strength (I) and uses the combined carrier+interference (S+I) in the decision making. Alternatively if signal to interference ratio (SIR), bit error rate, or distance from the BS are used the distinction may be done in a better way. The combined strength is used because of its simplicity and good performance in macrocellular systems. SIR is more desirable for microcellular systems.

In addition to the measurement parameter, two equally important parameters in a handover algorithm are the hysteresis and the window length over which the signal is averaged.

The signal strength averaging can be done by analog averaging over the window length, or more practically, using samples of the signal strength. In the latter we must define the required number and spacing of samples so that the effects of fading are mitigated. There is no specific formula for the determination of the hysteresis value, besides the guideline of keeping it well below the shadow standard deviation ~6dB.

- *POWER CONTROL*

Power Control has a dual operation. Firstly, it keeps interference at minimum levels by controlling the power transmitted, achieving further to minimize the power consumption at the mobile user (called User Equipment (UE) in UMTS) and the base stations (called Node Bs in UMTS). Secondly, it ensures an adequate quality of service (QoS) level so that the percentage of dropped calls is kept below the acceptable thresholds.

Power Control is important both in the uplink and the downlink directions. In the uplink direction control is required in the situations where UEs are located very close to the Node Bs and are transmitting with excessive power. This is called the near-far effect and can result in blocking the whole cell, with UEs that are close to the cell edge possibly overlooked. If the uplink power is too high interference in neighbouring cells (inter-cell interference) may also be a direct result of the near-far effect. In the downlink direction, Power Control directly affects system capacity. System capacity is determined by the total downlink transmission power for each cell i.e. when total downlink transmission power is minimized then the Node B can accept more UEs and the capacity is increased.

Therefore, it is essential to keep the transmission at a minimum level while ensuring adequate signal quality and level at the receiving end (UE) [3] [8].

There are three types of Power Control algorithms that are normally implemented in a mobile network. The Open-loop Power Control is responsible for setting the initial uplink and downlink transmission powers when a mobile terminal is accessing the network. The Inner-loop Power Control, also called fast closed-loop power control, adjusts the transmission powers dynamically at very small time intervals, based on SIR targets. The third Power Control algorithm is called Outer-loop Power Control and it estimates the received quality and adjusts the target SIR, in both the uplink and downlink directions. It operates at longer time intervals than the inner loop and aims at keeping the system operating stable.

III. SOFT HANDOVER ALGORITHM

In this section we provide a description of the implemented algorithm with the specific values for the thresholds and sampling intervals.

Prior to analyzing this algorithm, we will explain some terminology used in the description. First, by the term *Soft Handover* we mean that the mobile node is maintaining connections with more than one base stations. The *Active Set* includes the cells that form a soft handover connection to the mobile station. The *Neighbor/Monitored Set* is the list of cells that the mobile station continuously measures, but their signal strength is not powerful enough to be added to the *Active Set.*

The determination of the Active Set is based on the following conditions:

- If the signal strength of the measured quantity (not currently in the Active Set) is greater than the strongest measured cell in the Active Set (subtracting the soft handover threshold) for a period t (t = time to trigger) and the Active Set is not full, the measured cell is added to the active set. This event is called Link Addition.
- If the signal strength of the measured quantity (currently in the Active Set) is less than the strongest measured cell in the Active Set (subtracting the soft handover threshold) for a period t, then the cell is removed from the Active Set. This event is called Link Removal.
- If the Active Set is full and the strongest measured cell in the Monitored Set is greater than the weakest measured cell in the Active Set for a period T, then the weakest cell is replaced by the strongest candidate cell (i.e. the strongest cell in the Monitored Set). This event is called Combined Radio Link Addition and Removal.

- *IMPLEMENTED ALGORITHM*

With respect to the handover trigger criteria described in II.2, the implemented algorithm samples the signal strength of the surrounding base stations every 1 sec and uses 3dB as the threshold for soft handover and 6dB as the threshold for hard handover. The size of the Active Set may vary but usually it ranges from 1 to 3 signals. In this implementation it was set at 3. The algorithm is displayed below in its final format.

1. Each UE is connected to its *Primary_BS*, and keeps an *Active_ Set* (2 "closest" cells based on the conditions explained above)
2. Each UE measures the SIR received from the surrounding cells.
3. If (AS1_SIR – Pr_BS_SIR) >3dB OR (AS2_SIR – Pr_BS_SIR) > 3dB
   a. UE enters Soft Handover
   b. UE keeps a simultaneous connection to the *Primary_BS* and one or both of the *Active_Set* cells
4.
   a. If (AS1_SIR – Pr_BS_SIR) > 6dB for three measurements in a row: AS1 becomes the *Primary_BS*
   b. If (AS2_SIR – Pr_BS_SIR) > 6dB for three measurements in a row: AS2 becomes the *Primary_BS*
5. Neighboring cells replace the cells in the *Active_Set* if their SIR exceeds the *Active_Set* cells' SIR by 6dB.

The combination of the soft handover algorithm and the fast closed loop power control (FCL PC) algorithms is illustrated in Figures 1 and 2 for the uplink and downlink respectively.

In the uplink direction the value for UE_Trx_Power_MIN = -49dB and for UE_Trx_Power_MAX = 21dB giving a range of 70dB. The SIR_Target is a value provided by the outer loop power control and aims at providing the necessary quality. The SIR target is affected by the speed of the mobile node.

While in the uplink direction, the decision taken by the UE is affecting all base stations in its *Active Set,* in the downlink direction, every base station needs to update its own power. The minimum and maximum values of BS_Trx_Power are not constant as in the uplink case, but are ±30dB from the initial downlink BS_Trx_Power. The total BS_Trx_Power of each base station for all UEs in its cell is specified at 46dB. Again, the SIR_Targe is defined by the outer loop power control

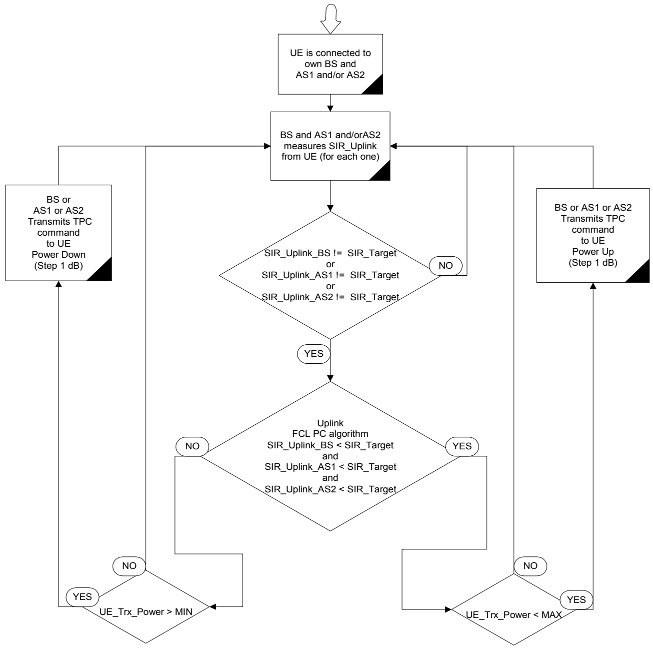

Figure 1: Fast Closed Loop Power Control - Uplink

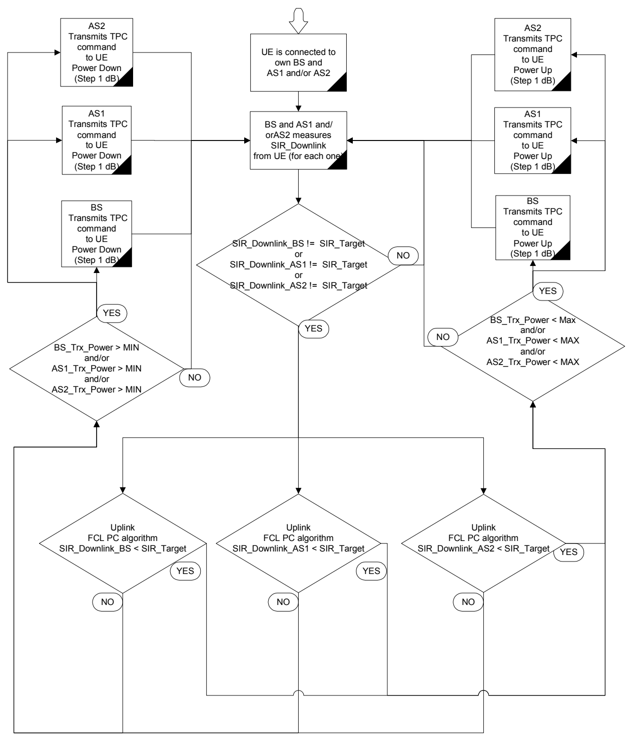

Figure 2: Fast Closed Loop Power Control - Downlink

IV. NUMERICAL RESULTS

There are three basic mechanisms used to evaluate the performance of handoff algorithms: Analytical, simulation, and emulation [12]. In this section a set of simulation results are shown in order to demonstrate how the developed E-UMTS system level simulator integrates and is able to evaluate different RRM algorithms, namely the soft handover and the power control mechanisms described in Section III.

- ### *SIMULATION METHODOLOGY*

The operation of the algorithms was simulated in the event-based system level simulator developed in the IST SEACORN project using ns-2. Each simulation scenario is defined by a variety of parameters. Traffic, propagation and mobility models are defined based on [14]. For the sample scenario, an urban/vehicular environment is modelled, which consists of a macro-cellular topology of size 9000mx5200m. The antennas are omnidirectional and are defined at a height of 15m. The mobile nodes were moving using a Gauss-Markov mobility model and the propagation model used was the COST231 Hata model. Traffic was introduced in the simulation according to a traffic mix combining applications corresponding to sound, high interactive multimedia, narrowband, and wideband services.

Once the environment is created and the mobile nodes are spread in the topology the simulation is run for 1200 sec. Results for five runs of the same scenario initiated with a different random seed are taken and the results are averaged. Simulations were run for mobile node speeds of 50Km/h and 120Km/h.

- ### *SIMULATION RESULTS*

It is important to note that in this sample scenario the power control is affected by the movement of the UE and the handover process, whereas the handover process is only affected by the receiving signal strength at the UE, which is only related to the propagation losses.

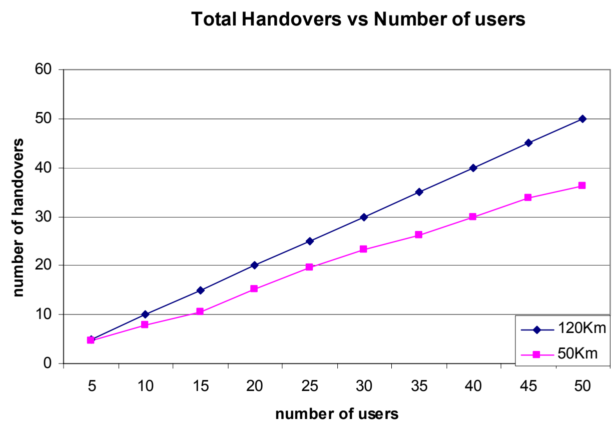

Figure 3: Total handovers per total number of users,

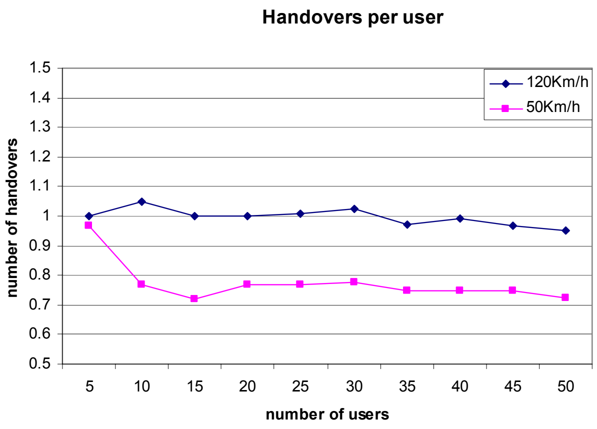

Figure 4: Average handover per user

Figures 3 and 4 show the total number of handovers and the number of handovers per user as the number of users per cell increases. The simulation results show that the number of handovers per user is not affected much by the total number of users present in the cell. The average value of handover per user is around 1.0 for speeds of 120Km/h and around 0.75 for speeds of 50Km/h. Both sets of results have a variation of ±5%. The total and the number of handovers per user are however affected by the mobility speed. Mobile nodes moving at faster speeds are covering bigger distances in the same amount of time and are more likely to cross a boundary.

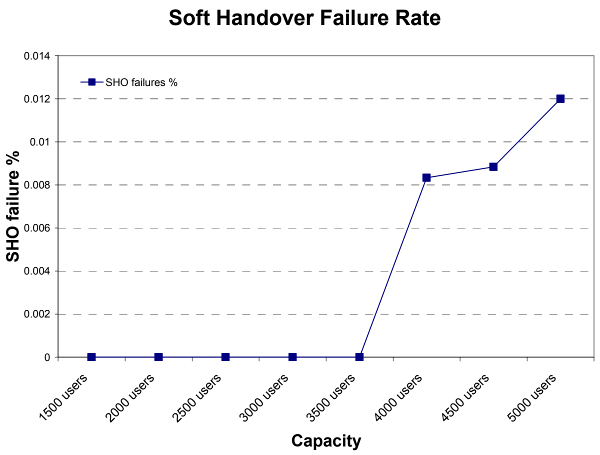

Figure 5: Rate of Soft Handover Failures

Another metric of interest is the number of soft handover attempts which fail without correctly connecting the user to the adjacent cell(s). We would like the number of these events to be minimal. The simulation results confirm just that. The system is behaving correctly and it would take above 3500 users in the 19-cell urban topology (>185 users/cell) to have any soft handover failures (Figure 5). Soft Handover failure rates are less than 0.015% for up to a total user population of 5000 in the same topology.

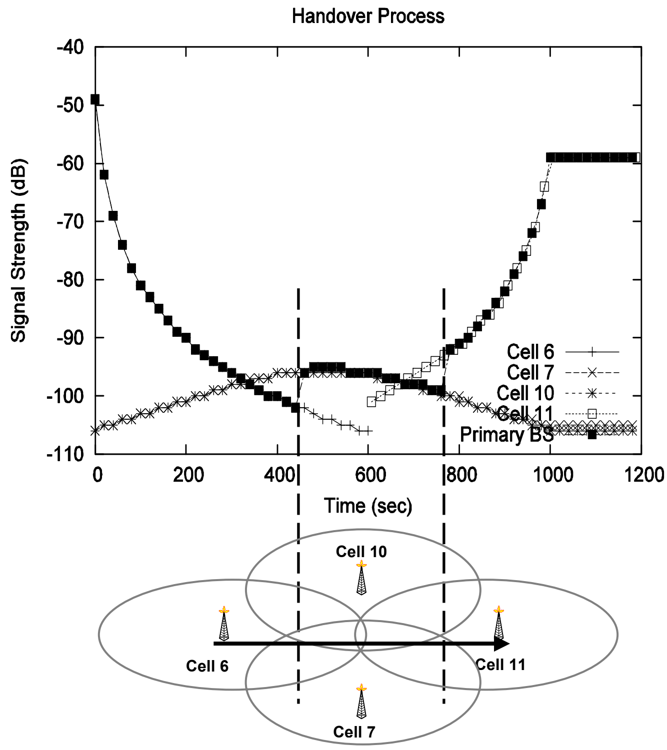

Figure 6: Soft Handover in an E-UMTS Environment

In Figure 6 we monitor the path of a single UE. The particular UE moves from Cell 6 to Cell 11 at a constant speed and on a straight line. Note, in the bottom part of the figure, that the UE crosses the coverage areas of Cells 7 and 10 as well.

In the example of Figure 4, the Primary_BS is cell 6 and cells 7 and 10 constitute the Active_Set. The figure contains the signal strengths of all base stations present in the path of this UE at any time during the simulation. The cell chosen by the UE as the Primary_BS at any given time is also shown.

At 385sec base stations 7 and 10 are included in the Active_Set and a soft handover period exists with base stations 6 and 7 serving the UE simultaneously until 445sec. At that point, Cell 7 becomes the Primary_BS and Cells 6 and 10 constitute the Active_Set. At 610sec Cell 6 is removed from the Active_Set and Cell 11 is included. At 675 a soft handover starts between the Primary_BS (Cell 7) and Cell 11. The handover completes at 775sec and Cell 11 becomes the Primary_BS.

Figure 7 shows the uplink transmit power and the downlink transmit power from each Primary_BS to the UE. The downlink transmit power for each UE is initially 30dB. As soon as the base station takes a reading of the SIR (every 1 second), it changes the downlink transmit power accordingly. In this case, since the UE is close to the base station in Cell 6, the power drops to 13dB. The downlink transmit power is relatively constant through the duration of the UE movement, with the exception of two instances immediately before the start of the soft handovers.

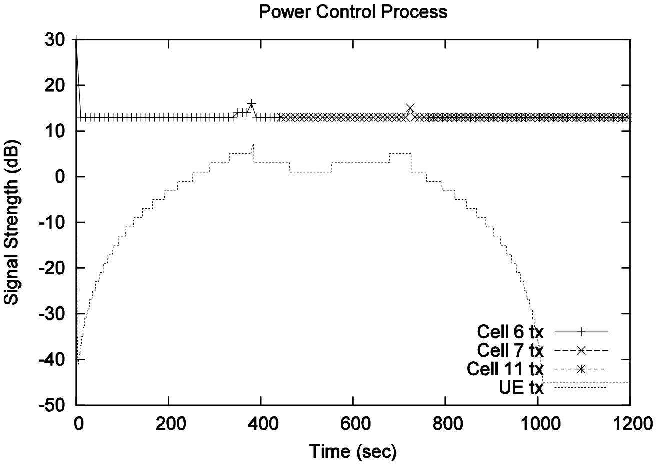

Figure 7: Power Control for the Transmitting Power of Base Stations and the User Equipment

During those moments the downlink transmitting power of the Primary_BS is increased by at most 3dB to maintain the necessary SIR given that the UE is getting out of range. Similarly the UE uplink transmitting power also experiences a slight increase. During the soft handover the signals received by one, or both, base stations of the Active_Set are not considered as interference; therefore the transmitted power drops again.

V. CONCLUSIONS

With the increasing load on cellular systems and the drive for smaller cells and the introduction of hot-spots, there is a clear need for understanding the behavior of handover algorithms and other radio resource management related mechanisms like the power control. This paper presented the design and implementation of a soft handover and its associated power control for use in WCDMA-based Enhanced UMTS networks. Design parameters and decision criteria were discussed, actual implementation parameters were presented and the algorithms for soft handover with and without integrated power control were illustrated. The results show that this implementation follows the design expectations through a step-by-step tracking of a handover and also shows the possibility of analysis options for the future.

VI. ACKNOWLEDGEMENTS

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