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PERFORMANCE ANALYSIS OF HANDOVER MEASUREMENTS AND LAYER 3 FILTERING FOR UTRAN LTE

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ABSTRACT

Handover is one of the key functionalities which tries to keep a user equipment (UE) connected to the best base station (eNodeB). Handover is usually based on the downlink received signal strength (RSS) and carrier-to-interference ratio (CIR) measurements. Processing of the handover measurement is usually done in Layer 1 (L1) and Layer 3 (L3) by the UE, and handover is initiated by the serving eNodeB if certain event criteria are met. L3 filtering can be done in linear domain or decibel (dB) domain. A hard handover algorithm based on the downlink RSS and CIR measurements along with linear and dB domain L3 filtering has been studied by using a dynamic system level simulator for a 3GPP UTRAN LTE recommended scenario. The results suggest that RSS measurement with linear or dB domain L3 filtering is a better criterion for handover in terms of reduced number of handovers for a small penalty on the downlink CIR.

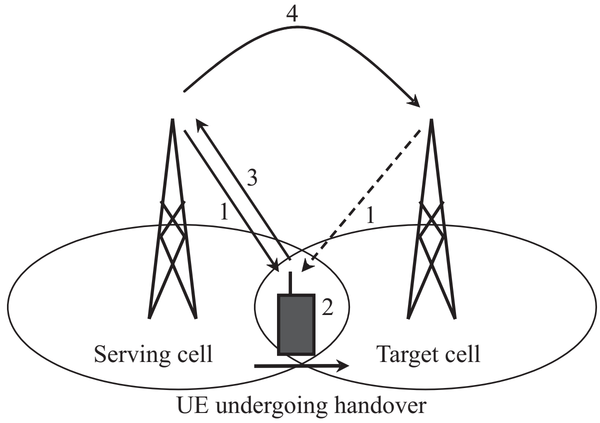


Figure 1: The different parts of handover process. 1) Downlink handover measurements, 2) processing of downlink measurements, 3) uplink reporting, 4) handover decision and execution.

I. INTRODUCTION

Universal Terrestrial Radio Access Network Long-Term Evolution (UTRAN LTE), also known as Evolved UTRAN (E-UTRAN), is a system currently under development within the 3rd Generation Partnership Project (3GPP) [1][2]. One of the main goals of UTRAN LTE is to provide faster and reliable handover from one cell, i.e. serving cell, to another, i.e. target cell. A handover process can typically be divided into four parts: measurements, processing, reporting, and decision and execution as shown in Figure 1. Handover is usually based on the channel measurements which consist of received signal strength (RSS) and/or carrier-to-interference ratio (CIR) [3]. Handover measurements are made in downlink from the serving cell and the neighboring cells and are processed in the user equipment (UE). Processing is done to filter out the effect of fast-fading and Layer 1 (L1) measurement/estimation errors using a Layer 3 (L3) filter. An event based on the processed measurements is reported back to the serving base station (BS/eNodeB) in a periodic or event based manner in uplink using radio resource control (RRC) signaling. Hence a handover is initiated based on the uplink event reporting if certain decision criteria are met. Handover is then executed by transferring the UE control to the target cell performing the network procedures with the assistance of the UE.

In Global System for Mobile communications (GSM) handover is based on received signal strength indicator (RSSI) measurement, while in Universal Mobile Telecommunication System (UMTS) it is either based on common pilot channel (CPICH) RSCP* or CPICH $E_c/N0^\dagger$ [4]. These measurements represent absolute and relative pilot signal strength received at the UE. In [3] it is shown that interference has a strong influence on the signal quality and hence should also be used when making handover decision. This motivates us to study and compare the handover based on RSS and CIR measurements for UTRAN LTE.

The L3 filtering of RSSI in GSM, and CPICH RSCP and $E_c/N0$ in UMTS is standardized to be done in decibel (dB) domain [5]. The performance gain for using dB domain filtering is shown in terms of reduced soft handover region in [6], while it is mentioned in [7] that dB domain filtering leads to delayed handover response. Aforesaid studies have been done for UMTS which supports soft handover, and the same conclusions may not hold true for UTRAN LTE which will support hard handover [2][8]. In this paper we study the difference between linear and dB domain L3 filtering for handover based on RSS and CIR measurements for UTRAN LTE. A realistic estimate of measurement error due to limited number of reference symbols (pilots) is added in the RSS and CIR measurements before L3 filtering. The performance is evaluated for the number of handovers and downlink CIR for UE speed of 3 to 120 kmph. The comparison is done by using dynamic system level simulations.

The rest of the paper is organized as follows. In Section II, handover measurements, filtering, and handover reporting

*Received signal code power (RSCP) is the absolute power level of the CPICH as received by the UE.

$^\dagger E_c/N0$ is the signal energy per chip over noise power spectral density.

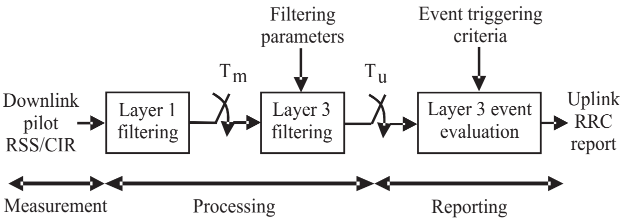


Figure 2: Handover measurement filtering and reporting [4].

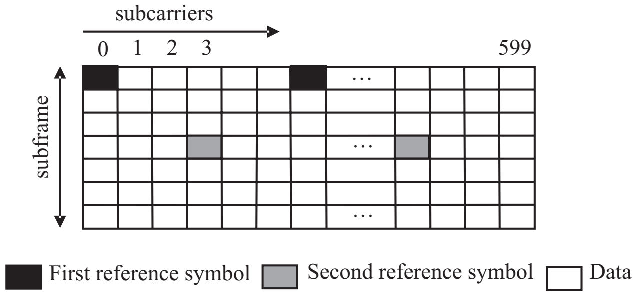


Figure 3: Downlink reference-signal structure for UTRAN LTE [1]

event criterion are analyzed. Handover based on RSS and CIR measurements, and linear and dB domain L3 filtering are evaluated using a dynamic system level simulator described in Section III. In Section IV, simulation results are discussed, and Section V contains the concluding remarks.

II. Handover measurements and filtering

Handover measurement and processing in UTRAN LTE are done in L1 and L3 as shown in Figure 2. The following section presents RSS and CIR measurements for handover, L3 filtering, followed by a realistic measurement error model and the handover event evaluation.

A. *Handover measurements and L1 filtering*

In UTRAN LTE handover measurements will be made at the downlink reference symbols as shown in Figure 3 [1][9]. The UE measures the RSS which includes pathloss, antenna gain, log-normal shadowing and fast fading averaged over all the reference symbols within the measurement bandwidth BW_m. This averaging of fast fading over all the reference symbols is done at L1 (physical layer) and hence is called L1 filtering.

The downlink RSS[‡] from k^{th} cell, RSS_k, is defined in (1), where P is the transmit power of each reference symbol, and G_{kj} is channel gain of j^{th} reference symbol from k^{th} cell.

$$RSS_k = P \sum_{j \in \text{all reference symbols in } BW_m} G_{kj} \quad (1)$$

The downlink received CIR from the k^{th} cell, CIR_k, is defined in (2), where N_0 is thermal noise.

$$CIR_k = \frac{RSS_k}{\sum_{i \in \text{all cells; } i \neq k} RSS_i + N_0} \quad (2)$$

B. *L3 filtering*

The filtered handover measurement of Q (i.e. RSS or CIR), $\overline{Q}$, is updated every handover measurement period (T_m) at the UE as the output of a first order infinite impulse response (IIR) filter as defined in (3). The relative influence on $\overline{Q}$ of the recent measurement and older measurements is controlled by the forgetting factor β. In this paper β is chosen depending on the handover decision update period (T_u) and T_m as $\beta = T_m/T_u$, where T_u is an integer multiple of T_m. T_u is also known as L3 filtering period (or averaging window). Since the successive log-normal shadowing samples are spatially correlated the filtering period is influenced by the degree of correlation present in the signal [10]. The filtering period can be adaptively chosen depending on this degree of correlation present in log-normal shadowing samples. At high speed, for example, the log-normal shadowing samples are not highly correlated, therefore it would be more accurate to have a shorter filtering period than for slow speed users in order to follow the log-normal shadowing.

$$\overline{Q}(n) = \beta Q(n) + (1-\beta)\overline{Q}(n-1) \quad (3)$$

In (3), the filtering is said to be "linear filtering" when Q and $\overline{Q}$ are expressed in linear units, while, when they are expressed in dB, the filtering is said to be "dB filtering".

C. *Handover measurement accuracy*

The limited number of reference symbols available in handover measurement bandwidth for RSS and CIR measurements introduces measurement error. This error is modeled as normally distributed in dB (log-normal) with zero mean and σ dB standard deviation as defined in (4) [11]. If Q is measured in dB the measurement error in (4) is added to it before the L3 filtering. While if Q is measured in linear domain the measurement error in linear domain ($\sim 10^{\Delta Q/10}$) is multiplied to it. For smaller measurement bandwidth (i.e. lower number of ref-

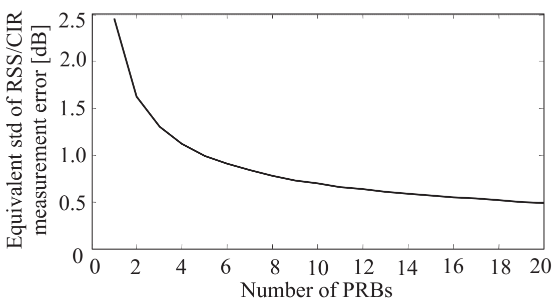


Figure 4: Impact of frequency domain averaging (L1 filtering) on RSS estimation error per transmission time interval (TTI) [8][12].

[‡]Reference signal RSS is known as reference signal received power (RSRP) in UTRAN LTE.

Table 1: Simulation Parameters

Parameter	Assumptions
Cellular layout	Hexagonal grid
Inter site distance (ISD)	500 m
Pathloss	$128.1 + 37.6 \log_{10}(R \text{ in km})$ dB
Log-normal shadowing	standard deviation = 8 dB
	correlation distance = 50 m
	correlation between sectors = 1.0
	correlation between BSs = 0.0
Fast fading	TU3 (20 taps) [15]
Antenna gain	UE: 0 dBi, eNodeB: 14 dBi
Antenna pattern	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$
	$\theta_{3dB} = 70°$, $A_m = 20$ dB
System bandwidth	10 MHz, 180 kHz per PRB
TTI	1 ms
Total BS TX power	46 dBm
eNodeB noise figure	5 dB
UE power class	24 dBm (250 mW)
UE noise figure	9 dB
UE distribution	Uniform distribution
UE speed	3 kmph, 30 kmph, 120 kmph
UE direction	randomly chosen within $[0°, 360°)$
Minimum distance -	
between UE and BS	35 m
Number of UEs	100 (fixed during simulation time)
Simulation time	50 s

erence symbols) we expect larger error level as compared to the larger measurement bandwidth (i.e. higher number of reference symbols) as shown in Figure 4 [8][12]. For example, 1.25 MHz of the measurement bandwidth will be equivalent to 6 physical resource blocks (PRBs) and the corresponding σ = 0.8 dB. Similarly, the measurement bandwidth of 2.5 MHz, 5 MHz and 10 MHz will correspond to the σ of 0.6, 0.45 and 0.35 respectively [8]. The PRB size in UTRAN LTE is determined as 12 subcarriers which is equivalent to 180 kHz [1].

$$\Delta Q \sim N(0, \sigma^2) \text{ dB} \quad (4)$$

D. Handover reporting event

The handover reporting event is based on the processed measurement, $\overline{Q}$, and the handover event is triggered if the condition in (5) is satisfied, where H_m is handover margin (in dB). Handover event in (5) is checked and reported every T_u as shown in Figure 5. The target cell (TC) is defined as the cell

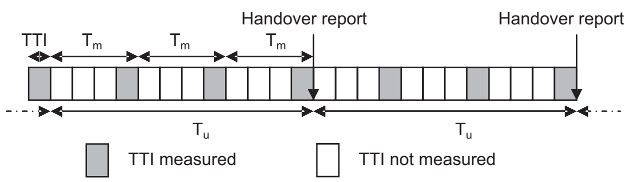


Figure 5: Handover measurement period (T_m) and decision update period (T_u)

Table 2: Handover Parameters

Parameter	Assumptions
Measurement bandwidth (BW_m)	[1.25, 2.5, 5, 10] MHz
Hysteresis margin (H_m)	[2, 4, 6] dB
Handover measurement period (T_m)	150 ms
Handover update period (T_u)	[300, 3000] ms
Handover avoidance timer	1 s

in the network, excluding serving cell (SC), from which the UE experiences maximum $\overline{Q}$.

$$\overline{Q}(n)_{\text{TC}} \geq \overline{Q}(n)_{\text{SC}} + H_m \text{ [dB]} \quad (5)$$

Handover decision and execution details are out of the scope of this paper. Handover decision is assumed to be based only on (5) and it is immediately executed if (5) is satisfied.

III. Simulation Methodology

ELIISE - Efficient Layer II Simulator for E-UTRAN, is a multi-cell, multi-user, dynamic system level simulator to study advanced radio resource management (RRM) in uplink [8][13]. The functionalities implemented include channel model, mobility, handover, power control and packet scheduling with fair as well as channel aware allocation schemes.

The network scenario considered assumes a hexagonal grid with 8 BSs and 3 sectors (or cells) per BS with a corner-excited structure. The active UEs are uniformly distributed over the network area. Each UE is given a uniform random direction in the range $[0°, 360°)$ and it moves in the same direction at constant speed during the whole simulation time. In order to avoid the drawback of a limited network area the wrap-around technique is deployed. Single transmit and dual receive antennas are used both in uplink and downlink with maximal ratio combining.

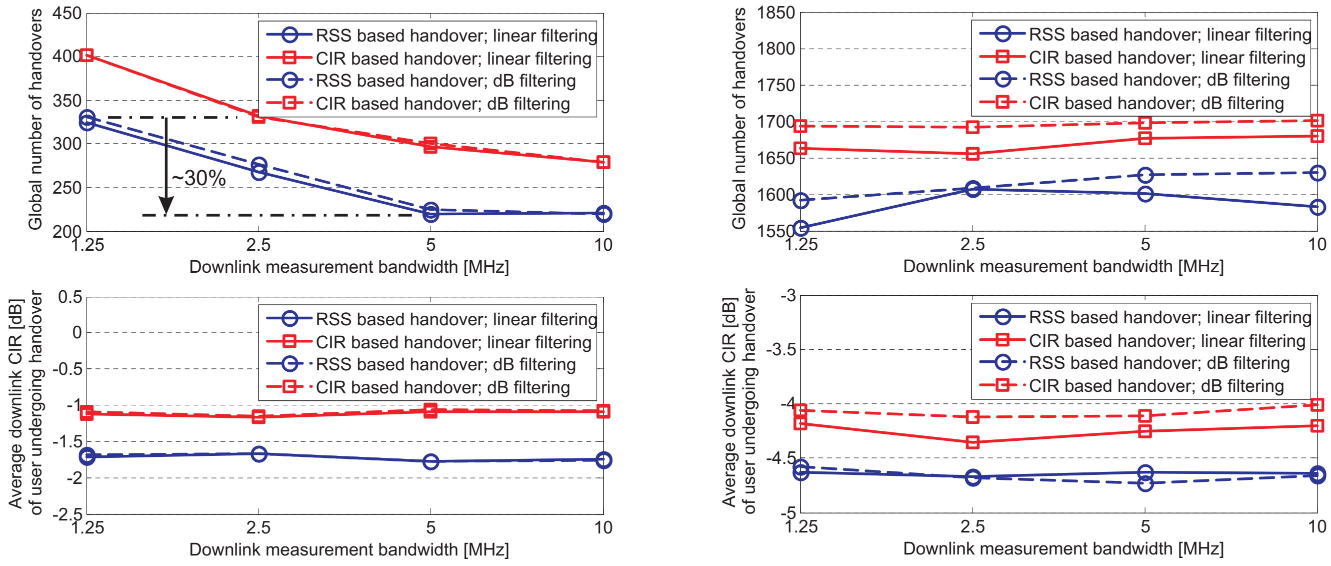
The channel model includes pathloss, log-normal shadowing and frequency selective fast fading. The log-normal shadowing samples are spatially correlated using a negative exponential function (Gudmundson's model) [14]. The fast fading is modeled using Typical Urban (TU) power delay profile with 20 paths [15].

Log-normal shadowing samples are assumed to be completely uncorrelated between BSs, hence the ping-pong handovers can be eliminated almost completely by L3 filtering if done over the sufficient filtering period depending on the user speed.

General simulation parameters listed in Table 1 are according to the assumptions in [1].

IV. Simulation Results

In this paper, system performance comparison is made in terms of number of handovers and average downlink CIR for the UEs undergoing handover for the handover parameters given in Table 2 [8]. All the results presented in this paper take into account the effect of measurement error as described in Section II *C*.



(a) UE speed = 3 kmph (b) UE speed = 120 kmph

Figure 6: Handover performance based on RSS and CIR measurements, and linear and dB domain filtering for different measurement bandwidths and $H_m = 2$ dB, $T_m = 150$ ms and $T_u = 300$ ms.

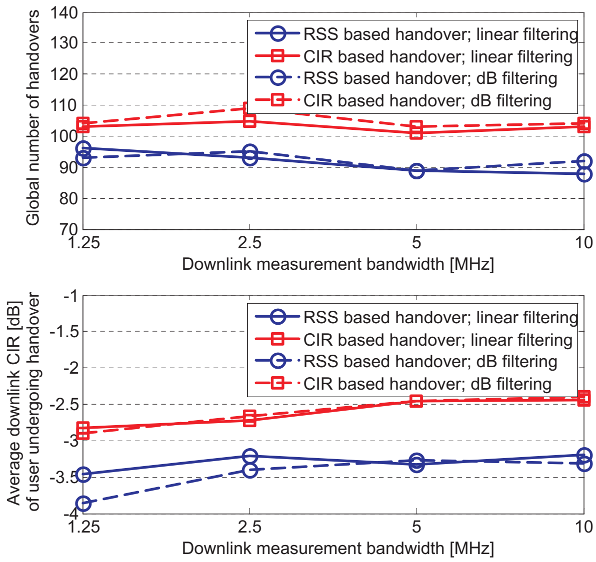


Figure 7: Handover performance based on RSS and CIR measurements, and linear and dB domain filtering for different measurement bandwidths at the UE speed of 3 kmph, $H_m = 2$ dB, $T_m = 150$ ms and $T_u = 3000$ ms.

Figure 6 shows the effect of handover based on RSS and CIR measurements, and linear and dB domain L3 filtering. Since UTRAN LTE supports scalable transmission bandwidth, the comparison is shown for the measurement bandwidth of [1.25, 2.5, 5, 10] MHz. The results show that handover based on RSS measurement performs much better as compared to handover based on CIR measurement in terms of reduced number of handovers but for a penalty of around 0.5 dB on the downlink CIR. The decrease in downlink CIR for RSS based handover is due to the delayed handover reporting and hence on average lower downlink CIR compared to CIR based handover. Moreover, for CIR based handover increase in number of handover will increase the signaling overhead and delay involved in handover execution. Larger value of H_m and T_u can be used to decrease the number of handovers for CIR based handover, but this would at the same time reduce the average downlink CIR and add to the delay in handover.

At low speed of 3 kmph, increasing the downlink measurement bandwidth we notice around 30% decrease in average number of handover in Figure 6(a). This is due to the improved L1 filtering at higher bandwidth. While at high speed of 120 kmph, increasing downlink measurement bandwidth there is a negligible change in number of handovers. The gain of using larger measurement bandwidth at 3 kmph can also be achieved by using longer L3 filtering period as shown in Figure 7 where $T_u = 3000$ ms instead of 300 ms as in Figure 6(a). This is due to the fact that log-normal shadowing samples are not highly correlated at high speed and hence require shorter T_u as compared to the slow speed users which require longer T_u. For longer filtering period of 3000 ms the number of handovers is halved for a penalty of around 2 dB on the downlink CIR. Hence for an optimal choice of T_u, depending on the user speed, the gain for using larger measurement bandwidth can be made negligible for a penalty on downlink CIR.

For CIR based handover at 3 kmph linear and dB filtering perform almost exactly the same in Figure 6(a). While for RSS based handover at 3 kmph and 1.25 MHz measurement bandwidth, linear filtering gives a small reduction in number of handovers for a negligible change in downlink CIR. The benefit of using linear filtering becomes more prominent at a speed of 120 kmph in terms of number of handovers and a small penalty in downlink CIR as seen in Figure 6(b).

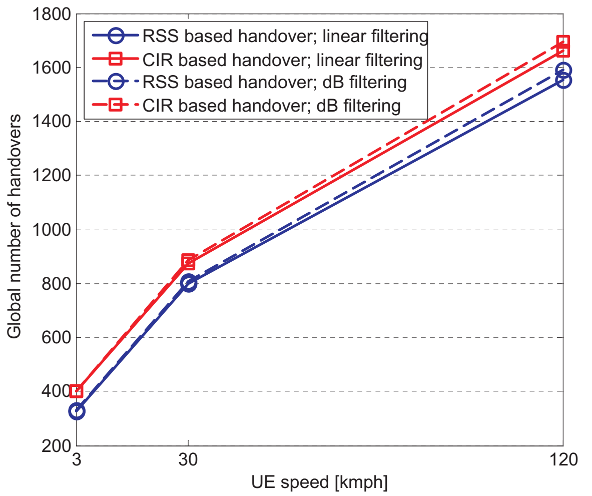


Figure 8: Handover based on RSS and CIR measurements for different user speeds at 1.25 MHz measurement bandwidth for $H_m = 2$ dB and $T_u = 300$ ms.

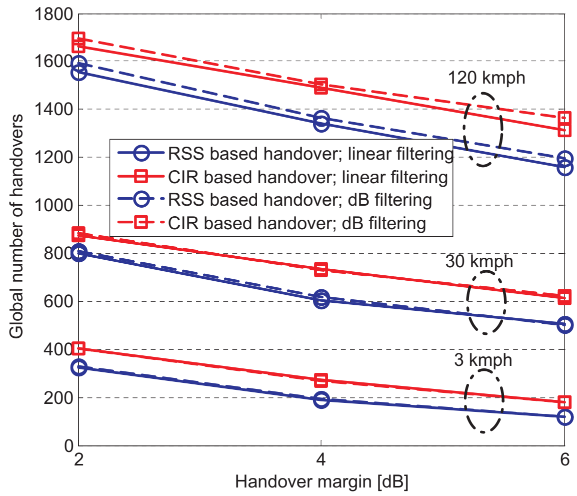


Figure 9: Handover based on RSS and CIR measurements for different user speeds and handover margins at 1.25 MHz measurement bandwidth for $H_m = 2$ dB and $T_u = 300$ ms.

Figure 8 shows the number of handovers for RSS and CIR measurement based handover and linear and dB domain L3 filtering for different user speeds. We notice that both the linear and dB domain L3 filtering works almost the same in terms of number of handovers, and the performance of linear domain filtering is a little better at higher speeds.

Figure 9 shows the effect of different handover margins on the linear and dB domain L3 filtering for handover based on RSS and CIR measurements. We notice that linear and dB domain L3 filtering gives almost no difference in the performance in terms of the number of handovers at different handover margins. Hence the performance difference in the scale of L3 filtering used is only due to increasing UE speed, and is not sensitive to the handover margin.

V. Concluding Remarks

In this paper, a handover algorithm based on the downlink RSS and CIR measurements, along with linear and dB domain L3 filtering has been studied. The results suggest that handover based on RSS measurement performs better than handover based on CIR measurement in terms of reduced number of handovers but for a penalty of around 0.5 dB on the downlink CIR. Moreover, linear and dB domain L3 filtering is shown to give almost the same performance in terms of number of handovers and average downlink CIR. Furthermore, the effect of measurement bandwidth on the handover performance is studied, and it is noticed that for an adaptive choice of filtering period, depending on the user speed, the gain for using larger measurement bandwidth can be made negligible for a penalty on signal quality.

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