# A3-Based Measurements and Handover Model for NS-3 LTE

Budiarto Herman, Dmitry Petrov, Jani Puttonen, Janne Kurjenniemi

Magister Solutions Ltd.

Jyväskylä, Finland

Emails: {budiarto.herman, dmitry.petrov, jani.puttonen, janne.kurjenniemi}@magister.fi

*Abstract*—This paper presents a Long Term Evolution (LTE) handover algorithm implementation based on Reference Signal Received Power (RSRP) measurements and Event A3 on top of the LTE module of NS-3 network simulator. Many simulation scenarios in various research projects rely on user mobility. However, until recently complete realisation of relevant functionality has been missing in free and open source tools such as NS-3. Detailed modeling of RSRP measurements, including sliding window averaging, time-to-trigger and hysteresis evaluations are considered in this paper. Received simulation results are verified through comparison with other publication, suggesting a promising direction for further studies of dynamic scenarios.

*Long term evolution; handover; simulation; ns-3*

## I. INTRODUCTION

Long Term Evolution (LTE) is a standard for radio technology developed by the 3rd Generation Partnership Project (3GPP). It is a significant change from the previous 3G/UMTS technology, providing higher data rates, simplified network architecture, and improved user mobility.

Simulation of a realistic LTE wireless network requires User Equipment (UE) mobility modeling, including UE measurements and handover. However, detailed modeling of this procedure has only been found in commercial or proprietary LTE simulators. This adds considerable cost to academia and researchers who are interested in the subject. Moreover, the source code of these simulators are not publicly available, imposing difficulties for professional community to study and verify the produced simulation results.

At least three prominent free and open source LTE simulators have been available at the moment of publication. Each of them has its own limitations in modeling user mobility. For instance, link and system level simulators from University of Vienna [1] have not modeled mobility. LTE-Sim [2] has included a modeling of handover procedure, but it has been based on Signal-to-Interference-Ratio (SIR) and location, which is not in accord with 3GPP specification. The LTE module of NS-3 has been developed within LENA project [3] and its recent development version is featuring a handover algorithm based on Reference Signal Received Quality (RSRQ) measurements and Event A2. This feature, however, has not been revealed in the stable release of NS-3 because it is still in the development phase.

We have extended the handover modeling in NS-3 by utilizing Reference Signal Received Power (RSRP) measurements and Event A3, as designed in [4]. In the case of RSRP as the measurement of choice, *Event A3* is defined as a reporting triggering event which is fired when there exists a neighbouring cell which measured RSRP is better than measured RSRP of the serving cell by certain offset [5]. The aim of this extension is to develop a measurements and handover model according to 3GPP specification, thus enabling detailed mobility studies with NS-3.

Moreover, the functionality we are introducing into the simulator is vital for Self-Organizing Networks (SON) and Cognitive Networks (CN), which have been under intense study in recent years. Many of SON and CN algorithms depend on information from Radio Access Network (RAN) signal levels and coverage. In addition, according to the 3GPP specification, UE must have the ability to provide RSRP and RSRQ measurements in Evolved UTRAN LTE [6]. Therefore, the developed measurement and reporting mechanisms can be used in the future for the study of SON and CN features.

LTE is based on distributed architecture, where Evolved NodeBs (eNodeB) are responsible for handover decision. Handover algorithms have serious impact on the cellular network performance. Taking into account that LTE is targeted to operate in different propagation environments, UE-based measurements should be carefully studied to enable robust handover in wide range of UE speed. Furthermore, an optimal tradeoff between number of handovers (signaling load, amount of connection disruptions) and signal quality in large realistic scenarios should be found. This requires utilisation of system level simulators with detailed implementation of UE measurement procedure.

The rest of the paper is organised as follow. Section II elaborates on the design of RSRP- and Event A3-based handover model developed for NS-3. In order to test the model, several simulation scenarios have been studied, as described in Section III. Finally, Section IV presents the conclusion and several ideas for future research.

## II. HANDOVER MODELING

In contrast with 3G/UMTS standard, handover in LTE is specified as hard handover or "break-before-connect". It is a UE-assisted and eNodeB-triggered procedure [7]. The handover model considered in this paper is based on this specification, and is presented in Figure 1 as a series of operations and message exchanges between UE, source eNodeB, and target eNodeB. Several steps of the procedure have been already provided out-of-the-box by NS-3. This paper is reusing this functionality while focusing on the first stages, which include the *measurement reports* and *handover decision*.
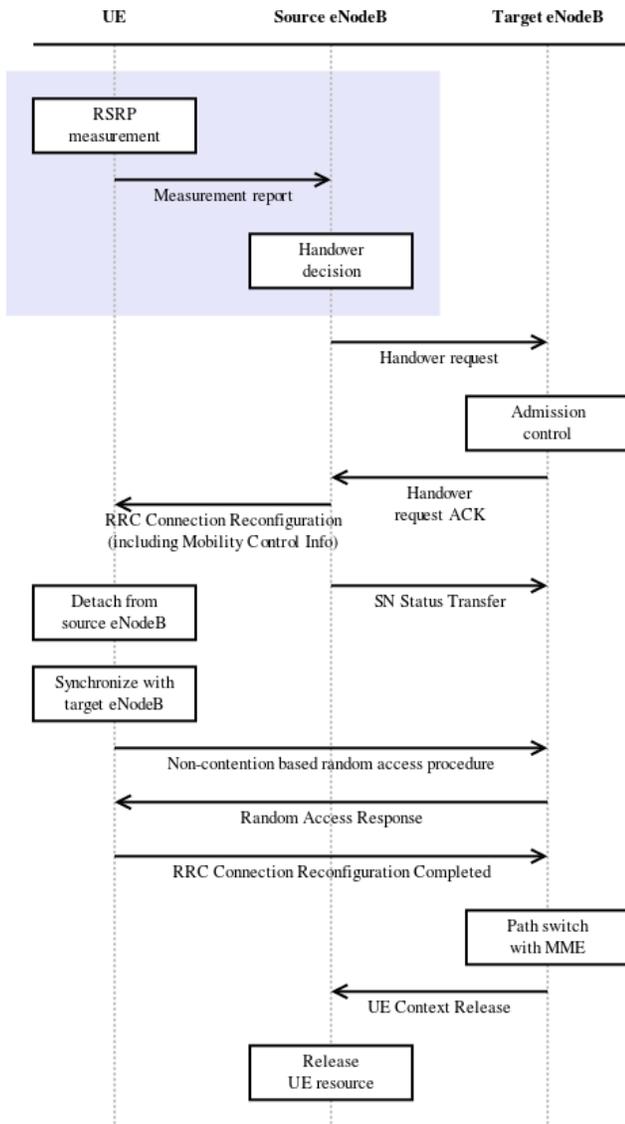
Fig. 1. Modeling of handover procedure in NS-3, where the shaded box indicates the part studied in this paper.

Measurement reports in the model are generated as follows. UE makes periodical measurements of RSRP at every time period $T_m$ from each identified cell over the whole bandwidth. These measurement samples are then forwarded from the physical layer (PHY) (*RSRP ChunkProcessor* in Figure 2) to the Radio Resource Control (RRC) layer. RRC applies time averaging to the measurements from every specific cell (*SlidingWindow*). Sliding window always holds the averaged value from $n = \frac{T_f}{T_m}$ measurements within the time window $T_f$. Thus, every time a new measurement sample comes, the oldest one is discarded. The objective of this averaging is to reduce the influence of channel fading component on RSRP measurements. As a result, the rate of ping-pong handovers in the system is expected to decline.

In event-triggered handover procedure, each UE evaluates the Event A3 condition every time a new averaged measurement sample is available (*A3Evaluator*). The evaluated condition is the entering condition of Event A3: whether the
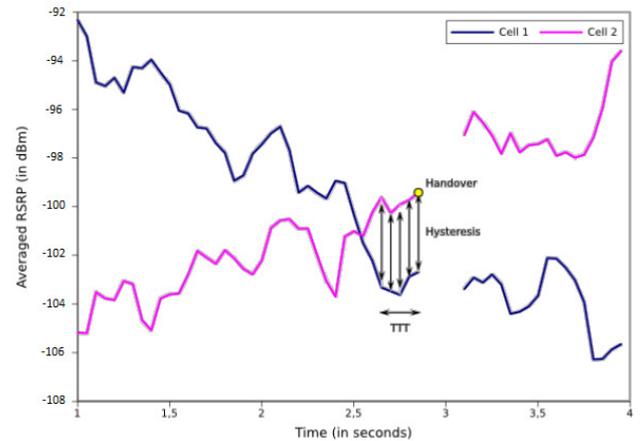


Fig. 3. Sample RSRP trace.

| Parameter | Values |
|---|---|
| Time-to-trigger | 50, 200, 400 ms |
| Hysteresis | 1, 3, 6 dB |
| UE speed | 3, 30 kmph |
| Sliding window size ($T_f$) | 200, 400 ms |

RSRP measured from a neighbouring cell becomes an offset better than the RSRP measured from the serving cell [5]. The offset is represented as *hysteresis*. This condition must stay true for at least a certain duration of time, which is called the *time-to-trigger*.

The actual Event A3 is triggered immediately after the time-to-trigger. The UE generates a measurement report and transmit it as an RRC message to the serving cell. This report typically contains measurement results of at least the serving cell, but is extendable with measurement results of neighboring cells. The whole process is demonstrated in Figure 3, which shows the trace of averaged RSRP measurements from serving *Cell1* and neighbouring *Cell2* before and after handover.

In practice, the eNodeB is responsible for deciding whether or not a handover is needed. In our case, we assume that an Event A3-triggered measurement report indicates that handover is really needed. Upon receiving this report, source cell immediately prepares a handover to the target cell. The rest of the handover procedure is performed as illustrated in Figure 1.

## III. SIMULATION RESULTS

We conducted a simulation campaign in order to validate the developed measurement and handover model. The main focus of the study was on confirming whether the available handover-related parameters, shown in Table I, behave as theoretically expected. Simulation assumptions were loosely based on 3GPP case 1 [8], as summarised in Table II.

The number of handovers and number of ping-pong handovers were the metrics collected from each simulation. The simulation regarded ping-pong handover as two consecutive handovers by a UE, which occurred within a short period of time (in this particular case, 2 s), provided that the first one is a handover from cell $A$ to cell $B$, while the second one is from
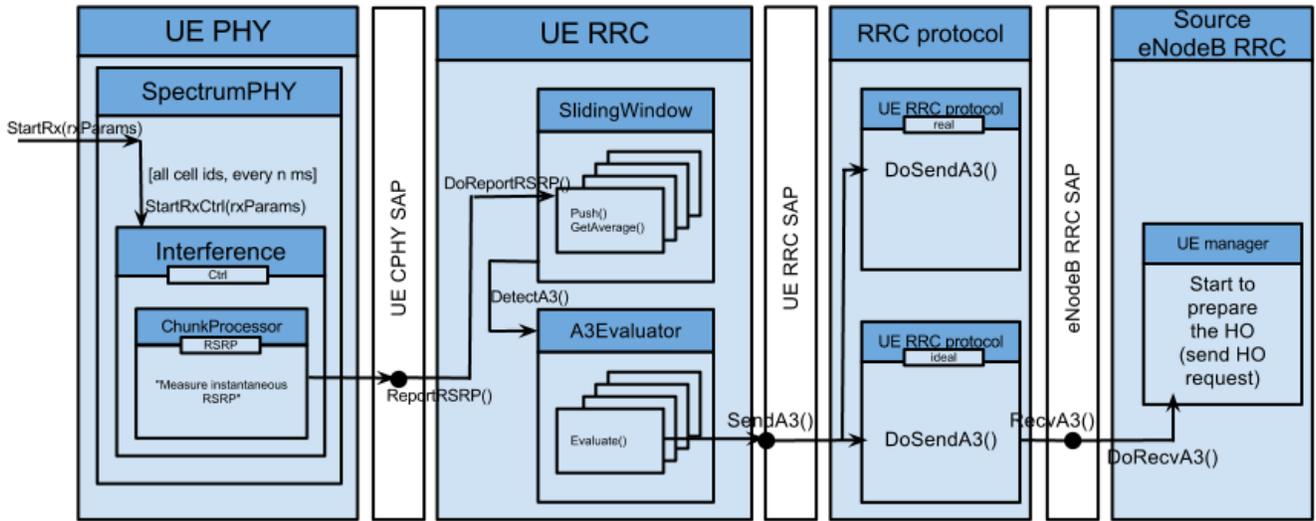
Fig. 2.    Implementation of measurements and handover model.

TABLE II.    SIMULATION PARAMETERS

| Parameter | Value |
|---|---|
| Cellular layout | 7 three-sectored sites in hexagonal layout (21 cells in total) |
| Inter-site distance | 500 m |
| Cell Tx power | 30 dBm |
| Path loss model | $L = 128.1 + 37.6 \cdot \log_{10} R$ |
| Channel fading | Typical urban |
| Carrier frequency | 2 GHz |
| System bandwidth | 5 MHz (25 RBs) |
| Traffic | Only control messages, no data traffic |
| Error model | None |
| UE distribution | 10 UEs distributed randomly in front of each eNodeB (210 UEs in total) |
| UE movement pattern | Constant speed to random direction (changing direction every 5 s) |
| UE measurement interval ($T_m$) | 50 ms |
| Simulation duration | 70 s |

cell $B$ back to cell $A$. Consequently, a series of handovers within cells $A$–$B$–$A$–$B$ counts as two ping-pongs.

Figure 4 and 5 show the average number of handovers per user per second for UE speed of 3 kmph and 30 kmph respectively. It is obvious that the increase in hysteresis parameter value significantly reduces the number of handovers. This behaviour was also observed in [9].

The number of handovers is also sensitive to time-to-trigger. As seen from the same figures, the increase of time-to-trigger has the effect of reducing the number of handovers. [9] and [10] observed the same behaviour.

Time-to-trigger variation is also known as one of the means to manipulate the number of ping-pong handovers [9]. This is demonstrated in Figure 6, which depicts the proportion of ping-pongs over the total number of handovers in the simulation.

Filtering period has also been identified as a parameter for tuning handover rates. Fast moving UE typically requires shorter filtering period than slow moving UE. It has been
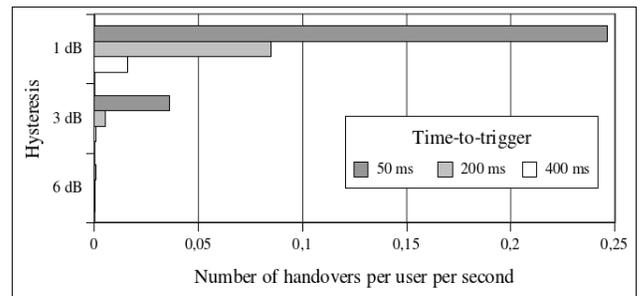


Fig. 4.    Simulation results with UE speed of 3 kmph and sliding window size $T_f$ of 200 ms.
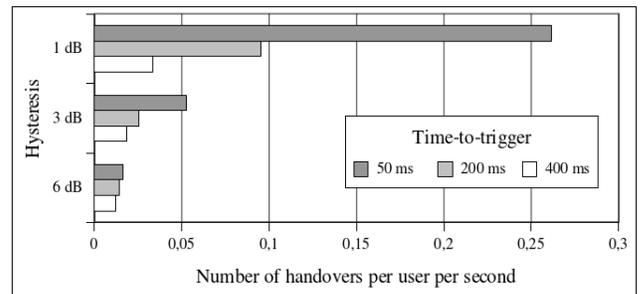


Fig. 5.    Simulation results with UE speed of 30 kmph and sliding window size $T_f$ of 200 ms.

confirmed that longer filtering period reduces the number of handovers [11]. In our study, the sliding window size $T_f$ plays the same role as filtering period, and its effect to handover rate is presented in Figure 7.

## IV.    CONCLUSION AND FUTURE WORK

In this paper, we have described the measurement and handover modeling on top of NS-3 LTE module. Simulation results have been presented in order to verify the implementation. The effect of handover parameters such as hysteresis, time-to-trigger, and filtering can be clearly seen from the results. For
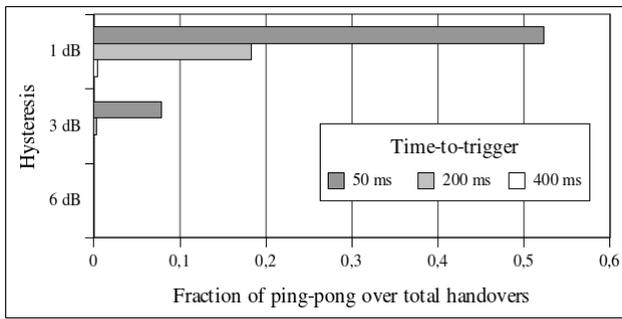
Fig. 6. Rate of ping-pong handovers in simulations with UE speed of 30 kmph and sliding window size $T_f$ of 200 ms.
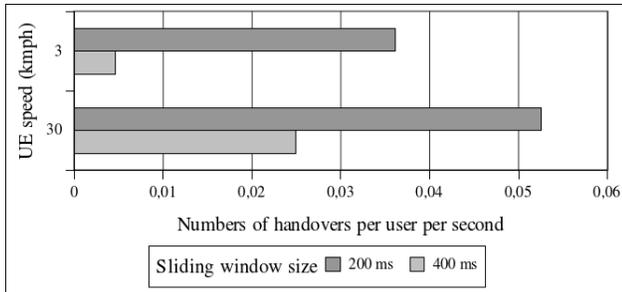


Fig. 7. Effect of $T_f$ to handover rate in simulations with hysteresis of 3 dB and time-to-trigger of 50 ms.

instance, simulation runs with small hysteresis and short time-to-trigger produced large number of handovers, especially of ping-pong type. The number of handovers can be substantially reduced with proper parameterisation. This proves that the simulated behaviour demonstrated by our model is sensitive to these parameters and in accord with results from several other published research works in the field. In the future, it will also be possible to conduct a comparison study of our results with alternative realisation of measurement and handover model, which is under development in NS-3.

It is necessary to mention that we have not yet considered some of the important mobility related statistics in LTE. In particular, features such as Radio Link Failure (RLF) and proper modeling of handover failures provide important input for SON and CN studies. For example, sleeping cell detection relies on analysis of UE measurements and RLF occurrences in the network [12]. We are aiming to incorporate RLF into NS-3 LTE module on top of the measurement and handover models presented in this paper, which altogether will be utilised in our CN research.

## REFERENCES

[1] C. Mehlführer, J. Colom Ikuno, M. Šimko, S. Schwarz, M. Wrulich, and M. Rupp, "The Vienna LTE simulators - enabling reproducibility in wireless communications research," *EURASIP Journal on Advances in Signal Processing*, vol. 2011, no. 1, pp. 1–14, 2011.

[2] G. Piro, L. Grieco, G. Boggia, F. Capozzi, and P. Camarda, "Simulating LTE cellular systems: An open-source framework," *Vehicular Technology, IEEE Transactions on*, vol. 60, no. 2, pp. 498–513, 2011.

[3] N. Baldo, M. Miozzo, M. Requena-Esteso, and J. Nin-Guerrero, "An open source product-oriented LTE network simulator based on ns-3," in *Proceedings of the 14th ACM international conference on Modeling, analysis and simulation of wireless and mobile systems*, ser. MSWiM '11. New York, NY, USA: ACM, 2011, pp. 293–298.

[4] K. Dimou, M. Wang, Y. Yang, M. Kazmi, A. Larmo, J. Pettersson, W. Muller, and Y. Timner, "Handover within 3GPP LTE: Design principles and performance," in *Vehicular Technology Conference Fall (VTC 2009-Fall), 2009 IEEE 70th*, 2009, pp. 1–5.

[5] *LTE; E-UTRA; RRC; Protocol specification (release 11)*, 3GPP Std. TS 36.331, 2013.

[6] *LTE; E-UTRA; Physical layer; Measurements (release 11)*, 3GPP Std. TS 36.214, 2013.

[7] *LTE; E-UTRA and E-UTRAN; Overall description; Stage 2 (release 11)*, 3GPP Std. TS 36.300, 2013.

[8] *E-UTRA; Further advancements for E-UTRA physical layer aspects (release 9)*, 3GPP Std. TR 36.814, 2010.

[9] M. Anas, F. Calabrese, P. Mogensen, C. Rosa, and K. Pedersen, "Performance evaluation of received signal strength based hard handover for UTRAN LTE," in *Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th*, 2007, pp. 1046–1050.

[10] C.-C. Lin, K. Sandrasegaran, H. A. M. Ramli, R. Basukala, R. Patacha-ianand, L. Chen, and T. Afrin, "Optimization of handover algorithms in 3GPP long term evolution system," in *Modeling, Simulation and Applied Optimization (ICMSAO), 2011 4th International Conference on*, 2011, pp. 1–5.

[11] M. Anas, F. Calabrese, P.-E. Ostling, K. Pedersen, and P. Mogensen, "Performance analysis of handover measurements and layer 3 filtering for UTRAN LTE," in *Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on*, 2007, pp. 1–5.

[12] F. Chernogorov, J. Turkka, T. Ristaniemi, and A. Averbuch, "Detection of sleeping cells in LTE networks using diffusion maps," in *Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd*, 2011, pp. 1–5.