

Real-time high-speed mobility management

Ahmed Abdelsalam Abuelgasim¹, Mohamed Khalafalla Hassan², Mutaz Hamed Khairi³,
Muhammad Nadzir Marsono⁴, Kamaludin Mohamad Yusof⁵

¹⁻⁵Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia

²Faculty of Telecommunication, Future University, Khartoum, Sudan

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ABSTRACT

High-speed mobility system has now become a serious concern for mobile operators due to the large frameworks of a heterogeneous network made up of multiple cell types and different frequency bands. Handover (HO) is conducted in a real-life scenario when the user equipment (UE) moves from one network coverage to another by performing proper measurement with high speed. HO breakdown and call loss are observed due to a high speed; thus, high-speed mobility system needs improvement by using the UE speed as one of the key measurement monitoring criteria for the long-term evolution (LTE) network. Vendor consultation has been considered in this paper in addition to real drive test measurement in highways. Results have shown that velocity has a direct impact on the handover quality and overall timing. Results also demonstrate that 120 km/h measurement is better than 140 km/h as UE speed.

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Corresponding Author:

Ahmed Abdelsalam Abuelgasim

School of Electrical Engineering, Faculty of Engineering

Universiti Teknologi Malaysia (UTM)

Skudai, 81310, Johor, Malaysia

Email: ahmedkhair22@gmail.com

1. INTRODUCTION

To ensure "seamless" standardization, relocation, and convergence within these heterogeneous networks, the synchronization of different cellular system technologies is essential. Hence, the use of vertical handover (VHO) approaches is required [1]. In contrast, both handover and handoff are recognized, identified once the user equipment passes to one or more cellular cells and attached to a new cell after detachment from the site of cellular origin. The handoff decision has to be made by multiple algorithms such as fuzzy logic and machine learning to address usability issues like latency and complete failure. A combination approach is being used to study cellular coverage and handover forecasts [2], [3]. The long-term evolution (LTE) technology provides stability for low user speeds from 0 to 15 km/h, and faster user speeds from 15 to 120 km/h, as per the 3rd generation partnership project (3GPP).

Furthermore, mobility via the mobile network can still be achievable at speeds ranging from 120 km/h to 350 km/h, but once again the effect on mobility management and quality (i.e. delay time) in the circuit switch (CS) system handover would be less than or similar to that [4]. The heterogeneous wireless networks are classified as a hybrid infrastructure of high and low power mobile cells. Some have restricted connectivity setup and others can ignore wired backhaul [5]. High frequencies are required when heterogeneous networks are introduced, as there is a correlation between frequency and cell coverage, so mmWaves are known for use in international mobile telecommunications (IMT) and the next-generation technology-5G [6]-[8].

This paper discusses the mobility management issues as handover delay may occur when user equipment (UE) moves with a high speed of 140 km/h between two adjacent LTE cells vertically. The handover (HO) preparation time, including HO measurement, will take longer than in typical HO situations and overall HO time. Therefore, the high-speed UE may cross the HO area between the cells before the required measurement report is received by the serving cell to decide whether to proceed with the HO procedure or the call is dropped.

Anas *et al.* [9] the author performed an algorithm for handoff using signal strength to accelerate a decline in HO amount. Whenever the UE velocity is between 3-120 km/h, the algorithm has to increase the time to trigger and reduce the signal to interference and noise ratio (SINR). Bai *et al.* [10] studied velocity and quality of service (QoS) for evolved node B (eNB) and femtocell handover to minimize unnecessary handoff. The UE velocity is categorized into three classes (0-15), (15-30), and (>30) km/h to prevent unsuccessful calls. The algorithm neglects services that are not in real-time. Lee *et al.* [11] provided a HO mechanism to analyze the ping-pong handover, the latency of handover, and the failure of radio links for each handover when the UE speed is in the range of 3, 15, 30, 60, and 120 km/h. The UE speed has a direct negative effect on radio link failure and ping-pong; however, radio link failure remains stable when the time to trigger is 5120 ms. Xu *et al.* [12] generated an algorithm that periodically (every 100 ms) measures the reference signal received power (RSRP) and UE speed value. The UE speed recorded in their framework is 3, 30, 60, and 120 km/h. This algorithm's primary goal is to reduce the failed handover and ping pong in both macro and pico-cells. In [12]-[14] estimate the UE speed using the handover number counting technique during the time frame expected. The handover is more likely to fail when UE speed is high. The UE speed estimation does not work for the LTE network, which is considered a high-density network, but speed estimation works when the network is full of small cells, especially in trains. Osifeko *et al.* [15] studied the effect of speed (60-120 km/h) in three different algorithms. Power, time to trigger (TTT), and handover margin (HOM) are used to avoid ping-pong via stopping the HO trigger within a certain time.

For today's wireless networks, both new and traditional systems are mixed because telecom carriers are not willing to change all of their access networks at once. In other words, a range of cellular systems offers versatile network connectivity and many solutions for end users because there are various cell sizes and various frequency bands operating on them. As a consequence, heterogeneous networks (HetNet) are composed of various cellular communication networks (i.e., 3G, LTE, and "5G" next generation). HetNet embraces the growing demand for data and the need for sufficient coverage, consistent access, and stable networks. Concerning cellular network issues, spectrum availability and capacity management are top of the list.

Given the vertical handover (VHO) of UEs through the networks, switching between various cellular technologies is a key problem. Service efficiency is affected by HO. Mobility on highways remains an unresolved and alarming problem for all mobile operators due to high-speed traffic movement that can surpass 140 km/h, which is the highway speed limit for most countries worldwide [14], [16]. To minimize the risk of call drops, UE speed must be part of handover planning, and the area of handover between adjacent cells must be measured and monitored.

2. PROPOSED METHODOLOGY

Conducted drive test measurements demonstrate that the cell distribution is different depending on the various cell types being introduced. The estimated coverage range is 0.4 to 3 km. The frequency and power of operation of the cells are changed accordingly. In congested environments, low-power cells with narrow coverage areas are used to ensure continuity of service, whereas high-power cells are deployed when large coverage is required. Our early success in mobility management [16] indicates the network coverage of each LTE cell which was conducted during our field evaluation. While trying to make the cell selection/reselection during the ideal mode and the HO decision in the connected mode, RSRP is viewed as one of the main measurement parameters. As stated in [16], the signal strength variation would be between -80 to -105 dBm as configured in most mobile operators, whereas the classic 3GPP range is somewhere between -44 and -140 dBm [17], so it is clear that mobile operators are attempting to raise their rules to ensure high service quality, to avoid regulatory parties' penalties due to bad customer experience and to meet their obligations.

Table 1 illustrates the drive test setup and measurement along with LTE configuration in mobile operator network as shown in base transceiver station (BTS) site manager software. 3GPP defined LTE handover procedure in different event-based reports A1, A2, A3, A4, A5, and A6 based on timer expiry and finding the strongest cell energy with accepted quality of the signal. 3GPP has also defined triggering methods for inter radio access technology (inter-RAT) handovers in two event-based reports B1 and B2 [18].

Table 1. Drive test and LTE cell setup

Real Mobile Operator Measurement and Setup	
Setup	Value
Drive test software	ACTIX
UE speeds	60-140 km/h
Handset type	Samsung Category 16
Global cell ID	10
Physical layer cell identity	163
E-UTRAN cell identifier	28461834
Uplink (RX) frequency	1775.0 MHz
Downlink (TX) frequency	1870.0 MHz
Uplink/downlink bandwidth	20 MHz
Carrier power	47.8 dBm/60.255 W
MIMO	Closed-Loop MIMO (4x4)
Virtual antenna mapping	No

Common network parameters are usually used during handover measurements and procedures, such as received signal strength, received signal quality, available bandwidth, UE residence time, any combination of two or more of these parameters. However, as per the common mobile operators, only received signal strength and received signal quality are used to perform the handover. Moreover, some vendors estimate the velocity of the user to achieve seamless connection. In our proposed algorithm, UE speed is added to the measurement report ahead of the handover procedure as one of the key parameters in the handover decision.

The addition of UE speed to handover measurement reports is aimed to decrease the total failure of connection during the handover and call loss. In other words, it helps to improve the overall mobile network quality and customer satisfaction. The proposed algorithm is designed for heterogeneous networks where both regular cells and small cells are implemented together.

2.1. Proposed system architecture

Spectrum frequency has been recently considered as a scarce resource due to the high demand for mobile and nonmobile technologies. Mobile services are currently taking the lead over other services such as broadcast and fixed services. Hence the existing and future cellular technologies are deployed in different operating frequency bands between 700 MHz and up to 3500 MHz, which is mainly allocated for next-generation (5G) technology in most parts of the world. Due to the high demand of the spectrum, high-frequency bands (above 6 GHz) are also considered to be used for mobility for the first time during the international telecommunication union (ITU) world radio conference (WRC-19).

The proposed system contains two different LTE cells in terms of the operated frequency bands and output power. In the first cell, named LTE cell#1, the frequency band is 1800 MHz and bandwidth of 20 MHz, whereas the second cell, named LTE cell#2, features 2600 MHz as operating frequency band and bandwidth 20 MHz. Frequency division duplexing (FDD) is used as multiplexing mode in both LTE cells.

Furthermore, the proposed network system is similar to implemented mobile network as per the used frequency band and cell types. LTE cell radius is considered 2.7 km, 0.5 km for macrocell with TX power of 46 dBm and small cell with TX power of 20 dBm, respectively, based on the real LTE deployment in mobile operators. The proposed system uses the UE speed and the RSRP of the LTE cell to consider the HO procedure, and the frequency band has to be defined in the configuration of LTE cells as it is vertical HO. Once the UE exceeds the defined speed threshold, the system will compare the current value of the RSRP with the defined RSRP threshold which is configured based on the average of the drive test measurements and the real configuration of the mobile operator. The handover is triggered from the serving cell to the target cell when the above mentioned conditions are met.

2.2. Proposed simulation environment

The proposed handover algorithm uses the MATLAB tool to simulate the handover process when UE moves at a high speed up to 140 km/h. Field measurements are performed ahead of simulation in order to compare both real measurements and simulated measurements in order to improve the overall handover. Also, the HO area between two adjacent cells has to be evaluated to minimize the total number of handovers and handover failures.

Frequency doppler is used in advance to measure UE speed according to 3GPP [19] as shown in (1), where $f_s(t)$ are the Doppler shift, and f_d is the maximum Doppler frequency, which is defined to be either 5, 70 or 300 Hz and the cosine of angle $\theta(t)$ is given in (2).

$$f_s(t) = f_d \cos \theta(t) \quad (1)$$

$$\cos \theta (t) = \frac{\frac{D_s}{2} - vt}{\sqrt{D \sin^2 + (\frac{D_s}{2} - vt)^2}} \tag{2}$$

As stated in [20], the (3) can also be used to calculate the maximum Doppler, where f_d is the maximum Doppler frequency, f_c is the carrier frequency, v is the velocity of UE, and c is the speed of light.

$$f_d = v \frac{f_c}{c} \tag{3}$$

There is a direct relationship between the RSRP, received signal strength indicator (RSSI), resource blocks, and cell bandwidth in LTE event A3 since the UE performs measurement for both serving and target cell ahead of handover decision. Table 2 shows the number of resource blocks against LTE-defined bandwidth [21]. Since RSRP is considered as a key parameter during the HO process, the (4) shows how the RSRPP is calculated [22], where P_{tx} is transition power, Pl is path loss, and L_s is additional shadow fading. The (5) and (6) described the calculation of path loss of macrocell and femtocell, respectively, according to 3GPP [23]-[25], where d is the distance between user and base station in meters and f_c is carrier frequency in MHz.

Table 2. Channel bandwidth against resource blocks

Bandwidth (MHz)	Resource blocks
1.4	6
3	15
5	25
10	50
15	75
20	100

$$RSRP = P_{tx} - Pl - L_s \tag{4}$$

$$Pl(Macro) = 128.1 + 37.6 \times \log_{10}(d) + 21 \times \log_{10}\left(\frac{f_c}{2}\right) \tag{5}$$

$$Pl(Femto) = 127 + 30 \times \log(d) \tag{6}$$

3. EXPERIMENTAL RESULTS

3.1. Drive test measurement

The optimized RSRP in network settings for telecom carriers is sufficient to keep the quality of service at a high level, even for normal low-speed users. Mobile operators face a significant threat in reducing call declines in real-time networks and delays in non-real-time networks when the UE limit is over 120 km/h. Frequent transfers occur several times through field measurement and increases as the UE speed increases, so the implementation of high-power cells will aim to minimize the risk of call decrease, but high-power cells do have drawbacks over small cells, as they cannot be used for density areas congested with humans. In addition, the inter-frequency handover was observed once the velocity is 140 km/h during the field tests. Depending on the maximum RSRP measured, the maximum power is -25 dBm, and if the resource blocks are 72 and the minimum bandwidth is 1.4 MHz, the maximum RSRP recorded is $10 \cdot \log_{10}(72)$, which is -44 dBm. The impact of UE speed was obvious during the conducted drive test measurement, particularly when the speed is 140 km/h, as shown in Figure 1, where the handover failure clearly happens during the handover area in the red circle.

The variation of measured RSRP during the field performed tests was recorded to be -65 dBm as the maximum detected value with the quality range of SINR between -11 dB and -105 dBm when the UE is moving with a velocity of 140 km/h. Figure 2 illustrates the measured RSRP when the UE speed is 140 km/h. Moreover, a connection failure has been occurred during the mobility between two adjacent cells due to the high speed of the user, as shown by the red circle in the figure.

The conducted field measurements show better RSRP variations when UE speed is 120 km/h through the same zone between two cellular cells in the same direction when the UE was moving with a velocity of 140 km/h. LTE signal has been impacted several times during the drive test measurement; however, no handover failure is registered. Figure 3 shows the RSRP when the UE speed is 120 km/h.

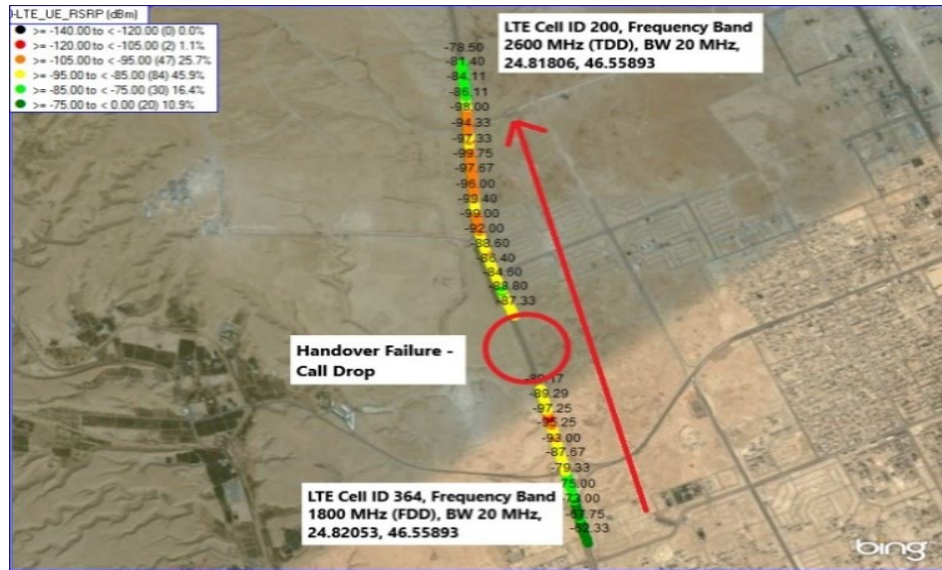


Figure 1. RSRP measurements when user equipment (UE) speed is 140 km/h (adapted from [16])

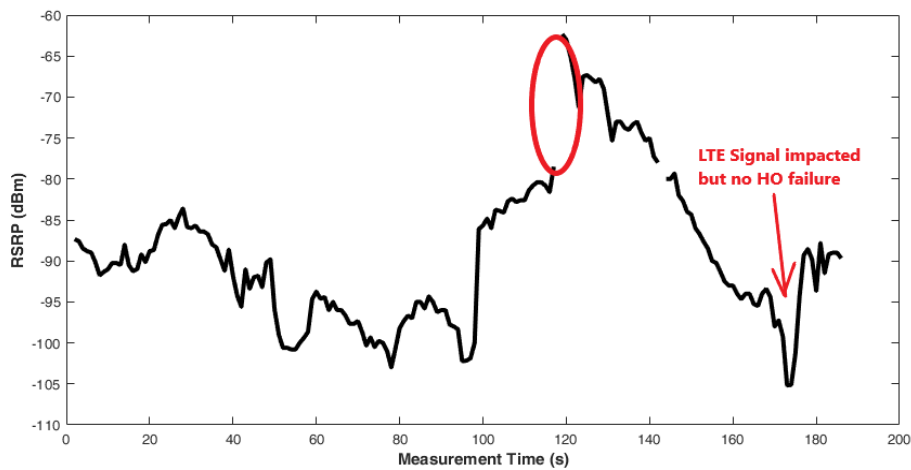


Figure 2. RSRP variations when UE speed is 140 km/h

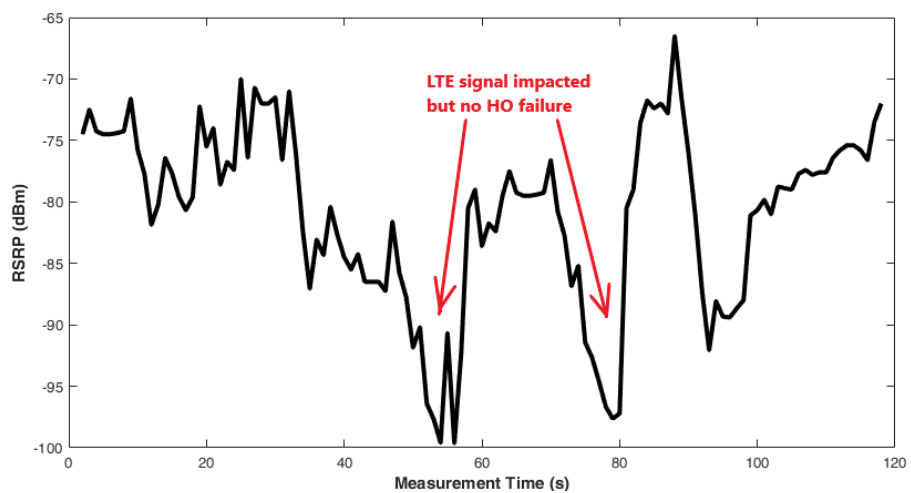


Figure 3. RSRP variations when UE speed is 120 km/h

3.2. Simulation results

The addition of UE speed in the handover preparation stage helped to improve the overall mobility management performance and maintain the network resource. Pathloss of LTE cells is included in the proposed methodology to get the received signal strength of LTE cell, either macrocell or small cell. Figure 4 shows the variation of path loss for both the standard macro cell and small cell (femtocell) according to simulated results based on (5) and (6).

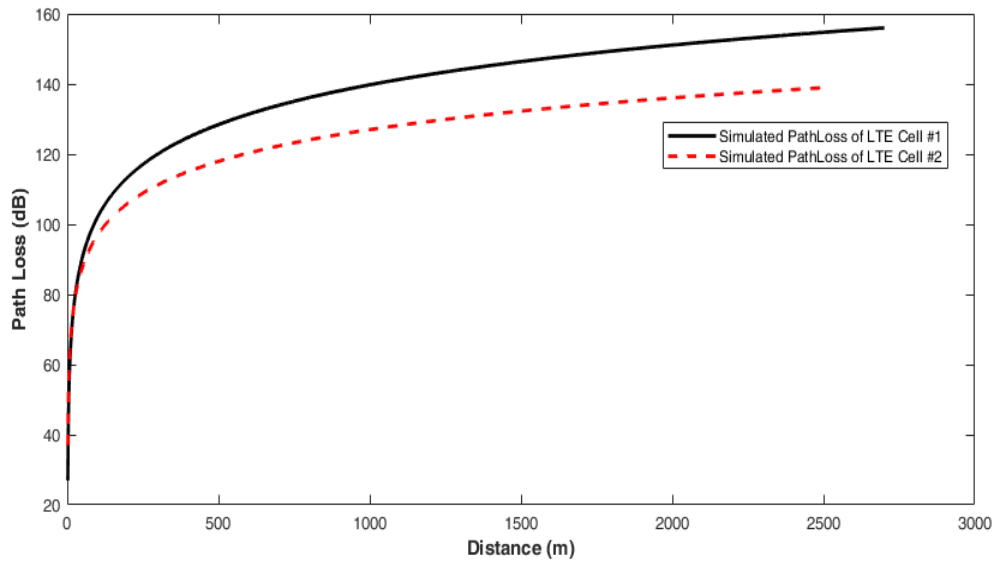


Figure 4. Path loss variations in Macrocell and Femtocell

The simulation results show that the RSRP varies by -60 dBm to -132 dBm for both LTE cells when UE speed is between 120-140 km/h; however, the mobility management performance recorded better results when the UE speed is 120 km/h. Figure 5 and Figure 6 illustrates the RSRP variation for cell ID 9, which operates with 20 dBm as transmit power, and the best-recorded RSRP is around -79 and -53 dBm. In comparison, the worse value is found around -100 and -87 dBm for drive test (DT) and simulation, respectively.

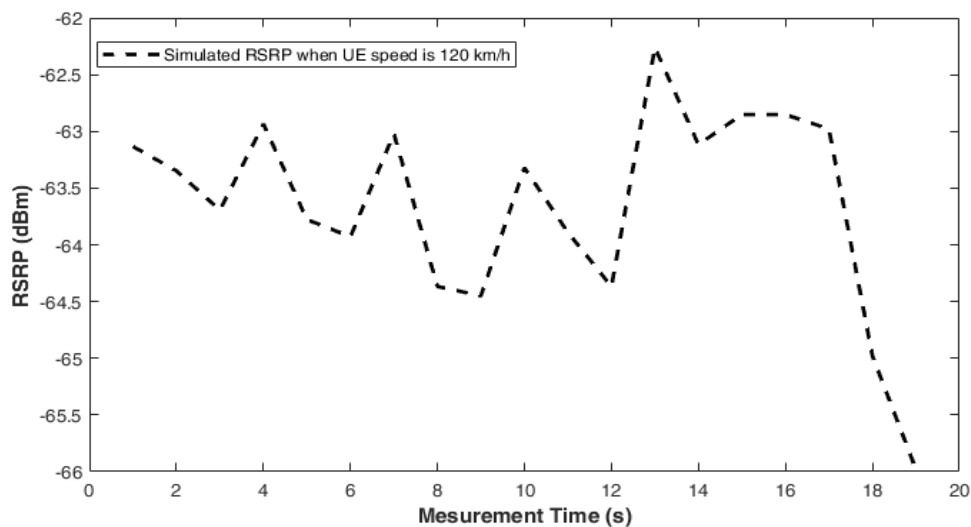


Figure 5. Simulated RSRP when UE speed is 120 km/h

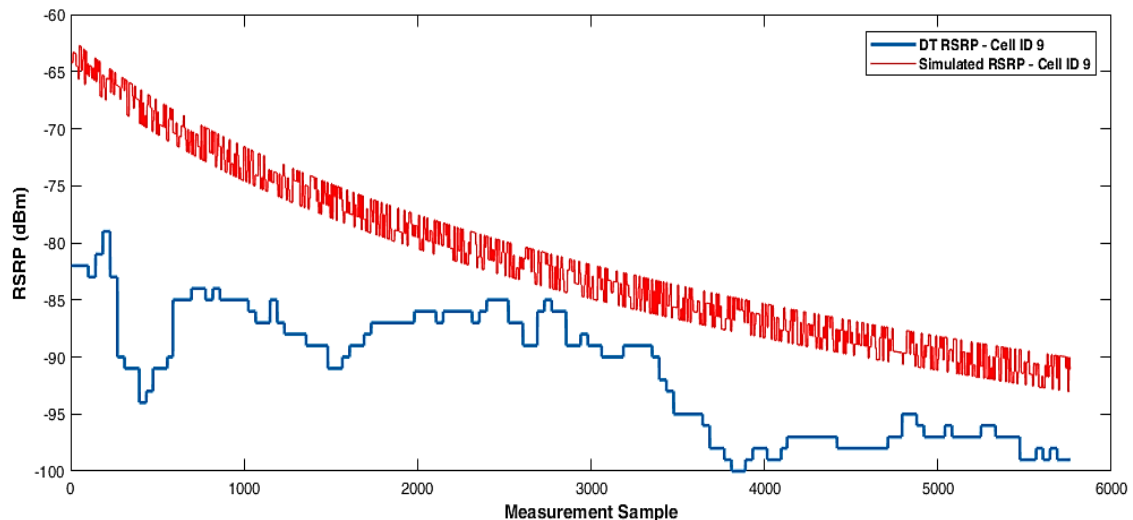


Figure 6. Simulated RSRP vs. DT RSRP for cell ID 9 and UE speed is 140 km/h

4. CONCLUSION

Mobility management has become annoying to mobile operators since it is directly affecting the quality of service provided to subscribers and corporates. Overall mobility management performance is evaluated for real mobile operators in the middle east by conducting a driving test for high-speed users to see how UE speed affects the overall network quality. The measured UE speed has been categorized into mid and high speed, which is 80 km/h and 120-140 km/h, respectively. Then UE speed is considered as one of the primary handover parameters in the proposed algorithm, and any user above the high-speed limit will be ignored in the handover procedure due to illegal use of speed. Handover failure and overall handover timing are directly affected by UE speed.

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