Impact Analysis of Layer 3 Filtering on LTE Handover Performance in High-speed Railway Scenario

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Abstract

Handover (HO) which can make user equipment (UE) communicate with the eNodeB (evolves NodeB) with the highest signal quality will have bad performance in high-speed railway scenario. In this paper, detailed introduction is made on Layer 3 (L3) filtering theory to help solve this problem. HO measurement and HO decision procedure based on L3 filtering are designed and implemented in a dynamic system level simulation platform modeling two kinds of radio channel environment—mountainous and rural scenario. The Reference Signal Received Power (RSRP) of source and target eNodeB has been simulated to research and achieve proper L3 filtering strategy. Ping-pong HO rate and radio link failure (RLF) rate have been investigated to verify the influence of L3 filtering to HO performance. Simulation results show that the best L3 filtering factor is 1/6 and its impact on Ping-pong HO rate and mountainous scenario is greater than on RLF rate and rural scenario.

Keywords: Layer 3 Filtering, High-Speed Railway, RSRP, Handover

1. Introduction

Universal Terrestrial Radio Access Network Long-Term Evolution (UTRAN LTE), also known as Evolved UTRAN (E-UTRAN), is the 4th generation cellular mobile system that is being developed and specified in 3GPP [1] [2]. LTE system is consisted of three elements: evolved-NodeB (eNodeB), Mobile Management Entity (MME), and Serving Gateway (S-GW)/Packet Data Network Gateway (P-GW). The eNodeB evolves all radio interface related functions such as packet scheduling and handover mechanism [3]. OFDMA (Orthogonal Frequency-Division Multiple Access) and SC-FDMA (Single Carrier-Frequency-Division Multiple Access) are used in LTE for the downlink and the uplink respectively, which makes it possible to provide peak cell data rates up to 100Mbps in downlink (DL) and up to 50Mbps in uplink (UL) under various mobility and network deployment scenarios [4]. Furthermore, LTE is designed to increase the capacity, coverage, and the speed of mobile wireless networks over the earlier wireless systems [5]. As one of the crucial aspects of E-UTRAN, the handover (HO) performance is very important, especially for real-time service, since this service is susceptible to delay and handover failure.

Handover algorithm relies on the channel measurement values which represent reference signal received power (RSRP) or reference signal received quality (RSRQ) or both in E-UTRAN. Handover measurements are made in downlink from the serving cell and the neighboring cells and are processed in the user equipment (UE) [6] [7]. Then a measurement report is generated in UE and delivered to the serving cell in a periodic or event based manner by a radio resource control (RRC) signaling in the uplink. When the serving eNodeB receives the report, a handover decision is made to see if certain decision criteria are met. And if met, a handover procedure begins to be executed by the serving eNodeB [8]. This procedure is shown in Figure 1.

The propagation path between the eNodeB and UE from simple line-of-sight (LOS) is severely blocked by buildings, mountains, and tunnel, which result in the shadowing effect and fast-fading. Therefore, different channel environment, velocity or measurement bandwidth may have great influence on the measurement of RSRP and RSRQ [9], and then the HO performance [10]. This is more prominent in high-speed railway scenario. To ensure the accuracy of handover decision, Layer 3 (L3) filtering is processed to reduce the effect of the shadowing effect and fast-fading. In this paper we study the impact of L3 filtering on handover measurement and decision in high-speed railway scenario,
in order to achieve the best L3 filtering factor and better handover quality in consideration of the high velocity.

![Handover measurement and decision diagram](image)

**Figure 1.** Handover measurement and decision

The rest of the paper is organized as follows. In Section 2, L1 and L3 filtering theory and handover reporting event criterion are analyzed. The simulation scenario and modeling are described in Section 3. Then in Section 4 simulation results are analyzed and finally conclusions are drawn in Section 5.

### 2. L3 Filtering and handover reporting

The measurement model adopted for LTE has been inherited from the UMTS [12][13]. The measurement and filtering processing procedures are done in Layer 1 (physical layer) and Layer 3 (RRC layer) as shown in Figure 2 which contains four different reference points. Reference point ‘A’ represents the handover measurement period of the Layer 1. Reference point ‘B’ represents the specific sampling rate by which Layer1 reports measurement values (i.e. RSRP or RSRQ) to Layer3. Reference point ‘C’ represents the handover decision update period of Layer 3. Reference point ‘D’ contains measurement reports sent to the eNodeB by RRC signaling when certain reporting criteria are met.

![E-UTRAN measurement model diagram](image)

**Figure 2.** E-UTRAN measurement model

#### 2.1. RSRP and L1 filtering

RSRP is defined as the linear average over the power contributions of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth BW[14]. Therefore, it’s calculation is as follow:
In Formula (1), $P$ is the transmit power of serving cell for each reference symbol; $G_i$ is channel gain of the $i^{th}$ reference symbol, which includes pathloss, antenna gain, log-normal shadow fading and fast fading averaged over all the reference symbols. Besides, the averaging of fast fading and shadow fading over all the reference symbols is done at L1 (physical layer). So it is called L1 filtering.

### 2.2. L3 filtering theory

Since the handover measurement (RSRP or RSRQ) is significantly affected by the channel environment, handover reporting criteria must use stable measurement values processed by L3 filtering. The L3 filtering formula is defined in [15] as shown in Formula (2).

$$\mathcal{F}_n = (1 - a) \cdot \mathcal{F}_{n-1} + a \cdot M_n$$

(2)

$\mathcal{M}_n$ is the latest received measurement result from the physical layer; $\mathcal{F}_n$ is the updated filtered measurement result; $\mathcal{F}_{n-1}$ is the old filtered measurement result, where $\mathcal{F}_0$ is set to $\mathcal{M}_1$ when the first measurement result from the physical layer is received. The measurement results of $\mathcal{M}_n$ and $\mathcal{F}_n$ are updated every handover measurement period which is defined as $T_m$. The relativity of latest received measurement result ($\mathcal{M}_n$) and the old filtered measurement result ($\mathcal{F}_{n-1}$) is controlled by the L3 filtering factor $a$. In this research, we define $a = T_m / T_u$, where $T_u$ is the handover decision update period, also known as L3 filtering period.

### 2.3. Handover reporting

In traditional A3 event-based triggering handover reporting algorithm, the reporting criterion is defined in Formula (3), where $Hyst$ is the handover margin, $\mathcal{M}_s$ and $\mathcal{M}_t$ represent the measurement values of serving cell and target cell respectively. The handover reporting is triggered if the criterion in Formula (3) is satisfied and can last for a standard period which is called Time-to-Trigger (TTT) period, as shown in Figure 3.

$$\mathcal{M}_t \geq \mathcal{M}_s + Hyst$$

(3)

Handover reporting event in Formula (3) is checked and reported every $T_u$. However, the details of handover decision are out of the scope of this research and therefore not included in this paper.

![Figure 3. Handover reporting criterion](image)

### 3. System simulation modeling

The traditional hexagonal grids model is unsuited to high-speed railway network, considering the velocity and the dedication of private railway network. Therefore we use the “chain structure” model in
which cells are arranged strictly in chain structure instead of hexagonal grids and eNodeB coverage areas are along the railway, as shown in Figure 4.

The main simulation parameters are shown in Table 1. The channel model includes large-scale pathloss, log-normal shadowing and Rayleigh fading. Since the railway network is dedicated, the assumption that the frequency resource is abundant is reasonable. Two typical channel model (mountainous area model and rural area model) are implemented to represent and sum up the complex and constantly changing environment which the train passes through. Handover procedure happens in the cell overlapping area which is related to the cell radius and inter site distance.

**Table 1. Simulation parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario</td>
<td>chain structure in mountainous scenario and rural scenario</td>
</tr>
<tr>
<td>Cell radius</td>
<td>1.6 km</td>
</tr>
<tr>
<td>Inter site distance</td>
<td>2.9 km</td>
</tr>
<tr>
<td>Minimum distance between UE and eNBs</td>
<td>100 m</td>
</tr>
<tr>
<td>Cell overlapping area</td>
<td>300 m (diameter)</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>2.6 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Pathloss</td>
<td>mountainous scenario: 140.729+34.768*log10(R in km)-10.03 dB</td>
</tr>
<tr>
<td></td>
<td>rural scenario: 140.729+34.768*log10(R in km)-19.32 dB</td>
</tr>
<tr>
<td>Log-normal shadowing</td>
<td>standard deviation = 8dB</td>
</tr>
<tr>
<td>Fast fading</td>
<td>Jakes model</td>
</tr>
<tr>
<td>eNB TX power</td>
<td>46 dBm</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>eNB: 17 dBi; UE: 0 dBi</td>
</tr>
<tr>
<td>TTI</td>
<td>1 ms</td>
</tr>
<tr>
<td>UE speed</td>
<td>350 km/h</td>
</tr>
<tr>
<td>HO measurement period (Tm)</td>
<td>10 ms</td>
</tr>
<tr>
<td>HO margin</td>
<td>2dB</td>
</tr>
</tbody>
</table>

**Figure 4.** Chain structure model in railway

4. Simulation results and analysis

In this paper, simulations are implemented in two aspects. Firstly, for mountainous area and rural area respectively with different values of factor $a$, variation curves of UE measured RSRP of source and target eNodeB with UE travels from serving cell to target cell are drown. Then we evaluate and analyze the curves to select the best factor $a$. Secondly, comparison of handover performance with and without L3 filtering is made to see the influence of L3 filtering on handover performance in high-speed
railway environment. PPHO rate and RLF rate are used to represent handover performance. Simulation results are shown as follows.

4.1. Selection of the best factor $a$

It’s obvious that with UE traveling away from serving cell and close to target cell, the RSRP of source eNodeB decreases while the RSRP of target eNodeB increases accordingly, which can be seen in figures below. From Figure 5, it’s shown that different factor $a$ which ranges in $1/2$, $1/4$, $1/6$ and $1/8$ has different influence on UE measured RSRP in mountainous scenario. Figure 5(1) shows that when factor $a$ is $1/2$, the value and variation of RSRP are the most similar to the real situation among the four figures because according to Formula (2), $M_n$ which represents the currently measured value has a greater proportion in the updated filtered measurement result $F_n$. Meanwhile, the shadowing effect and fast fading is the most serious of the four figures. With the decrease of factor $a$, the variation of RSRP is lower, which means the shadowing effect and fast fading are reduced by L3 filtering. But the value is less similar to the real situation, which can lead to the situation that the quality of RSRP after L3 filtering is ideal for handover but in the real situation it’s not suitable for handover.

Based on the simulation results and analysis above, as a balance of reducing shadowing effect and fast fading and keeping the instantaneous of measured RSRP, we select factor $a = 1/6$ as the most suitable parameter.

As for rural scenario, simulation results are shown in Figure 6. It shows that the fluctuation of RSRP is much feeble than that of mountainous scenario. Based on the same analysis of mountainous scenario and to consist with the result, we also select factor $a = 1/6$ as the most suitable parameter.

![Figure 5. RSRP of source and target eNodeB in mountainous scenario](image)
To judge the performance of L3 filtering, we use two parameters, ping-pong HO rate and radio link failure (RLF) rate. Ping-pong HO occurs when the RSRP of source eNodeB and target eNodeB meet the criteria shown in Formula (4) after HO has been executed successfully.

\[ M_s \geq M_t + Hyst \]  

(4)

Here Hyst is the handover margin, \( M_s \) and \( M_t \) represent the measurement values of source eNodeB and target eNodeB respectively. When ping-pong HO occurs, the call quality and user experience are strongly affected.

The phase of RLF is started upon radio problem detection, which corresponds to the \( Q_{out} \) (10% block error rate) detection. If the link quality is not increased to the level of \( Q_{in} \) (2% block error rate) for the duration of \( T_{310} \), a RLF is triggered [16]. When RLF occurs, the communication between UE and eNodeB breaks down. Here we define \( T_{310} \) as 500ms.

The ping-pong HO rate and RLF rate results are shown in Figure 7 for mountainous scenario and Figure 8 for rural scenario.

From Figure 7, it can be seen that when factor \( a \) is 1, which means no L3 filtering, the ping-pong HO rate is the highest, almost up to 70%. As factor \( a \) becomes lower, the ping-pong HO rate decreases accordingly. When it reduces to 1/6, the ping-pong HO rate almost approaches 0%. This clearly verifies that L3 filtering is effective and factor \( a = 1/6 \) can keep balance of reducing fluctuation of measured RSRP and persisting the similarity to the real situation. Moreover, the RLF rate nearly doesn’t vary with the reduction of factor \( a \) and keeps close to 0%. This indicates that L3 filtering has limited effect on RLF.
From Figure 8, it can be seen that in rural scenario, the ping-pong HO rate and RLF rate are much lower than that of mountainous scenario, which is caused by the better channel quality and measured RSRP quality. This shows that L3 filtering is not so necessary for rural scenario.

![Figure 7. Ping-pong HO and RLF performance in mountainous scenario](image1)

![Figure 8. Ping-pong HO and RLF performance in rural scenario](image2)

5. Conclusion

In this paper, the handover measurement and handover decision mechanism in high-speed railway environment and detailed theory of L3 filtering have been studied. Then simulation is made to study the influence of factor $a$ on UE measured RSRP and handover performance for
both mountainous scenario and rural scenario. The results suggest that the impact of factor $a$ on mountainous scenario is great, but on rural scenario is little. Moreover, the ping-pong HO rate decreases obviously with factor $a$ reducing, but RLF rate almost remains invariant. Based on the results, we select factor $a = 1/6$ to keep balance of reducing fluctuation of measured RSRP and meanwhile persisting the instantaneous of it.

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7. References