jet INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2023, VOL. 69, NO. 1, PP. 147–153
Manuscript received January 23, 2022; revised February, 2023. DOI: 10.24425/ijet.2023.144344

Quick Handover in 5G for High Speed Railways and Highways Using Forward Handover and PN Sequence Detection

Mohammad T. Kawser, Kazi Md. Abir Hassan, Md. Atiqul Haque, Sakif Ahmed, and Mohammad Rubbyat Akram

***Abstract*—The cellular users, on high speed railways and highways, travel at a very high speed and follow a nearly straight path, in general. Thus, they typically undergo a maximum frequency of handovers in the cellular environment. This requires a very fast triggering of the handover. In the existing method of handover in 5G cellular communication, for high speed users, neither the decision-making of handover nor the triggering of handover is sufficiently fast. This can lead to poor signal quality and packet losses and in the worst case, radio link failure (RLF) during a handover. This paper proposes a forward handover based method, combined with PN sequence detections, to facilitate a quicker handover for high speed users on railways and highways. The proposed method adds some complexity but can offer a significant improvement in the overall handover delay. A simplistic simulation is used to demonstrate the improvement of the proposed method.**

***Keywords*—5G; High Speed Vehicles; Forward Handover; PN Sequence; Radio Link Failure; Ping-Pong**

I. Introduction

IN the modern world, the rapid development of high-speed railways and highways demand highly adaptive processes for cellular technologies, which are currently developed as Long Term Evolution (LTE) and 5G. Wireless communications utilizing long-term evolution for railways (LTE-R) have been addressed recently [1]–[3]. In LTE and 5G, the UE mobility is supported through handover between eNodeBs in the RRC_CONNECTED state [4]. For users, moving at different speed levels, the parameter, *TimeToTrigger* (TTT) can be adjusted to perform the handover efficiently. However, the adjustment needs to ensure that neither ping-pong events between cells nor radio link failures (RLF) occur. This poses a challenge to implement successful handovers, especially, with the presence of very high speed users in the network. Thus, the existing handover procedures do not appear to be sufficiently capable of adapting to high-speed metro rails and highways and supporting the triggering of handover enough quickly. 5G networks, on the other hand, are expected to offer much better flexibility for unrestricted user mobility, providing higher data rates and smaller communication delays. Thus, it is of utmost importance for 5G to be able to offer the capabilities to implement faster and more efficient handover procedures.

The mobile relays struggle with regular handovers between serving donor eNodeBs (DeNodeBs) in the case of high-speed rails and a cell array-based solution that smartly organizes cells along a railway was suggested. The cell array predicts the upcoming cells in service and facilitates a seamless handover [5]. A simplistic yet efficient distributed load balancing method is described to minimize the service disruption owing to repeated handovers [6]. The authors of [7]–[10] propose different adaptive hysteresis schemes based on a cost function that takes into account some important aspects of the mobile relay, such as cell load, relay speed, and the requested service category by the UE. The authors of [11] present a HetNets-based scheme for scaling cell switching parameters that integrate Doppler spread estimation and adjust to changes seamlessly. Both the eNodeB and the UE are involved in a flexible scaling control. The authors of [12] attempt to determine the failure rate of hard handover under different high speed and traffic load environments. Algorithms using mobility trends attempt to create a mobility record to determine the predicted UE movement across the network and they search for the eligible cells for the handover in this way [13], [14]. The authors of [15] suggest the use of a smart mobility pattern recognition handover, known as Smart-HO. A fast handover procedure that calculates the weight of the neighboring cells depending on the location and the speed of the train is discussed in [16]. A 5G dual handover strategy based on concurrent horizontal and vertical handovers using two antennas installed on the train, called multi Radio-Access-Technology (multi-RAT) is presented [17]. An adaptive fuzzy logic model based on dynamic adjustment of the optimal time to trigger of the handover process is suggested [18]. The authors of [19] discuss a neighbor cell list management technique that prioritizes newly detected cells over the serving cells. Algorithms, based on the UE location, use previous reference locations to predict the moving direction of the UE. Suitable target eNodeBs are determined by estimating the UE direction with a cosine function. Thus, reducing unnecessary handovers [20], [21]. The authors of [22] present a self-optimization mechanism as part of the Self-Organizing Network (SON) based on cell ID information, such as the number of handovers performed by the UE. The signal strength is used as the criteria while selecting the target cell. Many studies

M.T. Kawser, K.M.A. Hassan, M.A. Haque and S. Ahmed are with Department of Electrical and Electronic Engineering, Islamic University of Technology, Gazipur, Bangladesh (e-mail: kawser, abirhassan, atiqulhaque, sakifahmed28@iut-dhaka.edu).

M.R. Akram is with Robi Axiata Ltd., Dhaka, Bangladesh (e-mail: rubbyat@gmail.com).

suggest modifying the traditional network architectonics or implementing a separate handover type than the hard handover. The authors of [23] propose a soft handover for TD-LTE in high-speed rail, pursuing consistent radio link quality as well as a reduced number of handovers. In comparison, a semi-soft handover algorithm for multi-bearer systems based on the *Site Selection Diversity Transmission* (SSDT) is proposed by the authors of [24]. MEN-NEMO is a femtocell-based network mobility scheme that supports smooth handover for high-speed rail systems by utilizing multiple egress network interfaces [25], [26] proposes a unique handover technique, called-*LTE Hard Handover Algorithm with Average Received Signal Reference Power Constraint* (LHHAARC). LHHAARC focuses on reducing the number of handovers and handover delays, additionally increasing the overall throughput. LHHAARC puts certain constraints on average RSRP to enhance hard handover performance. However, the research works, presented so far, apparently have a deficiency to support the triggering of handover enough quickly for high-speed metro rails and highways effectively. This paper proposes a method to trigger handover very quickly and thus, ensures smooth handovers for those very high speed cases while adding some features to the network.

The remainder of this paper is organized as follows. The handover problem is explained in Section 2 for the case of high speed users. In Section 3, we propose a remedy for the problem using forward handover and PN sequence detection. Simulation results are presented in Section 4 and the whole paper is concluded in Section 5.

II. PROBLEM STATEMENT

In general, the required values of handover parameters are a lot different between low speed users and high speed users. On the one hand, ping-pong events need to be avoided, which can occur when handover is triggered with large margin settings for the handover parameters. On the other hand, very low signal strength or radio link failures (RLF), from a dragging effect, need to be avoided, which can occur when handover is triggered with small margin settings for the handover parameters. To address this difference in the requirements, the current LTE specifications support scaling of handover parameters for high speed users. However, the two classes of users are identified and separately treated, merely counting the number of recent handovers and this does not always reflect the exact condition of the scenario. Also, the adjustments, from the existing scaling, can be found insufficient if the users travel at a very high speed. These deficiencies pose a great challenge, especially for the users on high speed railways and highways. This is because these users travel at a very high speed. Also, their travel path is near to straight in most parts. Thus, these users can move through many cells and require extremely frequent handovers. In this case, it is important to ensure that the timing for handover is decided appropriately, and also, this timing is maintained precisely.

The current 3GPP specifications use scaling of a parameter, *TimeToTrigger* for higher speed users. *TimeToTrigger* dictates when the UE starts sending measurement reports to eNodeB for both event-triggered and periodical measurement reporting. Since the eNodeB issues a handover command after particular measurement reports, the adjustment of *TimeToTrigger* can control the timing of handover to some extent. Thus, this adjustment can be considered sufficient for regular pedestrians or vehicles at moderate speed. However, the handovers are more time-critical when the users travel very fast on railways and highways. This requires a special method for the triggering of handover. In this case, it should be very promptly identified who require this special treatment. Thus, a sophisticated method is required to detect the high speed users on railways and highways.

The critical requirements for the high speed users on railways and highways can cause a delayed handover. This can result in very low radio signal as the user goes far into a new cell while staying connected to the old cell. This can cause a loss of data. In the worst case, RLF and handover failure (HO) can occur. To overcome this problem, a forward handover based scheme, using PN sequence detection, is proposed in this paper.

III. PROPOSED SCHEME

This paper proposes a scheme to address the challenges of handover for the users on metro railways and highways for 5G cellular services. The proposed scheme expedites the handover procedure and thus, it attempts to ensure smooth and timely handover between gNodeBs. Consequently, it can minimize the loss of packets, RLF, and HO. Also, a quicker handover can limit the maximum power transmitted by the UE in the network and thus, the interference in the uplink spectrum can be mitigated in the proposed scheme.

In the proposed scheme, the gNodeB first detects which UEs are on high speed railways and highways and it can use the following information for this detection.

1) Physical Cell Identities (PCIs) of the recent cells: The gNodeB can check, using PCIs of the cells, whether the UE has recently gone through the cells, which are covering the high speed railway and highway.

2) Frequency of handovers: The number of handovers over a recent particular length of the period, is an indication of user velocity and so, it can be used to check if the UE is on the high speed railway and highway.

Once a UE is found to be fast moving on the railway or highway, the gNodeB will send a message to the UE, which activates the proposed scheme for handover. The proposed scheme is a combination of two features, namely, PN sequence detection and forward handover, which are presented below.

A. PN Code Sequence

To ensure timely triggering of handover procedure despite the very high speed on railways and highways, we propose the use of PN code sequences. In most cases, the surroundings of high speed railways and highways have less clutter and the UEs on them follow a nearly straight path. These two conditions are the assumptions for the proposed use of PN code sequences. Because of the two conditions, the shadowing effect is not significant in the environment and consequently, the appropriate position of the handover primarily depends on the relative distance of the gNodeBs from the UE. Secondly, because of less clutter in the multipath environment, the coherence bandwidth of the multipath environment can be assumed to be small. Thus, it can be expected that the inter-symbol interference (ISI) will be low.

According to the aforementioned assumptions, the precise moment for the triggering of handover corresponds to a precise geographical position. Since the reception of a particular bit position and its phase, in the PN code sequence, relates to a particular period, a particular geographical position can be related to them. Using correlation, the UE will detect the precise position using a comparison of the chip position and the phase position of the chips, received from the serving gNodeB and the target gNodeBs. Thus, since the expected ISI is low, the UE should be able to detect the phase position within the chip period enough precisely. The proposed method of the use of the PN sequences is described below.

i) We propose that every gNodeB, around high speed railways and highways, apart from their conventional transmissions, transmit a special signal, which carries two PN sequences and they are as follows.
   - *Short PN code*: It is used to define the identity of an gNodeB. Each gNodeB is assigned a cyclically shifted version of the same short PN code sequence to differentiate the gNodeBs. All the gNodeBs are synchronized and they keep transmitting their versions of the short PN code. A UE can recognize each gNodeB correlating this short code. We suggest that the short PN code can be 512 chips long and there can be 64-bit shifts among gNodeBs. This supports a maximum of 8 neighboring gNodeBs to be recognized by a UE.
   - *Long PN code*: Each gNodeB, around the high speed railway and highway will be allocated a unique long PN code. A fixed symbol sequence will be scrambled by the different predefined long PN codes, assigned to different gNodeBs. The long code has a particular length for each cycle. The gNodeBs will be synchronized using Global Positioning System (GPS) and they will repeatedly transmit the cycles of long code one after another. Thus, these neighboring gNodeBs will start their predefined chip sequences together.

ii) The special signal requires additional bandwidth. To avoid interference with other operations, 3GPP uses a guard band. This guard band typically takes up around 5% above the upper limit and 5% below the lower limit of the operational bandwidth. The PN sequence transmission uses a narrow bandwidth. We propose that the special signal, carrying the PN sequences, uses the guard band, available around the band for downlink transmission. Thus, the transmission of the special signal in the guard band will not lead to significant spurious energy outside the operational bandwidth. However, a larger bandwidth may be allocated to allow a higher chip rate as the spectrum availability is getting easier in 5G, and in this case, instead of the guard band, a separate spectrum will be allocated.

iii) Correlating with the long PN code transmitted by different gNodeBs around, the UE will determine the precise triggering moment for handover. For this purpose, the UE will listen to both short and long PN codes of the gNodeBs around. The UE can identify the gNodeBs using their short codes. The appropriate triggering moment for handover will be indicated using the long codes transmitted by the respective gNodeBs.

iv) Using correlation, a UE finds that its neighboring gNodeBs transmit different chip sequences and all these transmissions are synchronized using GPS. The UE will also be synchronized using GPS. Thus, the UE will be able to detect the relative distances of the neighboring gNodeBs as the propagation delays from them are different. Based on these distances as well as based on the relative radio signal strength, the UE will create a list of potential gNodeBs for the upcoming handover. When the UE is around the proper position for handover, the distance from the target gNodeB will be slightly smaller than that of the serving gNodeB. The UE will detect this precise position using a comparison of the phase position of the chips, received from these two gNodeBs. To avoid ping-pong effects, the UE will allow a small margin period for triggering the handover after it detects a relatively shorter distance for the target gNodeB compared to the serving gNodeB. This small margin can be added using a small value for TimeToTrigger. There can often be multiple target gNodeBs to be included for the comparison and handover decision because of the proximity in their distances from the UE. During this whole procedure, the UE will also incorporate the measured radio signal of the gNodeBs to validate the method of PN sequences, which can often be marred by the shadowing effects, and in this case, the UE will rely on the measured radio signal instead.

B. *Forward Handover*

The conventional handover procedure is backward and its alternative, forward handover is not yet implemented. As opposed to the backward handover, in the case of forward handover, the UE selects the target gNodeB and performs handover. The exchange of measurement reports is not required in forward handover. Also, the UE does not have to wait for the handover decision and command from the gNodeB. Thus, the forward handover can be triggered more quickly. An additional advantage is that the handover takes place even when the serving gNodeB has too poor radio link to allow it to receive measurement reports from the UE duly. However, the handover decision is not centrally coordinated in forward handover and so, its handling is more complex.

To expedite the triggering of handover in the case of high speed railways and highways, we propose the use of forward handover. We propose a viable procedure for the forward handover and it is described below.

i) In the handover preparation phase, the source gNodeB receives a list of potential gNodeBs for handover from the UE. Then the source gNodeB communicates with the potential gNodeBs, prepares them for handover, and collects necessary information to access them.

ii) The source gNodeB sends RRCConnectionReconfiguration message to the UE. This message contains a list of the prepared target gNodeBs and the following information for each of these gNodeBs.

- PCI of the prepared gNodeB
- dedicated preamble to be used for non-contention based random access
- PRACH resources to be used for non-contention based random access
- new C-RNTI for use at the prepared gNodeB
- identities of the short and long PN codes of the prepared gNodeB

iii) The UE decides whether or not a handover is necessary with any of the prepared gNodeBs. If it is necessary, the UE selects a suitable gNodeB, from the prepared gNodeBs, as the target gNodeB for the handover, considering the signal strength.

iv) The UE triggers the handover procedure. The precise timing of this triggering is determined using the PN codes as described above.

v) As a part of the handover procedure, the UE initiates the non-contention based random access at the target gNodeB. For this purpose, the UE sends the suggested dedicated preamble to the target gNodeB on the suggested PRACH resources. Then the target gNodeB can identify the particular UE. The target gNodeB sends Random Access Response (RAR) message, which includes the following information.

- The Random Access Preamble IDentifier (RAPID) field of RAR identifies the random access preamble that the UE transmitted. As the RAPID matches the transmitted random access preamble, the UE considers successful random access.
- The RAR contains resource blocks (RBs) for the next uplink transmission of the UE, which is known as Message 3.
- The RAR contains modulation and coding scheme (MCS) for the transmission of Message 3
- The RAR contains the same C-RNTI that is to be used at the target gNodeB.

vi) Using the RBs and MCS allocated by the RAR, the UE sends an RRCConnectionReconfigurationComplete message as Message 3 to the target gNodeB notifying that it has successfully accessed the target cell. The C-RNTI MAC control element of this message contains the same C-RNTI of the UE. The UE may also send a buffer status report (BSR) along with this message to report pending data in its uplink buffers.

vii) Upon reception of the RRCConnectionReconfigurationComplete message, the target gNodeB verifies the C-RNTI and confirms the successful access of the UE. The data path from the serving gateway (S-GW) switches to the target gNodeB. This switching is initiated as the target gNodeB sends a Path Switch Request message to MME.

viii) After the successful handover, the target gNodeB sends UE Context Release message to the source gNodeB. Then the source gNodeB may indicate cancellation to other prepared gNodeBs.

IV. SIMULATION

A. Sample Calculation of Chip Rate

A numerical example is considered to demonstrate the calculation of the required chip rate. In this case, it is assumed that the minimum difference between the distances of two neighboring gNodeBs from the UE is 1 km. As the UE moves away from the serving gNodeB and gets closer to the target gNodeB, it triggers a forward handover. The UE detects a difference between the distances from these two gNodeBs based on the propagation delays from them. The difference is identified using both chip position in the sequence and the phase position within a chip period.

Assuming that the minimum difference to be identified between two distances using chip position is 500 m. So, the difference in propagation delays from these two positions will be

$$\frac{500}{c} = \frac{500}{3 \times 10^8} = 1.6667 \mu sec.$$

For the chip sequences from the two positions to arrive at the UE with different chip positions within their sequences, the minimum required chip rate is

$$\frac{1}{1.667 \times 10^{-6}} = 600 kcps$$

The required bandwidth for the transmission of chips at 600 kcps, the estimated bandwidth can be around 600 kHz. This bandwidth can be split into two 300 kHz wide parts and they can be allocated the sides of the operational bandwidth.

Assuming that the minimum difference to be identified between two distances using the phase position within a chip period is 7m. So, the difference in propagation delays from these two positions will be

$$\frac{7}{c} = \frac{7}{3 \times 10^8} = 0.0233 \mu sec.$$

So, the phase difference in the chip period for the two positions, 7m apart, is

$$\frac{2\pi \times 0.0233}{1.6667} = \approx 5^0$$

The phase difference between the two positions can be increased if a higher chip rate is allowed. The higher chip rate requires a larger bandwidth. However, in 5G, the range of operating frequency is up to 100 GHz and within this range, higher and higher carrier frequencies are being considered in the course of time. Thus, the availability larger spectrum is also getting easier with time. Therefore, the accommodation of a higher chip rate can gradually be easier.

B. Simulation to Compare the Proposed Scheme with the Existing Scheme

A MATLAB based simplistic simulation has been performed to demonstrate the outcome of the proposed handover scheme. The simulation assumptions are shown in Table I. It is assumed that a high speed user moves at the velocity *v* along a high speed railway or highway from one gNodeB to another gNodeB in a straight path. For an existing scheme, after a certain distance d from the serving gNodeB, it is found that the conditions for triggering handover are met. Assuming that the handover is triggered after n number of measurement reports at a reporting interval of tinterval, the actual handover is triggered at a distance

$$d' = d + (v \times TTT_{usual}) + (n \times t_{interval} \times v) \quad (1)$$

where TTTusual represents TimeToTrigger for the existing scheme.

For the proposed scheme, *n* is to 0 in (1) as the UE's handover decision-making process does not depend on any measurement reports. Thus, the handover is triggered at a distance,

$$d' = d + (v \times TTT_{proposed}) \quad (2)$$

The transmit power of the UE has been computed as [4]

$$P_u = P_{o\_pusch} + \alpha \times PL + 10 log_{10} M_{PUSCH} + \Delta_{TF} + f_{TPC} \quad (3)$$

where P_{O_PUSCH} is an gNodeB configured basic parameter for power control, used to achieve a suitable SINR at the gNodeB. The path loss associated with the radio link has been estimated using the Okumura-Hata model. The estimated PL in downlink, to represent path loss, is given by

$$PL = ReferenceSignalPower - FilteredRSRP \quad (4)$$

The gNodeB broadcasts *ReferenceSignalPower* and α to the UE on SIB type 2. M_{PUSCH} represents the number of resource blocks (RBs) allocated on the subframe. M_{PUSCH} allows the use of more power as a wider uplink bandwidth is utilized, and it attempts to keep the transmit Power Spectral Density (PSD) in an RB constant. The parameter Δ_{TF} or $\Delta_{Transport\_Format}$ facilitates the higher transmission power required when the UE uses a higher level of Modulation and Coding Scheme (MCS), and this compensation for MCS can optionally be deactivated, which sets Δ_{TF} = 0. The term f_{TPC} is used for continuous closed-loop power adjustments, and the gNodeB sends transmit power control (TPC) commands to set the value of f_{TPC}.

Figure 1 shows the minimum received power at the UE, P_{R_Min} for different fixed user velocities. P_{R_Min} is the power that the UE receives from the serving gNodeB right before it is handed over to another gNodeB. Since the current 3GPP specifications have an optional feature of scaling, the existing scheme is simulated with scaling as well as without scaling. As shown in Fig. 1, since the scaling expedites the triggering of handover, P_{R_Min} does not degrade with scaling for higher user velocities as much as it degrades when the scaling is not applied. However, the proposed scheme offers an even quicker handover and thus, P_{R_Min} is held at a good level of power. Thus, the proposed scheme can prevent the loss of data, RLF, and HO.

TABLE I
SIMULATION ASSUMPTIONS

Parameter	Value
Operating frequency (DL)	2 GHz
User velocity	50, 100, ..., 350, 400, 450, 500 km/hr
Path loss model	Okumura-Hata
EIRP at gNodeB	40 dBm
Separation between two gNodeBs	1 km
Antenna height for gNodeB	30 m
Antenna height for UE	2 m
Reporting method for HO	Event-triggered with event A3
TimeToTrigger (existing), $TTT_{existing}$	2.64 sec
TimeToTrigger (proposed), $TTT_{Proposed}$	0.42 sec
P_{O_PUSCH}	-102 dB
α	0.8
No. of RBs, M_{pusch}	10
ΔTF	0
f_{TPC}	0

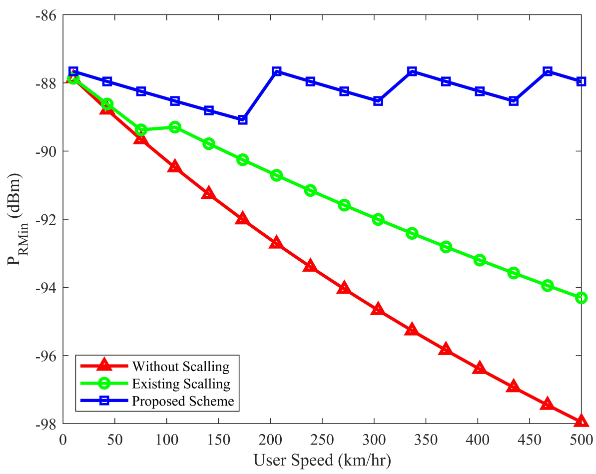

Fig. 1: Minimum Received Power at the UE, PR_{Min} vs. User Speed

Figure 2 shows the handover delay vs. user speed for the existing scheme without scaling and the proposed scheme. Here, the handover delay is calculated as the time that elapses between crossing the cell boundary and the moment for triggering the handover. The handover delays are determined for different fixed user velocities in the simulation and the proposed scheme is found to exhibit significant improvement in the delay. For the existing scheme, the lowest handover delay is 3.756 seconds, which occurs at a user velocity of 500 km/hr. At the same velocity, the lowest value of the delay is 2.556 sec for the proposed scheme, which is almost 32% lower than the existing scheme.

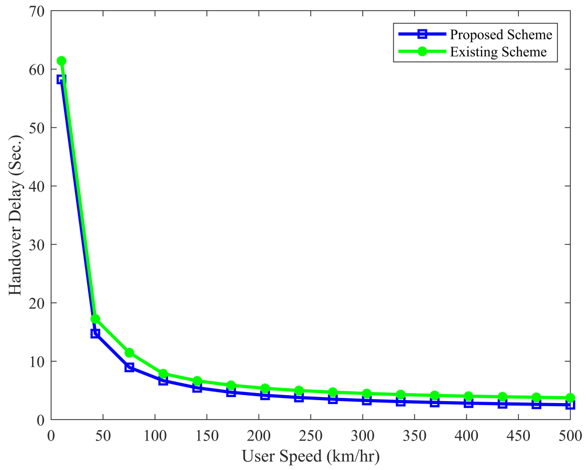

Fig. 2: Handover Delay vs. User Speed

Figure 3 shows the transmit power of the UE as the UE moves from the serving gNodeB toward the target gNodeB. Because of the quicker triggering of the handover, the proposed scheme better limits the maximum transmit power of the UE in the network. A lower limit, of the maximum transmit power of the UE, will lead to less interference in the uplink spectrum in the network.

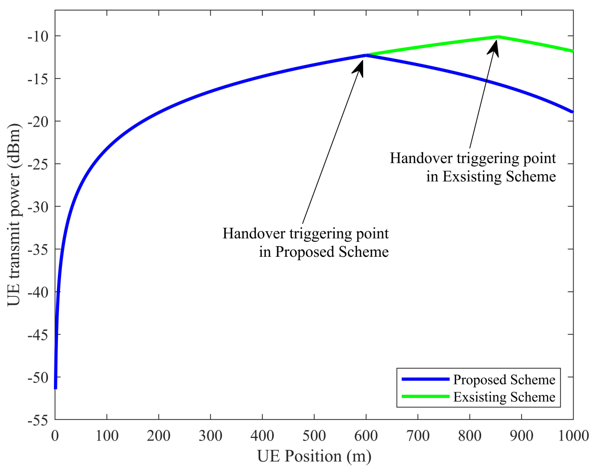

Fig. 3: UE Transmit Power vs. Distance of the UE from the Serving gNodeB

The simulation results corroborate the improved performance of the proposed quick handover scheme, for high speed railways and highways, in terms of lower packet losses, prevention from RLF and HO, and mitigation of the interference in the uplink spectrum.

V. Conclusion

The high speed users, on railways and highways, pose a challenge in timely handover between cells in 5G and thus, there are possibilities of very low radio link quality or packet losses, RLF and HO. For these high speed cases, a method is proposed in this paper to expedite the handover. The proposed scheme incorporates the forward handover and the PN code sequence detection and thus, it adds some complexity to the cellular network. However, the proposed scheme is found to significantly improve the handover delay. Consequently, it can prevent the degradation of minimum received signal power, and thus, it can reduce packet losses and prevent RLF and HO. Additionally, the proposed scheme mitigates the interference in the uplink spectrum by limiting the maximum transmit power of the UE. Thus, the simulation results corroborate the conspicuous improvement of the proposed scheme.

References

[1] R. He et al., ”High-Speed Railway Communications: From GSM-R to LTE-R,” in IEEE Vehicular Technology Magazine, vol. 11, no. 3, pp. 49-58, Sept. 2016, https://doi.org/10.1109/MVT.2016.2564446

[2] [2] J. Yang et al., ”An Efficient MIMO Channel Model for LTE-R Network in High-Speed Train Environment,” in IEEE Transactions on Vehicular Technology, vol. 68, no. 4, pp. 3189-3200, April 2019, https://doi.org/10.1109/TVT.2019.2894186

[3] Jayaram, P.; Menaka, R. Performance Evaluation of Modified Hybrid Handover Scheme in LTE Fast Moving Rail Networks. Int. J. https://doi.org/10.1504/IJWMC.2017.083056

[4] Mohammad T. Kawser, “LTE Air Interface Protocols”, Artech House, Boston, USA (2011). ISBN: 978-1-60807-201-9

[5] M. Pan, T. Lin, and W. Chen, ”An Enhanced Handover Scheme for Mobile Relays in LTE-A High-Speed Rail Networks,” in IEEE Transactions on Vehicular Technology, vol. 64, no. 2, pp. 743-756, Feb. 2015, https://doi.org/10.1109/TVT.2014.2322374

[6] J. You, Z. Zhong, Zhongzhao Dou, Jing Dang and G. Wang, ”Wireless relay communication on high speed railway: Full duplex or half duplex?,” in China Communications, vol. 13, no. 11, pp. 14-26, Nov. 2016, https://doi.org/10.1109/CC.2016.7781714

[7] B. Davaasambuu and T. Sato, ”A Cost Based Handoff Hysteresis Scheme in Wireless Mobile Relay Node,” 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall), 2014, pp. 1-5, https://doi.org/10.1109/VTCFall.2014.6965808

[8] Davaasambuu, Battulga & Semaganga, Frank & Sato, Takuro. (2015). Adaptive Handover Hysteresis and Call Admission Control for Mobile Relay Nodes. International journal of Computer Networks & Communications. pp. 87-98. https://doi.org/10.5121/ijcnc.2015.7606

[9] Davaasambuu B, Yu K, Sato T. Self-Optimization of Handover Parameters for Long-Term Evolution with Dual Wireless Mobile Relay Nodes. Future Internet. 2015; 7(2):196-213. https://doi.org/10.3390/fi7020196

[10] Lee, D.-W., Gil, G.-T., & Kim, D.-H. (2010). A cost-based adaptive handover hysteresis scheme to minimize the handover failure rate in 3GPP LTE system. In EURASIP Journal on Wireless Communications and Networking, 2010. id.750173, https://doi.org/10.1155/2010/750173

[11] Mohammad T. Kawser, Mohammad R. Islam, Muhammad R. Rahim, Muhammad A. Masud (2017). Versatile Controllability over Cell Switching for Speedy Users in LTE HetNets. Radioengineering, 26, NO. 1,(2017), pp.179-190. https://doi.org/10.13164/re.2017.0179

[12] K. Dimou et al., ”Handover within 3GPP LTE: Design Principles and Performance,” 2009 IEEE 70th Vehicular Technology Conference Fall, 2009, pp. 1-5, https://doi.org/10.1109/VETECF.2009.5378909

[13] Y. -H. Wang, G. -R. Huang and Y. -C. Tung, ”A handover prediction mechanism based on LTE-A UE history information,” 2014 International Conference on Computer, Information and Telecommunication Systems (CITS), 2014, pp. 1-5, https://doi.org/10.1109/CITS.2014.6878975

[14] H. Ge, X. Wen, W. Zheng, Z. Lu and B. Wang, ”A History-Based Handover Prediction for LTE Systems,” 2009 International Symposium on Computer Network and Multimedia Technology, 2009, pp. 1-4, https://doi.org/10.1109/CNMT.2009.5374706

[15] Tao, M., Yuan, H., Hong, X. et al. SmartHO: mobility pattern recognition assisted intelligent handoff in wireless overlay networks. Soft Comput 20, 4121–4130 (2016). https://doi.org/10.1007/s00500-015-1747-9

[16] Duan, B.; Li, C.; Xie, J.; Wu, W.; Zhou, D. Fast Handover Algorithm Based on Location and Weight in 5G-R Wireless Communications for High-Speed Railways. Sensors 2021, 21, 3100. https://doi.org/10.3390/s21093100

[17] R. El Banna, H. M. EL Attar and M. Aboul-Dahab, "Handover Scheme for 5G Communications on High Speed Trains," 2020 Fifth International Conference on Fog and Mobile Edge Computing (FMEC), 2020, pp. 143-149, https://doi.org/10.1109/FMEC49853.2020.9144880

[18] R. E. Banna, H. M. ELAttar and M. M. Abou El-Dahab, "Fast Adaptive Handover using Fuzzy Logic for 5G Communications on High Speed Trains," 2021 16th International Conference on Telecommunications (ConTEL), 2021, pp. 10-17, https://doi.org/10.23919/ConTEL52528.2021.9495988

[19] Y. Watanabe, Y. Matsunaga, K. Kobayashi, H. Sugahara and K. Hamabe, "Dynamic Neighbor Cell List Management for Handover Optimization in LTE," 2011 IEEE 73rd Vehicular Technology Conference (VTC Spring), 2011, pp. 1-5, https://doi.org/10.1109/VETECS.2011.5956456

[20] Chang, Fu-Min, et al. "An efficient handover mechanism by adopting direction prediction and adaptive time-to-trigger in LTE networks." International Conference on Computational Science and Its Applications. Springer, Berlin, Heidelberg, 2013.

[21] Wang, HL., Kao, SJ., Hsiao, CY. et al. A moving direction prediction-assisted handover scheme in LTE networks. J Wireless Com Network 2014, 190 (2014). https://doi.org/10.1186/1687-1499-2014-190

[22] D. Su, X. Wen, H. Zhang and W. Zheng, "A Self-Optimizing Mobility Management Scheme Based on Cell ID Information in High Velocity Environment," 2010 Second International Conference on Computer and Network Technology, 2010, pp. 285-288, https://doi.org/10.1109/ICCNT.2010.64

[23] Q. Wang, G. Ren and J. Tu, "A soft handover algorithm for TD-LTE system in high-speed railway scenario," 2011 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC), 2011, pp. 1-4, https://doi.org/10.1109/ICSPCC.2011.6061727

[24] H. Lee, H. Son and S. Lee, "Semisoft Handover Gain Analysis Over OFDM-Based Broadband Systems," in IEEE Transactions on Vehicular Technology, vol. 58, no. 3, pp. 1443-1453, March 2009, https://doi.org/10.1109/TVT.2008.927041

[25] C. -W. Lee, M. -C. Chuang, M. C. Chen and Y. S. Sun, "Seamless Handover for High-Speed Trains Using Femtocell-Based Multiple Egress Network Interfaces," in IEEE Transactions on Wireless Communications, vol. 13, no. 12, pp. 6619-6628, Dec. 2014, https://doi.org/10.1109/TWC.2014.2364179

[26] Lin, C. C., Sandrasegaran, K., Ramli, H., & Basukala, R. (2011). Optimized performance evaluation of lte hard handover algorithm with average RSRP constraint. International Journal of Wireless & Mobile Networks (IJWMN), https://doi.org/10.5121/ijwmn.2011.3201