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Evolution of High Speed Railway Communication system towards 5G: A Unique Scalable Model using Distributed Mobile Relays

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Abstract

Telecommunication network is gradually evolving to its 5th Generation by circumventing conventional wireless technologies and devices. The need for a seamless next generation wireless network in a highly mobile environment like High Speed Rail has thrown open significant challenges to system designers. The paper proposes a distinct model using Distributed Mobile Relays to enhance the cellular communication in an HSR scenario. The simulation study shows that the proposed model outperforms the existing single link based scheme and the implementation has significantly improved the HO Latency at higher speeds.

Keywords: 5G Network; Long Term Evolution (LTE); High Speed Railway (HSR); Handover; Quality of Service (QoS); Mobile Relays; Wireless Networks

INTRODUCTION

The world is currently migrating to an all-IP based 5G communication network to address the ever growing user requirements and socio-economic developmental needs. Tremendous transformation in the way we interact and display information along with the rapid growth in mobile phones has resulted in Long Term Evolution (LTE) [1], more popularly known as 4G, which was further upgraded by 3GPP to LTE Advanced [2]. The 3GPP technical report is further enhanced to Release 13, named LTE Advanced Pro [3], to mark the evolution of 5G with enhanced bandwidth and improved latency. The key attributes which define this standard being 640MHz of carrier bandwidth, data rate in excess of 3Gbps and latency of 2ms.

In the meantime, State-of-the-Art improvements in High Speed Railway (HSR) [4] networks is attracting more and more passengers to take this mode of transportation and the mobile devices which evolved as an integral part of most travellers has become essential and unavoidable during this long distance travel. A sudden surge in passenger traffic across this mode of transportation has resulted in a large scale increase in demand for high quality voice, video and data communication across HSR communication networks. The existing Cellular Technology implementations for mass transit has several limitations in handling such high bandwidth requirements and provide seamless communication across an HSR environment. Severe constrains in Bandwidth and reduced Handover (HO) success rate has posed significant challenges to existing LTE system designers.

To enhance the data handling capability and seamless user experience in an HSR environment, the paper introduces a Distributed Mobile Relay based approach. The proposed approach leverages deployment of multiple relay nodes through a coordinated Onboard Distribution Unit to enhance the Quality of Service (QoS) in an HSR communication environment.

The rest of the paper is organized as follows. In the following section we review the existing literature in HSR. Section 3 presents our proposed solution and the associated architecture. Section 4 details the implementation of simulation model and performance analysis. Finally, in Section 5 we summarize our results and present conclusion.

RELATED WORK

The architecture of LTE has two major components: (1) Access Network - Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and (2) Packet Switched Core Network - Evolved Packet Core (EPC). The E-UTRAN Network consist of interconnected Evolved NodeBs (eNBs), whereas EPC contains Mobility Management Entity (MME), Serving Gateways (S-GW), and Packet Data Network Gateway (P-GW) [5, 6] which provide various services like signalling, handover, security etc. These eNBs are interconnected using X2 interface and are further connected to EPC through S1 interface. Fig. 1 depicts in detail the Network Architecture of the system.

3GPP Technical Report 36.836 [7] elaborated in detail about Mobile Relay Nodes (MRN) for enhancing the communication on High Speed Trains. These nodes are mounted on Trains, which act as intermediate relay units between User Equipments (UE) and LTE. Though these MRN units provide significant improvement in Penetration Path Loss, Doppler Frequency Shift and Group HO, the mechanism would hardly improve the HO issues. Further, handling all the connectivity of passengers in a high speed train from a single interface would limit the bandwidth utilization and increase the failure rates.

Pan et al. [8] has proposed an enhanced HO method using control Mobile Relays (cMRs). These cMRs are equipped in front of the train and provide guidance to Mobile Relays thereby reducing signalling overhead and HO interruption. The drawback in this scheme is linked towards failure in cMR. Such a situation would significantly degrade the performance of the overall system. A two link architecture based on Distributed Antenna System (DAS) and Mobile Relay was proposed in [9]. The system is developed by multiple RAUs which are interfaced to remote station using RoF. In the propose system the handover is performed with the support of antenna selection and power allocation across antennas. Lin Tian et al. [10] has also introduced a HO scheme based on dual link architecture. The system employs antennas in the front and rear of train to carryout handover. However, both these models have neglected the period of HO, which affects performance in real network implementation [11].

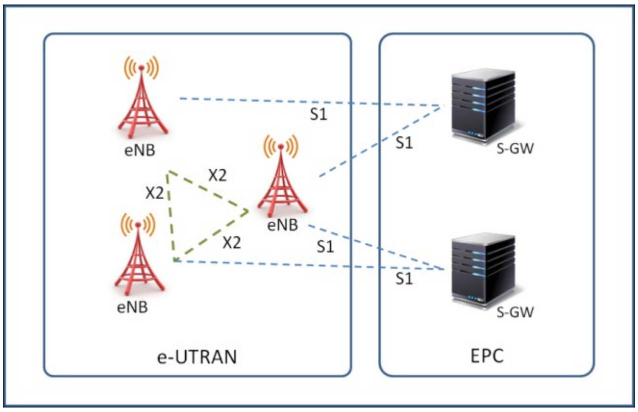

Figure 1: LTE Network Architecture

PROPOSED SOLUTION

The proposed system involves Distributed Mobile Relays (DMRs) mounted on trains which act as MRN. As multiple Relay Nodes are involved, the system would provide efficient resilience capability and would overcome the issue of single point failure. These DMRs are further interfaced to an Onboard Processing Unit (OPU).

The OPU unit incorporates a Load Balancer and Measurement Engine. The Measurement Engine facilitates effective event estimation whereas Load Balancer implements efficient distribution of connection request across multiple DMRs. DMRs are connected to the backhaul system using LTE and WiFi Link (LTE-LAA). This would facilitate effective utilisation of Unlicensed and Licensed Spectrum as envisaged in future 5G networks. Fig. 2 elaborates the System Architecture of the proposed system.

Measurement report in LTE can be configured as Periodic or Event Triggered. These events for HO as defined by 3GPP are elaborated in Table 1. and is calculated based on Technical Report TS 36.331. In the proposed system, the events are identified in advance by placing Torch Nodes in the front and rear of HST, thereby effectively predicting the upcoming eNBs. The measurement parameters are estimated by correlating the values of Torch Nodes and DMRs to have an effective decision making in varied environmental conditions. This method is in contrast to the conventional LTE method of measurement parameter identification wherein the values are taken from a single wireless node which is prone to error due to factors like climate, pollution, mobility conditions, multipath fading, penetration loss in tunnels etc.

OPU units are further interfaced to each of the Wireless Access Points (AP) placed in carriages using optical medium. This would facilitate faster data transfer and enhance the capacity of the overall system. The Wireless APs provides the last mile connectivity to UEs located at carriages. This would further reduce the issue of Path Loss and energy consumption and thereby limit battery drain of those equipments along with improving QoS. The APs deployed in trains can implement IP mobility thereby providing a seamless user experience On-board.

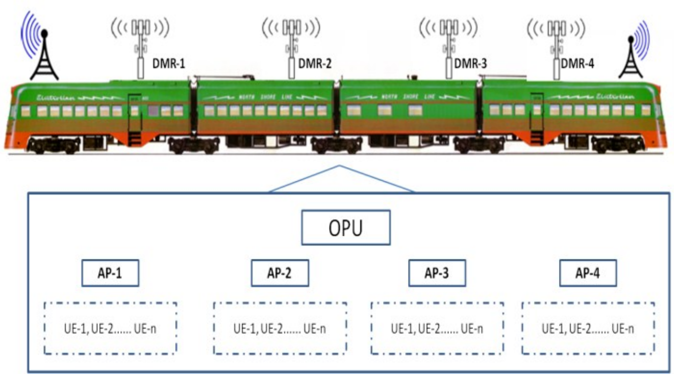

Figure 2: DMR System Architecture

The OPU units can be deployed specific to each DMRs or can be shared by a group of DMRs based on the network topology and the load being handled by the system. These units will dynamically link UEs to eNBs via Wireless APs and DMRs based on measurement reports as estimated from Torch Nodes and DMRs.

Table 1: Event Triggers for HO

Event	**Description**
Inter-LTE Mobility:	
A1	Serving eNodeB better than Absolute Threshold
A2	Serving eNodeB worse than Absolute Threshold
A3	Target eNodeB better than offset relative to Serving eNodeB
A4	Target eNodeB better than Absolute Threshold
A5	Serving eNodeB worse than one Absolute Threshold and Target eNodeB better than other Absolute Threshold
A6	Target eNodeB better than offset relative to Secondary eNodeB
Inter-RAT Mobility:	
B1	Target eNodeB better than Absolute Threshold
B2	Serving eNodeB worse than one Absolute Threshold and Target eNodeB better than other Absolute Threshold

SIMULATION AND PERFORMANCE ANALYSIS

The model was designed and implemented on an Object Oriented Discrete Event Simulator named Omnet++ [12]. The Omnet++ simulator functionality was extended for LTE support using SimuLTE package [13]. The HSR infrastructure simulated consists of eNBs, Routers, Gateways and Servers. These units were interconnected using X2 based interface. Implementation was carried out for HST components involving Torch Nodes, Distributed Mobile Relays with multiple access technologies, On-board Processing Unit, interconnected train networks with Wireless Access Points and User Equipments. In the simulated system only two DMRs were incorporated for implementation simplicity. The simulation parameters used for the system is as shown in Table II.

Table II. Simulation Parameters

Parameter	**Value**
Macrocell radius	1500m
Macro overlapped area	400m
Rail distance	5000m
Speed	350km/h
Carrier Frequency	2 GHz
Bandwidth	5 MHz (25 RBs)
Path Loss Model	ITU Urban Macro
eNB Tx Power	46 dB
Mobility Model	LinearMobility
Simulation Time	75s

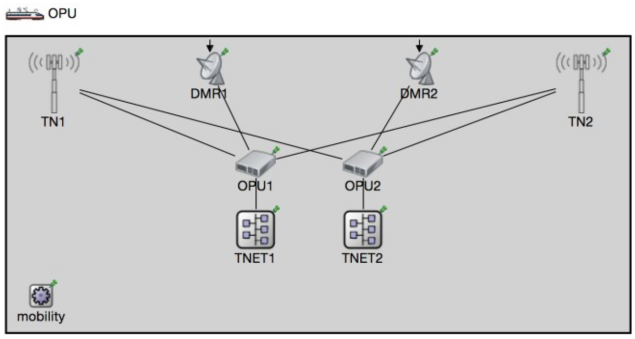

Figure 3: Screenshot of Implemented Model

Fig. 3 given below is the Omnet++ screenshot of the implemented model. The performance evaluation was carried out using Torch Nodes (Front and Rear), DMRs (2 Nos), OPU (2 Nos) and two TNETs involving Wireless APs and UEs.

The performance analysis of the proposed system was carried out in comparison with the single link Mobile Relay Node based system. Fig. 4 given below illustrates the HO latency plot as per the simulation run using DMR and single link MRN.

$$T_{HO(Latency)} = P_{SHO} \times T_{HO} + (1-P_{SHO})(T_{re\text{-}entry} + T_{re\text{-}connect}) \quad (1)$$

The latency value was estimated based on the above equation wherein the proposed approach has significantly reduced the values of $T_{re\text{-}entry}$ and $T_{re\text{-}connect}$.

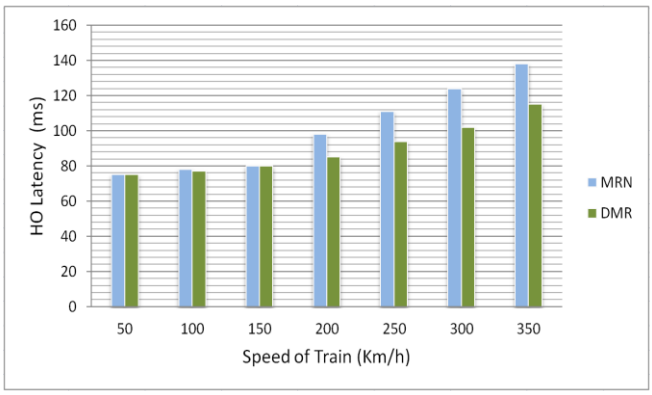

Figure 4: Comparison of Handover Latency

The simulation study demonstrates that the proposed scheme outperforms the MRN scheme by increasing the probability of HO success at each stage. As per the simulation, the HO Latency has significantly improved at higher speeds and has outperformed the MRN scheme.

CONCULSION AND FUTURE WORK

This paper evaluates the existing schemes for Mobile Relays in High Speed Railway communication and proposes a unique model using Distributed Mobile Relays to enhance the Quality of Service and Handover Latency. This unique model is scalable based on number of UEs and is flexible to be adapted to varied network topologies. The scheme can be implemented on existing HSR network with minimal infrastructure enhancements.

The model was simulated using Omnet++ and the On-board components were implemented. The performance is analysed with reference to Handover Latency and the simulation results proved that the proposed scheme outperformed the MRN scheme. In future, the authors plan to enhance the system performance based on Specific Content, Location and Adaptive Measurement Aggregation.

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REFERENCES

[1] 3rd Generation Partnership Project, "3GPP TR 25.913 Requirements for Evolved UTRA (e-UTRA) and Evolved UTRAN (e-UTRAN)," "Technical Report", 2009.

[2] 3rd Generation Partnership Project, "3GPP TR 36.913 requirements for further advancements for evolved universal terrestrial radio access (e-UTRA) (LTE Advanced)," "Technical Report", 2011

[3] P. Rost, A. Banchs, I. Berberana, M. Breitbach, M. Doll, H. Droste, C. Mannweiler, M. A. Puente, K. Samdanis, and B. Sayadi, "Mobile Network Architecture evolution toward 5G," IEEE Communications Magazine, vol. 54, no. 5, pp. 84–91, May 2016.

[4] A. G. Alvarez, "The advantages and advances of Electric Railways [viewpoint]," IEEE Electrification Magazine, vol. 2, no. 3, pp. 64–60, Sept 2014.

[5] Tara Ali-Yahiya, "Understanding LTE and its Performance", Springer, ISBN9781441964571 (online) 9781441964564, July 2011

[6] 3rd Generation Partnership Project, "3GPP TR 36.300 Evolved Universal Terrestrial Radio Access (e-UTRA) and Evolved Universal Terrestrial Radio Access Network (e-UTRAN); Overall Description," Technical Specification, 2016.

[7] 3rd Generation Partnership Project, "3GPP TR 36.836 Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (e-UTRA); Study on Mobile Relay," Technical Report, Jun. 2014.

[8] M. S. Pan, T. M. Lin, and W. T. Chen, "An enhanced handover scheme for Mobile Relays in LTE-A High-Speed Rail Networks," IEEE Transactions on Vehicular Technology, vol. 64, no. 2, pp. 743–756, Feb 2015.

[9] Z. Liu and P. Fan, "An effective handover scheme based on Antenna Selection in Ground - Train Distributed Antenna Systems," IEEE Transactions on Vehicular Technology, vol. 63, no. 7, pp. 3342–3350, Sept 2014.

[10] L. Tian, J. Li, Y. Huang, J. Shi, and J. Zhou, "Seamless Dual-Link Handover Scheme in broadband Wireless Communication Systems for High-Speed Rail," IEEE Journal on Selected Areas in Communications, vol. 30, no. 4, pp. 708–718, May 2012.

[11] T. Deng, Z. Zhang, X. Wang, and P. Fan, "A network assisted Fast Handover Scheme for High Speed Rail Wireless Networks," pp. 1–5, May 2016.

[12] A. Varga and R. Hornig, "An overview of the Omnet++ Simulation Environment," pp. 60:1–60:10, 2008.

[13] A. Virdis, G. Stea, and G. Nardini, "SimuLTE - a Modular System-Level Simulator for LTE/LTE-A networks based on Omnet++," pp. 59–70, Aug 2014.