Measurement and Analysis of LTE Coverage for Vehicular Use Cases in Live Networks

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Abstract — **We conducted drive test measurements in a live LTE 1800 MHz network to evaluate mobile network performance of User Equipments (UEs) located inside and outside a pickup truck. The measurement campaign is performed in Kosovo, starting from Prishtina to the south-western Albanian border. Knowledge of base station locations and cell load during the measurements is made available from the service provider. This is crucial to determine whether the bit rate is limited by network availability, cell load, or propagation effects. To provide reliable in-vehicle coverage, it is necessary to determine the penetration loss. In this paper, we present the first results and show that the penetration loss varies by up to 10.58 dB.**

1 Introduction

Internet usage has become ubiquitous. The users today are a mix of humans and smart machines using the connectivity to exchange information of all kind. The recent developments in vehicular industry towards smart, autonomous cars have even driven further the need for low delay emergency and high bandwidth data. Combining these two elements, it becomes clear that today highways need to provide large capacity as well as signal coverage along the route. However, another trend namely the electric car and energy saving has lead to windows with metal coating to protect from heat from infra-red radiation.

To provide reliable connectivity and large capacity for in-vehicle LTE users, it is necessarily to determine the penetration loss. This is one of the main goals of wireless providers and field experiments are crucial to design the wireless networks.

Independent from vehicle type, the increase of demand for high quality mobile communication services is tremendous. In [1–3] we performed drive test measurements on trains along different Austrian railway tracks. To overcome the effect of large

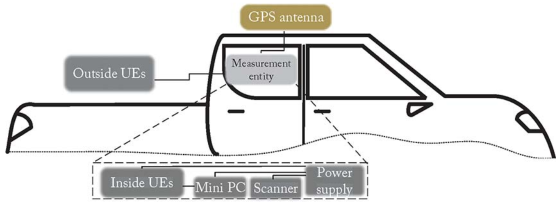

Figure 1: The vehicle setup.

Vehicular Penetration Loss (VPL), the trains were equipped with Moving Relay Nodes (MRNs) and leaky cables. To this extent, not only the chassis of various transportation vehicles is challenging in context of performance degradation, but also the windows of vehicles such as commercial cars and trains are substantially different. Nowadays, trains are equipped with windows of special features and add 9 dB penetration loss [2] while this is usually not the case for small vehicles. This imposes different propagation conditions.

Network performance of vehicular use cases, such as cars on highways and trains on railways, has technical challenges in common. First, both modern highways and railways are constructed along similar gentle curved tracks. In context of coverage, the network deployment is very similar, and cannot change drastically for future technologies, e.g. 5G or beyond. This leads to similar propagation conditions for mobile users moving on cars and trains. Second, the electric cars and current High Speed Trains (HSTs) are being built with metal coating windows. In terms of network performance, it is very important to observe whether VPL retains linear characteristic on the physical layer. Therefore, we first need measurements to find out how similar these problems are. Possible similar characteristics lead to apply the same technical solutions to both trains and cars.

Based on measurements and simulations the authors in [4] evaluate the VPL at different wireless frequencies such as at 600, 900, 1800, and 2400 MHz. The average penetration loss found in this work varies from 3.2 to 23.8 dB. The experiments are conducted on a minivan and the analysis of Line of Sight (LOS) conditions is performed. The authors in [5] conduct measurements in High-

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Table 1: UE measurement scenario.

Task	3G voice/data	4G data
FTP downlink file size [MB]	2	10
FTP uplink file size [MB]	0.5	2
Browsing	facebook	–
Video-streaming	–	youtube
Voice session	fixed line server	–

Speed Downlink Packet Access (HSDPA) network on a university campus. They provide the diagnostic of Radio Access Network (RAN) status by detecting some potential events. The analysis of HSDPA network is based on a conventional drive test tool. The authors in [6] perform measurements in LTE 1800 MHz network and analyse the signal quality along a railway track in Malaysia.

However, most of the studies related to drive test measurements are usually performed under the lack of crucial information such as base station location and cell load. The lack of knowledge about the base station deployment and cell load might lead to misinterpretation of measurement results. Especially the cell load is crucial to interpret performance drops.

In this work, we present the measurement setup as a first step toward full evaluation of LTE live network and provide the first measurement results. We specifically address the above challenges by having knowledge of physical location of LTE sites, antenna patterns, the number of directional antennas per site, vendor information, and cell load such as the number of active users and utilization of physical resource blocks.

2 Measurement Setup

The measurement route starts in Prishtina, the capital city of Kosovo, an urban environment, leads through the suburbs of Prishtina, and then southwest along the newly constructed "Ibrahim Rugova" highway to the Albanian border. The whole route encompasses a trajectory length of roughly 100 km and an allowable velocity of 120 km/h. This route is characterized with a significant number of bridges, a large number of terrain cuttings and few viaducts. Thus, both scenarios such as LOS and Non-Line of Sight (NLOS) are considered.

The measurements are performed with Rohde and Schwarz SwissQual QualiPoc Freerider UEs [7], which consists of six Samsung S5 mobile phones with measurement software, a performance logger, a mini PC, GPS positioning system, and power supply (see Figure 1). The UEs are mounted on a Mitsubishi KAOT L200 pickup truck.

The number of UEs is split up in two halves. Half of the UEs are placed on the back-seat of the vehicle and the other half is mounted on the outside of the vehicle, in order to evaluate the penetration loss. Two UEs are configured to measure 3G voice services, two UEs measure 3G data services, and two UEs measure 4G data services. Key performance parameters such as signal strength, block error rate, data rate and quality of service indicators are measured and recorded. In this sense, European Telecommunications Standards Institute (ETSI) proposed a measurement setup for inside and outside of the vehicle in [8].

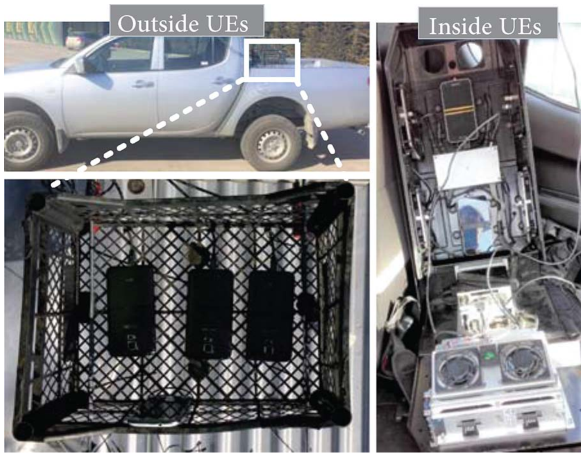

Figure 2: Placement of UEs inside and outside of the vehicle.

Figure 2 shows the placement of the UEs. The outside UEs were placed in a plastic box to keep the UEs away from metal parts and prevent them from falling during the measurements. The inside UEs were located on the back-seat. The LTE UE was pointed towards the driver seat, and during the campaign there were three passengers on-board the vehicle.

The UEs employed in this campaign reflect the best Quality of Experience (QoE) for end users. At the 3G UEs for voice services, we perform retainability tests, thus we establish long-duration and continuous voice sessions toward a particular fixed line server (i.e. multiple simultaneous call sessions). This allows to identify the main causes of failure and dropped calls. Next, at the 3G UE for data services, we configure parallel multi-tests. Due to possible lack of network resources and performance issues we choose appropriate size of files (see Table 1) in uplink and downlink File Transfer Protocol (FTP). Thus, it allows us to evaluate the differences of in-vehicle and outside characteristics for a 2x2 Multiple Input Multiple Output (MIMO) system. We also configure browsing tests linked to a social media server, e.g. facebook. Similar strategy is applied for 4G UEs, except we include video streaming instead of browsing tests.

Table 2: VPL at 95-percentile confidence interval.

Direction	VPL in urban [dB]	VPL in suburban–rural [dB]
Direction I	2.82 – 3.83	2.13 – 3.96
Direction II	1.88 – 3.19	3.29 – 4.38

3 Preliminary Results

3.1 Vehicular penetration loss

We measure the VPL for the vehicle moving along the route for two different scenarios: inside the city, Prishtina (urban environment) and, outside the city, including sites all over the route till Vermica (suburban and rural environment). Table 2 shows the measured VPL for both cases and different directions. The VPL is calculated as the difference of the averaged received power in Resource Elements (REs) of outside and inside UE. Such a definition takes into account the VPL itself (caused mainly by vehicle glasses) as well as other propagation effects (e.g. shadowing, reflections, multipaths) that occur outside and inside of the vehicle. The VPL is expressed in terms of different cell IDs at 95-percentile confidence intervals. There are cases during drive test where UEs are connected to different LTE cell IDs depending on the direction of route. This is dependent on a large number of parameters, such as variation of cell load during the day, different time of measurements, different propagation conditions, different direction of measurements and different vendors of LTE sites (15 MHz bandwidth of ALU and 20 MHz bandwidth of NOKIA sites). It is found that the VPL varies from 1.64 to 10.58 dB over the same cell IDs.

As VPL is important in designing LTE networks in order to provide in-vehicle coverage, we have found a significant number of cell IDs, where the Reference Signal Received Power (RSRP) falls below −100 dBm. This is quite severe, particularly in suburban and rural environments (see Figure 3a up and b up). Due to the VPL, the received power at inside UE is decreased further and in some cases it is similar to the cell edge conditions. This can be noticed in Figure 3a up, cell ID 14 for suburban and rural environment. Figure 3 shows the RSRP for outside and inside the vehicle UEs as well as for two different scenarios such as: urban environment, and suburban and rural environment. The results are also given for two different directions *Direction I* and *Direction II* (RSRP levels in case of urban environment are quite different in terms of directions because it is not the exact same route as we wanted to cover different part of the city). *Direction I* means the route from Prishtina to Vermica, and *Direction II* vice versa. The differences

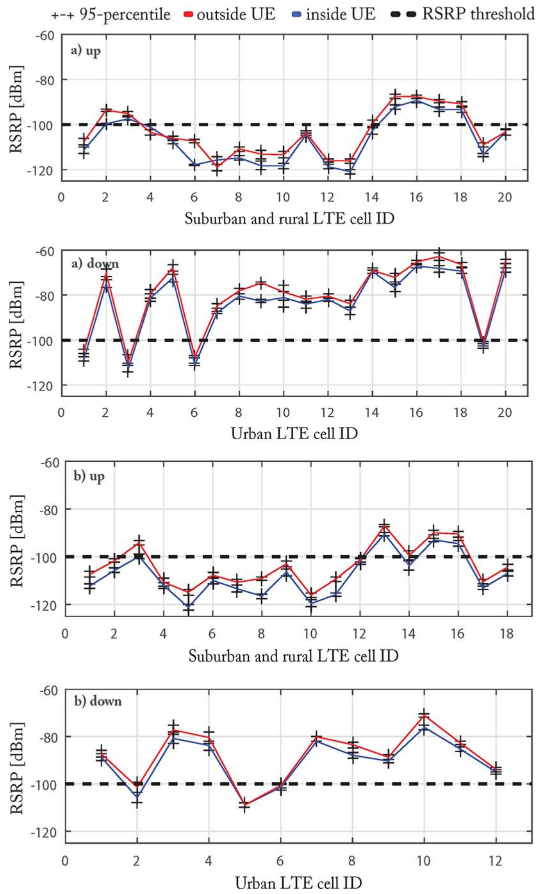

Figure 3: RSRP at inside and outside of the vehicle at 1800 MHz LTE. Up: Suburban-rural environment; Down: Urban environment. a) Direction I b) Direction II.

at RSRP between directions occur due to vehicle orientation (shadowing of the antennas by the vehicle) and different propagation conditions (different time of measurements, different multipath environment). The penetration loss is defined to be a positive value according to its definition $10\log(\frac{P_{out}}{P_{in}})$. However, during the measurements there are some cases where the difference between sample instances yields a negative penetration loss.

Figure 4 shows a Quantile-Quantile (Q-Q) plot of the RSRP in LTE 1800 MHz. The black dashed-line represents the distribution of values for inside UEs and is used as a reference to illustrate the difference of distributions between two different conditioned UEs (inside and outside UE). RSRP is up to 5 dB better for outside UEs. The Q-Q characteristic is almost linear and is comparable to prototype windows of HST (compare with [2]).

3.2 Poor coverage and interference levels

Figure 5 shows a map of the RSRP coverage along the route. 37.5% of samples (granularity of two samples/s) are below 100 dBm, which is considered

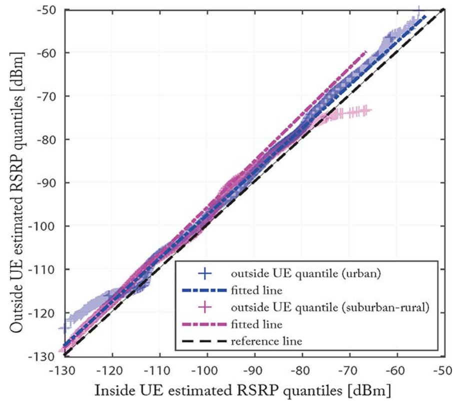

Figure 4: Quantiles of RSRP (4G) for UE placement inside and outside of the vehicle. Independent from environment, the quantiles follow the straight line, thus, only shift in statistical location is noticed.

Figure 5: The measured RSRP [dBm] along the route from Prishtina to Vermica (Albanian border).

the range where calls are dropped and data services are degraded. Good and very good coverage levels are recorded on areas close to cities, as can be noticed on the map. Particularly along the city, we have noticed a considerable number of large interference areas. At 99-percentile the averaged SINR is found to be from 7.66 to 7.97 dB, and from 8.89 to 9.18 dB at inside and outside UEs, respectively. Furthermore, we have also noticed a considerable number of cell IDs pointed to the opposite direction of the route (both environments) but were detected with high RSRP levels.

4 Conclusion

We analysed the LTE coverage and evaluated the effect of penetration loss caused by a pickup truck vehicle in a live network. The drive test measurements are conducted in Kosovo and the overall analysis is performed in scenarios such as urban, suburban and rural environments. Depending on the orientation of the car, in the urban environment we found the penetration loss to vary from 1.88 to 3.83 dB for most of the sites, which is not so severe inside the city. In suburban and rural environments, the penetration loss varies from 2.13 to 4.38 dB for most of the sites but can be as high as 10.58 dB in some cases. We have found propagation conditions along the highway to be quite comparable to rural railway measurements.

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