On the Impact of Velocity on the Train-to-Earth MIMO Propagation Channel

Statistical Observations and Qualitative Analysis

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***Abstract*— We provide measured data collected from 97 trains completing over 7000 journeys in Sweden showing that the throughput over LTE is impacted by train velocity. In order to explain these observations we assume that the underlying causes can be found in the implementation of the MIMO system into LTE Rel. 8 and the diffuse scattering of signals from ground reflections.**

***Keywords*— Train-to-Earth propagation channel; statistical data; velocity; MIMO; scattering.**

I. Introduction

Together with the Swedish train operator SJ, Icomera AB launched the world's first passenger internet system backhauled by LTE in 2011 [1]. The initial trial was conducted on the route between Stockholm and Gothenburg, and a mobile broadband link was provided to the train via an LTE (Rel. 8 [2]) 5MHz carrier [3].

During the trial the performance of the 2x2 MIMO channel was studied and there were two unexpected observations [3]:

1. Condition Numbers [4] of CN≥15dB were achieved with inter-antenna distances on the train of around 1m even though the base station antennas along the track and the train roof antennas are most of the time in LoS,
2. The MIMO performance improved with train velocity.

The result in (1) was a surprise since the theory used to model the LoS MIMO channel predicted inter-antenna distances on the train in the order of 10s of meters in order to achieve uncorrelated signals [5]. The second (2) unexpected observation, that the MIMO performance improved with train velocity, was initially treated as a measurement artifact since there were no similar observations published in the literature.

However, a recent statistical study by Garcia et al [6], including 97 trains performing more than 7000 journeys supports the latter observation. Furthermore, in another recent study by Kaltenberger et al [7], a geometrical channel model for the environment surrounding the train is presented and supported by measurements.

In this paper we first present a short summary of the statistical measurements performed in [6]. Using theory of scattering of radio signals in LoS [8] and some practical implementation aspects of MIMO in LTE [2], we present a plausible, qualitative analysis of the observations previously made in [1], [3] and [6].

II. Statistical Observations

The data reported was collected during six months in 2016 for three mostly non-overlapping stretches of rail track between four major cities in Sweden. Data was collected by the on-board router at five second intervals capturing general metrics such as number of active users, GPS position and current velocity of the train, as well as radio-related metrics and per link throughput. As the LTE cellular traffic that is examined here emanates from the users on the train a smaller, high-use, subset of the data is used in this evaluation, see [6] for details.

The data was processed per train, and an initial analysis showed no clear impact of train velocity on throughput. However, when the data was binned according to RS-SINR, a distinct pattern emerged. Figure 1 shows the values for two different 3dB RS-SINR intervals, for one train. The RS-SINR at the center of the interval is indicated in the sub-figure, along with the slope coefficient of a linear fit to the data.

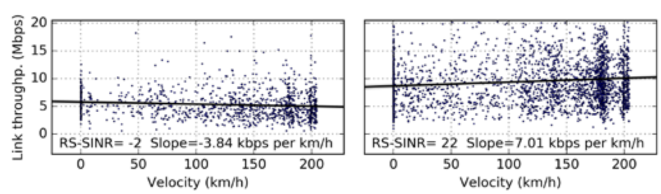

Fig. 1. Link throughput and linear fit for two RS-SINR bins.

For low RS-SINR values, such as -2, the slope shows a negative trend for the impact of velocity on throughput. The data shows that from around 12dB this changes and the slope shows an increasing positive trend. As seen in Figure 1, for 22dB there is a strong positive trend. The slope coefficients over all computed RS-SINR intervals, and for all 23 trains which had sufficiently large data sets, are shown in Figure 2. All trains show similar behavior, and a non-linear regression fit of a sigmoid function suggest 12dB to be the crossover-point where the slope coefficient goes from negative to positive.

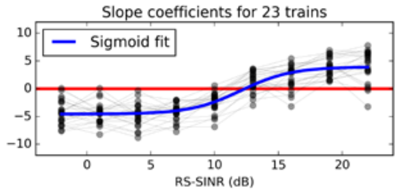

Fig. 2. Evolution of slope coefficient over 9 RS-SINR bins.

III. QUALITATIVE ANALYSIS

We assume that our observations have an underlying cause in the implementation of the MIMO system into LTE Rel 8 [2].

A. MIMO fundamentals

In order for spatial multiplexing to work, the antennas need to be deployed in a rich scattering radio environment. In the event that the channel rank is equal to or higher than the number of antennas at either side of the link, the system may choose to use the transmitter and the receiver to create multiple parallel communication "channels" over the radio interface, often referred to as spatial multiplexing.

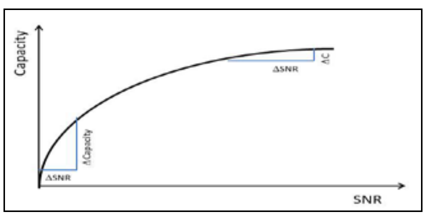

Fig. 3. Graphical illustration of Shannon's relationship

In addition to the rank of scattering channel, one must also consider Shannon's relationship for capacity and SNR: $C=\log_2(1+SNR)$.

As is evident from Fig. 3, it is at lower SNR highly beneficial in terms of capacity to improve the SNR. However, at higher SNR, the same increase will not result in the same amount of increased capacity. Hence, at lower SNR it is more rewarding not to "split the SNR" and instead phase all available antennas together and create a coherent beam.

B. Implementation of MIMO in LTE Rel 8.

In LTE Rel. 8 there are seven available transmission modes including beam-forming and spatial multiplexing [2]. The modes are based on the assumption that the base station contains of two or four transmit antennas per sector (often one or two antennas using two orthogonal polarizations (±45°)).

The Network's choice of transmission mode and antenna weights (the "precoder" matrix) is in closed-loop operations based on feedback from the terminal. Based on measurements on the cell-specific reference signals, the terminal selects a suitable transmission rank and precoder matrix and then reports it to the network. The exact implementation of this algorithm is vendor specific but in general the UE will suggest beam-forming at lower SNR and spatial multiplexing at higher.

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C. The scattering environment

As noted in [1] the average distance between train and base station was 2.4km and average tower height 45m. Even though the antennas are most of the time in LoS, one must remember that they are not in free space! First of all there are as described in [7] numerous scattering objects close to the railway. Furthermore, the BTS antennas are transmitting over a large and diffusively scattering plane which will create additional uncorrelated paths between the train and the base station [8]. Hence, since the receiver has a given integration time [2] the faster the train moves the more uncorrelated signals it will be able to receive and the richer the scattering channel will become. At low SNR the network will, as mentioned above, chose beamforming for which direction of arrival estimation is crucial for its performance and hence the train velocity will have a negative impact.

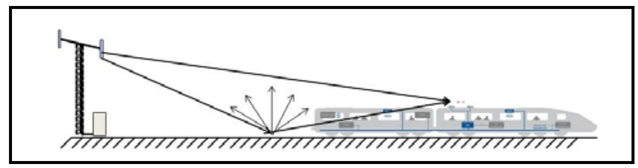

Fig. 4. Illustration of diffuse scattering of signals from ground reflections.

IV. CONCLUSIONS

In conclusion we find that our statistical findings regarding the impact on train velocity on data throughput may have a plausible explanation if one analyses the scattering environment surrounding railways and the implementation of MIMO in LTE.

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