Integration of High Speed Train Channel Measurements in System Level Simulations

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***Abstract*—The trade-off when simulating wireless cellular networks is mainly between accuracy on the one side and simulation time and supported maximum network size on the other side. A common approach in system level (SL) simulations is to utilize various abstractions that also include employing propagation models, which can be parameterized by only a small number of values. When investigating high speed train (HST) scenarios, the distinct effects of this particular environment have to be reflected in the chosen models. In order to verify the validity of SL simulations in this context, we incorporate the results of channel measurements, obtained in a real-world train transmission scenario, in our SL simulations and compare the obtained results to those of post-processed results obtained directly through the measurement data. We show that despite of the various abstraction steps in SL simulations, average throughput results are in good accordance and general trends are preserved. Additionally, we take advantage of the more flexible SL simulations and investigate the influence of feedback delay and jitter. In a last step, we then discuss the advantages of introducing a channel quality indicator (CQI) feedback backoff, in order to improve the reliability of the connection in this context.**

***Index Terms*—High speed trains, channel measurements, system level simulations, railway communications, wireless channels**

I. Introduction

Evaluating the performance of large-scale wireless networks is a challenging task. Measurements are generally too costly and detailed simulations require too much complexity. Therefore, system level simulations, which focus on scenarios with an extensive amount of network nodes (and thus resulting communication links), rely on abstraction models.

Especially for small scale fading, i.e., channel models, there is a large variety of different options available, ranging from classical power delay profile (PDP) based models to very sophisticated models such as the Third Generation Partnership Project (3GPP) 3D channel model. Nevertheless, for scenarios with very particular propagation conditions, the standard-models might not be sufficient. One such environment is given for HST scenarios, which pose specific challenges [1], but also have received a lot of attention from network operators as well as railway industry.

To analyze the performance of HST scenarios, several approaches have been employed. They range from ray-tracing approaches [2] to analytical considerations for utilizing beam switching [3] to the potential of remote radio unit (RRU) collaboration [4]. None of these results however were obtained by directly incorporating measured channel traces from a real-world HST environment.

In this paper, we combine the results of real-world measurements with system level simulations. This is done in order to verify that when appropriately parameterized, even for HST scenarios, the introduced abstractions still lead to realistic results. Therefore, we utilize channel traces that were obtained through field measurements to parameterize the path loss model as well as signal to noise ratio (SNR) and signal to interference ratio (SIR) values for SL simulations. Additionally, we rebuild the measurement geometry in the SL simulator and compare throughput results to results obtained through post-processing of the measurement data, which corresponds to link level (LL) simulations.

Due to the reduced complexity of SL simulations, further system parameters can be adjusted easily and their influence on the system performance can be investigated conveniently. Since the channel in HST scenarios tends to change rapidly, we specifically examine the impact of channel state information (CSI) feedback delay as well as the consequences for the jitter. This is of particular interest for safety related communication, that requires high reliability and thus is sensitive to variations in packet delays.

II. Measurement Environment and Procedure

We will give a brief introduction of the measurements, discussing the most important details for my comparison in the following. For a more detailed description please refer to [5]. The measurements were carried out in the south of Spain on a segment between Córdoba and Málaga from kilometric point (KP) 93.0 to KP 102.0, with a two-sector BS located at KP 97.075. A map of this train segment can be found in Figure 1.1. Each sector antenna was installed at a height of 20 m radiating along the tracks in exactly opposite directions in azimuth. The carrier frequency was set to 2.6 GHz and the BS transmitted a Long Term Evolution (LTE) signal of 10 MHz bandwidth. The transmit power was 46 dBm, but we are only interested in relative received power values, as it will be explained later. The receive antenna was mounted on top of the train roof, which means the signal does not experience penetration loss for entering the carriage. The measurements were carried out at different speeds, whereas we only consider results for a train speed[1] of 200 km/h (only measurement points with constant

[1] Note that only measurement points with constant speed are considered.

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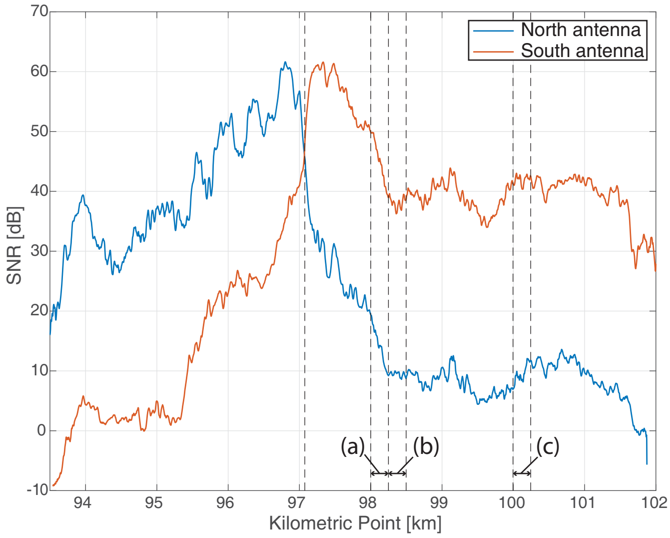
(1) Map of the measurement environment - BS position indicated with a green dot.



(2) Measured SNR for both sector antennas for the whole track. The BS is located at KP 97.075

Fig. 1: The two figures show the measurement track utilized in [5] and the corresponding measured SNR for the northern and southern sector antenna. It can be observed that even in back-fire direction of the respective sector antenna, the SNR is still considerably high. GPS location of BS site: 37°4'3.14", 4°43'12.52"W. Map Image by ©2017 DigitalGlobe, Cartography Institute of Andalucía, Map Data by ©2017 Google, National Geographic Institute of Spain.

speed are considered).

As of the time of the measurement, the used frequency band was otherwise unoccupied. Thus, the only source of interference was of one sector on the other, stemming from the back-fire direction of the transmit antenna. This can be observed in Figure 1.2, where the SNR of one receive antenna is shown for the full stretch of the measurement segment. The blue curve shows the SNR transmitting only with the antenna facing north, and the red curve transmitting only with the antenna facing south. As it can be seen, the SNR is considerably higher when the train is in the main radiation direction of the respective transmit antenna, but the difference between the SNR from northern and southern antenna is rather constant with 30 dB.

Due to the high SNR, larger than 20 dB, the LTE frames could be correctly synchronized, which is a necessity for accurately estimating the wireless channel response. For this estimation, the pilot symbols in the LTE transmit frame were utilized. Due to continuous transmissions, the wireless channel was estimated along the whole train path.

The thus obtained channel traces are then used in a post-processing step to acquire corresponding CQI and throughput values. Note that throughput results were not obtained directly from the measurements since the transmit data were not know a priori, but only afterwards, using the channel traces. Therefore, the so called GTEC 5G Simulator was used [6], which creates a simpler orthogonal frequency division multiplexing (OFDM) signal but closely resembling the characteristics of LTE regarding, e.g., fast Fourier transform (FFT) size or resource grid structure. To avoid saturation of the CQI, the interference power is boosted artificially by 15 dB (channel variations are left unchanged). All possible CQIs are transmitted and the largest successful transmission is regarded as actual transmission, which mimics perfect feedback without any feedback delay. We consider single-input single-output (SISO) transmission, i.e., one transmit and one receive antenna.

III. Necessary Adaptations of the Simulator

For system level simulations, we utilize the Vienna LTE advanced (LTE-A) SL Simulator [7]. This simulator is fully standard compliant and allows to simulate networks with several users and BSs with arbitrary locations, while providing a vast number of propagation models, that can also be adapted to the scenario under investigation.

Several adaptations have to be performed in order to simulate the measurement scenario. Firstly, the geometry has to be included in the simulation setup. Therefore, we place a user at the according distance and let it move away from the BS with a speed of 200 km/h. Usually, the noise power spectral density and the transmit power for all BSs is an input parameter for the simulator. Since we want to set the simulator parameters such that we obtain the SNR and SIR at the receiver - which are the values known from the measurements (cf. Figure 1.2) - we have to set these values relatively to each other. For a given position and a given path loss exponent and offset (w.r.t. the desired sector antenna), we then set the noise power spectral density and the path loss offset for the link of the interfering sector to the user in such a way, that the desired SNR and SIR values are obtained at the initial user position. These values are determined for each measurement segment individually.

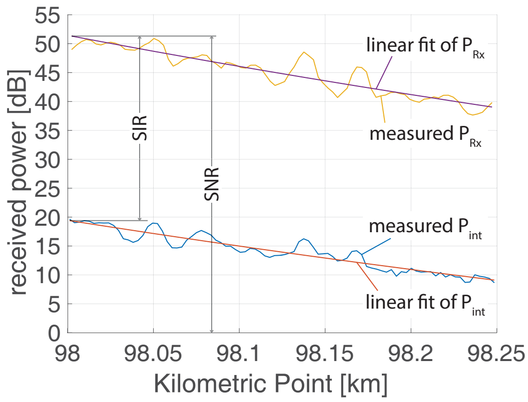


Fig. 2: Measured relative received power for desired and interfering sector for position (a), including linear fit; SNR and SIR at first point used for simulator-parametrization.

The path loss exponent can be calculated *globally* (for the whole trace of one sector), as it was done in [5]. There, the simplified distance dependent path loss is defined as

$$\widetilde{\mathrm{PL}}(d) = b + 10\gamma \log_{10}(d) + X_\sigma \tag{1}$$

where d is the link length, γ the path loss exponent and b corresponds to the path loss at breakpoint distance. The shadow fading is combined in X_σ, but is omitted in the following. We take the values for γ and b from the estimation in the reference for desired and interfering link and adjust the value of b for both links individually, according to SIR and SNR at the respective train segment. This can also be done *locally*, fitting the specific segment of the measurement. An example for this is shown in Figure 2 where the SNR for the transmit antenna of the southern sector (upper curve) and the northern sector (lower curve) is shown, including a linear fit. Since the fit is performed in a logarithmic scale, the slope of the curve directly corresponds to the path loss exponent of the log-distance path loss model. For the segment in Figure 2, the SNR decreases rapidly with $\gamma \approx 12$. The offset is determined at the first point of the trace.

The channel traces, in form of time-frequency channel coefficients, need to be adapted as well, in order to be imported into the simulation. Since the time-frequency granularity of the simulator is on resource block (RB) basis (made up of twelve subcarriers and seven time symbols), we pick one subframe per RB and average over seven symbols to represent the channel for this RB. For the interfering channel, we pick a random location in time and frequency and perform the same steps to get the channel information for the interfering sector.

IV. Comparison of Results

The results obtained through LL simulations and through SL simulations are compared in terms of throughput for three different positions (cf. Figure 1.2):

- (a) $\triangleq$ KP 98.00 - 98.25 km: Strong change in SNR
- (b) $\triangleq$ KP 98.25 - 98.50 km: Strong channel variations
- (c) $\triangleq$ KP 100.25 - 100.50 km: Almost constant SNR

For the SL simulations, we directly use the channel traces for the respective positions and calculate the path loss exponent *locally* (we perform the fit only for the considered segment). We perform SL simulations with a feedback delay of 0 ms as well as 1 ms (even though 3 ms delay is the smallest value defined in the standard, we present results for 1 ms to show that already for this smallest value supported in the SL simulator, the effects are quite severe). The corresponding results are shown in Figures 3 to 5.

In Figure 3 throughput results from LL simulations with the GTEC 5th generation of mobile networks (5G) Simulator are displayed. The temporal resolution per point is one LTE frame of 10 ms. The blue curves show throughput over train location, the red curves indicate the average throughput for the corresponding segment. We assume perfect channel knowledge and CQI choice, therefore all transmissions are successful.

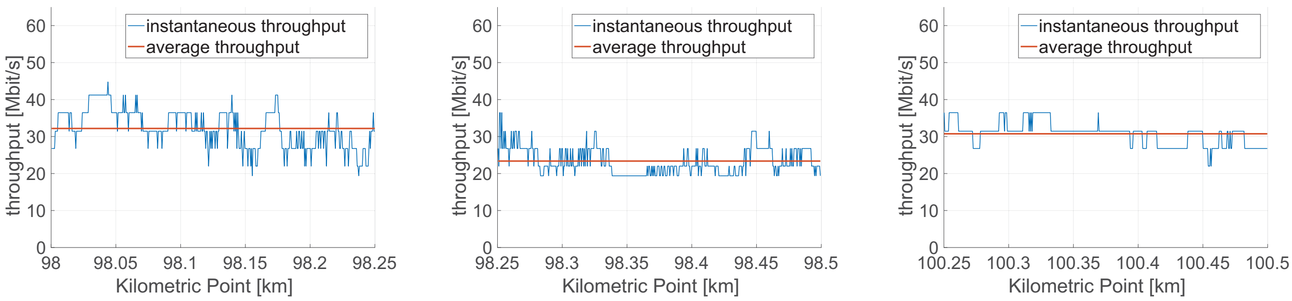
In Figure 4, throughput results of SL simulations are displayed. Note that here, the temporal resolution is one LTE subframe of 1 ms These results resemble the LL setup most accurately, since they use the measured channel traces, do not impose any feedback delay and use the path loss exponent estimated from the actual segment. It can be seen that (1) throughput trends over distance are preserved (especially visible for location (a)) and (2) that the average throughput results are in good accordance (only 5%-8% difference).

The effect of increasing the feedback delay to 1 ms is quite drastic, as it can be seen in Figure 5 and especially in Figure 5.2 which corresponds to a segment with large channel variations. The overestimation of CQI values leads to an increased amount of failed transmissions, and on the other hand, a reduced throughput when using a lower CQI than the channel would support. Even though there is a drop in average throughput compared to the LL results, it is not as drastic as it may seem (also due to the 1 ms resolution of the SL results) since the relative amount of failed transmissions is below 10%. The more critical issue here is the increased jitter, which may lead to problems for protocols or applications on a higher layer, that require a reliable connection and a constant packet delay. We have to state that no hybrid automatic repeat request (HARQ) is applied in the SL simulations. Nevertheless, also when allowing for retransmissions, the delay and jitter performance would suffer from constantly overestimating the CQI values.

Regarding the simulation complexity, it can be said that the LL simulations are very detailed and require even for such a simplistic scenario (one desired and one interfering BS and a single user) a considerable amount of simulation time, in the range of hours. The SL simulations on the other hand only require around 1.5 minutes simulation time.

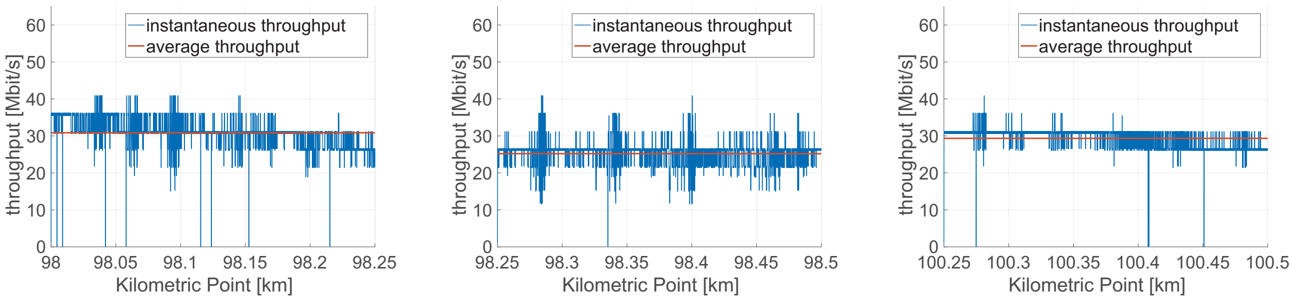
V. Jitter Improvement through CQI Backoff

To reduce the number of failed transmissions, we focus on position (b) (cf. Figure 1.2) with the largest channel fluctuations and the largest amount of 0-transmission instances for a feedback delay of 1 ms. Since for safety related applications the sum-throughput is not the most important metric, a feasible



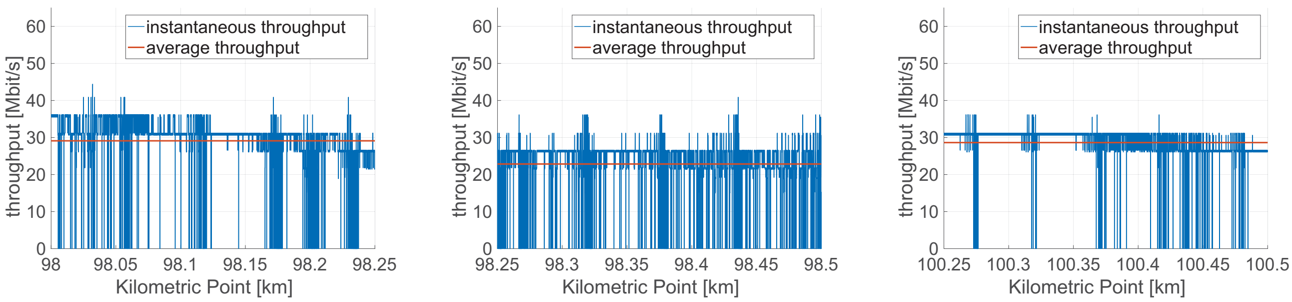
(1) Position (a) (2) Position (b) (3) Position (c)

Fig. 3: Throughput results obtained from LL simulations for all three considered positions.



(1) Position (a) (2) Position (b) (3) Position (c)

Fig. 4: Throughput results obtained from SL simulations for all three considered positions, with locally fitted path loss exponent, no feedback delay and direct channel trace input.



(1) Position (a) (2) Position (b) (3) Position (c)

Fig. 5: Throughput results obtained from SL simulations for all three considered positions, with locally fitted path loss exponent, 1 ms feedback delay and direct channel trace input.

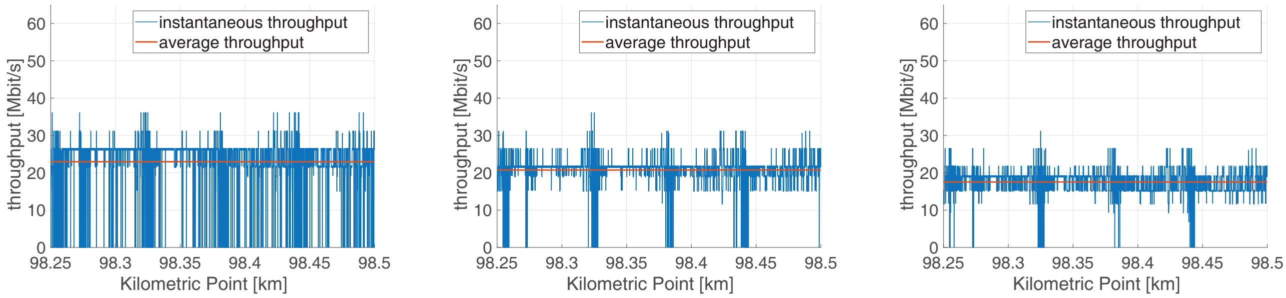
option is to introduce a back-off in the CQI feedback, as it is also promoted for future 5G networks [8]. This will reduce the average throughput, but will also avoid scheduling a higher CQI than supported by the channel.

The corresponding results for a constant CQI back-off of one or two levels (i.e., the CQI is by default reduced by one or two levels) are shown in Figure 6. As it can be seen in the results, the average throughput drops from around 23 Mbit/s to 21 Mbit/s for one level to 17.5 Mbit/s for two levels of CQI reduction. The total number of failed transmissions on the other hand drops from 345 to 85 to 38 out of 4429 total channel accesses respectively.

Since no actual data-packets are generated in our simulation, we represent the jitter by consider windows of 50 ms (which corresponds to roughly 1 Mbit at the given transmission rate) and plot the average number of failed transmissions in each window. The jitter will increase with the number of failed transmissions and also with the variation of failed transmissions over time. The corresponding results can be found in Figure 7. There, it can be seen that with no CQI back-off, there is almost no gap within the whole segment where a 50 ms transmission would happen without transmission failures. Introducing a back-off of one or even two CQI levels only leaves 4 to 5 spikes where transmission failures occur and thus the jitter is increased.

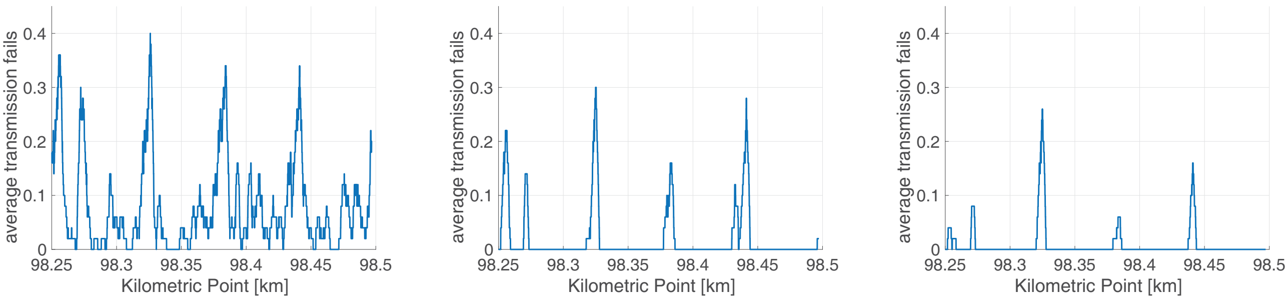
VI. Conclusions

In this paper, we compared the performance results obtained "directly" via LL simulations, utilizing measured channels for an HST environment to results of SL simulations. It can be said



(1) Position (a) (2) Position (b) (3) Position (c)

Fig. 6: Throughput results for position (b) with no CQI back-off, 1 or 2 level CQI back-off (from left to right).



(1) Position (a) (2) Position (b) (3) Position (c)

Fig. 7: Average number of failed transmissions in 50 ms windows for position (b) with no CQI back-off, 1 or 2 level CQI back-off (from left to right).

that even though several abstractions are performed in the SL simulations, the performance results show good accordance when the simulations are initialized with the corresponding parameters (around 5% difference in average throughput). SL simulations furthermore allow for the inclusion of further effects such as feedback delay and only take a fraction of computing time. Due to the fast varying channel, 1 ms of feedback delay causes a significant amount of failed transmissions. To combat this, we introduce a CQI back-off and discuss the impact on the jitter, which is especially critical for safety related applications. The presented results are obtained for 2.6 GHz - it would be interesting to investigate the application of mmWave transmission in HST scenarios, which comes with new challenges, as discussed in [9].

Acknowledgment

This work has been funded by the Christian Doppler Laboratory for Dependable Wireless Connectivity for the Society in Motion. The financial support by the Austrian Federal Ministry for Digital and Economic Affairs and the National Foundation for Research, Technology and Development is gratefully acknowledged.
This work has been funded by the Xunta de Galicia (ED431C 2016-045, ED431G/01), the Agencia Estatal de Investigación of Spain (TEC2016-75067-C4-1-R) and ERDF funds of the EU (AEI/FEDER, UE).

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