A Framework for RAN Performance Evaluations based on Software Defined Radio

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Abstract

In this paper we provide an overview of a comprehensive performance evaluation framework for RANs (radio access networks) based on SDR (software defined radio) equipment and corresponding open-source protocol stack implementations. The system setup is combined with radio channel emulations by means of dynamic pathloss adaptation that is controlled by channel quality measurements obtained from a live mobile radio network. The paper addresses LTE performance evaluations. The general framework concept is however not restricted to a specific RAT (radio access technology) due to the inherent flexibility provided by SDR concepts. The paper provides a detailed description of the framework and presents results of an exemplary performance study. We furthermore discuss different use cases for the developed evaluation framework.

1 Introduction

The virtualization of network functions represents one of the major technological trends within the area of mobile radio networks. Especially the imminent global deployment of 5G access and core networks is in this context of particular significance since concept related to NFV (network function virtualization) and the operation of virtual network slices within a single physical mobile radio network have been considered as a key component of the 5G architecture from the beginning [1].

The purpose of having SD-RAN (software defined radio access network) architectures is providing a simplified and flexible way of base station coordination for improving the spectral efficiency by means of coordinated resource allocation and scaling of system capacity. Especially the employment of advanced interference coordination strategies will become an extremely important asset in future 5G deployments due to inherent network densification and massive MIMO (multiple input multiple output) concepts with comprehensive beam management necessities. Software based concepts furthermore facilitates enhancements and extensions of RAN functions by means of software updates in a flexible and efficient fashion. Combining virtualization of RAN based functionality with cloud technology concepts is furthermore expected to provide additional benefits by increasing energy efficiency and reducing the TCO (total cost of ownership) in terms of CAPEX (capital expenditure) and OPEX (operational expenditure) [2].

The work presented in this paper focusses on establishing a comprehensive performance evaluation framework by combining an SD-RAN with a radio channel emulation controlled by input coming from live network measurements. The open-source implementation provided by srsLTE [3] is used for the SD-RAN since it provides a comprehensive open-source development environment for SDR (software defined radio) incorporating concepts such as SDN (software defined networking) and NFV.

The SD-RAN framework that is presented in this paper incorporates the LTE eNB and UE (user equipment) implementation of srsLTE and the corresponding EPC (evolved packet core). The National Instruments USRP 2944R [4] is used as SDR (software defined radio) equipment for both eNB and UE in the SD-RAN. More details regarding the hardware configuration can be found for example in [5].

The next section will provide an overview of the developed evaluation framework. Then we will describe relevant use cases and present an exemplary performance study based on the combination of live network measurements with the SD-RAN performance evaluation framework. The paper ends with concluding remarks and an outlook.

2 System Description

The SD-RAN based performance evaluation framework consists of a diverse set of components with specific tasks, ranging from measurement capabilities to an evaluation server with a database for storing and exchanging measurement results ,system configurations and adaptation parameters.

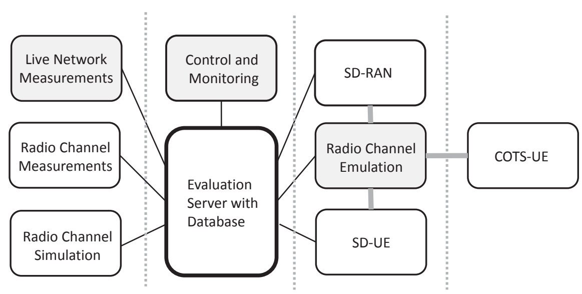

Figure 1: System framework

The system furthermore incorporates applications for controlling and monitoring individual components. An overview of the evaluation framework is provided by Figure 1.

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The individual components and their roles will be described in the following.

2.1 Live Radio Network Measurements

In order to conduct performance studies, it is first required to collect measurement samples from a live network. The measurements in the current setup are based on LTE mobility measurement and channel quality reports, such as RSRP (reference signal receive power), RSRQ (reference signal receive quality), CQI (channel quality indicator) and TA (timing advance) that are specified in [6] and [7]. Although the current implementation of the framework primarily addresses LTE, it is in general not restricted to any specific RAT (radio access technology).Wi-Fi, NB-IoT (narrowband internet of things) or the upcoming 5G-NR (new radio) could be supported as well. The current development activities related to the evaluation framework focus specifically on the latter due to its significant relevance within the context of the ongoing digital transformation.

In addition to these standardized measurement reports, it is furthermore possible to collect SINR (signal to interference plus noise ratio) estimations provided by the UE. These KPIs (key performance indicators) are obtained either by means of an Android application that has been developed specifically for that purpose at the HfTL (Hochschule für Telekommunikation Leipzig), or by means of specialized software tools such as Accuver XCAL-M [8] that provide direct access the UE chipset. The latter has the advantage that it provides measurements on TTI (transmission time interval) level, which corresponds to a one millisecond subframe in LTE.

2.2 Radio Channel Measurements

In addition to live network measurements, the import of results from radio channel measurement into the evaluation framework is supported as well. During a basic propagation measurement campaign, a transmitter that is not part of the live network is set up at a given location and configured. A mobile receiver measures localized signal parameters such as signal strength or receive power. The integration into the evaluation framework would be established by writing measurement results of a signal analyzer directly into the database together with the corresponding location information.

2.3 Radio Channel Simulations

Another approach for providing radio channel conditions is by means of simulations. This could for example be done by comprehensive system level simulations with propagation models based on standardized radio channel models such as the ones developed at 3GPP with the scope of corresponding study items [9] or further advanced channel models such as the QuaDRiGa model [10]. It is furthermore possible to conduct ray tracing simulations, for example with Altair WinProp [11], in order to generate deterministic channel and propagation models for given scenarios.

2.4 Evaluation Server with Database

The evaluation server represents the central component of the system. It comprises a database that stores measurement and simulation results, the positions of base station and mobile nodes. It furthermore acts as a distributor for the adaptation of configuration settings and dynamic parameter adaptations over a REST (representational state transfer) API (application programming interface).

An exemplary database content excerpt that is used for the performance study presented in Section **Fehler! Verweisquelle konnte nicht gefunden werden.** is shown in Table 1. It contains information related to both base stations (cells), corresponding to an LTE eNB, and UEs in the evaluated scenario.

The UE related information comprises the SINR level of the serving cell and lists for RSRP and RSRQ levels of all measured LTE cells within the scenario. During a measurement run all these contents are updated periodically together with geolocation information (longitude, latitude) and time stamp.

In addition to the radio network specific information, the database can furthermore store geographic data and information such as building and street locations. The latter could for example be obtained from projects such as OpenStreetMap [12].

Table 1: Exemplary database content excerpt

Base Station (Cell)	User Equipment
• ID • Location • Configuration • Parameters • … • …	• ID • Location • Time • Configuration • Parameters • … • SINR level (serving cell) • List of RSRP levels • List of RSRQ levels

2.5 Control and Monitoring

The database provides a generic interface for control and monitoring applications. A typical control application is used for periodically updating eNB and UE parameters such as transmission bandwidth and MCS (modulation and coding scheme) settings. It can furthermore control resource scheduling strategies.

The interaction between RAN, evaluation server and control applications basically corresponds to concepts currently discussed by the O-RAN Alliance which is focused on smart integration of real-time analytics and machine learning systems into evolving radio access networks [13]. Another approach for integrating interfaces for network optimization based on AI (artificial intelligence) has been proposed within the ETSI ENI (experiential networked intelligence) project [14].

A control application that plays a vital role in the overall framework performs the periodic adaptation of the radio channel conditions for the SD-RAN as described in the next subsection.

2.6 Radio Channel Emulation

The radio channel emulation is an integral part of the evaluation framework. It consists of software controlled RF (radio frequency) devices such as step attenuator or phase shifter embedded in a cabled RF network connected to a shielding box which accommodates COTS (commercial off-the-shelf user) UEs. Conventional radio measurement equipment such as an RSA (real-time signal analyzers) monitors the signal while running the emulation. The SINR levels obtained by means of measurements or simulations will be reproduced in the SD-RAN by the step attenuator. The attenuation can in general be adapted for both downlink and uplink where it affects the corresponding receive power levels in UE and eNB, respectively.
The combination of software controlled radio channel emulation and live network measurements or simulation results facilitates the replication of mobility patterns. It is for example possible to simulate propagation conditions for complete street grids within a city and let virtual SD-UEs move along these streets based on specific mobility models.

2.7 Traffic Load Generation

Depending on the class of UEs used in the SD-RAN, different kinds of traffic load generators can be used in the system. A major advantage of using software defined UEs is that it provides access to all protocol layers. This means that it is possible to directly inject traffic into individual layers or sublayers, such as PDCP (protocol data convergence layer) or MAC (medium access control) and corresponding transmission buffers.
Traffic load can be generated for multiple UEs of varying numbers for both uplink and downlink direction with individual characteristics in terms of packet inter-arrival time and packet size distributions and correlations.
In addition to these specialized traffic load generators, it is always possible to run conventional applications or services such as video streaming or VoLTE (Voice over LTE) on COTS UEs that are connected to the SD-RAN in order to obtain corresponding QoS or QoE evaluations under realistic conditions.

3 Use Cases for the Framework

The SD-RAN based evaluation framework described in this paper offers significant support for multiple relevant uses cases as will be described in the following.

3.1 Performance Prediction

In addition to evaluating the radio channel and propagation conditions, the framework facilitates the test of new applications and services. Since the SD-RAN is running based on reproductions of radio channel measurements results from a live network, it allows for detailed investigations of QoS (quality of service) and QoE (quality of experience) under controlled conditions. This concept can be used for predicting the performance of new air interfaces with advanced technological features such as 5G-NR (new radio) with massive MIMO and flexible transmission bandwidth adaptation.
The basic procedure is shown in Figure 2. Measurement samples are gathered from the live network and stored into the database within the evaluation server as described in Section 2. These results are then used as input for the SD-RAN radio channel emulation. The SD-RAN deployment can then incorporate new features and concepts that are not available in the live network.

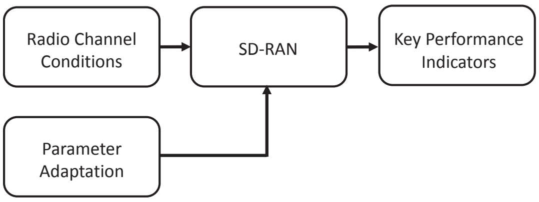

Figure 2: Performance evaluation based on measurements

3.2 Parameter Optimization

Based on results obtained by live network measurements, parameter reconfigurations of the RAN can be enforced. Such adaptations of the network can basically address all protocol layers and functional entities. Examples are resource scheduling strategies and transmission parameter settings such as priorities and MCS (modulation and coding scheme) selection. Another set of configuration parameters is related to base station antenna settings such as downtilt and horizontal antenna orientation.
Next to the parameter optimization, the evaluation framework can furthermore be used for detecting technical issue in the live network such as feeder swaps at base station antenna ports or performance degradations due to PIM (passive intermodulation).

3.3 Concept Development and Evaluation

A major advantage of the evaluation framework is that it provides the possibility to conduct early performance evaluations of new technical concepts and ideas under controlled conditions in an environment that represents an accurate reproduction of radio channel conditions from a live network. That means that it can directly be shown how new concepts would affect the performance experienced by the user.
Challenging concepts within the scope of 5G that are currently investigated with the evaluation framework address for example different degrees of network slicing and the splitting of VNFs (virtualized network functions) into CUs (centralized units) and DUs (distributed units) within a cloud based radio access network. An additional aspect that is investigated extensively with the scope of the EU funded 5G-MoNArch project addresses the computational elasticity in virtualized radio access networks [15]. The evaluation framework has here for example been used for

detailed studies of the computational resource requirements in such networks under realistic conditions [5].

3.4 Education and Training

An SD-RAN based network offers many advantages for students by providing deep insight into the interaction of all the functional entities involved in the operation of a mobile radio network. In comparison with simulations, the framework facilitates hands-on experience gained by operating a real network in combination with conventional UEs. The combination with measurement results from a live network furthermore helps consolidating the understanding of intricate interrelations between radio channel conditions and user experience.

4 Exemplary Performance Study

In the following exemplary study we will show how the framework is used for the downlink performance evaluation of a typical urban scenario in an LTE network.

4.1 Live Radio Network Measurements

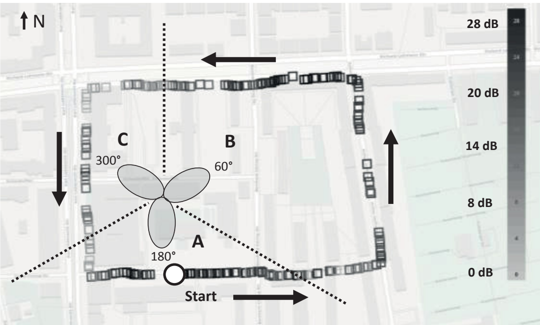

Figure 3: Evaluated Scenario

Figure 3 shows the scenario that will be evaluated in the following. The measurements have been conducted in a typical urban environment in the south of Leipzig around a single LTE site with three sectors, corresponding to cells A, B and C. The LTE network is operated at 1800 MHz with 20 MHz channel bandwidth. The measurement samples have been collected during a test run around the site as indicated in Figure 3.
UE measurement samples have been collected at distances between approximately 80 m and 300 m to the base station site. Due to the densely build-up area, there are for most locations non-line-of-sight conditions. The average inter-site distance is about 1000 m to 1500 m and the base station antenna height is 40 m.
The CDFs (cumulative distribution functions) of the downlink SINR samples observed during association to the three cells are shown in Figure 4. The results show that the SINR levels cover the range between -3 dB and 30 dB which is a typical observation for urban or suburban scenarios.
It can be seen that the SINR subsets associated to cells A and B show similar performance while cell C provides significantly lower SINR levels during the measurement campaign. This is an interesting observation since the measurement locations at which the UE was associated to cell C are quite close to the site. The reason for this effect is the increased interference level at these locations due to co-channel cells located in the vicinity (not shown in the scenario figure).

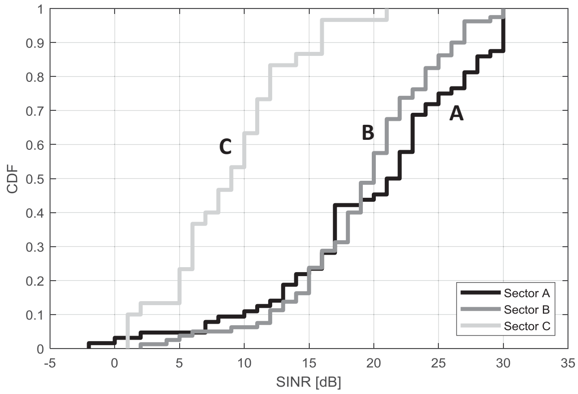

Figure 4: SINR distributions

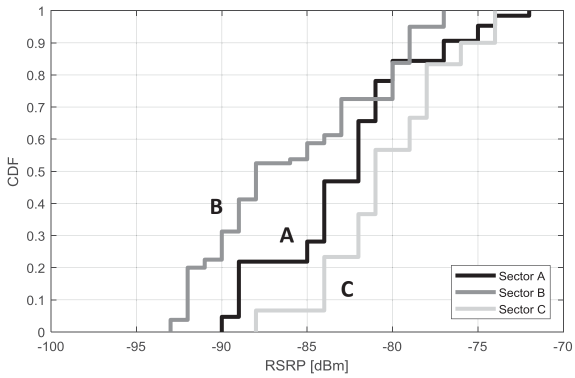

Figure 5: RSRP distribution

The latter is confirmed by the evaluation of the RSRP distributions shown in Figure 5. Here it can be seen that the UE experience the highest receive power levels when associated to cell C due to the small distance between site and UE. When associated to cell B, the UE experiences a smaller received power level due to the increased distance, as can be seen in Figure 3. This reveals that the low SINR levels in cell C stem from high interference levels and not from low received power levels.
Figure 6 shows how the SINR measurements can be used to reconstruct the radiation patterns of the base station antenna. For that purpose, the SINR samples are associated to the horizontal angle between the UE during the measurement and the base station site location. After sorting the samples, they have furthermore been filtered by means of a moving average.
The evaluation reveals that the SINR patterns apparently correspond to the expected characteristics provided by three sectors with 120° each. The horizontal angle of 0° corresponds to the northern direction. The main directions of cells A, B and C are 180° (south), 60° (north-east) and 300° (north-west), respectively.

Such an evaluation can be used for detection of antenna positioning and configuration issues within the live network. More advanced evaluation concepts can additionally take into account specific antenna patterns and beamforming characteristics.

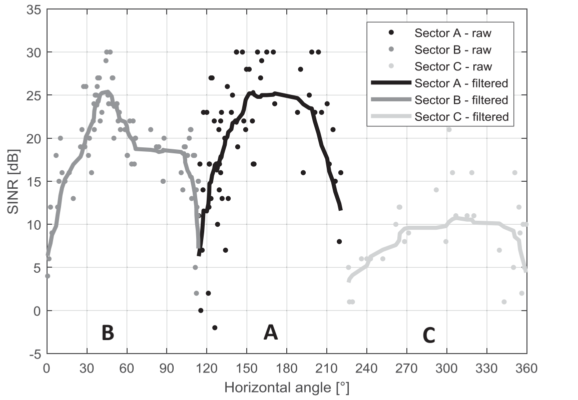

Figure 6: SINR samples depending on angle

4.2 Measurement Track Reproduction

Since all measurement results are stored in the database within the evaluation framework as described in in Section 2, the measurement track can be reproduced for the SD-RAN. During the experiment, the UE is repeating the track around the base station site as shown in Figure 3 two times. The measurement track representation in the database is depicted in Figure 7. In addition to location, time stamp and observed SINR level that data structure contains the PCI (physical cell ID) of the serving LTE cell.

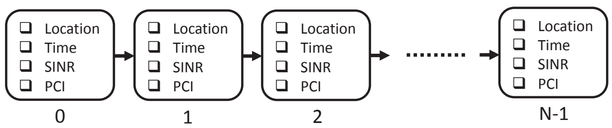

Figure 7: Stored measurement samples

The SINR setting in the SD-RAN are updated every 500 milliseconds meaning that the SINR values are read from the data base with that interval pattern and that the step attenuator for the downlink channel is adjusted accordingly. The traffic load generator is configured for full buffer in order to provide maximum throughput performance. During the study, the number of active UEs is furthermore restricted to one, which is the evaluated UE itself. Handovers between cells itself are not performed in the current SD-RAN implementation, but the resulting impact on the experienced SINR is modelled for the UE.
The SD-RAN eNB performs link adaptation according to the procedure specified in the corresponding 3GPP documents [6]. The UE periodically reports the wideband CQI (channel quality indicator) which is used at the eNB side for the selection of an appropriate MCS (modulation and coding scheme) index referring to a specific combination of MO (modulation order) and TBS (transport block size). The code rate of the channel coder is determined by the amount of available REs (resource elements) of the downlink resource allocation and the TBS. This procedure is known as rate matching and the details are described in the corresponding specification [6].

Table 2: Modulation and coding schemes

MSC index	Modulation order	Modulation scheme
0-9	2	QPSK
10-16	4	16QAM
17-18	6	64QAM

LTE supports 32 MCS levels, where indices 29, 30 and 31 are reserved for retransmissions while indices 0 to 28 indicate specific combinations of MO and TBS. The setup used for this performance study corresponds to LTE Rel-8 which yields the mapping given in Table 2.
The maximum achievable downlink throughput on MAC level depends on system bandwidth and number of spatial streams supported by the applied MIMO (multiple input multiple output) strategy. This study is restricted to a SISO (single input single output) deployment without spatial multiplexing and system bandwidth settings of both 10 MHz and 5 MHz. This results in theoretical maximum downlink throughput magnitudes of 36.7 Mbit/s and 18.3 Mbit/s, respectively, under the assumption of 100% availability of radio resource for downlink transmissions.

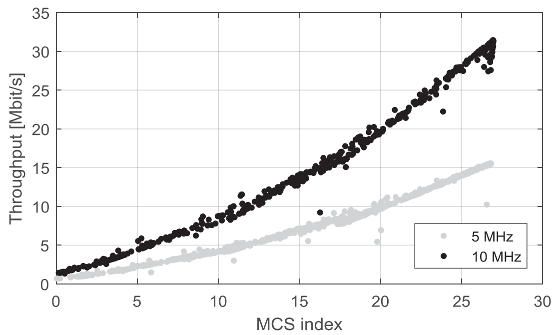

Figure 8: Throughput depending on MCS level

The dependency between MCS level and downlink throughput is shown in Figure 8. It can be seen that the throughput is approximately doubled when the system bandwidth is increased from 5 MHz to 10 MHz. The results furthermore show that the maximum throughput that is achieved with the current SD-RAN implementation stays below the theoretical maximum since not all radio resources can be used for downlink data transmissions in a typical LTE deployment. A certain amount of resources is always required at least for PBCH (physical broadcast channel) and PSS (primary synchronization signal) plus SSS (secondary synchronization signal).
The results of the performance evaluation can be seen in Figure 9. The curves show the MCS usage and the resulting throughput, respectively. One sample represents in both cases the average over 500 milliseconds, and the samples have been filtered by means of a moving average with a length of ten seconds (20 samples) in both cases.

One run of the measurement track given by the consecutive locations shown in Figure 3 takes approximately three minutes, corresponding to 300 samples.

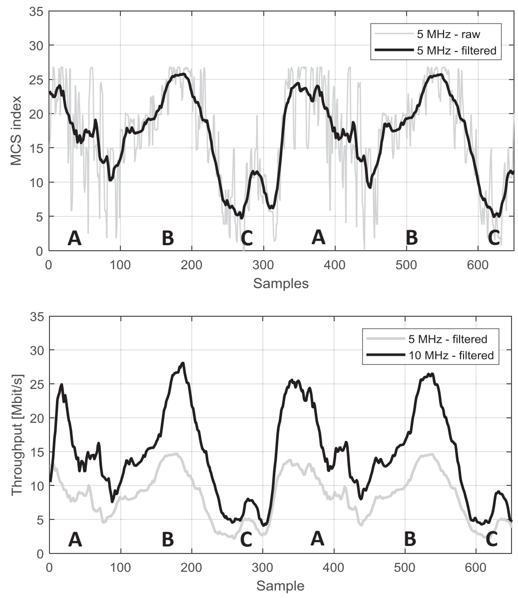

Figure 9: MCS and throughput evaluation

The repetitive pattern of the sequential runs including the individual cells (A, B and C) is clearly discernible in both figures. A comparison with the SINR evaluation provided in Figure 6 confirms the expected strong correlation between SINR level and MCS selection. It can be seen that cells A and B provide significantly higher MCS levels than cell C due to the higher SINR. The downlink throughput CDFs for both 5 MHz and 10 MHz are presented in Figure 10 which confirms that the average throughput is approximately when the system bandwidth is doubled.

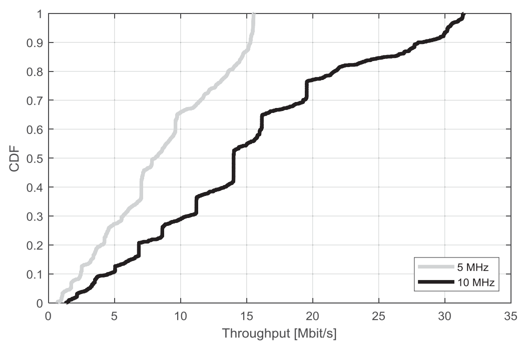

Figure 10: Throughput distribution

5 Conclusion

In this paper we provided on overview of a comprehensive RAN performance evaluation framework based on software defined radio. Different use cases have been discussed and the effectiveness of the evaluation approach has been shown by means of an exemplary detailed performance study. Currently ongoing development activities are focused on the integration of 5G-NR into the framework.

6 Acknowledgement

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