2015 IEEE GLOBECOM Workshop on SmartGrid Resilience, San Diego, USA, December 2015.

Spatially Distributed Traffic Generation for Stress Testing the Robustness of Mission-Critical Smart Grid Communication

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***Abstract*—Resilient Smart Grids require very robust communication infrastructures, which allow to support the control of the Smart Grid even and especially in critical situations. Current network quality assurance processes, such as drive tests in wireless systems, typically focus on cell coverage and quality of service parameters (e.g., max. data rate) at a specific geographical position, without considering the impact of overload situations. Therefore, this paper introduces a methodology for stress testing a communication infrastructure for Smart Grids by synchronized, distributed so-called Smart Traffic Generators (STGs). Due to their low cost, the STGs become a permanent part of the infrastructure and enable a network operator independent, continuous network quality monitoring. A case study leveraging a LTE deployment demonstrates how the proposed approach can prove the fulfillment of Quality of Service (QoS) requirements of time critical Smart Grid applications, even in stress situations with high cell load. Although, the proposed approach has been introduced for Smart Grids, it can also be used for ensuring the communication resilience for other critical infrastructures, e.g., public safety networks.**

I. INTRODUCTION

In consumer-oriented usage scenarios of mobile networks, the perceived satisfaction of the users is at the forefront of design considerations: mobile networks are optimized for cell coverage and highest possible achievable data rate. To make use of the available network resources in a most efficient way, user devices, which experience good channel conditions (i.e. no shading, short distance from the base station) are typically preferred. In those cases the data rate-to-spectrum ratio is optimized and a maximum return-on-investment will be generated for the operator. In a consumer-oriented network environment, limited resource allocations for user devices with unfavorable channel conditions (e.g., due to an indoor, non-line-of-sight or cell edge situation) lead to low application data rates and connection failures, which are perceived by users as a nuisance, but are accepted as part of the mobile network usage in some situations.

New usage scenarios, however, intend to use wireless communication systems for the control of so-called Cyber Physical Systems (CPS). A prominent example are Smart Grids, which aim to leverage networking technologies such as wireless networks and Power Line Communications (PLC). The suitability of a networking technology candidate for Smart Grid services depends on the traffic capacity and robustness of the system against radio propagation characteristics and anomalies in data traffic, that are caused by various incident types (e.g., natural disasters, technical errors, attacks). In case of energy systems (and other critical infrastructures), robustness in our understanding means that sufficient communication resources are assigned to the relevant control components even in unfavorable channel conditions, which means that a certain level of communication should always be possible. The reliability and robustness of the communication infrastructure needs to be validated with suitable methods in order to avoid damage of the infrastructure. Further on regulatory requirements need to be fulfilled by the operator of the power systems in terms of the availability of the overall system, which will have a corresponding impact on the required Key Performance Indicators (KPIs) of the communication system. The possibility to generate spatial-distributed as well as Smart Metering compliant traffic patterns within a mobile communication cell turns the STG system to an important tool to determine the cell behavior in Smart Grid scenarios.

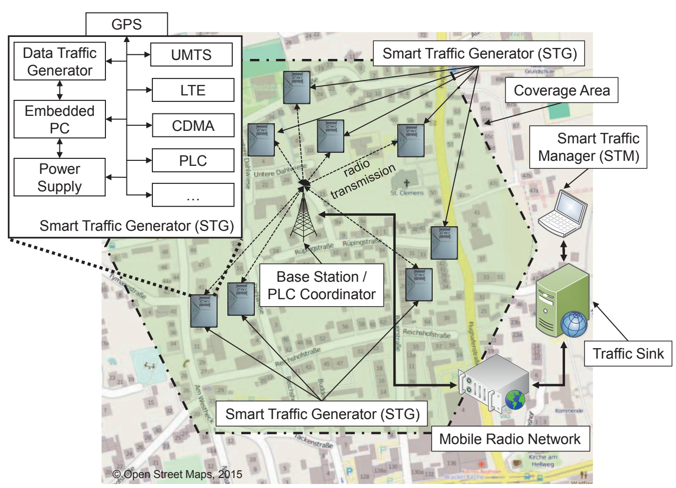

Fig. 1: Overview of the architecture for stress testing of critical communication infrastructures using distributed STGs.

In order to validate that the communication system meets the KPIs required for a specific application over the whole coverage area, network operators have to invest in detailed drive tests within the relevant region to create the relationship between a specific geographical position and the corresponding system performance for a user at this position. The disadvantages of this traditional method are the occasionally availability of the measurement data and high costs for creating a detailed connectivity map especially for large coverage areas.

To conquer against this problem, an innovative method to evaluate the spatial distribution of the system performance of a mobile network by using Smart Traffic Generators (STGs) is presented in this paper. With the help of the STG system depicted in Fig. 1, comprehensive field tests even for stress test situations can be performed in a most efficient way by automatically processing and evaluating multiple measurement studies with the help of an application scheduler, which is accessible by a Graphical User Interface (Smart Traffic Control Center, STCC). Afterwards, performance bottlenecks of the mobile cell can be detected easily by the post-processing methods of the STG system. Furthermore, optimization attempts for compensating the detected bottlenecks can then be quantified by the proposed system.

The rest of the paper is structured as follows: In Section II, an overview of traditional measurement methods as well as some basics about realizing Quality of Service (QoS) parameters in Long Term Evolution (LTE) networks are presented. In Section III, the structure as well as the hardware and software realization of the proposed STGs are described. An exemplary field test, which shows how the STGs can be used to optimize a dedicated LTE base station for Smart Grid applications, is given in Section IV. Finally, the paper is concluded in Section V.

II. Related Work

The following section contains background knowledge necessary for a detailed understanding of the proposed STG measurement method. Firstly, a general overview of existing and developing methods for network quality assessment is given in Section II-A. Afterwards, as a LTE network is used for performance measurements at the end of this paper, a method of realizing some QoS parameters in LTE networks with the usage of QoS Class Indicators (QCIs) is presented in Section II-B. Then, various selected Smart Grid related service profiles are described.

A. Network Quality Assessment

As part of the type approval of wireless systems, radio engineering parameters and compliance with standardized functions are tested extensively to ensure the interaction between the terminals and the network. Furthermore, dedicated devices are available, with which operators can check the operation of their networks [1]. Those network scanners can measure the reception quality within the network to enable so-called drive tests, in which coverage holes are systematically identified. Thereby, the network operator receives a detailed picture of the location-dependent availability and quality of the network.

Drive tests as described in [2] are characterized by the same methodology depicted in Fig. 2: A vehicle containing the network scanning equipment drives along predefined routes within the coverage area and periodically records the current position of the vehicle as well as the relevant KPIs (e.g., data rate, transmission delay or packet error rate) of the system at this position. Afterwards, a connectivity map containing the spatial distribution of the system performance can be created

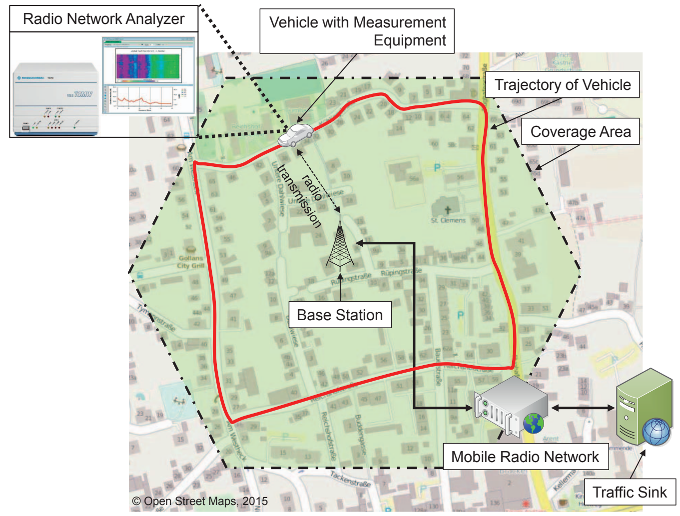

Fig. 2: Overview of a network quality assessment with a vehicle containing measurement equipment.

and used for further optimization of the communication system in order to create the suitability of the system for the given application. The disadvantages of this traditional method are the occasionally availability of the measurement data resulting in high costs for large coverage areas due to the high amount of time needed to collect measurement data, which are sufficient enough for creating a detailed connectivity map.

One approach as described in [3] to reduce the costs for drive tests is using monitoring devices realized by the usage of Network Field-Programmable Gate Array (NetFPGA). Nevertheless, it is still not possible to generate spatial-distributed traffic patterns because, therefore, it is necessary to synchronize and manage a high number of measurement nodes, which are distributed over the cell's coverage area. This means that this approach is not suitable for analyzing Smart Grid scenarios. New developments enable commercial devices to collect detailed network quality data during ongoing operation and transport them to the network operator by measurement reports [4]. However, those extensions are not suited to validate the robustness of the mobile network in extreme situations, because a synchronized behavior of the terminals is also not provided here.

In [5], the authors present a testing framework for analyzing the performance of heterogeneous and hybrid smart grid communication systems. For this purpose, several open source tools such as iPerf and Ping are used to analyze the network performance under normal and stressed conditions. Nevertheless, this methodology does also not allow a spatial distributed traffic generation inside the smart grid network due to the lack of synchronization and coordination of the measurement nodes.

In summary, all existing methods mentioned above allow to determine the communication service quality for a single or a low number of terminals at a particular location. However, it remains unsure how the radio cell will behave under extreme conditions, such as a massive overload within a specific geographical region. In this case, the cell is very occupied or overloaded by heavy traffic. As indicated above, this can result in the fact that terminals with unfavorable radio channel conditions are no longer connected unless a higher priority class is assigned to them. All in one, there is a lack of reproducible, application-specific stress testing methods, which are required for Smart Grid communications and other critical infrastructures.

B. Realization of Quality of Service (QoS) in Long Term Evolution (LTE) mobile networks

The ongoing growth of mobile data applications as well as the rapid growth of Machine to Machine (M2M) and Human To Human (H2H) devices during the last years are still huge challenges for public mobile network operators. In order to handle the high amount of data traffic over mobile networks, the 3rd Generation Partnership Project (3GPP) designed and established the LTE standard. LTE is an all-IP based technology providing high data rates up to 100 $^{\mathrm{Mbit}}/_{\mathrm{s}}$ and low latency, which is of high importance for modern mobile applications based on video or audio sources [6].

1) QCI: In order to cover the different QoS demands, LTE provides a solution called QCI, where various QoS requirements such as resouce type (i.e. Guaranteed Bit Rate (GBR) or Non-GBR), priority, packet delay and packet error rate are mapped to nine specific groups, where each QCI class $(1-9)$ describes the traffic priority [7]. For Smart Grid services, typical QoS demands on the mobile communication network are a guaranteed minimum data rate and a high level of connectivity to the mobile network even under harsh radio channel conditions.

2) Resource Scheduling: The LTE scheduler, which is a part of the eNodeB implementation, is responsible for the allocation of the mobile time-frequency resources in terms of Resource Blocks (RB) to terminals trying to send or receive data packets. The resource scheduling is conducted in every Transmit Time Interval (TTI) of 1 ms. The priority given for each QCI is used by the scheduling algorithm to determine the amount of resources given to a specific terminal for data transmission or reception. By taking into account the Modulation and Coding Scheme (MCS), the amount of allocated RBs directly influences the achievable data rate of the terminal [8].

In public mobile networks it is the intent of the mobile network providers to maximize the spectral efficiency and the load level of their LTE cells [9]. For this purpose, typically a Max Throughput (MT) scheduler is applied, which tries to maximize the spectral efficiency and the overall cell throughput by using only the current channel conditions of each UE for the metric calculation. This leads to the fact that users with favorable channel conditions are preferred by assigning them a higher number of available RBs in comparison to users with bad channel conditions leading to a lower spectral efficiency and lower metrics.

C. Smart Grid related service profiles

Wireless communication networks can possibly be used for the transportation of Smart Grid traffic because they provide advantages like cell coverage and traffic capacity for a distributed Smart Grid deployment in a very cost efficient manner [10].

Nevertheless, in order to guarantee a stable level of operation, Smart Grid applications have several QoS requirements, which have to be fulfilled by the transportation technology, e.g., frequency ranges, delay, guaranteed data rate, security and reliability [11]. For wireless networks this means that every terminal has to achieve a certain level of connectivity resulting in a minimum data rate necessary for a stable operation of the Smart Grid.

While security can be enhanced by the introduction of service windows [12], fulfilling QoS-requirements regarding data rate and latency are a huge challenge, especially for communication devices, which are installed in basement scenarios. In addition to this, for uplink data transmission, the situation gets even worse as available radio resources in terms of transmission power and bandwidth are strictly limited and basement walls can lead to a further attenuation of the radio signal up to 33.4 dB [10].

All service profiles related to Smart Grid services are concluded within the FNN project in the VDE [13]. One of the most important services in the uplink direction is the so called Secure Monitoring. For this service, every terminal must be able to send a certain amount of data within a short period of time, independently of its current radio channel conditions. On the one hand, each terminal must have a reliable connection to the mobile network and on the other hand, it also achieves a minimum guaranteed data rate in order to fulfill the time requirements.

If LTE is used as the underlying network technology, the QCI concept described in Section II-B1 can be used in order to meet the requirements of the Smart Grid services in terms of minimum data rate and reliability.

III. Distributed Traffic Creation by Smart Traffic Generator Modules

In this section, the proposed STG system is presented. First, the general concept of a spatial distributed traffic generation is introduced. Afterwards, the different parts of the Smart Traffic Generator system in terms of hardware and software components are described.

A. Concept

The proposed STG system enables to determine the performance indicators of wireless communication infrastructure using distributed, synchronized load generators. It allows the generation of different test cases with realistic, application-specific traffic and to move the network-under-test gradually to the load limits. The relevant performance indicators are in this case in particular the actual achievable traffic capacity and network stability in high load situations:

- The communication capacity is described with respect to the achievable total data rate of a radio cell or a network infrastructure to a normalized surface (e.g., in $^{\mathrm{Mbit}}/_{\mathrm{s\cdot km^2}}$). A related measure is the spectral efficiency (e.g., in $^{\mathrm{Mbit}}/_{\mathrm{s\cdot Hz}}$).
- The stability of the network is characterized by the behavior in overload situations. The goal is that the system should not crash under any circumstances. If the system supports priority mechanisms, it can be

checked whether those actually enforce the higher priority traffic classes in relation to the low-priority classes.

B. Smart Traffic Generator

The STG architecture is shown on the top left in Fig. 1. Leveraging a web server running on each STG device enables remote access for configuration and execution of the tests. Different types of traffic are produced by the STGs, e.g., "TCP max. data rate traffic", "Smart Meter Traffic", "Distributed Energy Device Traffic". An STG can emulate the behavior of a large number of terminals. Thus, an STG is able to produce the Smart Meter traffic of a larger number of households and, thus, generate an increased load, even if the systems are not yet fully installed in the field.

The STGs are distributed at various locations within the network under test. Attention is paid to the proper spatial distribution, as well as the occurrence of different unfavorable conditions (different distances from the base station, Line of Sight (LOS) conditions, shadowing by buildings, trees, etc., indoor and outdoor locations). The choice of locations should correspond to the application environment and should in particular cover even the most difficult conditions. Each STG acts as communication device that is able to produce typical Smart-Grid related data traffic. In general, an STG consists of a Raspberry Pi embedded computer and communication modules for data traffic transmission and exchange of control messages. Various communication modules can be connected either via USB or via Ethernet. In order to enhance the robustness of transferring measurement data to the STCC, it is possible to install a separate communication link at an STG device in order to access the measurement node and receive measurement data even if the cell under test is overloaded. For position information and highly accurate time synchronization of all devices, a Global Positioning System (GPS) module is also included into the setup. Optionally, the STG can be equipped with an autonomous power supply, independent of the Smart Grid, to be supported (important in case of blackout recovery scenarios). All in one, hardware costs of an STG are about 100$.

Smart Grid related service profiles are created using a specific traffic generator based on the open-source tool iPerf. The traffic generator of each STG is configured by the STCC in order to create the desired spatial-distributed traffic patterns within the cell.

C. Smart Traffic Manager and Smart Traffic Control Center

The STGs are controlled by a Smart Traffic Manager (STM). The STM enables to configure and control the STGs to produce the required data traffic, if required in a synchronized way. The STM also collects the measurement data and provides corresponding statistical analysis. To control complex scenarios with a larger amount of STGs, the STM provides a comfortable graphical user interface, the STCC (see Fig. 3), to simultaneously monitor, manage and control the traffic generation process. The STCC is based on an open-source map service to locate and show each STG at its correct installation position. Independently of the selected communication technology (e.g., LTE or PLC) of the STGs, traffic scenarios with no limit of duration and of any complexity can be scheduled.

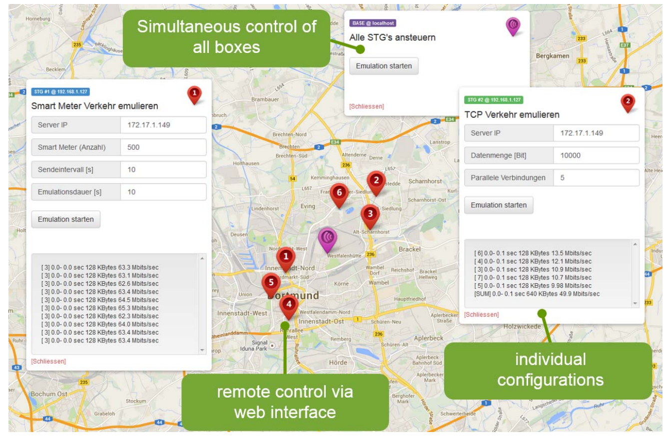

Fig. 3: Smart Traffic Control Center.

IV. Example Field Test: Performance of LTE for Smart Grid Applications

In the following, a field test in terms of a measurement campaign is presented in order to demonstrate the advantages of the proposed STG system compared to traditional drive tests. The aim of this case study is to analyze the suitability of a LTE mobile network for the transportation of Smart Grid data traffic and how the mobile network can be optimized to handle Smart Grid applications especially in stress situations with a high amount of spatial distributed traffic load. For this purpose, seven STGs are spatially distributed over the coverage area of a real dedicated LTE cell. The STGs are positioned on locations with various radio channel conditions characterized by different Reference Signal Received Power (RSRP) values. A high RSRP relates to good channel conditions resulting in a high probability for a high achievable data rate, whereas a low RSRP indicates bad radio channel conditions, which leads to a high probability for a low transmission rate due to the need for choosing a robust Modulation and Coding scheme (MCS). As it is displayed in Table I, STG#001, STG#002 and STG#004 - STG#007 have good (-30 to -100 dBm) to moderate (-100 to -110 dBm) channel conditions, whereas STG#003 is located at the cell edge resulting in bad channel conditions in terms of a RSRP of -119 dBm, which is near to the reception sensitivity (≈ -120 dBm).

TABLE I: Measured RSRP values for each STG.

STG Number	RSRP [dBm]	Channel Conditions Classification
STG#001	-78	Good
STG#002	-100	Moderate
STG#003	-119	Bad
STG#004	-82	Good
STG#005	-50	Good
STG#006	-77	Good
STG#007	-80	Good

Each STG transports uplink data traffic and evaluates the achieved data rate. The campaign consists of two measurements: In the first one, only one STG is transferring data at the same time. In the second one, all STGs are transferring data simultaneously. This leads to the planned stress situation because the scheduler at the LTE cell has to divide up all available radio resources between all STGs in order that data transmission is possible for every STG. All relevant cell and data transmission parameters are listed in Table II.

TABLE II: Configuration parameters of measurement campaigns.

Cell frequency	2.6 GHz
Cell bandwidth	20 MHz
Cell duplex mode	FDD
Cell transmission power P_{Tx}	8 W
Antenna Gain of base station G_{BS}	7 dbi
Number of cell sectors N	1
Number of Repetitions per measurement	30
Data packet size D	100 MByte
Number of active STGs	1..7
Antenna Gain of STGs G_{STG}	$\approx$ 0 dbi
Used QCI configuration 1	STG#001 to #007: QCI 9
Used QCI configuration 2	STG#001, #002, #004 to #007: QCI 9 STG#003: QCI 5

Using default cell configuration settings in general stress situations the MT scheduler favors STGs with good channel conditions so as to maximize the cell throughput (see Section II-B2). This leads to the fact that STGs with really bad channel conditions (e.g., at the cell edge or in basement installations) will receive a lower amount of resources resulting in a lower achievable data rate, especially when a robust MCS has to be chosen in order to realize a successful data transmission. The result is that STGs with bad channel conditions can not perform critical Smart Grid applications in a way satisfying the QoS-requirements defined by the FNN classes. A way to counter against this situation, the QCI classes, introduced in Section II-B1, can be used for the purpose to assign STGs with bad channel conditions a higher priority leading to the assignment of a higher amount of radio resources for the data transmission.

To analyze this problem more detailed, the following measurement campaigns are performed using two different configurations: In the first configuration, the default QCI (QCI 9) is assigned to all STGs in the cell, which means that all STGs have the same priority for the scheduling process. In the second configuration, QCI 5, which has a higher priority than QCI 9, is assigned to STG#003 since this terminal has the worst channel conditions compared to the other ones.

A. *Configuration 1: All STGs have the same priority*

The results for the first configuration are depicted in Fig. 4. In the first measurement where only one STG transmits data at the same time (colored gray), STGs with good channel conditions achieve an average data rate of about 42 Mbit/s because those STGs have similar RSRP values resulting in the usage of the same MCS and, thus, to similar data rates. STG#002 has only moderate channel conditions resulting in the choice of a more robust MCS. This leads to a reduced data rate (35 Mbit/s) compared to the STGs with good conditions. STG#003, which is located at the cell edge, has to choose the most robust MCS resulting to an average data rate of 8.7 Mbit/s.

In the second measurement, all STGs start the data transmissions at the same time (colored black). This means that the scheduler has to divide the available radio resource between all STGs. As the MT scheduler allocates the resources on the base of the channel conditions, the STGs with good channel conditions achieve a data rate of about 6.4 Mbit/s. STG#002 with moderate channel conditions achieves an average data rate of about 6 Mbit/s, which is also high enough for a stable communication process. STG#003 with bad channel conditions suffers from the problem that the scheduler often does not assign any radio resources to this STG resulting in a connection abort (indicated by an average data rate of 0.4 Mbit/s and many connection losses). This means that QoS requirements of time critical Smart Grid services (e.g., Secure Monitoring) are not fulfilled by the system leading to the fact that an LTE cell with default configuration settings is not suitable for the underlying network technology to transport Smart Grid traffic.

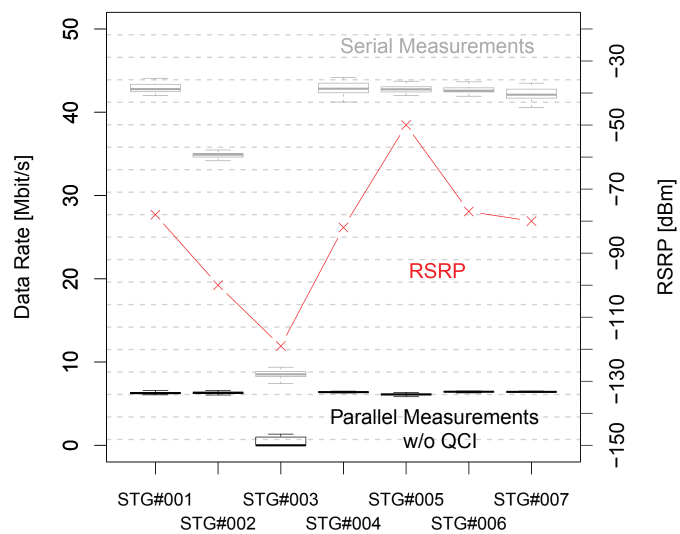

Fig. 4: Data rate boxplots for uplink direction w/o QCI.

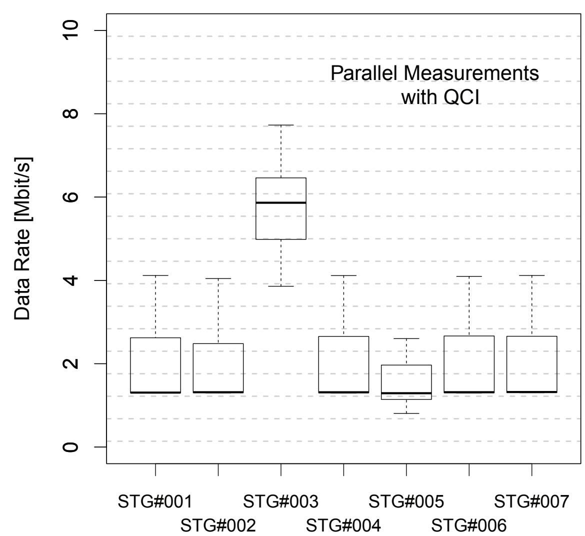

Fig. 5: Data rate boxplots for uplink direction with QCI.

B. *Configuration 2: Higher priority to the STG with bad channel conditions is assigned*

To enhance the problem exposed in the first configuration, higher priority (QCI 5) is assigned to STG#003 in order to enlarge the amount of radio resources allocated to this STG by the scheduling algorithm. Afterwards, the measurements (single and parallel data transmission) are repeated in order to analyze the enhancement regarding the data rate of all STGs in the cell. The results of the measurements are depicted in Fig. 5 as box plots with a confidence interval of 95%.

Now, when all STGs are transmitting at the same time, STG#003 achieves an average data rate of 5.7 Mbit/s due to the higher priority. This means that the scheduler allocates a higher amount of radio resources to this STG now. Since the total amount of radio resources in the LTE cell can not be enlarged, there is now a lower amount of radio resources available for the other STGs. This results in the fact that the average data rates for the other STGs with good channel conditions are reduced to 2.2 Mbit/s and the STG with moderate channel conditions now achieves an average data rate of 2 Mbit/s. Although the data rate is reduced for the other STGs, all STGs are now able to establish a stable data transmission, thus, a reliable communication channel because there is always a minimum achievable data rate of around 1.99 Mbit/s. It is worth noting that there is a high variation in the data rates (about 2MBit/s). The reason for this are the bad and highly dynamic radio channel conditions of STG#003 because the scheduler allocates as many RBs as necessary to achieve the data rate requirements of this measurement node, which means that the number of RBs allocated to this STG is also very dynamic. This results in the fact that the number of remaining RBs available for the other STGs is also changing very often resulting in variations in the data rate of the other STGs. This means that the LTE cell with a modified configuration is now suitable for the transportation of Smart Grid traffic.

This case study shows that the proposed STG system can be used to quantify the system behavior in stress situations as well as to analyze the influence of optimization approaches on the overall system performance. It is worth noting that those scenarios can not be induced or analyzed by a traditional drive test because there it is not possible to create parallel data transmissions over a wide spatial area. In addition to this, a temporal variety in the radio channel can not be determined by one single measurement campaign.

V. Conclusion

In this paper, an innovative methodology on how the robustness of mission critical Smart Grid communication can be stressed is proposed. For this purpose, we introduced the STG system, which enables a spatial distribution of traffic patterns on a communication network. In comparison to traditional drive tests, the STG system is able to analyze the behavior of the communication infrastructure in load and overload situations, which allows a more detailed study of the KPIs of a communication system. The operator of a communication network for critical infrastructure can use the STG system to continuously fine tune the system and provide proof that the service level agreements are properly fulfilled. In an example measurement campaign, the general functionality as well as an application of the STG system in terms of optimizing an LTE cell for the transportation of Smart Grid traffic was presented. In future works, further studies have to be performed to define a more sensitive QCI resulting in a lower degradation of the data rates for all STGs.

Although the paper addresses the application area of Smart Grid resilience, the approach and experiments presented here is valid also for any other critical infrastructure. For example in the context of the use of public networks for the control of Unmanned Aerial Vehicles (UAVs) [14] the STG system can be used to monitor the availability of an LTE cell before it is used for UAV control communication traffic.

Acknowledgment

Part of the work on this paper has been supported by Deutsche Forschungsgemeinschaft (DFG) within the Collaborative Research Center SFB 876 "Providing Information by Resource-Constrained Analysis", projects A4 and B4, by the research unit 1511 "Protection and control systems for reliable and secure operations of electrical transmission systems", also funded by the DFG and by the German Federal Ministry of Education and Research (BMBF) for the project ANCHORS (UAV-Assisted Ad Hoc Networks for Crisis Management and Hostile Environment Sensing, 13N12204).

References

[1] Rohde & Schwarz GmbH & Co. KG, "LTE Drive Test - How to benefit from using a R& S TSMW or R& S TSME," *Application Note*, 2014.

[2] F. Chernogorov and T. Nihtila, "QoS Verification for Minimization of Drive Tests in LTE Networks," in *Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th*, May 2012, pp. 1–5.

[3] R. Garroppo, S. Giordano, S. Roma, G. Foddis, and S. Topazzi, "Test and monitoring of LTE network: A step towards low cost solutions based on NetFPGA," in *Communications (LATINCOM), 2014 IEEE Latin-America Conference on*, Nov 2014, pp. 1–5.

[4] J. Johansson, W. Hapsari, S. Kelley, and G. Bodog, "Minimization of Drive Tests in 3GPP Release 11," *Communications Magazine, IEEE*, vol. 50, no. 11, pp. 36–43, November 2012.

[5] D. N. Quang, O. H. See, L. L. Chee, C. Y. Xuen, and S. Karuppiah, "Performance Testing Framework for Smart Grid Communication Network," *IOP Conference Series: Earth and Environmental Science*, vol. 16, no. 1, p. 012147, 2013.

[6] A. Elnashar and M. El-Saidny, "Looking at LTE in Practice: A Performance Analysis of the LTE System Based on Field Test Results," *Vehicular Technology Magazine, IEEE*, vol. 8, no. 3, pp. 81–92, Sept 2013.

[7] 3rd Generation Partnership Project (3GPP), *Technical Specifiaction, Group ServicePolicy and charging control architecture (3GPP TS 23.203 ver. 12.8.0 Rel. 12)*, Std.

[8] F. Capozzi, G. Piro, L. Grieco, G. Boggia, and P. Camarda, "Downlink Packet Scheduling in LTE Cellular Networks: Key Design Issues and a Survey," *Communications Surveys Tutorials, IEEE*, vol. 15, no. 2, pp. 678–700, Second 2013.

[9] C. Ide, B. Dusza, and C. Wietfeld, "Performance of Channel-Aware M2M Communications based on LTE Network Measurements," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2013 IEEE 24th International Symposium on*, Sept 2013, pp. 1614–1618.

[10] C. Hagerling, C. Ide, and C. Wietfeld, "Coverage and capacity analysis of wireless M2M Technologies for Smart Distribution Grid Services," in *Smart Grid Communications (SmartGridComm), 2014 IEEE International Conference on*, Nov 2014, pp. 368–373.

[11] V. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati, and G. Hancke, "A Survey on Smart Grid Potential Applications and Communication Requirements," *Industrial Informatics, IEEE Transactions on*, vol. 9, no. 1, pp. 28–42, Feb 2013.

[12] L. Katzir and I. Schwartzman, "Secure Firmware Updates for Smart Grid Devices," in *Innovative Smart Grid Technologies (ISGT Europe), 2011 2nd IEEE PES International Conference and Exhibition on*, Dec 2011, pp. 1–5.

[13] Verband der Elektrotechnik, Elektronik und Informationstechnik (VDE), "FNN Project Metering 2020." [Online]. Available: http://www.vde.com/en/fnn/pages/ms2020.aspx

[14] S. Subik, P.-B. Boek, D. Kaulbars, and C. Wietfeld, "Adem: Active delay management for critical group communication over heterogeneous public cellular networks," in *Communications Workshops (ICC), 2014 IEEE International Conference on*. IEEE, 2014, pp. 212–217.