Measurement Concept for Performance Evaluation of Lossy Networks

C. Lewandowski, S. Böcker, C. Wietfeld
Communication Networks Institute
TU Dortmund University, Germany
Email: {christian.lewandowski, stefan.boecker, christian.wietfeld}@tu-dortmund.de

C. Raquet, E. Mayer
Power Plus Communications
Mannheim, Germany
Email: {c.raquet, e.mayer}@ppc-ag.de

***Abstract*—Communication technologies with variation in the physical communication medium and consequently variability in the communication performance are summarized under the denomination of lossy networks. Typically different lossy communication technologies are used as communication platform for applications in a smart grid. Applications might be Automated Meter Reading (AMR), grid measurement or load control, whereat each application has its own requirements which the communication network has to fulfill. To evaluate the performance of the communication infrastructure at different points in the electrical grid, a measurement concept is required. Existing measurement concepts cannot be used for the performance evaluation of lossy networks, as it assumes a physical communication medium without variations. Therefore, this paper introduces a measurement concept for performance evaluation of lossy networks, with consideration of different performance indicators and tools. To prove the concept, exemplary measurements are performed for a smart metering scenario, which is currently discussed within the specification of the Smart Meter Gateway (SMGW), in an IEEE 1901 access network and a UMTS/LTE network.**

I. Introduction

In smart grids more and more frequently lossy communication technologies are used. A lossy communication network is operating on a physical medium that is changing over the time. This will have direct influence on the communication performance. Variations in data rate, packet error rate and latency are the consequences. Lossy communication technologies that are used usually in smart grids can be differentiated into wireless technologies as LTE, UMTS, GPRS, CDMA or Wifi and wired communication technologies as Powerline Communication (narrowband and broadband). Smart grid applications such as voltage regulation, measurements, metering, etc. specify different requirements for the communication platform, e.g. minimum data rate, maximum latency, maximum round trip time (RTT), jitter or packet error rate. To evaluate the performance of the communication infrastructure at different points of a smart grid, a measurement concept is required. Variability in the data transmission poses a challenge to the evaluation of communication performance. Existing measurement concepts such as RFC 2544 [1] assume a physical communication medium without variations and accordingly a constant performance of the data transmission. In lossy communication technologies, this is an invalid assumption. Consequently the measurement results are not repeatable and do not reflect the communication performance of a lossy network. Hence this paper introduces a measurement concept for performance evaluation of lossy networks, with consideration of different performance indicators (e.g. data rates for TCP and UDP, RTT and Packet Error Rate (PER)) and tools. With this measurement concept a consistent performance evaluation of lossy communication networks will be realizable, which allows for the first time a direct comparison of the different technologies. Especially as smart grid communication platforms are typically designed as a mixed network of different lossy communication technologies, the comparability has a high relevance. The measurements tools, which are used for evaluating the performance of lossy networks, are described in Section II, followed by Section III where the measurement concept is presented in detail. The measurement concept will be verified in an IEEE 1901 standardized Broadband Powerline infrastructure that is using the electrical grid as physical communication medium. If users of the electrical grid switch loads or generation this will trigger changes of noise, impedance or reflections. Also the IEEE 1901 [7] standard declares: ”[...] the medium is ”open” to almost every known kind of noise generator. No other wired medium can boast the variety of noise sources and noise types that power line technologies see on a daily basis [...]”. In addition these variations in the communication quality typically occur in daily and weekly cycles, which should be considered in the measurement concept. Such a high variation in the physical medium also exists in the above-mentioned wireless communication technologies. The verification of the measurement concept is described in Section III.

II. Tooling

This section introduces reasonable tools to measure network performance metrics and describes the exact purpose of each measurement tool in the proposed concept.

Iperf [3]
Iperf is a commonly used network testing tool and for measuring maximum TCP and UDP bandwidth performance. Iperf provides a client and server functionality to report throughput, delay jitter and Packet Error Error Rate (PER).

In our measurement concept, Iperf is used to evaluate the maximum TCP throughput by means of long-term measurements. In the case of UDP long-term measurements, we could not achieve reliable measurement results, so that for these purposes the the Lightweight Universal Network Analyzer (LUNA) tool is used. Nevertheless, the statistical inaccuracy of Iperf is discussed in [4]. Iperf calculates statistics over a time period and not for each packet.

LUNA [5]
Luna is a packet generation and measurement tool for communication networks. It is based on UDP and provides flexible traffic models. However, in our concept, Luna is used in static generation mode, parameterized with fixed packet sizes and inter send times. Luna is designed to allow per packet analysis and therefore provides an evaluation of RTTs, PERs and data rates.

RESTful web service traffic generator
As described above, in combination Iperf and Luna enable a meaningful network analysis. Nevertheless, traffic generated in these measurements is not based on real applications. In order to consider such specific scenarios, we propose the implementation of a specially developed traffic generator. This traffic generator provides client and server functionality based on a RESTful web service implementation. It provides the parameterization of scenario specific packet sizes, number of packets, which directly refers to a number of participants/technical units communicating in parallel and fixed periods for repetition of a transmission event. Thus, the traffic generator enables the determination of scenario related data rates, as well as RTTs, and enables the evaluation of different transmission technologies with respect to the requirements of the scenario.

Wireshark [6]
Wireshark is an open source software, that allows packet analysis and protocol evaluation. In this paper it is used to determine the required data rate for an AMR scenario described in Section IV-A.

III. Measurement Concept

The measurement concept is divided into three parts. In the first part, requirements of the scenario, which should be installed in the lossy network, need to be defined. Based on these requirement definitions, a measuring of the lossy network needs to be done to see, whether the network is applicable for the scenario. After that, requirements and results of the measuring need to be compared and the scenario can be tested in a long-term measurement.
In the following section, the concept is described in detail.

A. Definition of Requirements

First of all, the requirements of a desired scenario need to be defined. Possible requirements may be:

1) Available data rate (UDP or TCP)
2) Round-Trip-Time (RTT)
3) Packet Error Rate (PER)
4) Jitter
5) Direction of communication.

As not all parameters are important for every scenario, it is sufficient to define a subset of relevant performance parameters. E.g., if only UDP data is transmitted over the network, there is no need to define the required TCP data rate. For smart metering scenarios a low RTT is less important, than PER. On the other hand, in control reserve scenarios, where controllable loads have to be switched, the RTT is an important performance indicator.

B. Performance evaluation

After definition of the requirements for the predefined use of the lossy network, a measuring of the network can be done by executing following measurements:

1) Determine TCP data rate (Iperf).
2) Determine UDP data rate (LUNA).
3) Determine PER for max, min and mean UDP data rate (LUNA).
4) Determine RTT for packet sizes defined in requirements (LUNA).

These measurements should be done in a long-term measurement to ensure the reliability of the communication during the whole day. This is especially important in lossy networks, as noise can occur in cyclic order depending on the scenario (residential, industrial, etc.). Iperf is used to determine TCP data rates, while determination of UDP data rate, PER and RTT is done by LUNA.

C. Measurement Analysis

When the performance evaluation of the network is done, the results need to be compared to the requirements. If the network does not fulfill the requirements, it might be optimized e.g., by relocating or adding additional communication units. If the requirements are met, the scenario can be emulated by using LUNA or by emulating data with specific traffic generators (if available). Therefore the reliability should be tested with a long term measurement before installing the complete system.

IV. Application of measurement concept in a PLC IEEE 1901 Access Network

In this section, exemplary measurements are done to illustrate the measurement concept. The measurements are performed in a PLC access network in an industrial area in Mannheim, Germany. The setup of the network is illustrated in Figure 1.

It consists of one server S (laptop), which runs iperf and LUNA. The four clients C1 – C4 are based on a *Raspberry Pi*, so that they are easy to install in street cabinets of the DSO. The PLC modems in this network are based on the IEEE 1901 [7] standard.

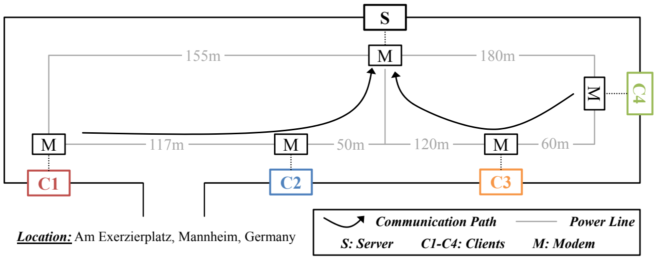

Fig. 1. Installation of measurement equipment in PLC access network.

A. *Requirements for smart grid scenario*

Before a performance evaluation of the lossy network can be done, this section deals with the definition of the requirements of a smart metering scenario. Figure 2 illustrates the defined scenario. Each of the four clients represent the last hop before the head end of the network, where the server is located. Hence, the part of communication infrastructure, where bottle necks will appear, can be considered.

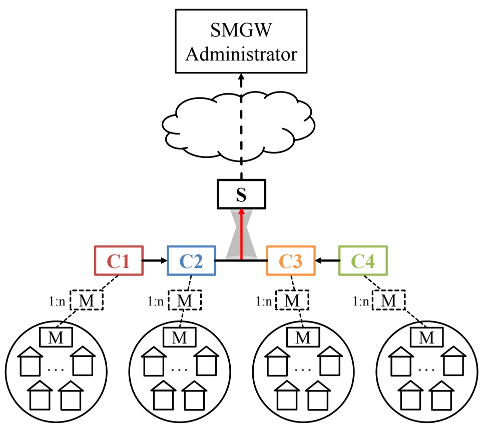

Fig. 2. AMR scenario based on BSI SMGW.

Multiple households are connected to the clients that emulate BSI compliant smart metering traffic using a Smart Meter Gateway (SMGW) [9]. In our network, the last meters before the head end represent a bottleneck, where traffic of all households is transmitted to the server. Therefore we have to prove, that performance of this link is sufficient for the application scenario.
Table II represents the configuration of the clients. It defines the transmission type, the data amount, the interval between data transmission and the number of SMGWs per node. The schedule is presented in crontab format. Transmission types not only include transmission of meter readings for AMR, it also includes e.g., firmware upgrades, time synchronization, and transmission from an Authorized External Entity (AEE) to a Controllable Local System (CLS), which can be e.g., an electric vehicle connected to a charge point to provide control reserve [10].

For approximation of the needed data rate for this scenario, we emulated the traffic with the developed *RESTful web service traffic generator* presented in Section II. As data security is important for SMGW due to privacy protection, all data is transmitted over a TLS secured channel. Figure 3 illustrates the needed data rate for this application, which has been evaluated with *wireshark*. The scenario contains 1000 SMGWs (250 for each client). At the beginning of the measurement, only low data rates are needed. During the day the data rate increases, as the transmission types have a temporal overlap. It should be mentioned that a uniformly distributed data traffic would result in a lower required data rate. But in this context, a uniform distribution of data traffic is assumed as too complex. Results are shown in Table I.

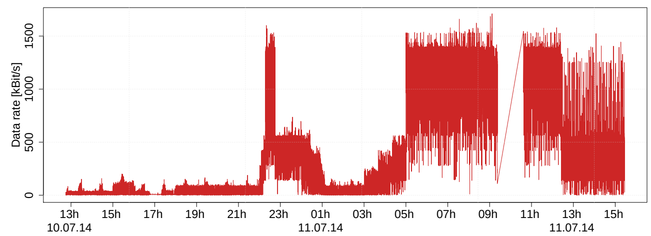

Fig. 3. Data rate for smart metering scenario.

Hence, the requirement for our application scenario is a minimum data rate of 1.7 MBit/s.

TABLE I
DATA RATES FOR SMART METERING SCENARIO.

Type	**Data rate**
Max. data rate	1709.7 kBit/s
Mean data rate	569.8 kBit/s
Min. data rate	0.48 kBit/s

To prove, whether our PLC access network is able to transmit the data reliably at all time, a performance evaluation of the network is done in the following section.

B. *Performance evaluation of PLC access network*

In the previous section, the data rate requirement of the scenario has been defined. In this section TCP and UDP measurements are done for performance evaluation of the network. Figure 4 shows the results of a TCP measurement with Iperf. Measurements are done every 20 minutes for a duration of 30 s. It can be seen, that all clients achieve different data rates, due to different positions in the power system and different cable length to the server. For C3 a maximum data rate of 39.2 MBit/s was measured, while C1 only achieves a maximum of 13.7 MBit/s.

In the next step, UDP performance is measured with LUNA, which supports packet by packet inspection. Hence, results are more accurate than iperf evaluation. Evaluation is only done for C2 and C3, as these communication links to the server represent the bottleneck. First of all, test measurements have been done to evaluate the maximum available data rate for each

TABLE II
CLIENT CONFIGURATION FOR SMART METERING SCENARIO.

Transmission type	Data [Byte]	Interval between data [s]	SMGWs per node	Schedule (crontab[1]) Pi 1	Pi 2	Pi 3	Pi 4
Client administration	10000	90	250	0 12 ***	0 18 ***	0 0 ***	0 6 ***
Firmware upgrade	10800000	1	250	0 13 ***	40 13 ***	20 14 ***	0 15 ***
Firmware patch	540000	1	250	0 16 ***	6 16 ***	12 16 ***	18 16 ***
Monitoring System Log	120000	300	250	1 12 ***	2 12 ***	3 12 ***	4 12 ***
Transmission to system admin	350000	300	250	5 12 ***	6 12 ***	7 12 ***	8 12 ***
Certificate Management	4000	300	250	3 12 ***	4 12 ***	5 12 ***	6 12 ***
Time synchronization	217	300	250	4 12 ***	5 12 ***	6 12 ***	7 12 ***
Network state	4000	90	250	7 12 ***	8 12 ***	9 12 ***	10 12 ***
				7 0 ***	8 0 ***	9 0 ***	10 0 ***
Wake Up	212	300	250	9 17 ***	17 15 ***	8 19 ***	12 12 ***
Transmission of meter readings	4000	1	125	30 23 ***	31 23 ***	32 23 ***	33 23 ***
Transmission to GWAdmin	4000	300	125	30 12 ***	31 12 ***	32 12 ***	33 12 ***
Transmission to AEE [2](rarely)	2145	90	125	45 12 ***	46 12 ***	47 12 ***	48 12 ***
				45 0 ***	46 0 ***	47 0 ***	48 0 ***
Transmission of meter readings	4000	1	50	31 23 ***	32 23 ***	33 23 ***	34 23 ***
Transmission to AEE (day profile)	2943	1	50	50 23 ***	51 23 ***	52 23 ***	53 23 ***
Transmission of meter readings	4000	1	50	40 23 ***	41 23 ***	42 23 ***	43 23 ***
Transmission to GWAdmin	4000	90	50	30 13 ***	31 13 ***	32 13 ***	33 13 ***
Transmission to AEE (rarely)	2145	90	50	30 15 ***	31 15 ***	32 15 ***	33 15 ***
Communication AEE and CLS [3]	4000	10	50	20 ****	21 ****	22 ****	23 ****
Transmission of meter readings	4000	1	25	32 23 ***	33 23 ***	34 23 ***	35 23 ***
Transmission to AEE (often)	2145	1	25	16 ****	17 ****	18 ****	19 ****
Communication AEE and CLS	4000	1	25	1 16 ***	2 16 ***	3 16 ***	4 16 ***

[1] Crontab format: minute hour day month weekday; * represents all values
[2] Authorized External Entity
[3] Controllable Local System

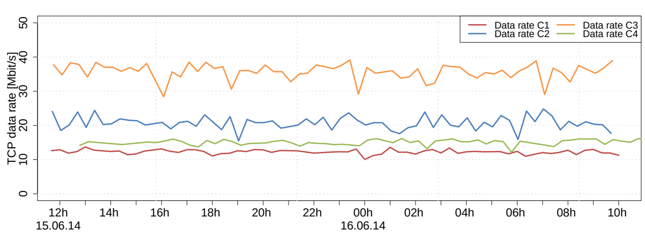

Fig. 4. TCP measurement with iperf for C1 - C4.

TABLE III
CONFIGURATION OF DATA RATE FOR UDP MEASUREMENT

Data rate [MBit/s]	C1	C2	C3	C4
Max. measured data rate	16.6	31.2	42.2	10.4
Data rate for LUNA measurement	18.26	34.32	46.42	11.44

client. Due to possible noise on the channel at the moment of test measurement, the measured data rates are increased by 10 % for configuration of the long term measurement (see Table III).

Measurements are done every minute for a duration of 20 s. Results are shown in Figure 5 and Figure 6 for C2 and C3. In Figure 5 a maximum data rate of 34.32 MBit/s is assumed for LUNA configuration. This data rate is only available a few times and is fluctuating over the whole measurement period. The average data rate is 27.5 MBit/s. Nevertheless, packet loss can occur when applying scenarios with high datarates. To minimize the risk of packet loss, between C2 and the server we propose only to use scenarios with data rates lower than the 1 % quantile. Nevertheless, no packet loss cannot be guaranteed using UDP within lossy networks. For reliable data transmission, TCP is inevitable.

Accordingly, for C2 only scenarios that require less than 19.6 MBit/s should be considered for this connection, so that packet errors are expected in max. 1 % of transmitted data packets. For C3, a higher and more constant data rate could be measured. The average data rate is 44.4 Mbit/s. For this communication channel, scenarios with less than 40.3 MBit/s data rate are proposed to reduce the risk of packet losses.

Table IV summarizes the results of the test measurement and defines possible data rates for applications in the PLC

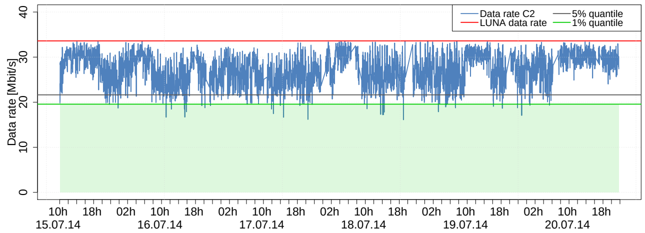

Fig. 5. PER and data rate measurement with LUNA for client C2.

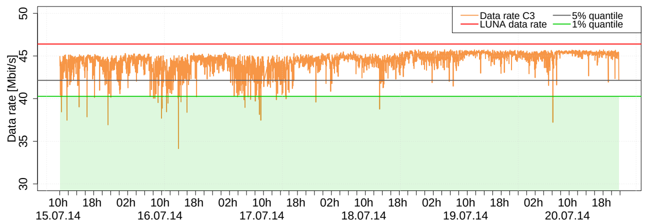

Fig. 6. PER and data rate measurement with LUNA for client C3.

access network.

TABLE IV
POSSIBLE DATA RATES FOR APPLICATIONS IN PLC ACCESS NETWORK.

Supported data rate for applications [MBit/s]	**C2**	**C3**
Mean TCP data rate	20.8	35.7
Max. UDP data rate	33.6	45.7
Mean UDP data rate	27.5	44.4
UDP data rate within 5 % quantile	21.6	42.1
UDP data rate within 1 % quantile	19.6	40.3
Min. UDP data rate	16.1	34.1

Sometimes, long term measurements are not applicable and results need to be available as soon as possible. In this case, short term measurements can provide an approximation. Therefore we propose:

1) Measurement of TCP data rate at least 10 times for a minimum of 20 s.
2) Measurement of UDP data rate at least 10 times for a minimum of 20 s.
3) Maximum available UDP/TCP data rate for the connection can be approximated by adding 10 % to the measured maximum value.
4) The maximum available UDP data rate with minimal packet loss depends on the fluctuations of the communication channel and *should* be measured.

For TCP, the approximation is uncrucial due to protocol characteristics, e.g., retransmissions.

C. Measurement analysis

In this section, the requirements and the performance analysis are compared. The requirement for smart metering scenario was, that a maximum TCP data rate of 1.7 MBit/s has to be available all the time. The long-term measurements show, that this requirement is fulfilled for all clients.

V. CONCLUSION

This paper illustrates a measurement concept for lossy networks and verifies the concept based on smart metering scenarios within a real PLC IEEE 1901 communication network. After introducing and comparing reasonable tools to measure network performance metrics, a detailed measurement concept is presented in three parts - *Requirement Definition, Performance Evaluation and Measurement Analysis.* This measurement concept is applied to a BSI compliant smart metering scenario within a PLC access network consisting of a total of 1000 SMGWs distributed to four installed clients (250 SMGWs per client). It can be shown that the PLC access network is able to fulfill all defined requirements reliably at all time. For applications that uses UDP transmission, we propose minimum data rates for a desired scenario less than the 1 % quantile, in order to achieve a reasonable packet loss.

The proposed measurement concept is verified as a proof of concept within a PLC IEEE 1901 network, but can be applied specifically to any type of lossy networks. Wherefore, in future work, a further verification of the proposed measurement concept by comparison of different lossy networks is intended.

ACKNOWLEDGMENT

The work in this paper was funded by the German Federal Ministry of Economics and Technology (BMWi) as part of the openECOSPhERE project with reference number 01ME12091. The authors would like to thank the project partners for fruitful discussions during the project.

REFERENCES

[1] S. Bradner and J. McQuaid. RFC2544: Benchmarking Methodology for Network Interconnect Devices. Technical report, Internet Engineering Task Force (IETF), Mar 1999.
[2] C. Lewandowski, S. Gröning, J. Schmutzler, and C. Wietfeld, "Interference Analyses of Electric Vehicle Charging Using PLC on the Control Pilot", Proceedings of 16th IEEE International Symposium on Power Line Communications and Its Applications (ISPLC 2012), Beijing, China, Mar 2012.
[3] Iperf, Website: http://sourceforge.net/projects/iperf, last accessed: 27th July 2014.
[4] I. Tsokaloa, R. Bernstein, R. Lehnert, "Measurement Software for Power Line Communication Network Traffic Analysis", Proceedings of the 6th Workshop on Power Line Communications 2012, Rome, Italy, Sept 2012.
[5] LUNA – Lightweight Universal Network Analyzer, Website: https://github.com/airtower-luna/luna, last accessed: 27th July 2014.
[6] Wireshark: A Network Protocol Analyzer, Website: http://www.wireshark.org/, accessed 27th July 2014.
[7] IEEE Std. 1901, "IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications", Sept 2010.
[8] C. Lewandowski, S. Böcker and C. Wietfeld, "An ICT Solution for Integration of Electric Vehicles in Grid Balancing Services", Proceedings of the 2nd International Conference on Connected Vehicles and Expo (ICCVE 2013), Las Vegas, USA, Dec 2013.
[9] BSI TR-03109-1, "Anforderungen an die Interoperabilitt der Kommunikationseinheit eines intelligenten Messsystems", Version 1.0, Mar 2013.
[10] S. Böcker, C. Lewandowski and C. Wietfeld. "ICT based Performance Evaluation of Control Reserve Provision Using Electric Vehicles", Proceedings of the 5th Innovative Smart Grid Technologies European Conference (ISGT 2014), Istanbul, Turkey, Oct 2014.