Field-Test Based Comparison of LTE and PLC Communication Technologies for Smart Grid Applications

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Abstract
In smart grids different assets and devices need to be able to communicate with each other and preferably with the grid operator as well. There are different technologies available to establish such a communication, with certain advantages and disadvantages over one another. In the research project "Smart Grid Demonstrator Sonderbuch" two different communication technologies are implemented and operated in parallel: wireless broadband LTE and wire-based broadband power line communication (PLC). In this paper, an overview of the scope and objectives of the project are presented; from which requirements for the communication infrastructure were derived. Comparisons of the operation of both communication technologies were drawn, regarding their usability and reliability for real-time applications. Overall, broadband PLC shows better performance in terms of network-latency, while LTE proofs to be less susceptible to short-term interruptions resulting in a higher overall reliability.

1 Introduction
The proper implementation of information and communication technology (ICT) is a key enabler of smart grid (SG) applications, which often require high data-rates and low latency as well as very high reliability. A wide range of technologies are available for this purpose, which can be divided into wireless and wire-based physical mediums. Most research involving field-test data focuses on just a single ICT type, e.g. PLC in [1], LTE in [2] and GSM/UMTS/LTE in [3]. The different testing environments limit the informative value of comparisons between different ICTs. In [4], the wire-based narrowband power line communication (NB-PLC) standard PRIME [5] and the wireless GSM/GPRS technologies are compared in terms of their reliability within a field-test.
The objective of this paper is to directly compare two different ICTs in a real test environment at the same time.

2 Field-Test Environment
An interactive field test of SG applications is conducted at a real low voltage (LV) grid in the village of Sonderbuch, Germany, in the scope of a cooperative research project between the German DSO Netze BW and the Institute of Power Transmission and High Voltage Technology (IEH) at the University of Stuttgart.

2.1 Project Overview
The power system of Sonderbuch is of special interest, because at peak times the local generation by photovoltaic (PV) plants can be up to six times higher than the consumption, which can cause issues in the operation of the LV system itself, or the upstream medium voltage system, by breaking voltage constraints or overloading system components. Similar high penetration levels of PV can be expected in other rural areas as well; consequently, this grid is being used to investigate SG solutions, with the objective to find alternatives to traditional grid reinforcement methods. Within the research project, one objective is to develop a monitoring system to observe the current state of the grid. In addition, a short-term prediction is developed. This allows optimizing the integration of renewable energies by an optimal application of local flexibilities, e.g. battery storage. The current state of the system is estimated based on a mix of measured and synthetic grid values. The short-term state prediction relies on weather reports and historical data.

2.2 Communication Infrastructure of the Field-Test
In order to be able to broadcast measurement data, as well as calculation results and control signals, a reliable communication needs to be established between the devices in the system. The implemented communication infrastructure allows the transmission of measurement data from the distributed devices in the grid to a central server. Two different ICTs are used in parallel: wireless LTE and wire-based broadband power line communication (PLC). The communication concept is shown in Fig. 1. The broadband PLC modules used in the field-test are based on the IEEE 1901 FFT Access Standard and form a meshed, TCP/IP-based network with dynamic routing and repeating functionality [6].

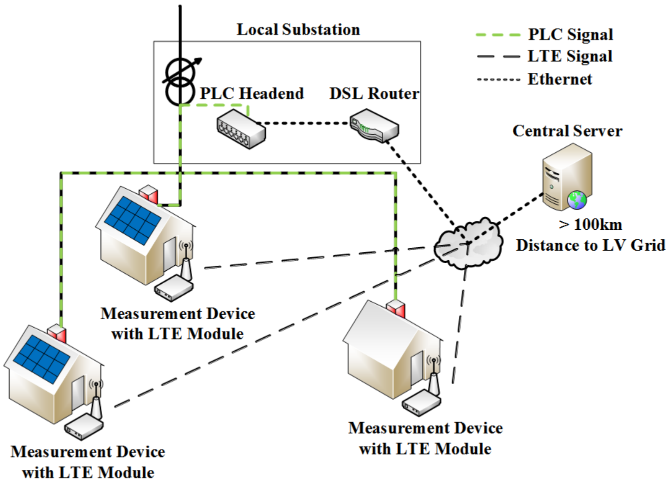

Fig. 1: Communication concept for measurement and control signals using PLC and LTE simultaneously

The placement of measurement devices in the power system of Sonderbuch is shown in Fig. 2. The end-to-end distance of the analyzed grid is lesser than the 1500m limitation of the operated broadband PLC technology, therefore this aspect did not provide any additional constraint [7].

2.2.1 Data Transmission Concept: The measurement devices are programmed to actively send the collected data to a central server, which processes the raw data and stores it in a database. The devices store all measurement data locally for 24 hours in case of a communication failure. Any unsuccessful transmission of measurement data automatically triggers a retry of the transmission. However, the transmission of the latest measurement value is prioritised, in order to supply the downstream applications with up-to-date input values. The data transmission processes are structured in the same way for both communication technologies and are completely decoupled from each other. The measurement data is therefore transmitted twice.

2.2.2 Time Synchronisation: The clock times of all measurement devices are synchronised via the Network Time Protocol (NTP). All devices, including the central server, use the same NTP server for time synchronisation. In order to increase clock precision, additional (hardware) modules for time synchronisation, e.g. GPS, would be necessary.

2.3 Latency

The term latency can be interpreted in different ways in the context of SG applications. For an active control application of distributed energy resources (DER), as implemented in the field-test, it corresponds to the time delay between the issue of a command and its activation, which comes down to network-latency. Alternatively, it can be defined as the time delay between the moment of measuring the current power demand and the moment at which this information is stored inside a central database and made available to other applications.

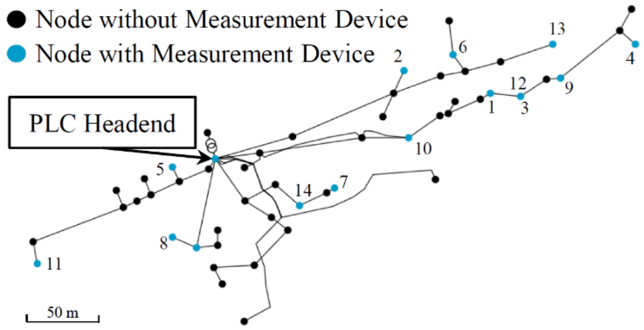

Fig. 2: Placement of measurement devices within the power system of the field-test

Each measurement has a timestamp assigned to its values, which includes the clock deviation of the measurement device. This timestamp indicates the actuality of the measurements to the downstream applications, therefore specifying the latency of the processes.

As a result, the latency in this case depends additionally on other tasks and delays, which are not directly caused by the communication technology itself. The observed latency is hence classified as application-latency. It describes the difference in time between the system clock on the central server upon receiving some measurement data and the timestamp associated to this data by the measurement device. In consequence, a differentiation between network-latency and application-latency is done in this paper.

2.4 Physical Installation Limitations

Many household meter-cabinets are flush-mounted, making it impossible to lead out an antenna without carrying out structural alterations to the walls. Older cabinets are made of metal and shield the interior particularly well from electromagnetic signals. This results in poor LTE connectivity for some of the field-test devices, resulting in them being connected only via PLC technology to the main server. It could be argued that the reliability of LTE for these devices is zero. However, it was decided not to include these devices in the later results, because the results would be distorted, due to the low number of field-test samples.

3 Requirements for the Communication System

All SG applications require some form of ICT. The requirements for reliability, latency or bandwidth can be different, depending on the SG application. Table 1 summarises the requirements of some SG applications at the distribution system level for ICT. The intended SG applications of the described field-test can be categorized in the following areas: Distribution Management, Distributed Energy Resources and Storage, Meter Data Management, Advanced Metering Infrastructure and Asset Management. All of these applications have near real-time requirements, demanding a latency of two seconds at most [8][9]. In [8] and [9] the term latency is to be understood as pure network-latency. The reliability requirements for SG applications are very high in general, with an allowed downtime of one percent or less [9].

Table 1: Requirements for ICT in SG applications [8][9][10]

Application	Reliability	Latency
Substation Automation	99 – 99,99%	15 – 200ms
Wide-Area Situational Awareness Systems	99 – 99,99%	15 – 200ms
Distribution Automation	99 – 99,99%	20 – 200ms
Distribution Management	99 – 99,99%	100ms – 2s
Meter Data Management	99%	2s
Distributed Energy Resources and Storage	99 – 99,99%	300ms – 2s
Home Energy Management	99 – 99,99%	300ms – 2s
Advanced Metering Infrastructure	99 – 99,99%	2s
Outage Management	99%	2s
Asset Management	99%	2s
Demand Response Management	99%	500ms – several min
EV Charging Management	99 – 99,99%	2s – 5min
Vehicle to Grid	99 – 99,99%	2s – 5min

4 Field-Test Results

4.1 Network-Latency

In the first analysis, a series of network ping tests were conducted over 24 hours, once per second. The minimum, average and maximum obtained network-latencies are depicted in Fig. 3. The average network-latency is very close to the respective minimal value of each measurement device. The PLC technology shows smaller maxima than the LTE technology. The overall reliability of both technologies satisfies the requirements for the intended SG applications of the field-test, as listed in Table 1.

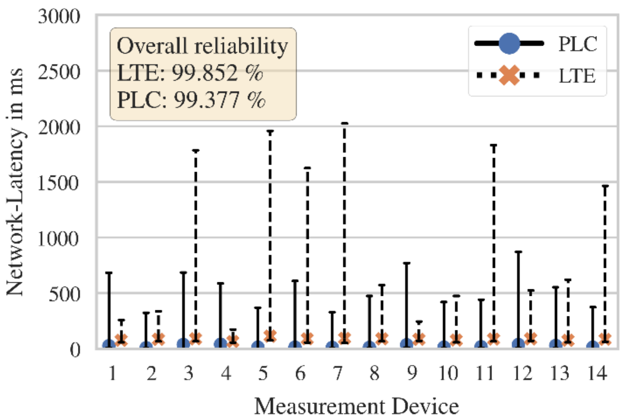

Fig. 3: Minimum, maximum and average network-latency for ping tests executed every second over 24 hours

4.1 Field-Test Application-Latency

The following results were recorded over seven subsequent days in late February 2020 at an interval of one second, resulting in approximately 20 million observations for PLC and LTE each. The application-latency describes the difference in time between the system clock on the central server upon receiving some measurement data and the timestamp associated to this data by the measurement device.

In Fig. 4 the application-latencies for both technologies are compared to each another. The y-axis is partially logarithmic in scale from the value 1 upwards. Some values are negative, due to the clock difference between measurement device and central server (see section 2.3). The maxima and minima, indicated by the horizontal whiskers, are calculated according to (1) and (2), with p_X being the x[th] percentile of the distribution. All values outside this range are outliers.

$$max = p_{75} + 1{,}5\,(p_{75} - p_{25}) \qquad (1)$$

$$min = p_{25} - 1{,}5\,(p_{75} - p_{25}) \qquad (2)$$

The device 5 has very poor LTE connectivity and experiences regular downtimes every day. The application-latency does not exceed five seconds, except for the outliers. On first glance the performance of LTE and PLC looks very similar. However, the distributions share of upper outliers, shown in Fig. 5, is much higher for PLC than for LTE. Some PLC connections show short, but frequent communication interruptions which are responsible for the high number of upper outliers, e.g. devices 1, 3, 4, 9, 10 and 12, all located in the same feeder. Device number 13, located at the very end of a feeder, also suffers from these interruptions.

The overall reliability displayed in Table 2 is calculated for a set of different allowed application-latencies. Any observation with an application-latency higher than the allowed maximum is considered a communication failure.

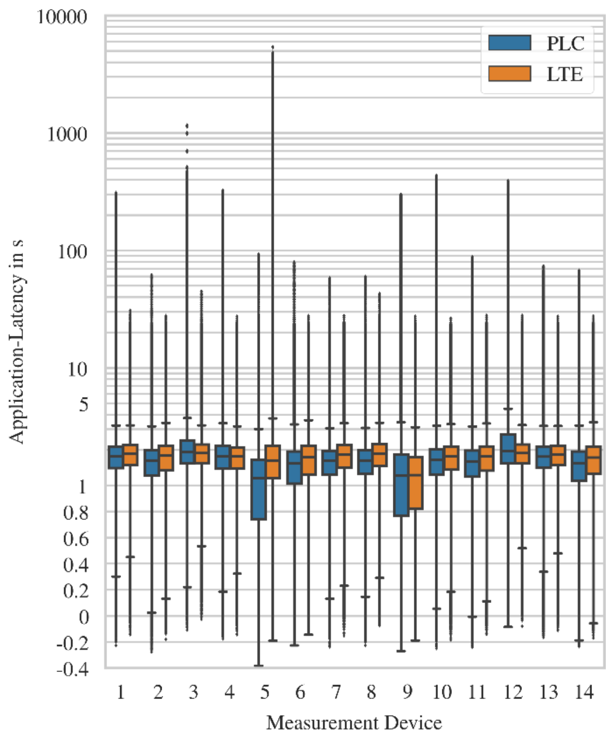

Fig. 4: Comparison of the application-latency for a test period of seven days at an interval of one second

Table 2: Share of upper outliers in the application-latency distribution and overall reliability for different allowed maxima in application-latency for all measurement devices

	PLC	LTE
Share of upper outliers	4,54 %	0,98 %
Overall reliability (≤60s)	99,77 %	99,64 %
Overall reliability (≤50s)	99,71 %	99,63 %
Overall reliability (≤40s)	99,60 %	99,62 %
Overall reliability (≤30s)	99,45 %	99,61 %
Overall reliability (≤20s)	98,78 %	99,55 %
Overall reliability (≤10s)	97,06 %	99,41 %

5 Conclusions

This paper provides a comparison between broadband PLC and LTE as communication technologies to broadcast measurement and control signals, based on data collected from a field-test in a small rural grid in south Germany. The direct comparison showed a superior performance of wire-based PLC technology in terms of network-latency. However, it was observed that PLC suffered from short but frequent transmission interruptions, resulting in a higher number of upper outliers in the application-latency distribution of some connections, hence displaying a lower overall reliability than LTE. This is a disadvantage for the usage of PLC in SG applications with (near) real-time requirements. No correlation between the activity of PV systems and the PLC communication interruptions could be observed, requiring to search for other possible causes.

The reliability of LTE around New Year's Eve was analysed separately as a worst-case scenario and did not show any significant differences compared to the rest of the year. It should be noted that the population density of the field-test area is relatively low and not representative for bigger communities and cities.

For a more complete comparison other, non-technical aspects need to be considered as well:

In contrast to PLC, LTE has the disadvantage of higher running costs and the complete dependency on cellular networks, to which the grid operators have no direct influence. In the conducted field-test, some of the installed end-devices showed extremely limited connectivity to the LTE network, showcasing the importance of having access to a mix of communication technologies, and not just relying on one.

Although the results of the field-test give insight on some obstacles that different communication technologies face in SG applications, the number of samples considered in this paper is insufficient for a conclusive comparison between the technologies. Therefore, a direct comparison within a larger field-test area and an increased number of partaking communication endpoints, should be targeted in future studies.

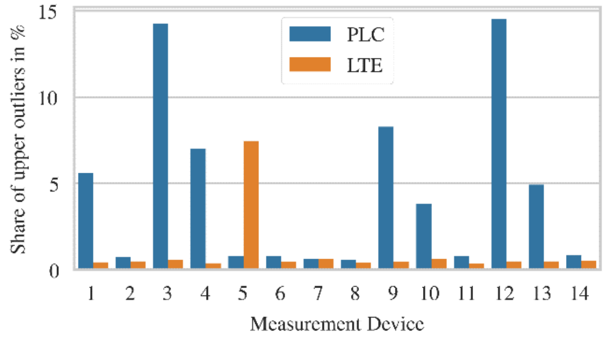

Fig. 5: Comparison of the share of upper outliers in the application-latency distribution per measurement device

6 References

[1] A. Sendin, J. Simon, I. Urrutia and I. Berganza, 'PLC deployment and architecture for Smart Grid applications in Iberdrola', 18th IEEE International Symposium on Power Line Communications and Its Applications, Glasgow, 2014, pp. 173-178.

[2] P. Ferrari, A. Flammini, M. Loda, S. Rinaldi, D. Pagnoncelli and E. Ragaini, 'First experimental characterization of LTE for automation of Smart Grid', 2015 IEEE International Workshop on Applied Measurements for Power Systems (AMPS), Aachen, 2015, pp. 108-113.

[3] N. Maskey, S. Horsmanheimo and L. Tuomimäki, 'Analysis of latency for cellular networks for smart grid in suburban area', IEEE PES Innovative Smart Grid Technologies, Europe, Istanbul, 2014, pp. 1-4.

[4] M. T. C. Chaves, R. S. Barbosa and L. M. C. Amorim, 'Smart metering communication performance analysis in EDP Distribuição', in CIRED Workshop 2018, Ljubljana, 7-8 June 2018, p.n. 103.

[5] G. López et al., 'The Role of Power Line Communications in the Smart Grid Revisited: Applications, Challenges, and Research Initiatives', in IEEE Access. pp. 1-1., 2019.

[6] 'Broadband Powerline Communication', https://www.ppc-ag.com/smart-grid-solutions/ broadband-powerline/, accessed 28 February 2020.

[7] IEEE1901-2010: 'IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications', 2010.

[8] V. C. Gungor et al., 'A Survey on Smart Grid Potential Applications and Communication Requirements', in IEEE Transactions on Industrial Informatics, vol. 9, no. 1, pp. 28-42, Feb. 2013.

[9] US Department of Energy: 'Communications Requirements of Smart Grid Technologies', Washington DC, 2010.

[10] Y. Yan, Y. Qian, H. Sharif and D. Tipper, 'A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges', in IEEE Communications Surveys & Tutorials, vol. 15, no. 1, pp. 5-20, First Quarter 2013.