Analysis of Latency for Cellular Networks for Smart Grid in Suburban Area

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Abstract— **The goal of this paper is to assess the communication latency of operational cellular networks. Latency plays an important role in time-critical smart grid applications. The motivation behind the work was to use cellular networks as communication technology for wireless M2M communications. The latest 3GPP cellular technology, Long Term Evolution (LTE), is considered to be a promising solution for smart grids as its latency is below 100 ms. Although, latencies of different radio access technologies have been studied in live networks, no 24-hour latency measurements have been performed in the proximity of smart grid entities in suburban area. Therefore, this paper presents the results of a feasibility study of using commercial networks, namely GSM, UMTS, and LTE, in terms of latency, for the remote control of medium voltage electric distribution networks.**

Keywords— latency, LTE (Long Term Evolution), Smart Grid

I. INTRODUCTION

Modern energy grid requires pervasive data communications to connect millions of smart meters and thousands of monitoring sensors on the low and medium voltage lines, devices, and substations. High availability of wireless communication systems enables remote control and automation of electricity distribution entities. As a result, fixed line communication used to manage the high-voltage transmission lines and grid components is gradually shifting towards wireless technologies as the number of controllable intelligent devices in smart grids exponentially increases. Communication networks have long been associated with electric power systems where it plays a vital role in monitoring, operation and control functions of the system. Conventionally, dedicated radio networks and power line communication have been used as the communication backbone of the electric grid.

Distributed energy generation (renewable energy sources) and consumption require more detailed information about grid dynamics and quality under different loads. For example, phasor measurement units (PMUs) are used for phase quality monitoring. Their synchronized sampling rate is about 20-120 samples per second [1], which sets strict latency and reliability requirements for the communication technology.

Smart Grid communication has still open issues for guaranteeing the communications of low latency real-time critical applications [2]. In [3], authors have specified the yet-unexplored communication requirements raised by smart grids. The growing demand for virtually zero latency and ultra-reliability has been acknowledged by 3GPP (3rd Generation Partnership Project) community. The development and standardization work in LTE is focusing on upgrading the features of 3GPP technologies to support better MTC (Machine Type Communications) [4].

In this paper, section II describes the motivation and the scope of this paper. Section III focuses on methods used in field measurements. In section IV, we discuss about the results and outcomes of the field trials. Finally, we conclude the paper with the discussion of the key findings and our planned future work.

II. SMART GRID COMMUNICATION

Disparate technologies have been used for smart grid communication, each having their own advantages and disadvantages. The energy companies have realized that no single communication technology is able to fulfill all technological and economical requirements. Therefore, smart grid communication needs to be built on the top of flexible, coexisting heterogeneous network technologies. With the introduction of smart meters and monitoring sensors, the communication solution needs to be highly cost-effective and easily deployable. In this context, wireless communication has more advantages over other communication technologies.

The combination of 4G/LTE technology and the IEC 61850 standard has potential to fulfill the requirements for Smart Grid communications [5]. The IEC 61850 standard defines stringent requirements for latency for automation of substation over medium- and low voltage networks (distribution network automation) [6]. The standard is very relevant for alleviating fault situations in the future smart grids, because a distant grid component needs to be quickly disconnected from the network when a fault has been detected in order to guarantee successful auto-reclosing and fast clearance of the fault. The GOOSE (Generic Object Oriented Substation Events) protocol was designed for fixed line communications for very low point-to-point transactions in order to be used for protection and automation purposes. Due to the fast evolution in wireless communications, the GOOSE protocol has also been experimented over wireless links. However, high network load can increase latency and thus, may prohibit the use of GOOSE traffic for protection and automation purposes.

LTE is a prominent wireless technology that is moving ahead to fulfil the technical requirements in utility communication. Today's LTE networks are still configured to support conventional human-centric mobile broadband traffic. They are not optimized for machine-centric traffic having versatile requirements for reliability and latency. Consequently, LTE 3GPP research and standardization are concentrating on ultra-dense and ultra-reliable networks that enable zero-latency, high data rates, massive capacity, and efficient spectrum sharing.

TABLE I. MESSAGE TYPE AND PERFORMANCE CLASS FROM IEC61850 [6].

Performance class	Requirement description	Transfer time Class	ms	Application
P1	The total transmission time shall be below the order of a quarter of a cycle (5ms for 50Hz, 4ms for 60Hz).	TT6	≤ 3	Trips, blockings
P2	The total transmission time shall be in the order of half a cycle (10ms for 50Hz, 8ms for 60Hz).	TT5	≤ 10	Releases, status changes
P3	The total transmission time shall be of the order of one cycle (20ms for 50Hz, 17ms for 60Hz).	TT4	≤ 20	Fast automatic interactions
P4	The transfer time for automation functions is less demanding than protection type messages (trip, block, release, critical status change) but more demanding than operator actions	TT3	≤ 100	Slow automatic interactions
P5	The total transmission time shall be half the operator response time of ≥ 1s regarding event and response (bidirectional)	TT2	≤ 500	Operator commands
P6	The total transmission time shall be in line with the operator response time of ≥ 1s regarding unidirectional events	TT1	≤ 1000	Events, alarms

III. FIELD MEASUREMENTS

The latency measurements were done in five indoor sites with different characteristics in Otaniemi (a campus and business area located 10 km from the center of Helsinki, Finland). The locations were chosen with the aid of a blueprint of the electricity distribution network provided by an energy distribution company.

The mobile network structure in suburban and urban areas differs from rural areas. Mobile operators are bound to provide capacity oriented services in urban areas. Microcells and indoor cells are deployed to compensate the growing numbers of mobile applications and their bandwidth demands. From the grid communications' viewpoint, the challenge is that a significant number of medium-voltage network entities are placed indoors in buildings' basements. Inside a building, the radio environment tends to change significantly as walls, ceilings, and large objects obstruct the radio signal and cause multi-path effects.

Latency is an important factor when remote control is planned to be deployed. Latency refers to the time required for messages to transit the communication network. Latency depends on network load, radio conditions, and the location of the data server in the network. In our measurements, latency is measured with RTT (Round Trip Time), which measures the 2-way time between a terminal and a data server. We conducted 24-hour stationary measurements in order to assess the latencies and changes in radio conditions during office and out-of-office hours. A tailored measurement script was repeated for 24 hours to collect information. The script included three phases. During the first phase, the device makes a vertical handover to a particular radio access technology. It records the success rate of different radio access technologies (GSM/UMTS/LTE). In the second phase, the device measures physical radio parameters i.e. signal strength, interference etc. In the final phase, the device sends 10 ping messages to Google DNS server in order to measure average RTT (Round Trip Time). This cycle was repeated for 24 hours.

IV. RESULTS

Fig. 1 shows variance of RTTs for different networks over a 24-hour period. We can see that LTE has the smallest latency of around 30–40 ms. The low penetration of LTE mobile terminals could partly explain why latencies in LTE are constant over the whole 24-hour measurement. Moreover, the simplified architecture of LTE helps to reduce latencies in the core network. Fig. 1 shows that UMTS has also small average latency, but the variance increases during the busy hours 7–9, 12–15, and 16–19 over 100 ms. UMTS is used as the primary network by operators and thus it suffers from increased network loads during the busy hours. GSM has the highest RTT values of around 300 ms. Alike UMTS, the GSM network suffers from increased network loads during the busy hours. Latencies of over one second were measured.

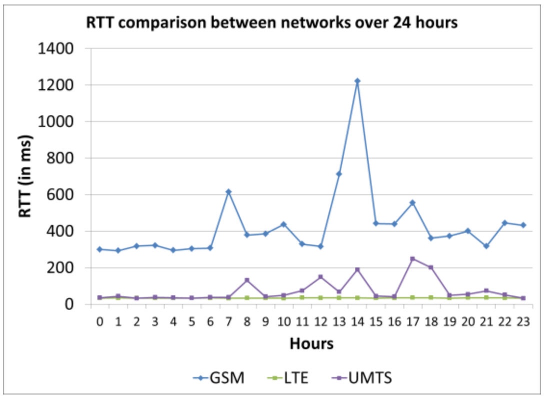

Fig. 1. RTT values in different networks over 24 hours.

Fig. 2 shows the deviation and average RTT values in the LTE network. RTT ranges between 20 and 50 ms for most of the hours of a day. High deviation was detected at 9 o'clock, which might be due to outliers or high control plane latency. Otherwise, latencies are very constant, which is crucial for the wireless remote control of grid entities.

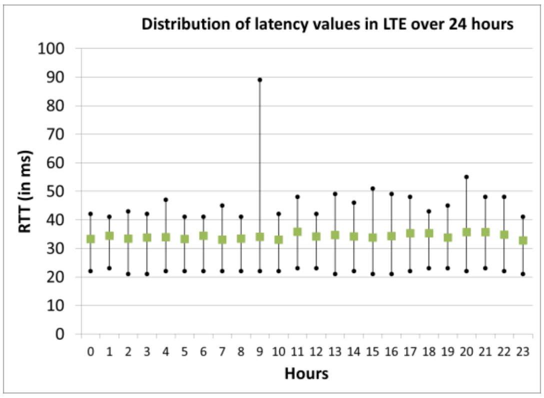

Fig. 2. LTE RTT latency distribution over 24 hours.

Fig. 3 shows the deviation and average RTT values in the UMTS network. We can observe that latencies are fluctuating more than in the case of LTE. During the peak load hours (8–

18) even close to 5 seconds' latencies were recorded. Variance is also significantly higher than in the LTE network.

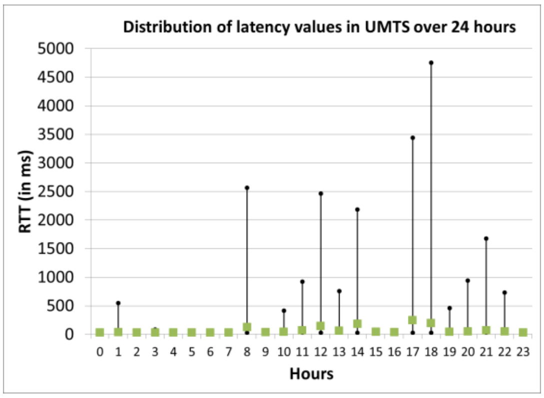

Fig. 3. UMTS RTT latency distribution over 24 hours.

Fig. 4 shows latency distributions of GSM, UMTS, and LTE. From the figure, we can deduce that 99 % of LTE's and 90 % of UMTS's RTT samples are within 50 ms. In UMTS, there exist latencies up to 5 seconds. Latencies are the highest in GSM ranging from 500 to 5000 ms. None of the samples were below 100 ms.

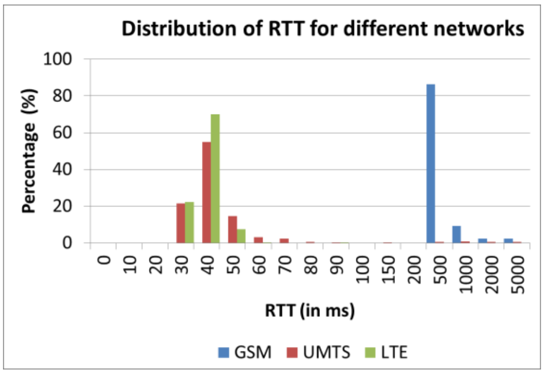

Fig. 4. RTT latency distribution in ms.

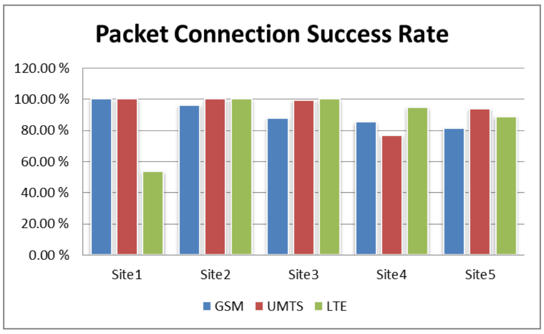

Fig. 5. Packet success rates in different indoor sites over 24 hours.

Reliability of different networks was assessed by calculating the success rates of packet data connections. The connection was established roughly 500 times over the measured 24-hour period. After making a vertical handover to the target radio access technology, the measurement script started a packet session for ping traffic. Differences between packet connection success rates in five indoor sites (Site1–Site5) are shown in Fig. 5. The success rate varies based on the base stations' locations and sites' indoor characteristics. We can see from Fig. 5 that UMTS is the most reliable technology in the majority of the sites. This is due to the fact that UMTS is used as a primary technology to provide broadband mobile services to customers. Therefore, most of the sites had indoor UMTS cells to improve indoor capacity and coverage. Fig. 5 shows that LTE also has good reliability except in Site1. In that location, poor radio conditions were experienced due to the absence of LTE indoor cells.

V. CONCLUSION

Numerous electric distribution entities in urban and suburban areas are placed in the basements of buildings. In those locations, radio conditions are often poor, which restricts the use of cellular systems for the remote control of grid entities. The radio environment is affected by the location of the serving base station, building's interiors, selected radio access technology, and operator's network configuration. It is evident that indoor cells can significantly improve availability and reliability of wireless systems. However, remote control is time sensitive requiring constant latency. Based on the measurements, we learnt that latency depends on the selected radio access technology and load in the network. To estimate latencies, we need to conduct measurements including busy and non-busy hours. We found out that latency significantly fluctuates during the busy hours in UMTS and GSM networks. Moreover, LTE had the least of fluctuations, which makes it a compelling technology candidate for remote control of grid entities. The packet connection success rate was also very high in commercial LTE networks, given that coverage was adequate enough. LTE technology is currently suitable for slow automatic interactions (< 100 ms), but in the future, forthcoming LTE based technologies are designed to support virtually zero latency and ultra-reliability, which will help to achieve IEC 61850 class P1 (< 3 ms) requirements and to enable the use of GOOSE protocol for control traffic.

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