5G NETWORK SLICING FOR SMART DISTRIBUTION GRID OPERATIONS

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ABSTRACT

The power distribution grid has to undergo substantial modifications in order to meet the future electricity needs. The increased flexibility in power consumption, local production and storage insist on smarter supervisory control and data acquisition (SCADA) operations which can restrain dynamic conditions of the power distribution grid. Furthermore, the grid connected and islanded operations of microgrids imply that advanced protection and control schemes are of utmost importance. This calls for high reliable, secure and low-latency communication services. 5G can be foreseen as a strong candidate to provide such services. Network slicing is a new paradigm in 5G which is intended to benefit many industries by slicing one physical network infrastructure into many virtual end-to-end networks. This paper proposes a scalable communication architecture which can provide customized communication services according to the diverse performance requirements demanded by the future smart distribution grid. It recommends the use of 5G network slicing to provide for the necessary communication services, proposing a network slice template to comprehend with respective requirements.

INTRODUCTION

The digitalization of the power grid or the future smart grid [1], [2] implies that the power distribution networks are foreseen to perceive substantial modifications. With the increasing penetration of distributed energy resources (DERs) into the power distribution grid, the need for better state estimation, protection and control schemes is pronounced. Hence, the smartness of the power grid can be achieved by deploying more sensors for better state estimation and controllers for automation at the distribution grid.

The dynamic structure and the versatile operating and fault conditions of such distribution grids necessitate the demand for secure and robust communication services. It is of utmost importance that the potential faults are handled with high speed and selectivity which should be supported by low-latency and dependable communication services. Better state estimation requires more communication capabilities and intelligence. In addition, the mission-critical operations such as protection and control applications in the smart grid domain cannot run without communication. The various grid operations impose different communication service requirements wrt. to the performance in terms of latency, bandwidth, reliability, security etc. For instance, teleprotection in smart grid network requires a latency of 8 ms and reliability at 99.999% in regard of the inter-substation communication between the relays for responding to a fault [3], while smart grid/utilities require user data rates in downlink of 1-100 kbps, uplink of 1-100 kbps, and latency of 50 ms up to hours [4].

In order to meet such diverse requirements, it is perceived that the smart distribution grid would benefit from the 5th generation mobile (5G) network. Network slicing is a new paradigm in 5G, which is foreseen to offer context-related and personalised services that are beneficial for many industries. It creates several virtual end-to-end networks by reserving virtual resources upon one physical network infrastructure. This is very appealing in the context of smart distribution grid operations, since network slicing enables dedicated, yet customizable virtual networks with differentiated service guarantees. Network slicing enables the low-latency, secure and dependable communication services the smart distribution grid demands. The 5G use cases can be classified in one of these three main groups with vastly heterogeneous objectives: enhanced mobile broadband (eMMB), massive machine-type communications (mMTC), and ultra-reliable low-latency communications (URLLC). Each of these use cases can be mapped to a separate network slice.

In this paper, we categorize the different message types used in distribution grid protection and control from the standard defined by IEC 61850 [5] according to two key performance requirements. Therein, the four identified categories are mapped onto the three major groups of 5G use cases. We discuss changes in different parts of the 5G mobile communication networks which includes increased use of softwarization, virtualization of network functions, and edge/fog computing. A network slice template is introduced, and an example of a network slice for the distribution grid is illustrated.

The remainder of this paper is organized as follows. Section II introduces briefly the novel trends in networking. In Section III the various message types used in grid protection and control are analyzed to understand their performance requirements, and they are mapped into 5G use cases. Next the proposed architecture is illustrated in Section IV and each component of the architecture is elaborated. Lastly, Section V concludes the paper.

TRENDS IN NETWORKING

In 5G networks, softwarization and virtualization will be essential for implementation, e.g., integration of multiple radio access technologies (multi-RAT), virtualized resource sharing for multiple tenants, and the creation of

Table 1: IEC 61850 message types and performance requirements mapped to 5G use cases

Category	5G use case	Network slice	Availability	Latency	IEC 61850 message type
1	Ultra-reliable low-latency communications (URLLC)	S_1	High	Low	1, 6
2	Massive machine type communications (mMTC)	S_2	High	High	3
3	Enhanced mobile broadband (eMBB)	S_3	Low	Low	4
4	Massive machine type communications (mMTC)	S_2	Low	High	2, 5

customized network slices, which are virtual networks for each tenant according to their need for performance, dependability and security.

Softwarization

Software Defined Networking (SDN) separates the data (packet forwarding) and control planes [6] which in traditional legacy communication systems have been integrated on the same device. The control plane is (virtually) centralized which reduces the (re)configuration complexity and promotes flexibility and customization, and through programmable interfaces (APIs) enables controlled tenant access to and provision of network functions.

Virtualization

Virtualization refers to the representation of hardware and/or software resources by a software considering both data and/or control plane functions [7]. Virtualizing the network functionality enhances the flexibility and scalability, such as network function virtualization (NFV) where network functions are virtualized and provided on data centers with general purpose hardware (called cloud, edge, fog, dependent on size, location and capabilities) in contrast to legacy networks with dedicated and specialized hardware.

Virtualized resource sharing

Legacy communication networks have been providing services by dedicating a single network infrastructure for each of the service requirement of various customers. In a software defined network with virtualized network functions, customized and virtualized networks can be provided to multiple tenants over a common physical infrastructure [8]. These virtual networks are referred to as *network slices* and each can be tailored for specific performance requirements. In a multi-tenancy network, the physical resources are shared between multiple virtual resources that are needed to provide such network slices. This poses a challenge to the management and orchestration of network resources to minimise the interdependencies (wrt. performance and dependability) between the different slices.

GRID OPERATION MESSAGE TYPE REQUIREMENTS

The support for grid operation is given by the supervisory control and data acquisition (SCADA) system. It collects data from the remotely deployed voltage and current sensor nodes and manages the data centrally to take control decisions needed to maintain the power quality. It is expected that the grid instrumentation will increase to enrich the support for grid operation with more sensors for accurate, up to date, and detailed state estimation and fault detection. In addition, new (remote and automated) controllers are expected, e.g. for substation automation systems, connecting the various protection, control and monitoring elements of the substation. The SCADA master utilizes control and protection functions to maintain the power grid stability in case of an overload or short circuit situations. The control signals are sent to intelligent electronic devices (IEDs) in the distribution substations to adjust the voltages and frequency in such occasion. The IEDs must be interconnected, and connected to the SCADA system, which means that a fast, robust, and secure communication system is required. The IEC 61850 [9] defines a standard for communication between all devices that form a substation.

In order to understand the performance requirements of communication service of such IED interconnections, we need look at the messages that are defined for IED interconnections as defined by IEC 61850 [5]:

- **Type 1**: Simple and short message via a binary value such as *trip, close, reclose order, start, stop, block, unblock* etc., serving mission critical services where receiving IED must act immediately on the receipt of the message (GOOSE protocol).
- **Type 2**: Medium speed messages.
- **Type 3**: Low speed messages used for commands and reports like data base updates at station level, operator commands, and updates for alarm and event lists.
- **Type 4**: Raw data messages in a continuous stream of synchronized samples of current and voltage values from the transducers to the protection IED (sampled measured value (SV) protocol).
- **Type 5:** File transfers.
- **Type 6:** Time synchronization messages.

Table 1 categorizes the above message types into four categories which are further mapped onto the three main 5G use cases according to their application in the distribution grid. URLLC is applicable for real-time monitoring and control, where end-to-end latency requirements are extremely low, and the need for reliability or the availability requirement are high. mMTC is designed to provide connectivity for thousands of devices spread over a wide coverage. eMBB provides extremely high data rates at low latencies.

In order to fulfil the above specified performance requirements, we propose to implement initially three network slices (S_1, S_2, S_3 in Table 1), which correspond to the three major 5G use cases. For instance, the message performance requirement of low-latency and high reliability can be served by the network slice corresponding to URLLC, i.e., S_1. Hence, a new communication architecture is needed which enables network slicing.

NETWORK ARCHITECTURE FOR GRID OPERATION

Although wired access technologies have a higher data transfer bandwidth, lower latency, and they are more reliable, commercial public cellular (mobile) networks are considered in this paper. The reason is that wired access is not available everywhere we need it, and installation has a high enterprise cost, while mobile networks cover most of the geographical areas where communication services for grid operation are required. Mobile network coverage is steadily extended, and new technologies are introduced, such as 5G networks discussed in this paper. Private radio mesh solutions are also an option that is considered by some grid operators but is outside the scope of this paper.

Figure 1 illustrates a wireless and cellular communication (mobile network) architecture for the smart distribution grid operations. In order to meet the stringent 5G requirements, not only the radio access network (RAN), but also the core network must be upgraded. In this section, the radio access and core network architecture is briefly described, with specific focus on providing communication services for distribution grid operation. Thereafter, we explain how end-to-end network slicing is applicable to the architecture.

Operation of LV and MV distribution grid

Distribution grid operations such as state estimation, voltage and frequency regulation, fault location, isolation and service restoration (FLISR) require new IEDs that have to be interconnected and connected to the SCADA control. One such example is phasor measurement units (PMUs) which obtain measurements samples from the current and voltage sensors, and the collected data is sent to the phasor data concentrators (PDCs) which are typically deployed at the distribution substation. In this architecture, PMUs and voltage/current sensors are assumed to be deployed such that they obtain the sufficient and necessary data with a minimum cost. Another example is smart meters that are now deployed in residents to measure the power consumption but can also be used as aid for e.g., earth fault detection.

In the context of the microgrid, a central approach is assumed for both protection and control schemes. The microgrid central controller is responsible for automating the functionality of the microgrid both in grid connected and islanded modes. It coordinates with other DERs, load and storage controllers to balance the power generation of the DERs comparing it with the demand of critical and non-critical loads. The microgrid is presumed to be connected to the main power grid unless at a fault situation.

We assume that the message performance requirements of the IEDs used in the distribution grid are similar to the classification in Table 1.

Cloud-RAN (fog and edge)

Uploading and storing all the sensor data to the centralized cloud increases the latency and traffic. Fog computing is a novel computing approach which brings cloud computing to the edge of the network. It provides a virtualized environment for distributed processing closer to the end nodes, which enables low latency and localized decision making. Hence, hierarchical fog-edge-core design is an approach to achieve low end-to-end latency and to reduce the amount of data to be transmitted to the core [10]. This also means that the proposed architecture supports distributed state estimation of the power grid [11]. Furthermore, if the measurements are aggregated using data aggregation units, that will reduce the processing and storage demand in the RAN.

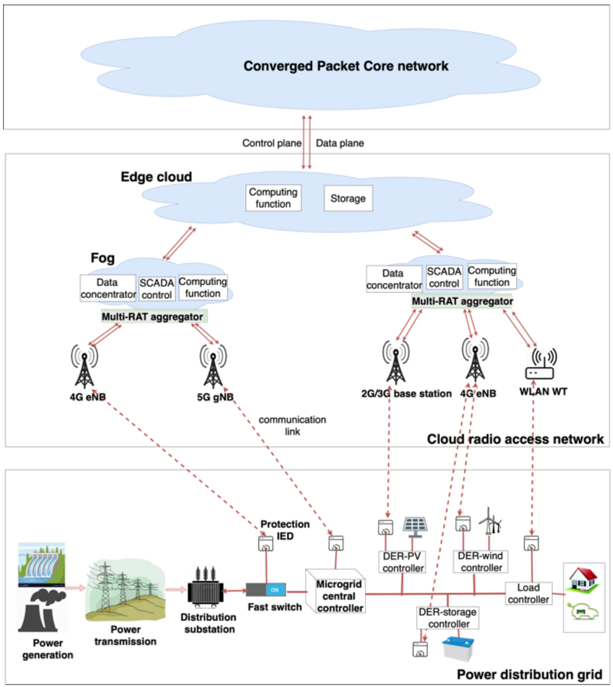

Figure 1: Proposed architecture for distribution grid operations

IEDs that are deployed in the distribution grid, which have the equivalent functionality of PMUs and smart meters, send the measured data via any available radio access technology (RAT) to the data concentrating functions deployed on the fog. Henceforth, fog computing is performed and if any control actions have to be taken in the distribution grid, the decisions are sent back to the respective IEDs.

It is expected to have software-defined base stations composed of centralized baseband processing units and remote radio heads. Certain RAN functions might be deployed at cloud platforms. Additionally, some of the RAN functions may be virtualized and deployed in the edge depending on the service performance requirements. Dynamic spectrum sharing RAN virtualization approach is desirable for the efficient and optimum use of radio resources. This might somehow challenge the radio resource isolation. It might be necessary to pre-configure certain slices with guaranteed performance requirements, with dedicated radio resources for its operation time.

Multi-RAT aggregation

In 5G mobile network a new RAT will be standardized [12], which provides lower latency and higher bandwidth per connected device due to the smaller cells and improved antenna technology. In addition, 5G will support multi-RATs, such as LTE-A (4G), UMTS (3G), EDGE (2.5G), which will enhance the wireless coverage in the areas where the aforementioned IEDs will be installed in the power grid. We then propose that the mobile network architecture should provide multi-connectivity and fast switching between RATs. Multi-RAT aggregation is sometimes also known as multi-flow scheme, since it aggregates data flows of different RATs. Multi-connectivity allows an end device to connect to different RATs simultaneously, and/or switch fast and seamlessly from one RAT to another. To enable fast RAT switching, the end device should be able to receive control signals from different RATs but receive user data only from the connected RAT.

Core network

In order to achieve the stringent 5G requirements, not only the RAN, the core network must also be upgraded. Since the 5G core architecture is expected to evolve substantially compared to 4G evolved packet core, we assume that the service requirements demanded by the smart distribution grid will also benefit from fundamental changes in the core network. Purpose-specific hardware in the legacy mobile core network makes it difficult to meet the increasing service demands. Virtualizing and orchestrating the core network enable the scalability and provide a single management view of the entire network. Thus, the dedicated hardware in the core network has to be replaced by network functions which are separated in the user plane and control plane.

End-to-end network slicing

The 5G network is envisioned to support a diverse set of devices and to meet diversified service requirements. Network slicing is a key technology pillar within 5G that lets the operators to "slice" one physical network into multiple, virtual, end-to-end networks. According to diversified service requirements, networks generate corresponding virtual network topologies and a series of virtual network function sets for each corresponding service. For each network slice, dedicated resources such as virtualized servers, network bandwidth etc. are guaranteed. This enables the network operators to fulfil different types of services with different requirements. Herein, we explain how end-to-end slicing can deliver the perceived services to the grid operator.

The service level agreement (SLA) is the official agreement between the grid operator and the network service provider which ensures that the services are provided according to the specifications and the service characteristics. In the SLA, there is a part that is called service level objectives (SLOs) where e.g., performance and dependability requirements are specified. The network slices will be specified in a *network slice template* based on the SLO specification which is implemented by the network management and orchestration (MANO) or the network slice orchestrator [13], as illustrated in Figure 2.

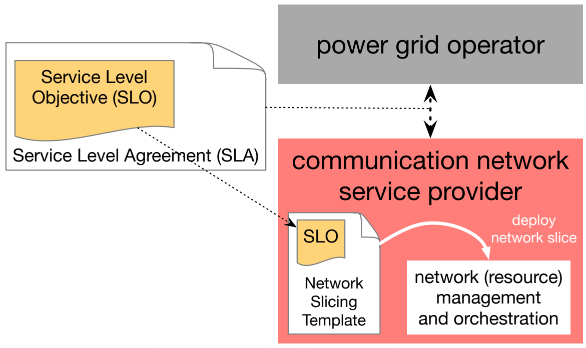

Figure 2: Role of SLA and SLO

A network slice template contains all the necessary information for the deployment of a network slice. It represents virtual network function(s) (VNF) and network resources linked to the services and network capabilities required. An example of a network slice template is shown in Figure 3. It represents a blueprint of a network slice template for URLLC service which is applicable for category 1 in Table 1. Likewise, network slice templates will be defined by the network service provider for each 5G use case corresponding to Table 1.

Field	Attributes
Slice Type	URLLC
Slice performance requirements	**End-to-end latency:** 5 ms **Reliability:** 99.999% **Bandwidth:** 100 Mbps **Security:** High isolation **Mobility:** No mobility
Temporal requirements	**Active period:** long term
Service chain (for network operator's use only)	Chain of VNFs on a set of available network resources in RAN and core network

Figure 3: An example of a network slice template for category 1 messages

The network slice orchestrator has the more complex task of identifying the appropriate network elements such as network functions and technologies for the network slice creation and deployment on the physical infrastructure. The chosen network elements will guarantee the fulfilment of the functional requirements given in the network slice template which in turn reflects the SLOs [14]. The network slice orchestrator is responsible for the network slice life cycle management (creation, update and deletion). Efficient slice creation should guarantee slice isolation where traffic of one slice should not interfere with another. However, slice isolation is the most important yet challenging feature of network slicing. A particular network slice may be uniquely identified by a *slice ID*.

Figure 4 illustrates two possible network slices that can be created within the proposed architecture. For instance, the URLLC network slice (S_1) can be dedicated for the mission-critical operation like category 1 in Table 1. The protection relays will be supported by the RATs that provide high bandwidth such as 4G/ 5G in the RAN. The computing functions and SCADA control will be placed on the fog for fast decision making.

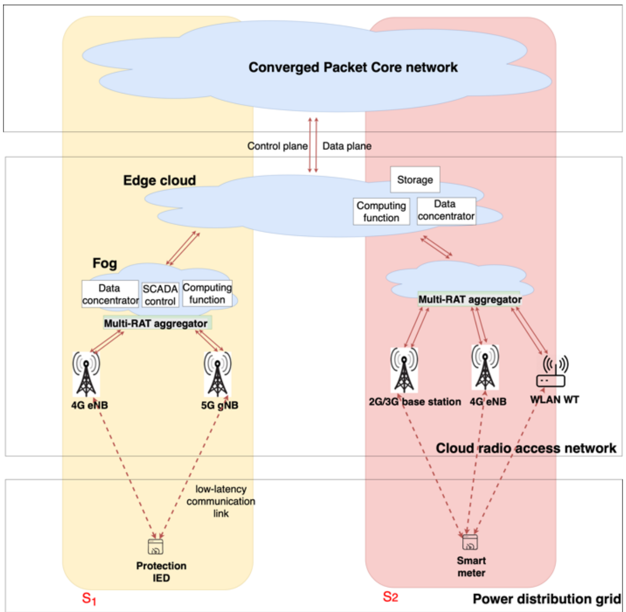

Figure 4: Example illustration of S_1 and S_2

Closing remarks

It is important to incorporate the benefits offered by the next generation mobile network in the distribution grid for smarter grid operations. The new paradigm in 5G, i.e., network slicing seems to be a promising and optimal solution for the diverse performance requirements of the distribution grid. We have discussed how the distribution grid can benefit from 5G and proposed a scalable communication architecture. We classified the different message types for grid protection and control into categories which were later mapped into 5G use cases. The end-to-end network slicing approach is explained for a smarter grid operation upon a virtualized communication infrastructure.

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REFERENCES

[1] X. Fang, S. Misra, G. Xue, and D. Yang, “Smart grid the new and improved power grid: A survey,” *IEEE communications surveys & tutorials*, vol. 14, no. 4, pp. 944–980, 2012.

[2] Y. Kabalci, “A survey on smart metering and smart grid communication,” *Renewable and Sustainable Energy Reviews*, vol. 57, pp. 302–318, 2016.

[3] Ericsson, white paper, “5G Systems,” Tech. Rep., Jan. 2017.

[4] G. A. white paper, “5G network transformation,” Tech. Rep., Dec. 2017.

[5] I. E. Commission, “TR 61850-90-1 communication networks and systems for power utility automation part 90-1: Use of IEC 61850 for the communication between substations,” Tech. Rep., Mar. 2010.

[6] D. Kreutz, F. M. Ramos, P. E. Verissimo, C. E. Rothenberg, S. Azodolmolky, and S. Uhlig, “Software-defined networking: A comprehensive survey,” *Proceedings of the IEEE*, vol. 103, no. 1, pp. 14–76, 2015.

[7] F. Z. Yousaf, M. Bredel, S. Schaller, and F. Schneider, “NFV and SDN–key technology enablers for 5G networks,” *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 11, pp. 2468–2478, 2017.

[8] H. Zhang, N. Liu, X. Chu, K. Long, A. H. Aghvami, and V. C. Leung, “Network slicing based 5G and future mobile networks: mobility, resource management, and challenges,” *IEEE Communications Magazine*, vol. 55, no. 8, pp. 138–145, 2017.

[9] R. E. Mackiewicz, “Overview of IEC 61850 and benefits,” in *Power Systems Conference and Exposition*, 2006, pp. 623–630.

[10] Z. Yang, N. Chen, Y. Chen, and N. Zhou, “A novel PMU fog based early anomaly detection for an efficient wide area PMU network,” in *IEEE 2nd International Conference on Fog and Edge Computing*. IEEE, 2018, pp. 1–10.

[11] M. Cosovic, A. Tsitsimelis, D. Vukobratovic, J. Matamoros, and C. Anton-Haro, “5G mobile cellular networks: Enabling distributed state estimation for smart grids,” *arXiv preprint arXiv:1703.00178*, 2017.

[12] NGMN Alliance, “5G white paper,” Next generation mobile networks, white paper, pp. 1–125, 2015.

[13] 3GPP, “Study on management and orchestration of network slicing for next generation network,” Tech. Rep., Jan. 2018.

[14] X. Foukas, G. Patounas, A. Elmokashfi, and M. K. Marina, “Network slicing in 5G: Survey and challenges,” *IEEE Communications Magazine*, vol. 55, no. 5, pp. 94–100, 2017.