Implementation and Verification of 5G Network Slicing for Smart Grids

Lei Sun*, Li Wang¹, Peng Yang³, Yuqing Zhong², Danke Hong², Guoyi Zhang², Hailong Zhu², Peng Qian³ and Jing Li³

¹ Guangzhou Power Supply Bureau, Guangdong Power Grid Co., Ltd
² China Southern Power Grid Co., Ltd
³ Guangzhou Branch, China Mobile Communications Group Guangdong Co., Ltd

*Corresponding author email: sunlei@guangzhou.csg.cn

Abstract. In this paper, 5G slicing networks are proposed to be deployed to address the issues associated with current communication networks in power grid systems and to enable smart grid applications. 5G slice architecture and the corresponding schemes including radio resource reservation, QoS scheduling strategy, VLAN, VPN and 5QI are applied for the access network, the transport network and the core network in the system, based on which a real 5G slicing network is implemented for smart grid applications. It is shown by field trial that the performance requirement regarding service isolation, bandwidth, delay and reliability required by various smart grid applications can be satisfied using the proposed schemes in the real system.

Keywords: 5G; network slicing; Smart Grids; service isolation; QoS.

1. Introduction

1.1. State of Art

Wireless communication has played an important role in the power grid systems in China. Until the end of 2018, the China southern power grid has employed nearly 3 million 2G/3G/4G terminals for a variety of services, including measuring automation, electric-power distribution automation, wireless video monitoring, mobile inspection, low-voltage emergency repair, vehicle monitoring and vehicle charging, etc. As immediate meter reading services are being deployed, the total wireless connections will reach more than 80 million and in the near future reach 100 million as more and more new types of distributed power supplies, such as wind power generation, solar power generation, electric vehicle charging stations, energy storage devices, and micro networks are being deployed in power grids. It can be expected that the cost of renting mobile terminal cards will increase significantly.

However, there exist a couple of problems in using public wireless communication systems for power grid systems as follows.

Service Isolation. Before the fifth generation (5G) network [1], wireless communication techniques are not able to fulfill the requirement of service isolation in power grid systems. Multiple services with different security requirement levels can not be supported simultaneously in the current wireless communication systems but require additional measures such as using encrypted terminal, setting up security access zones, etc.
**Bandwidth and Delay Requirement.** Before 5G, wireless communication techniques are not able to meet the requirement of large bandwidth and low latency. 2G networks can only support 20~100kbps and the single way communication delay is longer than 100ms. 3G/4G system can support higher date rates but still suffer from high delay between 40 ~100ms.

**Remote Administration and Failure Alarm.** There exist nearly 2.5 million public network modules in China southern power grid. However, information regarding service charges, traffic volume, network online situation, signal strength, failure alarm and warning can not be monitored remotely. It is not possible to locate the fault if a service terminal goes offline, i.e., whether it is caused by service terminal itself or due to communication failure.

**Scalability Issues for Power Grid Service Application.** Previous wireless communication techniques are deployed based on certain scenarios. For example, 2G is deployed in power grid systems to offer narrowband data service. LTE/4G is for large bandwidth mobile communication and NB-IoT [2] is for low-power wide-area networks. These techniques, however, can not meet the requirements for power grid systems with rich application scenarios.

### 1.2. 5G Networks

5G networks have several advantages over the previous generations. It can be used for more service scenarios. It can also provide stronger network capacity and offer more secure and open services to vertical industries. The value of 5G and to smart grids was discussed in [3] and the commercial value of 5G network was analyzed in smart grids for operators [4].

**More Service Scenarios.** Compared with 4G networks, 5G networks not only solve the communication problems between person and person, but also address the communication problems between things and between person and things. ITU has defined three application scenarios for 5G networks [1][5], i.e., enhanced Mobile BroadBand (eMBB), ultra Reliability Low Latency Communication(uRLLC) and massive Machine Type Communication (mMTC).

**Stronger Network Capability.** Compared with 4G networks, 5G networks adopt several key techniques including using larger frequency band (100MHz), higher modulation order, 3D-MIMO and Low Density Parity Check (LDPC) codes, which results in 3 times spectral efficiency as higher as the 4G systems. In eMBB scenarios, it can reach 4~6 Gbps data rate in practise. In uRLLC scenarios, delay in air interface is within 1ms and in mMTC scenarios the connection density can reach $10^6$/km$^2$. It should be noted that the bandwidth, time delay and the connection density mentioned above can not be reached simultaneously but require efficient management of the network resources.

**More Secure and Open Service for Verticals.** 5G adopts NFV(network function virtualization) and SDN (software defined network) [6], which makes the 5G network evolve from 4G dedicated hardware to general hardware with software deployment. Network functions can offer various capabilities to the outside world through the unified enabling platform of the operator, such as network slice customization design, planning and deployment, operation monitoring ability, various user data, and data collected by terminals or modules, so as to realize the connection management, equipment management, service management, specific network slice management, certification and authorization management, which better supports the operation and maintenance management of public network business for verticals.

In this work, we implemented a real 5G network and applied different strategies in the core network, the transport network and the air interface to support service isolation, large bandwidth and reliable connection for smart grid applications, which will be described in the subsequent section. Furthermore, field trial was conducted in the above networks and promising results were observed for different smart grid applications.
2. 5G Network Architecture for Smart Grids

![5G Network Slicing Architecture for Smart Grids](image)

**Figure 1.** 5G network slicing architecture for smart grids.

In order to meet the requirements of various services in power grid systems [7], we propose to employ network slicing techniques [8] as shown in Fig. 1. As an example, 6 network slices are applied, including 4 slices for safety production zones and 2 slices for management information zones.

2.1. Slicing Schemes for Core Network

**UPF (User Plane Function).** Three sets of edge UPFs [9] were installed in the tested power grid system. They are the UPF 1 (vendor 1), UPF 1 (vendor 2) for the safety production zone and UPF 3 (vendor 1) for the management information zone.

**DNN (Data Network Name) [10].** Different services were assigned to different DNN. The corresponding UPF was selected by network slicing and DNN.

**5QI (5G QoS Identifier).** 5QI [11] is a pointer to a set of QoS (Quality of Service) characteristics such as priority level, packet delay or packet error rate. It controls QoS forwarding treatment for the QoS Flow (e.g., scheduling weights, admission control, queue management thresholds, link layer protocol configuration, etc.). In practice, it can be applied to QoS flow where different services were assigned to different 5QI to meet the required QoS. For simplicity, in the tested scenario, 5QI=6 was assigned to all To B (Business) services and 5QI=9 was assigned to all To C (Customer) services.

2.2. Slicing Schemes for Transport Network

**SPN (Slicing Packet Network) [12] is employed in the transport network, which supports FlexE (Flexible Ethernet) based physical isolation and VLAN based logical isolation. Services in the production zones and those in the management information zones are carried by different FlexE slices. In one FlexE slice, different services can be mapped to different VPN tunnels with different QoS strategies, in order to achieve service isolation and meet the QoS requirement.

2.3. Slicing Schemes for Access Network

**IP Address Planning Principle.** The IP address planning principle for the signalling plane of the base station (vendor 2) is as follows.

1) For the base station carrying services in the management information zone, routing should be available from the base station to the N2 port of the AMF of vendor 1.
2) For the base station carrying services in the production zone, routing should be available from the base station to the N2 port of the AMF of vendor 2.

The IP address planning principle for the user plane of the base station (vendor 2) is as follows.

1) The IP address of the user plane corresponds to that of the network slice, i.e., the number of network slices equals to that of the user plane IP address.
2) For the base station carrying services in the management information zone, routing should be available from the base station to the N3 port of the UPF of vendor 1 in the management information zone.
3) For the base station carrying services in the production zone, routing should be available from the base station to the N3 port of the UPF of vendor 2 in the production zone.
**SLA (Service Level Agreement) Strategy.** Different smart grid services require different 5G network performance to meet their communication requirements. For the services in the production zone, such as differential protection, distribution network PMU and electric-power distribution automation, which require high reliability, low delay and high precision timing communication connection, we proposed to apply PRB reservation scheme and assign high scheduling priority for the corresponding network slice deployment. For the services in the management zone, such as substation services and integrated services, QoS parameters can be used. The wireless SLA strategy involved in the test is depicted as follows.

| Table 1. Wireless SLA strategy of the network slices in the tested scenario. |
|---------------------------------------------------------------|
| Slice Name | Slice ID (Hexadecimal) | Slice ID (decimal) | SLA Strategy |
| Management zone III | SST= 0x80, SD= 0x4c8003 | 128-5013507 | QoS |
| Management zone IV | SST= 0x80, SD= 0x4c8004 | 128-5013508 | PRB reservation |
| Production zone I | SST= 0x80, SD= 0x4c8005 | 128-5013509 | PRB reservation |
| Production zone II | SST= 0x80, SD= 0x4c8006 | 128-5013510 | PRB reservation |

- **QoS:** For the tested scenario, we adopt equal logical channel priority (MLCP, 5QI6=5QI9=4) but assign different relative priority (weighting factor for 5QI queue, 5QI6:5QI9=4:1) to allocate radio resources as follows in **Table 2.**

| Table 2. QoS based resource allocation scheme. |
|-----------------------------------------------|
| Slice | 5QI | MLCP | Weighting Factor |
| 2B Slice | 6 | 4 | 4 |
| 2C Slice | 9 | 4 | 1 |

- **PRB:** According to the network characteristics (bandwidth, delay, etc) required by the service in the production zone, the percentage of PRB reservation is calculated and adjusted according to the test results, which is depicted in the last column of **Table 3.**

| Table 3. Suggested PRB configuration for different service in smart grids. |
|---------------------------------------------------------------|
| Slice Name | S-NSSAI | Service | Data Type | Delay | Bandwidth | Reliability | PRB reser. percen |
| Safety Production zone 1 | 0x80-4C8005 | electric-power distribution automation (Three-remote techniques) | telemetering, remote signalling and remote control data | Telemetering, remote signalling ≤ 3s; remote control ≤ 1s | ≥ 20kbps | 99.999% | 3% |
| | | Intelligent power distribution zone | Three-phase current, three-phase voltage, active power and reactive power, overvoltage, phase break, over-current and power failure warning | ≤ 1s | ≥ 20kbps | 99.999% |
| | | Distribution network differential protection and control | Differential protection measurement information | ≤ 15ms | 2Mbps | 99.999% | 25% |
### Distribution network synchronous phasor measurement

**Voltage/current**
- Fundamental phasor, harmonics, power, frequency

**S-NSSAI**
- 0x80-4C8006

- **Measurement automation**
- According to “China Southern Power Grid Measurement Automation Terminal Uplink Communication Protocol”

| S-NSSAI: Single network slice selection assistance information |
|---------------------------------------------------------------|

### Safety Production zone II

- Distribution network micro-perception controller
- Voltage/current fundamental phasor, harmonics, power, frequency, load identification, temperature and other non-electrical quantities, fault recorder

| ≤30ms | ≥2Mbps | 99.999% | 15% |
|-------|--------|---------|------|

| ≤3s   | ≥10kbps| 99.9%  | 2%   |
|-------|--------|---------|------|

| ≤100ms | ≥160kbps | 99.999% | 2%   |
|--------|-----------|---------|------|

3. **Performance Evaluation and Verification**

A pilot project was launched in China southern power grid to evaluate the performance of 5G slicing networks for smart grids. A real network was set up as shown in Fig. 2 according to the architecture described in Fig. 1. Different experiments were conducted to verify whether the proposed architecture and schemes could satisfy the performance requirements of smart grid applications.

In order to verify isolation of the network slicing, firstly two test UEs (UE 1 and UE 2) were configured to subscribe to the production slice and the management slice, respectively. Then we attempted to let UE 1 register in the management slice with its subscribed S-NSSAI, since it was an unauthorized ID for the management slice, the “registration reject” warning message was prompted. Next, let UE 1 and UE 2 register in the production slice and the management slice, respectively. After successfully registration in the corresponding slice, we attempted to ping the server in the management zone from UE 1 and ping the server in the production zone from UE 2. The “connection timeout” message was prompted, which implied that the services in the production zone and in the management zone were isolated with each other.

To evaluate the performance of the service which requires large bandwidth in smart grids, let UE 1 subscribe to management information zone III (2B service) with 5QI6 and UE 2 subscribe to a default slice (2C service) with 5QI9. We set MLCP 5QI6=5QI9=4 and relative priority weighting factor 5QI6:5QI9=4:1. In this experiment, UE 1 performed non-full buffer UDP service (uplink: 60 Mbps; downlink: 200 Mbps) and UE 2 performed full buffer UDP service. It was observed that UE 1 achieved the target data rate although UE 2 performed full buffer service, which implied that
increasing relative priority for scheduling was able to effectively allocate sufficient radio resources for UEs performing smart grid applications without impact on the 2B services.

To evaluate the effect of the PRB reservation scheme, 4 slices are configured for the test cell, which are production zone I slice, production zone II slice, management zone III slice and management zone IV slice. UE 1 ~ UE 4 were then subscribed to the above four zones, respectively. Let the PRB reservation ratio to be 3% and 2% for production zone I and production zone II, respectively, and the rest PRBs were shared by the management zone III and management zone IV. First, we let UE 3 register in the management zone III and perform full buffer UDP services in the UL. Afterwards, UE 1 registered in the production zone I, then UE 2 in the production zone II and UE 4 in the management zone IV. The test results were shown in Table 4, Table 5, Table 6 and Table 7. It could be observed that UE 1 (production slice I) and UE 2 (production slice II) occupied 3% and 2% of the resources respectively as expected, since PRB reservation strategy was applied for them. Other available resources (excluding uplink public resources) will be then jointly occupied by UE3 (Management slice III) and UE4 (Management slice IV), since QoS strategy was used for them.

Table 4. UE 3 subscribed to management slice III, perform full buffer UDP service.

| Terminal | Slice             | RSRP (dBm) | SINR (dB) | Grant UL | RB UL | PRB Ratio UL | Throughput UL(Mbps) |
|----------|-------------------|------------|-----------|----------|-------|--------------|---------------------|
| UE3      | Management zone III | -86.04    | 24.97     | 398.78   | 241.49| 88.18%       | 105.6               |

Table 5. UE 1 subscribed to production slice I and UE3 subscribed to management slice III.

| Terminal | Slice             | RSRP (dBm) | SINR (dB) | Grant UL | RB UL | PRB Ratio UL | Throughput UL(Mbps) |
|----------|-------------------|------------|-----------|----------|-------|--------------|---------------------|
| UE1      | Production zone I | -80.66    | 23.71     | 23.57    | 140.93| 3.04%        | 3.06                |
| UE3      | Management zone III | -86.75 | 23.12     | 386.24 | 241.78| 85.51%       | 100.39              |

Table 6. UE 1 subscribed to production slice I, UE 2 to production slice 2 and UE3 to management slice III.

| Terminal | Slice             | RSRP (dBm) | SINR (dB) | Grant UL | RB UL | PRB Ratio UL | Throughput UL(Mbps) |
|----------|-------------------|------------|-----------|----------|-------|--------------|---------------------|
| UE1      | Production zone I | -77.58    | 24.7      | 23.56    | 140.91| 3.04%        | 3.24                |
| UE2      | Production zone II | -81.98 | 21.41     | 19.07    | 116.75| 2.03%        | 2.12                |
| UE3      | Management zone III | -81.5   | 26.04     | 377.42 | 241.76| 83.55%       | 95.9                |

Last, end-to-end delay was considered. Let two UE1 and UE 2 reside in the same base station and let them ping each other for more than 10000 times. The round trip distance between UE1 and UE2 is about 30km. It was observed that the maximal delay was 9.8ms and the average delay was 8ms. Therefore, the tested network was considered feasible to meet the delay requirement as shown in Table 3 for differential protection in electric-power distribution networks.
Table 7. UE 1 subscribed to production slice I, UE 2 to production slice 2, UE3 to management slice III and UE 4 to management slice IV.

| Terminal | Slice                  | RSRP (dBm) | SINR (dB) | Grant UL | RB UL | PRB Ratio UL | Throughput UL(Mbps) |
|----------|------------------------|------------|-----------|----------|-------|--------------|---------------------|
| UE1      | Production zone I      | -78.12     | 25.7      | 23.59    | 140.74| 3.04%        | 3.28                |
| UE2      | Production zone II     | -82.13     | 21.84     | 19.02    | 116.84| 2.03%        | 2.12                |
| UE3      | Management zone III    | -81.72     | 25.73     | 189.28   | 240.88| 41.75%       | 47.23               |
| UE4      | Management zone IV     | -84.27     | 23.29     | 192.87   | 236.59| 41.78%       | 40.8                |

4. Conclusions and Future Work

In this paper, we studied the 5G network slicing for smart grid applications. We proposed a slicing architecture and employed PRB reservation, QoS scheduling strategy, VLAN, VPN and 5QI schemes in 5G networks to enable service isolation, large bandwidth and reliable connection required by smart grid applications. A real network was built in China southern power grid to evaluate and verify the performance promised by 5G networks. It was shown in the field trial that the key performance indicator including service isolation, bandwidth, delay and reliability can be satisfied, which paves a way for more sophisticated applications for smart grids. Future work is in progress to consider implementation and applications using 5G for power electric-power distribution automation and differential protection in power distribution network.

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