Research on Time-Sensitive BBU Shaper for Supporting the Transmission of Smart Grid

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Abstract. Large-scale of data terminals are deployed in the smart grid, especially the power distribution network. The effectiveness of data collection or scheduling for Source-Grid-Load-Storage is affected to some extent by the accuracy of the time synchronization of the terminal equipments. Here we propose a design of BBU Shaper to deal with time synchronization error on the above issues. This article analyzes the impact of synchronization errors between terminal devices within the coverage of a single base station which provides deterministic transmission for the power IoT. For the time-sensitive service flows, when the terminal has different priorities according to the service type, the time synchronization error of the terminal will affect the stability and effectiveness of the time-sensitive service flow transmission on the network. It is mainly reflected in timestamp deviation of the data collection, disrupting the determinism of other service flows and reducing the overall network resource utilization. Based on the analysis of the above problems, we proposes an edge data shaper which can reduces the impact of air interface time synchronization errors on big data services through mechanisms such as "ahead awaits; overtime elevates". Evaluation shows that the Shaper can reduce the impact of time synchronization errors on the average delay of services to a certain extent.

Keywords: Edge shaper · Power big data · Smart grid · Time synchronization

1 Introduction

With the development of 5G-based power IoT, many kinds of power services have benefited from the low latency and high reliability of 5G networks. The research on Ultra-reliable low-latency communication (uRLLC) is continuing to follow up in the field of Smart Grids [1]. Considering the demands of stable transmission in plenty of power IoT scenarios, the Time-Sensitive Networking

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(TSN), which is developed from IEEE AVB, has been discussed to provide the deterministic transmission ensurance for Smart Grid. TSN is a set of standards under development by the IEEE 802.1 working group. It defines mechanisms for the time-sensitive transmission of data over deterministic Ethernet networks [2].

Although the TSN technologies are relatively mature, there are still many problems to be solved before TSN can be perfectly converged with 5G system [3]. TSN can realize the network's deterministic delay based on time synchronization and traffic scheduling technology, ensure the reliability of the network through reliable transmission technology and achieve interoperability between different networks through resource management technology. However, Time Awareness Shaper will cause packet loss due to incorrect gate control status. It highly depends on accurate time synchronization between network nodes [4]. The introduction of the frame preemption mechanism increases the waiting time of low-priority data, it is necessary to balance the average delay and the maximum delay of the network. Due to the uncertainty of wireless channel, i.e. the air interface, determinism at the mobile edge is hard to reach, especially the reliability and stability on uplink. In addition, the accuracy of absolute time synchronization is also restricted by the asymmetry of wireless channel. It brings problems such as timestamp deviation of the data collection, disrupting the determinism of other service flows and reducing the overall network resource utilization. Since the SmartGrid services that use the most wireless connections are the power big data services, which includes various types of power data collection and real-time monitoring, it is most necessary to consider the impact of time synchronization errors on these services. What's more, in the context of the continuous improvement of the electricity market, system power balance can be achieved through demand-side management. To achieve high effect Source-Grid-Load-Storage, coordinated and optimized scheduling is essential, which highly depends on accurate time synchronization.

The remainder of this paper is organized as follows: Sect. 2 shows the related work and the description of our solutions. Section 3 presents the evaluation and future work directions. Finally, we conclude the paper in Sect. 4.

2 Design of the Time-Sensitive BBU Shaper

2.1 Related Work

In our opinion, SmartGrid will adopt 5G & TSN converged network as a wireless business solution for power IoT in the future [5]. Based on the integration of 5G and TSN in the aspect of core network, bearer network and network time synchronization, the power IoT can provide the following features for the big data terminals: service admission, charging, grant of priority and preemption authorizations; real-time deterministic resource allocation based on network status awareness; absolute time synchronization based on gPTP; TSN data adapter and TSN configuration adapter for other parts of the SmartGrid.

At present, the 5G core network, based on network function virtualization and microservices, already has the conditions to implement dynamic network slicing and open network configuration interfaces. In the core network of 5G-TSN converged network, network-aware TSN microservice network elements is able to perform power IoT service management and control based on dynamic network slicing technology to ensure isolation from other services; Grand Master Clock nodes with precise network timing capabilities are introduced to realize that each node can only rely on the network to achieve sub-microsecond level absolute time synchronization [6].

For the absolute time synchronization, traditional TSN network frequently exchange the time synchronization information between the network entities on a regular basis. It will increase the load on the control plane and eventually affect SmartGrid services [7]. The centralized time synchronization system only exchanges messages between the central synchronization controller and each network entity, which can reduce the overhead of the control plane. However, it also may cause a single point failure when the GMC or its service link fails. This will cause the entire network to lose synchronization. Therefore, the 5G-TSN converged network uses IEEE gPTP protocol and a distributed time maintenance architecture which combines the best clock algorithm (BMCA). When a GMC fault occurs, the nodes of the network can still maintain accurate time synchronization for a period of time.

2.2 Problem Description

Most applications/devices of power big data are of large amount, their transmission data is periodic and sensitive to transmission delay, and the size of data transmitted each time is relatively small. Thus they require the following transmission features:

- stable transmission delay;
- accurate timestamp for the data;
- take precedence over normal service transmission;

The terminals have different priorities according to their type. The priority determines the ability of preemption. Normally, each terminal will be assigned to a fixed resource and the BBU does not transmit any other packages even the UE sends no data. Thus the terminals must transmit their data at the right time. Methods of time synchronization used for wireless devices are restricted by the air interface. Although a high synchronization accuracy can be achieved by various of methods, a larger error may still occur [8,9]. The time synchronization error of the terminal, together with the channel delay instability, will cause the data to arrive at the BBU at the wrong time (beyond the resource which they are assigned). This will affect the stability and effectiveness of the time-sensitive service flow transmission on the network. It is reflected in the following aspects:

- time stamp deviation of the data collection;
- excessive transmission delay;
- disrupting the certainty of other service flows;

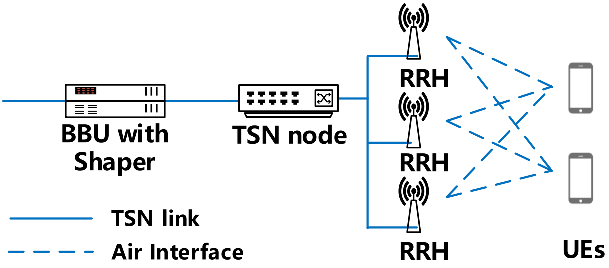

Fig. 1. The application scenario of BBU shaper.

- reducing the overall network resource utilization due to the overhead of preemption.

State Grid Corporation has built a distributed photovoltaic cloud network which realized 1.12 million users' access and full-process one-stop service. However, the application of photovoltaic operation and maintenance cloud platform technology still stays in the passive operation and maintenance of fault detection and resolution, lacking mechanism to prevent malfunction caused by time synchronization.

In summary, it is necessary to discuss the impact of time synchronization errors on the service and the corresponding solutions.

2.3 BBU Shaper

We propose a solution to use time-sensitive Shaper at the edge of the network in response to the requirements of the power big data service for the uplink transmission delay. We choose to shape the upstream at the BBU as it is the entrance of the terminal to access the network. The shaper aims to achieve the abilities of stabilizing the transmission delay of the stream and reduce the delay of the timed-out stream, meanwhile control the reasonable utilization of the network. Figure 1 shows the application scenario of BBU shaper.

The Mechanism of Stabilizing Transmission Delay. First, we set up a threshold for each uplink stream according to their ideal arrival time to make the upstream traffic relatively stable. As shown in Fig. 2, for packages arrives within the threshold, the shaper set up a queue and waits for the threshold. When forwards the data, the shaper checks whether there are multiple queues that need to preempt resources at the current moment.

Reducing Worst Delay. For packages arrives overtime, the shaper temporarily elevates the priority of this stream. Then the shaper forward the streams according to their priorities. By increasing the priority of the timeout stream, we can reduce its waiting delay in other parts of the network. At the same time,

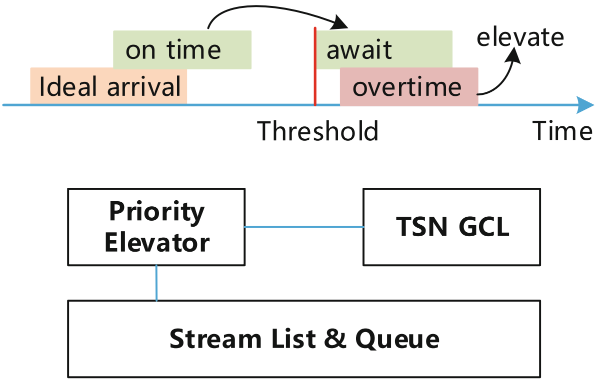

Fig. 2. Stabilizing transmission delay mechanism of BBU shaper.

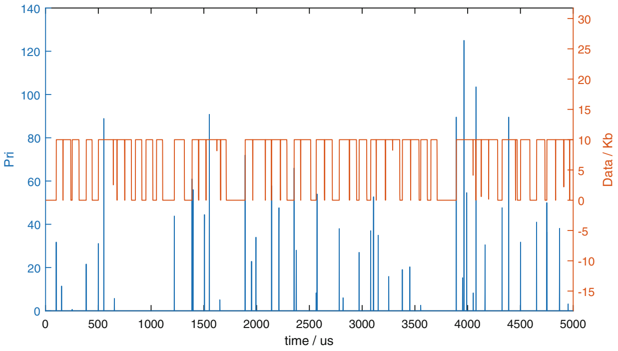

Fig. 3. Schematic diagram of elevator and data forwarding.

although the stream has missed its reserved TSN resources, there is still hope to avoid resource occupancy for subsequent services by occupying resources outside the TSN slice. For the flow with lower priority which has been interrupted, the shaper needs to recalculate the priority according to how much the flow is delayed. The priority elevator need to be carefully designed as unreasonable escalation can lead to large scale of preemption which requires overhead and raises overall delay.

Design of BBU Shaper. The priority elevator is the core function of the BBU Shaper as it directly affects the gate control list (GCL). The shaper also need to form the stream list from the TSN configuration and establish the corresponding queue. Specifically, the following parameters and corresponding functions are essential:

- α_{slice}: resource allocation rate of current slice in converged network. The smaller this rate is the average delay the faster grows. That is, the shaper will be more sensitive to the increase in average delay.
- *slot_length*: minimum time-domain unit for traffic shaping.
- *pmac_min*: minimum preemptible frame length. 124 byte normally.
- *stream.threshold*, *.resource*, *.delay*, *.DPri*: used to record stream information.
- *stream.id*: it is used to identify the stream. When the priority is the same, the stream with a smaller ID has a higher authority.
- *Pri_max*: the maximum priority. Normally it is only assigned to Pri_max-1, the maximum authority is reserved for emergency or control data flow.
- *total_delay*[]: record the transmission delay of each stream in a certain period of time. It is used to measure the effect of the shaper. If the current stream is unable to preempt normal service resource, its final delay will be:

$$fix(delay/(t*\alpha_{slice}))*t+mod(delay,t*\alpha_{slice}) \tag{1}$$

And for the priority elevator, the problem it needs to solve is how to reduce the worst delay by sacrificing the average delay while taking into account network utilization. Typical designs include multiplier elevator, linear elevator, dynamic elevator based on load and average delay, etc. The fixed multiplier elevator:

$$DPri=min(stream.Pri*f,(Pri\_max-1)); \tag{2}$$

The delay-based linear elevator:

$$\begin{aligned}DPri=min(stream.Pri+(stream.late\\ -stream.Threshold)*k,(Pri\_max-1));\end{aligned} \tag{3}$$

The load-based linear elevator:

$$DPri=min(stream.Pri/load*k_l,(Pri\_max-1)) \tag{4}$$

where k, f and k_l are the scale factors.

3 Evaluation and Future Directions

In this section, we evaluate the design of the BBU shaper with different kind of priority elevators. Also, in order to further evaluate the BBU shaper, we propose a revenue model to evaluate the effect of current traffic shaping.

Assume a base station is connected to *N_devices* terminals. Each terminal is allocated exclusive resources within a slice of one hundred microseconds. All the terminals have a random synchronization error for some reason. Therefore, they will transmit data at the wrong time, and coupled with the unstable delay of the channel, the stream will exceed the expected situation. The uRLLC slice takes $\alpha_{slice}=0.1$ ratio of time domain with full bandwidth $BW=100\,\text{Gbps}$, the terminals has synchronization error within 4 times of their threshold with

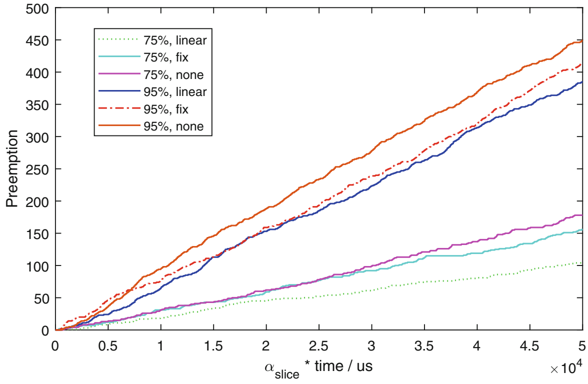

Fig. 4. The amount of preemptions that occur in different situations. $f = 1.5, k = 0.635$

random initial priority from 0 to $Pri_{max} = 127$. Their thresholds are set to $T = 50\,\mu\text{s}$ and their data rates are all within 100 Mbps.

Figure 3 shows how the linear elevator works and the corresponding BBU data forwarding output. This kind of elevator increases the priority of those delayed stream with dynamic maximum priority limit.

As shown in Fig. 4, Fig. 5 and Fig. 6, we used delay-based linear elevator and fixed multiplier elevator in the shaper when the uRLLC load is 75% and 95% respectively.

The time synchronization error results in preemption per 4.31 Mb data transmitted when the load is 75%, and the worst delay reaches to about 1 ms which is 20 times longer than the expected transmission delay. We can see that the shaper can reduce the total preemption rate under the same load compared to the

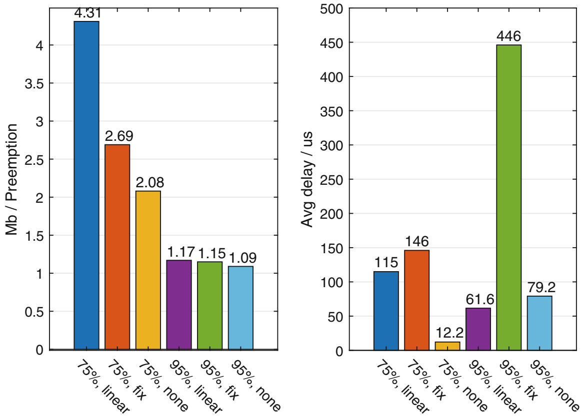

Fig. 5. Network overhead and average delay in different situations.

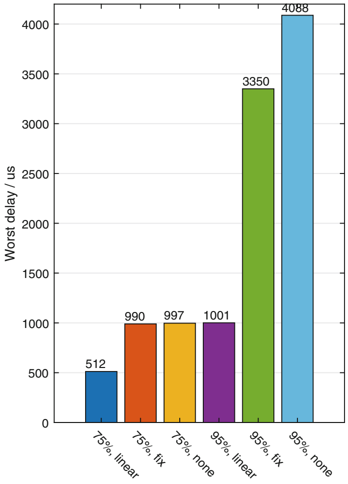

Fig. 6. Worst delay in different situations.

case without the elevator. Under 75% load, the shaper can effectively offset the preemptive signaling overhead required to transmit each MB of business data. But as the load increases to 95%, this effect almost ceases to exist. For average and worst delay, the shaper sacrifices average latency to reduce worst latency. But we also find that unreasonable elevator design will lead to disastrous consequences: the delayed streams preempt the later streams, causing the later streams to get on the priority elevator and to preempt even later streams. The fixed elevator rudely promotes the priority and leads to snowslide of preemption. While linear elevator reduces the worst delay by about 3 ms and only increases the average delay 0.1 ms (even reduce average delay at 95% load), the fixed elevator slightly decreases worst delay but greatly increases the average delay.

It can be concluded that the BBU Shaper has to predict the consequences of promoting priority. Thus we need a revenue model to evaluate the effect of the shaper. Essentially, the output of the elevator is a strategy π with continuous action space $A =$. The state space S is determined by the current network load to preemption ratio DP, the average delay AD and the worst delay WD in a period of time. The revenue model G_t can be expressed as:

$$\begin{aligned} G_t &= \sum_{k=0}^{\infty} \gamma^k R_{t+k+1} \\ R_t &= f_0(load) * DP_t + f_1(AD_t) * AD + f_2(WD_t) * WD \end{aligned} \tag{5}$$

where $f_0()$, $f_1()$ and $f_2()$ are the functions that determine the corresponding coefficients based on network conditions which is expressed in A. We will solve this model through dynamic programming or reinforcement learning in our future work, so as to obtain a specific and better elevator setting strategy.

4 Conclusion

The devices used for power big data, Source-Grid-Load-Storage, etc. in smart grid have characteristics like large amount, the transmission data is periodic and sensitive to transmission delay, and the size of data transmitted each time is relatively small. The absolute time synchronization error of these devices can lead to increases in preemption, average transmission delay and worst transmission delay. We propose a design of the BBU Shaper to deal with the time synchronization error and uncertainty of channel delay. We propose a mechanism named AAOE to stabilize the transmission delay and reduce worst delay. Evaluation shows the shaper is able to alleviate the negative impact caused by the synchronization error. But there are still some problems remain to be solved such as efficient design of priority elevate. Based on our discussion, we believe that the BBU Shaper will have a role in supporting the transmission of Smart Grid in the future.

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