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Traffic Scheduling Strategy of Power Communication Network Based on SDN

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ABSTRACT

Due to the complicated structure, power communication network is difficult to guarantee the quality of service (QoS) of power services. A two-level scheduling algorithm based on software defined network (SDN) is proposed in this paper. Firstly, the priority-based scheduling method is used to meet the latency-sensitive of power service. Then, in order to alleviate congestion, queue bandwidth is adjusted according to network state information, which can be collected by the centralized control of SDN. Finally, the Mininet and Ryu controller are made use of building simulation environment. The test results show that the algorithm proposed in this paper reduce delay and packet loss rate significantly, which achieves QoS.

Keywords: Software Defined Network, Power Communication Network, Quality of Service, Traffic Scheduling, Dynamic Bandwidth Adjustment.

1. INTRODUCTION

As the communication infrastructure of grid, power communication network serves all aspects of power system, including its production, operation, and management [1]. With the development of smart grid, the architecture of power communication network becomes more complex, and new power services increase gradually. It is difficult for power communication network to configure resources flexibly [2, 3]. Based on the feature of centralized control, SDN can perceive network topology and state information, and concentrated scheduling resources [4, 5]. And providing end-to-end QoS for service is easier in SDN network [6]. Besides, the programmable interface is provided by SDN, which can be used to customize the privatized application. Therefore, SDN is widely introduced into power communication network to improve the transmission quality of power service [7-9].

At present, SDN, based on the OpenFlow (OF) protocol, merely implements a coarse-grain QoS provision [10]. For example, they are creating queues of different bandwidth. The existing QoS policy hardly satisfies multi-character power service. And queue bandwidth is always fixed, which may contribute to queue congestion and packet loss seriously. Most SDN devices run on the Linux system (e.g., Open vSwitch (OVS)), which offers traffic control (TC) tool to guarantee QoS [9, 10]. So, some proposals have been proposed. Yan et al. [11] make use of multipath routing and queue mechanism to realize QoS. Nevertheless, they ignore the network congestion. Ishimori et al. [12] link datapath module with queue configuration module through the OF-CONFIG protocol to provides QoS-configuration. But it is hard to implement because of requiring the cross-layer protocol. Wu et al. [13]

adjust bandwidth based on queue congestion feedback, which can ensure the QoS of high-priority service. Huang et al. [14] propose a hybrid scheduling algorithm, which combines priority with the PGPS method. The algorithm not only can decrease latency but also share bandwidth. This paper has similarities with it.

In summary, an SDN-based traffic scheduling algorithm (SDNTS) is proposed in this paper, which uses the programmable interface and traffic control tool to implement two-level scheduling. The two-level scheduling fulfills priority-based latency guarantee and congestion-based bandwidth fairly. Through OF protocol and Restful API, SDNTS algorithm would be implemented in power communication network.

2. SDNTS ALGORITHM

2.1. CLASSIFICATION OF POWER SERVICE

Two categories of service are carried by the power communication network, including production control and management. The production control service is different from ordinary network service, which may cause a widely range of power failure when the transmission quality cannot be protection. Consequently, based on the QoS requirements and power service importance, all power services are divided into three classes, including expedited forwarding (EF), assured forwarding (AF), and best-effort (BE). EF is mainly for the power service that has the characteristics of delay-sensitive, reliability-high, and burst. With the features of bandwidth-sensitive and low delay, the power service could be classified as AF. And the power service without any QoS requirements belongs to BE. The division of part power service is shown in Table 1.

TABLE 1.
Classification of part power service

Service type	Power service
EF	relay protection
AF	security and stability control system; dispatching automation; dispatching telephone; electric energy remote-metering; substation video monitoring; wide-area vector measurement; video conference; protection information management; administrative telephone; lightning location detection;
BE	office automation

The header of IP packet contains a ToS field, which can distinguish the power service type. The ToS field occupies 1 byte, and its format is shown in Table 2. The P2, P1, and P0 are mainly for indicating service type (e.g., 100 for EF, 010 for AF, and 001 for BE). The T3, T2, T1, and T0 are made use of depicting power service. The CU is a reserved bit and set to 0.

TABLE 2.
Composition of the ToS field

Bit	7	6	5	4	3	2	1	0
Tos	P2	P1	P0	T3	T2	T1	T0	CU

2.2. SDNTS ARCHITECTURE

SDN centrally controls and manages switches and network topology, which makes up for the shortcomings of power communication network. By differentiated scheduling and bandwidth adjustment, the algorithm proposed in this paper can support reliable transmission for power service. The network architecture is shown in Figure 1, which adds functional modules at each plane of SDN. The apply plane fulfills bandwidth weight calculation and queue configuration modules. It assigns queue bandwidth according to network state, deploys queue scheduling information by TC command, and interacts with the control plane through Restful API. The control plane provides various interfaces and functions, including maintaining network topology, identifying power service, generating and sending flow tables, collecting state information, selecting a route, and parsing queue configurations. The queue schedule module in the data plane is mainly for receiving queue configuration information and forwarding packets. The forward process is shown in Figure 2. EF queue is given the highest priority, and BE queue is the lowest. First, power service is filtered to a queue based on the ToS value. Then, the priority-based scheduling method is adopted for preferentially outputting the packets in the high-priority queue. Nevertheless, if there always exits power service, the low-priority queue would lack bandwidth to be “starved.” Therefore, it is necessary to limit the transfer speed of the high-priority queue. Finally, AF queue is divided into multiple sub-queue, which share resources fairly through the dynamic bandwidth adjustment method.

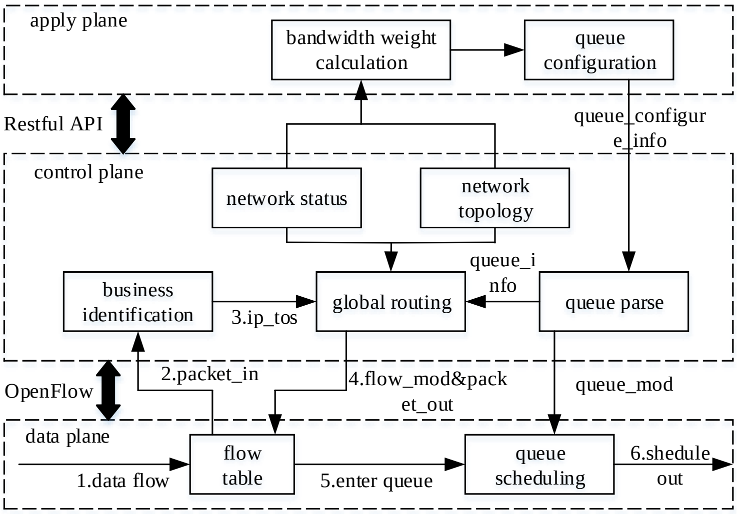

FIGURE 1. The network architecture of SDNTS algorithm

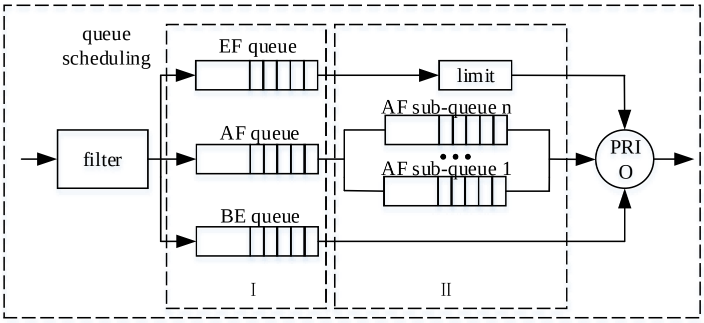

FIGURE 2. The process of two-level scheduling

Therefore, traffic scheduling in the power communication network based on SDN is as follows:

1. Power service matches the flow table firstly. If it gets a rule, the power service is mapped into a queue to wait for being outputting. Otherwise, switch sends a packet_in message to SDN controller to require a forwarding decision, which includes power service information (e.g., ToS).
2. SDN controller will identify service type when it receives the packet_in message; Then, it executes a series of operations, including selecting an optimal path and a queue, sending a flow table to switch, and outputting packet to a specific port.
3. Switch transfers all power service in queues according to the configured queue scheduling order.

2.3. DYNAMIC BANDWDITH ADJUSTMENT

Fixed queue bandwidth is likely to cause network congestion, resulting in power services loss. Dynamic adjusting bandwidth plays a vital role in resources share. The three factors that affect bandwidth allocation are queue length, power service importance, and QoS satisfaction. And can be collected by the SDN controller. Through these factors, this paper designs a bandwidth allocation machine, which realizes bandwidth adjustment periodic.

2.3.1. QUEUE LENGTH

Queue length is the sum of packets in a queue, which reflects queue congestion state. Generally, it is obtained by the input rate and the output rate. In the SDN network, network state statistics can be made use of computing the output rate. But the input rate cannot be gained. There are two reasons:1) packet that has matched a flow table may be dropped because of queue congestion, resulting in inconsistent between flow table statistics and actual queue length; 2) the timestamps of statistics gathered may in consistent. Therefore, based on the method proposed in [13], this paper computes the queue length by Equation 1.

$$L=\int_{0}^{1}(\text{v\_in-v\_out})dt \qquad (1)$$

where v_in and v_out represent the input rate and output rate, and L is the queue length. L is hard to evaluate the real queue congestion, because burst power service might cause short congestion. Thus, this paper utilizes the moving-average method to smooth queue length, as shown in Equation 2.

$$L_{\mathrm{avg}} = (1 - \omega_L) L_{\mathrm{pre}} + \omega_L L \tag{2}$$

where L_{avg} is the average queue length, L_{pre} is the previous queue length, and ω_L is a regulator of queue length.

2.3.2. POWER SERVICE IMPORTANCE

Power service importance reveals the influence on the power system when services is interrupted or defective, which can be marked by symbol *I*. In general, the higher the power service importance, the greater impact on the grid. Power service importance has a critical effect on bandwidth allocation. Up to now, power service importance has been widely studied [14]. It is not the focus of this paper to estimate more accurate power service importance. Therefore, this study cites the power service importance of AF type in [15], as shown in Table 3.

TABLE 3.
The importance of AF power business *(I)*

Power business	*I*
security and stability control system	0.91
wide-area vector measurement	0.86
dispatching automation	0.72
dispatching telephone	0.57
electric energy remote-metering	0.53
video conference	0.38
substation video monitoring	0.34
protection information management	0.29
lightning location detection	0.29
administrative telephone	0.19

2.3.3. QoS SATISFACTION

The QoS requirements of AF services are significant difference. For example, the latency of dispatching telephone service is less than 150ms, and the error rate is not more than 10^{-3}. However, the latency in the lightning location detection service is less than 250ms, which increases 100ms. And, the error rate is not more than 10^{-5}, which reduces by100 times. If QoS provision only ensures a single requirement (e.g., bandwidth, delay), power service may be interrupted during the transmission process. Therefore, this paper presents the concept of QoS satisfaction, which describes the satisfaction degree of SDN network to multiple QoS indicators. QoS satisfaction can be made available as Equation 3.

$$S_i = \frac{B_i}{b_i} + \frac{t_i}{T_i} + \frac{p_i}{P_i} \tag{3}$$

where i is a AF service; S_i is the QoS satisfaction; B_i represents the QoS demand in bandwidth, T_i is in latency, and P_i is in packet loss rate; b_i is the actual bandwidth, t_i is latency, p_i is packet loss rate.

2.3.4. BANDWIDTH ALLOCATION

Bandwidth weight is assigned by the queue length, power service importance, and QoS satisfaction, which can be made by Equation 4.

$$w_{j,k,i} = \frac{S_i}{\sum_{i=1}^{N} S_i} + \frac{L_{\text{avg}_{j,k,i}}}{\sum_{i=1}^{N} L_{\text{avg}_{j,k,i}}} + \frac{I_i}{\sum_{i=1}^{N} I_i} \tag{4}$$

where j is the number of SDN switch, and k is the number of port; $w_{j,k,i}$ respects the bandwidth weight; N is the total number of AF service; $L_{\text{avg}_{j,k,i}}$ is average queue length; I_i is the power service importance.

Therefore, queue bandwidth of AF service can be made available as Equation 5.

$$\text{bw}_{j,k,i} = \frac{w_{j,k,i}}{\sum_{i=1}^{N} w_{j,k,i}} \text{Bw}_{j,k} \tag{5}$$

where $\text{bw}_{j,k,i}$ respects queue bandwidth, and $\text{Bw}_{j,k}$ is the port bandwidth.

2.4. SDNTS ALGORITHM STEMS

The steps of SDNTS algorithm is shown in Figure 3. Steps 1 to 8 allocate bandwidth of AF service. Step 9 encapsulates the two-level scheduling through TC command. Steps 10 to 12 send queue configuration information to the data plane. And steps 13 to 17 shows the output process of power service in a switch.

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Input: power service importance, the requirements of AF service in bandwidth, delay,
       packet loss rate

Output: the output order of power service

/*****apply plane*****/

Step 1: gets network topology and state information through Restful API

Step 2: calculates $L_{\text{avg}_{j,k,i}}$ based on Equation 1 and Equation 2

Step 3: gets $b_i$ and $p_i$ by iperf tool

Step 4: gets $t_i$ by ping tool

Step 5: calculates $S_i$ according to Equation 3

Step 6: calculates $w_{j,k,i}$ based on Equation 4

Step 7: gets $\mathrm{Bw}_{\mathrm{j,k}}$ through network state information

Step 8: computes $\mathrm{bw}_{j,k,i}$ of AF service by Equation 5

Step 9: configures priority and bandwidth by TC command

Step 10: sends configuration information to SDN controller through Restful API

/*****control plane*****/

Step 11: receives and parses configuration information, and sends it to switch by OF protocol

/*****data plane*****/

Step 12: receives and installs queue configuration information

/*****scheduling*****/

Step 13: whether EF queue is empty or the token of EF queue is zero. If yes, go to Step 15,
         otherwise, go to Step 14

Step 14: outputs a packet from EF queue, and go to Step 13

Step 15: whether AF sub-queues are empty. If yes, go to Step 17; otherwise, go to Step 16

Step 16: outputs a packet from AF sub-queues, and go to Step 13.

Step 17: outputs a packet from BE queue, and go to Step 13
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FIGURE 3. SDNTS algorithm steps

3. RESULTS AND DISCUSSION

For evaluating the performance of SDNTS algorithm, a simulation topology is built in Mininet, shown as Figure 4. The topology uses Ryu controller and OVS switch to realize SDN network. At the same time, all link bandwidth is set to 100Mbps. Host1sends different flow to host2, including EF type (flow1), AF type (flow2, flow21, flow22), and BE type (flow3). In order to verify the bandwidth adjustment of AF service, this paper sets the bandwidth requirement of flow21 and flow22, shown in Table 4. Then, other parameters setting is shown in Table 5. Besides, the max-min fair sharing bandwidth allocation (MFSBA) algorithm [16] is used to compare with SDNTS algorithm. MFSBA algorithm means that queue bandwidth weight is allocated according to service priority, and bandwidth is equally distributed by the same-priority service. Therefore, the weight of flows is assigned to 6:3:1.

TABLE 4.
The bandwidth allocation of AF flow

Time (s)	Bandwidth-flow21 (Mbps)	Bandwidth-flow22 (Mbps)
[0, 10]	20	30
[10, 20]	60	10
[20, 30]	10	60

TABLE 5.
The parameters setting of bandwidth adjustment

AF flow	T_i (ms)	P_i (%)	I_i
flow21	$\leq$100	0.10	0.72
flow22	$\leq$250	0.01	0.29

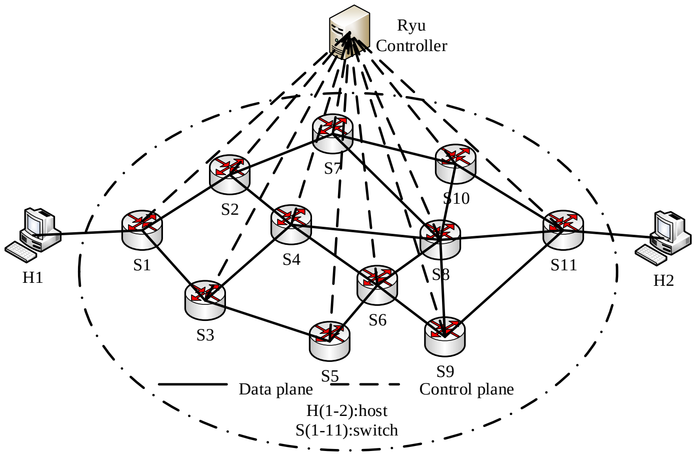

FIGURE 4. Simulation topology

Table 6 depicts the impact of packets increase on delay. It can be seen that the delay of flow1 reduces 51.22% when the amounts of packets is maximum, flow2 reduces 48.57%, but flow3 rises 41.22%. Under the SDNTS algorithm, no matter how many packets are sent by host1, flow1 always can preempt bandwidth to satisfy the delay requirement, even the delay of flow3 grows rapidly. Flow2 can get the minimum bandwidth guarantee in SDNTS algorithm. It means that the delay of flow2 would gradually increase when the network load is serious.

TABLE 6.
The impact of the increase of packets on delay

The amount of packet	Delay-flow1 (ms)		Delay-flow2 (ms)		Delay-flow3 (ms)	
	MFSBA	SDNTS	MFSBA	SDNTS	MFSBA	SDNTS
148811	0.39	0.21	0.28	0.42	0.84	1.26
297614	1.61	0.51	6.35	2.44	24.14	54.83
445844	4.54	1.63	16.30	7.81	97.93	147.48
591688	8.73	3.47	38.13	12.93	180.72	338.89
758376	13.29	5.94	50.86	23.57	274.53	408.94
891903	18.86	9.20	72.59	37.33	354.43	500.54

Figure 5 shows the delay sensitivity of different flow on the change of bandwidth. Compared to MFSBA algorithm, the delay of flow1 is always lower under the SDNTS algorithm. When the bandwidth requirement of flow1 increases, MFSBA algorithm would not adjust the bandwidth of flow2 to flow1 until the QoS of flow2 is meet. Because the MFSBA algorithm only provides bandwidth guarantee. In contrast, all resource would be allocated to flow1 in the SDNTS algorithm; because flow1 has the highest priority. The delay of flow1 does not increase with the change of bandwidth. But the delay of flow2 would increase dramatically because of lacking bandwidth

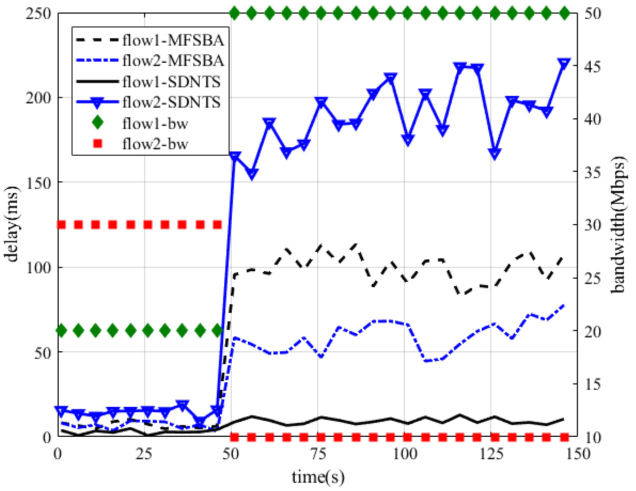

FIGURE 5. The sensitivity of delay on the changing of bandwidth

Figure 6 shows the result of bandwidth with the change of sending rate. The sending rate is defined as the number of packets sent per second, represented by the symbol v. All flows can get enough bandwidth when the sending rate is not too large. But bandwidth is competed by three flows as the sending rate increases, and only the flow1 is not affected. This is because that flow1 take precedence to be served in any condition, flow2 only get a minimum network guarantee, and flow3 release resources to the higher-priority flow.

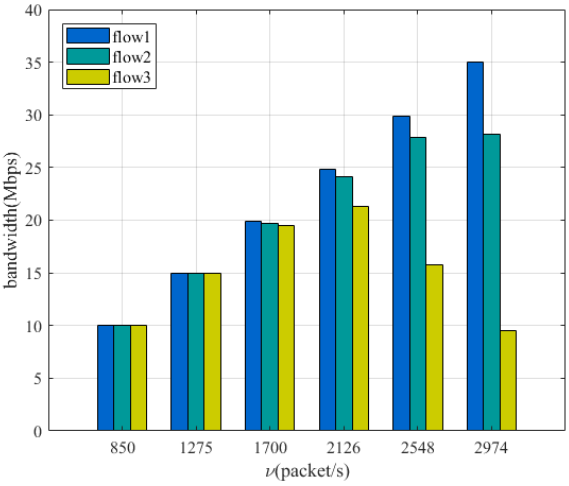

FIGURE 6. The bandwidth with the change of sending rate in the SDNTS algorithm

Table 7 depicts the result of packet loss rate with the changing of sending rate. It can be seen that the packet loss rate of all flows increases gradually. However, due to the priority-based scheduling in the SDNTS algorithm, the packets in EF queue would be outputted preferentially, and the packets in BE queue would be lastly. The rise speed of flow1 is the slowest, and flow3 is the highest.

TABLE 7.
The packet loss rate with the changing of sending rate in the SDNTS algorithm

v (packet/s)	Packet loss rate-flow1 (%)	Packet loss rate-flow2 (%)	Packet loss rate-flow3 (%)
850	0.082	0.54	0.56
1275	0.099	0.77	0.79
1700	0.57	1.58	2.41
2126	1.13	5.36	16.25
2548	2.47	13.51	47.18
2974	3.85	20.83	73.06

Table 8 shows the result of packet loss rate in the changing of bandwidth. Compared to MFSBA algorithm, the packet loss rate of flow21 and flow22 reduces obviously. Fixed bandwidth allocation is adopted by the MFSBA algorithm, which causes queue congestion leading to serious packet loss. Conversely, SDN controller detected queue state, and adjust the bandwidth of idle queue to congestion queue. Thus, the packet loss rate decreases a lot in the SDNTS algorithm.

TABLE 8.
The packet loss rate of AF service with the changing of bandwidth

Bandwidth (flow21, flow22)	Packet loss rate-flow21		Packet loss rate-flow22	
	MFSBA	SDNTS	MFSBA	SDNTS
(20, 30)	1.2	0.014	1.4	0.071
(60, 10)	11.95	6.0	1.42	0.017
(10, 60)	1.69	0.039	12.47	3.9

Figure 7 depicts the delay result of AF service with the change of bandwidth. It can be seen that the delay of flow21 is lower than flow22. In the process of adjustment, flow21 always has more bandwidth than flow22, because the delay sensitivity of flow21 is higher than flow22.

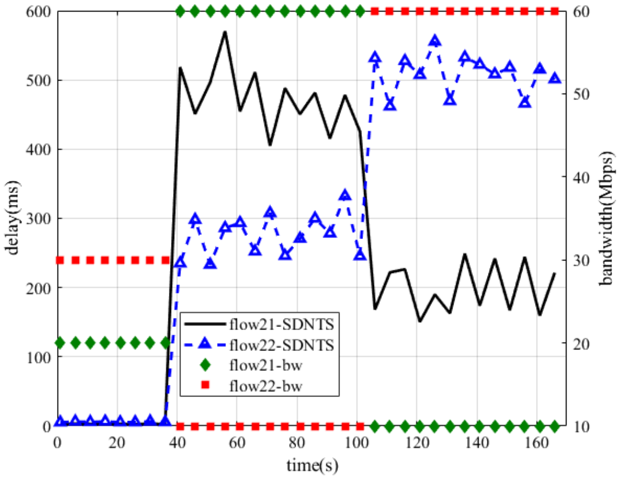

FIGURE 7. The result of delay in the changing of bandwidth

4. CONCLUSION

This paper proposes a traffic scheduling algorithm based on SDN centralized control architecture, which can support end-to-end QoS. First, the SDNTS algorithm make use of queue mechanism and programmable interface to implement two-level scheduling. The scheduling based on priority has achieved the delay requirement of power service. And the dynamic bandwidth adjustment has realized resource share through weight quantization. Then, by OF protocol and Restful API, SDNTS algorithm is applied to power communication network based on SDN. Finally, experiment results show that the algorithm proposed in this paper can decrease delay and packet loss rate of power service.

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