# Burst Traffic Awareness WRR Scheduling Algorithm in Wide Area Network for Smart Grid

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**Abstract.** Smart grid achieves optimal management of the entire power system operation by constant monitoring and rapid demand response (DR) for power supply-demand balance. Constantly monitoring the system state realized by Wide Area Measurement Systems (WAMS) provides a global view of the power grid. With a global view of the grid, Wide Area Control (WAC) generated DR command to improve the stability of power systems. When the regular monitoring data flow and the sudden DR data coexist, the suddenness of the demand response may result in delay or loss of the data packet due to uneven resource allocation when the network communication resources are limited, thereby affecting the accuracy of the power system state estimation. To solve this problem, this paper proposes a burst traffic perception weighted round robin algorithm (BTAWRR). The proposed algorithm defines the weight of the cyclic scheduling according to the periodicity of the monitoring data and the suddenness of the demand response. Then it adopts the iterative cyclic scheduling to adjust the transmission of data packets in time by adaptively sensing the changes of the traffic flow. The simulation results show that the proposed algorithm can effectively reduce the scheduling delay and packet loss rate when the two data coexist, and improve the throughput, which is beneficial to ensure the stability of the smart grid.

**Keywords:** Burst traffic · Scheduling algorithm · Weight · Monitoring data · Demand response

## 1 Introduction

Smart Grid achieves optimal management of the entire power system operation by collecting, integrating, analyzing, and mining data obtained by real-time monitoring of the key equipment in different parts of power grid such as generation,

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transmission, distribution, and power consumption [1]. With its rapid development, a huge number of monitoring data and DR data are transmitted and exchanged in order to ensure the stability and efficiency of its operation. Monitoring data comes from WAMS, which implements real-time high-rate acquisition of main monitoring data for grid operation by arranging GPS-based Phased Measurement Units (PMUs) at key measurement points in the power grid. DR data comes from the control commands which are used to change the power consumption of an electric customer to better match the demand for power with the supply. Monitoring data traffic is generally periodic. DR traffic is generally burst traffic. Two kinds of data traffic are required to transmit to the primary station system in power grid. Therefore, the efficiency, integrity and low latency of data transmission for two coexisting data traffic are an important guarantee for the stability of power grid [2,3].

There are many scholars who have studied data preprocessing of PMU in recent years. The focus of their study is to ensure the completeness and efficiency of power grid monitoring data transmission [4]. A new approach to the application of compressed sampling techniques in the field of power system synchronous phasor measurement is proposed in [5]. Multi-scale compression processing for PMU is proposed in [6]. There are also many scholars who have studied DR command data transmission. The focus of their study is to ensure the rapid and reliable response of the changes in state of power grid. A multicast tree construction method considering both load power and communication delay is introduced, which is called multicast routing algorithm based on DR capability constraint in [7]. A DR energy management scheme for industrial facilities based on the state task network (STN) and mixed integer linear programming (MILP) is proposed in [8]. However, it is rarely noted that monitoring data and DR data usually coexist in the communication networks in power grid. The burst of DR leads to the sudden change of the traffic flow in smart grid. When the network bandwidth is limited, the sudden change of the traffic will cause the data packet transmission to be late, which leads to the loss of data and ultimately affects the stability of the system [9,10].

Aiming at the above problem, this paper proposes a kind of Burst Traffic Awareness Weighted Round Robin (BTAWRR) algorithm, which takes the periodicity of PMU data traffic and the burst traffic of DR command into account. The proposed algorithm adopts the iterative cyclic scheduling to adjust the transmission of data packets in time by adaptively sensing the changes of the traffic flow. The goal of the proposed algorithm is to reduce latency and packet loss due to sudden changes in traffic, and increase throughput. By analyzing the BTAWRR algorithm and WRR algorithm, the results show that the BTAWRR algorithm is superior to the WRR algorithm in terms of average delay, packet loss rate and throughput.

The rest of paper is organized as follows: Sect. 2 describes the WAMS structure. Section 3 introduces the algorithm we propose. Section 4 gives the results and analysis of the simulation and final conclusions are drawn in Sect. 5.

## 2 WAMS Structure

Smart grid could provide wider view of the grid through WAMS. The WAMS structure is shown in Fig. 1. The basic components of WAMs are PMUs, Phasor Data Concentrator (PDCs), and the associated wide area network (WAN) [11,12]. PMUs can measure high resolution measurements of voltage, phase angle, frequency and current phasors from different parts of the power grid and export these measurements to a PDC [13]. The global positioning system (GPS) is used to synchronize the phasor measurements to a common time base. The most important function of a PDC is to collect the phasor measurements from a set of PMUs and align the measurements according to their GPS time stamp. The main stations collects measurements from different PDC pools, time-aligns them, and sends them to the control center for state estimation, dynamic monitoring, and transient stability analysis of the power system. The power demand response is that when the power consumption of an electric customer doesn't match the demand for power with the supply, the control centers need to send DR commands to the supply side and customer side in order to make them match. Therefore, PMU monitoring data and DR commands coexist in WAN. If their transmission in WAN was to experience abnormal delays or packet losses, some measurements or DR commands can be lost. Such cases will affect the stability of the entire power grid.

As can be seen from Fig. 1, multiple PDCs transmit the aggregated PMU data to the primary station through the WAN. There is a need to exchange PMU data and DR data between the primary stations. In the future, with the continuous development of smart grids and the constant changes in demand, DR commands from WAC may produce burst traffic flow. If the traffic flow in power grid suddenly increases, the insufficient allocation of network communication resources will cause an increase in delay and a large amount of packet loss. If the traffic flow in the power grid suddenly decreases, excessive allocation of network communication resources will result in waste of resources, while other PMUs will have lower throughput due to insufficient resource allocation. The lack of PMU measurement value will lead to the accuracy of the main station's estimation of the power system state, which is not conducive to the related protection, detection and control of the power grid, thus affecting the stability of the power grid.

In order to solve the above problem, a scheduling algorithm running on the primary station system are introduced in this paper. By adaptively sensing the burst traffic, the proposed algorithm can dynamically allocate network communication resources to the PMU in a balanced manner, which reduces the delay and packet loss rate of PMU data and DR data transmission.

## 3 BTAWRR Algorithm

Among many classic scheduling algorithms, the performance of WRR algorithm on scheduling real-time and packet loss rate is relatively good. The WRR algorithm assigns a weight to each queue and sets the associated weight counter.

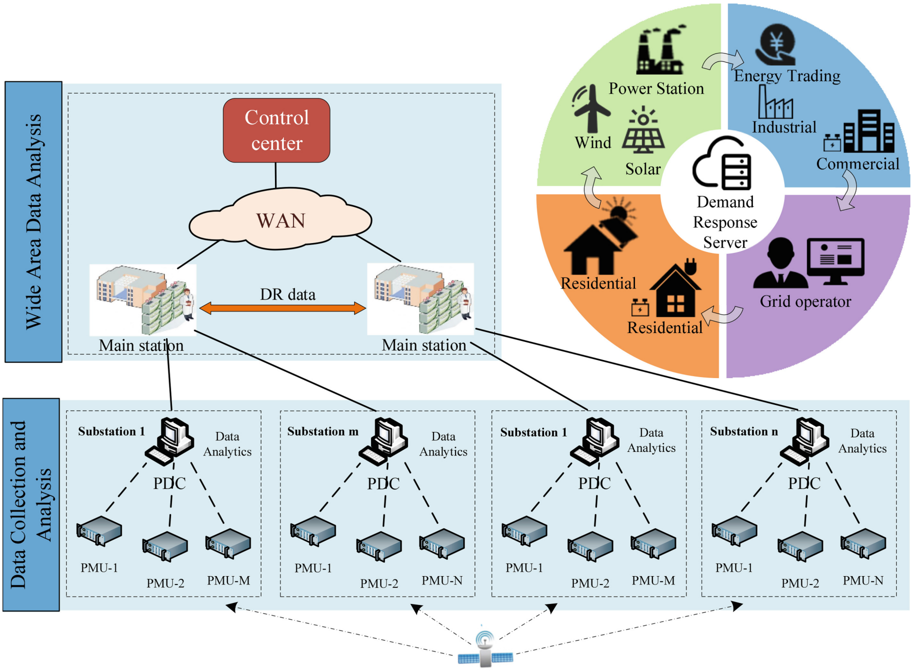


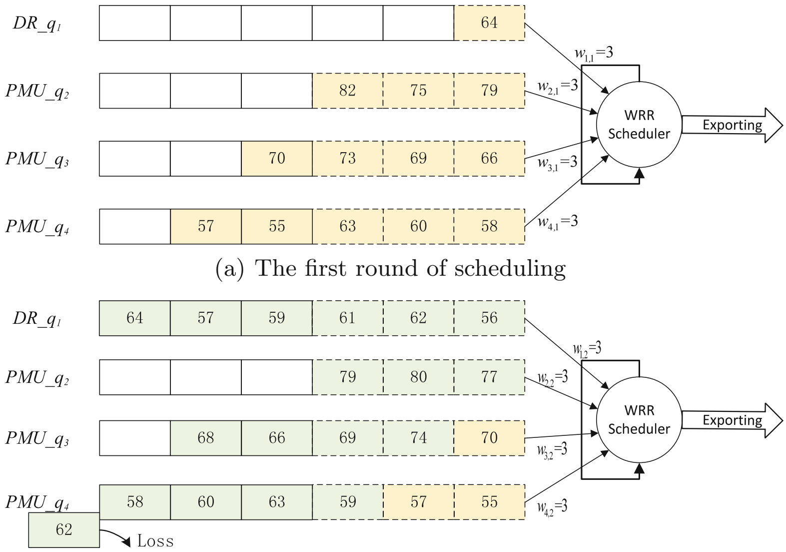

**Fig. 1.** WAMS structure.

Before scheduling, the weight is assigned to corresponding counters, which specify the number of packets transmitted in the corresponding queue in one round. If a queue sends a packet, the queue weight counter is decremented by one. Continue to send packets until the counter reaches zero or the queue is empty. Finally, all queue counters are reset to their weight values.

When WRR is introduced in the WAMS to allocate network communication resources in a reasonable and balanced manner, there are three characteristics of WAMS that need to be considered: (1) PMU sampling frequency; (2) PMU data packet size; (3) The variance of the normal distribution DR_traffic.

### 3.1 Weighted Design

Figure 2 shows two rounds of scheduling of three PMU queues (named $PMU\_q_2$, $PMU\_q_3$ and $PMU\_q_4$) and one DR queue (named $DR\_q_1$) where the weight of each queue is 3. Figure 2(a) indicates the first round of scheduling, and Fig. 2(b) indicates the second round of scheduling. The dotted box indicates the packets that are scheduled to be sent out of the queue, and the solid line box indicates the remaining packets in the queue. Figure 2(a) shows the situation after the queue has passed the first round of scheduling. It can be seen from the picture that there are fewer data packets in $q_1$, and the allocated resources are not used up. At this time, there are 1, 2 packets of $q_3$ and $q_4$, respectively, which are not transmitted. Figure 2(b) shows the results of the queue after the second round of scheduling, we can see that $q_1$ suddenly increased, at this time due to insufficient allocation of resources, there are still 3 packets stranded, and $q_4$ has a packet loss in the second round due to more stranded packets in the first round. As the DR queue service flow changes continuously, more resources are wasted and packets are lost if the weight in WRR is not changed.




(a) The first round of scheduling

(b) The second round of scheduling

**Fig. 2.** Example of WRR algorithm.

In order to solve the above problem, it is necessary to redefine the weight in combination with the sampling frequency and the packet size of the PMU data, and the variance of the normal distribution DR traffic. There are two main steps in this weight calculation:

1. Multiple queue traffic flows are normalized
   The mean square error of the current plurality of queue traffic flows is determined according to the current round of queue traffic flow size. This step can decide the traffic flow dispersion of all the queues. Assume that at round $k$, the traffic of queue $i$ is $traffic_{i,k}$, where $1 \leq i \leq n$ with $n$ queue. $\langle traffic_k \rangle$ is the mean from round $k$,

$$\langle traffic_k \rangle = \frac{1}{n} \sum_{i=1}^{n} traffic_{i,k} \tag{1}$$

the standard deviation at round $k$ ($\beta_k$) are determined as:

$$\beta_k = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(traffic_{i,k} - \langle traffic_k \rangle\right)^2} \tag{2}$$

2. Determine the new weight $w_{i,k}$
   It can be seen from the first step that the larger the $\beta_k$ value is, the larger the current queue traffic flow difference is, and the scheduling weight of multiple traffic flows should be adjusted accordingly. In this case, the bandwidth division module needs to be reduced, and the resource allocation is more balanced; the smaller the $\beta_k$ value is, the smaller the difference between the current queue traffic flows is, the traffic is more balanced, and the scheduling weight of multiple traffic flows should be close. However, when $\beta_k$ is less than 1, it is necessary to add 1 to avoid large quantization errors [17]. Therefore, the weight adjustment factor $\omega_{i,k}$ can be defined as:

$$\omega_{i,k} = \left\lceil \frac{traffic_{i,k}}{\beta_k + 1} \right\rceil \tag{3}$$

   The current weight of queue $i$ in round $k$ ($w_{i,k}$) is given by:

$$w_{i,k} = \omega_{i,k} W_i \tag{4}$$

### 3.2 BTAWRR Algorithm

Based on the above weight design, the BTAWRR algorithm is proposed in Fig. 3. When establishing the WAM model, the number of queues $n$ is defined, which corresponds with the number of PMUs and DR controls flows. The length of all the queues (the maximum number of packets in the queue) is assumed as the same, and is defined $l$. The number of packets of queue $i$ in the $k^{th}$ round scheduling is $q_{i,k}$. The weight of $q_{i,k}$ is $w_{i,k}$, and its weight counter is $WC_{i,k}$, which specifies the number of packets transmitted in queue $i$ of the $k^{th}$ round scheduling. For the convenience of performance observation, the maximum number of scheduling rounds is assumed as $k_{max}$.

Once the queues get scheduled in each scheduling round, the proposed algorithm first computes the weight for each queue using Eq. 4 according to the current flow traffic and sets weight counter for each queue. If a queue sends a data packet, the queue weight counter is decremented by 1. The algorithm continues to send packets until the weight counter reaches zero or the queue is empty. Then the next queue gets scheduled and repeats the above process until all the queues are scheduled in current round.

Due to the iterative calculation of Eq. 4, the proposed algorithm can calculate the weight as the DR traffic changes. Therefore, BTAWRR algorithm can adaptively perceive the DR traffic change, and adjust the weight in the each scheduling round according to the traffic flow in the current queue in time.

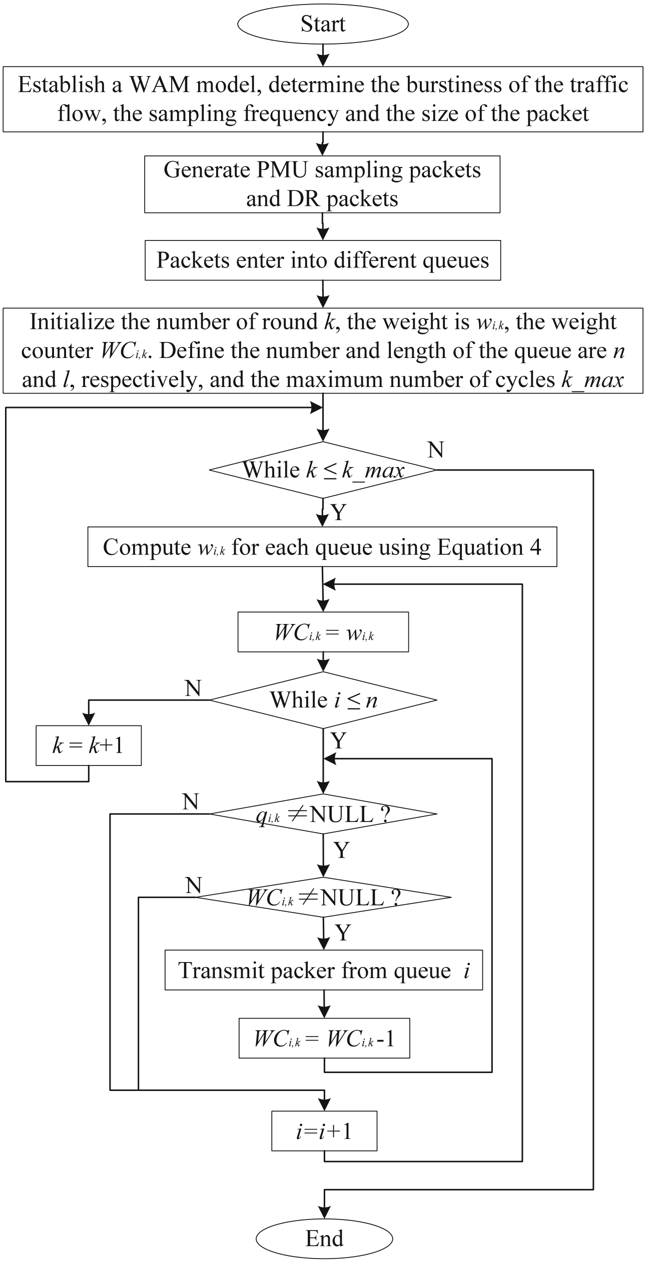



**Fig. 3.** The flow chart of BTAWRR algorithm.

By running the BTAWRR scheduling algorithm at the primary station of Fig. 1, it is possible to reduce the queuing delay of the data packets.

Applying the BTAWRR algorithm to Fig. 2 for scheduling, it can be calculated that the traffic flow of each queue in Figure (a) is 64, 236, 278, and 293, respectively. According to Eq. 4, the current round of each queue can be obtained. The weights that follow are 3, 9, 12, and 12, so no packets are stuck in the first round. Because the queue is empty after the first scheduling round, the second scheduling round of packets can enter the queue without packet loss. The transmission efficiency is significantly improved.

# 4 Simulation Results

In this section, we analyze the impact of the BTAWRR algorithm on the efficiency, integrity and timeliness of data transmission in smart grid through simulations.

## 4.1 Simulation Model

The transmission scheduling model on main stations are developed and simulated on MATLAB. The performance of BTAWRR algorithm and WRR algorithm are compared in terms of delay relative reduction rate, packet loss rate and relative increase rate of throughput. We assume that DR traffic is normally distributed and the simulation parameters are shown in Table 1.

The variance of the DR traffic is a scalar that describes the degree of burst traffic flow. The smaller the variance value, the smaller the degree of burst traffic flow, which means that the distribution of DR traffic data is relatively concentrated. The larger the variance value, the greater the degree of burst traffic flow, which means that the distribution of DR traffic data is relatively discrete.

**Table 1.** Simulation parameter

| Parameter | Value |
|---|---|
| Number of queues | 1 DR, 99 PMU |
| Length of the queue | 200 |
| Sampling frequency | 50 150 times/round |
| Packet size | 60 80 byte |
| The mean of DR_traffic | 100 |
| The variance of DR_traffic | 2/4/6/8/10/12/14/16/18/20 |
| Maximum number of rounds | 100 |

### 4.2 Simulation Result Analysis

Figure 4 shows the delay reduction rate of the BTAWRR algorithm relative to the WRR algorithm. The scheduling delay of the BTAWRR algorithm is reduced by about 95% compared to the WRR algorithm. In the case of the same DR traffic burst, the weight of the BTAWRR is determined by the current queue service flow, so the network communication resources can be more effectively utilized, which results in timely data packet transmission. Accordingly, the scheduling delay of the BTAWRR algorithm for the data packet is less than that of the WRR algorithm scheduling.

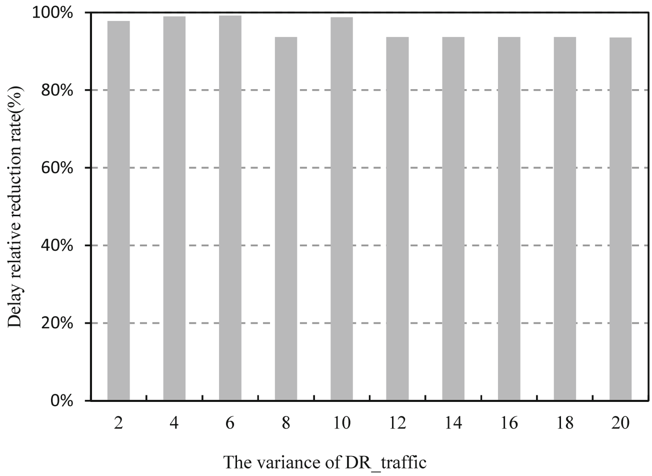



**Fig. 4.** Delay relative reduction rate.

Figure 5 shows a comparison of packet loss rates for the two scheduling algorithms. As the variance of DR traffic increases, the DR traffic flow changes a lot. The packet loss rate of the two algorithms does not change significantly, so the scheduling is stable for both two algorithm. However, the packet loss rate of the BTAWRR algorithm is lower than that of the WRR algorithm. Since the BTAWRR can adaptively sense the DR traffic changes and adjust the weight in each round, the BTAWRR algorithm schedules packets among the queues in a more balanced way and the possibility of queue overflow is also reduced.

Figure 6 shows the throughput increase rate of the BTAWRR algorithm relative to the WRR algorithm. The throughput of the BTAWRR scheduling algorithm is increased by about 230% compared to the throughput scheduled by the WRR algorithm. In the case of the same DR traffic burst, the total throughput of the BTAWRR algorithm is more than that of the WRR algorithm because the BTAWRR algorithm transmits more data packets than the WRR algorithm in each scheduling round.

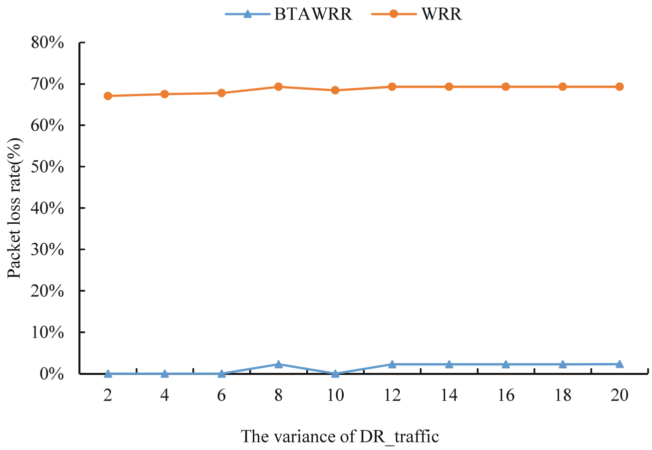



**Fig. 5.** Packet loss rate.

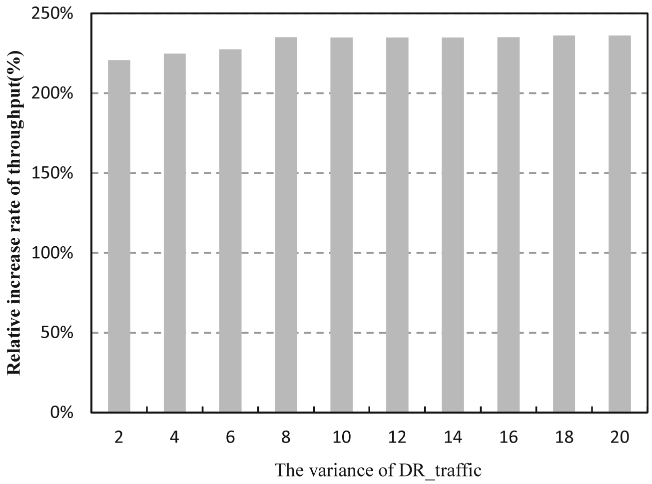



**Fig. 6.** Relative increase rate of throughput.

## 5 Conclusions

This paper proposes a kind of BTAWRR algorithm to solve the problem that network communication resources may be unevenly distributed when DR burst traffic occurs. The proposed algorithm used the periodicity of PMU data traffic as well as the burst traffic of demand response to define the weight of the cyclic scheduling, so that the scheduled data packets are efficiently transmitted. Due to the iterative calculation of weight, the algorithm can adaptively sense burst traffic changes and adjust packet transmission in time. The simulation results show that the proposed algorithm can increase the throughput of the data packet and reduce the scheduling delay and packet loss rate. The BTAWRR algorithm can be applied to the transmission of data packets for the main station in smart grid to ensure the efficiency, integrity and timely data transmission. It is conducive to the stability of the smart grid.

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