Name Weighted Round Robin (NWRR) Algorithm for Named Data Networking

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***Abstract*—Named Data Networking (NDN) is an emerging communication paradigm to resolve a traffic explosion problem due to repeated and duplicated delivery of large multimedia content. To make NDN being useful more widely, however, it should support various types of traffic and their Quality of Service (QoS) requirements. In this paper, we propose a queue scheduling algorithm named Name Weighted Round Robin (NWRR) that can work on top of the diffserv model in NDN. The proposed algorithm performs combined scheduling of Interest packets and Data packets and modifies the weight of each queue according to the average packet length of different queues. Results in ndnSIM simulator demonstrate that NWRR can provide different levels of service for different priority applications as well as can cope with the issue of lack of fairness caused by different average packet length in each queue.**

***Index Terms*—Named Data Networking, Quality of Service, DiffServ Model, Queue Scheduling Mechanism**

I. Introduction

With the explosive growth of application types and users on the Internet, its usage has shifted from traditional end-to-end communications to the acquisition of content. This transformation has accelerated the exploration of a content-centric next-generation network architecture. Named Data Networking (NDN) proposes to replace the IP address with content name for routing and delivery in the network, which has become the most concerned representative [1].

QoS mechanism is an important research topic of NDN. With the continuous increase in the types of Internet applications, the future network must be able to satisfy different requirements of different traffic classes such as voice traffic, multimedia streaming traffic, and web traffic [2] . As a new paradigm of future network, NDN should inevitably carry various traffic types if it is to be deployed successfully on a large scale in the future. Therefore, how to ensure the QoS of different traffic in NDN has become an important topic for Internet research.

In order to improve the service quality of NDN, a differentiated service (diffserv) model for NDN was proposed in [3]. Similar to the diffserv model in IP networks, the diffserv model in NDN still classifies and marks service classes through edge routers. The core routers provide corresponding services based on the service levels of the packets. At the same time, this model also supports the interest aggregation and content caching features of NDN. The diffserv model in NDN provides a new method for addressing the QoS issue of NDN.

Queue scheduling is a key technology in differv model [4]. However, at present, there is no queue scheduling mechanism that can be used in the diffserv model of NDN to provide scheduling services. This also restricts the development of QoS mechanism in NDN to some extent. Due to different characteristics of NDN and IP networks, however, the queue scheduling mechanism for IP networks cannot be directly applicable to NDN. In NDN, the interest packets and data packets belonging to the same service exist in the uplink and the downlink of two network nodes respectively, and they have a one-to-one correspondence [5]. However, there is no correspondence between Interest packets and Data packets that exist on a single link at the same time. Therefore, the queue scheduling mechanism of NDN needs to schedule the Interest packets in the uplink and the Data packets in the downlink simultaneously. This makes the queue scheduling mechanism in NDN complicated.

To address the issues, this paper proposes Name Weighted Round Robin (NWRR) algorithm based on the idea of Weighted Round Robin (WRR) algorithm in IP networks which can provide different levels of QoS guarantees for different priority services in NDN. NWRR algorithm performs combined scheduling of Interest packets and Data packets to simplify the NDN scheduling problem and modifies the weight of each queue according to the average packet length of different queues to eliminate the affect due to different packet length in each queue.

Organization of the paper is as follows: In section II we introduced the diffserv model in NDN. Section III introduced the proposed NWRR algorithm in NDN. Section IV provide performance evaluation. Finally, we conclude in Section V.

II. DiffServ model in NDN

In order to improve the service quality of NDN, scholar Yusung Kim et al. proposed a differentiated service (diffserv) model for NDN. There are several service levels in this model. When consumers need to retrive some content, an Interest packet which containing the contents name will be sent, and the edge router at the consumer side in the diffserv model will mark service level information on this Interest packet

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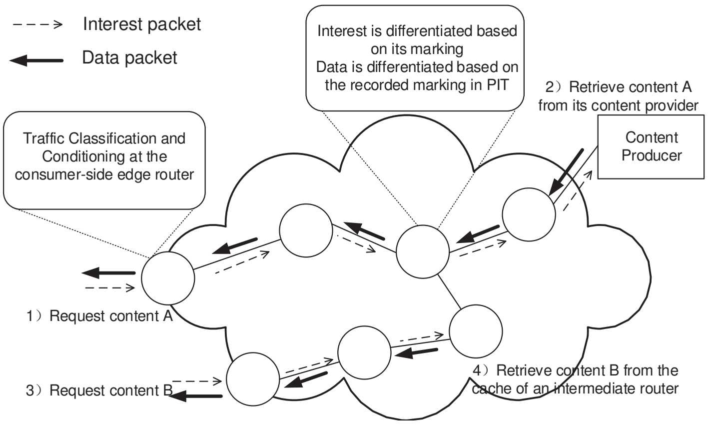


Fig. 1. Diagram of differentiated service model in NDN

according to a predetermined rule. Edge routers also control the marking rate to prevent too many Interest packets from entering the network and causing network congestion. When the core router in the diffserv model receives the Interest packet, it provides different forwarding services based on the service level carried in the Interest packet, and records the service level in the PIT table of the core router. When the Interest packet retrieves the corresponding Data packet by any node in the diffserv network, the Data packet will be forwarding back to the consumer along the reversed forwarding path of the Interest packet by tracking PIT table. The routers in the diffserv network will provide different classes of service according to the marking information recorded in the PIT table. The working principle of the diffserv model in NDN is shown in Figure 1.

The service level in the diffserv model is determined by the Service-level Agreement (SLA) between the content producer and the consumer or with the Internet Service provider. SLA specifies the service level supported by the model and the maximum amout of services allowed for each level. Edge routers in diffserv network perform classification, metering and rate shaping of Interest packets.

In NDN each Interest packet corresponds to only one Data packet. Therefore, the Data packet receiving rate can be indirectly controlled by controlling the sending rate of the Interest packet. However, the size of content chunk is unknown, so it is difficult to determine the number of Interest packets to mark. The size of the content chunk generated by different applications is different, even the size of the content chunk generated by the same application may be different. So its necessary to add a traffic conditioner to control the marking rate of the Interest packet by measuring the receiving rate of Data packet. The process at the receiver-side edge router is presented in Figure 2.

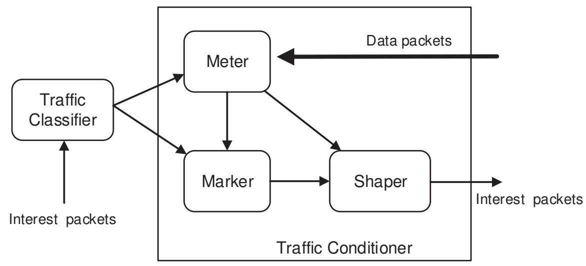


Fig. 2. Traffic classifying and conditioning at receiver-side edge networks

In the diffserv model, a collection with the same service level groupings (including Interest packages and Data packages) is called a Behavior Aggregates (BA). At the core routers of the network, each BA is associated with a Per Hop Behavior (PHB). In diffserv network, three kinds of service quality are defined: Best Effort (BE), Expedited Forwarding (EF) and Assured Forwarding (AF). The network node can map each data packet to the PHB according to the service level information carried in the Interest packets. The PHB then allocates forwarding resources (bandwidth and buffer) to each BA to provide resource guarantee and different levels of service. Since the PHB concept in this model is the same as the diffserv model in IP network, this model ensures the simplicity and scalability of the core network.

In diffserv model, service level information is marked on the header of Interest packets. Data packets do not contain any information related to service levels, which allows multiple users with different service levels to retrieve the same data. This mechanism can provide consumers with flexible and dynamic data pricing. For example, some users want to use AF-level services to download certain video files with higher bandwidth, and other users can use BE-level services to retrieve the files without spending. In addition, users can also request the same data using different service levels depending on network conditions. When the network is congested, some users need to lower their service levels to get some files, while other users can still maintain higher speed to retrieve the same files faster. Of course, Internet service providers should charge the latter higher fees.

III. Name Weighted Round Robin in NDN

A. Problem Description

In Section I, we explain why queue scheduling algorithms in IP networks cannot be directly used in NDN. The Interest packets and Data packets that exist on a single link have no correspondence makes the queue scheduling mechanism in NDN complicated.

To simplify this issue, we can rethink this issue from the perspective of the entire network. Firstly, NDN provides users with one service including two processes of transmitting an Interest packet and returning a Data packet, and each Data packet in the network will have an Interest packet corresponding thereto. From the perspective of the entire network, the process of sending an Interest packet and returning a Data packet by the network can be understood as providing one service to the user. Therefore, when performing queue scheduling, an Interest packet and a Data packet can be considered as a whole and they can be combined scheduled. In other words, what scheduled in the network is one service rather than one packet. Based on the above analysis, when queue scheduling is performed in NDN, the packets are still scheduled on the output link, and the number of Interest packets and the number of Data packets sent out in each scheduling are guaranteed to be the same. This is to ensure what scheduled in the network is a complete one service every time.When the network is in poor condition and packet loss is required, Interest packets are discarded preferentially to save network resources.

The diffserv model in NDN mark only the Interest packets when marking the service level. However, queue scheduling needs to schedule Interest packets and Data packets at the same time. Therefore, it is necessary to extend the diffserv network and increase the tag of Data packets. In this way, when providing the queue scheduling, the NDN first maps the traffic to the queue corresponding to its service level according to the classification result of the classifier and waits for the scheduling.

In the same queue, we need to distinguish between Interest packets and Data packets, and divide them into different service flows. In each queue, there are both Interest flows and Data flows. When the scheduling algorithm begins to schedule the services in the queue, an Interest packet and a Data packet are dispatched from the same queue at a time to ensure that each scheduling is a completeone service.

At present, the research on the queue scheduling mechanism in IP networks is relatively complete, and there are as many as tens of existing queue scheduling algorithms. The most common ones are: First In First Out (FIFO), Weighted Fair Queueing (WFQ), Priority Queueing (PQ), Weighted Round Robin (WRR), etc. Among them, because of its simple implementation method, easy-to-expand characteristics, and support for multiple-priority services, the WRR algorithm is to distinguish the best choice of queue scheduling algorithms in the diffserv network. Although the WRR algorithm can not be directly used in NDN, we can learn from its ideas, improve it, and propose a queue scheduling algorithm based on WRR, which suitable for NDN.

When the WRR algorithm schedules services of different priorities, the factors affecting the bandwidth allocation are not only the weights but also the average length of the data packets in each queue. However, the WRR algorithm does not take into account the important influence of the packet length, which results in poor fairness of the algorithm [6]. We need to consider this issue when designing the NDN queue scheduling algorithm.

B. Name Weighted Round Robin

The queue scheduling mechanism is a key technology for providing differentiated services for different levels of services in the network. The technology uses certain rules to schedule packets in different queues, and achieves different allocation of different packets in terms of transmission delay, network bandwidth and other resources. Different networks have different requirements for scheduling algorithms. In the diffserv model in NDN, the scheduling algorithm should be able to meet the following three requirements:

- Provide hierarchical services for different levels of applications in the network;
- Guarantee the relative fairness between all levels in the network, that is, ensure that high priority applications can get more network resources;
- Ensure the simplicity and extensibility of the algorithm.

In accordance with the above three requirements, we propose a queue scheduling algorithm named Name Weighted Round Robin (NWRR) that can provide differentiated services for NDN. NWRR algorithm retains the features of simple, efficient and easy to extend of WRR algorithm [7]. At the same time, to address the issue of poor fairness in WRR algorithm , a method that can dynamically change the queue weights according to the average packet length of the queues is proposed in NWRR, thus solving the problem of fairness caused by different packet length. In the case of insufficient network resources, it can preferentially provide more network bandwidth for high priority applications and ensure that high priority applications can obtain better service quality.

The NWRR algorithm consists of three modules. Based on the Weighted Round Robin (WRR) algorithm, an average packet length measurement module and a weight calculation module are added, as shown in Figure 3. The algorithm firstly obtains the average packet length of each queue through the average packet length measurement module (the average packet length is not distinguished from the Interest packet and the Data packet), and then the weight calculation module recalculates the weights according to the average packet length of each queue. Finally, the WRR scheduler schedules the queues according to the new weights.

Assuming that there are N queues in the router, the bandwidth of the output link is C, the initial weight of each queue is ω_i, the average packet length of the queue is l_i, and the revised weight is $\omega_i^{'}$. The revised weight formula is:

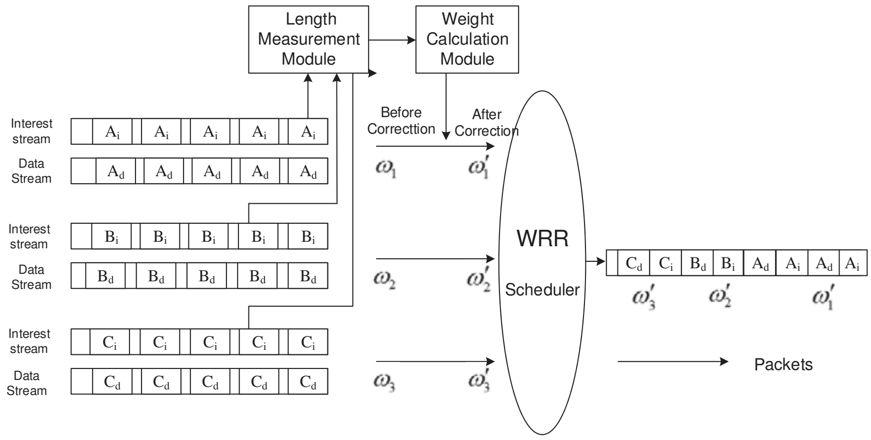


Fig. 3. Diagram of Name Weighted Round Robin

$$\omega_i^{'} = \frac{\omega_i}{l_i} \times \sum_{i=1}^{N} l_i \quad (1)$$

C. Theoretical Analysis

The NWRR algorithm uses the modified weights of equation (1) to perform round robin scheduling among various queues. This ensures that packets with different priorities receive differentiated service quality, and thus satisfies the first requirement of the scheduling algorithm. At the same time, the NWRR algorithm only increases the average packet length measurement module and the weight calculation module, retains the simple, efficient, and easy-to-expand characteristics of the WRR algorithm, satisfies the third requirement of the scheduling algorithm.

Next, analyze the relative fairness between all levels of services. First, without considering the packet length, according to the initial weight ω_i, the actual bandwidth B_i required by each queue in the network can be expressed as:

$$B_i = \frac{\omega_i}{\sum_{i=1}^{N} \omega_i} \times C \quad (2)$$

However, in actual network, different packet length result in a difference between the actual allocated bandwidth of each queue and the actually required bandwidth value of each queue. Now considering the difference in average packet length values for each queue, assume that the average length of queue$i$ is l_i, calculated according to the initial weigh ω_i, the actual allocated bandwidth $B_i^{'}$ for each queue is:

$$B_i^{'} = \frac{\omega_i \times l_i}{\sum_{i=1}^{N} \omega_i \times \sum_{i=1}^{N} l_i} \times C \quad (3)$$

When the average packet length in a queue with a high weight is small, there is a case where the actual allocated bandwidth of the low-priority queue is more than the bandwidth allocated by the high-priority queue. In order to eliminate the influence of different average packet length, we use Equation (1) to modify the weight of each queue according to the average packet length of each queue. Using the revised weights to recalculate the actual bandwidth $B_i^{''}$ allocated by each queue is:

$$B_i^{''} = \frac{\omega_i^{'} \times l_i}{\sum_{i=1}^{N} \omega_i^{'} \times \sum_{i=1}^{N} l_i} \times C = \frac{\omega_i}{\sum_{i=1}^{N} \omega_i} \times C = B_i \quad (4)$$

Therefore, it can be concluded that when using the modified weights to schedule the queues, it is possible to eliminate the impact caused by different average packet lengths of the queues and ensure that the actual bandwidth $B_i^{''}$ allocated by each queue is consistent with the actual bandwidth B_i required by each queue. It is also proved that the NWRR algorithm has relatively good fairness, can meet the requirements of differv networks, and provides effective queue scheduling for NDN.

IV. Implementation and Evaluation

To evaluate the NWRR algorithm proposed in this paper, we created a dumbbell topology as shown in figure 4. The S_0, S_1, and S_2 in the figure are consumers, and D_0, D_1, and D_2 are producers of data. E_1 and E_2 represent edge nodes in the diffserv network, C_1 and C_2 represent core nodes. The link bandwidth and link delay settings are shown in Figure 4. The link bandwidth and link delay settings are shown in Figure 4. So the link between C_1 and C_2 becomes the bottleneck link. In the simulation process, the content requested by S_0, S_1, and S_2 is set to exist at D_0, D_1, and D_2 in the network, and the service flow from S_0 to $D_0$is marked as the highest priority, and the EF service is provided for it. Mark the service flow from S_1 to D_1 as the second highest priority, and provide it with the AF service. Mark the traffic flow from S_2 to D_2 as the lowest priority, and the BE service is provided for it.

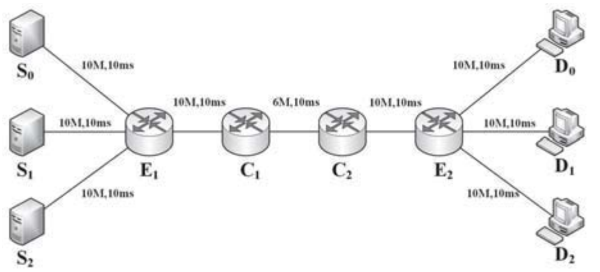


Fig. 4. Experimental Topology for NWRR Algorithm

We have implement our NWRR algorithm on ndnSIM which is a prototype of NDN in NS-3 [8]. We designed two experimental scenarios. In the first case, there is no surplus in the high-priority service bandwidth, and in the second case, there is a surplus in the high-priority service bandwidth. We compare the average throughput of core nodes when using the NWRR algorithm and the WRR algorithm in two scenarios respectively.

Detailed experimental parameters are set as follows: The size of the Interest packets sent by the consumers S_0, S_1, and S_2 is 20 bytes, and the size of the Data packets generated by D_0, D_1, and D_2 is 1 KB, 2 KB, and 3 KB, respectively. The interest packet sending rates of consumers S_0, S_1, and S_2 differ depending on the test scenario. The forwarding and caching strategies adopted by the nodes in the network are BestRoute and LRU respectively. The weights of the EF service flow, AF service flow, and BE service flow are set to 5, 4, and 3, respectively. The performance metric considered in this paper is the throughput of each service flow.

A. Scenario1: High-priority services without bandwidth surplus

In this case, the Interest packets of the consumers S_0, S_1, and S_2 are all at a rate of 3000 Kbps and following the ConsumerZipfMandelbrot distribution to request data from the producer. First, WRR algorithm is used to perform round-robin scheduling on the EF traffic, AF traffic, and BE traffic with weights of 5, 4, and 3, respectively. The throughput of each service flow is shown in Figure 5(a).

It can be seen from the figure that the throughput of the three service classes are 1.36 M, 2.18 M, and 2.45 M, respectively. This does not provide higher link bandwidth for high-priority services obviously, and it has not been able to divide link bandwidth by initial weight. The reason for this phenomenon is that the packet length of the three service flows are different. The ratio of the three queue packets average length is 1:2:3. When three levels of service packets are scheduled, the actual bandwidth allocation ratio of each queue becomes (51): (42): (33), that is, 5:8:9. Therefore, if the impact caused by different queue length is not eliminated, then high-priority queues cannt obtain sufficient bandwidth resource guarantees.

After using the NWRR algorithm, the throughput of each service flow is shown in Figure 5(b). The NWRR algorithm corrects the weight according to equation (1) and uses the revised weight to schedule the queue. The revised weights of each queue become 5(6/1), 4(6/2), 3(6/3), ie 30, 12, and 6. The actual bandwidth obtained by each service level is 2.5M, 2M, and 1.5M, respectively after using the revised weights. Therefore, the NWRR algorithm can not only ensure the relative fairness of all levels of services, but also can divide the bottleneck bandwidth according to the ratio of initial weights.

B. Scenario2: High-priority services have bandwidth surplus

In this case, the Interest packets of consumer S_0 are at a rate of 1000 Kbps, and the Interest packets of S_1 and S_2 are at a rate of 3000 Kbps, and following the ConsumerZipf-Mandelbrot distribution to request data from the producer. In this case, the EF flow will only occupy 1M of bandwidth resources. But 2.5M of network bandwidth will be allocated for this level of service, so there will be bandwidth surplus.The second highest priority service and lower priority service can divide the remaining bandwidth resources. First of all, we still uses WRR algorithm to perform round robin scheduling for the three levels of service flow with weights of 5, 4, and 3, respectively. The throughput of each service flow is shown in Figure 6(a).

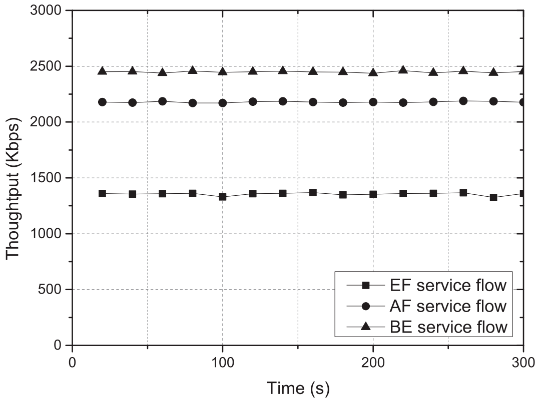
From figure 6(a), it can be seen that EF-class service packets occupy 1M bandwidth resources, but the BE-class service throughput is already higher than the AF-class service throughput, so this method has lost relative fairness.

After using the NWRR algorithm, the throughput of each service flow is shown in Figure 6(b). From the figure, it can be seen that the EF class service still occupies 1M network bandwidth, and the AF class service and the BE class service classify the remaining network bandwidth according to the weights.

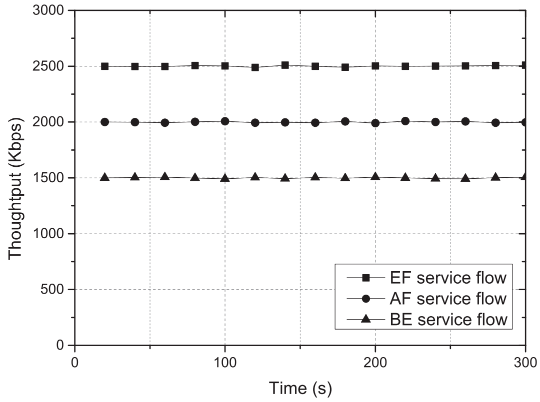
It can be concluded that the NWRR algorithm can divide the bottleneck bandwidth according to the initial weight no matter if the high-priority service bandwidth has surplus or not. The algorithm can effectively provide a hierarchical QoS guarantee for NDN, and has a great relative fairness.

V. Conclusion

This paper focuses on how to provide hierarchical QoS guarantees for different priority services in NDN networks and proposes a queue scheduling algorithm named NWRR algorithm for NDN. First of all, we analyze the key technical issues to be overcome in the queue scheduling in NDN, and propose to ”combined scheduling” the Interest packets and Data packets in the network to address this issue. Then, based on the WRR algorithm, an improved scheduling algorithm for NDN is proposed, that is NWRR algorithm, which can eliminate the lack of relative fairness due to the difference in the average packet length of each queue. Finally, we evaluate the NWRR algorithm by experiments. The results show that NWRR algorithm can effectively provide different QoS for different levels of services in NDN, and also can allocate network resources according to the initial weights set by the network administrator.

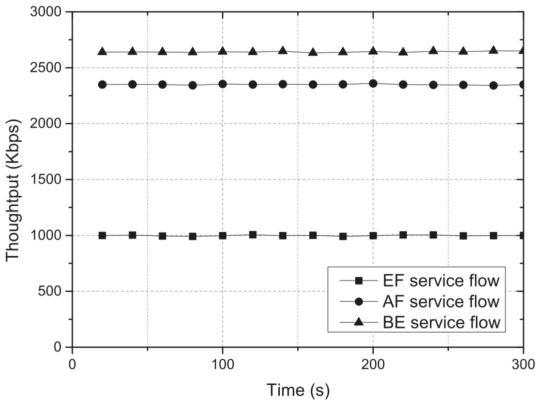


(a) The throughput of core nodes when using WRR

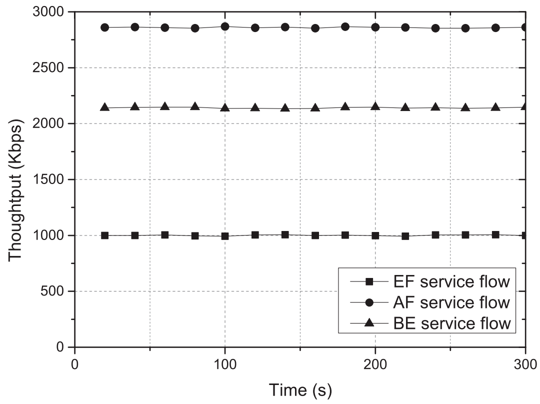


(b) The throughput of core nodes when using NWRR

Fig. 5. The throughput of core nodes when no surplus of high-priority service bandwidth



(a) The throughput of core nodes when using WRR



(b) The throughput of core nodes when using NWRR

Fig. 6. The throughput of core nodes when there is surplus of high-priority service bandwidth

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