Weighted Fair RIO (WF-RIO) for Fair AF Bandwidth Allocation in a DiffServ-Capable MPLS Network

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Abstract. RIO is the primary active queue management technology for handling AF(assured forwarding) class traffic for services that have minimum bandwidth guarantees. However, RIO unfairly allocates the excess AF bandwidth among LSPs(label-switched paths) which have TCP flows aggregated as AF class in a DiffServ-Capable MPLS Network. This issue obstructs the business model in which ISPs promote LSP users to expand the LSP-required bandwidth for enriching the quality of AF traffic. In this paper, we propose a way, called weighted fair RIO (WF-RIO), to resolve this issue. WF-RIO can allocate the excess AF bandwidth among LSPs in proportion to their AF minimum guaranteed bandwidth by multiplying the dropping probability of RIO by an LSP-specific weight which is simply calculated from the traffic rates for the individual LSPs. We evaluate the proposed method by computer simulation and demonstrate its effectiveness.

1 Introduction

1.1 MPLS supporting Diffserv

In recent years, the systemization of business processes through the use of computer communication technology is rapidly increasing the demands for VPN services that economically provide secure virtual lines connecting geographically dispersed offices to a private company network, using the public Internet as a backbone. MPLS is one of the major technologies employed by ISPs to offer these services. The MPLS protocol resides between the middle of the second layer and the third layer, and it inserts a shim header between these layers. The shim header has two fields, label and exp.

Labels are applied in MPLS to create virtual lines called LSPs (label-switched paths). The LSP required bandwidth is determined beforehand according to a contract between the LSP user and the ISP. An LSP is set up on an appropriate route that can accommodate the required bandwidth. Therefore, each link will likely operate in the over-provisioned case, meaning that the cumulative total demand bandwidth for the LSP is lower than the link speed on each link.

The exp field is utilized by MPLS to support Diffserv classes characterized by different per-hop-behaviors (PHBs) [1] . The exp value of each packet is mapped to a

PHB, which is implemented at each MPLS router. The Diffserv architecture defines three classes: EF (expedited forwarding), AF (assured forwarding), and BE (best effort). The EF PHB provides low packet loss, low latency, low jitter, and the maximum guaranteed bandwidth. The EF PHB is usually implemented by applying priority queuing in accordance with the order EF > AF > BE at the output queues of the routers. The EF inflow rate at the edge router must be lower than the EF maximum guaranteed bandwidth, which is determined by the contract and is in the range of the LSP required bandwidth.

The AF PHB provides a minimum bandwidth guarantee, as well as efficient utilization of excess bandwidth. The AF minimum guaranteed bandwidth of each LSP is the balance of the LSP required bandwidth that is not consumed by EF traffic. To use this excess bandwidth effectively, AF packets are allowed to inflow at a higher rate than the AF minimum guaranteed bandwidth, as long as they are labeled with a out-of-profile flag specifying a high drop preference at the edge router. An AF packet with the flag "$\mathrm{AF}_{\mathrm{out}}$ packet" may thus be discarded at the AF output queue of the core router, depending on the availability of resources. Most implementations of AF PHB use RIO (RED with IN/OUT) [2] . RIO is based on RED [3] , which drops packets with a certain probability according to the average queue length and avoids the synchronization of TCP flow control caused when many TCP packets overflow together from the buffer. Therefore, this paper assumes that TCP packets with an optional condition belong to the AF class of service.

1.2 Unfair AF bandwidth allocation in MPLS network supporting Diffserv

RIO employs two probabilities, as shown in Fig.1. One is the probability of dropping an in-profile AF packet ($\mathrm{AF}_{\mathrm{in}}$ packet), which increases from 0 to $\rho_{\mathrm{max\_in}}$ as the queue length varies from *min_in* to *max_in*. The second is the probability of dropping an out-of-profile packet ($\mathrm{AF}_{\mathrm{out}}$ packet), which increases from 0 to $\rho_{\mathrm{max\_out}}$ as the queue length varies from *min_out* to *max_out*. Accordingly, $\mathrm{AF}_{\mathrm{in}}$ packets have preference over $\mathrm{AF}_{\mathrm{out}}$ packets. In the over-provisioned case, in which the cumulative total of the AF minimum guaranteed bandwidth is lower than the link speed, service with the AF minimum bandwidth guarantee is facilitated by RIO discarding $\mathrm{AF}_{\mathrm{out}}$ packets preferentially at times of AF output queue congestion. It has been reported, however, that RIO has a problem in that the excess AF bandwidth is unfairly distributed among users competing for bandwidth at the AF output queue of the IP router, according to the following parameters: (1) the RTT (round trip time), (2) the number of TCP flows, (3) the target rate, which is the AF minimum guaranteed bandwidth, and (4) the packet size [4] .

Usually, an MPLS router has a separate PHB output queue to satisfy the QoS of each PHB [5] . Then the output queue of each class is shared with more than one LSP. As a result, as in the above-mentioned problem, the excess AF bandwidth will be unfairly distributed among the LSPs competing at the AF output queue.

This problem suggests that there is a possibility that the excess AF bandwidth allocated to some LSP with a small AF minimum guaranteed bandwidth is more than that of some LSP with a large AF minimum guaranteed bandwidth, that is, some LSP with a small AF minimum guaranteed bandwidth may have more total AF bandwidth than some LSP with a large AF minimum guaranteed bandwidth. This uncertain excess AF bandwidth allocation without consideration of AF minimum guaranteed bandwidth decreases the desire for each LSP user to contract more LSP-required bandwidth in order to enrich the quality of AF traffic with more AF minimum guaranteed bandwidth. Finally, the issue of the unfair excess AF bandwidth allocation obstructs the business model in which ISPs sell LSP-required bandwidth to LSP users to satisfy the above-mentioned desire.

In this paper, we thus consider a way to resolve the issue of the excess AF bandwidth being unfairly distributed among LSPs in the over-provisioned case. In other words, this paper presents a method of fair AF bandwidth allocation for aggregated AF class TCP flows on LSPs.

1.3 Related work

Several methods for improving the unfair AF bandwidth allocation produced by RIO and RED have been proposed [6, 7, 8, 9] . AFC [6] regulates customer traffic with aggregated TCP flows at the edge router in order to evenly share the excess AF bandwidth among competing customers. The edge router, however, must have a traffic conditioner function, along with a queue for each customer and feedback congestion information from the core router at the edge node. Other methods [7, 8, 9] are mainly intended to lessen the unfairness of bandwidth allocation among TCP flows. For example, RED-PD [7] detects high-bandwidth TCP flows and preferentially drops packets from them. ARIO [8] evenly shares the excess AF bandwidth among the TCP flows. SCALE-WFS [9] allows the flows to share the excess AF bandwidth in a fairly weighted distribution. These technologies, however, are not applicable to fair AF bandwidth allocation for aggregated TCP flows.

1.4 Proposal

In this paper, we propose a method, called weighted fair RIO (WF-RIO), that achieves the fair policy that all LSPs share the excess AF bandwidth in proportion to their AF minimum guaranteed bandwidth. WF-RIO enables a congested router to autonomously provide fair AF bandwidth allocation by applying different discard probabilities for each LSP. WF-RIO obtains the discard probabilities by multiplying the dropping probability of RIO by weights based on the AF bandwidth allocated to the aggregated AF-class TCP flows on each LSP. We show that an effective weight can be calculated from the traffic rates for each LSP and that this weight is independent of the LSP-specific parameters for the aggregated flows.

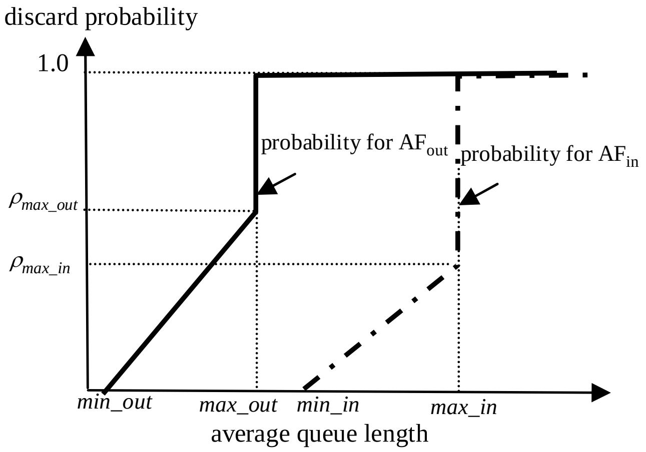


Fig. 1. Probablities of Discard Probabilities in RIO

2 Analytical models

In this section, we describe the analytical models we utilized in deriving and evaluating the weighting scheme of WF-RIO. It is well-known that given a random packet loss at a dropping probability P due to a congestion avoidance algorithm like RED or RIO, the average throughput *avr* of a TCP flow is defined in terms of the RTT, the MSS (maximum segment size) of the flow, and a constant value C which depends on the type of TCP as follows [10] :

$$avr = \frac{MSS}{RTT} \times \frac{C}{\sqrt{P}} . \tag{1}$$

We use the letter i (= 1, 2, …, n) to denote the LSP_i that share the AF output queue. For each LSP_i, we denote the AF-class TCP flow number by f_i, the AF_{in} traffic rate (in bits per second, or bps) by a_i, the AF_{out} traffic rate (bps) by b_i, the packet discard probability per AF-class TCP flow by $\rho^{tcp}{}_i$, and the discard probability of an AF_{out} packet by ρ. We can easily measure a_i and b_i at the router, based on the label and exp fields in the shim headers of each packet. We can then estimate $\rho^{tcp}{}_i$ as follows:

$$\rho_i^{tcp} = \frac{b_i / f_i}{(a_i + b_i) / f_i} \times \rho = \frac{b_i}{(a_i + b_i)} \times \rho . \tag{2}$$

For each LSP_i, we denote the RTT of an AF-class TCP flow by RTT_i, the MSS of the flow by MSS_i and the constant value C of the flow by C_i. Then we estimate avr_i, the average throughput per AF-class TCP flow on LSP_i, as follows:

$$avr_i = \frac{MSS_i}{RTT_i} \times \frac{C_i}{\sqrt{\rho_i^{tcp}}} \cdot \tag{3}$$

From this, we estimate $\boldsymbol{f_i}$ as

$$f_i = \frac{a_i + b_i}{avr_i} = \sqrt{(a_i + b_i) \times b_i \times \rho} \Big/ k_i , \tag{4}$$

$$k_i = \frac{MSS_i}{RTT_i} \times C_i \cdot \tag{4a}$$

Eq. (4) can also be derived from the analytical model that Baines et al. [11] developed for the allocation of bandwidth to aggregated TCP flows in the over-provisioned case.

3 Weighted Fair RIO

We propose a new active queue management technology, called weighted fair RIO (WF-RIO), which can realize a fair policy for allocation of AF bandwidth such that all LSPs sharing the congested AF queue have the same ratio of the allocated AF bandwidth to the AF minimum guaranteed bandwidth, that is, all LSPs share the excess AF bandwidth in proportion to their AF minimum guaranteed bandwidth. Therefore WF-RIO can stimulate the desire for LSP users to buy more LSP-required bandwidth in order to enrich the quality of AF traffic with more AF minimum guaranteed bandwidth, and promote the business model in which ISPs sell LSP-required bandwidth to LSP users to satisfy the above-mentioned desire.

The cause of the unfair AF bandwidth allocation problem lies in the fact that RIO applies the same $\mathrm{AF_{out}}$ packet discard probability, ρ, to each LSP. Thus, we propose a fair allocation method that autonomously applies a specific probability, ρ_i, to each $\mathrm{LSP_i}$ at each output interface of the MPLS router. The discard probability ρ_i is calculated by multiplying ρ by a weight w_i for each $\mathrm{LSP_i}$. The weights are determined according to the AF bandwidth allocation of each LSP, with an initial value of 1. Before describing this method in detail, we first illustrate its algorithm, with reference to Fig. 2:

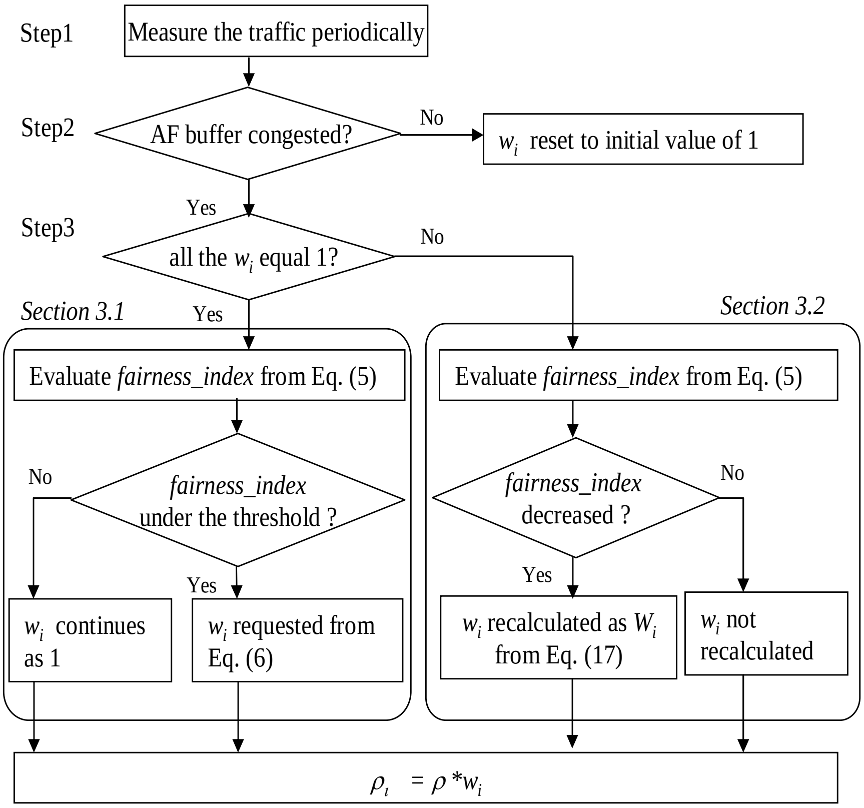


Fig. 2. Algorithm of Weighted Fair RIO

1. Each output interface manages the required bandwidth $\boldsymbol{c_i}$ of LSP$_\mathrm{i}$ and periodically measures and refreshes the traffic rates (e_i, a_i, b_i) for each service class (EF, AF$_\mathrm{in}$, AF$_\mathrm{out}$) according to the label and exp values in the shim headers of the packets switched at the interface.
2. If the average length of the AF output queue exceeds *min_out* and WF-RIO determines the discard probability ρ of an AF$_\mathrm{out}$ packet based on the average length in the same manner as RIO, the algorithm proceeds to the next step to calculate the weights w_i for each LSP$_\mathrm{i}$. Otherwise, the w_i are reset to 1.
3. Depending on the situation, one of two methods is used to calculate w_i. In the first case, w_i is requested for the first time after the AF bandwidth allocation is judged as unfair at the time of congestion. In the second case, w_i is recalculated after the AF bandwidth allocation is judged as even more unfair as the congestion continues. The situation can be determined from the current value of w_i. Specifically, the first case results when all the w_i equal 1, while the second case results when not all of the w_i are equal to 1. The calculation methods for these two situations are described in the next two subsections.

3.1 Calculating the first set of weights w_i

When WF-RIO detects that the average length of the AF output queue exceeds *min_out*, it determines the discard probability ρ of the $\mathrm{AF}_{\mathrm{out}}$ packet based on the average length in the same manner as RIO. Then, as all the weight w_i equals the initial value of 1—that is, as all the ρ_i equals ρ, WF-RIO applies ρ to the $\mathrm{AF}_{\mathrm{out}}$ packets of all LSPs. Later, each time the traffic rate is measured and refreshed; it evaluates the fairness of the AF bandwidth allocation according to a *fairness_index*, which is defined as

$$fairness\_index = \left(\sum r_i\right)^2 \Big/ \left(n \sum r_i^2\right), \tag{5}$$

$$r_i = af_i \big/ \left(c_i - e_i\right) = \left(a_i + b_i\right) \big/ \left(c_i - e_i\right). \tag{5a}$$

The *fairness_index* applies Jain's index [12] which quantifies the throughput fairness among flows with the dispersion degree of the ratio of the measured throughput to the fair throughput. As expressed in Eqs.(5) and (5a), the *fairness_index* evaluates the fairness of the AF bandwidth allocation among LSPs with the dispersion degree of the ratio r_i. This value r_i is the ratio of the AF measured throughput af_i, which is the $\mathrm{AF}_{\mathrm{in}}$ traffic rate a_i plus the $\mathrm{AF}_{\mathrm{out}}$ traffic rate b_i, to the AF minimum guaranteed bandwidth, which is the required bandwidth c_i minus the EF traffic rate e_i. If all LSPs sharing the congested AF queue have the same ratio r_i of the allocated AF bandwidth to the AF minimum guaranteed bandwidth, that is, all LSPs share the excess AF bandwidth in proportion to their AF minimum guaranteed bandwidth, the *fairness_index* gets the maximum value of 1. As the AF bandwidth allocation increasingly conforms to the fairness policy—that is, as the dispersion degree of the ratio r_i gets smaller—the *fairness_index* gets closer to its maximum value of 1. In the opposite case, the *fairness_index* approaches 0. If the *fairness_index* becomes smaller than a predefined threshold (i.e., the degree of conformance is insufficient), then the weight w_i for each $\mathrm{LSP}_{\mathrm{i}}$ is calculated by using Eq. (6):

$$w_i = r_i^2 \times \sum b_i \Big/ \sum \left(r_i^2 \times b_i\right). \tag{6}$$

This equation is derived from two conditions. First, after applying the ρ_i, all the expected ratios, r'_i, should be constant. Second, the number of $\mathrm{AF}_{\mathrm{out}}$ packets discarded by applying the ρ_i should be the same as the number that would be discarded by generically applying ρ.

After applying the discard probability ρ_i to the $\mathrm{AF}_{\mathrm{out}}$ packets of each $\mathrm{LSP}_{\mathrm{i}}$, the expected average throughput, avr'_i, of the AF-class TCP flow on $\mathrm{LSP}_{\mathrm{i}}$ can be predicted from the following equation, which is derived from Eqs. (2) and (3):

$$avr'_i = k_i \times \sqrt{\frac{\left(a_i + b_i\right)}{b_i \times \rho_i}} = k_i \times \sqrt{\frac{\left(a_i + b_i\right)}{b_i \times \rho \times w_i}}. \tag{7}$$

As it is reasonable to assume that applying the ρ_i doesn't affect the TCP flow number f_i given by Eq. (4), the expected AF bandwidth af'_i of LSP$_\mathrm{i}$ can be afterward expressed as follows:

$$af'_i = f_i \times avr'_i = af_i \big/ \sqrt{w_i}\ , \tag{8}$$

$$af_i = a_i + b_i\ . \tag{8a}$$

Similarly, as it is reasonable to assume that applying the ρ_i doesn't affect the AF$_\mathrm{in}$ traffic rate a_i or the EF traffic rate e_i, the expected traffic rates a'_i and e'_i can be expressed as follows:

$$a'_i = a_i\ , \tag{9}$$

$$e'_i = e_i\ . \tag{10}$$

The expected ratios r'_i should be equal to some constant g, as expressed from Eqs.(5a), (8), (8a), and(10) by

$$r'_i = \frac{af'_i}{(c_i - e'_i)} = \frac{(a_i + b_i)}{(c_i - e_i) \times \sqrt{w_i}} = \frac{r_i}{\sqrt{w_i}} = g\ . \tag{11}$$

Thus, the weight w_i can be expressed as follows:

$$w_i = (r_i / g)^2\ . \tag{12}$$

In addition, the second condition, that the number of AF$_\mathrm{out}$ packets discarded by applying ρ_i should be the same as the number discarded by applying ρ, leads to Eq. (13).

$$\left(\sum b_i\right) \times \rho = \sum (b_i \times \rho_i) = \sum (b_i \times \rho \times w_i)\cdot \tag{13}$$

From Eqs.(12) and (13), the square of the constant g can be derived as

$$g^2 = \sum \left(r_i^2 \times b_i\right) \Big/ \sum b_i\ . \tag{14}$$

Equation (6) can be derived from Eqs. (12) and (14). Consequently, as expressed in Eq. (6), we find that the weight w_i of each LSP$_\mathrm{i}$ can be calculated from the traffic rates (e_i, a_i, b_i) for each class (EF, AF$_\mathrm{in}$, AF$_\mathrm{out}$) and the LSP required bandwidth $\boldsymbol{c_i}$, without considering the values of f$_\mathrm{i}$, RTT$_\mathrm{i}$, and MSS$_\mathrm{i}$ for the aggregated AF-class flows.

3.2 Recalculating the weights w_i

In the case of continuing congestion after the w_i are first requested, the number of TCP flows or the AF minimum guaranteed bandwidth of each LSP may be changing, and thus, the w_i may need to be recalculated. To determine whether this is necessary, each time the traffic rate is measured periodically, the conformance of the AF bandwidth allocation to the fairness policy is evaluated according to the *fairness_index* from Eq. (5). If the *fairness_index* is lower than its most recently calculated value, i.e., if the conformance is judged to be decreasing, the w_i are recalculated to produce new values, W_i, in the following way. Otherwise, the existing w_i are retained.

The current traffic rate measured during a period of congestion may have been influenced by the values of the $\rho_{i.}$ On the other hand, the $\mathrm{AF}_{\mathrm{out}}$ traffic rate b_i and the ratio r_i used in Eq. (6) to calculate the w_i correspond to the case in which all the ρ_i equal ρ. Accordingly, to recalculate the w_i, it is necessary to infer b_i and r_i such that all ρ_i equal ρ by utilizing the current traffic rates (e'_i, a'_i, b'_i), the current ratio r'_i, and the w_i. Both b_i and r_i can be inferred from the relation between them and the current traffic rates(e'_i, a'_i, b'_i) ,which are influenced by ρ_i , expressed in Section3.1.

From Eqs.(8) and (9), the $\mathrm{AF}_{\mathrm{out}}$ traffic rate b_i can be derived as

$$b_i = af'_i \times \sqrt{w_i} - a'_i\,, \tag{15}$$

$$af'_i = a'_i + b'_i\,. \tag{15a}$$

Then, from Eq. (11), the ratio $\boldsymbol{r_i}$ can be derived as

$$r_i = r'_i \times \sqrt{w_i}\,. \tag{16}$$

Consequently, the w_i are recalculated as the following W_i based on the above equations:

$$W_i = r'^2_i \times w_i \times \frac{\sum \left(af'_i \times \sqrt{w_i} - a'_i\right)}{\sum \left\{r'^2_i \times w_i \times \left(af'_i \times \sqrt{w_i} - a'_i\right)\right\}}\,. \tag{17}$$

Note that if we assign w_i 1, Eq. (17) becomes the same as Eq. (6).

4 Evaluation Results

In this section, we evaluate the performance of WF-RIO by using the simulation tool, OPNET [13] . For the simulation experiment, we adopted the network model shown in Fig. 3. In this model, all links are 10-Mbps duplex. The link delay time between user_1 and ER_1 is fixed at 10 msec, that between user_2 and ER_2 is fixed at 40 msec, and that between user_3 and ER_3 is fixed at 80 msec. Three LSPs are thus established. The route of each $\mathrm{LSP}_{i(=1,2,3)}$ is from $\mathrm{ER}_{i(=1,2,3)}$ to ER_4 through the core router, so each has a different RTT. The MSS fields for $\mathrm{user}_{1,}$,user_2, and user_3 select segment lengths of 1500, 1024, and 512 bytes.

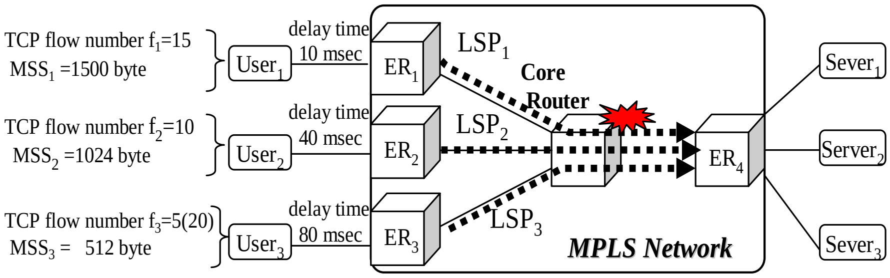


Fig. 3. Experimental network model

For the AF class of service, several TCP connections for file transfer from user$_i$ to server$_i$ are established through LSP$_i$. At the start of the simulation, the number of TCP connections triggered by user$_1$, user$_2$, and user$_3$ are 5,10, and 15, respectively. The TCP type of user1, user2, and user3 is TCP Reno, TCP Reno and TCP Sack. Then user$_3$ adds 15 TCP connections when the simulation time reaches 34–35 minutes. As the file size is too large for transfer to finish before the simulation ends, each TCP flow continues for the duration of the simulation. For the EF class, video frames are transferred by UDP from user$_i$ to server$_i$ through LSP$_i$ at 0.4 Mbps, which is assumed to be lower than the EF maximum guaranteed bandwidth of 0.5 Mbps. Each LSP is assumed to have a required bandwidth of 1 Mbps. Thus, 0.6 Mbps is available for AF guaranteed-minimum bandwidth traffic from each user. Therefore each LSP has the same bandwidth available for AF traffic in accordance with the fair policy. Congestion occurs at the AF output queue from the core router to ER$_4$. In this scenario, RIO is utilized until a time of 20 minutes; after which the WF-RIO method takes over. In executing WF-RIO, the interval of traffic rate measurement is fixed at 30 seconds and the threshold of the *fairness_index* is fixed at 1.

Figure 4 shows a time chart of the AF$_{out}$ bandwidth b_i allocated to each LSP$_i$. The chart illustrates that the values of b_i were balanced to become equivalent after WF-RIO was initiated. These values were then balanced again soon after b_3 became much larger than the others at the time LSP$_3$ initiated additional AF-class TCP flows.

Figure 5 shows a time chart of the *fairness_index*, while Figure 6 shows a time chart of the weights w_i. These charts illustrate that the *fairness_index* rose after WF-RIO became active, and that the weights w$_i$ differs largely mutually. Then these charts illustrate that all of the w_i changed as soon as the *fairness_index* declined as a consequence of LSP$_3$ initiating the additional flows.

The results show that subtle variation in the AF$_{out}$ bandwidth allocation caused the *fairness_index* to vary even when the number of TCP flows for all LSPs was unchanged. Moreover, we observe that the *fairness_index* increased after a decrease in it caused the w$_i$ to be recalculated. This suggests that WF-RIO attempts to improve the degree of fairness even if the fairness is reduced by a cause other than the number of TCP flows. For example, in the case when the AF minimum guaranteed bandwidth fluctuates due to variations in the EF traffic rate, WF-RIO will attempt to allocate the AF bandwidth to each LSP according to the fair policy.

Figure 7(a) shows a bar graph of the average throughput of each service class through each LSP before WF-RIO became active, while Fig. 7(b) shows a bar graph for the average throughput afterward. We observe from these graphs that WF-RIO eliminated the unfair AF bandwidth allocation due to RIO.

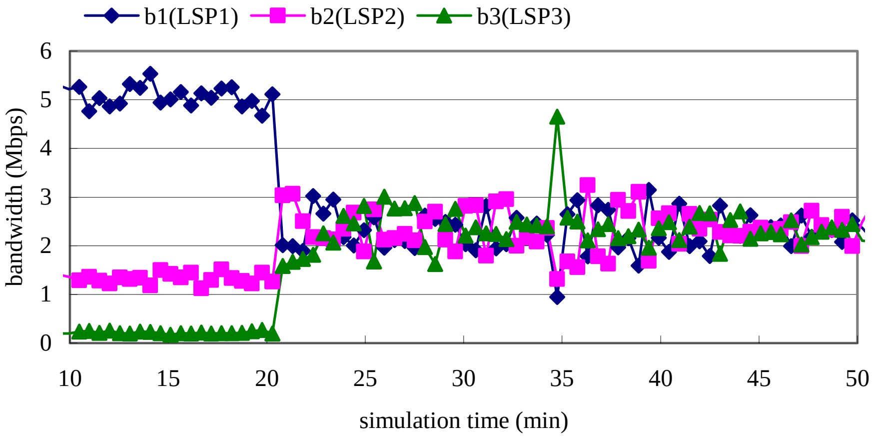


Fig. 4. Time chart of the AF_{out} bandwidth $b_{i(=1,2,3)}$ allocated to each $LSP_{i(=1,2,3)}$

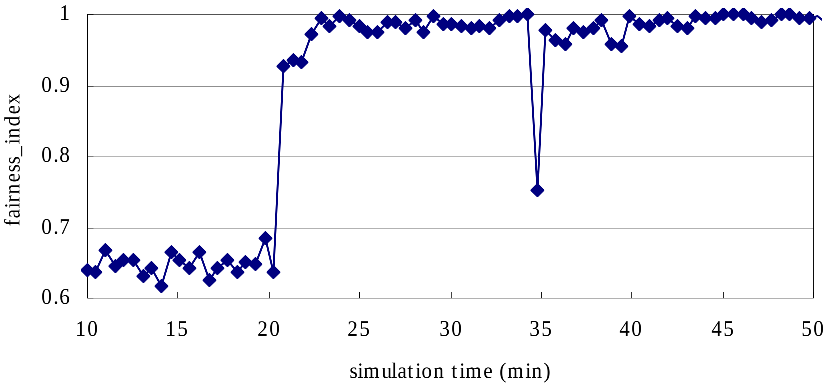


Fig. 5. Time chart of the fairness_index

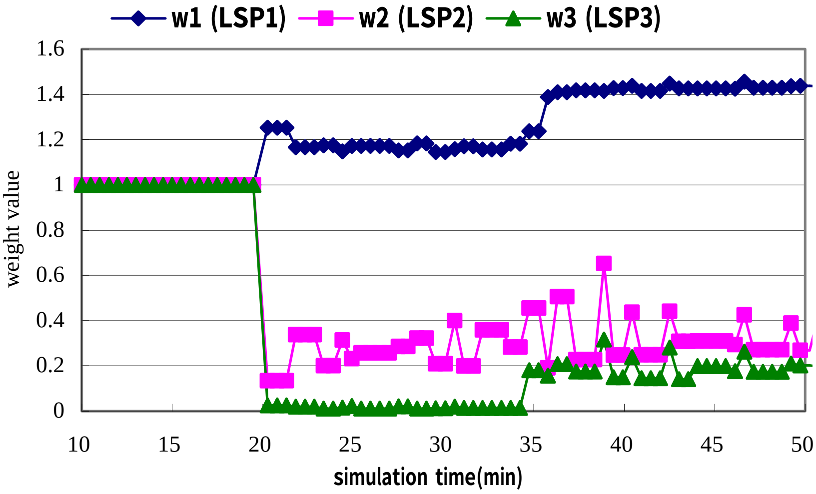
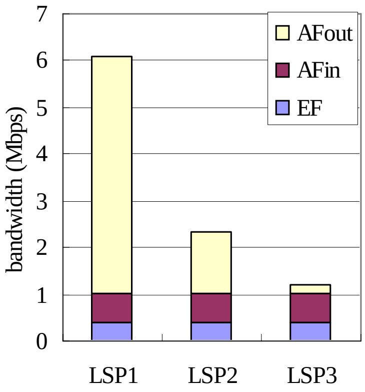


Fig. 6. Time chart of the weight $w_{i(=1,2,3)}$ of each LSP $_{i(=1,2,3)}$



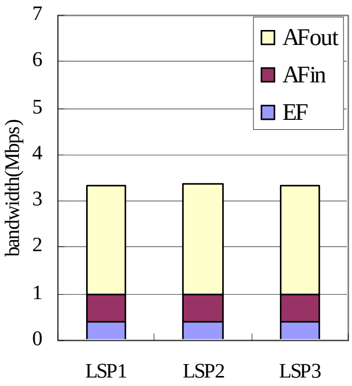


Fig. 7(a). Bandwidth allocated by RIO **Fig.7(b).** Bandwidth allocated by WF-RIO

5 Conclusion

In this paper we have presented WF-RIO, a new method of fairly allocating AF bandwidth among LSPs competing at a congested AF output queue. WF-RIO achieves the fair policy that all LSPs share the excess AF bandwidth in proportion to their AF minimum guaranteed bandwidth to improve the unfair excess AF bandwidth allocation among the LSPs according to the LSP-specific parameters of the aggregated AF class flows. WF-RIO obtains a per-LSP probability of discarding out-of-profile AF packets by multiplying the dropping probability of RIO by an LSP-specific weight, and then drops packets at that probability. We have shown that the weight of each LSP can be calculated from the traffic rates for each service class (EF, AF_{in}, AF_{out}) and the required bandwidth of the LSP without considering the LSP-specific parameters of the aggregated AF-class flows. Through our evaluation results, we have shown that WF-RIO can eliminate unfair AF bandwidth allocation based on these parameters, and it can thus provide fair AF bandwidth allocation among LSPs sharing a congested AF queue. WF-RIO can stimulate the desire for LSP users to buy more LSP-required bandwidth in order to enrich the quality of AF traffic with more AF minimum guaranteed bandwidth, because WF-RIO can allocate the excess AF bandwidth among LSPs in proportion to their AF minimum guaranteed bandwidth. WF-RIO can promote the business model in which ISPs sell LSP-required bandwidth to LSP users to satisfy the above-mentioned desire.

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