ABSTRACT

IEEE 802.17 RPR is a MAN candidate due to its ability to achieve fairness and fast restoration. However, the proposed fairness scheme may lead to slow convergence and permanent oscillation. This letter proposes a novel fast-convergent scheme to provide fairness using estimated number of unbounded flows in each link. After detailed evaluations and simulations, the proposed scheme is proven to allocate bandwidth fairly among flows fast-convergently and achieve high utilization at the same time.

1. INTRODUCTION

IEEE 802.17 RPR [1] is an innovative and potential technique to replace expensive SONET. It can achieve fast restoration in 50 ms. Furthermore, RPR achieves fairness and high utilization with “spatial reuse” [2]. However, RPR fair rate with traffic unbalance may oscillate permanently.

Basically, RPR fairness scheme lacks knowledge of actual number of unbounded flows in each link. (The “unbounded” flow in this letter means that the flow is unbounded elsewhere in the other links or the source but is limited in the local link.) Therefore, Fair-rate tracking is hard with varying network condition. For example, as shown in Figure 1, in the RPR CM mode [1], two flows (2 and 4) passes link \( c \). When congestion occurs, RPR fairness scheme estimates a fair rate (unreserved rate divides active flow number) and the router \( C \) sends control message with this rate to upstream sources. This fair rate implies that the two flows are all limited by the link \( c \). In fact, it may not be always right. If the rate of flow 2 is bounded by link \( b \), the surplus rate of flow 2 is unused in the link \( c \). Furthermore, if the source rates of flows 2 and 4 are a negligible fraction of the bandwidth and the whole bandwidth of link \( c \), respectively. The utilization of link \( c \) oscillates permanently between the whole and the half of the bandwidth.

2. THE PROPOSED FAIRNESS SCHEME

Similar to RPR fairness scheme, the proposed scheme needs network information including input rate and active number of flows in each link. Note that input rate is sum of transit traffic and admissible station traffic. This admissible station traffic means the rate of station traffic admitted by congested links. The only estimation of the scheme needed is number of unbounded flows in each link. Surplus bandwidth is shared by the unbounded flows.

In a congested link, each flow may be unbounded or bounded in the source or in the other links. Define that a flow in the former situation is in state 1 and in the latter in state 0. As shown in Figure 2,

\[
R = K_i \cdot F + r, \tag{1}
\]

where \( R, K_i, F \) and \( r \) are input rate of the link, number of unbounded flows, local fair rate and total rate bounded by the other links or sources, respectively. Based on this model, the estimated number of unbounded flows in link \( i \) in the \( n \)th iteration, \( K_i(n) \), is defined as follows.

\[
K_i(n) = \frac{R_i(n)}{F_i(n)}, \tag{2}
\]

where \( R_i(n) \): measured input rate of link \( i \) in the \( n \)-th iteration; \( F_i(n) \): estimated fair rate of link \( i \) in the \( n \)-th iteration; If all flows are assumed unbounded in the beginning, the initial fair rate is

\[
F_i(0) = C_i / N_i, \tag{3}
\]

where

\( C_i \): capacity of link \( i \);
\( N_i \): number of active flows in link \( i \);
With Eq. (1), (2) and (3), a fair-rate iteration algorithm is proposed as follows.

\[ F(n+1) = \min \{C, C/K_i(n) \} \] ..............................(4)

where

\[ K_i(n) = K_i(n-1) + \Delta N_i, \text{if } (\Delta N_i \neq \text{zero}) \] ..............................(5)

\[ K_i(n) = \left[ K_i(n-1) + N_i \right]/2, \text{if } (P_i = 0 \& T_i > T_f) \] ..............................(6)

\[ K_i(n) = R_i(n)/F_i(n), \text{otherwise} \] ..............................(7)

Define that \( \Delta N_i \) is the change of active flow number in link \( i \). \( P_i \) is the ratio of time in an iteration used by station traffic. \( T_i \) is number of iterations and \( T_f \) is a threshold of iterations with \( P_i = 0 \). The estimation of number of unbounded flows is based on division of input rate by local fair rate in Eq. (7). However, two situations must be considered. One is that a new flow joins in or leaves the link and the other one is that some flows become unbounded (state 1) from bounded (state 0). In the first case, it takes lots of unnecessary time to tune its fair rate; hence, Eq. (5) is used. In the latter case, transit flows are under-throttled and station traffic starves. For example, there are 51 flows in a link and 50 flows of them are bounded. If the 50 bounded flows contribute 0.5 of utilization, Fair rate is 0.5 in this situation. Later, a case may occur, these 50 flows at state 0 change their states simultaneously. The rate of transit traffic is higher than the link capacity and station traffic starves. Furthermore, we need 50 iterations to get a proper fair rate (0.196) using Eq. (7). For alleviating this slow convergence, we set \( T_i \) and \( P_i \) to constraint iterations using Eq. (7) and Eq. (6) is used to estimate a proper fair rate in this situation. When \( P_i \) equals 0, \( T_i \) starts to count. The Eq. (6) is used when \( T_i \) is larger than the threshold \( T_f \).

\[ F(n) = 1 - \frac{1-r^*F(n)}{1-rF(n)} \] ..............................(8)

When \( K_i \) is larger than or equal to 1, \( F(n) \) is close to \((1-r)/K_i \), for \( n \) large enough in Eq. (8). So, the estimated fair rate is the surplus bandwidth, \( 1-r \), shared by unbounded flows and the link utilization is close to 1 finally. Furthermore, from Eq. (1) and (2), our proposed scheme also guarantees \( F(n+1)/1 \geq 1/N \), where \( N \) is always larger than \( K_i+r/F(n) \) since \( r \) is smaller than \((N-K_i)*F(n) \). Now, we compare our scheme with DVSR, which has the following iterations [3].

\[ F(n) = \frac{1}{K_i(1-r^*)}/\frac{1-r^*}{F(0)} \] ..............................(9)

If \( n \) is large enough, the proposed scheme (Eq. (8)) has the same fair rate \((1-r)/K_i \) as DVSR (Eq. (9)). Our proposed scheme can also provide RIAS [4] fairness. Furthermore, we want to discuss the speed of convergence. If \( n_1 \) and \( n_2 \) are the convergent iterations of DVSR and our scheme, respectively, the fair rate in Eq. (8) and that in Eq. (9) must approach \((1-r)/K_i \). If \( F_{avg} \) is the average rate of bounded flows, \( r \) is \( F_{avg}*(K_i-K_i) \) and we can get the following ratio.

\[ \text{ratio} = \frac{n_2}{n_1} = \log(1-K_i/N) \log(F_{avg}, (N-K_i)) \] ..............................(10)

The ratio in Eq. (10) is smaller than 1 since the average bounded rate, \( F_{avg} \), is smaller than \( 1/N \). So, DVSR should have more iterations than our proposed scheme.

In the case that the total input rate is larger than the link capacity, Eq. (7) still works except for the other two cases described in Section II. In both cases, \( r \) may vary drastically and that causes buffer overflow. The proposed scheme uses the estimated number of unbounded flows as described in Eq. (5) or (6). In Eq. (6), \( T_i \) is used to tolerate small variation of rate of transit traffic. Once when iterations over \( T_i \) are still not enough to bring the rate of transit traffic under the link capacity (\( P_i \) equals 0), Eq. (6) is used. Assume that \( P \) is the probability that a flow in state 0 changes to state 1 and \( k \) is number of flows which change the state from 0 to 1. The probability of \( k \), \( P(k) \), is as follows.
The estimated $E(K_c)$ is the expected value of number of that flows which change the state from 0 to 1. If we set $P=1/2$, the number of unbounded flows in the $n$th iteration is the average of number of active flows and the number of unbounded flows in the $(n-1)$th iteration in Eq. (6).

\[ P_r(k) = \frac{(N-K(n-1))!}{(N-K(n-1)-k)!k!} P^k (1-P)^{N-K(n-1)-k} \] ...(11)

\[ E(K_c) = \sum_{k=0}^{N-K(n-1)} k \cdot P_r(k) \]

\[ = (N-K(n-1))P \] ...(12)

The estimated $E(K_c)$ is the expected value of number of that flows which change the state from 0 to 1. If we set $P=1/2$, the number of unbounded flows in the $n$th iteration is the average of number of active flows and the number of unbounded flows in the $(n-1)$th iteration in Eq. (6).

4. SIMULATIONS

We compare our scheme with DVSR and original RPR AM fairness scheme [1]. We use NS-2 [5] to simulate a four-node RPR network, as shown in Figure 1, and the threshold, $T_m$, is set as 3. Flow(i,j) means that it goes from node i to node j. Demands of flow(1,3), (2,4) and (3,4) are 600, 600 and 100Mbps, respectively, and the link capacity is 600Mbps. The three flows begin transmission at times 0.1, 0.2, 0.3 seconds and end at times 0.4, 0.5 and 0.9 seconds, respectively. Figures 3 and 4 show that our proposed scheme is fast convergent and avoids oscillation of throughput. As shown Figure 3, RPR AM scheme has severe oscillation after the 0.4 second. DVSR can achieve the similar fairness to our scheme. However, the convergence iterations of our scheme are less than DVSR, as shown in Figure 5. It confirms the results of our discussion in Eq. (10).

5. CONCLUSIONS

Our proposed fairness scheme employs number of estimation of unbounded flows in each link. The proposed scheme is simple and fast convergent. Through discussions and simulations, our scheme solves the oscillation problem of the original RPR AM scheme, achieves RIAS fairness, and converges faster than the recently proposed DVSR scheme.

6. REFERENCES


