In our case $f_{CLKT} = 6.25\,\text{MHz}$, $f_{CLKR} = 5\,\text{MHz}$, $n_T = 55$, $n_R = 44$ and $L_T = L_R = L = 15.85\,\mu\text{s}$. The spectrum bandwidth of the transmitted signal is determined by the Δ/L ratio (a complete analysis will be published elsewhere). There is a compromise in the selection of Δ; the higher its value the wider obtained bandwidth, the upper limit of Δ being imposed by the Euler method. Smaller values give a better discretisation of the dynamical system; in our experiments the best choice was $\Delta = 0.035$.

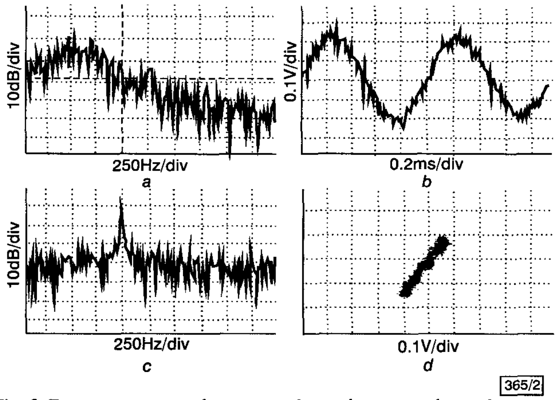

Fig. 2 *Fourier spectrum of transmitted signal, recovered signal i^r against time, spectrum of i^r and synchronisation between original and recovered speech signals*

a Fourier spectra of transmitted signal *s* with sinusoidal information signal (marker on 1 KHz)
b Recovered signal i^r
c Spectrum of i^r
d Synchronisation (shown on Tektronix TDS210 display)

Results: Several information signals were used to evaluate the system. We report two particular cases: a 1 kHz, $200\,\text{mV}_p$ sinusoidal signal, and a speech signal. Fig. 2*a* shows the Fourier spectrum of the transmitted signal *s*, as measured by an HP54520A scope. The screen marker is on the 1 kHz position to stress that the information signal spectrum is hidden. Fig. 2*b* shows the recovered sinusoidal signal; the corresponding spectrum (Fig. 2*c*) shows a peak at 1 kHz ~30 dB over the background noise.

The case of a speech signal is shown in Fig. 2*d*, where the recovered information signal i^r is plotted against the sent information signal i^t to show the synchronisation between them. Perfect synchronisation corresponds to a straight line. Thus, the width of the cloud of points is a measure of the full system synchronisation noise.

Conclusion: The design presented in this Letter makes a simple and versatile communication system with a significant degree of security.

Acknowledgments: This work was supported by grants from the UNMDP. We acknowledge P.G. Farrell for very useful discussions.

3 July 2001
Electronics Letters Online No: 20010784
DOI: 10.1049/el:20010784

R.M. Hidalgo, J.G. Fernández, R.R. Rivera and H.A. Larrondo (*Facultad de Ingeniería, Universidad Nacional de Mar del Plata, Juan B. Justo 4302, (7600), Mar del Plata, Argentina*)

E-mail: larrondo@fi.mdp.edu.ar

References

1 PECORA, L.M., CARROLL, T.L., JOHNSON, G.A., and MAR, D.J.: 'Fundamentals of synchronization in chaotic systems, concepts and applications', *Chaos*, 1997, **7**, pp. 520–543
2 KOCAREV, L., and PARLITZ, U.: 'General approach for chaotic synchronization with applications to communication', *Phys. Rev. Lett.*, 1995, **74**, (25), pp. 5028–5031
3 MELCZARSKI, I., HIDALGO, R.M., and LARRONDO, H.A.: 'Sistemas de Comunicaciones Empleando Portadora Caótica'. Proc. VIII RPIC, Mar del Plata, Argentina, 1999, pp. 66/11–75/11

Fairness criterion for allocating resources in input queued switches

D. Liu, N. Ansari and E. Hou

A new fairness criterion, queue proportional fairness (QPF), is proposed. It employs the cell loss ratio as the fairness metric to improve the utilisation of switch resources. QPF provides a fairness criterion for allocating bandwidth by considering the current buffer occupancy for best effort traffic in an input queued switch.

Introduction: Fairness is a universal concept required in flow control, buffer management, and scheduling [1 – 3]. Regardless of how differently fairness is defined, there is common agreement that traffic with the same priority should be treated in the same way. However, many different allocation metrics exist such as rate, throughput, etc., indicating that fairness criteria are rather application specific [3, 4].

A space division switch can be classified into an input, output, or input-output queued switch depending on the location of buffers [5]. In an input queued (IQ) switch, each input port keeps a separate buffer so that both the fabric and the buffers are only required to run at the same rate as that of the line rate, i.e. there is no speedup requirement. In an IQ switch, we define three types of fairness: intra-queue, intra-input, and inter-input fairness. Intra-queue fairness is defined as the fairness among connections that enter into the same input port and destine to the same output port. Intra-input fairness is defined as the fairness among aggregated connections that enter into the same input port and destine to a different output port. Inter-input fairness is defined as the fairness among different input ports that contend for the same output port. From the perspective of an IQ switch, although the intra-queue fairness can affect the throughput of each individual connection, it has little effect on the total throughput of the switch. However, as shown in this Letter a proper definition of the intra-input and inter-input fairness can notably improve the total throughput of the switch. Normally, both buffer management and scheduling are involved in the intra-queue fairness and intra-input fairness, and scheduling should consider the inter-input fairness.

To handle multiple classes of traffic in an IQ switch, we should first allocate resources to satisfy the requirements of guaranteed traffic. The leftover resources are then allocated fairly among competing best effort traffic. Previous works [3, 6] have allocated bandwidth of an IQ switch to competing best effort traffic according to the well-known Max-Min fairness criterion [1]. The Max-Min fairness criterion is essentially a rate-based, light traffic prioritised criterion [6, 7]. The basic idea of Max-Min fairness is to allocate as much bandwidth as possible to the connection that has the minimum requirement among all connections. Although Max-Min fairness criterion can achieve a fair bandwidth allocation, it is quite clear that it is not sufficient for best effort traffic, which may suffer from shortage of bandwidth as well as buffer space. Therefore, for best effort traffic, we need a new fairness criterion, which can inclusively consider the fairness issue in allocation of both buffer space and bandwidth. Furthermore, estimating the rate of best effort traffic requires a complex procedure and the estimated errors can greatly degrade the performance of the switch.

Queue proportional fairness: Let $Q^k_{i,j}$, $R^k_{i,j}$ be the queue length and allocated bandwidth of connection k that is originated from input i and destined to output j, respectively. Here $k = 1, 2, \ldots, K_i$, and i, $j = 1, \ldots, N$. Let $Q_{i,j}$ and $R_{i,j}$ be the aggregated queue length and allocated bandwidth of all connections from input i to output j, respectively.

$$Q_{i,j} = \sum_{k=1}^{K_i} Q^k_{i,j} \quad \text{and} \quad R_{i,j} = \sum_{k=1}^{K_i} R^k_{i,j}$$

Let Q_j and R_j be the total virtual queue length and available bandwidth of output j, respectively.

$$Q_j = \sum_{i=1}^{N} Q_{i,j} \quad \text{and} \quad R_j = \sum_{i=1}^{N} R_{i,j}$$

Let ϕ_j be the set of inputs that have backlogged traffic destined to output j, and θ_i be the set of outputs at which input i has backlogged traffic to be transmitted.

Definition 1: For each input-output pair, the queue proportional fairness is satisfied if at least one of the following equalities is satisfied:

$$\frac{R_{i,j}}{Q_{i,j}} = \frac{R_{h,j}}{Q_{h,j}} \quad i,h \in \phi_j \quad \text{and} \quad j = 1,...,N \qquad (1)$$

$$\frac{R_{i,j}}{Q_{i,j}} = \frac{R_{i,l}}{Q_{i,l}} \quad j,l \in \theta_i \quad \text{and} \quad i = 1,...,N \qquad (2)$$

Eqns. 1 and 2 give us a criterion for allocating bandwidth to guarantee the inter-input fairness and intra-input fairness in an IQ switch. A maximum threshold of queue length may be required to avoid a non-compliant flow taking too much bandwidth from compliant flows.

Max-Min fairness can be reached by the water filling procedure where allocated rates (bandwidth) for all input-output pairs increase linearly until the minimum one reaches its rate limitation. Other pairs continue to increase their rates similarly until all bandwidths are allocated. QPF can also be satisfied by the water filling procedure as the weighted Max-Min fairness by replacing the weight with the queue length [7].

Let $P_{i,j}$ be the cell loss ratio of the aggregated connections from input i to output j, then we have:

Lemma 1: For each input-output pair, at least one of the following equalities is satisfied:

$$P_{i,j} = P_{h,j} \quad i,h \in \phi_j \quad \text{and} \quad P_{i,j} = P_{i,l} \quad j,l \in \theta_i$$

Proof of Lemma 1 is a direct result from Definition 1.

By employing the QPF criterion, maximum throughput of an IQ switch can be obtained as stated in Lemma 2 which results from the intuition that bandwidth is not wasted if QPF is satisfied.

Lemma 2: The maximum throughput of an IQ switch can be obtained if QPF is satisfied.

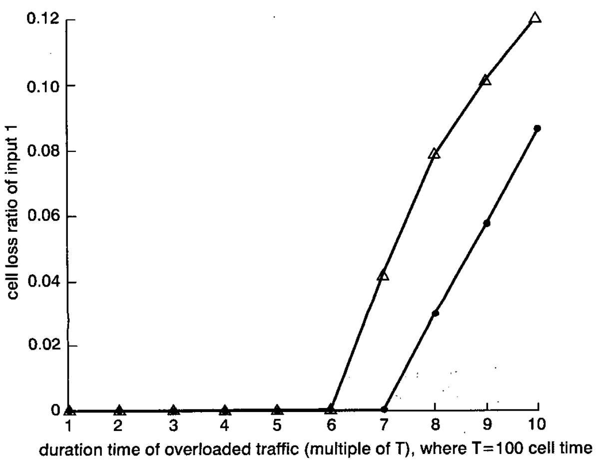

Fig. 1 *Cell loss ratio of input port 1 using QPF and Max-Min fairness criterion*

—●— QPF
—△— Max-Min

Performance evaluation: To compare the performance of QPF and Max-Min fairness criterion, we allocate bandwidths of each output port to competing input ports according to the QPF and Max-Min fairness criterion separately in a 2 × 2 IQ switch.

The Bernoulli source with probability ρ = 1 is generated at each input port. To generate the severe overloaded condition, without loss of generality, we assume that 80% of traffic from input 1 goes to output port 1, and another 20% goes to output 2; half of the traffic from input port 2 goes to output port 1, and another half goes to output 2.

Fig. 1 shows that if the buffer space is limited to 400 cells, the cell loss ratio using QPF criterion is improved by about 25 to 100% compared to that using Max-Min fairness criterion. The throughput using QPF, shown in Fig. 2, has improved by about 4 to 6% compared to that using Max-Min criterion. The reason for the improvement is that Max-Min fairness is a bandwidth based, light traffic prioritised criterion while QPF criterion inclusively consider the fair allocation of both bandwidth and buffer space.

In our simulations, we assume that the rates of best effort traffic are known exactly when we apply the Max-Min fairness. Thus, in practice, additional improvement by using QPF criterion is expected since there are no inherent rate estimation errors as in Max-Min fairness.

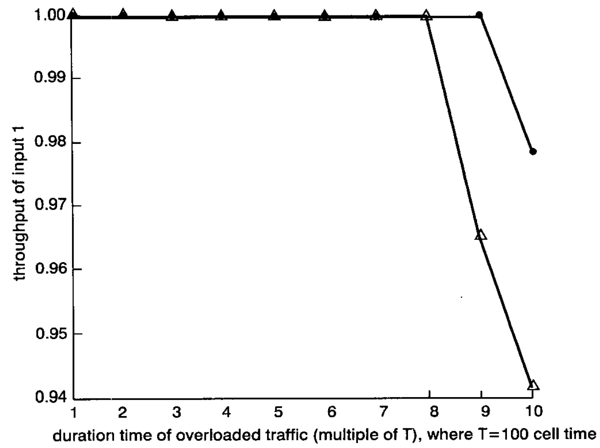

Fig. 2 *Throughput of input port 1 using QPF and Max-Min fairness criterion*

—●— QPF
—△— Max-Min

Conclusion: To guarantee intra-input fairness and inter-input fairness as well as to efficiently allocate switch resources for best effort traffic in an IQ switch, QPF criterion has been proposed. By properly selecting the fairness metric, QFP criterion can greatly improve the utilisation of switch resource compared to Max-Min fairness.

27 June 2001
Electronics Letters Online No: 20010792
DOI: 10.1049/el:20010792

D. Liu, N. Ansari and E. Hou (*Department of Electrical and Computer Engineering, New Jersey Institute of Technology, Newark, NJ, USA*)

E-mail: hou@njit.edu

References

1 Traffic Management Specification Version 4.1, af-tm-0121.000, The ATM Forum, March, 1999

2 WU, G., and MARK, J.: 'A buffer allocation scheme for ATM networks: complete sharing based on virtual partition', *IEEE/ACM Trans. Netw.*, 1995, **3**, (6), pp. 660–670

3 CHANG, C., CHEN, W., and HUANG, H.: 'Birkhoff-von Neumann input buffered crossbar switches'. Proc. Infocom'00, Tel Aviv, Israel, 2000, pp. 1614–1623

4 JAIN, R., CHIU, D., and HAWE, W.: 'A quantitative measure of fairness and discrimination for resource allocation in shared computer system'. DEC Tech. Rpt. 301, 1984

5 TOBAGI, F.: 'Fast packet switch architectures for broad-band integrated services digital networks', *Proc. IEEE*, 1990, **78**, (1), pp. 133–167

6 KAM, A., and SIU, K.: 'Linear complexity algorithm for QoS support in input-queued switches with no speedup', *IEEE J. Sel. Areas Commun.*, 1999, **17**, (6), pp. 1040–1056

7 MASSOULIE, L., and ROBERTS, J.: 'Bandwidth sharing: objectives and algorithms'. Proc. Infocom'99, New York, USA, 1999, pp. 1395–1403