ThI2 **11:00 am**

Throughput limitations in ultrafast all-optical soliton mesh networks using deflection routing

Alberto Bononi, Fabrizio Forghieri, and Paul R. Prucnal, *Department of Electrical Engineering, Princeton University, Princeton, New Jersey 08544*

Deflection routing[1] may be used in regular two-connected all-optical multihop fiber networks, such as the Manhattan Street network (MS)[1] and ShuffleNet (SN),[2] to ease the problems arising from all-optical buffering at intermediate nodes. The loss in efficiency of deflection routing with respect to the classical store-and-forward routing due to the increased average number of hops can be offset by the higher bit rates permitted by the all-optical channel so that the throughput, proportional to the bit rate, can be increased.[3] However, the bit rate is constrained by the maximum allowed packet error rate. In the all-optical approach no regeneration of the optical signal can be provided at intermediate nodes nor can error control be performed on a link-by-link basis. Under deflection routing, repeatedly deflected packets travel long distances before reaching their destination and are thus more likely to be in error at the receiver, particularly at very high bit rates.

Fixed-size packet transmission at ultrahigh bit rates is addressed in these slotted networks. Solitons have been considered because of their dynamic compensation of fiber chromatic dispersion, which is the major source of distortion for non-soliton pulses at ultrahigh bit rates. Recently, optical sampling techniques[4] have been proposed for demodulating data streams at bit rates far beyond the speed of conventional optical receivers. Solitons have been shown to have the highest sampling efficiency of all pulses.

The optical receiver is assumed in this analysis to be a bank of such optical samplers, and each sampler is modeled as a gating sampling window. Ideal slot synchronization is assumed at all nodes. Errors are due to jitter of the soliton arrival time in excess of the sampling window. This jitter is due to amplified spontaneous-emission noise (ASE) added to the packet by optical amplifiers placed at each node, to soliton self-frequency shift (SSFS) due to Raman scattering, and to short-range interaction of neighboring solitons (SRI) and to their interplay.

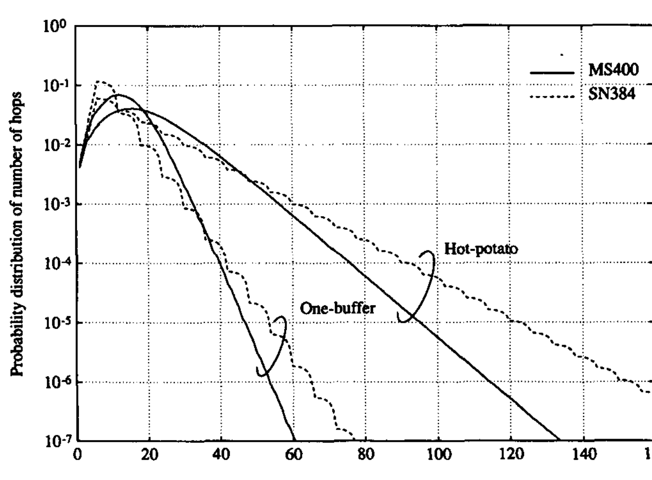
The packet error rate is obtained by conditioning on the number of hops n as

$$P(e) = \sum_{n=1}^{\infty} P(e/n)P(n). \qquad (1)$$

The average hop distribution $P(n)$ depends only on the network topology, routing, and load, whereas the conditional probability of packet error $P(e/n)$ depends on the noise and distortion introduced by the optical channel. Hop-distribution curves $P(n)$ for MS and SN using both single-buffer deflection routing and hot-potato routing (no buffers) for a 400-node network size (MS400 and SN384) have been used in Eq. (1) and are shown in Fig. 1 at full load. SN has a lower mean, but the tail probability is much higher than in MS.[5]

The network throughput is *inversely* proportional to the mean of the hop distribution and *directly* proportional to the bit rate. The throughput is maximized by using the highest bit rate permitted by a given packet error rate. Figure 2 shows the packet error rate at full load plotted versus the optical bit rate R for a 1-km node-to-node fiber span. The results have been obtained for a fiber-dispersion parameter $D = 1$ ps/nm/km and a node amplifier gain per node channel of 10 dB. Since errors are mostly due to packets that have hopped a high number of times, the error probability in SN is higher than in MS for low values of $P(e)$ because of the tail behavior of $P(n)$. The use of deflection routing with a single- fiber delay-line buffer drastically lowers the hop distribution tail, so that much higher bit rates can be obtained for the same packet error rate with respect to the case of no buffers (hot potato).

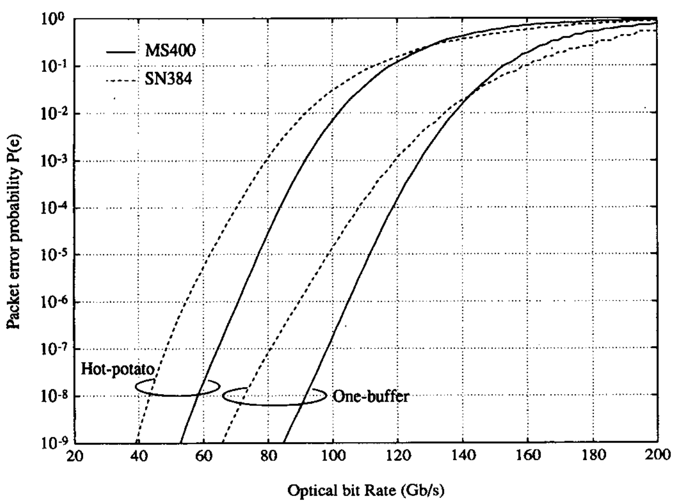
Figure 3 shows the maximum throughput per node at $P(e) = 10^{-6}$ versus the probability of packet generation g (i.e., the offered load). It can be noted that, since higher bit rates are possible in MS for a given value of $P(e)$, MS has higher throughput under hot potato, when the tail of the hop probability in SN is very high, whereas the lower mean permits a higher throughput in SN when its tails are decreased, as with single-buffer deflection routing.



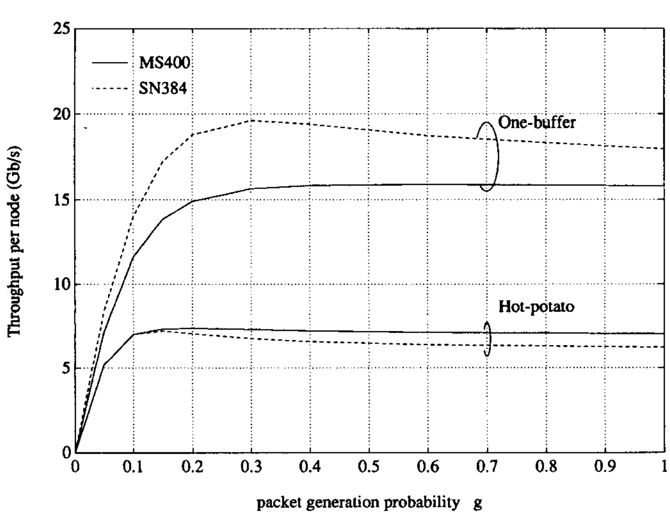
ThI2 **Fig. 1.** Hop distribution for MS and SN with hot-potato routing and one-buffer deflection routing at full load ($g = 1$).

Therefore SN should be preferred to MS in this ultrafast soliton channel whenever at least one optical buffer is provided.

1. N. F. Maxemchuk, AT&T Tech. J., **64,** 1659 (1985).
2. A. S. Acampora, M. J. Karol, and M. G. Hluchyj, AT&T Tech. J. **66,** 21 (1987).
3. A. S. Acampora and A. Shah, IEEE Trans. Commun. **COM-40,** 1082 (1992).
4. P. A. Andrekson, N. A. Olsson, J. R. Simpson, D. J. DiGiovanni, P. A. Morton, T. Tanbun-Ek, R. A. Logan, and K. W. Wecht, IEEE Photon. Technol. Lett. **4,** 644 (1992).
5. F. Forghieri, A. Bononi, and P. R. Prucnal, "Analysis and comparison of hot-potato and single buffer deflection routing in very high bit rate optical mesh networks," submitted to IEEE Trans. Commun.



ThI2 Fig. 2. Packet error probability for a 1-km link length in MS400 (solid curve) and SN384 (dashed curve) with hot-potato and one-buffer deflection routing at full load.



ThI2 Fig. 3. Throughput per node at $P(e) = 10^{-6}$ versus packet-generation probability g in MS400 and SN384 with a 1-km node-to-node fiber span.

THURSDAY