1. The diagram below shows the consecutive copy+route multicast architecture. In this architecture, the copy network delivers copies of an original multicast cell to consecutive outputs (wrapping around from the last output to the first, if necessary). Show how the multicast routing table entries should be initialized to support a multicast session from input 3 to outputs 0, 4 and 5. Assume there is just one fanout class.

If this multicast session has a bandwidth of 100 Mb/s, how much bandwidth does it use on each of the copy network outputs?

\[ 100 \times \frac{3}{8} = 37.5 \text{ b/s} \]

Suppose we simplify the architecture by eliminating the wrap-around feature. In this case, how much bandwidth does the example multicast session place on each of the copy network outputs?

Outputs 0 and 7 get \( \frac{100}{6} = 16.7 \text{ Mb/s} \), outputs 1 and 6 get \( \frac{100}{3} = 33.3 \text{ Mb/s} \) and outputs 2, 3, 4 and 5 get \( \frac{100}{2} = 50 \text{ Mb/s} \).

In general, what is the minimum load that a multicast session with fanout \( F \) and input bandwidth \( B \) places on any copy network output in a system with \( n \) ports? What is the maximum?

The minimum is \( \frac{B}{n-(F-1)} \) and the maximum is \( FB/(n-(F-1)) \), so the load on some outputs is \( F \) times the load on others. Also, the most heavily loaded outputs can have a total load which is \( 1+(F-1)/(n-(F-1)) \) times larger than the load they can have, if the wrap-around feature is included. This is a strong argument in favor of including the wrap-around feature, when \( F \) can be a large fraction of \( n \). On the other hand, if \( F \) is limited to no more than say \( n/10 \), it may be reasonable to omit the wrap-around feature, since the effect on the required bandwidth is relatively small in that case.
2. Suppose you are asked to design a switching system that uses static routing, has 2048 inputs and outputs, uses the three stage Clos network topology and supports external links of 1 Gb/s with session rates from 0 up to 100 Mb/s. Assuming that the first stage switches have 64 inputs and the last stage switches have 64 outputs, how fast should the internal links be to make the system nonblocking for unicast traffic if there are 32 middle stage switches? How fast should they be to make it nonblocking for multicast traffic? How fast to be reroutably nonblocking for multicast traffic? In this last case what is the fanout restriction in the first stage? Repeat the above, assuming 1 and 8 middle stage switches. Organize your answers in the form of a table with three rows and four columns.

In the table below, the first column gives the internal link bandwidth needed to make the network nonblocking for unicast traffic. The second column gives the internal link bandwidth needed to make it strictly nonblocking for multicast. The third column gives the bandwidth needed to make it reroutably nonblocking for multicast, assuming that the first stage fanout is restricted to the value given in the last column. Other values for the fanout restriction result in larger internal link bandwidths.

<table>
<thead>
<tr>
<th></th>
<th>unicast</th>
<th>multicast s.n.b.</th>
<th>multicast r.n.b.</th>
<th>fanout restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>r=32</td>
<td>4.1 Gb/s</td>
<td>64 Gb/s</td>
<td>11.4 Gb/s</td>
<td>3</td>
</tr>
<tr>
<td>r=8</td>
<td>16.1 Gb/s</td>
<td>64 Gb/s</td>
<td>38.4 Gb/s</td>
<td>3</td>
</tr>
<tr>
<td>r=1</td>
<td>64 Gb/s</td>
<td>64 Gb/s</td>
<td>64 Gb/s</td>
<td>1</td>
</tr>
</tbody>
</table>

3. For each of the following systems give the speedup needed to make them nonblocking for multicast traffic. Assume that the minimum session rate is zero and that the highest session rate equals half the link rate.

Static routing network with topology $B_{100, 10}^2; B_{100, 10}^2$, assuming that routes are setup with a maximum fanout of 10 in each of the two subnetworks. Give the speedup required to make it wide-sense nonblocking and the speedup needed to make it reroutably nonblocking.

The inequality for the wide-sense nonblocking case is $S \geq \frac{1}{2} - \frac{1}{d} (1 - 1/d)(k - 1) + \frac{f + 1}{d} + B$. In this case, we have $S \geq (11.9 + 11/10 + 1/2 = 11.5$. For the reroutably nonblocking case, the inequality is $S \geq 2(1 - 1/d)(k - 1) + (1 - 1/d)B + 2/d = 1.8 + .45 + .2 = 2.45$.

The multipass architecture using binary copying and the Benes network $B_{100, 10}$ with a multicast fraction of 1 and a multicast fraction of 0.25.

In this case, the appropriate inequality is $S \geq 2(1 + \delta)((1 - 1/d)(k - 1) + 1/d) + (1 - (1 + \delta)/d)B$. For a multicast fraction of 1, this gives us $S \geq 4 + .8/2 = 4.4$ and for a multicast fraction of 0.25, we get $S \geq 2.5 + .875/2 = 2.9375$. 

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