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MULTIPLE-RING ARCHITECTURE AND ITS FDDI APPLICATIONS

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ABSTRACT

This paper discusses a networking concept referred to as Multiple-Ring Architecture (MRA). In FDDI reliability applications, MRA is an attractive alternative to the popular dual homing architecture for the following reason. Unlike the requirement of several reliable concentrators needed in the dual homing architecture, the MRA only requires several routing interfaces at each backbone node (i.e., at each router node); different fiber cables and networks share the same set of routers, creating a set of highly fault tolerant networks of low overall cost and complexity.

1 MULTIPLE-RING ARCHITECTURE

An important consideration in the design of a computer network is the reliability and availability of communication paths among all nodes of the network. Implementing some form of network redundancy can improve in reliability; however, the resulting system cost and complexity also increase. Generally, it is desirable to maximize the number of links and nodes that must fail in order to disrupt the operation of the network, subject to fixed cost constraints.

This paper presents a networking concept, which we refer to as Multiple-Ring Architecture (MRA), that is closely related to the *multiple-channel ring network* mentioned in [1]. We use the ring topology [e.g., a Fiber Distributed Data Interface (FDDI) token ring] to illustrate the main concept, though the MRA is applicable to many other types of network topologies. Suppose that one would like to use a number of links to connect N stations. A simple ring configuration shown in Fig. 1 will satisfy this need; however, such a simple ring is vulnerable to link failures. To increase the reliability of the network, its nodes can be dual homed with the cost of two additional concentrators (CONs) as well as many additional links (see Fig. 2). Generally, there is a trade-off in reliability and cost in network design.

As an alternative to dual homing, the MRA shown in Fig. 3 can offer some reliability with lower cost. The MRA is accomplished by requiring each station that is connected to multiple rings to be able to route the traffic among different rings. Such a station can be fulfilled by a modern router or a gateway, which is capable of directing the traffic from one ring to another when a link is congested or disconnected either by system mal-function or by scheduled outage. Therefore, network management (e.g., taking a station out of the ring for service) can be simplified with the MRA, whose required number of links is only slightly more than that of the simple ring network.

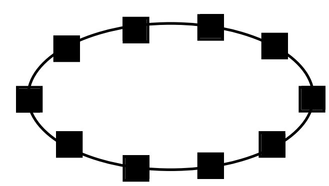

Fig. 1 Simple Ring Configuration

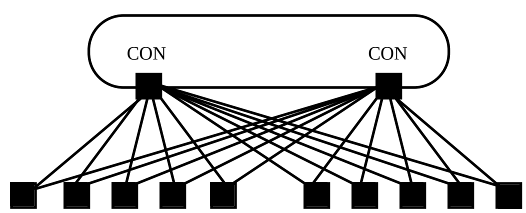

Fig. 2 Dual Homing Architecture

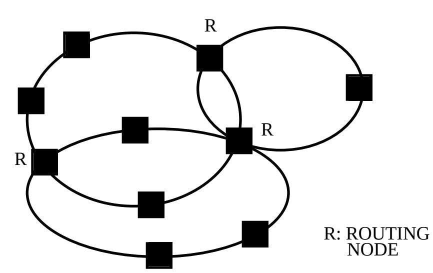

Fig. 3 Multiple-Ring Architecture

2 NETWORK CONNECTIVITY ANALYSIS

In this section, we restructure the general MRA shown in Fig. 3 to result in the symmetrical MRA as shown in Fig. 4, where two routing nodes are used to direct the traffic from one ring to another. Our goal is to study the connectivity of the three types of networks shown in Figs. 1, 2, and 4; then the network reliability can be derived from the obtained network connectivity.

We restrict our studies to FDDI, which is a fiber-optic token network consisting of two counter-rotating rings; therefore, each line/arc in Figs. 1, 2, and 4 represents two (fiber) links [1, 2, 3]. Notice that, in most FDDI applications, all stations constituting a backbone network are routers. A network is defined to be connected if communication paths exist among all of its nodes. As in [3], we concentrate on link failures only; i.e., we assume that all nodes (such as workstations, CONs, and routers) do not fail, only links do. Moreover, the root ring of the dual homing network (i.e., the ring connecting the two CONs) is assumed to be always connected.

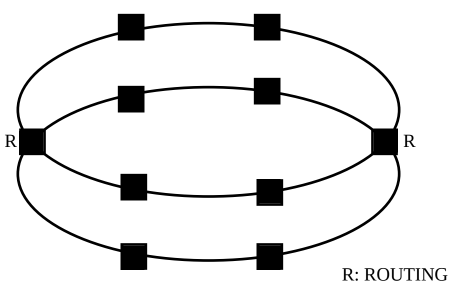

Fig. 4 Symmetrical Multiple-Ring Configuration, $n = 2$, $N = 4n + 2 = 10$

Let $C(k)$ denote the number of ways that k links fail and the network is still connected; C is called the connectivity function and must satisfy $C(0) = 1$. It is desirable to design networks such that k and $C(k)$ are as large as possible under a cost constraint. In this paper, the cost refers to the number of links (e.g., fiber optic cables) and connecting devices (e.g., CONs required in a dual homing network or routers required in MRA). This section compares the connectivities for the above 3 networks; each network is assumed to have $N = 4n + 2$ nodes. Thus, let C_1, C_2, and C_3 denote the connectivity functions of the dual ring, of the dual homing network, and of the multiple-ring network, respectively. Correspondingly, let L_1, L_2, and L_3 denote the number of links used in each network to connect the N nodes; therefore, $L_1 = 2N$, $L_2 = 4(N+1)$, and $L_3 = 8(n+1) = 2N+4$. Hence, the dual ring requires the least number of links; the dual homing network requires the most number of links; whereas the multiple-ring network offers a compromise between the other two cases. As shown below, the multiple-ring network has connectivity that is lower than that of the dual homing network and higher than that of the dual ring network.

For the dual ring network (Fig. 1), we have

$$C_1(1) = 2N,\ C_1(2) = N, \tag{1}$$

$$\text{and } C_1(k) = 0 \text{ for } k > 2.$$

Therefore, the dual ring can tolerate at most two link failures and can still be operational. To compute the connectivity function for the dual homing network (Fig. 2), let k be the number of links that fail and that the dual homing network is still connected. Suppose that k is composed of i pairs of links and $k - 2i$ single links. Notice that $0 \le k \le 2N$ and $0 \le i \le \lfloor k/2 \rfloor$, where $\lfloor x \rfloor$ denotes the largest integer smaller than or equal to x. Then there are

$$\frac{2N(2N-2)(2N-4)\ldots(2N-2(i-1))}{i!} = 2^i \binom{N}{i}$$

ways for i pairs of links to fail and the dual homing network is still connected. Furthermore, there are

$$[(4N-4i)(4N-4(i+1)) \ldots (4N-4(i+k-2i-1))]/(k-2i)! = 4^{k-2i}\binom{N-i}{k-2i}$$

ways for $k - 2i$ single links to fail and the dual homing network is still connected. Thus, the connectivity function of the dual homing network is

$$C_2(k) = 2^i \binom{N}{i} 4^{k-2i} \binom{N-i}{k-2i}, \tag{2}$$

where

$$0 \le k \le 2N \text{ and } \max\{0, k-N\} \le i \le \lfloor k/2 \rfloor.$$

Furthermore, $C_2(k) = 0$ for $k > 2N$. Therefore, the dual homing network can tolerate up to $2N$ link failures and can still be connected.

To compute the connectivity function of the multiple-ring network shown in Fig. 4, notice that the network is composed of 4 halves; each half (sharing 2 routing nodes) has n nodes and $2(n+1)$ links. The connectivity of the MRA highly depends on the routing capability of the two routers. In the following analysis, we assume that the routers are capable of directing the traffic to the correct nodes as long as all the subnetworks remain valid FDDI subrings that are connected to each other. A multiple-ring network that uses less capable routers will have lower connectivity. Thus, the network is still connected if (a) at most 3 halves have failed; and (b) when a half fails, it has either one single failed link or one pair of failed links. Therefore,

$$C_3(1) = \binom{4}{1} 2(n+1),$$

$$C_3(2) = \binom{4}{1}(n+1) + \binom{4}{2}[2(n+1)]^2,$$

$$C_3(3) = \binom{4}{2}(n+1)\,2(n+1) + \binom{4}{3}[2(n+1)]^3,$$

$$C_3(4) = \binom{4}{2}(n+1)^2 + \binom{4}{3}(n+1)\,[2(n+1)]^2, \qquad (3)$$

$$C_3(5) = \binom{4}{3}(n+1)^2 2(n+1),$$

$$C_3(6) = \binom{4}{3}(n+1)^3,$$

$$C_3(k) = 0 \text{ for } k > 6.$$

Therefore, the multiple-ring network can tolerate up to 6 link failures and can still be connected.

The knowledge of the connectivity function of a network allows the calculation of its reliability function, which is the probability that the network will be connected beyond an amount of time. Generally, if X is the random variable representing the life time of a component, the reliability function of the component is $r(t) \equiv \Pr\{X > t\}$. The reliability function of a network can be computed or estimated from the reliability functions of its components. In the following, we assume that the reliability function of the links connecting the network nodes is f. Let r_1, r_2 and r_3 be reliability functions of the dual ring, of the dual homing network, and of the multiple-ring network, respectively. The reliability function of a network can be calculated by assigning weights to its connectivity function; such weight assignments highly depend on the applications and the characteristics of the network. For example, assume that the links of the networks fail according to identically independent random variables, each with reliability function f. Then from (1)

$$r_1 = f^{2N} + 2N(1-f)f^{2N-1} + N(1-f)^2 f^{2N-2}$$
$$= N f^{2N-2} - (N-1) f^{2N},$$

which agrees with the results in [2, 3]. From (2)

$$r_2 = \sum_{k=0}^{2N} \sum_{i=\max\{0,k-N\}}^{\lfloor k/2 \rfloor} 2^i \binom{N}{i} 4^{k-2i} \binom{N-i}{k-2i} \times f^{4N-k}(1-f)^k,$$

which can be simplified to $r_2 = (2f^2 - f^4)^N$ as found in [3]. Similarly, the reliability function of the multiple-ring network shown in Fig. 4 can be calculated via the relation

$$r_3 = \sum_{k=0}^{6} C_3(k) f^{L_3 - k}(1-f)^k,$$

where $C_3(k)$ is given by (3).

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