Performance of Ring-Structured Access Networks using Generic Object Models

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ABSTRACT. Modelling of telecommunications access networks which concentrate traffic is essential for architectural studies, design and traffic studies. Ring-structured access networks based on low order PCM multiplexes are examined in this paper. Generic components are used in this work to simulate the networks. Three networks are simulated: an existing unidirectional ring network, a bidirectional ring network and a network with a cross link. A network is simulated with mixed traffic (telephone, payphone and Internet dial-up traffic) and under link failure conditions to establish the quality of service.

1 INTRODUCTION

The access network is the most cost sensitive part of the public telecommunications network. Modern narrowband access networks elements concentrate traffic and require traffic engineering, formerly restricted to the core network. Simulation is an essential tool for traffic engineering. Simulation in turn requires models for the traffic handling components. A companion paper [1] describes a method of identifying generic models for the components of an intermediate access network (termed the Intermediate Services Access Network or ISAN). ISAN networks are based on low order PCM multiplexes, G.703/704 links, advanced concentrating exchange interfaces and intelligently controlled nodes. Access networks in this class have inherent concentration of traffic and require traffic engineering. Traffic engineering must be performed for heterogeneous traffic sources: domestic and business telephones, payphones and Internet dial-up users.

Within the ISAN class of access networks, an important structure is the ring structure. Ring network architectures are being used increasingly in telecommunication access networks. SDH rings and the DCR-300 access network [3] are examples of access ring architectures currently being used. Ring networks are favoured because of their simplistic design and cost benefit to the service provider. Another advantage of ring networks is the ability to design networks which are robust with respect to link failure.

In an ISAN ring, customers are connected to remote nodes (concentration terminals) via short copper drops or wireless local loop (WLL) drops. The ring is connected to the end exchange via a central station. The exchange interface is a concentrating type such as V5.2 or R2 [2,3]. An example of such a ring network is the Digital Concentrator Ring (DCR-300) [3].

This paper examines the traffic carrying capacity of ring networks based on links carrying low-order PCM multiplexes, such as E1 multiplexes. Models of generic components from which to build traffic models and generic object classes used in access network simulations have been presented in [1]. The essential object classes for access network ring network simulations are described in Section 2. The simulation of the DCR-300 ring-structured access network is revisited in Section 3. A bidirectional ring network is presented in Section 4 to enhance the traffic capacity of ring networks. Section 5 simulates the bidirectional ring network with a non-uniform customer distribution in the ring generating telephone and mixed traffic. Section 6 discusses the performance of the bidirectional ring which uses a single backup link under link failure conditions.

2 RING NETWORK MODELLING

Modelling of components in a system is a two-stage process described in [1]: top down component identification followed by object-oriented design (OOD). Top-down modelling of ISAN architectures has identified generic object classes [1]. These generic object classes can represent a range of network topologies. Ring structured networks use the generic objects shown in Figure 1.

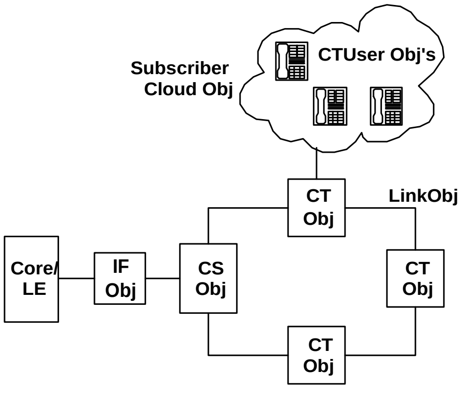

Figure 1 Generic object classes in a ring network

The concentrator terminal (CT) is one of the most commonly found nodes in the access network. Its primary function is to connect users to the access network via subscriber line interfaces. The link object

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represents links in a network. The central station (CS) is used to connect the access network to the local exchange interface (IF).

Figure 1 shows a ring-network modelled using the generic objects, which when implemented as generic object classes, are used to simulate this and other ring-structured access networks.

3 THE DCR-300 REVISITED

The DCR-300 access network is a low cost solution providing POTS to customers connected to access network. The network is based on short-haul 2Mbit/s PCM links in a closed loop configuration connecting concentration terminals. Each concentration terminal (CT) can serve up to 128 subscribers. The CTs are connected together in a simplex or unidirectional loop. The actual links are full duplex but are used unidirectionally in normal operation of the ring. The local exchange interface is a R2 interface. The R2 interface requires that the 30 available channels be sub-allocated to originating and terminating calls. The allocation in the DCR-300 implementation is 15 and 15 channels to originating and terminating calls respectively. In the case of link failure, a backup link is used in conjunction with the part of the primary link that has not failed when there is a link failure.

This network lends itself to prediction of grade of service for homogeneous traffic sources using the Erlang B formula. Simulation of the DCR-300 using the objects discussed in Section 2 and the simulation language MODSIM III has been presented in [4]. It was shown in [4] that the results obtained from the simulator agree with Erlang B theory.

In terms of the performance of the DCR-300, the bottleneck in the access network was shown to be the R2 interface. Removing the bottleneck would increase the traffic in the access network without an increase in blocking. The next section discusses methods of achieving higher traffic capacities in ring architectures.

4 DEVELOPMENT OF A RING STRUCTURED NETWORK

In this section, we examine the expansion of the capacity of ring architectures relative to that of the DCR-300. Traffic generated in the various studies consists of telephone only, and telephone, payphone and Internet dial-up traffic.

4.1 REMOVAL OF INTERFACE RESTRICTION

In terms of the performance of the DCR-300, the bottleneck in the DCR-300 access network is the R2 interface. Removing the bottleneck allows originating and terminating traffic to compete for a single pool of slots at the exchange interface. The situation is illustrated in Figure 2. Removing the bottleneck increases the traffic from 14.22 Erl to 18.405 Erl with the same grade of service (GoS).

The method of dealing with a single link failure is the same as in the DCR-300 and therefore there is no degradation in the GoS if there is a link failure.

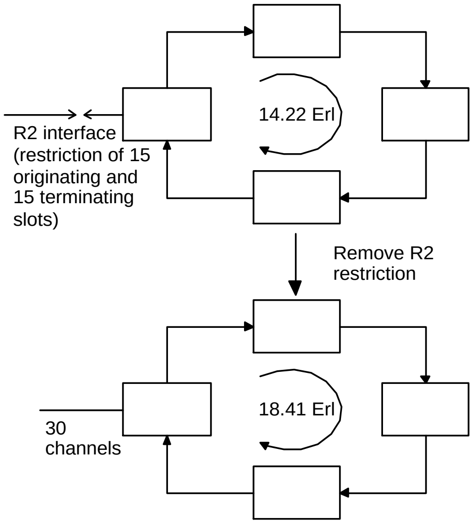

Figure 2 Removal of the R2 interface restriction

4.2 USE OF BIDIRECTIONAL LINKS

Unidirectional links in the ring limit the number of customers in the ring. By making the links in the ring bidirectional, the number of users in a ring can be increased without increasing the blocking. To maximise the capacity of the bidirectional loop, the interface links to the local exchange are increased to two links with 30 channels each.

The ring network architecture examined in this section and the sections that follow consists of seven-concentration terminals (CT) connected together in a ring with 30-channel bidirectional links (Figure 3). The ring is terminated at each end by the central station (CS) element. Subscribers are connected to the ring network through subscriber line interfaces located in each CT. Routing of a subscriber attempt is based on acquiring a slot on each link making up the primary or secondary route. The primary and secondary routes are configured when the ring is setup to keep blocking to a minimum. The routing strategy considers the user distribution in the ring, the type of traffic in the ring and the number of links required to route a call. Blocking is caused when the network controller cannot route a call attempt using the primary or secondary routes. The first and last link in the ring set the capacity limits of the ring and no further concentration of traffic occurs in the central station (CS).

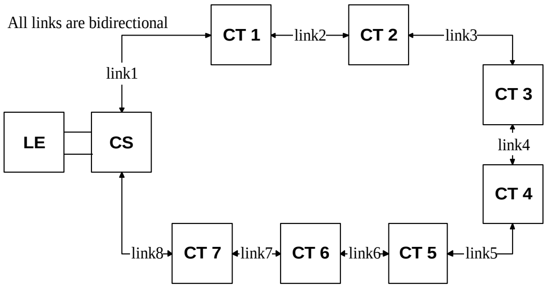

Figure 3 Seven-CT ring network

4.2.1 ROUTING STRATEGY IN THE RING

The routing strategy used in this ring study is as follows:

1. Divide the nodes in the ring into two groups of adjacent CTs giving a division of users as close to equal as possible.
2. The primary route for CTs in the group containing CT1 is via link1. Likewise the primary route for CTs in the group containing CT*n* is via link(*n+1*).
3. Similarly the secondary route for CTs in the group containing CT1 is via link(*n+1*), while the secondary route for CTs in the group containing CT*n* is via link1.

The rationale behind dividing the subscribers into two groups is based on a consideration of first choice routes. The Erlang B formula can be used to calculate the blocking because the simulation is based on originating and terminating events occurring randomly and calls encountering congestion are lost.

Assume that the ring is cut giving two groups of CTs, as described above, with N_1 users in one group and N_2 users in the other group. Applying the Erlang B formula to each group gives the following blocking probability per group:

$$B_1 = \frac{\frac{A_1^S}{S!}}{\sum_{k=0}^{S} \frac{A_1^k}{k!}}, \quad B_2 = \frac{\frac{A_2^S}{S!}}{\sum_{k=0}^{S} \frac{A_2^k}{k!}}$$

where S = number of slots in the ring, and

$A_1 = N_1 \cdot \alpha$

$A_2 = N_2 \cdot \alpha$

are the originating and terminating traffic.

B_1 and B_2 represent the blocking probability of the two groups. Routing is based on the principle of making $B_1 \approx B_2$. For a first approximation make $N_1 = N_2$.

4.2.2 THE NON-UNIFORM DISTRIBUTION OF TRAFFIC

The distribution of traffic in a ring with bidirectional links is important since not all users in the ring have the same chance of making a successful call attempt. In the simulations that follow, the following customer distribution will be used:

The ratio of customers on each node to total ring users chosen for the case studies that follow for CTs/nodes 1 to 7 is: 30%, 12%, 8%, 12%, 8%, 20% and 10% respectively.

5 NON-UNIFORMLY DISTRIBUTED RING NETWORK SIMULATION

A seven-CT ring network is simulated, firstly with customers generating only telephone traffic and secondly with customers generating mixed traffic.

5.1 NON-UNIFORMLY DISTRIBUTED TELEPHONE TRAFFIC RING NETWORK SIMULATION

A seven-CT ring network is simulated with 1000 users generating only telephone traffic, distributed in the ring using the non-uniform user distribution defined in Section 4.2.2. The number of users per CT and the routing strategy is shown in Table 1. The primary and secondary routes in the table are a result of applying the routing strategy discussed in Section 4.2.1.

	Number of users	Routing Strategy (link numbers shown, see Figure 3)	
		Primary Route	Secondary Route
CT1	300	1	2 3 4 5 6 7 8
CT2	120	2 1	3 4 5 6 7 8
CT3	80	3 2 1	4 5 6 7 8
CT4	120	5 6 7 8	4 3 2 1
CT5	80	6 7 8	5 4 3 2 1
CT6	200	7 8	6 5 4 3 2 1
CT7	100	8	7 6 5 4 3 2 1
Total	1000		

Table 1 Routing strategy for telephone only traffic simulation

Traffic in the ring is made up of originating and terminating telephone traffic totalling 45 mErl per user with average holding time of 180 seconds. Simulation runs of the above case gave an average grade of service (GoS) of 0.25%. Simulation runs showed that the average Erlang per user in the ring network was 43.25 mErl. This figure is close to 45 mErl per user used to generate originating and terminating traffic.

If we compare the average GoS from the simulation runs with Erlang B theory, then 1000 users at 43.25 mErl per user (originating and terminating) competing for 60 slots gives a GoS of 0.29% according to theory. The GoS from Erlang B theory agrees with the average GoS from simulations. Small variations in the generated Erlang at this level have a large effect on the GoS

Analysis of a simulation run showed that the average slot occupancy of the first and last link in the network was 21.63 and 21.53 slots respectively, out of 30 possible slots for each link. The closeness of these values shows that the routing strategy chosen divides the traffic almost equally among the network links thereby minimising blocking.

5.2 NON-UNIFORMLY DISTRIBUTED MIXED TRAFFIC RING NETWORK SIMULATION

In this section, the effect mixed traffic has on the blocking experienced in a ring network is simulated. A seven-CT ring network is simulated with telephone, payphone and Internet dial-up traffic present in the ring. A total of 500 users are distributed non-uniformly in the ring using the distribution described in section 4.2.2. The routing strategy is identical to the previous example (see Table 1). Each CT generates 80% telephone, 10% payphone and 10% Internet dial-up traffic (see Table 2).

CT	Number of Users	Telephone Users	Payphone Users	Internet Users
1	150	120	15	15
2	60	48	6	6

3	40	32	4	4
4	60	48	6	6
5	40	32	4	4
6	100	80	10	10
7	50	40	5	5
Total	500			

Table 2 Distribution of users in the ring generating mixed traffic

Average holding times and Erlang per user used in the simulation are shown in Table 3.

Traffic Type	Originating		Terminating	
	Holding Time (sec)	Erlang per user	Holding Time (sec)	Erlang per user
Tele-phone	180	22.5 mErl	180	22.5 mErl
Pay phone	180	0.2 Erl	180	0.02 Erl
Internet dial-up	900 (log-normal)	0.5 Erl	180 (negative exponential)	0.02 Erl

Table 3 Mixed traffic parameters

Simulation runs of the above case gave an average grade of service of 0.18%. This grade of service is almost equal to the previous case grade of service of 0.25%. This comparison shows that 1000 users generating only telephone traffic (originating and terminating) were reduced to 500 users generating mixed traffic (originating and terminating), if the GoS remains relatively constant. The introduction of mixed traffic, in particular Internet dial-up traffic, has a significant effect on the number of users that can be accommodated in the ring network to give a comparable GoS. Analysis of a simulation run showed that the average slot occupancy of the first and last link in the ring network was 21.69 and 21.71 slots respectively, out of 30 possible slots for each link. As in the previous case, the closeness of these values shows that the routing strategy chosen divides the traffic in the ring almost equally.

6 PROTECTION AGAINST SINGLE LINK FAILURE

A method of reducing blocking in the event of link failure is to provide a backup ring that becomes active when the primary ring fails. There is however a significant cost in providing the backup ring. The cost of the backup ring increases as the ring becomes larger.

On the grounds of economy, another method of reducing blocking in the case of link failure is to provide a backup link to a particular CT.

6.1 LINK FAILURE IN THE RING

A link failure in the ring results in an increase in blocking, since the routing of calls in each resulting group of CTs is limited to one direction only. In this section, in the event of link failure, the effects a single backup link has on relieving the traffic disrupted due to the link failure is presented.

A backup link connected to a particular CT provides relief to the group of users affected most by the link failure. The strategy used to locate the CT to which to connect the backup link is summarised as follows:

1. A link is chosen which separates the CTs into two groups with approximately equal numbers of users.
2. The backup link is then connected to the CT on the end of the link that ends the larger half of the two groups. If the two groups have the same number of users then the backup link is connected to the CT on the periphery of either of the two groups.

For example, if CTs 1 to 3 represent half the total ring users and CTs 4 to 7 the other half, then CTs 3 and 4 are on the periphery of the two groups of users. A backup link can be connected to either CT3 or CT4. The backup link becomes active when a link fails in the network. Figure 4 illustrates the above example with the backup link connected to CT3.

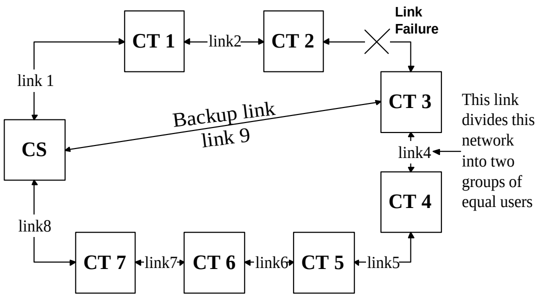

Figure 4 Link failure in a ring network with a backup link connected to CT3

CT	Routing Strategy (link failure on link3) (link numbers shown, see Figure 4)	
	Primary Route	Secondary Route
1	1	-
2	2 1	-
3	9	4 5 6 7 8
4	5 6 7 8	4 9
5	6 7 8	5 4 9
6	7 8	6 5 4 9
7	8	7 6 5 4 9

Table 4 Routing strategy if the third link fails

The routing strategy in the event of a link failure is as follows:

1. Determine which group of CTs primary routing strategy is affected by the link failure. Each CTs primary routing strategy in this group is then chosen to use the least amount of links (including the backup link if necessary) to route a call to the CS.
2. The other group of CTs continue using their existing primary routing strategy, but change their secondary routing strategy to include the backup link.

6.2 PERFORMANCE OF THE RING NETWORK UNDER LINK FAILURE

In the previous section, the effect mixed traffic has on the GoS experienced by users in the ring was discussed. The case studies in this section illustrate the effects link failure has on the GoS experienced by users generating mixed traffic in the ring. The simulator in the link failure cases that follow uses the same traffic parameters and user distribution as in the previous case, summarised in Table 2 and Table 3.

Based on the distribution of users in the ring, the backup link can be connected to the third or fourth CT/node in the ring. The method of choosing to which CT the backup link is connected to is discussed in Section 6.1. Worst case scenarios of the first or last links in the ring failing are simulated.

6.2.1 LINK FAILURE WITH THE BACKUP LINK CONNECTED TO THE 3^RD^ NODE ON RING

The backup link in this simulation case is connected to the CS and the third node in the ring network (i.e. CT3).

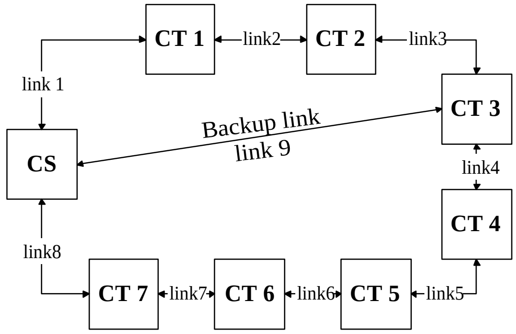

Figure 5 Seven-CT ring network with the backup link connected to CT3

The simulation is run until all transients have died down and then a link is broken to see the effects of blocking in the ring network. The two worst case failure conditions, namely failure on the first and last links in the ring are simulated.

FAILURE ON THE FIRST LINK IN THE RING

The routing strategy used in this case study is shown in Table 5 and is based on the routing strategy discussed in Section 6.1.

Simulation runs gave an average grade of service in the ring after link failure of 0.25%. This figure is higher than the GoS figure of 0.18% with no link failure in the ring. The small increase is due to calls lost when the first link failed. These lost calls especially affected the blocking experienced by the group containing CTs 1,2 and 3 in the ring, since the first link was one of the links in this group's primary routing strategy. Analysis of a simulation run revealed that the average slot occupancy of the last link and backup link in the ring was 21.72 and 21.72 slots respectively, out of 30 possible slots for each link. The closeness of these values shows that although there was a link failure, the backup routing strategies divide the traffic equally among the links.

CT	Primary Route	Secondary Route	Backup Primary Route	Backup Secondary Route
1	1	2 3 4 5 6 7 8	2 3 9	2 3 4 5 6 7 8
2	2 1	3 4 5 6 7 8	3 9	3 4 5 6 7 8
3	3 2 1	4 5 6 7 8	9	4 5 6 7 8
4	5 6 7 8	4 3 2 1	5 6 7 8	4 9
5	6 7 8	5 4 3 2 1	6 7 8	5 4 9
6	7 8	6 5 4 3 2 1	7 8	6 5 4 9
7	8	7 6 5 4 3 2 1	8	7 6 5 4 9

Table 5 Routing strategy if the first link fails and the backup link is connected to CT3

FAILURE ON THE LAST LINK IN THE RING

The routing strategy used in this case study is shown in Table 6 and is based on the routing strategy discussed in Section 6.1

CT	Primary Route	Secondary Route	Backup Primary Route	Backup Secondary Route
1	1	2 3 4 5 6 7 8	1	2 3 9
2	2 1	3 4 5 6 7 8	2 1	3 9
3	3 2 1	4 5 6 7 8	3 2 1	9
4	5 6 7 8	4 3 2 1	4 9	4 3 2 1
5	6 7 8	5 4 3 2 1	5 4 9	5 4 3 2 1
6	7 8	6 5 4 3 2 1	6 5 4 9	6 5 4 3 2 1
7	8	7 6 5 4 3 2 1	7 6 5 4 9	7 6 5 4 3 2 1

Table 6 Routing strategy if the last link fails and the backup link is connected to CT3

Simulation runs gave an average grade of service in the ring after link failure of 0.92%. This figure is higher than the GoS figure of 0.25% with link1 failing and the backup link connected to CT3. The worse grade of service can be attributed to increased blocking experienced by CTs 4 to 7, due to all these CTs using link4 to route a call attempt. Link4 in this case can be considered to be a bottleneck contributing to traffic congestion. Analysis of a simulation run revealed that the average slot occupancy of the first link and backup link was 21.74 and 21.69 slots respectively, out of 30 possible slots for each link. The closeness of these values shows that the backup routing strategy divides the traffic equally among the links in the ring.

6.3 LINK FAILURE WITH THE BACKUP LINK CONNECTED TO THE 4^TH^ NODE IN RING

The backup link in this case is connected to the CS and the fourth node in the ring network (i.e. CT4).

The simulation is run until all transients have died down when a link is broken to see the effects of blocking in the ring network. Two worst case failure conditions, namely the first and last links in the ring are simulated.

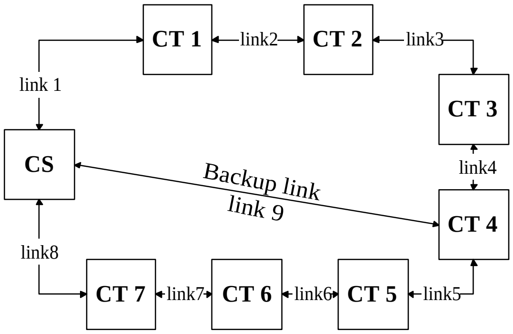

Figure 6 Seven-CT ring network with the backup link connected to CT4

FAILURE ON THE FIRST LINK IN THE RING

The routing strategy used in this case study is shown in Table 7 and is based on the routing strategy discussed in Section 6.1.

CT	Primary Route	Secondary Route	Backup Primary Route	Backup Secondary Route
1	1	2 3 4 5 6 7 8	2 3 4 9	2 3 4 5 6 7 8
2	2 1	3 4 5 6 7 8	3 4 9	3 4 5 6 7 8
3	3 2 1	4 5 6 7 8	4 9	4 5 6 7 8
4	5 6 7 8	4 3 2 1	5 6 7 8	9
5	6 7 8	5 4 3 2 1	6 7 8	5 9
6	7 8	6 5 4 3 2 1	7 8	6 5 9
7	8	7 6 5 4 3 2 1	8	7 6 5 9

Table 7 Routing strategy if the first link fails and the backup link is connected to CT4

Simulation runs gave an average grade of service in the ring after link failure of 0.72%. This figure is higher than the GoS figure of 0.25% if the backup link were connected to CT3 and the same link failed. The increase is due to CTs 1, 2 and 3 all using link4 to route their call attempts under link failure. Link4 is therefore a bottleneck in this case. Analysis of a simulation run revealed that the average slot occupancy of the last link and backup link was 21.59 and 21.82 slots respectively, out of 30 possible slots for each link. The closeness of these values again shows that the backup routing strategy used divides the traffic in the network equally among the links in the ring.

FAILURE ON THE LAST LINK IN THE RING

The routing strategy for this case study is shown in Table 8 and is based on the routing strategy discussed in Section 6.1.

Simulation runs gave an average grade of service in the ring after link failure of 0.24%. This figure is better than the GoS figure of 0.72% for the previous case with link1 failing and the backup link connected to CT4. This better grade of service can be attributed to CTs 4 to 7 not having to use an extra link to route a call attempt (under link failure), as in the previous case. Analysis of a simulation run revealed that the average slot occupancy of the first link and backup link was 21.77 and 21.70 slots respectively, out of 30 possible slots for each link. The closeness of these values shows that the backup routing strategy used divides the traffic in the ring network equally among the links in the ring.

CT	Primary Route	Secondary Route	Backup Primary Route	Backup Secondary Route
1	1	2 3 4 5 6 7 8	1	2 3 4 9
2	2 1	3 4 5 6 7 8	2 1	3 4 9
3	3 2 1	4 5 6 7 8	3 2 1	4 9
4	5 6 7 8	4 3 2 1	9	4 3 2 1
5	6 7 8	5 4 3 2 1	5 9	5 4 3 2 1
6	7 8	6 5 4 3 2 1	6 5 9	6 5 4 3 2 1
7	8	7 6 5 4 3 2 1	7 6 5 9	7 6 5 4 3 2 1

Table 8 Routing strategy if the last link fails and the backup link is connected to CT4

7 CONCLUSION

The expansion of the capacity of ring architectures relative to that of the DCR-300 has been shown. The ring simulator's ability to generate mixed traffic has also been demonstrated. In particular, the simulator's ability to generate asymmetric traffic was demonstrated by having different interarrival times for originating and terminating payphone traffic, and different holding and interarrival times for Internet dial-up calls.

The introduction of mixed traffic in the ring network resulted in 1000 users generating only telephone traffic being reduced to 500 users generating mixed traffic, with the same grade of service. The reduction in users is due to the assumed long tailed holding times of originating Internet dial-up calls, and the high Erlang of originating payphone calls.

From the case of a link failure in the ring network with 500 users generating mixed, it has been shown that the GoS is better if the backup link is connected to a CT in the group of CTs whose primary routing strategy is affected by the link failure.

The proposed routing strategy in a ring architecture where users in the ring are not uniformly distributed was shown to be effective, dividing traffic equally between the first and last links in the ring.

The routing strategy proposed to reduce blocking in the event of a link failure was also shown to be effective resulting in an acceptable increase in blocking which was largely due to calls lost on the link that failed.

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