

Look-ahead Rerouting of Preempted Calls

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Abstract— When communication resources are shared between *Instantaneous Request (IR)* and *Book-Ahead (BA)* connections, activation of future BA connections may cause preemption of on-going IR connections due to resource scarcity. Rerouting of preempted calls via alternative feasible paths is often considered as the final option of choice to restore and maintain service continuity. Existing rerouting techniques however, do not ensure acceptably low service disruption times and suffer from high rerouting failure rates and low network utilization. In this paper a new rerouting strategy is proposed that estimates the future resource scarcity, identifies the probable candidate connections for preemption and initiates the rerouting process for those connections in advance. Simulations on a widely used network topology suggest that the proposed rerouting scheme achieves more successful rerouting rate with lower service disruption times, while not compromising other network performance metrics like utilization and call blocking rates.

Keywords: Resource Reservation, QoS, Service Continuity, Preemption.

I. INTRODUCTION

Recently resource reservation schemes have gained increasing popularity as a research topic mainly due to the tremendous growth in *Quality-of-Service (QoS)* applications, which demand a predefined level of guarantee for a number of key parameters including end-to-end delay, packet loss rate, delay jitter and bandwidth availability. Researchers have proposed two types of resource reservation techniques depending on the application and their dependency on resource availability. The reservation types are: i) *Instantaneous Request (IR)* and ii) *Book-Ahead (BA)*. IR calls generally require low bandwidth and reservation for these calls is attempted upon the arrival of requests. In contrast, BA calls require high bandwidth and resource reservations for these calls are not often possible immediately upon the arrival of the requests. Reservation requests are required to be made in advance so that sufficient resources can be made available at the activation time of a BA application. Applications like multi-party video conferencing, video on demand, live TV broadcast programs, telemedicine, grid computing and distributed simulations which demand high bandwidth and have time-sensitivity significance mandate BA reservations. One of the problems in BA reservation is the need to preempt a number of on-going IR calls in order to supply the required resources for a BA call if resource scarcity arises at the starting time of that BA call. Preemption is a major obstacle to service continuity which is an important and essential element of any users' perceived QoS [1], [2], [3]. In both wired and wireless networks, preemption of on-going QoS required calls causes severe user dissatisfaction and is considered worse than not admitting the call at the first place. Long term revenue prospects of a network provider are very much dependent on user satisfaction, which is clearly influenced by the preemption rate. A number of strategies have been proposed in the literature to achieve low IR call preemption rate. Researchers showed that IR call preemption rates can be successfully reduced at the routing and call

admission control (CAC) stages.

Ahmad *et al.* [4] for instance presented a preemption-aware routing scheme that selected a path for an incoming IR call with the lowest probability of preemption amongst all available paths. The preemption probability was calculated for each link and this information in addition to hop count, was used to form a link cost function. The preemption-aware routing scheme successfully reduced IR call preemption rate. Schelen *et al.* [5] proposed a look-ahead time based CAC scheme that reduced IR call preemption at the CAC stage. The main idea was to set aside resources for BA calls for a certain period in advance (known as *look-ahead time*) so that BA calls do not experience scarcity at the point of activation. Ahmad *et al.* [6] proposed an analytical method to determine the look-ahead time dynamically taking traffic conditions into consideration and showed that the dynamic look-ahead time based CAC model performed better compared to the constant look-ahead time based CAC model proposed by Schelen *et al.* Preemption-aware routing scheme at the routing stage in conjunction with dynamic look-ahead time based CAC model further reduce the IR call preemption rate. Another approach proposed in [7], [8] to reduce the preemption rate involved the strict partitioning of link capacity that divides the network resources into two disjoint subsets dedicated to each class of call and thereby eliminating the problem of preemption of any on-going calls. Optimizing the partition usage however, is difficult and can drastically reduce the network utilization [9]. Greenberg *et al.* [9] proposed an admission control scheme based on an approximate calculation of interrupt probability which showed that resource sharing even at the cost of some preemption, gave better utilization than that in strict resource partitioning. Although all the aforementioned schemes can significantly reduce the IR call preemption rate, it remains a highly complex task to maintain a near zero value, while maintaining satisfactory network performance in terms of other network performance metrics like call blocking rate and resource utilization.

When preemption of an IR call becomes inevitable, rerouting of the preempted call remains the final option for attempting to restore and maintain service continuity. Rerouting techniques search for an alternative path that restores the service of the preempted call. The most critical consideration for a rerouting technique is the connection rerouting time, defined as the time duration required for reconnecting a connection through an alternative path once the connection along the primary path fails. Lower connection rerouting time ensures minimal service disruption time, which is the time interval during which reserved bandwidth for that connection is unavailable at any of the links across the path from the source to destination. When service disruption time is limited to an acceptably low range, the degradation in perceived QoS of the applications is often insignificant and end users do not perceive any interruption in service. None of the existing rerouting techniques yield a service disruption time which is sufficiently low to reroute a connection without service interruptions to the agreed QoS. This paper presents a new rerouting technique that aims to reduce the service disruption time of rerouted IR calls and thereby provide improved QoS assurance.

II. EXISTING REROUTING TECHNIQUES

There are mainly two groups of schemes proposed in literature to address the problem of rerouting: i) proactive ii) reactive. In the former, additional resources are reserved and dedicated *a priori* along a back-up path so that they can be used immediately once the primary connection fails. Schemes like *multiple copy* [10], *dispersity routing* [11] and *spare allocation* [12] fall into this category. Connection rerouting time is lower for proactive rerouting schemes as there is no need to compute and reserve resources once the primary connection encounters a problem. However, maintaining a back-up path for each connection in a network incurs heavy costs and is in practice, infeasible as it restricts future calls from using the resources. This results in unacceptably low resource utilization and high call blocking rates, which simply renders them unusable for a commercial network. In reactive schemes, an attempt to reserve resources and reroute the connection is initiated only after it is realized that maintaining the connections is no longer feasible along the current path. Such schemes do not have the overheads of maintaining resources along a back-up path, but suffer from long connection rerouting times and/or no rerouting at all if the network is highly loaded.

From an implementation perspective, Doverspike [13] classified the rerouting approaches along three axes: link rerouting vs end-to-end rerouting; centralized vs distributed schemes; pre-computation vs dynamic computation rerouting schemes. The first of these focuses on the network point (e.g., source or uplink node) at which rerouting has to be initiated, while the second focuses on the controlling point of rerouting. In a centralized scheme, the rerouting process is governed by a central point, though this approach suffers from the problem of unscalability, single point failure of the control unit, high latency and communication bottlenecks. Distributed approaches do not have these problems, but provide sub-optimal solutions. Pre-computation vs dynamic computation rerouting schemes focus on the time it takes to select an alternative path. Banerjea *et al.* [14] further explored rerouting schemes along three components: locus to reroute, reroute timing and retry model. The ‘locus to reroute’ model explored the link (local) vs end-to-end (global) choice of rerouting schemes. With a local rerouting model, the immediate upstream node of the failed link/node takes the responsibility to determine a path segment from that node to destination and thereby reroutes the connection. In ‘end-to-end’ rerouting model, any failure information is sent to the source which then determines a path from that source to the destination and completes the restoration. The reroute component chooses the start time for the rerouting attempt and the decision concerning this time is governed by the reroute timing model. Possible approaches for reroute timing include immediate, random and sequential. Immediate timing attempts to reroute the path as soon as the failure information is reported, so this is the least cooperative approach and requires an instant solution. For random rerouting, the reroute time is determined by generating a random value from a uniform distribution over an interval of time. This approach offers some level of cooperation among the nodes trying to reroute. Under sequential timing, all rerouting attempts are initiated sequentially with only one controlling node initiating a rerouting attempt at any given time. The ‘retry model’ governs the number and timing of retry attempts if the attempt for connection restoration initially fails. Immediate retry attempts to reroute the connection immediately following the failure of the previous attempt to reroute the connection, while a delayed retry attempts to reroute after a randomly selected waiting interval.

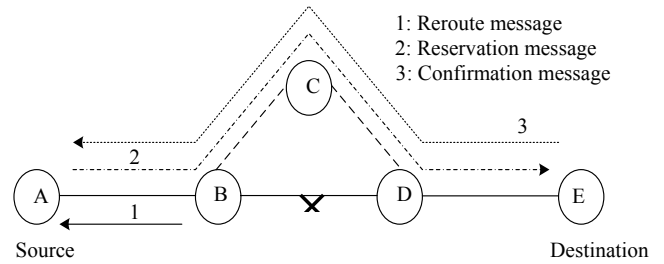


Fig. 1: Connection rerouting in reactive approach.

Although rerouting is considered as a useful tool to restore preempted IR calls, the key consideration is the service disruption time. None of the aforementioned rerouting schemes are sufficiently efficient to reroute a call with an acceptably low service disruption time. Moreover, they are not designed for a network platform where BA and IR reservation calls share the same network resources. In the next section, we present a new reactive rerouting scheme for IR calls with an aim to reduce service disruption time of preempted IR calls in an environment where resources are shared between IR and BA calls.

III. PROPOSED LOOK-AHEAD REROUTING SCHEME

As discussed in the previous section, proactive schemes are not applicable in commercial networks due to their low resource utilization while reactive scheme require long rerouting time. Since high resource utilization is highly desirable in commercial networks, reactive routing is more attractive which forms the basis of the proposed scheme. As shown in Fig. 1, connection time in reactive rerouting is comprised of delays at the following three stages: i) time required for the rerouting message to reach the source/uplink node (Step 1 in Fig. 1), ii) Time required for source/uplink node to compute an alternate path, and iii) Time required for the reservation message to traverse the whole round trip path to reserve the requisite bandwidth (Steps 2 and 3).

The time required for the rerouting message to reach the source/uplink node depends on the choice of the locus of rerouting, which determines whether the uplink or source node will attempt to reroute the connection. Banerjea *et al.* [14] demonstrated that source (global) rerouting always outperforms uplink (local) rerouting in terms of successful rerouting rate. Since unsuccessful attempts of rerouting result in complete termination of the service, the choice of locus that contributes to higher successful rerouting rates should be exercised in QoS-enabled networks. The locus of rerouting requires a time duration to select an alternate path from that node to the destination. The duration time depends on both the routing algorithm and its computational complexity. Once a path has been selected by the locus of rerouting, resource reservation protocols send a reservation message across that path which cross-checks (CAC) the feasibility of allocating resources to that connection and if found feasible, reserves the necessary resources. This involves a complete round trip of the reservation message. If the round trip message reaches the locus with the confirmation of resource being reserved, the locus starts to transmit data via the new path. In such cases, the service disruption time equals the connection rerouting time. In this paper, we propose a technique to reduce the service disruption time by initiating the rerouting process in advance before the actual resource scarcity occurs. An early start of rerouting process results in low service disruption upon preemption. To initiate the rerouting process in advance *a priori* knowledge of resource scarcity is required by the preemption policy to identify the probable candidate calls for rerouting. In a network where resources are shared between

IR and BA calls (Fig. 2), future resource scarcity can be predicted based on future BA and current IR loads [4], [6].

Consider the network scenario shown in Fig. 2. Let t_s be the nearest BA call activation time (potential resource scarcity point), T_r the time required for the rerouting message to reach the locus of rerouting, T_p the time required by the routing algorithm to select a path from the locus to the destination, and T_r the time for a reservation message to make a round trip travel and reserve bandwidth across the path.

The total rerouting time T_R can then be expressed as:

$$T_R = T_f + T_p + T_r \quad (1)$$

If n_1 is the total number of links from the failure node (due to resource scarcity or hardware malfunction) to the source node and the average delay for message traversal between two nodes is Δ_1 , then T_f is expressed as:

$$T_f = n_1 \Delta_1 \quad (2)$$

If n_2 is the length of newly selected path and the average delay for call admission control per link is Δ_2 , then T_r becomes:

$$T_r = n_2 (\Delta_1 + \Delta_2) + n_2 \Delta_1 \quad (3)$$

Existing reactive rerouting techniques are initiated only after experiencing resource scarcity, so the rerouting of connections (if feasible) will be possible no sooner than time $(t_s + T_R)$, so the length of service disruption equals the length of connection restoration time T_R . This can be reduced if the rerouting process is initiated in advance at time $t_o < t_s$, so if $(t_o + T_R) < t_s$ then the service disruption time is zero and rerouting is achieved without any interruption of service, which is the ideal case. As mentioned earlier, estimation of resource scarcity is required for the preemption policy to select the candidate connections for rerouting. A BA table that contains future activation time, duration and load of BA calls is maintained at each link and using these tables, the resource scarcity s at t_s expressed as a fraction of IR load at t_0 is estimated as [15]:

$$s = \max(R(t_0) + A(t_s) - C, 0) / R(t_0) \quad (4)$$

Here, $R(t_0)$ is the aggregate bandwidth currently used by IR calls at t_0 , $A(t_s)$ is the amount of bandwidth required at the nearby BA activation time t_s and C is the link capacity. Preemption policy takes the information of resource scarcity s into consideration and provides a list of IR calls that are to be preempted. Mathematically, the preemption policy is expressed as [15]:

Given $\alpha, \beta, \gamma, \delta, \mathbf{y}, \mathbf{b}, \mathbf{d}$

Find \mathbf{z} that minimizes $F(\mathbf{z})$ subject to $\mathbf{z} \cdot \mathbf{b}^T > s$

where $F(\mathbf{z}) = \alpha(\mathbf{z} \cdot \mathbf{y}^T) + \beta(\mathbf{z} \cdot \mathbf{1}^T) + \gamma(\mathbf{z} \cdot \mathbf{b}^T) + \delta(\mathbf{z} \cdot \mathbf{d}^T)$

Here \mathbf{z} is a vector comprised of m binary variables where m is the total number of on-going IR call connections in the system. Each component of \mathbf{z} takes the form of

$$\mathbf{z}(l) = \begin{cases} 1 & \text{if call } l \text{ is preempted} \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

Vectors \mathbf{y} , \mathbf{b} and \mathbf{d} indicate the priority, bandwidth and estimated user dissatisfaction of the existing call connections respectively. The term $\mathbf{z} \cdot \mathbf{y}^T$ represents the priority of the preempted calls, $\mathbf{z} \cdot \mathbf{1}^T$ represents the number of preempted calls, $\mathbf{z} \cdot \mathbf{b}^T$ the total preempted bandwidth and $\mathbf{z} \cdot \mathbf{d}^T$ the loss in user satisfaction due to service disruption. α, β, γ

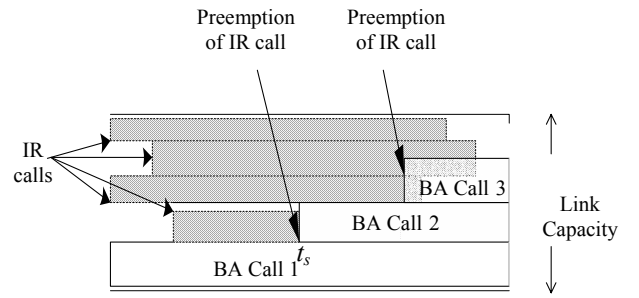


Fig. 2: Preemption scenario of IR calls.

and δ are weights that define the level of preference. Since estimation of resource scarcity at time t_o is made based on the assumption that the current pattern of IR load continues until t_s , the greater the time difference between t_o and t_s , the higher the chance for estimation error, so the rerouting process of IR calls cannot be initiated very far in advance. A shorter than necessary time in advance to initiate rerouting will cause service disruption while a longer than necessary time may result in an inaccurate number of reroutes due to a higher likelihood of errors in estimating the scarcity. It is thus appropriate to compute the advance rerouting time conservatively based on the worst case computational complexity for connection rerouting time.

For a network with E edges and V nodes, the maximum length that a link failure message may have to traverse is $(|E|-1)$ in source rerouting. The length of the alternative path in the worst case may contain all the links except the failed one, so therefore the reservation message in the worst case may have to traverse up to $(|E|-1)$ links. The routing algorithm (Dijkstra's shortest path [18]) in such cases requires time complexity of $O(n \log n)$ where n equals $(|E|-1)$. For a network with known system (hardware and software) performance, the worst case routing complexity represents a value (Ω) in real time. Using the notations Δ_1 and Δ_2 for the delay in message traversal and CAC respectively, the worst case restoration time $\max(T_R)$ is:

$$\max(T_R) = (|E|-1)\Delta_1 + \Omega + (|E|-1)(\Delta_1 + \Delta_2) + (|E|-1)\Delta_2 \quad (6)$$

While (7) can be generically used for all types of network, the calculation of maximum rerouting time can be made more realistically once connectivity information is available. For a network with fixed and known physical connectivity, it is possible to compute the longest possible path in the network between any pair of nodes using the *all pair longest path* algorithm, which is essentially the *all pair shortest path* algorithm [18] with a modification (maximization instead of minimization of length) in the objective function. If N indicates the length of all pair longest path, then the worst case rerouting time takes:

$$\max(T_R) = (|N|-1)\Delta_1 + \Omega + (|N|-1)(\Delta_1 + \Delta_2) + (|N|-1)\Delta_2 \quad (7)$$

This indicates that if the rerouting process is initiated at $\max(T_R)$ time in advance (i.e., at time $t_s - \max(T_R)$), service disruption time will be zero for successfully rerouted connections. The algorithm for the proposed rerouting technique in advance can be formalised as:

Step 1: At time $t_s - \max(T_R)$ estimate the resource scarcity s for the nearest BA activation time t_s .

Step 2: If $s > 0$, find the candidate IR calls for preemption using the preemption policy.

Step 3: Initiate rerouting process of the candidate IR calls.

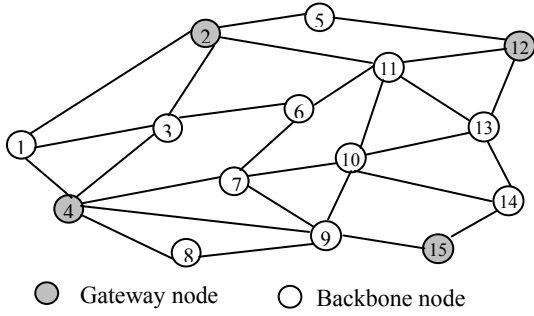


Fig. 3: Simulation test bed topology.

IV. SIMULATION RESULTS

The test bed that has been used for the simulations is shown in Fig. 3. The topology represents a typical ISP network that follows the ATT backbone network structure and has been simulated in previous studies [4], [16], [17]. Call connections enter or leave the network through the gateway nodes. Bandwidth demand of each BA call is uniformly distributed in the range of 1 to 2 Mbps and that of each IR call is uniformly distributed in the range of 64 to 256 kbps. Lifetime of BA and IR calls is exponentially distributed with a mean of 300s and 90s respectively. Arrival of BA and IR calls is assumed to follow a Poisson distribution with a mean arrival interval of 10s and 200ms respectively. Average propagation latency for each link is considered as 10ms and average time requirement for CAC is considered as 2ms for each link [14]. Since the study is based on BA reservation, each simulation is repeated for different BA limits β . BA

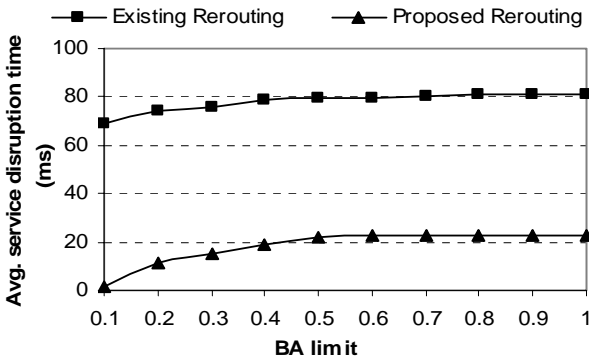


Fig. 4: Average service disruption time across different BA limits.

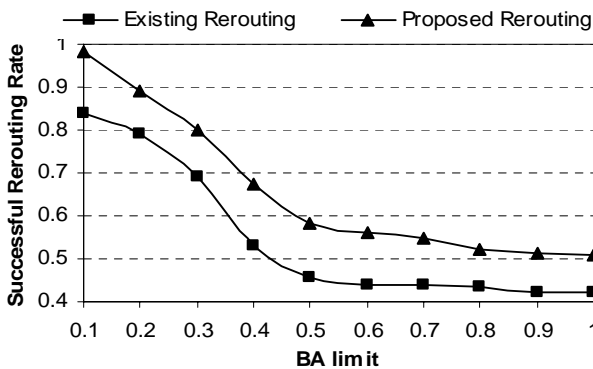


Fig. 5: Successful IR call rerouting rate for different BA limits.

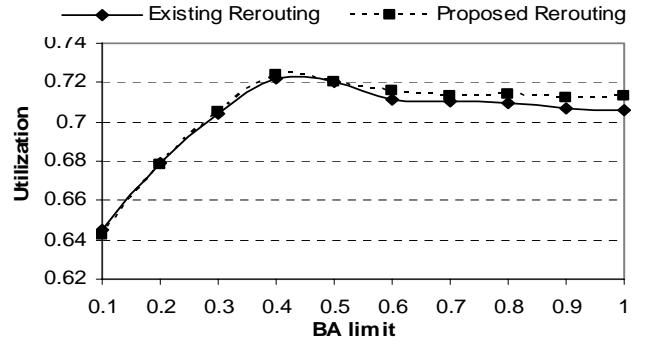


Fig. 6: Resource utilization in different BA limits.

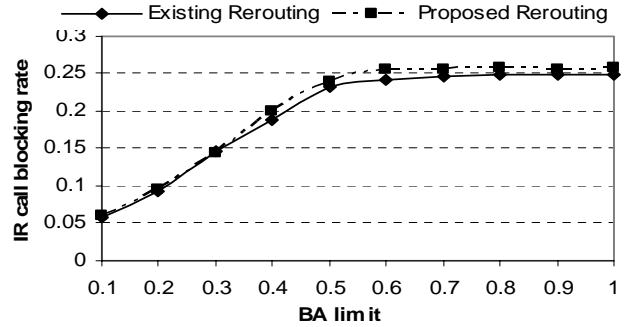


Fig. 7: IR call blocking rate for different BA limits.

limit β sets the normalized limit on link capacity that the aggregate BA load can use so that starvation for IR load is avoided. In our simulations the average service disruption time is investigated per successfully rerouted call, successful rerouting rate (SRR) and SRR with tolerable service disruption. Successful rerouting rate is the ratio of the total number of successfully rerouted calls to the total number of attempted rerouting calls, with the former including those preempted calls that are reconnected through alternate paths at zero or finite time disruption in service continuity. We also investigated the effect of the proposed technique on network utilization and call blocking rates.

Figure 4 shows the average service disruption time per successfully rerouted connection in the proposed and existing reactive rerouting schemes. The results indicate that the average service disruption time is much lower in the proposed rerouting scheme, so validating the benefit secured of initiating rerouting in advance to reroute IR calls. The proposed scheme consistently outperforms the standard reactive rerouting scheme by a margin of up to 60ms. The average service disruption time increases with increasing BA limits because more BA calls are then allowed in the network resulting in an overall increased load. With this increased load, the length of feasible alternative paths is often longer and hence it takes longer time to reroute IR calls.

Figure 5 shows the total IR call rerouting rate in the proposed and standard reactive rerouting schemes, from which it is again evident that the proposed rerouting scheme reroutes more preempted calls compared to the existing rerouting scheme. This is because the proposed rerouting scheme allows an advanced attempt to reroute the probable preempted calls in addition to the standard attempt at the point of resource scarcity. Those calls that do not succeed in being rerouted in the advance attempt get another chance for restoration at the point of resource scarcity. The proposed scheme yields up to 12%

V. CONCLUSION

In this paper, a new rerouting scheme has been proposed with the objective of improving the service disruption time and successful rerouting rate of preempted IR calls when both IR and BA calls share the same resources. The existing rerouting schemes do not consider the sharing of resources between IR and BA calls and so have limited use in such environment. In the new scheme, the estimation of future resource scarcity has been successfully applied to initiate rerouting in advance for those IR calls which are at particular risk of preemption upon activation of BA calls in the immediate future. The appropriate time to initiate rerouting of candidate IR calls in advance is derived. Simulation results indicate that the average service disruption time and successful rerouting rate improve significantly when the proposed rerouting scheme is used. Future work will address the problem of longer messaging delay for resource reservation in the rerouting process for further reduction of service disruption time.

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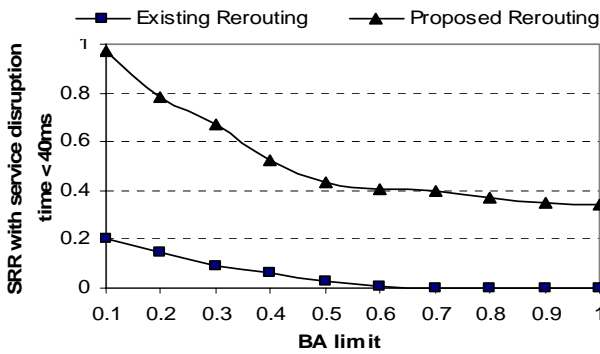


Fig. 8: IR call rerouting rate with tolerable (<40ms) service disruption.

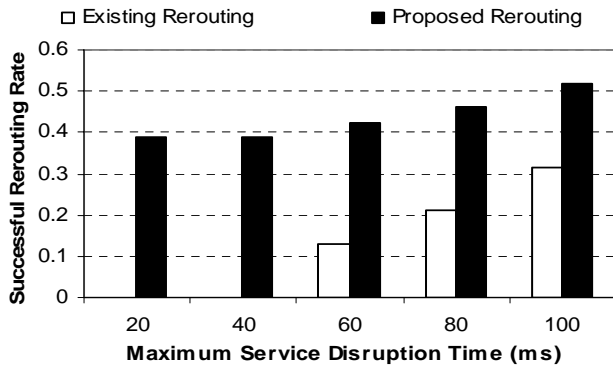


Fig. 9: Successful rerouting rate across different maximum allowable disruption limit at BA 0.7.

more successful rerouting rate compared to existing rerouting scheme across different BA limits. Lower service disruption times mean significantly higher number users are satisfied in a QoS-enabled network. We also investigated average data loss, IR call blocking rate and resource utilization in both rerouting schemes. It is observed that the proposed rerouting scheme performs better compared to existing rerouting scheme in terms of average data loss and resource utilization (Fig. 6). For call blocking rate, both schemes perform comparably (Fig. 7).

The benefit is further depicted in Fig. 8 where the proposed approach reroutes significantly higher number of IR calls when the maximum allowable service disruption time is restricted to 40 ms. Here, the limit assumes that if the connection can be rerouted within 40ms limit following preemption, the degradation in perceived QoS will be still acceptable to the users as per the service level agreement. The proposed rerouting scheme outperforms the existing reactive rerouting scheme by a margin up to 70% in successful rerouting rate across different BA limits. Fig. 9 shows the successful rerouting rate when different maximum allowable service disruption time is exercised with a BA limit of 0.7. The figure suggests that the improvement achieved by the proposed rerouting scheme is consistent across different values of maximum allowed service disruption time. The computational complexity involved with the proposed rerouting scheme is insignificant because the worst case length of look-ahead rerouting time is fixed for a particular network and hence requires a single time computation.