Dynamic Multipath Routing in Networks and Switches Carrying Connection-Oriented Traffic

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Abstract— **We propose a dynamic multipath routing (DMPR) scheme to improve resource utilization of a network for a given quality of service (QoS) in carrying delay sensitive traffic. The proposed scheme takes advantage of available alternate routes which can be used beneficially in communication networks or switches, without increasing the network latency. Through simulation study of circuit-switched, virtual circuit-switched (ATM) and packet-switched (Internet) networks we demonstrate the benefit of using DMPR over single-path routing (SPR) scheme. We also discuss the implementation aspects of DMPR scheme in data networks and the overhead associated with it.**

Keywords— **Dynamic multipath routing, single-path routing, QoS, latency, network efficiency.**

I. INTRODUCTION

Traffic in a telecommunication network can be broadly classified into two categories − delay-tolerant or non-real-time traffic (*e.g.,* data file, email) and delay-sensitive or real-time traffic (*e.g.,* voice, multimedia). For delay-sensitive traffic, it is required to set up a source-to-destination route before the call is initiated so that the delay jitter and synchronization problem are minimized. The routing problem at the call initiation stage in circuit-switched, virtual circuit-switched (VC-switched), and packet-switched networks have been studied by many authors in the past (see, *e.g.,* [1]-[10]). The main motivation behind these studies was to optimize the resource utilization at the call initiation stage. However, the issue of dynamic resource optimization in a network or switch, while a connection-oriented (*i.e.,* delay-sensitive) call is in progress, has got little attention in the literature. In this paper we address this issue to enhance the network efficiency by increasing the of resource utilization.

In general, a network or switch can have a number of alternate routes between any source-destination pair with certain preferential hierarchy, where the hop count can be a measure for route preference. It is also possible that due to congestion during initiation of a call, a less preferable (*i.e.,* non-optimal) route with longer path length is selected. This would require more *network resources* [1] than that in case of the highest priority route. Selection of a non-optimal route for a call may lead to selection of longer routes for future calls. Moreover, recent trends in Internet access such as voice over IP (VoIP) application and multimedia communications dictate an increase in the average call duration [11]. Therefore, while a call is in progress, if the availability of the network resources could be monitored continuously, and the call is dynamically rerouted through a shorter path, it may be likely to result in a more efficient utilization of network resources in terms of higher call success rate and/or reduced access delay.

It was reported in [1] and [5] that dynamic routing may hurt the network performance at times when the traffic is high. We note, however, that these approaches alleviate instantaneous congestion by allowing rerouting of a call through a longer route. In contrast, in our approach, rerouting of an ongoing connection-oriented call is allowed only if the new route is more preferable (*i.e.,* shorter) than the current one. Experimental results show that the scheme proposed in this paper improves network performance by up to $20\ \%$ in terms of call success rate, and by reducing access delay.

II. NETWORK EFFICIENCY

In this section we demonstrate the efficiency in network efficiency with the proposed dynamic multipath routing (DMPR) scheme through a simple example. We discuss network access delay using conventional single-path (*i.e.,* static) routing (SPR) and then compare it with the DMPR scheme.

A. Network Access Delay

Let us consider a simple 3-node network (Fig. 1), where source and destination node pairs are denoted as S_i and D_i, for $1 \leq i \leq 3$. Intermediate nodes are denoted as N_i, for $1 \leq i \leq 3$. The following assumptions are made:

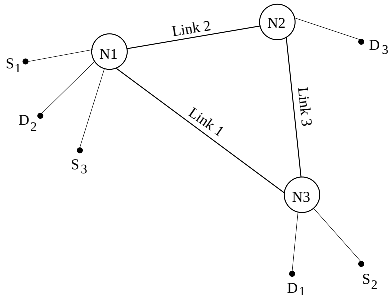

Fig. 1. A 3-node circuit-switched network

(1) Priority-wise routing options:
S_1-D_1: (i) Link 1; (ii) Link 2, Link 3.

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[1] By *network resources* we mean link bandwidth and processors. Henceforth we will use the term *network* generically for any interconnection network (*e.g.,* a wide area communication network, a multistage switch, or a multiprocessor computer).

S_2-D_2: (i) Link 1; (ii) Link 3, Link 2.
S_3-D_3: Link 2.
(2) Poisson distributed traffic generation rate at each node, with parameter λ.
(3) Exponentially distributed call duration, with mean $\frac{1}{\mu}$.
(4) A link can carry only one call at a time (circuit-switched network).

Suppose S_1 initiates a call to D_1 at time instant T_1 with an average call duration $\frac{1}{\mu}$. To consider the worst case delay, we assume sources S_2 and S_3 attempt to initiate calls nearly at the same time to destinations D_2 and D_3, respectively, τ time instant later than T_1, where $0 \leq \tau \leq \frac{1}{\mu}$. If S_2 is able to access the network prior to S_3, then depending on the routing scheme (SPR or DMPR), delay encountered by S_3 to access the network varies, as described below. Timing requirements for these two routing schemes in a given traffic scenario are shown in Fig. 2.

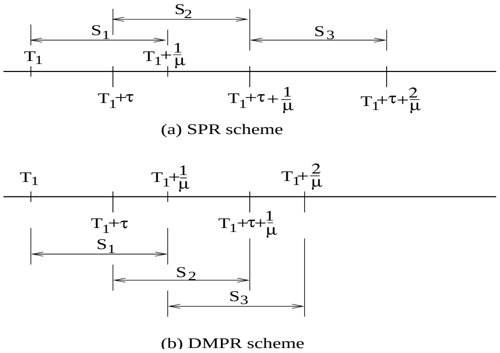

Fig. 2. Timing requirements in the two routing schemes for the network shown in Fig. 1. (a) SPR scheme (b) DMPR scheme

Case 1: SPR Scheme

If the call $S_2 - D_2$ starts at time $T_1 + \tau$, it occupies links 2 and 3. The source S_3 gets access to the link 2 at the time instant $T_1 + \tau + \frac{1}{\mu}$. So, in the worst case (if S_3 attempts to access the network almost simultaneously with S_2) the average waiting time for S_3 is $\frac{1}{\mu}$. The average total time the network remains busy to complete these three calls is $\frac{2}{\mu} + \tau$.

Case 2: DMPR Scheme

In this case, while the call $S_2 - D_2$ is in progress, S_2 attempts to reach link 1 (the shortest path from S_2 to D_2). As soon as S_1 frees the link 1, S_2 reroutes its call via link 1 and frees link 2, for which S_3 is waiting. Since S_2 started τ time instant later than S_1 and both S_2 and S_1 have the same average call duration $\frac{1}{\mu}$, S_2 switches to link 1 on an average $\frac{1}{\mu} - \tau$ time unit later. Therefore, the average delay encountered by S_3 is now $\frac{1}{\mu} - \tau$. The average total time the network remains busy to complete these three calls is given by $\frac{2}{\mu}$.

We note here that DMPR helps reduce the delay in network access, thus improving network utilization. Furthermore, as the average call duration ($\frac{1}{\mu}$) increases, the efficacy of DMPR over SPR scheme becomes more prominent.

The DMPR scheme acts by minimizing the number of hops required for a given source (S) to a destination (D) connection, so that an ongoing call uses only the minimum possible network resources under a given circumstances. The idea can be best described pictorially as shown in Fig. 3. Here, call duration is denoted as t_h. (a) Initial number of hops is 5 (shortest route requires ONE hop : DMPR algorithm is active). Intermediate nodes visited are “i”, “j”, “k”, and “l”. (b) At time t_1 ($0 < t_1 < t_h - t_1$), the number of hops reduces to 3. Intermediate nodes visited are “a” and “b”. (c) At time t_2 ($t_1 < t_2 < t_h - t_2$), the number of hops reduces to 2. Intermediate node visited is “p”. (d) At time t_3 ($t_2 < t_3 < t_h - t_3$), the number of hops reduces to 1 (shortest route : DMPR algorithm is no longer active for the given S-D call)

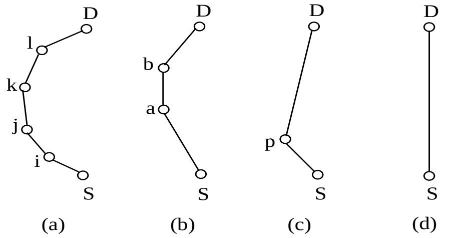

Fig. 3. An example of rerouting a call in the DMPR scheme.

III. Simulation Study

We consider two separate scenarios for studying the impact of the DMPR algorithm on network performance. The first case we simulate is a circuit-switched network carrying delay-sensitive traffic. The second case deals with VC-switched and packet-switched networks.

In simulating the circuit-switched, VC-switched and packet-switched networks, the following assumptions are made :
(A1) Links are bidirectional, of equal capacity, and speed.
(A2) All nodes act as sources and destinations with equal probability.
(A3) Poisson distributed call arrival process, with parameter λ.
(A4) Exponentially distributed call duration, with parameter μ.
(A5) Source routing technique is adopted (which is particularly required for connection-oriented traffic). DMPR algorithm is activated before every call initiation.
(A6) Erlang-B model for circuit-switched network; Erlang-C model for VC-switched and packet-switched networks.
(A7) Finite delay buffer at each node. Immediately unsuccessful calls are stored in delay buffer for future action. Calls generated in excess to the buffer capacity are dropped (VC-switched and packet-switched networks).
(A8) Before call admission, necessary negotiation is done on burstiness of traffic source (VC-switched and packet-switched networks).
(A9) Resource allocation is done on the basis of maximum burst size to avoid the possibility of packet dropping (VC-switched and packet-switched networks).

A. Simulation Results

Based on the above assumptions we study call success rate and delay performance with respect to degree of connectivity, call duration, network size, and maximum burst size. Call success rate and access delay are considered as indicators of the *quality of service* (QoS) of the network. We define the degree of connectivity of a node by its connection probability (p) with other nodes, where a lower p value (*e.g.*, $p = 0.3$) indicates a sparsely connected network, and a higher p value (*e.g.*, $p = 0.9$) indicates a densely connected network. In addition, the following parameter values are considered in the simulation. Call inter-arrival time at a node is $\frac{1}{\lambda} = 2$ *min*. Typical value of call holding time is $\frac{1}{\mu} = 15$ *min*. Call duration is varied from 5 *min* to 35 *min* to study its effect on the call success rate and delay. Link capacity for circuit-switched networks is $L = 4$, and in case of VC-switched and packet-switched networks $L = 1$. In VC-switched and packet-switched networks, link capacity and maximum burst size are, respectively, 1000 *Bytes* and 400 *Bytes*. Number of nodes in circuit-switched networks is considered up to 9, whereas, because of computational overhead, that in case of VC-switched and packet-switched networks are taken up to 8.

Fig. 4 shows the variation of call success rate for different network connectivity with SPR and DMPR schemes in a circuit-switched network. For a fully connected network of a given size, we consider the reference values of link capacity, average values of call inter-arrival time and call duration, for which SPR and DMPR give the same call success rate. We then reduce the degree of connectivity and observe that performance of network with DMPR scheme is always superior until the connectivity is very low. In a 9-node network with connection probability 0.4, DMPR scheme is observed to give around 10 % improvement in call success rate. At very low network connectivity the available alternate paths from a source to any destination tend to vanish, thus reducing the benefit of DMPR.

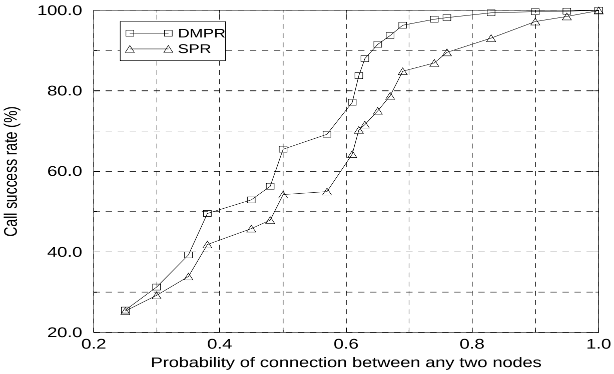

Fig. 4. Call success rate versus degree of connectivity in a circuit-switched network.

Fig. 5 shows the variation of call success rate for different call duration in a circuit-switched network. We select initial set of parameters for a given call duration for which the call success rate with DMPR as well as with SPR is 100 %. For an increase in call duration from 5 min to 20 min, observe that DMPR scheme provides a 20 % improvement in call success rate. Therefore, we expect that with the present trend of longer duration in Internet calls and long distance multimedia communications, the DMPR scheme would be an attractive choice.

We show the variation of call success rate for different network size in a circuit-switched network in Fig. 6. For a given set of parameters and connectivity pattern, improvement in call success rate increases as the network size grows. This is because, for a larger network there is a greater possibility of finding a better alternative path. For a fully connected 9-node network, the DMPR scheme performs up to 20 % better than the SPR scheme.

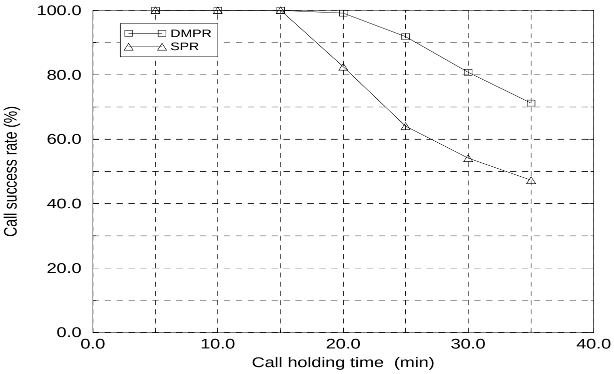

Fig. 5. Call success rate versus call holding time in a fully connected ($p = 1$) circuit-switched network.

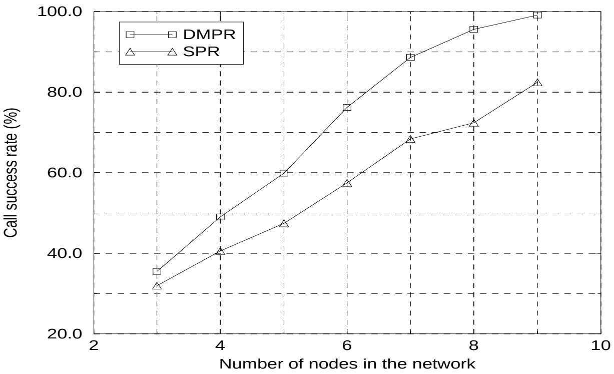

Fig. 6. Call success rate versus number of nodes in a fully connected ($p = 1$) circuit-switched network.

Fig. 7 displays the variation of delay and call success rate for different network connectivity in VC-switched and packet-switched networks. In an 8-node network having connection probability 0.6, we observe around 30 % improvement in access delay and around 12 % improvement in call success rate with the DMPR scheme.

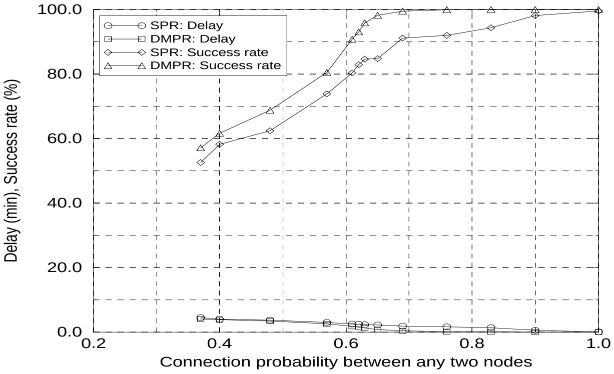

Fig. 7. Access delay call success rate versus degree of connectivity in VC-switched and packet-switched networks.

Fig. 8 shows the variation of delay and call success rate with call duration in VC-switched and packet-switched networks. For 20 min call duration, we observe, for example, 100 ms access delay and 100 $\%$ call success rate with DMPR scheme versus 2 sec access delay and 90 $\%$ call success rate with SPR scheme.

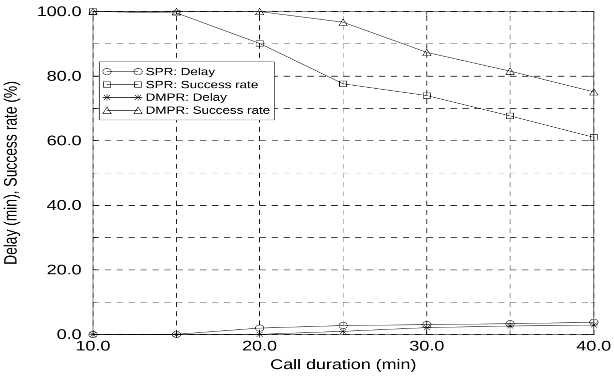

Fig. 8. Access delay and call success rate versus call holding time in VC-switched and packet-switched networks ($p = 1$).

Fig. 9 shows the variation of delay and call success rate with network size in VC-switched and packet-switched networks. We observe that for larger networks, the benefit of DMPR algorithm is more, both in terms of call success rate and delay. For example, in a fully connected 8-node network, access delay and call success rate are 150 ms and 100 $\%$ with the DMPR versus 2 sec and 90 $\%$ with the SPR scheme. Although we have shown this for a fully connected network, similar trends are observed in sparsely connected networks, because as the network size grows, the DMPR algorithm finds more room to play with alternate routes.

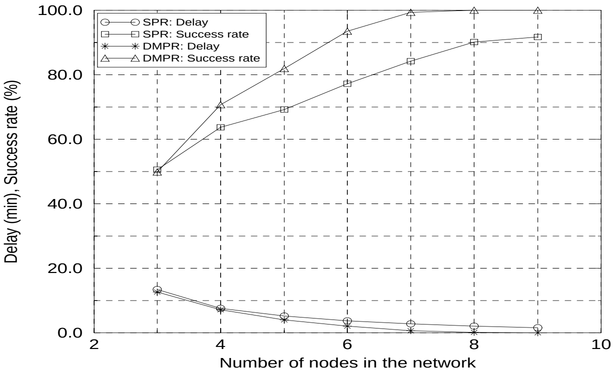

Fig. 9. Access delay and call success rate versus network size in VC-switched and packet-switched networks ($p = 1$).

Fig. 10 depicts the variation in network performance for different maximum burst sizes in VC-switched and packet-switched networks. We observe that as the maximum burst size tends towards the limit of circuit capacity, the benefit of DMPR algorithm diminishes. This is because of the fact that, for larger burst size the choice for rerouting becomes less as the entire circuit between two nodes is blocked by an ongoing call.

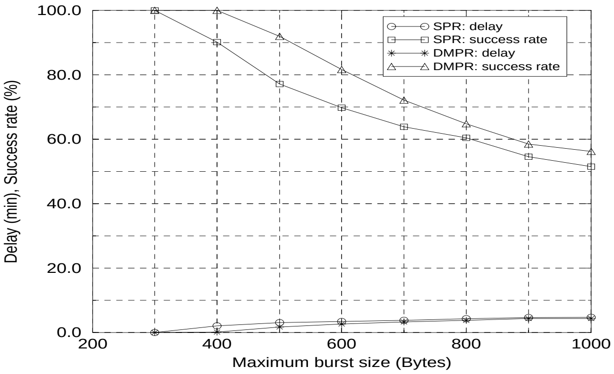

Fig. 10. Access delay and call success rate versus maximum burst size in VC-switched and packet-switched networks.

B. *Discussions*

We observe from Figures 4, 6, 7 and 9 that the improvement in network efficiency (call success rate, delay) with DMPR scheme is more as the network connectivity and size grow. From [12] we note that the degree of connectivity in a practical wide area network may be very low (connection probability between any two nodes is approximately 0.06 in the sample network given in [12]). Similar connectivity pattern in our 9-node circuit-switched network indicates that its connection probability would be approximately 0.3, and in the 8-node VC-switched and packet-switched network it would be approximately 0.4. From the plots in Fig. 4 and Fig. 7 we observe that DMPR scheme still shows an appreciable gain in performance which indicates that it would provide substantial benefit in terms of resource utilization and QoS in wide area networks.

It may be noted here that the DMPR scheme is also well suited for large multistage switches. Generally, the switches, being fully connected, would benefit substantially from the DMPR scheme.

In VC-switched and packet-switched network simulation, channel allocation is done based on the maximum burst size. Although this normally under-utilizes network resources, our comparative study of routing schemes virtually remained unaffected.

We consider connection-oriented traffic in packet-switched networks to indicate voice over IP (VoIP) and multimedia communication over the Internet, which requires adoption of some sort of resource reservation protocol. Since only connection-oriented traffic is considered, VC-switched and packet-switched networks treat it in the same fashion with respect to resource allocation, thus giving identical performance in both the cases. The effects would be different if datagram traffic is also included, in which case these two networks have to be treated separately.

The proposed scheme is essentially an on-line algorithm. Contrary to the belief that on-line algorithms perform poorly in terms of latency (see *e.g.,* [10]), the DMPR algorithm does not increase network latency, since this algorithm runs while a call is in progress (*i.e.,* in parallel with the call) at the source nodes, and rerouting is done only when a better route is available. With the DMPR algorithm, time taken to select an available better route for an ongoing call would be of the same order as initiating a call (which may be less than or equal to a few seconds), whereas the average call duration may be up to 15-20 minutes (specifically true for Internet applications [11]). Therefore, the network would have enough time to implement dynamic rerouting of a call, thus reducing the number of resources used for it.

IV. IMPLEMENTATION ASPECTS

There are several factors which should be considered before implementing the DMPR algorithm in practice. The source node has to search periodically for a better alternative path to the destination while a call is in progress. In circuit-switched networks this task may be performed by exchanging signalling information between a source-destination pair. In VC-switched and packet-switched networks, this monitoring job may be done by resource management (RM) cells.

For selection of a better alternate route an approach similar to that described in [8], for initiating a call, may be adopted. In *serial enquiry (ENQ)* approach, all possible better routes are tried sequentially. Once a better alternate route is obtained the searching scheme stops, the traffic is rerouted through the newly selected path, and the resources in previous route are relinquished. In *parallel ENQ*, all possible better alternative routes are tried simultaneously. If more than one route is found free, the best one is selected. Although the parallel ENQ is a faster searching mechanism, more network resources are associated with this.

Rerouting delay and delay jitter are two major issues that are also to be addressed while implementing DMPR scheme in a network. Unless suitable measures are taken, rerouting of real-time traffic packets through a shorter route may lead to delay jitter and out-of-order delivery at the destination. However, with the knowledge of delay difference between two paths, one can avoid these problems. The source node has to be equipped with an elastic buffer of suitable size (depending on the network size) so that the delay effects are smoothed out.

Because of limited space, we omit here the details of network overhead measure and buffer size requirements.

V. SUMMARY AND CONCLUSIONS

We have studied the network congestion performance of a communication network carrying delay-sensitive traffic. We observe that given a network connectivity, size, and traffic pattern, QoS performance of our proposed dynamic multipath routing (DMPR) scheme is better than that of single-path routing (SPR) scheme. In other words, for the same QoS performance the DMPR scheme requires less network resources.

We have considered circuit-switched networks with Erlang-B (blocked-call-lost) model, and VC-switched and packet-switched networks with Erlang-C (blocked-call-delayed) model. The impact of the DMPR scheme is studied with only one type of traffic (delay-sensitive traffic). However, the study reported in this paper is expected to be helpful in further probing into more practical network scenarios carrying heterogeneous traffic, where some kind of scheduling mechanism has to be incorporated into the system.

We have also highlighted some implementation aspects of the DMPR algorithm in practical networks. Although tackling the delay jitter problem would add extra computational and traffic overhead, our results show that the use of DMPR scheme would offer an overall benefit in terms of resource utilization.

Application of the DMPR scheme to switches appears to be much simpler. A switch can be thought of as a concentrated network, where the propagation delay due to finite speed of the transmission line is negligible. The absence of propagation delay, along with very high switching speed makes the delay jitter problem minimum, and thus obviating the need for additional elastic buffer due to the DMPR. Moreover, the different levels of switches are densely connected, leading to the room for the DMPR to operate. Therefore, switches can extract more benefit from the DMPR scheme.

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