Some Studies on the Impact of Dynamic Traffic in a QoS-based Dynamic Routing Environment*

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Abstract

In this paper, we consider dynamic QoS Routing in an integrated-services environment where some of the offered traffic streams are dynamic. While there has been work on routing performance in the presence of purely stationary traffic, the presence of dynamic traffic has received very little attention. We consider here three routing schemes: Dynamic Random Routing (DRR), Maximum Available Capacity Routing with Periodic update and Crankback (MACRPC) and Maximum Available Capacity Routing with Instant Computations (MACRIC). Based on simulation, we have found that while DRR performs and adapts better than MACRPC in the case of no trunk reservation, it is other way around when there is moderately high trunk reservation (even for less frequent routing updates). Further, we found that dynamics of a traffic class can result in dynamic flow blocking behavior even on stationary traffic, especially at a low or no trunk reservation level.

I Introduction

In an integrated services network where reservation-oriented services require certain guarantees (in terms of bandwidth, delay, loss etc), it is desirable to have routing mechanisms that addresses these aspects. In this context, quality-of-service based routing has been receiving considerable attention in recent years[1, 3, 6, 8]. The goal of a QoS routing mechanism is to determine a path that provides the guarantee to a flow (or call) when the flow is first accepted and then continue to provide the guarantee during the lifetime of the flow. Without loss of generality, in this paper, we will concentrate on bandwidth as the the guarantee needed by any reservation-oriented service. Further, in an integrated services environment, every flow may have a different bandwidth requirement, and is not accepted into the network if the network can not provide the bandwidth guarantee. Thus, the network operates in a loss mode. For the ease of manageability and understanding, we assume that all traffic are classified into multiple traffic classes based on the bandwidth requirement of a flow – we will refer to this as the "multi-service" environment. Our primary interest is the flow-level performance in the multi-service environment where dynamic flow-level QoS routing is employed.

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An important aspect which is not within the control of the network is the network traffic. While network performance has been studied in the presence of dynamic routing in the literature [1, 2, 6, 7, 8], most studies assume the traffic to be stationary. On the other hand, it is known that the connection arrival process for wide-area voice traffic follows nonstationary Poisson process [4]; similarly, while studying Internet packet traffic, Paxon and Floyd [9] have reported that session arrivals are well-modeled by Poisson Process that changes with time. Thus, time-dependent Poisson Process is a good candidate for modeling the flow-level offered traffic to the network. However, the existing literature is essentially silent in taking into consideration non-stationary traffic towards understanding the network performance, especially in the presence of dynamic QoS routing.

Thus, our aim here is to consider the performance of dynamic QoS routing in the presence of dynamic traffic characterized by a non-stationary Poisson process. Specifically, we are interested in seeing how the dynamics of a traffic class may impact the network performance, and more importantly, what is the adaptiveness capability of a routing scheme in the presence of dynamic traffic. In our case, we would also like to consider this in a multi-service environment.

We start the next section with the description of various routing scheme considered in this study, followed by the simulation setup in Section 3. Finally, we present our results and observations based on our study.

II Dynamic QoS Routing Schemes

In QoS routing schemes, the criteria used for computing the routing table are mainly dependent on one or more QoS parameters such as bandwidth, packet delay, packet loss. In this study, we use bandwidth as the only criterion for acceptance of a flow to the network. Given this, we now briefly describe the routing schemes used in our study.

Maximum Available Capacity Routing with Periodic update and Crankback (MACRPC): this scheme always selects the direct path, if one exists. The direct path is the direct link from the source node to the destination node. In a fully connected network, every node pair has a direct link path. If the direct path does not exist, MACRPC scheme selects a path from the set of all possible paths which has available capacity. The scheme updates the routing table periodically based on the link-state update that reports the available capacity of a link, and creates an ordered path set based on the path-available capacity; the duration of the update period (*Route Update Interval*) is a variable parameter of the scheme. Depending on the update period, the routing table from which a path of maximum available capacity is selected for a newly arriving flow can be out-dated. If a newly-arrived flow is blocked on this path, MACRPC scheme allows the flow to *crankback* and try the next best path from the current path set, and keeps trying until all the possible paths which have been cached at the time of last update interval have been exhausted. The flow is considered blocked *only* after all these paths are tried. The performance of this scheme is expected to be dependent on the routing update interval which we will discuss in the results section by considering different update intervals.

Maximum Available Capacity Routing with Instantaneous Computation (MACRIC): In this routing scheme, when a new flow arrives, the entire network is scouted to find the path with the most available capacity; this process is done for *every* newly arrived flow. MACRIC can be thought of as the limiting case of MACRPC. MACRIC is an utopian routing scheme and is hard to implement in practice; it is considered here primarily for benchmarking.

Dynamic Random Routing (DRR): this routing scheme is based on the sticky random routing scheme, Dynamic Alternate Routing (DAR) [5]. At any time, the routing table maintains two paths: the direct path, and an alternate path. A newly arrived flow tries the direct path first, if it exists and the bandwidth can be guaranteed. Otherwise the flow tries the stored alternate path and leaves the system (i.e., is blocked) if bandwidth is not available. In case a newly arrived flow is blocked and cleared, the alternate path is updated by picking randomly a new path for use by future flows; on the other hand, if the flow is accepted on the alternate path, the stored path is not changed.

III Simulation Environment

We have recently developed a Multi-Service Dynamic Routing Simulator (MuSDyR). This is a flow-level simulator where arrival of a new flow is noted along with its bandwidth requirement and then its duration time is generated based on the given average duration provided for this service class; the flow is accepted and routed on a path based on a specific routing scheme – it leaves the system once the flow duration time is over. There is no packet-level details in this simulator which allows us to simulate thousands of simultaneous flows in an efficient manner.

In this tool, we have implemented several routing schemes including the three described above. For MACRPC, we do consider several routing update intervals to see how much does the outdated information impact the network performance. To study the impact of dynamic traffic, we have implemented a time-dependent dynamic flow generator for various dynamic traffic behavior. The arrival of flow is modeled by time-dependent Poisson process. In this paper, we will limit our results to sinusoidal traffic behavior.

Our focus is primarily on the comparative behavior of different dynamic routing schemes in a dynamic traffic environment. It is worth mentioning that a higher-level admission control (such as flow and/or policy-based) can have interesting impact on network performance in the presence of routing (see, for example, [8]); this is, however, outside the scope of the present paper. Within our overall scope, we do consider trunk reservation[1]. To obtain meaningful results and to isolate any behavior, it is not necessary that the entire network traffic be dynamic (this will become clear when we discuss results in the next section). To address this and to consider the variation in bandwidth requirement of a flow, we have divided the network traffic into three traffic classes where some are dynamic and some are stationary, and some have higher bandwidth requirement per flow than the others. Specifically, we consider three traffic classes: SCBRV is a stationary stream with a unit bandwidth requirement per flow. DCBRV is a dynamic sinusoidal traffic stream while it has the same per-flow bandwidth requirement as in SCBRV. The third traffic class, CBRLV, is stationary as in SCBRV, but requires six units of bandwidth per flow. For all work here, we consider a 4-node fully interconnected network.

We consider three different scenarios in our study:

- Scenario-A: all node pairs except one has SCBRV traffic and the remaining pair has DCBRV traffic. The stationary load is 1000 erlangs, while DCBRV follows a sinusoidal curve with 1000 erl as the mean load and 100 erlang as the amplitude (thus, the load range is 1000 ± 100 erl). The average flow duration time for both traffic classes is set to 180 sec. This means that the average flow arrival rate per node pair is 5.55 flows/sec.
- Scenario-B: All node pairs also have CBRLV traffic in addition to Scenario-A. Offered load for SCBRV and CBRLV are 1000 erl and 100 erl, respectively. The Offered load range for dynamic traffic class, DCBRV, is 900 ± 100 erl. The average flow duration time is 180 sec for SCBRV and DCBRV, and is 450 sec for CBRLV.
- Scenario-C: Of six node pairs, four pairs have have SCBRV and CBRLV traffic. The remain two pairs (placed in opposite links in the 4-node network) have DCBRV and CBRLV traffics. The offered load and the average flow duration time for the different traffic classes are the same as in Scenario-B.

IV Results and Observations

In a 4-node network, there are altogether 5 paths possible between any two node pairs. For instance, if the nodes are numbered 1 through 4, then traffic between node 1 and node 4 can possibly take the following paths 1-4 (direct), 1-2-4, 1-3-4, 1-2-3-4, 1-3-2-4. In our experiment, we have cached all the five paths for each node-pair for all routing schemes.

[1] Trunk reservation reserves a part of a link capacity for its own direct traffic in the sense that when this threshold is triggered, an alternate routed flow is not admitted to this link, but a direct call would be admitted[10].

A Scenario-A

First, we discuss results for Scenario-A starting with the no trunk reservation case. The performance measure of interest is the flow blocking probability of each traffic class (all results reported are based on the average value over 20 simulation replication runs). In Figures 1 and 2, the flow blocking probabilities of dynamic traffic class (DCBRV) plotted for routing schemes DRR, MACRIC and MACRPC (for different RUIs). Corresponding figures for the static traffic class (SCBRV) are plotted in Figures 3 and 4.

There are a couple of important observations. The performance of DRR is almost comparable to that of MACRIC. On the other hand, when the traffic load is low, all three routing schemes have similar performance. From Figure 2, we also note that the performance of MACRPC is similar when the RUI is either 240 or 480 sec while the performance is somewhat better for RUI of 15 sec (at higher load). It is interesting to observe also the wide difference in performance between the limiting case, MACRIC, and MACRPC, even at RUI of 15 sec at higher load. (Note that at the mean load, in a 15 sec cycle for each pair, about 83 new flows are generated while at the peak rate of the sinusoidal curve, about 92 new flows are generated). The poor performance of MACRPC at higher load can be perhaps attributed to the out-dated routing table used in the selection of a route and the crankback being detrimental in this operating region. Finally, a crucial observation is that *the dynamic traffic stream has forced the performance of the stationary traffic stream to also have a sinusoidal behavior*.

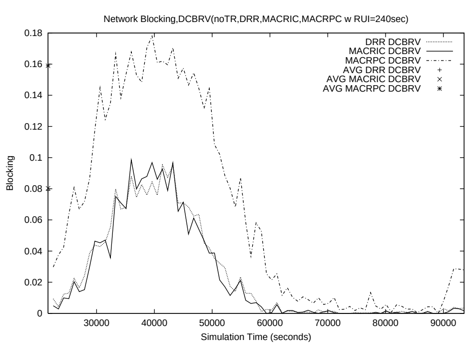

Figure 1: Flow Blocking of DCBRV with no TR

To see if the results would be any different, we have done the simulation runs with trunk reservation set at 10% of the capacity of a link (10%TR). In Figures 5 and 6, the flow blocking probabilities for dynamic traffic class, DCBRV, are shown for various dynamic routing schemes. Comparing these plots with those in Figures 1 and 2, we observe that with 10 % trunk reservation, the performances of all the routing schemes have improved *dramatically*. For example, at the peak load, the flow blocking with MACRPC has dropped from 17% for the noTR case to about 10% for the 10%TR case. It is interesting to note that the performance of DRR scheme is better than that of MACRIC in the presence of trunk reservation at higher load. Also, note that the perceived improvement in performance of MACRPC(RUI=15sec) over

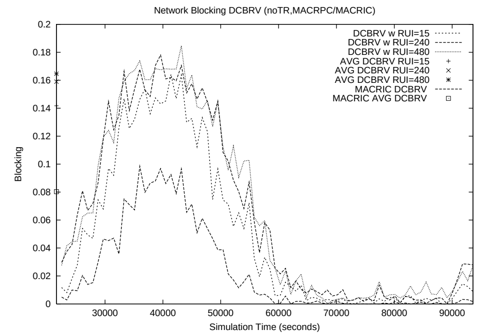

Figure 2: Flow Blocking of DCBRV for different RUIs with no TR

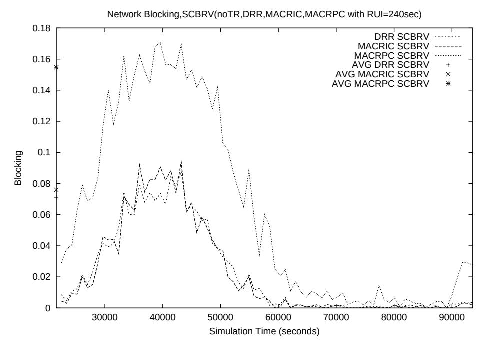

Figure 3: Flow Blocking of SCBRV with no TR

MACRPC(RUI≥240 sec) disappears in the presence of trunk reservation. Again, we have found that at 10% trunk reservation, the dynamic of DCBRV traffic still affects the performance of the stationary traffic class, SCBRV.

From the above results an important question, although not directly within the purview of routing, arises: should a network allow a dynamic traffic stream to impose its behavior on a stationary traffic stream; in other words, should a stationary traffic stream suffer higher flow blocking just because the load for the dynamic traffic stream is increasing. It is fairly clear from the results so far that this can not be addressed solely by a routing scheme. To see if trunk reservation can help in this matter, we imposed a moderately high trunk reservation

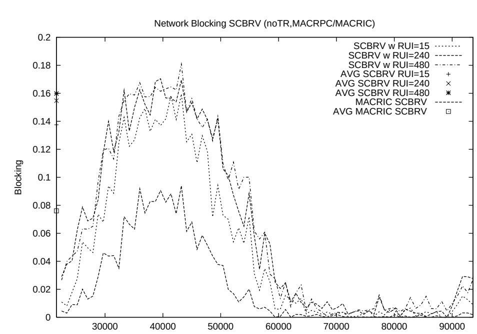

Figure 4: Flow Blocking of SCBRV for different RUIs & noTR

level of 40% uniformly on all links, and ran scenario-A again. The results are dramatically different (see Figures 7). Indeed now, the stationary traffic stream has a fairly stationary blocking behavior irrespective of the change in the dynamics of the dynamic traffic stream. We also note an interesting change in behavior: at the peak load, DRR has *higher* flow blocking than MACRPC (even with RUI of 240 sec!) in the presence of moderately high trunk reservation (while it was other way around for no and low trunk reservation); further, the highest flow blocking level even for DRR is only around 3.5%.

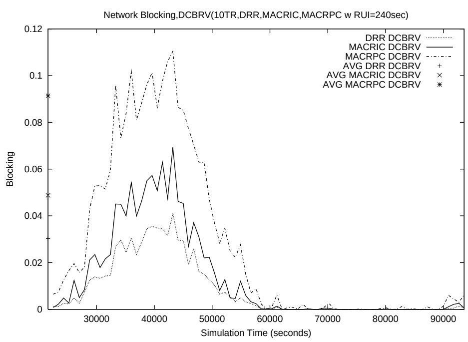

Figure 5: Flow Blocking of DCBRV with 10 % TR

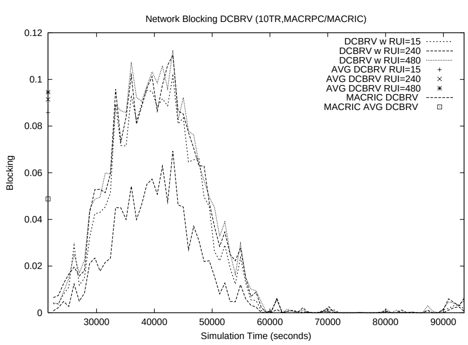

Figure 6: Flow Blocking of DCBRV for MACRPC scheme with different RUIs, 10 % TR

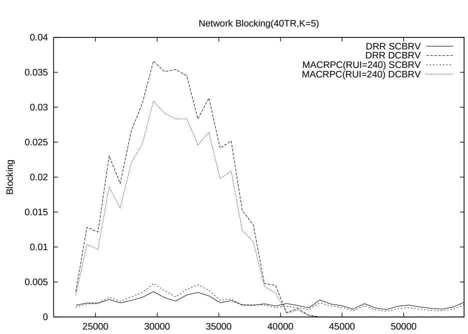

Figure 7: Flow Blocking of DCBRV/SCBRV for DRR & MACRPC schemes with 40 % TR

B Scenario-B & Scenario-C

There are a couple of differences between these scenarios compared to scenario-A. We now have a third traffic class with higher bandwidth requirement per flow; and as such, the traffic offered load is different as well as the total network bandwidth used in the study. The performances of routing schemes for Scenario-B are plotted in Figure 8, 9 and 10 for the no trunk reservation case. It can be seen again that the behavior of the dynamic traffic determines the flow blocking behavior of other traffic streams including the high bandwidth stream (note the right axis of the figures for the range of the value for high-bandwidth traffic class, CBRLV). As in scenario-A, MACRPC scheme performs somewhat poorer compared to DRR and MACRIC schemes with no trunk reservation. In the absence of higher-level flow admission control and trunk reservation, bandwidth based dynamic routing schemes are biased towards low bandwidth flows than higher bandwidth flows, i.e., lower bandwidth services have significantly lower flow blocking than higher bandwidth services. When 10% trunk reservation is imposed, the overall behavior remains the same, but the blocking for all traffic classes are lower relative to the no trunk reservation case (figures not shown due to space limitation).

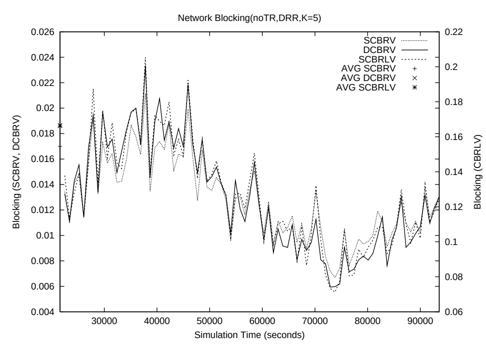

Figure 8: Flow Blocking for DRR scheme (Scenario-B) with no TR

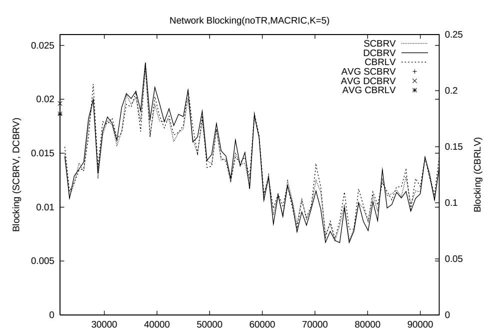

Figure 9: Flow Blocking for MACRIC scheme with no TR (Scenario-B)

Finally, in Figure 11 and 12, the flow blocking probabilities are plotted for Scenario-C with 10% trunk reservation for MACRIC and MACRPC with different values of RUI. In this

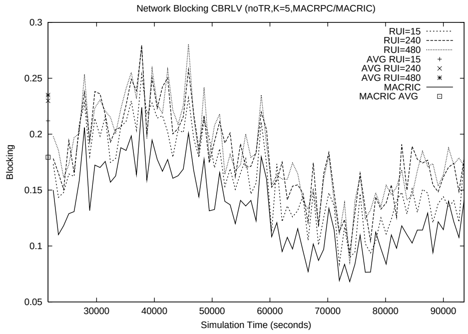

Figure 10: Flow Blocking of CBRLV traffic for MACRPC scheme with no TR (Scenario-B)

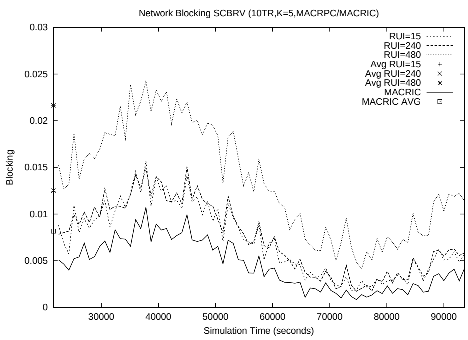

Figure 11: Flow Blocking for SCBRV (Scenario-C)–10%TR

scenario also, we can see that MACRIC has lower blocking than MACRPC for low trunk reservation value while stationary traffic classes blocking is also impacted in the presence of other streams' traffic dynamism. (Due to space limitation, additional results will be reported in a subsequent paper).

V Conclusion

With the emergence of integrated services networks, QoS-based dynamic routing schemes are very essential for maintaining better quality of service (QoS) in the network. However the performance characteristics of these schemes are not known, especially in the presence of dynamic traffic loads. In this work, we have attempted to address this area in a multi-service environment. Using the *MuSDyR* simulator, we have

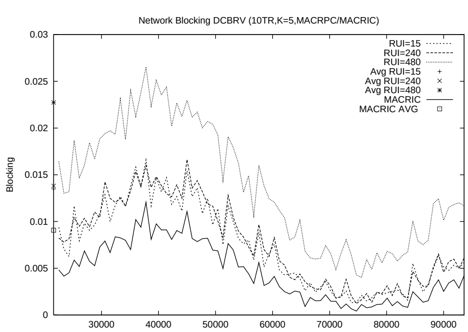

Figure 12: Flow Blocking for DCBRV (Scenario-C)–10%TR

studied the effect of various dynamic routing schemes on the flow blocking probabilities of different service classes.

Some of the main observations of this work are summarized here. Due to dynamic routing, the dynamic traffic load on one node pair can affect the flow blocking probabilities of not only that node pair but also other node pairs in higher load situation in the case of no or low trunk reservation. The performance of Dynamic Random Routing (DRR) scheme is consistently better compared to other two schemes, MACRPC and MACRIC in no and low trunk reservation cases, but MACRPC can perform better than DRR at moderately high trunk reservation level. In the absence of higher-level flow Admission Control mechanisms, these dynamic routing schemes are observed to be biased towards low bandwidth services irrespective of the high and the low of a dynamic traffic stream. Additional studies are ongoing to understand possibly other implications of network traffic dynamics on dynamic routing schemes and the role network control plays.

References

[1] G. Apostolopoulos, R. Guerin, S. Kamat, S.K. Tripathi, "Quality of Service Based Routing: A Performance Perspective," *Proceedings of ACM SIGCOMM'98*, Aug 31 - Sept 4, Vancouver, Canada, pp. 17-28, 1998.

[2] G. R. Ash, *Dynamic Routing in Telecommunication Networks*, McGraw-Hill, 1997.

[3] E. Crawley, R. Nair, B. Rajagopalan, and H. Sandick, "A Framework for QoS-based Routing in the Internet," Internet RFC 2386, August 1998. available from `www.ietf.org`

[4] S.G. Eick, W. A. Massey and W. Whitt, "Nonstationarity in Offered Traffic to the AT&T Long Distance Network," *AT&T Joint Symposium on Performance Analysis and Teletraffic Restoration Theory and Application*, 1990.

[5] R.J. Gibbens, F. P. Kelly, P.B. Key, "Dynamic Alternate Routing," *Routing in Communication Networks*, M. Steenstrup (ed.), Prentice Hall, Englewood Cliffs, pp. 13-47, 1995.

[6] Q. Ma and P. Steenkiste, "Quality-of-Service Routing for Traffic with Performance Guarantees, *IFIP 5th Intl. Workshop on Quality of Service*, pp. 115-126, NY, May 1997.

[7] D. Medhi and S. Guptan, "Network Dimensioning and Performance of Multi-Service, Multi-Rate Loss Networks with Dynamic Routing," *IEEE/ACM Trans. on Networking*, Vol. 5, pp. 944-957, 1997.

[8] D. Medhi and I. Sukiman, "Multi-Service Dynamic QoS Routing Schemes with Call Admission Control: A Comparative Study," *J. Network & Systems Management*, Vol. 8, No. 2, June 2000.

[9] V. Paxson and S. Floyd, "Wide-Area Traffic: the Failure of Poisson Modeling," *IEEE/ACM Trans. on Networking*, Vol. 3, pp. 226-244, 1995.

[10] J. H. Weber, "A Simulation Study of Routing and Control in Communication Networks," *Bell Sys. Tech. J*, Vol. 43, pp. 2639-2676, 1964.