Scheduling for Fair Allocation of Rates in Multirate Multicast Networks

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I. Extended Summary

We study fair allocation of service rates for real time loss tolerant traffic in arbitrary networks with multicast capabilities. Multicasting poses some specific fairness challenges. The fairness objective is that every receiver receives service at a rate commensurate with its capability and the capacity of the path from the source. Hence, different receivers should receive information at different rates. The source encodes the signal into several layers that can be incrementally combined to provide progressive refinement. Every receiver must receive the most significant layer (layer 1) for basic information. If a receiver has additional bandwidth, it can subscribe to other layers for better reception quality. A layer carries meaningful information, only when all the more significant layers have been successfully decoded. Thus the objective is to provide fair rates of service to the receivers, and to limit the packet losses to the less significant layers.

We have previously proposed distributed algorithms for computing the fair rate allocation[1]. Once the fair rates are known, many congestion control policies such as fair queueing can be used to attain the computed rates. However, rate computation requires the exact knowledge of system parameters, such as link bandwidths. In general, the schedulers at the nodes may not have exact knowledge of this link capacity. It is also necessary to exchange messages between neighboring nodes. This increases information overhead. We propose a scheduling policy which attains the maxmin fair rates without computing them beforehand. In addition to guaranteeing fairness, this policy confines packet losses to less significant layers, and protects the more important layers, when there is shortage of bandwidth. Furthermore, this policy does not require any knowledge of traffic statistics, is computationally simple, and is essentially local information based.

II. Scheduling Policy

We propose a scheduling policy based on prioritized round robin with window flow control for multirate multicast networks. Let session i traverse through link l. Then, the "logical buffers" $B_{(i,k,l)}(t)$ denotes the number of layer k packets of session i waiting for transmission in link l at time t. Logical buffers $B_{(i,k,l)}(t)$s are monitored at each node, for every session i traversing the node (Figure 1). A window parameter (W) is associated with the policy.

All sessions traversing a link are sampled in round robin order. Consider a session i traversing link l. When session i is sampled, it first tries to send a packet of the most significant layer (layer 1). If it does not succeed, it tries to send the second most significant layer packet (layer 2), and so on. If all layers of session i are exhausted, the scheduler switches to the next session in the round robin order. Let $\tau_i(l)$ be the set of links originating from the destination of link l that lie on the path of session i. A $k-$layer packet of session i will be successfully transmitted at time t if

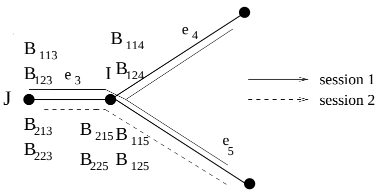

Fig. 1. Each session transmits two layers only. We show the logical buffers associated with source and destination of link e_3. For example, B_{124} consists of session 1 layer 2 packets waiting for transmission in link e_4. Consider the scheduling of link e_3. Here, $\tau_1(e_3) = \{e_4, e_5\}$ and $\tau_2(e_3) = \{e_5\}$. Session 1 and 2 are sampled in round robin order. When session 1 is sampled, it sends the most significant layer (layer 1) packet, if $B_{113}(t) > 0$, and $\min(B_{114}(t), B_{115}(t)) < W$. Otherwise, it tries to send a layer 2 packet. It sends a layer 2 packet if $B_{123}(t) > 0$, and $\min(B_{124}(t), B_{125}(t)) < W$. If it can not send a layer 2 packet, it passes its chance to session 2. Now session 2 tries to send a lowest layer packet first, and so on. Let $W = 5$, $B_{113}(t) = 2$, $B_{123}(t) = 1$, $B_{114}(t) = 5$, $B_{124}(t) = 2$, $B_{115}(t) = 7$, $B_{125}(t) = 6$. In this case, session 1 is not able to transmit a layer 1 packet. However, session 1 transmits a layer 2 packet.

1. no session i packet from layers $1, \ldots, k-1$, can be transmitted,
2. a $k-$layer session i packet is waiting at the source node of the link, for transmission in the link ($B_{(i,k,l)}(t) > 0$) and
3. at least one of the logical buffers for the kth layer of session i at the destination node of the link has less than W packets (i.e., $\min_{l' \in \tau_i(l)} B_{(i,k,l')}(t) < W$).

Refer to figure 1 for an illustrative example. We have proved that for all sufficiently large window and physical buffer sizes, this policy allocates the maxmin fair rates to all receivers of all sessions. Note that congestion related packet loss is possible at any node. The policy offers an inherent priority to more significant layers of a session at every node. Thus the presence of less significant layers is transparent to more significant layers. In fact we have shown analytically that the more significant layers suffer negligible packet loss, and the packet losses are confined to the least significant layer served.

References

[1] S. Sarkar and L. Tassiulas: Distributed Algorithms for Computation of Fair Rates in Multirate Multicast Trees *Proceedings of IEEE INFOCOM'* 2000, Tel Aviv, Israel, March' 2000