A New Deterministic Traffic Model for Core-Stateless Arrangement to Prevent the Collapse

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ABSTRACT

Core-stateless scheduling algorithms have been proposed in the literature to overcome the scalability problem of the state full approach. Instead of maintaining per-flow information or performing per-packet flow classification at core routers, packets are scheduled according to the information (time stamps) carried in their headers. They can hence provision quality of service (QoS) and achieve high scalability. In this paper, which came from our observation that it is more convenient to evaluate a packet's delay in a core-stateless network with reference to its time stamp than to the real time, we propose a new traffic model and derive its properties. Based on this model, a novel time-stamp encoding scheme, which is theoretically proven to be able to minimize the end-to-end worst case delay in a core-stateless network, is presented. With our proposed traffic model, performance analysis in core-stateless networks becomes straightforward.

Index Terms—
Core-stateless network; quality of service (QoS);traffic model; traffic scheduling.

I. INTRODUCTION

The Internet is expected to accommodate a variety of applications with different quality-of-service (QoS) requirements, such as video conferencing, interactive TV, and Internet telephony, as it evolves into a globe commercial infrastructure. However, today's Internet only provides one simple service: best-effort datagram delivery, in which data packets may experience unpredictable delay and packet loss rate and arrive at the destination out of order. Hence, more sophisticated mechanisms are urgently needed to provide less oscillatory and more predictable services for various applications.

Two fundamental frameworks, namely, Integrated Services (Intserv) and Differentiated Services (Diffserv), have been proposed for this purpose. The Intserv approach [3]–[8], which aims to provide "hard" end-to-end QoS guarantees to each individual data flow, requires per-flow-based resource allocation and service provisioning and, thus, suffers from the scalability problem due to the huge number of data flows that may coexist in today's high-speed core routers. The proposed Diffserv model simplifies the design of core routers by aggregating individual flows at edge routers and provisioning only a number of services to the aggregated data flows at each core router. However, in this model, it is difficult to identify each individual flow's QoS requirements at core routers and to contrive efficient resource allocation mechanisms to guarantee the end-to-end QoS of each individual data flow.

In addition, it has been shown [9] that, if all packets are served in a first-in-first-out fashion, the worst case delay bound is a function of the hop count and explodes at a certain utilization level. Thus, the overall utilization in such networks may be limited to a small fraction of its link capacities in order to provide guaranteed service delay. Various alternatives have been proposed in order to exploit the benefits of both Intserv and Diffserv and, at the same time, to mitigate their drawbacks. The operation of Intserv over the Diffserv model was introduced in [10]. In this model, the admission control and resource allocation procedures are adopted from those in the Intserv model so that sufficient resources can be reserved to satisfy the data flows' QoS requirements, while the data flows are served in the network domain in a Diffserv fashion, i.e., data flows are aggregated and provided only with a limited number of services.

Along with two new classes of aggregated packet scheduling algorithms, the static earliest time first (SETF) and dynamic earliest time first (DETF), Zhang *et al.* [11] showed that the maximum allowable network utilization level can be greatly increased while the worst case delay bound is decreased if additional time-stamp information is encoded in the packet header. In [12], a core-stateless version of jitter virtual clock (CJVC), which achieves the same worst case delay bound as jitter virtual clock (JVC), has been proposed. Like JVC, CJVC is nonwork-conserving, i.e., the server may be free even if there are packets in the buffer and, therefore, the network resource may be underutilized.

Capable of providing the same delay bound as the corresponding stateful Guaranteed Rate (GR) server, a methodology to transform stateful GR per-flow scheduling algorithms into core-stateless version ones was proposed [13]. Based on the methodology [13], the authors also proposed the core-stateless guaranteed throughput (CSGT) network architecture in [14], which is a work-conserving network architecture that provides throughput guarantees to flows over finite timescales without maintaining a per-flow state in core routers. In [15], a distributed admission control to support guaranteed services in core-stateless networks has been proposed. Based on the virtual time reference system [16], admission control under the bandwidth broker architecture has been studied in [17].

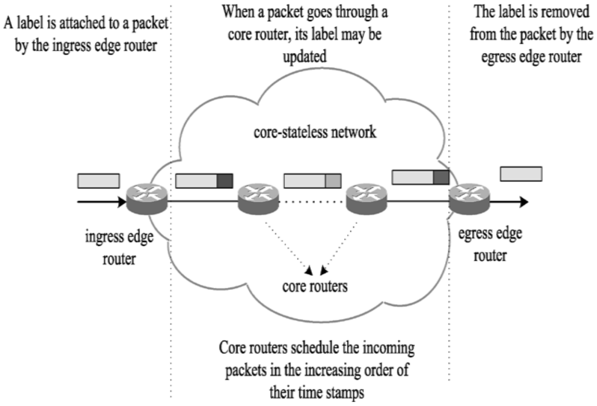

Fig. 1. Core-stateless network model.

Meanwhile, many core-stateless queueing schemes [18]–[23] have been proposed in literature, which are, however, beyond the scope of this paper. In the literature, many traffic models have been proposed to characterize network traffic. Among them, the traffic model [24], owing to its simplicity and efficiency, has been widely adopted for the network performance analysis; here, the network performance analysis is referred to as the analysis of the worst case delay, worst case jitter, packet loss ratio, and so forth.

In this paper, we show that the traffic model is not efficient for characterizing traffic in a core-stateless network. Instead, we introduce a new traffic model, which will be referred to as the traffic model, which can better describe flows in a core-stateless network. Based on this model, three important issues are addressed: time-stamp encoding at the network edge, traffic pattern distortion in a core network, and worst case delay analysis. The remainder of this paper is organized as the follows. We introduce the traffic model and derive its properties in Sections II and III, respectively. Based on the model, a novel time stamp is presented in Section IV. Finally, the conclusion is provided in Section V.

A. Network Model

We first introduce the core-stateless network model adopted in this paper. As shown in Fig. 1, routers in a core-stateless network are classified into two categories: edge routers and core routers. Namely, edge nodes are located at the network boundary, through which connections join and leave the network. Core nodes are located inside the network. When a packet arrives at the network boundary, the edge router will attach a label to the packet. The label includes some per-flow information such as the reserved bandwidth of the flow and a time stamp, which could be a function of the arrival time of the packet, the packet length, and the reserved bandwidth. The time stamp may be updated at each core router. The label will be removed from each packet after it traverses the network.

At all routers, packets are served by the increasing order of their time stamps. Here, we adopt the Dynamic Earliest Time First (DETF) [11] scheduler1 as an example and consider a special case: all flows injected to the core-stateless network are constant bit rate (CBR),2 and the propagation delay and link capacity of any link are 0 and , respectively. Here, the sequence of packets transmitted by a source to a destination is referred to as a flow [25], and we assume that the path is predetermined and fixed throughout its duration. Using the DETF scheduler, the worst case delay of flow at any router is no larger than if the following conditions exist.

1) At the ingress edge router, packet flow is attached with a time stamp of , where , , and are
the input rate, packet length, and the arrival time of packet at the ingress edge router of flow respectively.
2) At a core router, the time stamp of packet of flow is updated with an increment of , and packets are served at the increasing order of their time stamps, where is the maximum packet length of all flows.

It should be noted that, in order to update time stamps by core routers, the per-flow information should also be carried by the packets of flow throughout the core-stateless network. On the other hand, since each router has the per-flow information in a stateful network, it is not necessary to attach packets with labels to provide guaranteed services. Even though this example considers an extreme case, it provides us an insight as to how a core-stateless network operates.

B. Traffic Model and Assumptions

In literature, the traffic model [24] has been widely adopted for characterizing traffic in a network, i.e., if the total traffic of a flow arriving in the time interval is bounded by

1DETF is an output queuing scheduler that does not perform traffic shaping and reshaping inside the network. We assume that the total arrival rate (at the network edge) of the flows that share a same link is less than the corresponding link's capacity.

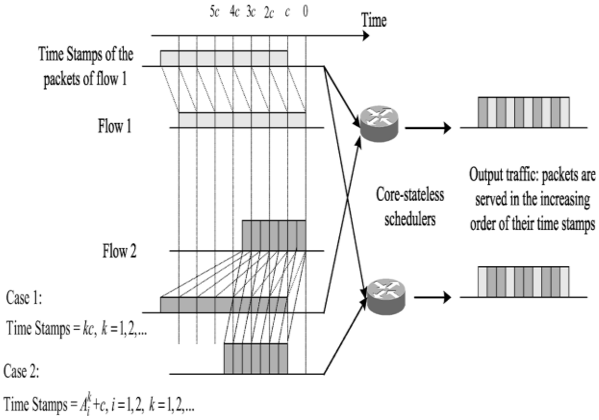

Fig. 2. Illustrative example.

This flow is referred to as conforming to the traffic parameter . In other words, we can claim that a flow conforms to the traffic parameter if no overflow occurs when this flow is injected to a leaky bucket with parameters of (buffer size) and (output rate).We can also view as the long-term average traffic rate bound of the flow and as its burst bound. We adopt the following assumptions in this paper.

1) We only consider an arbitrary network topology with links and switches where each link is associated with a delay bound (propagation delay) and each switch is non blocking.

2) A packet is considered "arrived" only after its last bit has arrived, and the delivery time of a packet at a node is the time when the last bit of the packet leaves the node.

3) Since a packet will only be delayed at a node if there is a packet being served or there are packets waiting in the buffer with earlier time stamps, we assume that the start time of each busy period is initialized at 0. Here, a busy period is an interval of time during which the transmission queue of the output link is continuously backlogged.

4) We assume that the time stamp of each packet lags behind its arrival time at any given node. This assumption may not hold for some core-stateless scheduling algorithms. However, note that packets are served by the order of their time stamps; the delivery order of packets will not change (thus, the delay for each packet to traverse the network remains the same) if the time stamps of all packets are increased by a constant at the network boundary. Therefore, if is large enough (for example, let be the worst case delay of any packet through a given network, if such a bound exists), our assumption can be satisfied.

We assume that, if the burst of each flow is bounded and the capacity of any link is no less than the average rate of the flows traversing the link, there exists a worst case delay bound in the network, i.e., the worst case delay of a flow to traverse any pair of nodes in the network with a limited number of hops is bounded. The framework proposed in this paper is only applicable to a work-conserving core-stateless network with bounded delay.

C. Traffic Model

In a stateful network, packets are served by the order of their time stamps. Note that per-flow information is maintained at core nodes in the stateful network, and the performance parameters of each flow are static. Therefore, only one time parameter (arrival time) associated with each packet is enough for performance analysis in the stateful network, i.e., given the arrival times and sizes of all packets, the delivery time of each packet can be derived, and thus the worst-case delay and jitter of each flow can be computed. However, in a core-stateless network, per-flow information is not maintained in core nodes, and packets in the buffer are served by the order of their time stamps, not their arrival times. There is also no distinct relation between the time stamp of a packet and its arrival time. Consider the following example.

As shown in Fig. 2, two CBR flows 1 and 2 are contending for the bandwidth of a link with a capacity of . The reserved bandwidths of the two flows are both , and all packets are of size . However, the inter-arrival times of two consecutive packets of flows 1 and 2 are and , respectively. Assume that the first packets of both flows arrive at time 0, and the arrival time of the th packet of flow , , 2, is , where if , and if . The time stamp attached to the packet of flow is, however, , which is independent of and will make each flow attain its reserved bandwidth. Therefore, it can be observed that the worst case delay of flow 1 is , and it is infinity for flow 2. However, if the time stamp of the th packet of flow , , 2, is set to , then the worst case delays of both flows become infinity. With , the worst case delay of the aggregated traffic (the aggregation of flows 1 and 2), which is infinity, can be computed.

However, we cannot tell which flow will experience such delay. Therefore, instead of using the traffic model, we will develop another traffic model to characterize traffic in a core-stateless network that could enable us to easily compute the worst case delay of all packets with respect to their time stamps. Moreover, from the point of view of a node, packets are served only by the order of their time stamps, and their arrival times seem irrelevant. Thus, a packet with an earlier time stamp than another packet, though it arrives later, may be served first. Thus, it is more reasonable to evaluate a packet's delay with reference to its time stamp, which is referred to as the *virtual delay* of a packet, rather than merely its arrival time. Therefore, a new mechanism to characterize traffic in the core-stateless network is necessary.

Since we evaluate the delay of a packet with reference to its time stamp, an intuitive idea to characterize a flow in the core stateless network is to define a parameter such that the total traffic of the flow of packets, whose time stamps are in the range of , is no larger than , which is similar

to the traffic model. Assume that packets are ordered by their time stamps as (, if , where is the time stamp of packet). Equivalently, for any two packets and , , where is the size of . In this case, the parameter for the aggregated traffic of flows 1 and 2 in the above example is . However, note that the virtual delay of each packet is 0, and the intuitive implication of the virtual traffic parameter is that the worst case virtual delay of a packet (i.e., the worst case delay with reference to its time stamp) is . A packet may receive service as long as there is no packet in the buffer when it arrives. Thus, it is necessary to take into account the arrival time of a packet to characterize traffic in the core-stateless network.

Therefore, we define the virtual traffic parameter (,) of a flow as follows: for any two packets and of this flow , , where is the arrival time of packet , ; we refer to in the time interval as the virtual traffic function of this flow with the virtual traffic parameter , and the traffic model for characterizing traffic in the core-stateless network with the virtual traffic parameter is referred to as the traffic model. The intuition of our traffic model is illustrated in Fig. 3. As shown in Fig. 3, imagine that there exist two virtual concatenated buffers, whose sizes are infinity and, respectively. The bandwidth between the two buffers is infinity, and the packets in the second buffer are served sequentially at a rate of . When packets arrive, they are stored in the first buffer. At the times equal to their time stamps, they are moved to the second buffer. If the second buffer never overflows, we claim that the arriving traffic conforms to the traffic model. Our proposed traffic model, which is the traffic model, is different from those proposed in the literature. A virtual reference system that has the virtual space property is introduced in [16]. It can be observed that, only when , the traffic model possesses the virtual space property. A scheduler is said to possess the coordinated multi hop scheduling (CMS) property [26] if the following is true:

- At the entrance node;
- at a core node.

For these conditions, , and are two constants that may vary with different nodes and flows. Since we do not place any constraint on the difference of the time stamps of two consecutive packets (and could be infinity in our traffic model), the traffic model does not possess the CMS property. Note that the time stamp is referred to as the priority index in [26].

V. CONCLUSION

In this paper, a new framework for a bounded-delay work conserving core-stateless network has been presented, covering three important issues in the core-stateless network: time-stamp encoding, traffic distortion, and worst case delay analysis. All of these are achieved based on a new and efficient traffic model, which is the traffic model, for characterizing traffic in acore-stateless network. Based on this model, a time-stamp encoding scheme has been proposed and proven to be effective in minimizing the end-to-end worst case delay bound.

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