Queueing Models for Performance Evaluation of Computer Networks -- Transient State Analysis

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Queueing models play an important role in modelling and performance evaluation of computer networks. Already the origins of queueing theory were related to the transmission of information: first queueing models were created a hundred years ago by Agner Krarup Erlang and by Tore Olaus Engset. Both of them were studying -- in these days of human operators and cord boards to switch telephone calls by means of jack plugs -- how many circuits were needed to provide an acceptable telephone service or how many telephone operators were needed to handle a given volume of calls.

In a computer network the total transmission time has two components. The first is composed of signal propagation time between nodes which is constant and determined by the length of links and the speed of light in the link. The second is packets waiting time at each node which is unknown and depends on the highly irregular current load of the network. It is estimated with the use of queueing models. In these models packets are the customers and the service time is the time needed to send a packet, bit-by-bit through an output gate of a router, hence its distribution is the same as the distribution of the size of the packets. Its estimation is important because it determines the quality of service measured by transmission time, its variability and loss rate.

Queueing models used in telecommunication are usually limited to steady-state analysis. It is in glaring contrast with the flows observed in real networks where the perpetual changes of traffic intensities are due to the nature of users, sending variable quantities of data, and also due to the performance of traffic control algorithms which are trying to avoid congestion in networks, e.g. the algorithm of congestion window used in TCP protocol which is adapting the rate of the sent traffic to the observed losses or transmission delays. The presentation discusses three most useful methods which may be applied in practice to analyse in a quantitative way transient states of queues in presence of time varying traffic, namely: numerical solution of Chapman-Kolmogorov equations for continuous time Markov chains with very large state space, diffusion approximation, and fluid flow approximation. Numerical examples coming from the author experience are presented.

Markov models are essential for the evaluation of the performance of computer networks. However, they are not scalable: the number of states is increasing rapidly with the complexity of a modelled object. At the moment we are able to generate and solve Markov chains having hundreds millions of states. A suitable method of solution is a projection method based on Krylov subspace with Arnoldi process to project the original chain onto a small Krylov subspace.

In diffusion approximation a diffusion equation (second order partial differential equation) defining the position of a particle in diffuse motion is used to describe the probability distribution of a queue length. This approach is merging states of the considered queueing system and needs much less computations than the Markov models.

Fluid-flow approximation is a simplified version of this method -- only mean values of packet flows, queue length and service times are considered. Differential equations are simpler, and the computations can be completed in a reasonable time even for very large network topologies. It is also easier to model mechanisms used to control queues in nodes, e.g. the principles of IP congestion window and active queue management (RED mechanism) at IP routers.

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