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FSPN MODEL OF P2P STREAMING SYSTEM WITH ADMISSION CONTROL

Zoran Kotevski
St. Kliment Ohridski University
Faculty of Technical Sciences
Bitola, Macedonia

Pece Mitrevski
St. Kliment Ohridski University
Faculty of Technical Sciences
Bitola, Macedonia

ABSTRACT

Peer to Peer live streaming is relatively new paradigm that aims for streaming live video content to large number of clients with low cost. Modelling and performance analysis of Peer to Peer live video streaming systems is challenging task which requires addressing many properties and issues of such systems that create complex combinatorial problem. Inspired by several related articles, in this paper we present a Fluid Stochastic Petri Net model for performance analysis of a bufferless, mesh based Peer to Peer live video streaming system that accounts for peer churn, peer upload bandwidth heterogeneity and incorporates admission control for lesser contributing peers.

I. INTRODUCTION

The use of Internet video streaming services is spreading rapidly. Web locations for live video broadcast attract more visitors every day. In the classical client/server system architecture the increase in number of clients requires more resources in manner of high bandwidth transmission channels with large upload rates. Since they are extremely expensive it results in a limited number of Unicast connections that a server can support at a given time.

In the early ’90^s it was expected that IP Multicast will be the natural technology to satisfy the requirements of large number of users with lower cost. However, lack of support for functionality of higher level, scalability issues and requirements for hardware Internet technology changes have prevented its wider deployment. In the last decade, the limited deployment of IP Multicast has motivated the science community to work in the field of new approach for Internet video streaming by the use of Peer to Peer (P2P) networking technologies. In this paradigm every user (peer, node) maintains connections with other peers and forms an application level logical network on top of the physical network. Video stream originates at a source and every peer acts as a client as well as a server, forwarding the received video packets to the next peer after some short buffering. Peers join and leave the system at free will (peer churn), which has high negative influence on system’s performance.

P2P logical networks are used to deliver video without the need of broadband server connections. This class of “One to Many” video streaming is easy to deploy because P2P technologies do not require network infrastructure support and offer scalability of resources having peers act as clients and servers. Hence, P2P networks offer huge economic benefit in deploying and managing IP video streaming, but bring a lot of open issues and research challenges that need to be tackled. Besides the existing numerous applications, P2P video streaming systems are still in their early stages, especially in the area of modeling and performance analysis of such systems. In our research we have found several research articles that propose mathematical models for performance analyses of P2P streaming systems, which inspired us to make a contribution to this area. We base our idea on [3] and propose our modeling approach with Fluid Stochastic Petri Nets (FSPN) [13], [14]. The partial analytic solution to this model is provided using queuing networks and probability theory, and the FSPN model is solved using process-based discrete-event simulations. The rest of this paper is organized as follows. Section 2 gives a brief review of related work, which is followed by FSPN model definition of a P2P live video streaming system in section 3. In section 4 results and analysis are presented, and section 5 gives main conclusions and future work.

II. RELATED WORK

D. Qiu, et al. [1] modelled mesh based, file sharing P2P system, developing simple deterministic fluid model that provides insights in the system’s performance. This deterministic fluid model is described by a set of differential equations which are solved in steady state. Then, simple stochastic fluid model is developed which characterizes the variability of the number of peers around the equilibrium values predicted by the deterministic model. *S. Tewari et al.* [2] proposed analytical model for BitTorrent (mesh) based live video streaming. This paper provides analytical expressions that concentrate on the fraction of the total peer upload capacity that can be utilized, the number of fragments available for sharing, fragment size and video playback latency. It also shows that peer group size of 15 to 20 peers is sufficient to achieve any benefits that a large peer group size can offer. *R. Kumar et al.* [3] developed stochastic fluid theory for mesh P2P streaming systems. Their simple model exposes the fundamental characteristics of such systems as well as its limitations. The analysis includes modelling a streaming system without buffering and churn, bufferless system with churn and P2P model with peer churn and buffering, while its analytical expressions bring insights in service degradation in all this cases. *Zhou Y. et al.* [4] developed a simple stochastic model for data driven system. They developed simple stochastic model, given by differential equations in discrete and continuous case that are solved numerically. Both, discrete model and continuous model are then compared to simulations. *Wu J. et al.* [5] presented an extension of [3] focusing on the problem of maximizing universal streaming rate in P2P streaming networks. The difference compared to [3] is in taking in consideration neighbourhood constraints. Similarly as in one part of [3] this model is based on assumption that all peers are bufferless. Situations with peer churn, video packets buffering and heterogeneous peers aren’t taken in consideration. *Yue, Y. et al.* [6] developed a general fluid model to study the performance and fairness of BitTorrent-like networks. This fluid model is defined by a set of differential equations which are then solved in steady state. *F. C. Perronnin et al.* [7] proposed a stochastic fluid model for analysis of scalable file sharing systems. The basic idea in this modelling is presentation of HTTP requests as fluid flow modulated by random arrivals and departures of nodes. *Y. Lu et al.* [8] presented analytical fluid model for mesh based P2P Video on Demand (VoD) system. Similarly like previously described fluid models, this model is described by ordinary differential equations, solved in steady state. *A. Yazici et al.* [9] introduces Markov chain based model to study mesh based, multi-stream, P2P VoD systems. The model accounts for peer churn, and query and setup times for a new connection with exponential probability distribution. *Y. C. Tu et al.* [10] present a study of the capacity growth of P2P media streaming systems using a discrete time analytical model. The explicit expressions for the load transition time from servers to peers are derived using exponential and Pareto distributions. *F. Liu et al.* [11] studies the inherent relationship between time and scale in P2P streaming systems during a flash crowd. For this study a mathematical framework is developed. *D. Wu et al.* [12] developed a tractable analytic theory for multi-channel P2P live streaming systems. These analytic models capture the essentials of multi-channel video streaming systems including channel switching, peer churn, upload bandwidth heterogeneity and channel popularity. However, only [2,3,4,5,11,22] are models for P2P live streaming system, but none of them accounts for Admission Control (AC). In this paper we present an FSPN model for performance analysis of a bufferless, mesh based P2P live video streaming system that incorporates AC for peers that contribute less resource compared to what they require from the system. Also, the model takes into account peer churn and peer upload bandwidth heterogeneity.

III. FSPN Model of a P2P Streaming System

The FSPN representation of our model of P2P live streaming system that accounts for peer churn and admission control is given in Fig. 1.

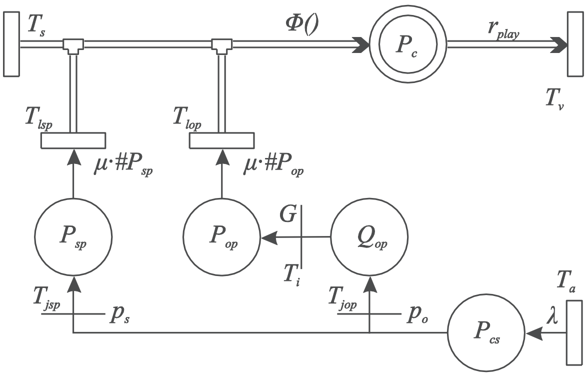

Figure 1: FSPN model of a P2P live streaming system

T_a – Peer arrival
T_{jsp} – Joining of super peers with rate $\lambda * p_s$
T_{lsp} – Leaving of super peers with rate $\mu * \# P_{sp}$
T_{jop} – Joining of ordinary peers with rate $\lambda * p_o$
T_i – Immediate transition for OP
T_{lop} – Leaving of ordinary peers with rate $\mu * \# P_{op}$
T_s – Represents the server streaming with rate u_s
T_v – Represents the video play out rate r_{play}
P_{op} – Discrete place for ordinary peers
Q_{op} – Queuing station for OP (discrete place)
$\# P_{op}$ – The number of OP in P_{op} (further denoted by Y)
P_{sp} – Discrete place for super peers
$\# P_{sp}$ – The number of SP in P_{sp} (further denoted by X)
P_c – The fluid place
u_s – Upload bitrate of the server
u_{sp} – Upload bitrate of super peers
u_{op} – Upload bitrate of ordinary peers
r_v – The rate of the video stream
G – The Guard function

Our model is mostly inspired by [3] and introduces one extension of incorporating AC. Similar as [3] we assume two types of peers: **Super peers** (SP) with upload bitrate higher than the video rate, and **Ordinary peers** (OP) with upload bitrate lower than the video rate. Single line circles are discrete places that can contain discrete tokens which represent peers. The tokens move via single line arcs into and out of the discrete places (representing peers joining and leaving the system). Double line arcs represent pipes through which fluid (bits) is transferred. The double line circle is fluid place that represents peer's buffer that in this analysis is assumed to have zero capacity. The important thing is the rate at which the fluid is pushed through fluid arcs to the place P_C. The rectangles represent timed transitions with exponentially distributed firing times, and the thin short lines are immediate transitions.

T_a is timed transition with an exponentially distributed firing times and represents peer arrival. T_{jsp} and T_{jop} are immediate transitions that fire with probabilities p_s and p_o respectively. p_s and p_o represent the occurrence probabilities of SP and OP. T_s and T_v are always enabled and constantly pump fluid through fluid arcs. T_{lsp} and T_{lop} are enabled only when there are tokens in P_{sp} and P_{op} respectively. These are marking dependent transitions, which, when enabled consume tokens from P_{sp} and P_{op} and constantly push fluid to the continuous place P_c with rate linearly dependant to the number of tokens in discrete places ($\# P_{sp}$ and $\# P_{op}$).

As in [3], the fluid function (Φ) is defined as the maximum bitrate that can be streamed to each individual peer at any given time, presented in Eq. (1):

$$\Phi = \min \left\{ u_s , \frac{u_s + \# P_{sp} * u_{sp} + \# P_{op} * u_{op}}{\# P_{sp} + \# P_{op}} \right\} \tag{1}$$

clearly, $\Phi = \phi\left(u_s , \# P_{sp} , \# P_{op} \right)$ (2)

Transition T_v tends to drain fluid from the continuous place P_c with rate equal to r_v. So, universal streaming is possible if and only if $\phi(u_s, \#P_{sp}, \#P_{op}) \geq r_v$. To calculate the performance of the system we need to answer the question: what is the probability for universal streaming for a given scenario? Using the probability theory and queuing networks, in the next few lines, the equations for calculating the probability for universal streaming are derived.

Since, $u_{sp} > r_v > u_{op}$, the $\#P_{op}$ that one super peer can support is $(u_{sp} - r_v)/(r_v - u_{op}) = k$, and the $\#P_{op}$ that the server can support is $u_s/(r_v - u_{op}) = c$.

Universal streaming is achievable only if $\#P_{SP}$ is sufficient to support $\#P_{op} - c$ peers i.e. the probability for universal streaming ($P_{UniStream}$) is:

$$P_{UniStream} = P\left(X \geq \frac{Y-c}{k} \right) \tag{3}$$

In our model we have two independent $M/M/\infty$ processes where $X(t)$ and $Y(t)$ are independent random variables with Poisson probability distribution. The total number of peers is a two dimensional random variable with parameters X, and Y. The joint cumulative distribution function for this two dimensional random variable is given in Eq. (4):

$$F(x,y) = \sum_{x \leq x} \sum_{y \leq y} P(x) \cdot P(y) \tag{4}$$

The joint probability mass function of this bivariate is given in Eq. (5):

$$P(x,y) = P(X = x, Y = y) \tag{5}$$

If we express the Y_{max} for which universal streaming is achievable for any value of X, then Y would be limited by Eq. (6):

$$Y \leq kX + c \tag{6}$$

Represented in a Cartesian coordinate system, $P_{UniStream}$ is the area presented in Fig. 2. The probability for universal streaming is calculated by Eq. (7):

$$P(Y \leq kX + c) = \sum_{x \leq x} \sum_{y \leq kx+c} P(x) \cdot P(y) \tag{7}$$

Varying the video rate for a certain case we can calculate $P_{UniStream}$ for a variety of scenarios. For a system with large average number of users the solution using Poisson probability distribution is not feasible and therefore, using the Central Limit Theorem, Poisson distribution is approximated with Normal (Gaussian) probability distribution.

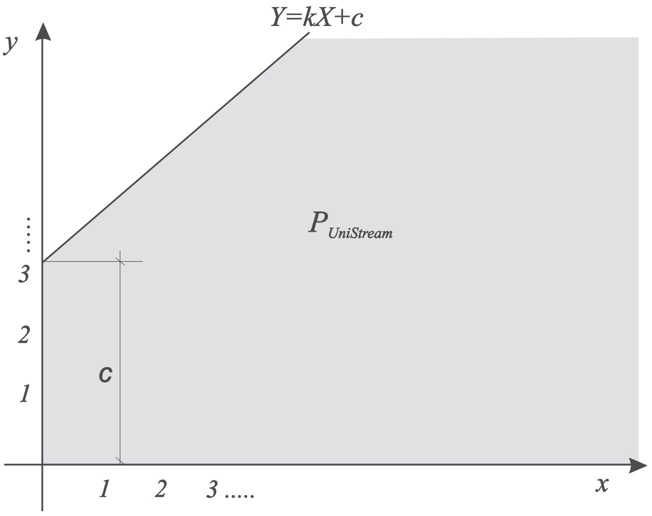

Figure 2: Probability for Universal Streaming

Next, we include AC for OPs. To solve this problem we set Guard (Boolean) function to transition T_i as in (12):

$$G = \left\{ \frac{u_s + \#P_{sp} * u_{sp} + \left(\#P_{op} + 1\right) * u_{op}}{\#P_{sp} + \#P_{op}} \geq r_v \right\} \tag{12}$$

If G evaluates to true T_i is enabled. Otherwise T_i is disabled. This means that OP are allowed to enter only when the system is idle.

IV. RESULTS AND ANALYSIS

For the performance analysis we used the following input parameters: u_s = 700 kbps, u_{sp} = 700 kbps, u_{op} = 100 kbps and r_v = 300 kbps. Analytical calculations are performed for small system with an average of 50 peers and medium system with an average of 500 peers, both without AC. The results were verified through simulations and are approximately identical. All other results were gained using discrete-event simulations of the FSPN model with the use of SimPy package [16] in Python [15] programming environment.

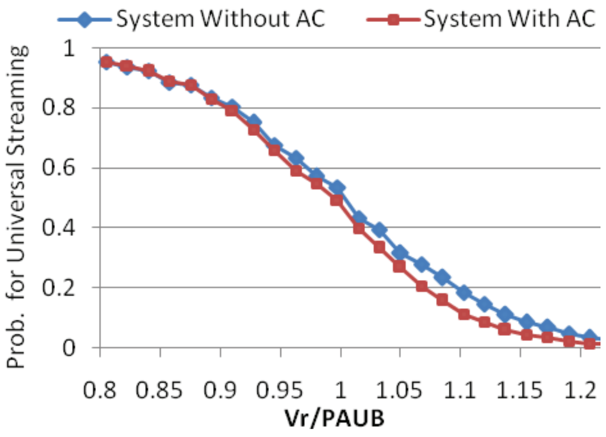

Figure 3: Probability for Universal Streamimng for small system with an average of 50 peers

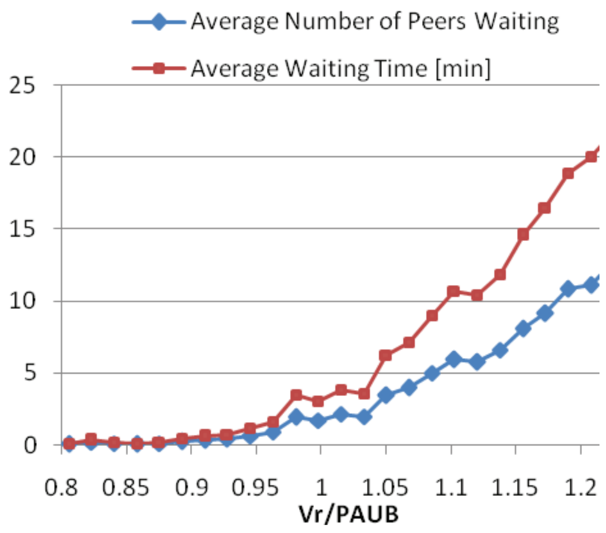

Figure 4: Small system with AC for OP

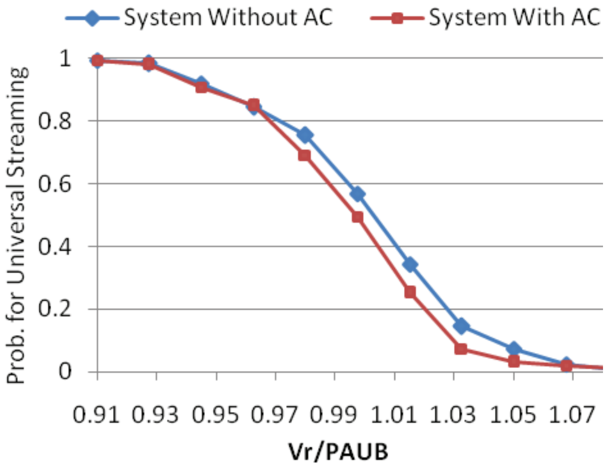

Figure 5: Probability for Universal Streamimng for medium system with an average of 500 peers

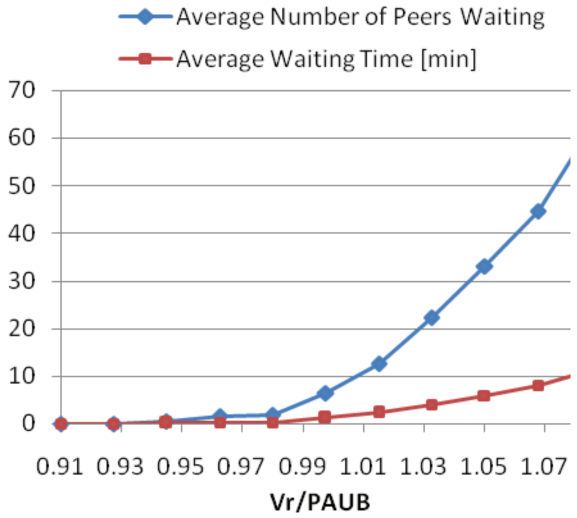

Figure 6: Medium system with AC for OP

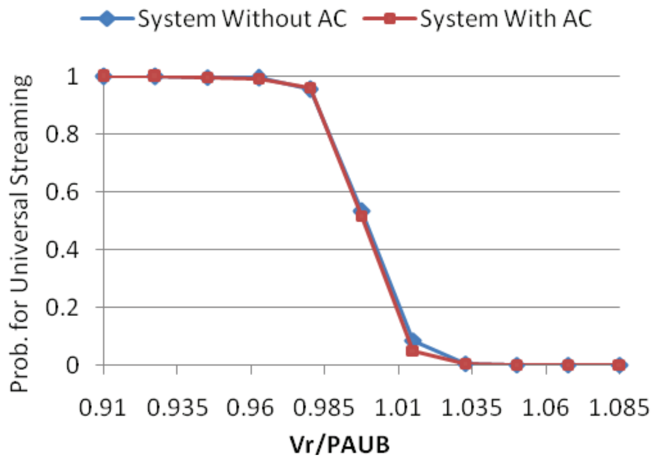

Figure 7: DSP for large system with an average of 5000 OP

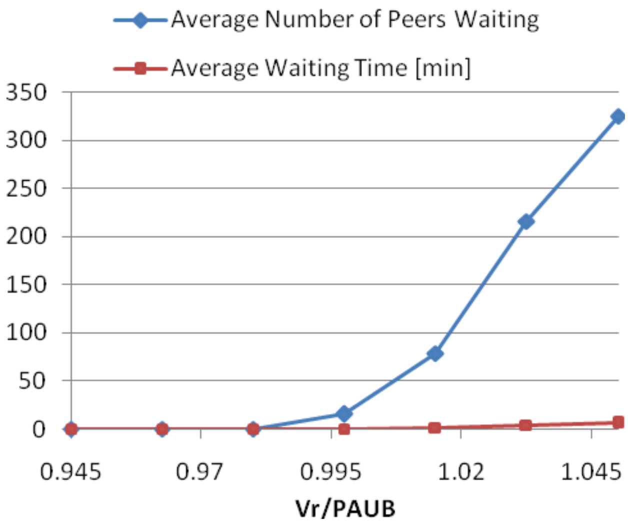

Figure 8: 5000 OP System with AC for OP

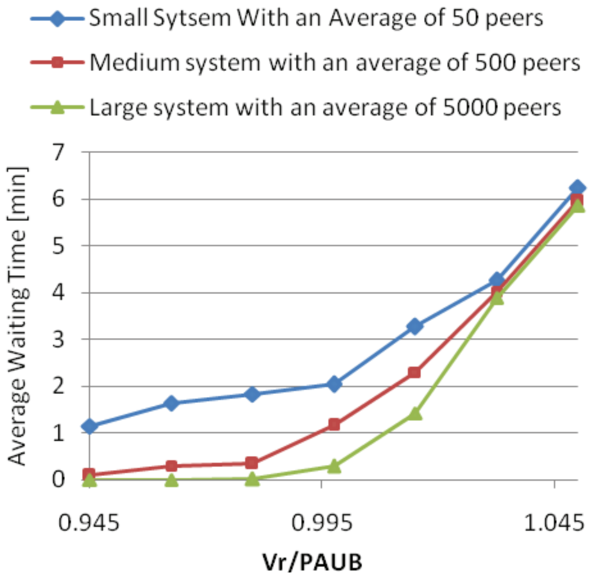

Figure 9: Average waiting times in all system sizes

All the results for degraded service probability for the systems without AC comply with results given in [3]. Results that are given for a system with admission control are unique and present solid foundation for planing purposes. The most interesting observation for system with AC is that implementation of AC does not bring any benefit to performance and, on the contrary, it reduces the quality of offered services by forcing the weaker peers to wait longer times to join. Besides this, the average number of peers that are forced to wait rises with system scaling, but the average waiting times appear to be similar for all system sizes.

V. CONCLUSION AND FUTURE WORK

In this paper we present FSPN model for performance analysis of P2P live video streaming system that accounts for peer churn, peer bandwidth heterogeneity and AC for peers with low contributing capabilities. The model does not take in consideration video buffering. The main conclusion is that we have confirmed that AC does not improve the performance and implies that its implementation should be avoided since it introduces greater initial delay which leads to diminished quality of offered services. Our future work will be concentrated on analysis of a model with buffering by defining certain capacity of the fluid place P_c, as well as incorporating other characteristics of P2P live video streaming systems, such as: control traffic overhead, internet traffic packet loss and several degrees of degraded service.

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