

Analysis of P2P Streaming Based on the Characterization of Live User-Generated Video

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Abstract—Services that offer users the possibility of transmitting their own live streaming video content, using Web 2.0-based platforms, are increasing in popularity. In this context, we propose and evaluate solutions that contribute to improve the scalability of this type of system. This work encompasses two major steps. First, we collected data from a popular online live video sharing service, and provide a characterization of key aspects of user dynamic behavioral patterns. Next, we used our characterization findings to drive the design and evaluation, via simulation, of alternative content distribution architectures. In particular, motivated by some of our findings, we combine the traditional Peer-to-Peer and client-server architectures into a new hybrid strategy, evaluating its cost-effectiveness in comparison with the two more conventional schemes. Simulation results, covering different metrics and scenarios, indicate that the hybrid strategy yields the best tradeoffs between quality of service and bandwidth requirements.

I. INTRODUCTION

There are a number of recently created companies which offer the users the possibility of transmitting, free of charge, live streaming video using Web 2.0-based platforms. Despite the short time of operation on the Internet, it is already possible to observe a significant popularity increase of those services. One of the pioneer companies, Justin.tv¹, attracted 11 million visitors in November of 2008. Ustream.tv² and Mogulus.com³, providing the same service, had reported, around 5.6 million and 2.1 million visitors, respectively, around the same time [1].

Many of these systems are built on top of centralized client/server architectures, and thus, require a significant amount of resources (notably server and network bandwidth), thus incurring large costs, to provide quality of service to their users. Alternatively, decentralized Peer-to-Peer (P2P) architectures offer more scalable infrastructures as resource requirements are shared among all participants. Nevertheless, peers may leave and (re-)enter the system independently, at their own discretion, which may cause interruptions in the transmission to other clients and, ultimately, hurting quality of service [2].

There is a large body of studies of live streaming video services. One set of studies, closely related to this present paper, focuses on characterization of network properties, and/or

analysis user behavioral patterns of systems that offer the users the possibility of transmitting live streaming video, considering Peer-to-Peer based architectures [2], [3], [4], [5], [6]. However, we do not restrict our analysis to P2P architectures only. Rather, we compare alternative strategies, evaluating them in scenarios built from representative models of user behavior patterns, which, in turn were observed in a real system of this type. A second group of prior work proposes and compares different live video streaming strategies. The authors in [7] proposed a P2P solution that combines a tree-based with a mesh-based architecture. Comparing the new strategy with a traditional tree-based P2P network, the authors find that the new strategy offers similar or better results in terms of transmission delay and response to peer dynamic behavior. However, no comparison with a pure mesh-based solution, a widely used P2P architecture, is provided. A hybrid P2P architecture, combining a structured with an unstructured network, and aiming at finding stable partners to construct the transmission tree is proposed in [8]. A hybrid overlay strategy is also proposed in [9], but focusing on the transmission of stored videos.

All of these previous studies focus, mostly in Peer-to-Peer based solutions for live streaming video transmissions. Whereas the former group aims at understanding the properties of their overlay networks, and/or analyzing user behavioral patterns of those systems, the latter propose solutions that are built on specific architectures. Our work differs from them because we propose and evaluate solutions, which are independent of the specific P2P architecture adopted. Moreover, we also consider a hybrid strategy that combine elements of both P2P and client/server architectures.

Our work is built on two major steps. First, we collected data from a popular Web 2.0 live video streaming service, and provided a characterization of key aspects of user dynamic behavioral patterns. Our characterization findings were then used to drive the design of a simulator of different content distribution architectures, including the traditional client-server (C/S) and Peer-to-Peer solutions. They also motivated the proposal of a new hybrid strategy, which combine the benefits from the C/S and P2P architectures. Finally, we evaluate the three strategies, considering different scenarios as well as metrics that reflect both the interests of the users and of the server. Our results indicate that the hybrid strategy yield the best tradeoffs between quality of service and resource

¹<http://www.justin.tv>

²<http://www.ustream.tv>

³<http://www.mogulus.com>

consumption.

The rest of the work is organized as follows: Section II presents the main characterization results. Section III presents the alternative strategies for live video streaming considered in this work. Section IV presents the evaluation methodology used in the experiments, along with the main experiments results, whereas Section V concludes the paper.

II. CHARACTERIZATION

The YahooLive is a service which offers the users the possibility of transmitting, free of charge, live streaming video using Web 2.0-based platform. It offered in its website an API which allowed the access to information, among others, all live channels in certain moment, and the users connected in those channels. This was a decisive point for choosing this system, because, to the best of our knowledge, it is the currently unique system that offered the information necessary to perform the analysis of user behavioral patterns.

Each registered user in the YahooLive system is associated to a channel, which is unique and has the same name of the user, channel owner. A user can go live anytime, for any duration, and he can perform this action as many times as he wants. The interval time when a channel is live is called **transmission**. In a transmission all participants has a unique ID, and with this ID is possible to calculate the time a user spends in a transmission (**session time**).

During the period of 05/30/08 to 06/22/08, we performed periodic collections of complete snapshots of all video channels in the system. Our collection consisted of the identifiers of all users transmitting or visualizing content of the system, and was performed at the granularity of 20 seconds. Overall, our data encompassed 48338 video transmissions, distributed in more than 7000 channels.

We determined several statistical models for user behavioral patterns. Next we will present only the models used in the performed simulation (presented in Section IV).

A. User Arrival Time

We characterized the distribution of the user arrival time relative to the transmission duration time. For instance, if a user arrives after 40 seconds have passed since the beginning of a 100-second long transmission, its arrival instant is set as 40%. In other words, we characterized the initial fraction of the transmission missed by the user. Figure 1 presents the cumulative distribution function (CDF) of the measured arrival times. As shown in the figure, this distribution is reasonably well modeled by an uniform distribution. In other words, users join a transmission mostly uniformly across all its duration. We believe that this may be a result of the lack of effective mechanisms for channel/content announcement and advertising, which could motivate users to join transmissions closer to their start-up.

B. Session Duration

In this section, we characterize user session duration, another aspect that drives our simulation model. In order to

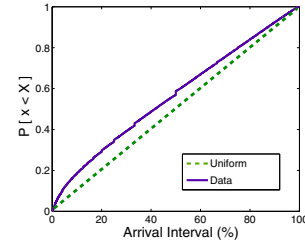
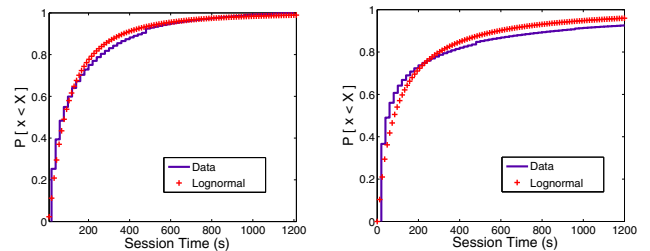


Figure 1. Arrival Interval Time

characterize session durations, we consider two classes of video transmissions, namely, (1) *short*, that is transmissions that last up to 20 minutes, and (2) *long*, transmissions with durations longer than 20 minutes. The threshold of 20 minutes was set by comparison with other thresholds, which were chosen randomly. We then characterized user session durations separately for each transmission class, so as to avoid aggregating very distinct user behaviors, observed in our data.

Figures 2a and 2b present the CDFs of the session durations in short and long transmissions, respectively. Figure 2b shows only session's durations of up to 1200 seconds so as to emphasize the most relevant part of the curve. We opted to present the session duration in the absolute form because it better represents the user behavior, which stays in the transmission during certain time, without knowing the total transmission duration. Using the method Maximum Likelihood Estimation (MLE) [10], we determine that both curves are well approximated by Lognormal⁴ distributions with parameters $\mu = 4.424$ and $\sigma = 1.161$, and $\mu = 4.421$ and $\sigma = 1.527$, respectively, for short and long transmissions.



(a) Transmission Duration Smaller than 20 min. (b) Transmission Duration Bigger than 20 min.

Figure 2. User Session Duration

Figures 2a and 2b also show that sessions with duration under 20 seconds represent approximately 33% of all identified sessions. This significant fraction of very short sessions, which may be a result of channel surfing [11], poses a challenge to the construction of P2P-based infrastructures to content distribution systems [11]. As the overlay network may undergo frequent changes, peers may suffer delays in receiving the content and thus quality of service may degrade. This result

⁴Probability Density Function (PDF): $\frac{1}{x\sigma\sqrt{2\pi}} \exp\left(\frac{-(\ln x - \mu)^2}{2\sigma^2}\right)$

motivated us to propose a new hybrid transmission strategy, described in the next section.

III. LIVE TRANSMISSION STRATEGIES

In this section, we briefly describe the three live transmission strategies considered in this paper: Pure P2P (Section III-A), client/server (Section III-B) and the new hybrid strategy (Section III-C).

A. Pure P2P Strategy

We consider a mesh-pull based P2P live streaming system. In this type of system there is a special peer, the server, from which the transmission originates. When a new peer connects to the system, he receives from the server a list with n other peers. The new peer contacts the n other peers. Each contacted peer may add the new client to its partner list, and after that they can exchange data. Each peer recognizes and exchanges data only with established partnerships. The initial peer subset is randomly built from all system peers, through a bootstrapping mechanism. A new partnership is established provided that the number of partnership of the peer has not reached a maximum number, and regardless of the amount of resources available at each peer.

In the partner selection we implemented a heuristic which is similar to the heuristic used in [12]. There are two situations when a node can form partnerships, namely, when it joins the system, and when it needs to change/replace partners, for instance, to improve the transmission quality. In our simulation, we do not address any specific mesh-based P2P system, although our model is consistent with that behind many existing system, such as the currently popular PPLive⁵.

B. Client/Server Strategy

The server is responsible for transmit the content to all peers. When a client arrives in the system, to visualize a channel content, he connects directly to the server, which must then allocate enough bandwidth to create a new live stream and transmit it directly to him.

C. Hybrid Strategy

Motivated by the large fraction of very short user sessions, observed in our data characterization, we proposed a new strategy, called **hybrid**. In the hybrid strategy the nodes first connect to the centralized server (**phase 1**), and, after a certain threshold ω , they are redirected to a P2P network (**phase 2**). The server is unique and must act in the centralized network as well in the P2P network.

During phase 1, while receiving the transmission directly from the server, a node also contacts the P2P network, and then tries to establish partnerships, getting ready to receive the transmission from that network. Once phase 2 starts, after the threshold ω , the node participates only in the P2P network, following the description presented in Section III-A.

⁵<http://www.pplive.com>

IV. EVALUATION

Throughout this section we will present the methodology used in the evaluation performed in this work.

A. Evaluation Metrics

We consider two metrics in our evaluations:

- **Continuity index:** this metric is related with the quality observed by the client during the transmission. This index measures the number of video chunks which arrives before their playback time. It is also used in [12];
- **Contribution:** this metric is related to number of video stream (δ) provided for each node of the system. It measures the network bandwidth consumption of each node, expressed in a standardized way in relation to the rate of video encoding. A contribution equal to $5 \times \delta$ represents a bandwidth equals to 5 video streams.

B. Simulation Model

We used the network simulator J-SIM⁶. Based on the information obtained by characterization, performed in this work, we developed new components for that simulator, which were responsible to represent all peers of a live streaming system based on pure P2P architecture, as well in client/server architecture. The component relating to the P2P network organizes the peers in a mesh-based network, following the mesh-pull model, which is used in popular systems as Coolstreaming and PPLive.

1) *Peer Model:* In all strategies the peers arrive in the transmission in a uniformly distributed time interval along the transmission. The residence time of a node in the transmission is described by a Lognormal distribution ($\mu = 4.421$, $\sigma = 1.527$).

For Pure P2P strategy we also consider that the peers have a limit of patience regarding to startup delay: $\min(2 \times p, T)$ (p = residence time in a transmission⁷ and T = range of maximum waiting time). We did not define any limit of patience for the C/S strategy, because we assume that the simulated client/server architecture would not present excessive startup delay, since the server always has resources to meet all requests.

The peers can be classified in two categories according to the available upload bandwidth. We use the parameters B_{high} (high upload bandwidth) and B_{low} (low upload bandwidth) for that. We also consider the parameter θ (which inform the percentage of nodes with low upload bandwidth - B_{low} - in the system). The parameter θ is used to create different variations of a scenario, as will be discussed in the next section. Furthermore, we consider that all nodes in all strategies are aware of the network bandwidth of its partners.

In all strategies we assume that the nodes have enough network bandwidth to correctly receive the streaming. The nodes also have enough storage and processing capacities to visualize the stream. The server always has enough network bandwidth and any other resources to serve the nodes.

⁶<http://www.j-sim.org>

⁷range of time that a user would be willing to watch a channel

Table I
EVALUATION SCENARIOS

Scenario	B_{high}	B_{low}
1	4δ	1δ
2	2δ	1δ
3	1δ	$0,5\delta$
4	$0,5\delta$	$0,25\delta$

C. Evaluation Scenarios

We consider 4 scenarios in our evaluation. In all scenarios the nodes present two variations of network bandwidth, which occur on upload bandwidth. In all 4 scenarios we consider 4 variations of the θ parameter (0%, 25%, 50% and 75%). Table I presents all scenarios considered in the simulation.

We refer a scenario as follows: scenario 2 ($\theta=25\%$), which represents the scenario 2 (where the nodes with the best upload bandwidth have $B_{high}=2\delta$, and the nodes with the worst upload bandwidth $B_{low}=1\delta$), and 25% of the nodes have the worst upload bandwidth (B_{low}) considered in the scenario.

D. Experiment

We consider a network composed of 1000 nodes, one being the server. The server streams 6 chunks per second, each chunk has 7220 bytes. All transmissions simulated lasted 30 minutes (based on the performed characterization, a typical transmission last approximately 30 minutes). Values to other parameters used in the simulations are: $T = 120$ seconds; $\omega=1, 2$ and 5 minutes.

E. Results

The results presented below are averages of 5 experiments. We have calculated a 90% confidence interval for all experiments. In order to improve the readability of the graphs we are omitting those confidence interval. In the metric continuity index, the results have the precision of 1.2% on average (17% on the worst case). In the metrics clients and server contribution, the results precision is 13% and 12% (on average), respectively.

1) *Average Quality of Transmissions:* Figure 3 presents the continuity index observed along the transmissions for the scenarios 2 and 4 for $\theta=50\%$ and $\theta=75\%$. We decided to approach the scenario 2 due to its representation of real scenarios reported in [13], and the scenario 4 because it is the worst scenario. As shown in the figure, in many situations (except for the C/S strategy) the continuity index decays along the transmission, until it achieves a point of certain stability. It can be explained in all strategies. In the pure P2P strategy, the first nodes that enter in the transmission tend to form partnerships and receive portions of the stream video from the server, which explain the good continuity index at the beginning of the transmission. During the transmission new nodes arrive in the system, which increases the probability of receive video stream from other nodes besides the server. It increases the chances of a node request data from nodes with low upload bandwidth, and also stays more susceptible to the short session's duration of some users.

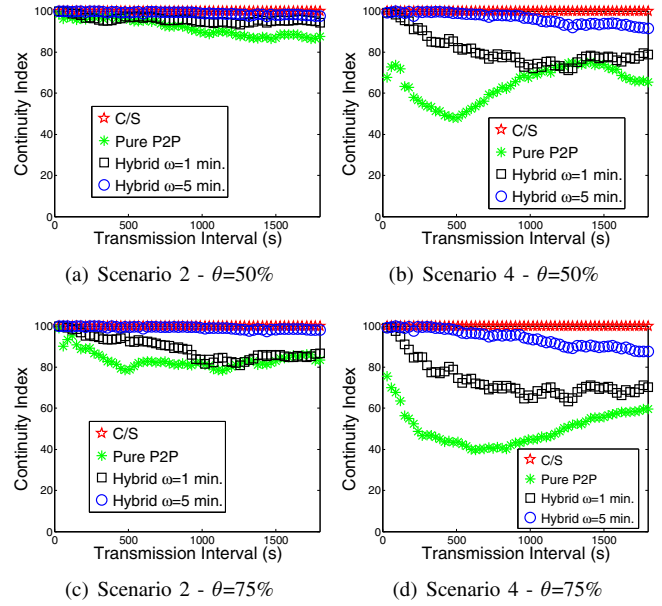


Figure 3. Continuity Index

In the hybrid strategy as the value of ω increases, this strategy resembles the C/S strategy. And as this value decreases, it becomes closer to the pure P2P strategy. Thus, the results for the continuity index follow similar trends to those strategies. Consequently, in the hybrid strategy the best results are obtained for $\omega=5$ minutes, since it is the case that allows the greater approximation of the C/S strategy, which implies a greater number of nodes in phase 1, and reduces the number of nodes in phase 2, providing a better transmission quality.

In some scenarios, we also can observe that the pure P2P strategy (specially $\theta=50\%$ and $\theta=75\%$) provided a considerable improvement of continuity from a certain moment of the transmission. This situation is illustrated in the Figure 3d. One explanation for this phenomenon is that many peers failed to enter in the system, mainly due to the low quality of service provided by this strategy in scenarios with low network bandwidth available, such as scenario 4 ($\theta=75\%$). This makes the number of simultaneous peers decrease over time, which consequently increased the overall continuity index.

We find that the C/S strategy presents the best results regarding to this metric, since in all scenarios the continuity index remained above 95%. The cost of this result is a greater utilization of the server network bandwidth, as will be explained in the Section IV-E3. In order to achieve a closer continuity index as the provided by the C/S strategy, the most recommended strategy is the hybrid with $\omega=5$ minutes, because it provided, 90% of the transmission time, for all cases and scenarios, a continuity index above 95%.

2) *Client Contribution in the System:* We observe that peers of a transmission supported by the hybrid strategy, usually contribute less than the ones of a transmission supported by a pure P2P strategy. In a pure P2P strategy, on average, approximately 46% (against 15% in the worst case of the

hybrid strategy, $\omega=1$ minute) of the nodes contributed more than half that they have received. This is explained by the fact that customers in hybrid strategy remain part, or all, of its time spent in transmission connected directly to client/server architecture, only requesting data from the server. The server in its turn ends up using a larger amount of network bandwidth. This reduces the number of data requests to other nodes, which reduces the overall client contribution. We observed that the hybrid strategy with $\omega=5$ minutes provided the better result in this metric, i.e., provided the greater economy for the clients in terms of upload bandwidth (on average 94% of the clients contributed less than the half that they have received).

3) *Server Contribution in the System:* Figure 4 illustrates the server contribution to all considered strategies for the scenario 2 $\theta=0\%$, and $\omega=1$ and 5 minutes.

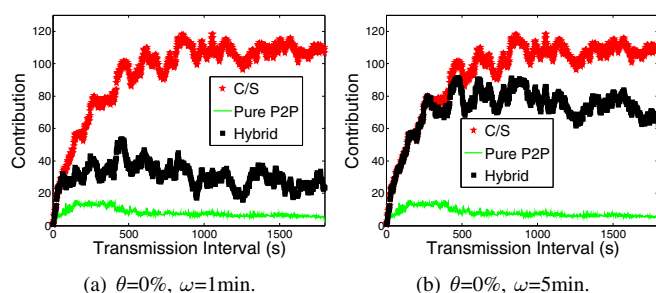


Figure 4. Server Contribution in the System, Scenario 2

We observe that the server in the pure P2P strategy tends to contribute less in the system with the increasing of simultaneous nodes in the system. This happens due to the fact that, with a larger number of nodes in the system the options to get a particular video chunk are higher, thus the server tends to become less requested. This results in a greater peer's contribution in the system. Regarding to the C/S strategy the server contribution was proportional to the number of simultaneous clients in the transmission, because in this strategy the server provides a unique video stream to each client. In the hybrid strategy, increasing the ω value also increases the server contribution in the system. This happens because, in this strategy, with a higher value of ω more clients participate simultaneous in the phase 1.

Analyzing the saving of network bandwidth, provided by all strategies in comparison with the C/S strategy, we observe that the pure P2P is the most economic one (it provided 91.9% of saving). The cost of this saving is the low continuity index and a greater contribution of clients in the system. We also observe that the saving of network bandwidth provided by the hybrid strategy is inversely proportional to the value of ω . The higher the value ω lower the saving. However, as we can observe in the results, for this strategy, related to the continuity index, the higher the value ω the higher the transmission quality.

Despite the hybrid strategy provides a saving of network bandwidth comparing to the C/S strategy, is valid to question whether these savings would be worth for all cases. If we analyze, for example, the case where we consider

$\omega=5$ minutes, which provided the best continuity index, the network bandwidth saving was on average 22%. Not in all cases this economy justifies the maintenance of two network architectures (C/S and P2P), necessities in this hybrid strategy. For those cases one should consider, for example, the reduction of ω value, which reduces the network bandwidth utilization (for $\omega=1$ and 2 minutes, the savings are 64% and 47% respectively), in exchange for lowering the transmission quality (for $\omega=1$ and 2 minutes the continuity index stayed above 95%, on average, 31% and 53% respectively).

V. CONCLUSION

In general we see that the C/S strategy stands for offering a good quality transmission to users, without requiring them to contribute with resources, however this cost is transferred to the server. The pure P2P strategy is the most economic in terms of server network bandwidth, however this strategy is the less economic in terms of clients network bandwidth, and is also the strategy that presents the worst continuity index. The hybrid strategy provides a saving of server contribution comparing to the C/S strategy (on average 22% in the worst case), despite to be less economic than the pure P2P strategy, in this same metric. This strategy, in its best case ($\omega=5$ minutes), is able to provide a continuity index above 95%, on average, during 90% of the transmission, being the best alternative to replace the C/S strategy.

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