# Active bandwidth sharing for multi-layered video in multi-source environments

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ABSTRACT. *Multicast distribution of multi-layered video is one of the most important challenges in current multimedia networks. Nevertheless, little attention has been devoted to the quality of the video at the receivers in multi-source environments. In this paper, we use the active networks paradigm for the management of many video sources that share common links crossed by different multicast trees. We present a new scheme that is based on the priority assigned by the different receivers to each required video flow. We investigate the efficiency of applying such adaptive system by using receiver's profile to manage network resource.*

RÉSUMÉ. *La distribution de la vidéo multicouche dans les environnements multicast est un des challenges les plus étudiés ces dernières années. Par contre, la distribution de cette vidéo dans un environnement multisources est un axe important mais malheureusement peu d'attention lui est consacrée. En effet, il faut considérer en plus l'influence des sources entre elles et d'autres problèmes relatifs, notamment, au partage des ressources. Dans cet article, on étudie l'utilisation des réseaux actifs pour la gestion de plusieurs sources vidéos à travers différents arbres multicast. Cela constitue une base pour mieux comprendre les principaux problèmes concernés.*

KEYWORDS: *Active network, Multi-layered video, Multi-source, Multicast.*

MOTS-CLÉS : *Reseaux actifs, vidéo multi-couche, Multi-source, Multicast.*

## 1. Introduction

One of the greatest challenges of the last years is to provide large-scale video distribution with the required quality of service [LI 99, NON 99]. Dedicated networks and specific mechanisms have been introduced to allow the delivery of such strict applications with the best possible quality of service. Nevertheless, with the explosion of the Internet, new proposals have emerged to integrate video distribution in traditional best-effort networks. This integration offers many advantages including larger coverage, great flexibility, and reduced cost. But such as the Internet was conceived, several limitations can be identified like the heterogeneity of the receivers and the scalability. New schemes must then be introduced to manage the transmission of the video streams in such a shared and not reliable environment [LI 99, AMO 00, SAP 00, RUB 99, SAR 00].

In the video system proposed in [AMO 00], each multicast tree is composed of one source that communicates periodically with a number of receivers. The exchanged information allows the source to calculate the rates of the video layers. The corresponding procedures form an adaptive control system that aims at optimizing the quality of the video at the receivers. In this architecture, the source sends a control packet that marks the available bandwidth, $c_s(l)$ in each traversed link *l* through the multicast tree. When a receiver $r$ belonging to the multicast session $m$ receives this packet, it compute the maximum rate it can receive,

$$b^{r,m} = \min_{l \in L_{s,r}} c_s(l), \qquad [1]$$

where $L_{s,r}$ is the set of links traversed by the control packet between the source $s$ and the receiver $r$. The receiver builds then an acknowledgment packet containing this information and sends it back to the source. This mechanism optimizes the video quality in the way the source is aware about the receivers' capacities. However, this mechanism must be controlled to avoid scalability problems like feedback implosion at the source if the multicast session has a large number of receiver. In order to avoid this problem, nodes must implement a merging mechanism to reduce the load. This mechanism can be easily implemented if we have one multicast session. Unfortunately, if we consider a multi-source system where multiple multicast sessions share somme links in a network, other problems related to the bandwidth control and the quality of the video in the receivers must be solved. Whether the nodes experiment congestion, a mechanism must act in order to decide which flows must be forwarded. From the point of view of the receivers, the node should prioritize the flows that she/he considers more important.

In order to achieve this target and to solve the fairness problems in the case of conflict among the receivers, we use the active network concept to provide a higher degree of fairness among the different flows. In our scheme, the receivers define an array where each entry $i$ has two fields: the required multicast session, $m_r^i$, and the priority assigned to this session, $w_{m_r^i}$. We define a topology in order to analyze the behavior of one link traversed by different flows. The bandwidth is allocated to each flow in conformity with the priority assigned by the receivers to each required video. The obtained results show that the resource sharing is effective according to the priorities assigned to the flows. The system proves to be fair and fast, because it quickly provides the receivers with at least the base layer. Furthermore, the proposed scheme is efficient attaining a bandwidth utilization of about 90% of the bottleneck link's capacity.

This article is organized as follows. In section 2 we discuss the active network approach for the effective control of the video in the best-effort networks such as the Internet. Section 3 presents the problems and potential solutions. The analysis of the proposed model is detailed in the section 4. Finally, we present the conclusions in the section 5.

## 2. Video and Active networks

Best-effort environments such as the Internet have some intrinsic characteristics for the deployment of applications requiring some level of quality of service. First, the receivers are heterogeneous in their data-handling capacities and the required video quality. Second, the available bandwidth of the links are variable. A good approach to face these limitations is the use of multi-layered video coding where each layer is transmitted in a different multicast tree. By conveying several video layers, the receivers can adjust the video quality by subscribing to different multicast groups. The larger the number of received video layers the better is the quality of the presentation. On the other hand, adhesion to a small number of multicast trees implies a worse quality but has the advantage of reduced allocated bandwidth. This method has the advantage of reduced interaction between the source and the receivers. Nevertheless, establishing multiple multicast trees means that a larger number of network states must be kept at the nodes.

We prove in this paper that the use of active networks is interesting for providing high performance and fairness in multi-source multicast video using the multi-layered approach. An active network allows intermediate nodes to perform tasks until now reserved to the application layer [WET 98, ALE 98, TEN 97, PSO 99, DEC 98]. Users can program the network by injecting their own codes in order to dynamically exploit the equipments of the network. The network becomes then active because it takes part in the packet processing instead of limiting itself to the simple data routing.

The use of active networks eliminates the need for establishing several multicast trees. Only one tree including all receivers that have subscribed to a video is created (Figure. 1). Nevertheless, the subscription list includes information about the required video quality for each subscriber. This information is used by the active nodes to distribute the same video (perhaps a subset of the layers) through the appropriate outgoing ports. The reader should note that this information is smaller than the one of

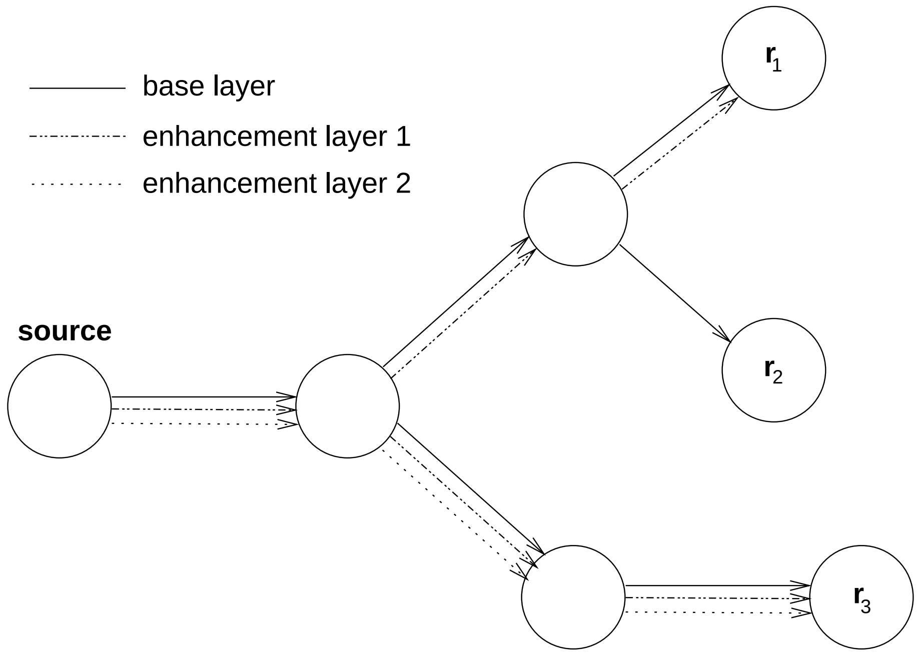


**Figure 1.** *Multi-layer video transmission in active networks.*

multiple multicast trees. Therefore, the number of layers of video can be large without overloading the nodes.

## 3. Multi-source multi-layered video

The advantages of using multicast are confronted with a great number of problems like the routing algorithms in the nodes, the management of the joins/leaves of the various groups, and the computation of the maximum rate of the sources. These problems form a complex system and even more in the case of heterogeneous receivers. In such scenario, either the receivers or the path from the sources to the receivers are limited in resources. [1]

In this work we identify the most important problems related to the multi-source video transmission in heterogeneous multicast networks. First, we are interested in the bandwidth management in the links traversed by more than one video flow. We consider a network in which we have at least one receiver subscribed to different multicast sources, as shows Figure. 2.

1. We use here the terminology “network resources” as any resource given to a traffic, for example a certain amount of bandwidth, the priority in a queue, etc.

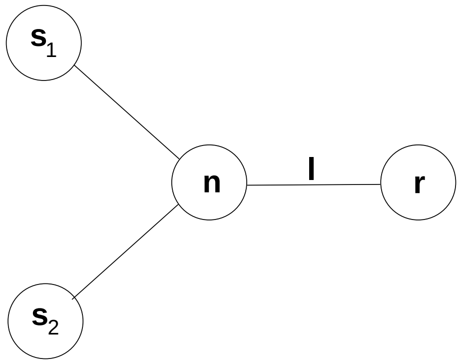


**Figure 2.** *The multi-source scenario.*

If the paths between the sources and the receivers have enough resources to transmit all of the flows, there is no conflicts between the flows and they can be normally forwarded. We are interested in the case where at least a link is limited in terms of available bandwidth and the correspondent ingress node must somehow implement a control algorithm. In Figure. 2, we consider that source $s_1$ transmits at a rate $d_{s_1}$ and source $s_2$ at a rate $d_{s_2}$. If the bandwidth $bw$ available in the link is greater than the sum of the rates of the sources, i.e., if $bw > (d_{s_1} + d_{s_2})$, then we fall in the first case where there is no conflict between the flows. On the other hand, when the sum of the flows exceeds the available bandwidth, then node $n_1$ must decide how flows will be forwarded to the receivers. We consider a first case where the receivers require 100% of the flows in order to play the video. There are in this case four possibilities of bandwidth allocation:

– $bw < d_{s_1}$ and $bw < d_{s_2}$: in this case the link does not have enough bandwidth and none of flows is transported.

– $(bw > d_{s_1}$ and $bw < d_{s_2})$ or $(bw < d_{s_1}$ and $bw > d_{s_2})$: only the supported flow is accepted in the link.

– $(bw > d_{s_1}$ and $bw > d_{s_2})$ but $(bw < d_{s_1} + d_{s_2})$: only one of the flows can be accepted in the link. The node must implement a priority mechanism.

– $bw > (d_{s_1} + d_{s_2})$: both flows are accepted in the link.

As multi-layered video is coded in several hierarchical levels, the same source can be viewed as having different rates.[2] We have then more possibilities of resource allocation since for the same available bandwidth we can admit a more significant number of flows with lower rates, or a reduced number of flows with high rates.

2. We mean a first rate equal to the base layer, the second rate equal to the base layer plus the rate bandwidth of the first enhancement layer and so on.

We suppose in our scheme that each receiver must provide a profile. This profile is a classification by priority of the flows required by a receiver. A change of the profile can occur either in the case of a new subscription to a video source or in the case of a change of priorities. The network of the Figure. 3 consists of 4 video sources, $S = \{s_1, \ldots, s_4\}$, and of 3 receivers $R = \{r_1, \ldots, r_3\}$. Let $F = \{f_1, \ldots, f_4\}$ be the video flows transmitted respectively by the sources $s_1, \ldots, s_4$. Each receiver must give its profile based on the hierarchy of the required video flows. Table **??** represents the various profiles of the different receivers in our example.

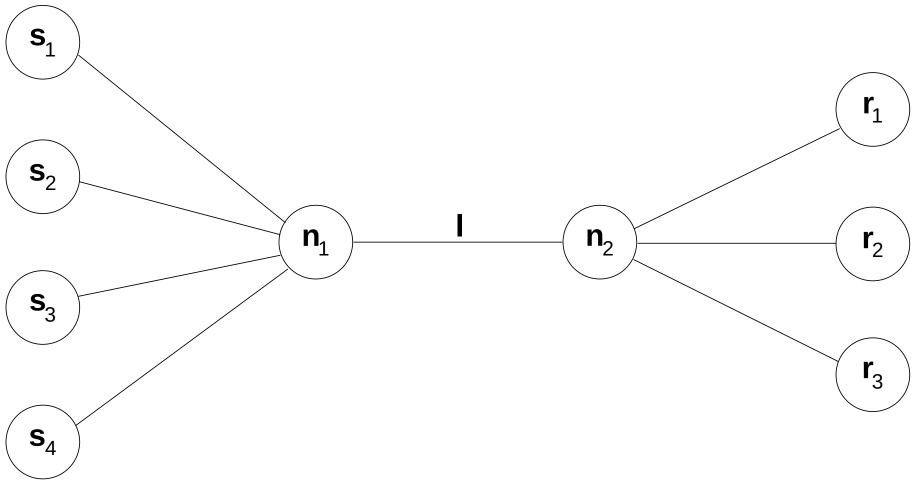


**Figure 3.** *Multi-source and muti-receiver topology.*

| Receiver | Hierarchy |
|---|---|
| $r_1$ | $f_1 > f_2 > f_3$ |
| $r_2$ | $f_4 > f_2$ |
| $r_3$ | $f_4$ |

**Table 1.** *Flows hierarchy*

We note that receiver $r_1$ gives the highest priority to the flow $f_1$, then to $f_2$, and finally to flow $f_3$. Receiver $r_2$ gives the highest priority to flow $f_4$ and then to flow $f_2$. In the same way, receiver $r_3$ requests only the flow $f_4$ and gives then the highest priority to this one.

First, we show that a problem can arise in the links shared by several multicast trees (the link $l$ in Figure. 3). To solve this problem, a priority must be established between the different flows traversing this link. Our algorithm consists of giving a weight to each flow at each receiver. This weight, initialized at the number of sources in the network, is decrement of one every time we go down in the hierarchy of the flows given by the receivers (profile). Therefore, for receiver $r_1$ the flow $f_1$ has a weight equal to 4 (since there are 4 sources in the network), a weight of 3 is given to flow $f_2$, and finally a weight of 2 to flow $f_3$. Since the receiver $r_1$ has not subscribed to the multicast tree associated with the source $s_4$, a weight equal to 0 is allotted to flow $f_4$. If we apply the same mechanism for all of the other receivers, we have then the different values indicated in the table 2.

| Receivers | Weight (P) |
|---|---|
| $r_1$ | P($f_1$)=4 ; P($f_2$)=3 ; P($f_3$=2)=2 ; P($f_4$)=0 |
| $r_2$ | P($f_1$)=0 ; P($f_2$)=3 ; P($f_3$=2)=0 ; P($f_4$)=4 |
| $r_3$ | P($f_1$)=0 ; P($f_2$)=0 ; P($f_3$=2)=0 ; P($f_4$)=4 |

**Table 2.** *Weights of the flows in the receivers*

The weights of each flow are transmitted downstream towards its source. Each intermediate active node calculates the new weights of the flows by performing a simple sum, for each flow, of the weights received from the different receivers. Therefore, for the nodes $n_1$ and $n_2$ we have the weights indicated in table 3.

| Node | Weight (P) |
|---|---|
| $n_1$ | P($f_1$)=4 ; P($f_2$)=6 ; P($f_3$=2)=2 ; P($f_4$)=8 |
| $n_2$ | P($f_1$)=4 ; P($f_2$)=6 ; P($f_3$=2)=2 ; P($f_4$)=8 |

**Table 3.** *Weights of the flows in the active nodes*

In the link $l$ the highest priority is given to the base layer of the flow $f_4$, then to the base layer of the flow $f_2$, then the base layer of the flow $f_1$, and finally to the base layer of the flow $f_3$. In the same way for the first enhancement layer and so on until the totally consumption of the link bandwidth.

## 4. Analysis

In this paper, we are interested in the performance of a node when this one has to manipulate a large number of feedback priority messages with pseudo-random characteristics. We consider the network shown in Figure. 4. The topology consists of a set of links $L$, the set of receivers $R = \{r_k\}_{k\in\{1,M\}}$, and a number of sources $S = \{s_k\}_{k\in\{1,N\}}$, where $s_k$ is the sender of the multicast session $m_k$.

We suppose one multicast session per video source. On the other side, a receiver $r$ can participate in many multicast sessions. Each receiver $r_k$ must provide a profile classifying the different flows required by this receiver. We define $p^k_{r_j}$ as the weight of flow of the $k$th multicast session for receiver $r_j$.

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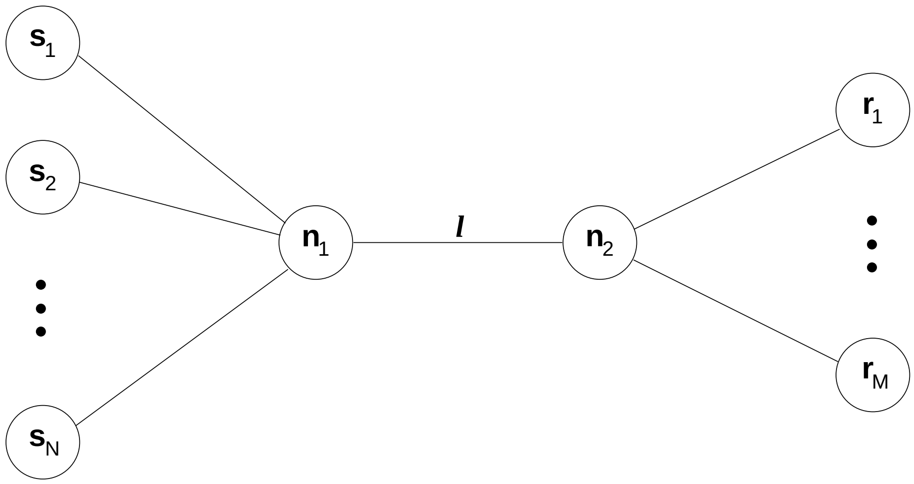


**Figure 4.** *Analysis topology.*

These weights corresponds to the priorities of the flows at each one of the receivers and allows the algorithm to classify the different flows in the upstream nodes shared by a number of multicast trees. The computation of the weights depends on the position of the flow in the classification table. To the most important flow, the algorithm gives a weight $p^1_{r_k}$ equal to number of sources in the network. The weight $p^1_{r_k} - 1$ is given to the flow in the second position of the classification table. This is repeated for all flows required by receiver $r_k$ as shows the following equation.

$$p^i_{r_k} = \begin{cases} \#\text{ of sources} & \text{if } i = 1\,; \\ p^{i-1}_{r_k} - 1 & \text{for the } i\text{th flow required} \\ & \text{by receiver } r_k; \\ 0 & \text{for the flows not required} \\ & \text{by receiver } r_k. \end{cases} \qquad [2]$$

Once the weight have been given to each one of the flows and at each one of the receivers, a vector with all of the weight is transmitted to the source. At the reception of the packets sent by its downstream nodes, the active intermediate node $n$ merges the correspondent vectors to create a new "combined" classification of the flows. The merging procedure is simple and the resulting vector is obtained through the sum of the weights of each one of the flows, as represented in the equation below.

$$p^{f_i}_n = \sum_{k=1}^{m} p^{f_i}_{r_k}, \qquad [3]$$

where $m$ is the number of receivers connected to node $n$.

We have at the intermediate node $n$ a new classification based on the weight obtained from the received vectors. This classification allows the node to fair allocate the bandwidth of the links shared by different flows. This allocation respects the following rules:

**Algorithm 1** Bandwith Sharing

$i \Leftarrow 1$
$j \Leftarrow 1$
**while** ($i$ <= Nb_max_sources) **and** ($j$ <= Nb_max_levels) **do**
  **if** ((BW_consumed + rate(**level** j of **flow** i) <= BW_total) **then**
    $\text{Transmission of } \mathbf{level}\ j \text{ of } \mathbf{flow}\ i$
    $\text{BW\_consumed} \Leftarrow \text{BW\_consumed} + \text{rate}(\mathbf{level}\ j \text{ of } \mathbf{flow}\ i)$
  **end if**
  $i \Leftarrow i + 1$
  **if** $i == \text{Nb\_max\_levels}$ **then**
    $j \Leftarrow j + 1$
  **end if**
**end while**

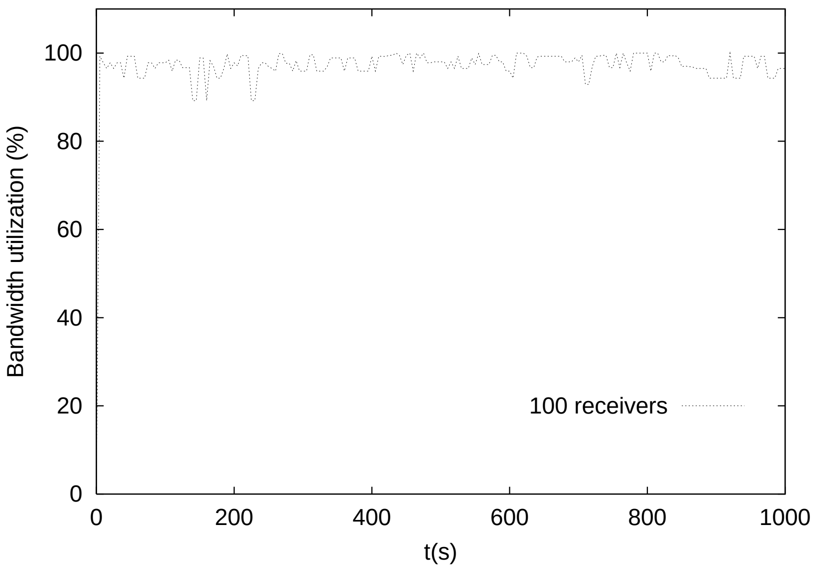


**Figure 5.** *Bandwidth utilization.*

We have simulated the topology of Figure. 4 with ten three-layer video sources and one hundred receivers. We consider the link $l$ as the bottleneck link, i.e. all of the other links can transmit the required rate without congestion or losses. The capacity of link $l$ is 1 Mbps. For the video sources, each layer has a constant rate of 300 Kbps.

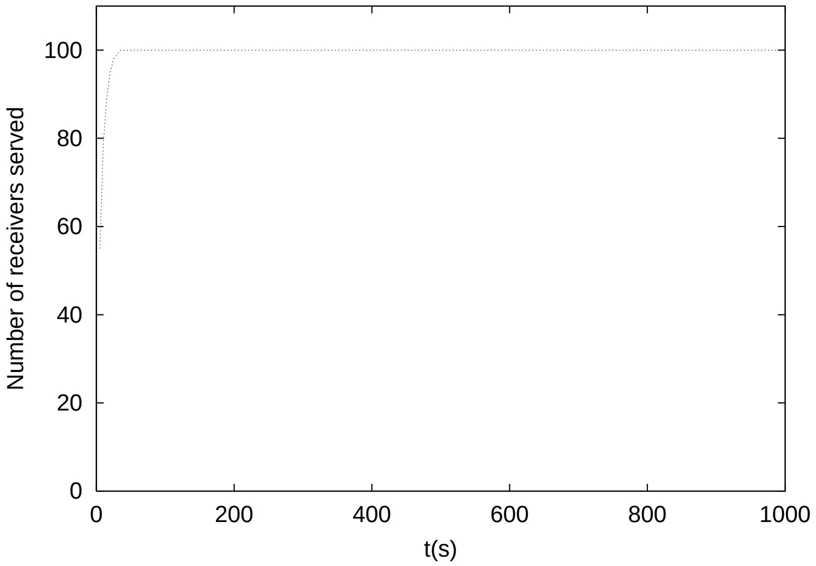


**Figure 6.** *Number of receivers served with at least the base layer.*

The curve plotted in Figure. 5 shows the total amount of bandwidth allocated in the link $l$. We can observe that almost all of the resources are used, which means an almost optimum bandwidth utilization. Even in the worst case the proposed algorithm results in a bandwidth consumption greater than 85%.

The second analysis corresponds to the responsiveness of the proposed scheme, and is represented in Figure. 6. The correspondent curve shows the number of clients served with at least the base layer of all of the required flows. We note in this graphic the high speed of convergence of the system, with 100% of the clients being quickly served.

## 5. Conclusion

We have shown in this paper that an active management of multi-source multicast distribution of multi-layered video offers a better quality of service for the whole set of receivers. Indeed, in this paper we observe that a simple classification at the receivers yields a more efficient distribution of the resources for shared links. The obtained results show that the bandwidth is efficiently allocated and that our proposal leads to fair resource sharing among the multicasts groups. We can note also that this mechanism provides quickly all the clients with at least the base layer, so no receivers are neglected for the benefit of other ones.

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