A Comparative Analysis of Flexible and Fixed Size Timeslots for Advance Bandwidth Reservations in Media Production Networks

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***Abstract*—Due to high-demand transfers and predictable network traffic in media production networks, timeslot-based advance bandwidth reservation has been proven to be an efficient solution for collaboration among different geographically distributed media production actors. Timeslot-based advance reservation approaches can be deployed based on flexible or fixed timeslot sizes. This paper makes a comparison between predefined fixed and customized flexible timeslot sizes in timeslot-based advance bandwidth reservation in media production networks. We show the restriction of predefined timeslot sizes and elaborate on the issues with scheduling based on flexible time intervals, with a specific focus on the characteristics of media transfer. We end the paper with a discussion on which context is the best fit for fixed timeslot based approaches, and likewise, which benefits from flexible timeslot based approaches.**

***Index terms*—** Advance bandwidth reservation, flexible timeslot, fixed-size timeslot

I. Introduction

In recent years, the amount of various types of data that needs to be transferred for processing and analysis collaboration between geographically distributed sites is increasing at a phenomenal rate in several industries. This data must usually be transferred between multiple end sites in a time-bound manner. For example in the media production industry, due to the proliferation of higher bitrate videos, large quantities of video files and streaming sessions must be processed on time by multiple geographically distributed collaborating parties. In media production networks bandwidth requirements, timing constraints and locality of network transfers are mostly known in advance. Consequently, deploying advance bandwidth reservation techniques leads to an increase in requests' admittance ratio and network utilization.

Timeslot-based advance reservation approaches can be classified based on either flexible or fixed size timeslots [1]. In our previous work, we have shown that using advance reservation is a viable solution for efficient bandwidth allocation for the media production industry. We proposed several timeslot-based advance bandwidth reservation approaches based on fixed size timeslot sizes, e.g. an optimal solution [2], near optimal solution [3], robust near optimal solution [4], etc. However, according to [1], the fixed-size timeslot based advance reservation approaches are inefficient for networks with a small number of reservation requests. This motivates us to make an investigation on fixed and flexible size timeslot-based approaches, taking into account the characteristics of requests in media production industry. In this paper, we compare the quality and complexity of both approaches and show under which conditions, which approach is more appropriate for media production network transfers.

It should be noted that current research to support advance reservations mostly focuses on optical networks in combination with wavelength division multiplexing [1]. Recently, Software Defined Networking (SDN) techniques can provide high-level prioritization and bandwidth reservation abstractions, hiding the details of the underlying physical mechanisms. Research performed in this paper on advanced reservation network scheduling assumes such SDN reservation mechanisms are present and can be configured and used by the control elements.

The remainder of this paper is organized as follows. We describe the work related to advance reservations in Section II. Section III elaborates on the advance bandwidth reservation approach, customized for media production networks. The comparison between fixed and flexible sizes timeslot-based approaches is discussed in Section IV and finally we conclude in Section V.

II. Related work

As advance bandwidth reservation is an essential feature of any shared network in which network capacity needs to be co-allocated at predetermined times, there have been significant investigations in research and education networks to date [5], [6], [7], [8]. In [9], a deadline-aware and flexible bandwidth reservation algorithm is proposed. However, these works differ from our work as they focus on generic data transfers and give little attention to video transfers such as video files and video streams with specific requirements, which mainly exist in media production industry, as well as interdependencies among different transfers. The static advance reservation problem is initially presented in [10], [11] for optical infrastructures, by proposing heuristics and meta-heuristics and focusing on

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requests with specified start time and duration. The authors in [12], [13] were the first to propose dynamic advance reservation in fixed time-slotted networks.

The work presented in this paper is in line with our previous works on media production network bandwidth reservations. We first presented optimal [2] and near optimal deadline-aware advance bandwidth reservation algorithms [3]. Then, our advance reservation algorithms were extended to provide resilient scheduling [4]. In the resilient advance reservation approach, backups are ready for use, but are only activated when failures occur. Therefore, we designed a dynamic event-driven approach in order to increase network utilization and request admittance ratio. In this approach, the underutilized network capacities, e.g. unused backup reservations, are exploited to transfer more data than what has been scheduled at runtime (as long as no failure is detected) [14], [15]. However, the work presented in this paper differs from our other works as in all our proposed approaches a fixed size timeslot-based approach has been followed and the main focus of this work is to compare the quality and complexity of fixed and flexible timeslot-based approaches in media production or similar industries.

III. Advance bandwidth reservation in media production network

In general, media production network transfers are of two types: video streams (VS) or file-based videos (FB). We assume that for FB requests, volume and for VS requests duration is always known. The allocated bandwidth for the video streams must be equal to their required bandwidth demand, from the start time (t_s^n) to the end time (t_e^n), because their demand is fixed and non-variable. However, for file-based requests, the volume of file is the determinative factor. The file can be transferred whenever possible from the time the file is ready to be transferred (t_s^n) till its deadline (t_e^n). The residual demand of file-based videos is modified whenever a part of the video file is transferred.

In the media production industry multiple actors, which are involved in one production project, are interacting and transferring media content. If one of those transfers is not successfully done the whole project can be affected. This forms dependencies among different transfers. We refer to the set of all transfers of a project as a scenario. The scenario consists of several interdependent video transfers. We refer to each single transfer as a request. A request can have a fixed start time, end time and/or duration, or may depend on other requests. These interdependencies must be taken into account during the scheduling process.

Video delivery requests can therefore be classified in 4 different categories: 1) Requests with specified start time and fixed duration, the independent video streams are in this class. 2) Requests with specified start time and flexible duration to which the independent file transfers are related. 3) Requests with unspecified start time and fixed duration, dependent video streams can be seen in this group. 4) request with unspecified start time and flexible duration, independent file based videos can be found in this set.

A. Time domain classifications

In advance bandwidth reservation approaches, management of the time domain is of great importance [1], [16]. As an efficient solution, a timeslot-based approach is introduced which maintains aggregated information about network capacity consumption. Based on this solution, the entire time span is discretized into a set of timeslots. The information about resource usage and network residual capacity is held for each timeslot. Timeslot-based solutions can be static or dynamic. In static timeslot-based classification, the timespan is broken into a fixed number of predetermined-length timeslots which makes it easy to implement. The amount of network state information is independent of the number of requests. In the dynamic timeslot solution, duration and number of timeslots are allowed to vary, according to the number of reservation requests in the network. Although the majority of timeslot-based proposed approaches in the literature have followed the static solution, it is inefficient for advance reservation systems with a small number of reservation requests [1].

In the next section, we analyze the impact of flexible (dynamic) and fixed size (static) timeslot-based advance bandwidth reservation in media production networks, taking into account the characteristics of media requests.

IV. Analysis of flexible and fixed time slot size advance reservation approaches

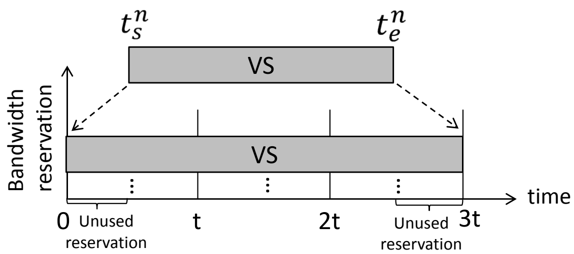
In this section, we thoroughly discuss the benefits and disadvantages of flexible and fixed size timeslot-based approaches for media production advance reservation system.

A. Fixed timeslot sizes

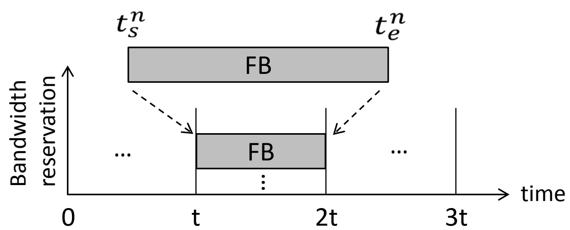
Using fixed time slot size approaches leads to regular and periodic reconfigurations of network intermediate routers and switches. The number, start time and duration of timeslots is not altered, even in highly dynamic network traffic conditions. The size of the timeslots can be set to a suitable value in networks with predictable traffic pattern [3]. This makes fixed-size timeslot approaches appealing for network managers due to facile implementation and predictable performance.

However, we have distinguished the factors which restrict the capabilities of fixed timeslot-based approach and make the variable time slot sizes more suitable for advance bandwidth reservation in media production networks. These factors are related to the characteristics of requests in media production industries and nature of fixed timeslot-based advance reservation approaches in general.

1) Request characteristics in media production industries: **Type of requests**: In fixed timeslot-based approach, the duration of reservations has to be tuned to the size of timeslots. To elaborate more on this, Figure 1 is depicted which reveals how the reserved bandwidth is restricted by the size of timeslots. These restrictions are shown in Figure 1a and 1b for a video streaming and a file-based request respectively. As can be seen,



(a) Allocation for a video streaming request.



(b) Allocation for a file-based request.

Fig. 1: Allocations for video streaming and file based requests in fixed size timeslot-based advance bandwidth reservation approach.

different behavior is developed for different types of requests. Since in our fixed timeslot-based approach the amount of allocated bandwidth is unchangeable within each time interval, for the video streams the reservation has to be made from the start of the timeslot in which the start time of request (t_s^n) fits, till the end of the timeslot to which the request's end time (t_e^n) belongs. Therefore, the bandwidth capacity reserved from 0 to t_s^n and from t_e^n to $3t$ is unused. However, for file-based transfers, the reservation has to be started after the time when the file is ready to be transferred (t_s^n) and it must be finished by the request's deadline (t_e^n), so the start of reservation for a file is restricted to the beginning of the next timeslot and the start of the timeslot in which the request deadline fits. This restriction implies that the file has a tighter time opportunity for transmission and therefore the probability of timely transfer is decreased.

Contrary to this, the use of flexible time windows can eliminate these restrictions for both request types. Regardless of the type of request, the start and the end of time windows can be tuned up to the start and end time of each request.

Dependencies among requests: The second point is that the fixed size of timeslots is more restrictive when there are dependencies among different transfers. To make this more clear, Figure 2 illustrates a schedule which has been made for 3 requests: a video streaming request (VS) and two file-based requests, FB1 and FB2. VS has no dependencies, the start time and the end times have been specified at time 10 and 40 respectively. The start of FB1 depends on the time when VS is finished and there is no deadline for this request. For the third request (FB2), the start time depends on FB1 fulfillment and this request has to be transferred by time 200.

As has been shown in Figure 2a, with the fixed interval duration of 60 unit: the reservation for the VS is extended to the entire first timeslot, which is more than twice of the required capacity for the VS request. FB1 can not be started earlier than the start of the second time slot due to its dependency on request VS and the reservation can not be finalized earlier than 120, even if there is enough capacity on the physical infrastructure. The start time of the reservation for FB2 depends on the end of the FB1 transfer. Therefore, this request is also restricted to the third time slot.

As can be seen in Figure 2b, these restrictions are eliminated by deploying variable time intervals and all three requests have been scheduled e.g. by time 140. Therefore, the flexible timeslot-based approach can potentially improve the result of advance reservation scheduling approaches when dependencies among requests exist.

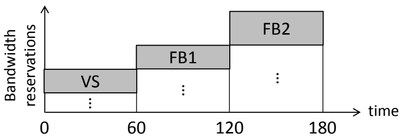
2) Predefined size of fixed-size time slots: The size of time slots has a relatively high impact on the quality and complexity of the advance bandwidth reservation schedule. We show that, although more timeslot size granularity increases the resource utilization in our proposed approach, the complexity of the algorithms significantly increases as well.

Quality of the schedule: We now analyze how the size of time intervals impacts the quality of the reservation system in media production networks. For this analysis, the near-optimal SARA (Static Advance Reservation Algorithm) approach [3] is evaluated in which all the requests are known in advance, before the start of scheduling.

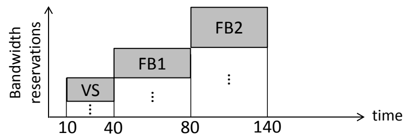
In Figure 3 and 4, the number of admitted requests in SARA approach for different time slot granularities, varying from 5-minute to 1-hour sizes, are evaluated. An 8-node network topology is used and the simulated timespan of the scheduling is 24 hours. In Figure 3, the network capacities vary from 200 Mbps to 500 Mbps. In total, 209 interdependent requests are submitted to the bandwidth reservation system. The specification of requests and network topology can be observed from [3] and [15] respectively. As can be seen in this figure, the longest timeslot size of 1 hour shows the worst performance in terms of number of admitted requests and this quality is improved as the time interval size is more fine-grained. For example, for the 12-times shorter time interval size (i.e. 5 minutes) and 250 Mbps capacity, the SARA approach achieves up to 15.47% higher percentage of admitted requests. The same trend can be seen in Figure 4 with 67 requests and lower network capacities.

Execution time for producing the schedule: The fixed-size algorithms have a high computational overhead, particularly with fine-grained timeslot sizes and large scale networks. As shown in Figures 3 and 4, the fine-grained experiment with shortest timeslot size results in the highest request admittance ratio. However, the execution time of the algorithm also increases. The SARA approach with 1-hour timeslot granularity is between 12.3 up to 16.7 times faster than the solution with 5-minute timeslot sizes, as can be seen in Figure 5. The same trend is observed when the number of requests is decreased to 67 in Figure 6.

Optimized timeslot size: In the fixed size timeslot-based



(a) Fixed size timeslot-based approach.



(b) Flexible size timeslot-based approach.

Request	t_s^n	t_e^n	t_s^n depends on	t_e^n depends on
VS	10	40	-	-
FB1	-	-	VS	FB2
FB2	-	200	FB1	-

Fig. 2: Impact of dependencies on the performance of flexible and fixed size timeslot-based advance bandwidth reservation approaches.

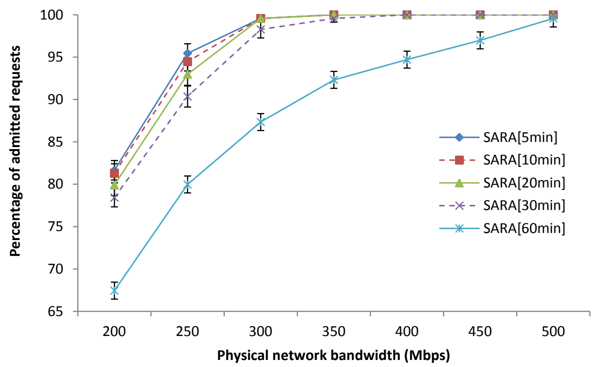


Fig. 3: Comparing the request admittance ratio in fixed-size SARA approach with different timeslot sizes in the 8-node topology (20 iterations). The number of requests is 209.

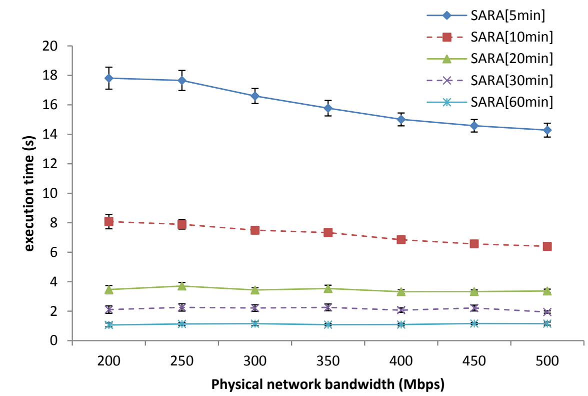


Fig. 5: Comparing the execution time of fixed timeslot-based SARA approach with different timeslot sizes in the 8-node topology (20 iterations). The number of requests is 209.

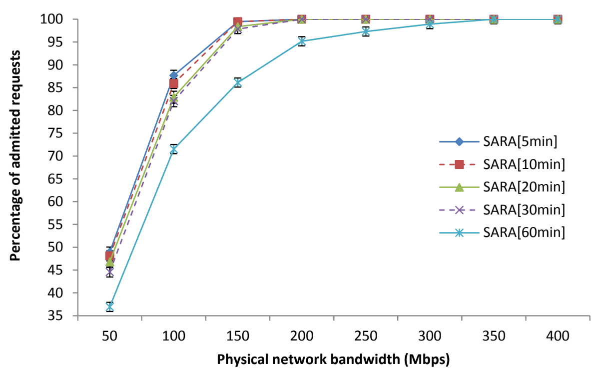


Fig. 4: Comparing the request admittance ratio in fixed-size SARA approach with different timeslot sizes in the 8-node topology (20 iterations). The number of requests is 67.

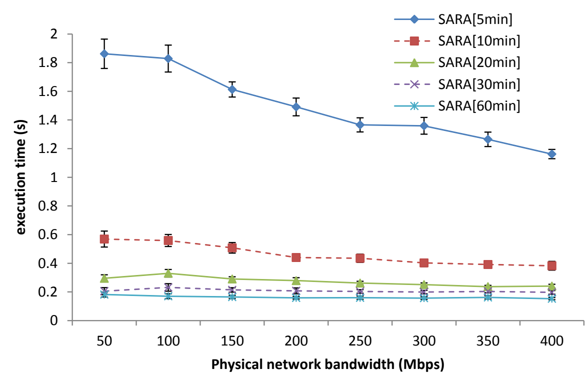
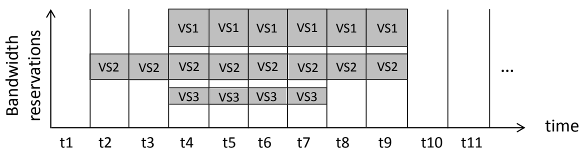


Fig. 6: Comparing the execution time of fixed timeslot-based SARA approach with different timeslot sizes in the 8-node topology (20 iterations). The number of requests is 67.

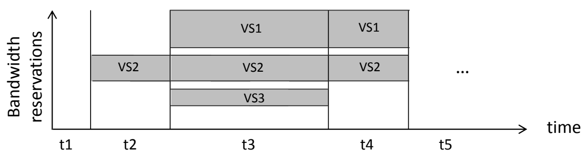
approach, we need to make an informed decision on the optimal size of the timeslots, which is not an issue with variable time window.

In [3], we showed that a time slot size of 600 seconds optimizes the trade-off between optimality and complexity of the solution. Although based on the results for this timeslot size, we stay within 1.6% of the optimum in all evaluated cases, this was not the most optimal value for all possible configurations. This is a challenging issue as other values for the size of timeslots might suit other evaluation scenarios better. The available network capacity is an important factor in low-demand networks. As can be seen in Figure 4, when network capacity is higher than 200Mbps (enough capacity for 67 requests), 5-minute and 30-minute timeslot sizes provide the same results. As such, longer timeslot sizes are preferred as long as all the requests can be scheduled.

Delay prior to request processing: Newly submitted requests to the fixed timeslot-based advance bandwidth reserva-



(a) Allocations based on fixed size timeslots.



(b) Allocations based on flexible size timeslots.

Fig. 7: Comparing the number of timeslots for 3 video streaming requests in flexible and fixed size advance reservation approaches.

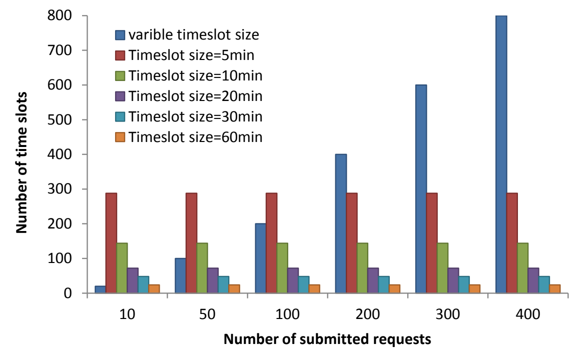


Fig. 8: Comparing the number of timeslots in function of number of requests in fixed and flexible size timeslot-based advance bandwidth reservation approaches.

tion system have to wait till the beginning of the next timeslot for processing. The maximum wait time depends on the size of the timeslots. The bigger the timeslot size, the higher the potential processing delay.

Unnecessary periodic computations for long transfers: Another issue with fixed timeslot sizes relies on the periodic nature of these solutions. In fixed size advance bandwidth reservation approaches, the residual demand of ongoing requests are periodically updated at each timeslot, and new and updated requests are reallocated together. For long-term video streaming requests and large video files, this may lead to unnecessary periodic computations. Figure 7 elaborates more on this with an example. In this figure, we assume three long-term video streaming sessions have been submitted to the advance reservation system. The number of timeslots in the fixed timeslot approach, Figure 7a, is twice the number of timeslots in the flexible solution, as can be seen in Figure 7b. The flexible timeslot-based approach shows higher network utilization because only a start time of new request or the end of an ongoing transfer tears down the connection and creates new timeslot allocations.

B. Flexible timeslot sizes

In the previous subsections we argued that due to the imposed restriction of fixed size timeslot-based approach, the quality of schedules in flexible timeslot-based approaches should be higher when compared to fixed size approaches. We have however identified drawbacks of using flexible timeslot based approaches in 3 cases detailed below.

1) Dependency to the network load: In fixed size approaches, the number of timeslots stays unaffected when increasing the network load. Nevertheless, Figure 8 reveals that the number of requests affects the number of timeslots (in 24 hours) in the solution with flexible timeslot sizes. In this approach, to calculate the number of timeslots we need to know which factors play a role. Typically, timeslots are started with any request start time and end with either the arrival of a new request or the earliest end time of current requests. As such, in the worse case the number of time slots is twice of the number of request.

Comparing the predefined 5-min and variable timeslot sizes in Figure 8, the complexity of variable timeslot is negligible only when the number of requests is lower than 144. For example, in Figure 4 with 67 requests, the computational overhead of variable timeslot-based approach is expected to be significantly lower, comparing to Figure 3 with 209 requests. Dependency to the number of requests could be detrimental in networks with growing number of resource reservations and releases as it may lead to unpredictable complexity.

Unpredictable Complexity: The number of timeslots is a factor which directly increases the complexity and computational overhead of timeslot-based advance reservation systems. In flexible timeslot-based advance reservation approaches, the number of timeslots and the complexity of the scheduling highly depends on the number of requests. In highly dynamic environments, the number of future timeslots is not predictable and therefore the complexity of the flexible timeslot-based algorithms is unmanageable. The benefit of using variable timeslot size approaches may be defeated due to excessive complexity and here is where the fixed-size timeslots plays its trump card: the complexity of the scheduling can be easily managed by consciously adjusting the timeslot size.

2) Irregular network devices' reconfiguration: Contrary to the fixed-size timeslots in which the number and duration of timeslot remains unchanged, flexible time window approach results in unpredictability of future timeslots. The number and duration of timeslots is frequently being adjusted during the scheduling process, as soon as new requests are admitted to be scheduled.

3) Impractical timeslot duration: The next negative feature of flexible time slot approach comes to light when a large quantity of short-lived or low-demand requests with overlaps or with a very short time-based gap in between, needs to be scheduled. This leads to a considerable number of time slots with quite brief duration, which is impractical. For example, duration of transmission of a video file of 1GB, in a network with 10 Gbps leftover capacity, is 10ms which is not a practical

TABLE I: The summary of the benefits and disadvantages of flexible and fixed-size timeslot based advance reservation approaches in media production industry.

	Benefits	**disadvantages**
fixed-size timeslots	• Regular reconfigurations of network devices • Independence number of timeslots • Easy to implement	• Quality and execution time dependency on timeslot size • Hard to find optimized timeslot size • Delay prior to request processing • Unnecessary periodic computations for long transfers
Flexible timeslots	• Compatibility with media network transfers • Higher expected quality • suitable for low demand networks with bursty traffic	• Unpredictable Complexity due to dependency on network load • Irregular network devices' reconfiguration • Impractical timeslot duration

timeslot size in operational bandwidth reservation systems. It should be noted that this issue can be resolved by defining a threshold for minimum timeslot size.

C. Comparative discussion

To sum up, we can conclude that theoretically the use of variable time slots can improve the success rate of advance bandwidth reservation systems. However, the complexity of this approach should not be neglected. The flexible size timeslot-based approach is highly beneficial when the media production network deals with long-term downtimes and bursty traffic conditions. Burst traffic in this context is defined as large and high-bandwidth transfers over a short time period. Having said that, with a large number of small-size file transfers and short-lived video streaming requests, not only the complexity of the scheduling process is unpredictable, but also the highly frequent reconfiguration of physical network devices is impractical or at least expensive. Therefore, fixed size timeslots can be considered as a convenient solution in such situations. The advantages and disadvantages of each approach are summarized in Table I.

V. Conclusion

In our previous work, we have proposed fixed size timeslot-based advance bandwidth reservation approaches optimized for media production networks. In this paper, we pointed out the restrictive characteristics of requests in media production industry and limitations of advanced reservation scheduling based on predefined timeslot sizes. We argued that flexible time slots should increase the quality of advance bandwidth reservation in media production networks. We further distinguished the drawback of deploying flexible time slot reservations, such as dependency to the number of requests, irregular re-configuration of network devices, unpredictable complexity, etc. and discussed which approach should be used in which situation.

In our future work, we intend to design and implement the variable timeslot-based advance reservation approach and evaluate the quality and complexity of this approach compared to the fixed-size solution.

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