Design of a Dynamic Adaptive Reservation System in Media Production Networks

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Abstract—Due to the predictable nature of network transfers in media production industry, advance bandwidth reservation results in higher bandwidth utilization and improved network performance. However, in unreliable networks, this may fail. As a first provisional stage, deploying protection mechanisms ensures that the schedule remains valid when the system is in operation. Constant monitoring and modification is also required in order to be capable of dynamically adapting the network to changing conditions. In this paper, we propose an efficient dual approach consisting of two processes. First, a schedule is produced by a resilient advance reservation algorithm. Then, the generated schedule is continually updated over time using a runtime adaptation approach. As this step uses the interconnecting network links’ leftover capacity, following this approach leads to increased performance in case of steady network conditions, or neutral performance when transmitting admitted requests in uncertain network conditions.

Index Terms—Advance bandwidth reservation, media production network, runtime adaptation.

I. INTRODUCTION

Over the years, media production processes have become more complex and more data intensive as they are dealing with enormous amounts of high bitrate videos such as full ultra-HD recordings and a geographically distributed workforce. Large quantities of data may be processed by multiple collaborating parties from different locations. The data related to different aspects of a media production system is analyzed, processed, and stored at different video warehouses which can be geographically distributed. In order to provide high-performance collaboration between different sites, next generation network reservation systems have to be deployed with predictable performance and efficient bandwidth utilization.

The media production environment is highly dynamic due to the arrival and departure of several concurrent requests of different sizes and requirements. Therefore, it is necessary to perform advance reservations to ensure bandwidth availability and to meet the requirements of different transfers.

Advance Reservation (AR) scheduling of network transfers [1] is very important in order to make correct decisions on rejection or acceptance of future requests. However, updating this schedule over time, based on the current state of the network and transfers is similarly important. When a file is actually transferred in accordance with the AR schedule, two scenarios may occur: either the file is completely transferred within the scheduled time period, or due to uncertain network conditions, such as sudden changes in network configuration, network fluctuations, failures, etc, it is not fully transferred.

In our previous work [2], we modeled the advance reservation problem based on the time constraints given by the user, stating the earliest start time and latest completion time for a couple of interdependent requests of two types, video streams and video files. The reservation can be flexible for file transfers and start and finish times of both types can be unspecified due to dependencies on other requests. We devised an Integer Linear Programming (ILP) based mathematical model for an exact solution, and presented heuristic approaches, which we referred to as Sequential Priority Based (SPB) algorithms, to achieve approximate solutions. We showed that the heuristics yielded favorable results in much less time complexity than the linear programs.

In our advance reservation approaches, we deal with dynamic time-dependent reservations. We discretize dynamic graphs into time steps and apply bandwidth allocation algorithms efficiently on every snapshot of the graphs and produce a schedule which consists of distinct reserved capacities in every time interval for each admitted flow. This scheduling is employed by the reservation system as long as no new scenarios are submitted to the system. A time interval or time slot is a period of time in which reservations remain invariant.

In line with our earlier work, we have also presented the resilient version of the SPB approach based on a protection mechanism to improve the reliability of the advance reservation system [3]. The proposed scheme is capable of covering single link failures using the pre-reserved disjoint back up paths. Figure 1a illustrates a simple example of four file transfers and one video stream based on the resilient AR algorithm in a time span of 10 time intervals. For the file transfers, the parts in blue show the primary bandwidth allocations and the parts in gray refer to the backups which are provisioned to be used when a failure occurs in order to be able to transfer the video according to the agreed SLA.

Although the reliability of the media production network is enhanced by the resilient approach, a large portion of network capacity will be wasted if the redundant reservations cannot be reused. Figure 1b shows how the network operates in practice and how the backup paths seldom are in use. This figure also
(a) Reservations based on the resilient advance reservation algorithm

(b) The transfers based on the resilient AR approach in practice

(c) The transfers based on the runtime adaptation approach in practice

Fig. 1: Comparing the resilient AR algorithm in theory, in practice and the runtime adaptation approach contribution. (Blue: Primary reservation for file transfers, Gray: Backup reservations for file transfers, Green: Video stream transfers)

illustrates that the reserved bandwidth for the video streams are not continuously utilized as videos may be resumed/played-back multiple times during the requested connection period.

As can been seen in Figure 1c, to have a higher performance and network utilization, in this work we propose a hybrid approach that combines the advance reservation scheduling and an on-line adaptive optimization system. We consider the resilient SPB heuristic for advance bandwidth reservation scheduling. The proposed adaptive optimization system makes use of backups and idle bandwidth capacities to push more data into the network as long as no failure occurs and while reserved video streaming capacity is unused.

The envisioned media production network is depicted in Figure 2. The different actors and locations involved in the media production process, such as recording studios, on-site filming crews, broadcasters, and storage datacenters, are connected to a shared wide-area network. The management layer provides a reservation interface, that allows the users of the network to submit their requests. The management layer also contains two complementary algorithms of our proposed approach: The AR scheduler and then runtime adaptive algorithm. The AR scheduling component is responsible for reserving the required amount of bandwidth including extra capacities as back ups for all requests and the runtime adaptive optimization component, dynamically re-optimizes the request transmissions. We also assume that controllers, shown in this figure, can make use of Software Define Network (SDN) techniques to provide high-level prioritization and bandwidth reservation abstractions.

The rest of this paper is organized as follows. Section II, describes related work. In Section III, we present our proposed methodology of using a dual approach to better handle the transfers in media production networks. Section IV concludes the paper with some guidelines for future work.

II. RELATED WORK

The concept of advance reservations has attracted some attention in practical and theoretical studies in recent years. Xie et al. in [4] proposed ILP-based models and heuristic approaches on re-routing in advance reservation networks in order to maximize admittance of new requests. The authors in [5] focused on advance bandwidth reservation for on-demand data transfer in scientific applications. However, these approaches purely focus on data transfers, not video streaming sessions, their routing mechanism is based on single-path in contrary to our multi-path approach, dependency among different transfers are ignored and no fault tolerance techniques are considered against possible failures.

Adding resilience into a reservation system can be achieved through restoration or protection failure recovery mechanisms [6]. In protection schemes, physical connections are protected against failures by pre-assigning backup paths which is a fast but expensive approach. Using a restoration mechanism, an alternate path is discovered for each failed path as soon as a failure occurs. Providing resiliency in optical WDM networks through shared path protection has been proposed in [7]. In [8] a resilient advance reservation mechanism is proposed in optical grids, however due to the lower cost of restoration mechanisms, the latter is used. Since meeting deadlines is of great importance in our approach, using protection mechanisms tend to be more reliable.

This work proposes a dual approach which partially makes use of our previous works [9] and [3]. In [9] the near-optimal advance reservation algorithms are proposed and thoroughly evaluated. However, no mechanism to cope with failures were considered. In [3], we enhanced the media production network...
reservation system and made it more reliable in case of failures by following a protection mechanism. This work differs from our previous work, as it provides a complementary approach which improves the reliability and performance of media production reservation systems over the time when the network is in operation. Throughout the next sections, the advance reservation algorithm refers to the resilient version.

III. RUNTIME ADAPTATION METHODOLOGY

Our advance reservation algorithms support rescheduling in order to incorporate new requests at runtime. Since a fixed time slot based approach has been followed, whenever new scenarios enter to the reservation system, if the scenario is admitted, the entire scheduling will be updated from the next time interval. When using adaptive reservation, the AR scheduling algorithm is invoked in two circumstances: First, when new scenarios enter to the reservation system which leads to update the entire schedule for all admitted and unfinished requests. Second, when the schedule needs to be updated during the periodic update, which will be discussed later. In both cases the scheduling is modified at the start of the next time slot.

As illustrated in Figure 3, our runtime adaptation methodology consists of seven components: the advance reservation component, the global state manager, the monitoring system, the job manager, the connection manager, the reservation manager and the adaptive optimization component. This approach follows two sequential phases in every time slot: 1) periodic update and 2) periodic adaptation. Dynamic network conditions such as fluctuations, failures, etc. affects the allocated capacities and network status. The periodic update is repeated before the end of every time slot to take into account the real transmitted data instead of scheduled ones and update the schedule based on recent information. Periodic adaptation is a complementary step to adapt the future schedule which is performed before the start of next time interval. From the second time slot, periodic adaptation has to be performed after periodic update.

Periodic update: During the periodic update, first the current status of network and transfers are monitored and then the resilient AR algorithm is invoked. This process updates the entire schedule based on the information retrieved from the monitoring system. The monitoring system keeps track of demand, time and last allocated bandwidth for all requests. The information will be set in the global state manager. The global state manager contains all the information about the scheduling, the network and request reservations, connections, demands, deadlines, etc. Then the next time slot reservations are derived from the AR schedule and are set as advance-scheduled requests in Job manager. The list of advance-scheduled requests contains all requests which have been scheduled to be transferred during the next interval. However, there are other flows which can be started, but because of bandwidth constraints they have been postponed. These requests are kept in a waiting list for further steps throughout periodic update phase.

Periodic adaptation: In periodic adaptation, the Adaptive Optimization algorithm (AO) is triggered. Based on this algorithm, in this step the scheduling over the next time slot is analyzed and modified to make use of idle bandwidth capacities. To achieve this, the advance-schedule requests are retrieved from the job manager and then the reservations for backups and video streams are ignored. This gives us a network in which only the primary reservations occupy the network capacities. Then for the next time slot, a new schedule for transfers over this residual bandwidth graph is computed. Therefore, extra reservations will be aggregated with the primary reservations of requests and their assigned bandwidth will be increased. For each request the new allocations will be updated in the reservation manager. Based on the new allocations, the start time and finish time of the requests are set and kept in the connection manager. According to this new schedule, in steady network conditions, the requests will be finished earlier than what the AR scheduling had envisioned. During the runtime, any early finish will trigger an event which indicates that the present connection can be torn down. The links which were in use by this request are now free. This may allow other active requests, from the advance-scheduled list, to use more bandwidth if the shared links were in use. Furthermore, there can be other future requests in the AR schedule which could make use of some of these links. Since these links have already been reserved for a finished request, the future requests stored in the waiting list, could be analyzed and potentially scheduled. To achieve this, the finished request is removed from the request list and the AO algorithm is re-triggered. In doing so, the corresponding file transfers begin earlier than they were scheduled by the AR scheduler. This helps improve link utilization. As the reserved capacities for video streams and backups are used have a double purpose, pre-determining how to manage the conflicts before they happen is crucial. To achieve this, another important function called allocations adjustment, determines that if...
any video stream or backup reservations are active for their original purpose, which flows are affected and how. During the runtime, any failure or any video streaming start/stop or resume/playing back will prompt an event and the information provided by this function allows the management system to quickly handle the event. In uncertain network condition, using the idle bandwidth might not improve the network utilization, but it helps in providing more margin for incomplete file transfers. The Adaptive Optimization algorithm (AO) consists of the following steps:

1) Get advance-scheduled requests list from job manager.
2) Get the waiting-list requests from the job manager.
3) Remove the video stream reservations and the backups.
4) Monitor and update network status and requests’ demands.
5) Sort both lists based on their requests’ priorities.
6) For each requests in the advance-schedule sorted list:
   a) Call bandwidth allocation algorithm to calculate:
      i) Maximum aggregated bandwidth for request.
      ii) The transfer finish time.
   b) set the connection and reservations for the request.
   c) Set an event for the request finish time.
7) Repeat step 6 for the requests in the waiting-list.
8) Determine if video streams or Backups are active for their original purpose, which flows are affected and how.

In order to model the dynamic aspect of our model, we have designed a discrete-event based simulator. Discrete-event driven simulation is a popular simulation technique, which is applicable to a large variety of problems in the real world. Discrete-event simulation is being done in a sequential manner. A clock variable holds time up to which the system has been simulated and an event list, maintains a set of events, with their associated times of actions, that are scheduled for the future. In the implementation of our dual approach, the following events are noteworthy:

- Scheduling update: When the AR algorithm is finished this event is raised.
- File based video transfer start time: When a file transfer starts, the adaptive optimization algorithm is invoked for all active and new requests.
- File based video transfer stop time: The fully-completed request is removed from the request list, the other active requests’ demands are updated and adaptive optimization algorithm is invoked. The previously calculated end times of other active requests are canceled.
- Video stream start time/ play back: The video stream transmission is started and allocated bandwidth for the affected file transfers are updated based on the information provided by the allocations adjustment function.
- Video stream stop time/ resume: The allocated bandwidth for the affected file transfers turns back to the value provided by the adaptive optimization algorithm.
- Global state update: When the periodic adaptation is performed, this event is raised to update the requests reservations and connections, etc.

- Failure: This event happens when a failure in the system in detected. The related backups go back to their original use while the scheduling is getting updated.
- Repair: When the failure is resolved and the network is back in operation. Again, the back up reservations can be re-used for extra transmissions.

We are currently in the process of implementing our proposed approach using MASON multi-agent simulation toolkit [10] and in Java environment.

IV. CONCLUSION

This paper dealt with the design of a novel approach to structure media production reservation systems as an adaptive system able to constantly re-optimize in view of failures or changes. The primary concern of this work was coming up with reliable schedules in case of uncertain network conditions. Improving the performance of media production reservation system is an added advantage, provided that the network is stable. Our future work includes the implementation and evaluation of proposed runtime adaptive optimization approaches.

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