Media Streams Planning Problem in CoUniverse

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Talk Overview

- Motivation
- CoUniverse Overview
- Media Streams Planning Problem in CoUniverse
- Proof of Concept Implementation Evaluation
- Conclusions and Future Work
Motivation

- Advanced collaborative environments and distributed applications
  - Using high-quality, high-definition media streams to build collaborative environment
    - bandwidth demands comparable to network link speeds (10 GbE) requires careful planning and configuration of infrastructure
    - lacks adaptivity to changing networking conditions
  - Large numbers of components needed to build the environment
    - each one of them needs to be configured
    - hard to orchestrate them manually to build the desired environment
    - virtually impossible to cope with network events manually
CoUniverse Overview

- Middleware aimed on self-organization and orchestration of applications to build ad-hoc environments for real-time data transmissions on top of physical networking infrastructure
- Support for legacy applications producing streams with bitrate comparable to capacity of the network links
- User-empowered approach where possible
  - end-to-end view of networking topology
- Self-organization based on careful planning of media streams transmissions over network links
- Continuous adaptation to changing networking infrastructure
- Capable of interfacing with optical networks provisioning middleware
  - DCN – dynamic on-demand provisioning of user-requested network circuits over multiple networks (administrative domains)
CoUniverse Building Blocks

- **Components**
  - Network nodes running CoUniverse peers, holds the local configuration (network interfaces, applications)
  - Media applications organized into application groups
  - Application Group Controller (AGC)
    - updates the network topology
    - plans the transmissions of streams over the network infrastructure
    - orchestrates the applications
  - Network control
  - Monitoring
  - Visualisation
Modeling CoUniverse orchestrated applications

- nodes $v \in V$ with configured media applications
  - producers $p \in P$ producing/sending media streams
  - consumers $c \in C$ consuming/receiving media streams
  - distributors $m \in M$ distributing media streams over several network links to the consumers
- network link $e \in E$ with its properties
  - beginning node $\text{begin}(e)$
  - ending node $\text{end}(e)$
  - capacity $\text{cap}(e)$
  - latency $\text{lat}(e)$
Modeling CoUniverse orchestrated applications

- Streams $s \in S$ media stream transmitted between two media applications
  - $bw(s)$ is a bitrate of the stream
  - for each stream $s \in S$ we can tell its source media application $begin(s) \in P \cup M$
  - for each stream $s \in S$ we can tell its target media application $end(s) \in M \cup S$

- Simplified model is presented
  - let us assume that we can obtain $consumers(p)$ for each $p \in P$, $consumers(p)$ is a set of all consumers that request to receive the media stream produced by particular producer $p$
  - we also omit the ability of media distributors to transcode the media streams
Introduction

CoUniverse

Media Streams Planning Problem in CoUniverse

Conclusions

Media Streams Planning Problem in CoUniverse

- Variant of the path placement problem
- The problem of many applications in networks is to decide which path to use for satisfying certain demands under constraints given by the network
- A demand acceptance problem, Link-based planning model (Simonis, 2006)
  - For each demand (transmission of stream \( s \in S \)) we have one decision variable per link \( e \in E \) which states if the link is used or not
  - Stream link \( s/(e, s) = \begin{cases} 1 & \text{if } s \text{ in transmitted over } e \\ 0 & \text{otherwise} \end{cases} \)
  - Goal: find all stream link values considering given constraints and optimization criteria
Media Streams Planning Problem in CoUniverse

Constraints Based on Data Distribution and Network Links Properties

- Each producer with only one consumer must send the stream through at least one link and at most $\|M\| + 1$ links
  \[ \forall p \in P, (\|\text{consumers}(p) = 1\|) : 1 \leq \sum_{e \in E} s_l(e, s) \leq (\|M\| + 1) \]

- Each producer with more than one consumer must send the stream through at least $\|\text{consumers}(p)\| + 1$ links and at most $\|\text{consumers}(p)\| + \|M\|$ links
  \[ \forall p \in P, (\|\text{consumers}(p) > 1\|) : (\|\text{consumers}(p)\| + 1) \leq \sum_{e \in E} s_l(e, s) \leq (\|\text{consumers}(p)\| + \|M\|) \]

- The bandwidth requested by the streams transmissions must not exceed the capacity of the network links
  \[ \forall e \in E \sum_{s \in S} b_w(s) \cdot s_l(e, s) \leq \text{cap}(e) \]
Media Streams Planning Problem in CoUniverse

Constraints Based on Producers and Consumers Properties

• Each producer \( p \) is producing/sending the stream \( s \) using exactly one network link \( e \)

\[
\forall p \in P : \sum_{e \in E, p=\text{begin}(s)} \| sl(e, s) = 1\| = 1
\]

• Each consumer \( c \) is receiving/consuming the stream \( s \) using exactly one network link \( e \)

\[
\forall c \in C : \sum_{e \in E, c=\text{end}(s)} \| sl(e, s) = 1\| = 1
\]

• There is no direct stream link between producer and its consumers if there is more than one consumer requesting stream from this producer

\[
\forall p \in P, \forall c \in \text{consumers}(p) : ((\| \text{consumers}(p) \| > 1) \land (p = \text{begin}(s)) \land (c = \text{end}(s))) : sl(e, s) = 0
\]
Media Streams Planning Problem in CoUniverse

Constraints Based on Media Distributors Properties

- Media distributor is used to distribute streams coming just from a single producer (or media distributor)
  \[ \forall m \in M : \sum_{e \in E, m = \text{end}(s)} \|sl(e, s) = 1\| \leq 1 \]

- Media distributor is capable to distribute the streams to more consumers (or media distributors)
  \[ \forall s \in S, \forall m \in M : \sum_{e \in E, m = \text{end}(s)} \|sl(e, s) = 1\| = 0 \iff \sum_{e \in E, m = \text{begin}(s)} \|sl(e, s) = 1\| = 0 \]
  \[ \sum_{e \in E, m = \text{end}(s)} \|sl(e, s) = 1\| = 1 \iff \sum_{e \in E, m = \text{begin}(s)} \|sl(e, s) = 1\| \geq 1 \]
Media Streams Planning Problem in CoUniverse

Optimization Criteria

- Global latency minimization

\[
\text{minimize } \sum_{e \in E} \sum_{s \in S} \text{lat}(e) \cdot \text{sl}(e, s)
\]

- Global stream quality maximization

- Path latency balancing
  - videoconferences, latency between all producers and consumers is balanced
Media Streams Planning Problem Complexity

- Linear reduction of 1-0 Multiple Knapsack Problem

\[
\begin{align*}
\text{maximize} & \quad \sum_{i=1}^{m} \sum_{j=1}^{n} (LAT - lat_i) x_{ij} \\
\text{subject to} & \quad \sum_{j=1}^{n} \text{max}_{j} b_j x_{ij} \leq \text{CAP}_i, \quad \text{for all } 1 \leq i \leq m \\
& \quad \sum_{i=1}^{m} x_{ij} \leq 1, \quad \text{for all } 1 \leq j \leq n \\
& \quad x_{ij} \in \{0, 1\}, \quad \text{for all } 1 \leq j \leq n \text{ and all } 1 \leq i \leq m
\end{align*}
\]

where \( x_{ij} \) corresponds with a stream link \( sl(i, j) \)

- MSPP belongs to the class of \( NP \)-complete problems
Simplifying the MSPP

- Reduction of the MSPP state space size (number of stream links)
- Elimination of network links
  - capacity based elimination
  - loop links elimination
  - intra site network links elimination
  - consumers and producers based links elimination
Proof of Concept Evaluation

• Based on CoUniverse prototype using Choco solver 1.2.5 library to implement the constraint based programming solving the media streams planning problem

Table: CoUniverse scheduling evaluation (all feasible solutions)

<table>
<thead>
<tr>
<th>Distribution scheme</th>
<th>Sites</th>
<th>Nodes</th>
<th>Network links</th>
<th>Media applications</th>
<th>Media distributors</th>
<th>Planning time [s]</th>
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</table>
Summary and Conclusions

- Working open-source prototype implementation of CoUniverse aimed on high-quality ad-hoc collaborative environments
- Source code available to download
  - [https://www.sitola.cz/CoUniverse/](https://www.sitola.cz/CoUniverse/)
- Several successful demonstrations of CoUniverse features
  - GLIF 2007
  - SC’07
  - I2 Winter Joint Techs Meeting 2009
  - I2 2009 Spring Member Meeting
Future Work

- Media stream planning improvements
  - media streams scheduling utilizing improved monitoring
  - not relying on constraint scheduler to find the plan for media applications
    - find and use a heuristic approach to find a mapping of media streams to particular network links
    - use the constraint scheduler to verify such a plan
  - more sophisticated scheduling
    - media streams transcoding, point-to-multipoint media streams
  - less sophisticated scheduling
    - applications using low-bandwidth streams
Thank you for your attention!

Q?/A!

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