MISL

An SDN-Based Device-Aware Live Video Service For Inter-Domain Adaptive Bitrate Streaming

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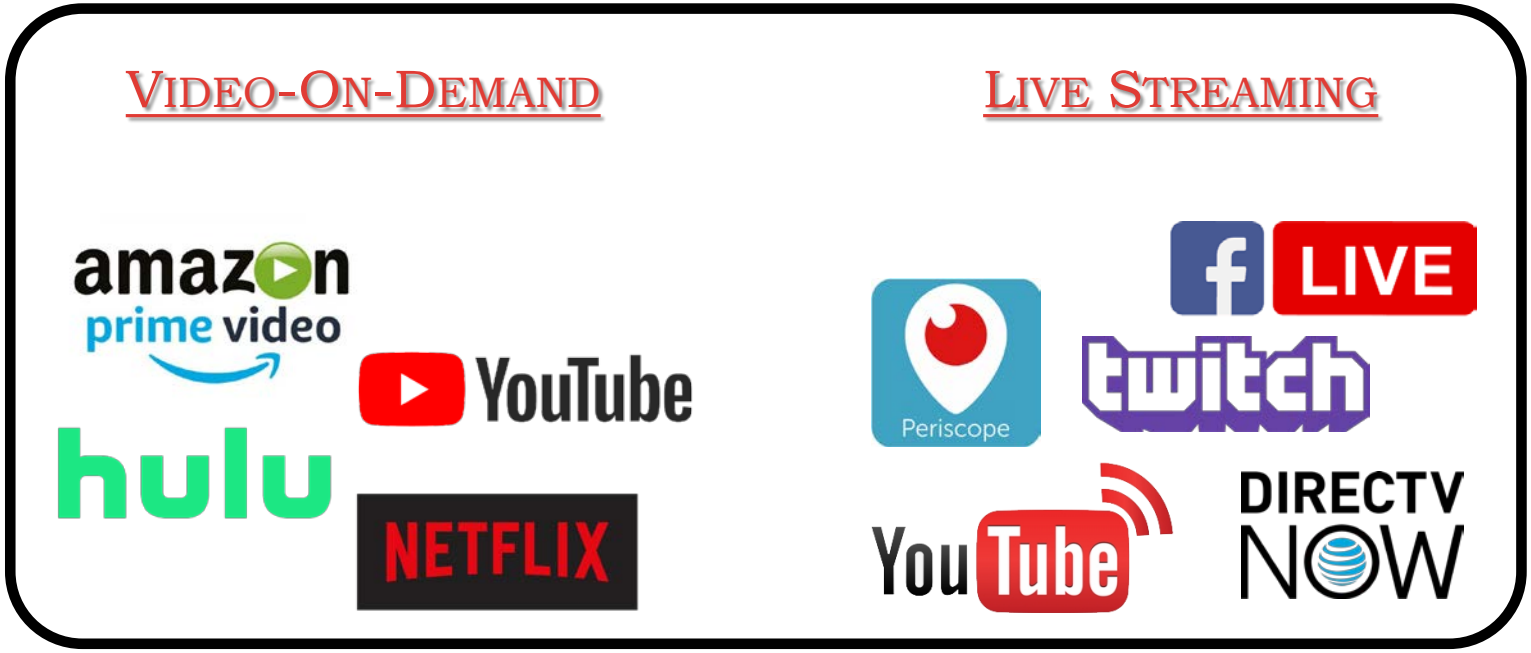
WHY LIVE VIDEO?

- Live video is the **fastest growing traffic** over the Internet
  - 20% of all video traffic by 2022. 15-fold increase from 2017

https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html



- **Flash-crowds and mega-events** are challenging and expensive to handle for Internet Service Providers (ISPs) and Content Delivery Networks (CDN).

Transmission Modes

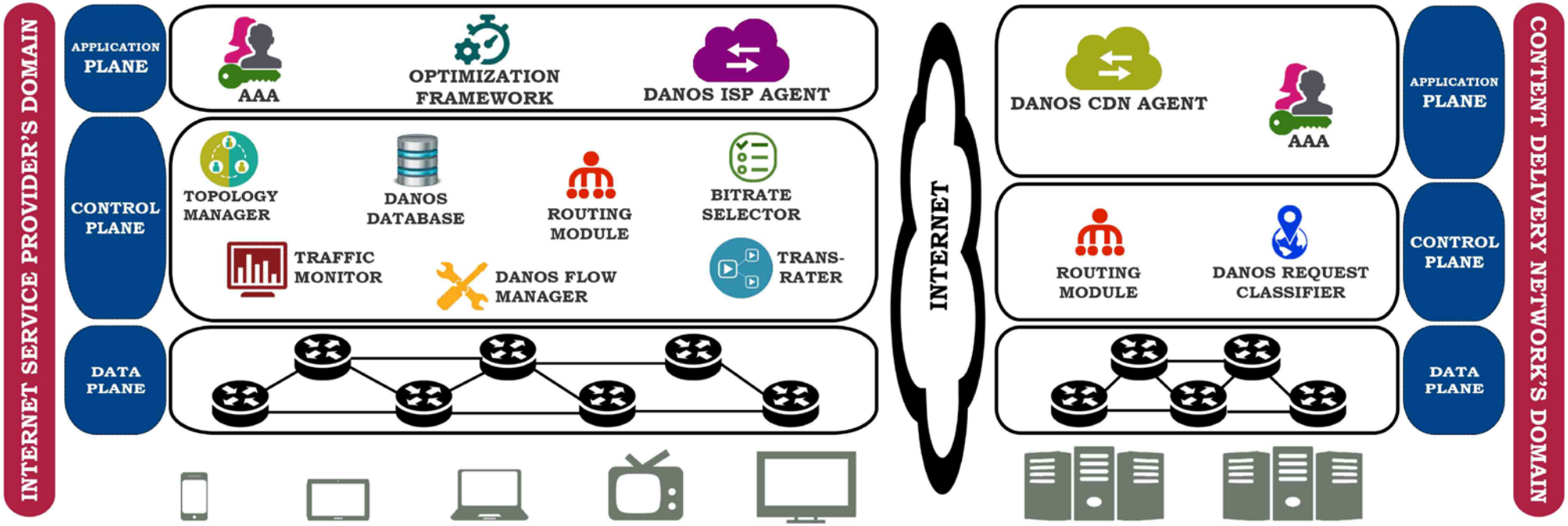
	Unicast	Broadcast	IP Multicast	Overlay Multicast
Bandwidth Efficiency	Low	Good	High	Low
Server Load	High	Low	Low	Low
Inter-Domain Operability	High	Very Low	Very Low	High
CDN Controllability	High	Low	Low	Good
Reliability	TCP/UDP	–	UDP Only	TCP/UDP
Client-Side Requirements	None	System Dependent	Must support IPM protocols	Runs overlay application

Our Contributions

- An SDN-based Internet architecture to:
  - Enable **network-layer multicast** for inter-domain live streaming
  - deliver **adaptive bitrate** video to clients
- An optimization problem to:
  - Maximize **users' perceived video quality**
  - Minimize the utilization of ISP's network
  - Respect device, ISP and CDN **operation constraints**
  - **Real-time** guided optimization for practical deployment
- Addressing **design challenges** of:
  - Switching client bitrates smoothly
  - Synchronizing various architectural components
- An emulated prototype implementation with:
  - Multiple videos encoded at **multiple bitrates**
  - **Large number** of video clients
  - **Real-world** network topologies and scenarios

Architecture Overview

- Software Defined Network (SDN) based architecture:
  - Utilizes the **global view** and **centralized control** of SDN
- Device Aware Network-Assisted Optimal Streaming (**DANOS**) service



Application Plane

INTERNET SERVICE PROVIDER'S DOMAIN

Interfaces with Danos CDN Agent using east-westbound interface and orchestrates **multicast operations** using northbound interface

Runs an optimization model periodically or based on events and **reconfigures the network paths** to improve the system utility

Authentication, Authorization and Accounting

CONTENT DELIVERY NETWORK'S DOMAIN

Implements **policies** to determine whether/when a stream should be served as unicast or multicast and **interfaces** with Danos ISP Agent

Authentication, Authorization and Accounting

CONTROL PLANE

INTERNET SERVICE PROVIDER'S DOMAIN

DANOS DATABASE — **Gathers and stores the information** provided by CDN and collected by different SDN modules

BITRATE SELECTOR — Finds the **best or the highest bitrate** that a new user can support

DANOS FLOW MANAGER — Installs **forwarding rules** on forwarding nodes and **transparency rules** on egress switches

TRANS-RATER — Provides trans-rating services to a CDN to **further reduce the cost of serving multiple bitrates** per video

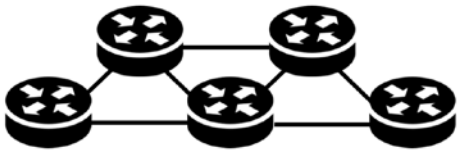
CONTENT DELIVERY NETWORK'S DOMAIN

DANOS REQUEST CLASSIFIER — Identifies the client's ISP network

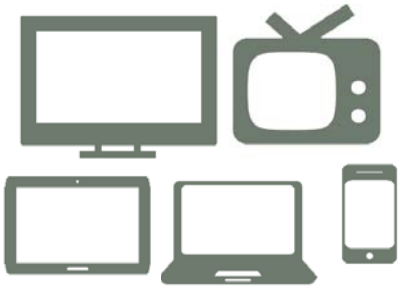
ROUTING MODULE — Implements the CDN routing policies

Data Plane

INTERNET SERVICE PROVIDER'S DOMAIN

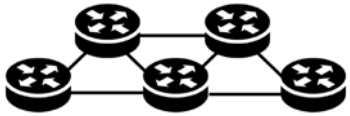


A network of **SDN-enabled forwarding nodes** (switches)



Standard **UDP-based live video clients** with varying device capabilities and a minor consideration at the application layer

CONTENT DELIVERY NETWORK'S DOMAIN



A network of forwarding nodes, **preferably SDN-enabled**

Live streaming servers with an **API to communicate with Danos CDN Agent**

Optimization Model

Inputs: **Users and their allowed bitrates, Network nodes and links**

M_v $m_{v_{min}}$ $m_{v_{max}}$ N L_i

Output: **Bitrates to transmit from one node to another**

B_{ijvr}

Maximize **Cumulative bit-rate based system utility for all users**

$$\sum_{v \in V} \sum_{m \in M_v} \sum_{r \in R_v} \sum_{j \in L_m} f(m,r) \cdot B_{mjvr}$$

Subject to: **Available capacity for multicast**

$$\sum_{v \in V} \sum_{r \in R_v} r \cdot B_{ijvr} + \sum_{v \in V} \sum_{r \in R_v} r \cdot B_{jivr} \leq \alpha_{ij} \cdot c_{ij}$$

Each user assigned a bitrate

$$\sum_{r=R_v[m_{v_{min}}]}^{R_v[m_{v_{max}}]} \sum_{j \in L_m} B_{mjvr} = 1$$

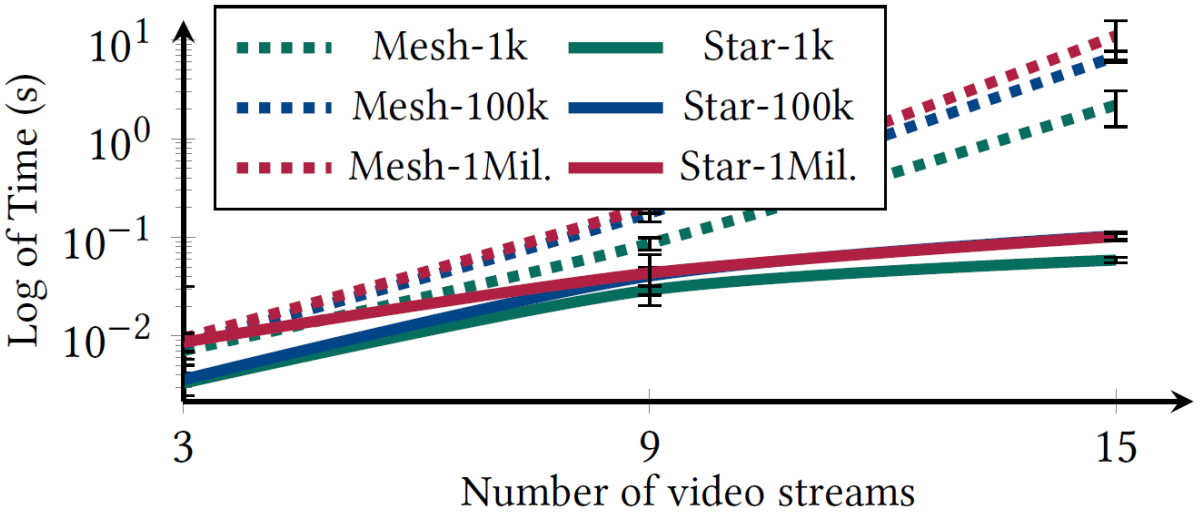
Nodes only transmitting the bitrate that they received

$$B_{ijvr} - \sum_{k \in L_j} B_{jkvr} \leq 0 \; \forall v \in V, i \in N - e_v, j \in L_i$$

REAL-TIME GUIDED OPTIMIZATION

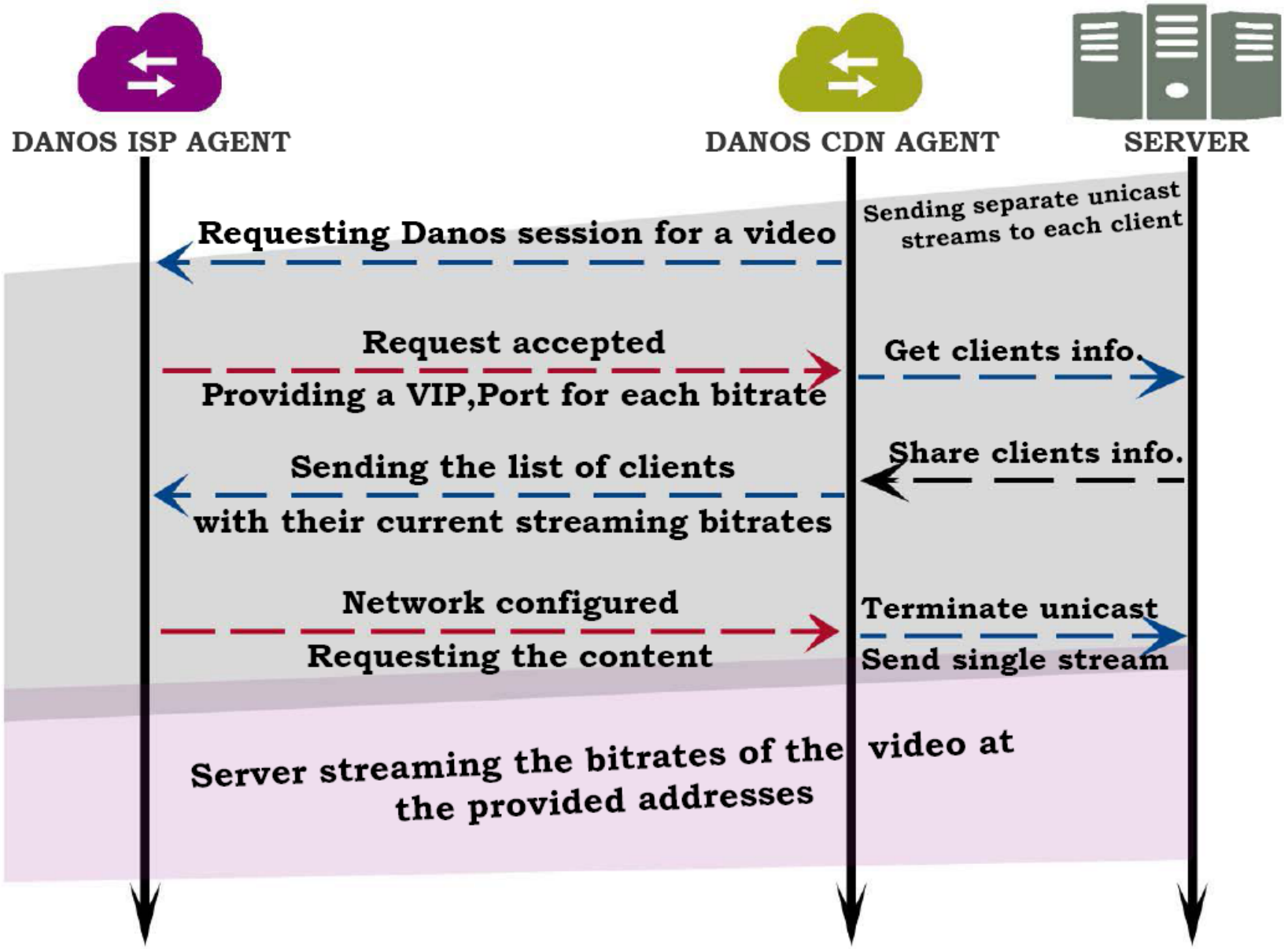
Maximize **Cumulative bit-rate based system utility for all user groups**

$$\sum_{v \in V} \sum_{g \in G} \sum_{r \in R_v} \sum_{j \in L_g} w_{gj} \cdot f(g,r) \cdot B_{gjvr}$$



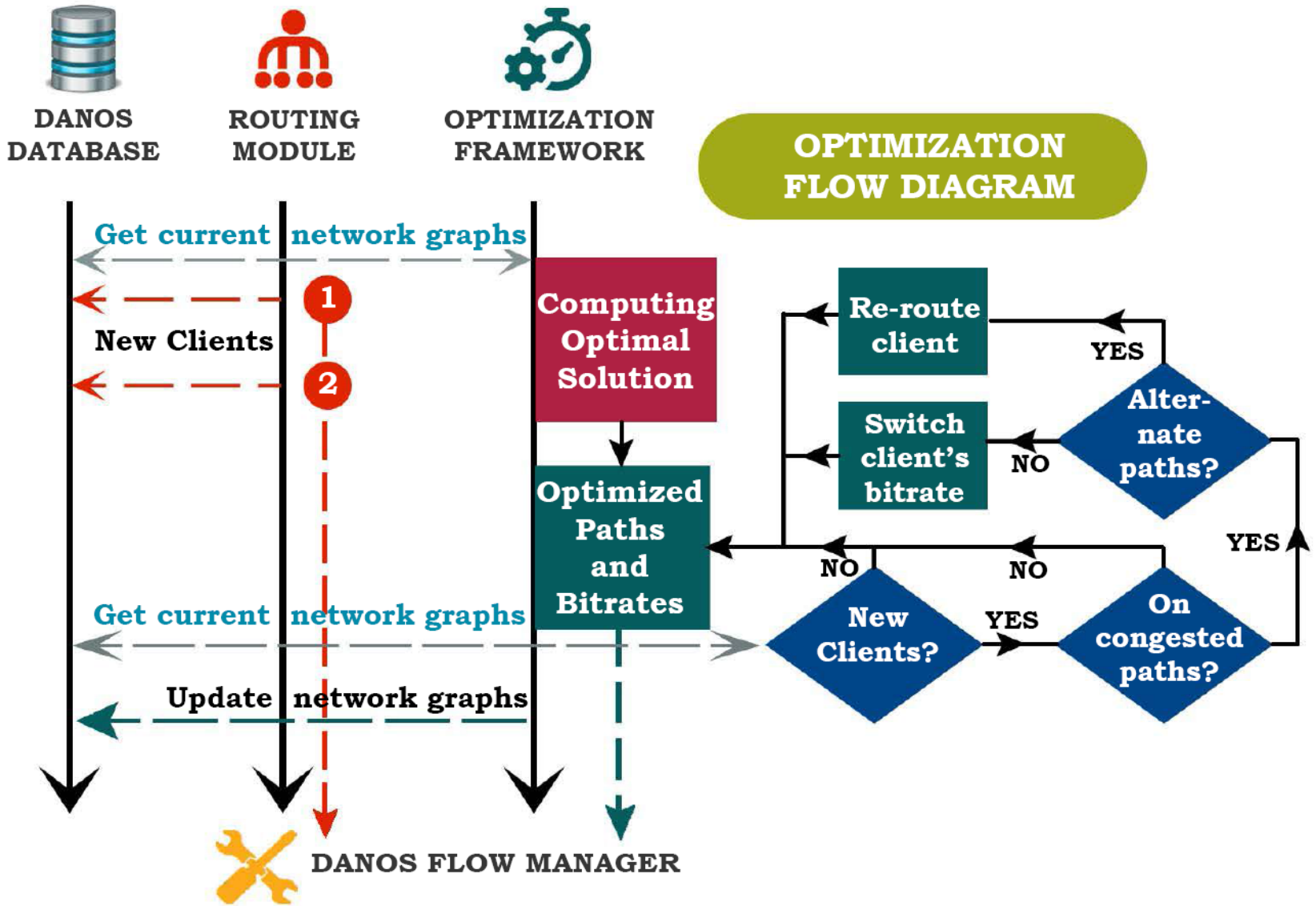
Time taken to find optimal solution by Danos for videos served at three bitrates each

EXAMPLE: SESSION INITIATION

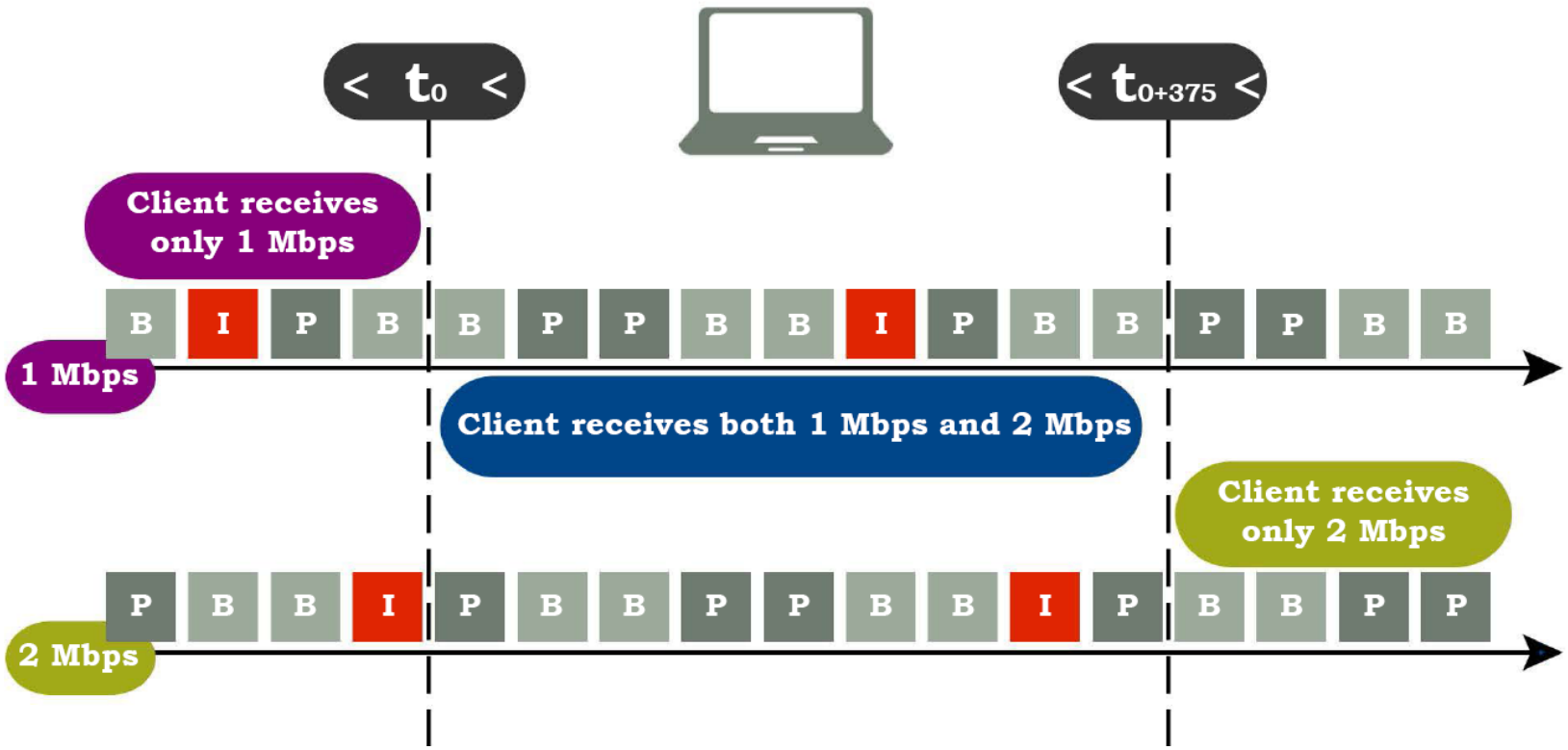


EXAMPLE: ADDING CLIENT

DESIGN: SYNCHRONIZING FLOW ENTRIES



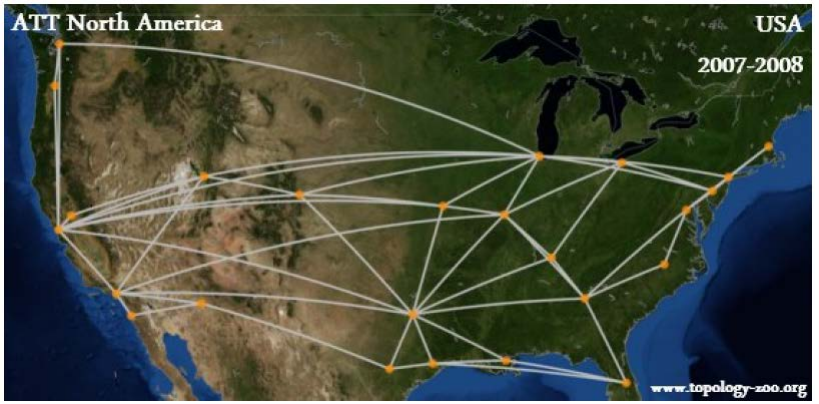
DESIGN: SMOOTH SWITCHING



Extra network queue lengths required to enable the smooth switch-over process should be considered by ISPs when planning the network topology

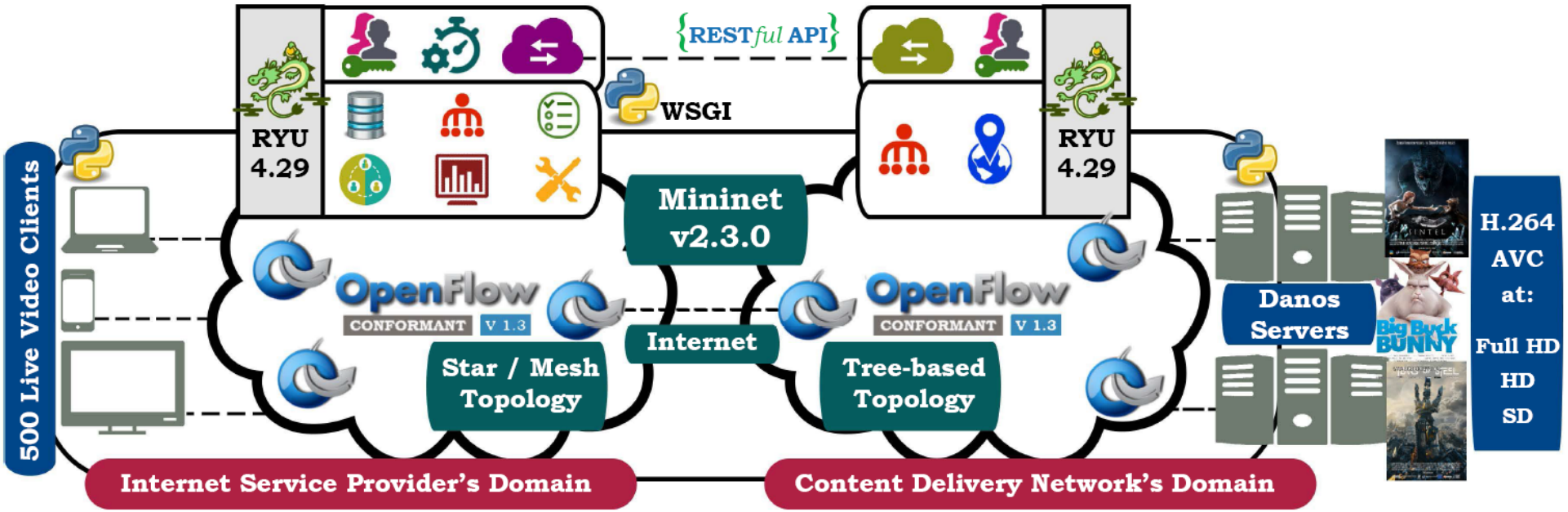
Experimental Evaluation

- Large-scale emulation with real videos served at multiple bitrates
- Comparison with mCast [1]:
  - network-layer multicast but **no explicit congestion handling**
- Two realistic scenarios:
  - **Flash crowds:** Multiple clients joining in a short duration
  - **Cross-traffic:** Due to unicast users
- ISP Topologies from Topology Zoo database
  - Mesh: 25 switches
  - Star: 13 switches
- Performance metrics:
  - Percentage of **lost frames**
  - **Average goodput:** Completely received GOPs
  - Probability Mass function (**PMF**) of user bitrates
  - **Signaling messages** between SDN controller and switches



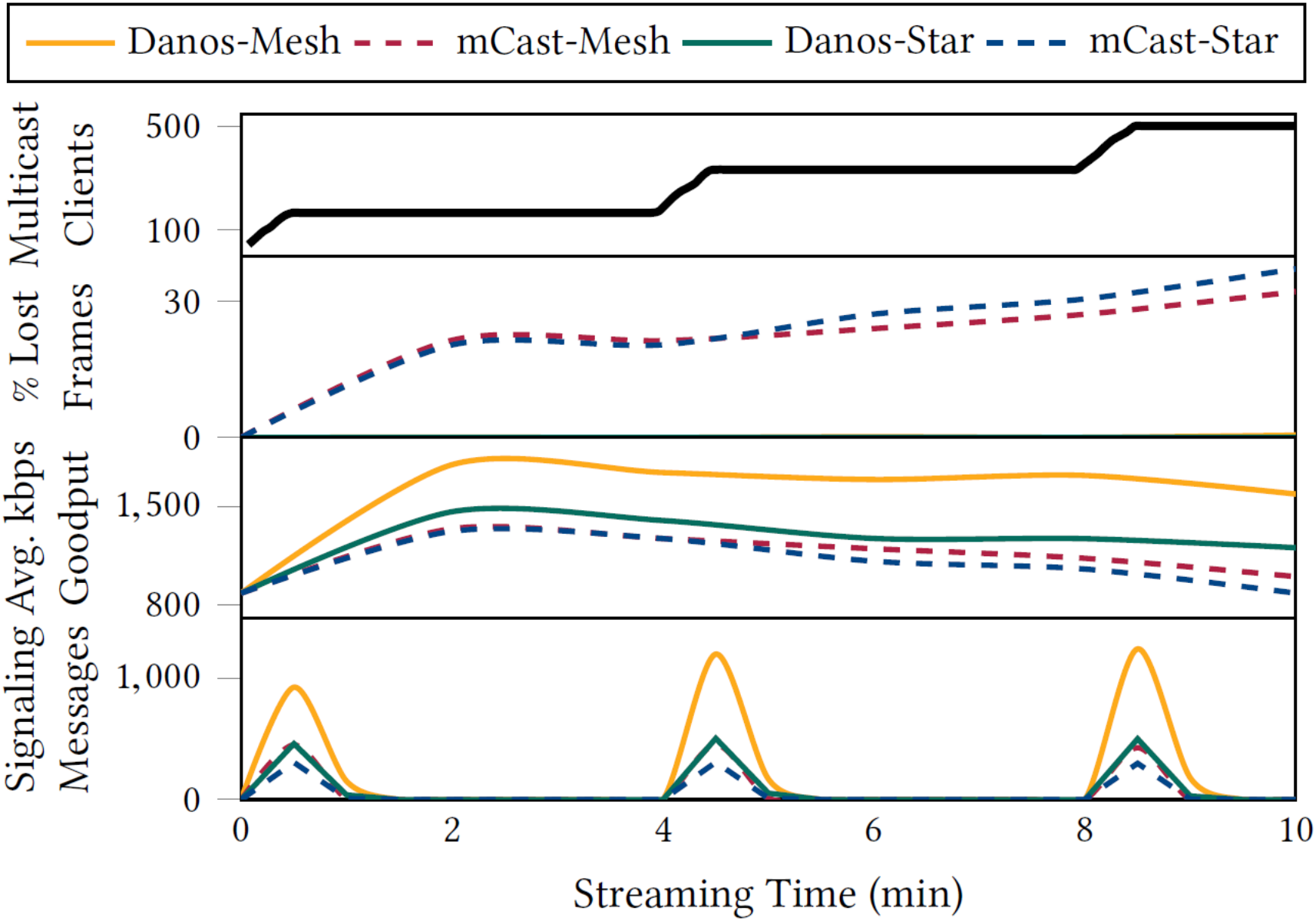
[1]: A. Khalid et al., "mCast: An SDN-Based Resource-Efficient Live Video Streaming Architecture with ISP-CDN Collaboration", LCN 2017

PROTOTYPE IMPLEMENTATION



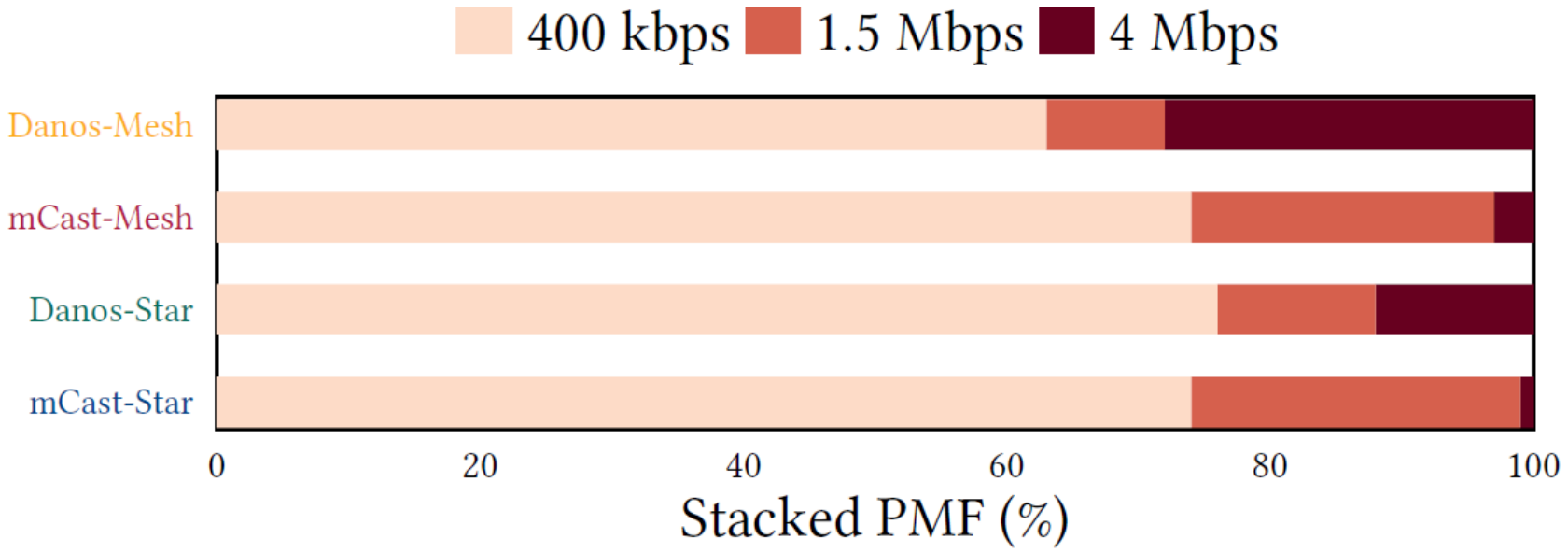
Prototype implementation of Danos over an emulated test-bed

Results: Flash-Crowd Scenario



Results: PMF Of Flash-Crowd

- Our approach:
  - **Increases the number of users** receiving high bitrates (**5% to 30%**), or
  - Reduces the bitrates of **clients affected by congestion in the network**



SUMMARY

Rapid increase in popularity of live video streaming creates challenges for ISPs and CDNs

IP multicast can improve network efficiency but does not work across domains

We maximize user experience while minimizing network load and considering device capabilities

We implement a prototype to show the feasibility, scalability and efficacy of our proposal

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