ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΡΗΤΗΣ

# Δίκτυα Καθοριζόμενα από Λογισμικό

## Ενότητα 4.3: Leveraging SDN for Video Content Distribution

Ξενοφώντας Δημητρόπουλος
Τμήμα Επιστήμης Υπολογιστών

# Leveraging SDN for Video Content Distribution

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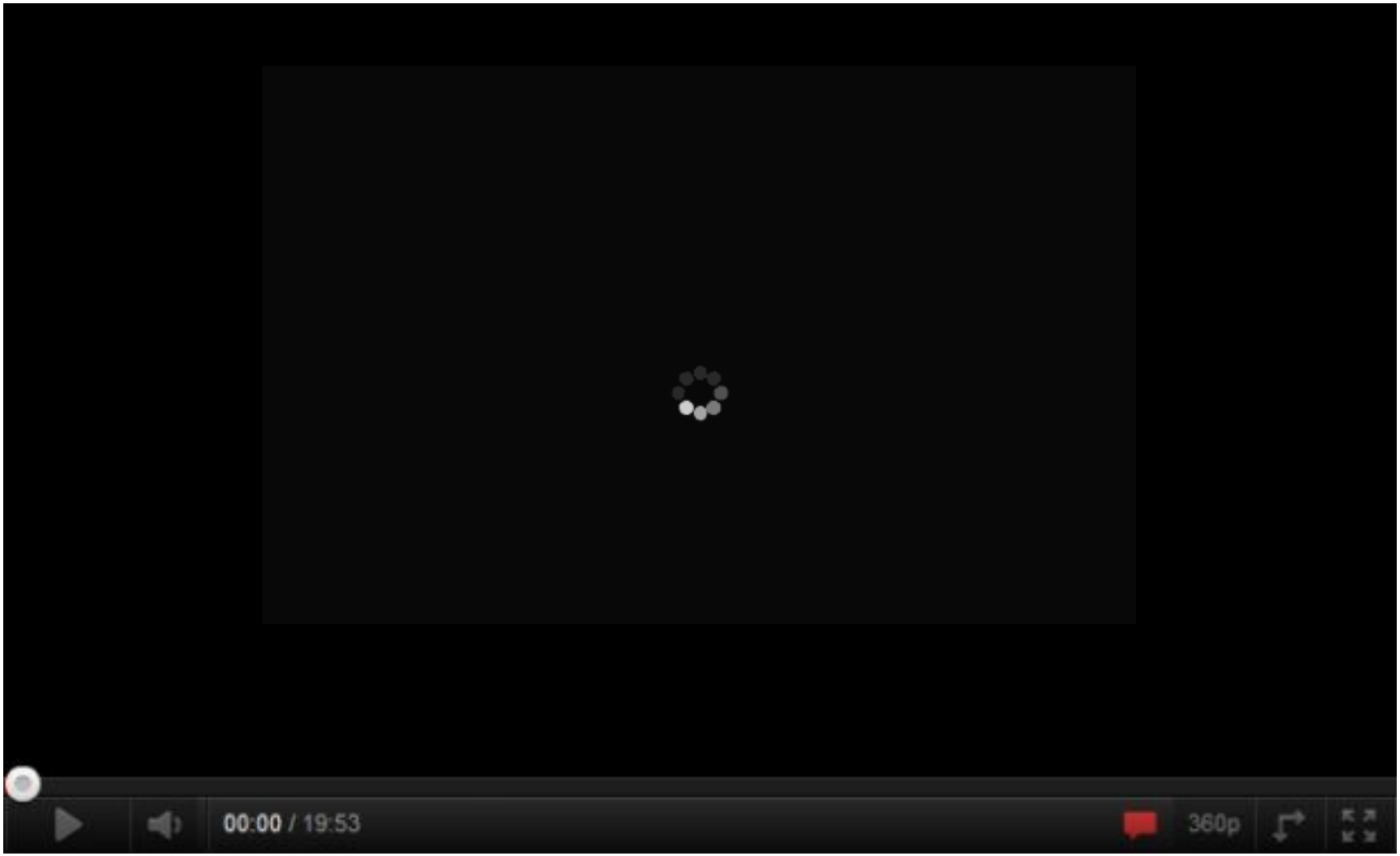
**HY- 436 - Software Defined Networks (SDN)**
**CS Department, University of Crete**
**15/12/2014**

# Are you familiar with this?

# Are you familiar with this?



# …or this ?

# …or this ?

[IPTV]

# …or this ?


NETFLIX
36%
Buffering
The Diary of Anne Frank
00:00 - 2:50:36
Full Screen

# Overview

Theme : How can we use SDN to improve Video Content Distribution ?

**VoD Traffic Benefits Network and Users**

**OpenCache:**
OpenFlow-based in-network caching service for Video-on-Demand traffic

**Live Video Traffic Benefits Users**

OpenFlow-assisted QoE Fairness Framework (QFF)

- **Present :**
  - Why ? : Motivation
  - Hard ? : Challenges
- **The process :**
  - Requirements Analysis
  - Design & Implementation
  - Evaluation on SDN Testbeds

…plus interactive discussion & projects-in-progress

LANCASTER UNIVERSITY

- Prof. David Hutchinson
- Prof. Nicholas Race
- Dr. Arsham Farshad
- Dr. Mu Mu
- Dr. Yehia El-Khatib
- Matthew Broadbent

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Swiss Federal Institute of Technology Zurich

- Prof. Bernhard Plattner
- Dr. Bernhard Ager
- Vasileios Kotronis



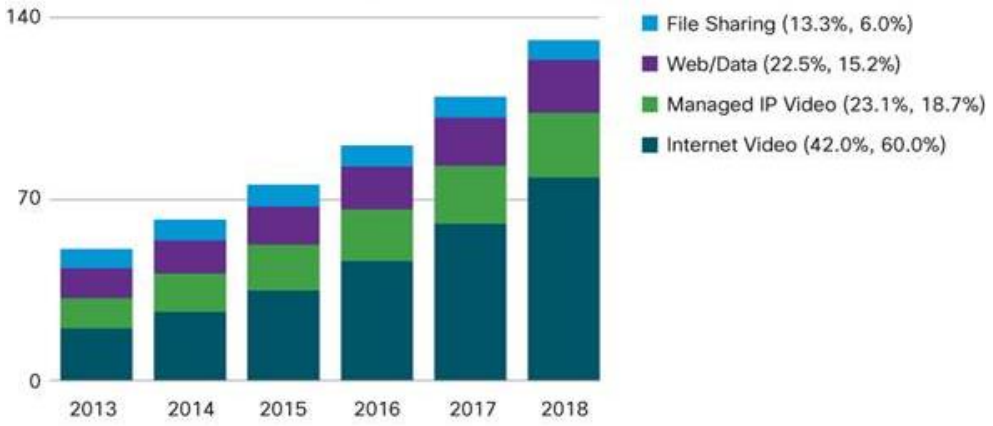






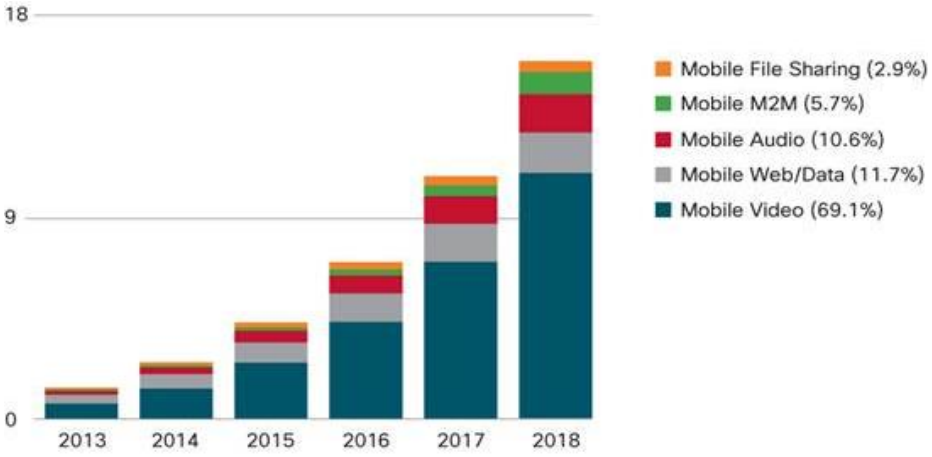
# Motivation : Why research on Video traffic ?

- Globally, **video traffic was 66% of all consumer Internet traffic** in 2013 and will be 79% in 2018 [1]




*Global consumer Internet traffic in Exabytes per month [1]*

- **Mobile video traffic** exceeded 50% for the first time in 2012 [2]
- Mobile video will increase 14-fold between 2013 and 2018
- 69% of the world's mobile data traffic will be video by the end of 2018




*Mobile consumer Internet traffic in Exabytes per month [2]*

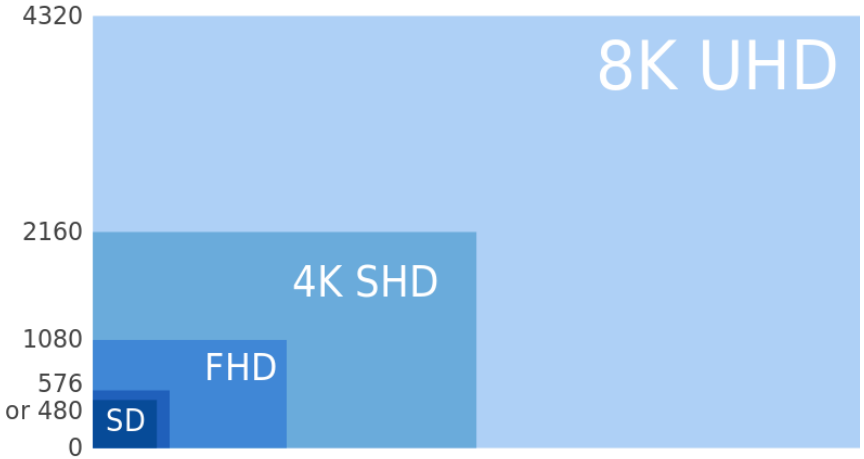
[1] Cisco VNI Global Forecast (2014)
[2] Cisco VNI Mobile Forecast (2014)

# Motivation : Why research on Video-on-Demand traffic ?

- With a **VoD service** (e.g. Netflix, Amazon's LOVEFiLM, Swisscom/Cablecom's IPTV) consumers can retrieve previously recorded content at a different time that the content was initially made available

- **VoD traffic will triple by 2017 :** equivalent to 6 billion DVDs per month [1]
- **Internet video to TV traffic** doubled in 2011, will **increase six fold by 2016** [1]

- **High-Definition VoD surpassed Standard-Definition VoD** in 2011 [requires ~1-10 Mbps]
  - By 2016, HD Internet video will comprise 79% of VoD [1]
- **Trend to improve video quality even more :**
  - Moving to Ultra-HD (4K - 8K) and 3DTV :
    4 times higher resolution than HD
    [requires ~20-600 Mbps]



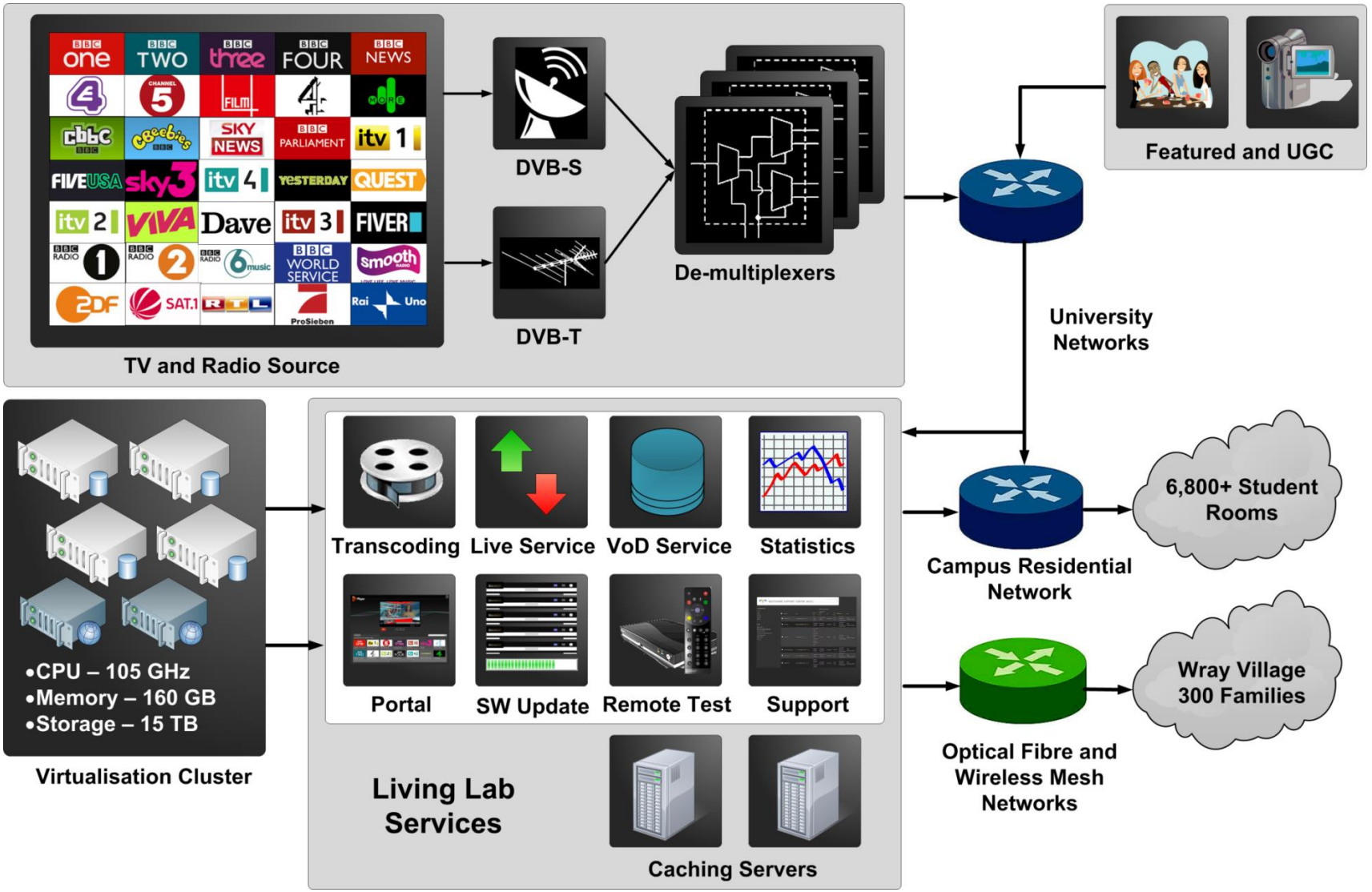

*Evolution of video resolution for online streaming*

[1] Cisco VNI Global Forecast (2012)

# So…what does all this mean?

- On the one hand :
  - High-quality video streaming (live and on-demand) is fast becoming an **essential part of consumers' lives**
- On the other hand :
  - The network has to transfer an **enormous amount of video traffic** (~75.000 PB/m. in 2018) -> **Big strain on the network**
    - High-throughput requirements end-to-end (especially with HD)
    - Quickly and reliably to the user ; high Quality of Experience (QoE)

# Lancaster University IPTV Living Lab



# Quick Live Overview of Vision IPTV

VISION TV Radio

Feedback Messages Logout

Dashboard | What's On | On Demand | My Library 2 | Programme Guide | History

Search

Like 43 people like this. Be the first of your friends.

## Recommended for you:

Watch On Demand

The Big Bang Theory
E4 | Duration 30mins
12 October, 2013 - 00:05
The Psychic Vortex: Sheldon and Raj go to a university party, Leonard disapproves of Penny's belief in psychics, and Raj lusts after a girl called Abby. [AD,S]

Watch On Demand

Fake Britain
BBC ONE | Duration 45mins
22 October, 2013 - 09:15

Watch On Demand

Hairy Bikers' Meals on Wheels Back on...
BBC TWO | Duration 60mins
02 October, 2013 - 09:00

Watch On Demand

A Car Is Born
QUEST | Duration 25mins
03 October, 2013 - 09:35

Watch On Demand

Homes Under the Hammer
BBC ONE | Duration 60mins
07 October, 2013 - 10:00

Watch On Demand

Independence Day
Film4 | Duration 165mins
06 October, 2013 - 18:15

Watch On Demand

Family Guy
BBC THREE | Duration 20mins
27 October, 2013 - 22:25

## You recently viewed:

Watch On Demand

BBC News
BBC ONE | Duration 345mins
07 October, 2013 - 00:15
You watched 0 mins

Watch On Demand

The Simpsons
Channel 4 | Duration 30mins
09 October, 2013 - 18:00
You watched 0 mins

Watch On Demand

The Inbetweeners Movie
E4 | Duration 120mins
25 September, 2013 - 21:00
Time remaining 53 mins

Watch On Demand

UEFA Champions League
ITV1 | Duration 150mins
22 October, 2013 - 19:30
You watched 37 mins

Watch On Demand

The Big Bang Theory
E4 | Duration 30mins
27 October, 2013 - 18:30
Time remaining 11 mins

## Currently trending:

Previous Next 1 2 3

Watch Live watching: 3

Suburgatory
E4 | Duration 30mins
11 November, 2013 - 15:30

Watch On Demand views: 13

Family Guy
BBC THREE | Duration 25mins
01 October, 2013 - 23:00

Watch On Demand views: 12

Independence Day
Film4 | Duration 165mins
06 October, 2013 - 18:15

Not available

The X Factor
ITV1 | Duration 95mins
09 November, 2013 - 20:00

Watch On Demand views: 9

Angus, Thongs and Perfect...
Channel 4 | Duration 120mins
20 October, 2013 - 14:55

| | Now airing: | Next on: |
|---|---|---|
| BBC one |  **Pressure Pad**<br>15:00 - 15:45 \| Duration 45 mins<br>6/25. John Barrowman hosts the quiz where two teams compete in a series of head-to-head games. Also in HD. [S]<br>Watch Live Save for Me |  **Paul Hollywood's Pies & Puds**<br>15:45 - 16:30 \| Duration 45 mins<br>6/20. Paul uses cheese from Yorkshire, lavender from Kent and chocolate from Paul A Young. Also in HD. [S]<br>Save for Me |
| BBC TWO |  **Cagney and Lacey**<br>15:00 - 15:45 \| Duration 45 mins<br>A Cry for Help: Cagney and Lacey are contacted by an anonymous woman in need of help, who reveals that her violent husband is a police officer. Also in HD. [S]<br>Watch Live Save for Me |  **Are You Being Served?**<br>15:45 - 16:15 \| Duration 45 mins<br>3/7. Forward Mr Grainger: Classic department store sitcom. Mr Grainger is promoted to departmental manager when Mr Rumbold is called away for a one-month management seminar. [S]<br>Save for Me |
| itv |  **The Alan Titchmarsh Show**<br>15:00 - 16:00 \| Duration 60 mins<br>Teatime chat and music with Alan Titchmarsh. [S]<br>Watch Live Save for Me |  **Tipping Point: Lucky Stars**<br>16:00 - 17:00 \| Duration 60 mins<br>Hoping to hit the 20,000 pound jackpot this time are Loose Woman Jane McDonald, celebrity chef Rosemary Shrager and dancing star Louie Spence. Presented by Ben Shephard. [S]<br>Save for Me |
| 4 |  **Countdown**<br>15:10 - 16:00 \| Duration 50 mins<br>Nick Hewer and Rachel Riley host as contestants race against the clock to pit their wits against vowels, consonants and numbers. Alistair McGowan is the Dictionary Corner guest. [S]<br>Watch Live Save for Me |  **Deal or No Deal**<br>16:00 - 17:00 \| Duration 50 mins<br>Noel Edmonds asks the all-important question as contestants do battle with the Banker in their quest to leave the Dream Factory with £250,000. [AD,S]<br>Save for Me |
| 5 |  **Mary Higgins-Clark's Remember Me**<br>15:10 - 17:00 \| Duration 110 mins<br>Psychological thriller starring Kelly McGillis and Conner Smith. A young mother begins to doubt her own sanity and fears for her life following the death of her son. (1995) [S]<br>Watch Live Save for Me | **5 News at 5**<br>17:00 - 17:30 \| Duration 110 mins<br>International and national news update. [S]<br>Save for Me |
| itv2 |  **The Jeremy Kyle Show**<br>15:05 - 16:10 \| Duration 65 mins<br>Jeremy Kyle deals with more dilemmas, fiery confrontations and topical issues all in front of a studio audience. [S] |  **Real Housewives of Orange County**<br>16:10 - 17:05 \| Duration 65 mins<br>Are You In or Out?: Reality show. The drama intensifies at Heather's opulent party. Brooks instigates an explosive fight between Vicki and |

Genre



















New Girl

The Big Bang Theory

How I Met Your Mother

Suburgatory

Frasier

Cheers

Everybody Loves Raymond

Ben & Kate

Will & Grace

Up All Night

According to Jim

Man About the House

Some Girls

Life's Funniest Moments

Stephen Merchant: Hello Ladies

New: The Revolution Will Be Televised

Fresh Meat

Misfits

American Dad!

Family Guy

Toast of London: Submission

Father Ted

The Inbetweeners

New: Family Guy

Drifters

The Cleveland Show

Fuzzbox

Happy Endings

Rules of Engagement

Stand Up for the Week

# Challenge with Video-on-Demand : Distribution Efficiency

- VoD requests **handled naively** – independent flow per request
- These are duplicated minutes, hours or days later (by same or different user)
- Identical delivery of media objects through the same network segments
- End-to-end capacity of network infrastructure must grow continuously to match the increasing number of Internet video users
- The increasing popularity of VoD and especially of HD content worsens this

- **Stark problem especially for the last mile**

# Key Characteristics of Video-on-Demand

1. High-throughput end-to-end
   - Not just high egress capacity at origin video servers, but also adequate bandwidth available in all networks in between video source and users
2. Distance matters between source VoD server and user
   - (Standard) TCP used for VoD can become bottleneck as it requires ACKs for every window of data packets sent
   - TCP's throughput is inversely related to network latency or RTT

| Distance (Server to User) | Network RTT | Typical Packet Loss | Throughput | 4GB DVD Download Time |
|---|---|---|---|---|
| Local: <100 mi. | 1.6 ms | 0.6% | 44 Mbps (high quality HDTV) | 12 min. |
| Regional: 500–1,000 mi. | 16 ms | 0.7% | 4 Mbps (basic HDTV) | 2.2 hrs. |
| Cross-continent: ~3,000 mi. | 48 ms | 1.0% | 1 Mbps (SD TV) | 8.2 hrs. |
| Multi-continent: ~6,000 mi. | 96 ms | 1.4% | 0.4 Mbps (poor) | 20 hrs |

*Effect of Distance on Throughput and Download Time [*]*

- We need a solution that :
  - Ensures high-throughput end-to-end
  - Minimizes distance between source video content server and user

SDN?

[1] E. Nygren, R. K. Sitaraman, and J. Sun. The Akamai Network: a Platform for High-Performance Internet Applications. SIGOPS Oper. Syst. Rev., 44(3):2–19, 2010.

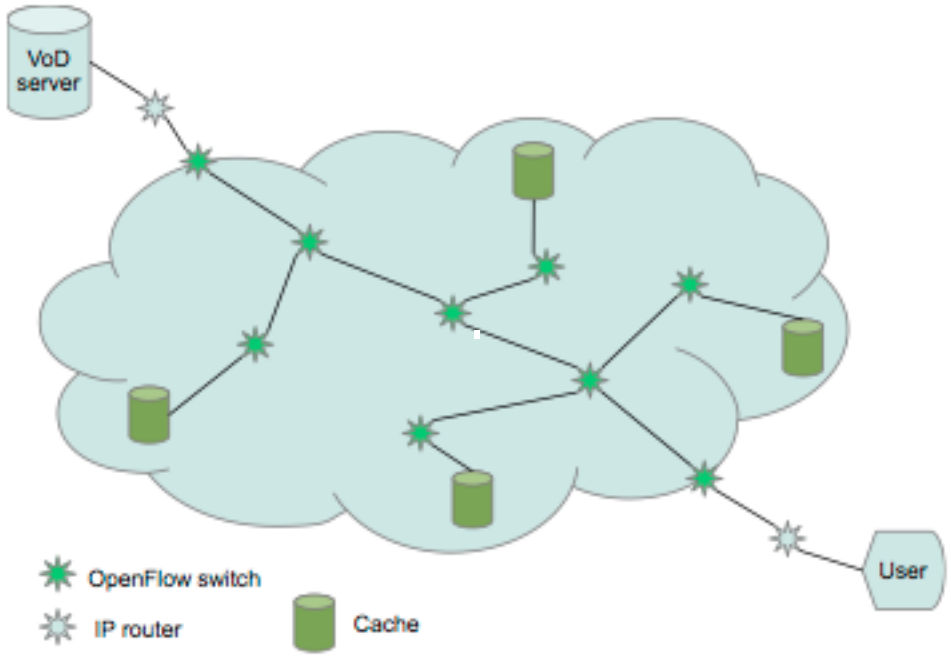
# Related Work

- **Multicast :**
  - Good for live streaming but VoD requests are not for the same content at the same time
  - If applied to VoD, it involves high complexity and changes to end-devices (not transparent)
- **Peer-to-peer** :
  - Depends heavily on participation of users and on their limited storage and uplink resources -> cannot guarantee high QoE for the users
- **Traditional cache & proxy approaches :**
  - Good for static web content, not designed for high storage/throughput VoD requirements
  - Most of them too complex to customise and configure and either require constant attention and tuning from admins or require third party support and become black boxes in the network
- **Content Delivery Networks (CDNs) :**
  - From a content provider's perspective they are an excellent distribution and cost effective solution, but what about the consumer ISP's perspective and the last mile?
    - No reduction in network utilisation : still fetch content over the external link (often costly)
    - Content still far away from user : distance does matter for QoE

# What does SDN provide? What benefits do we get by using it?

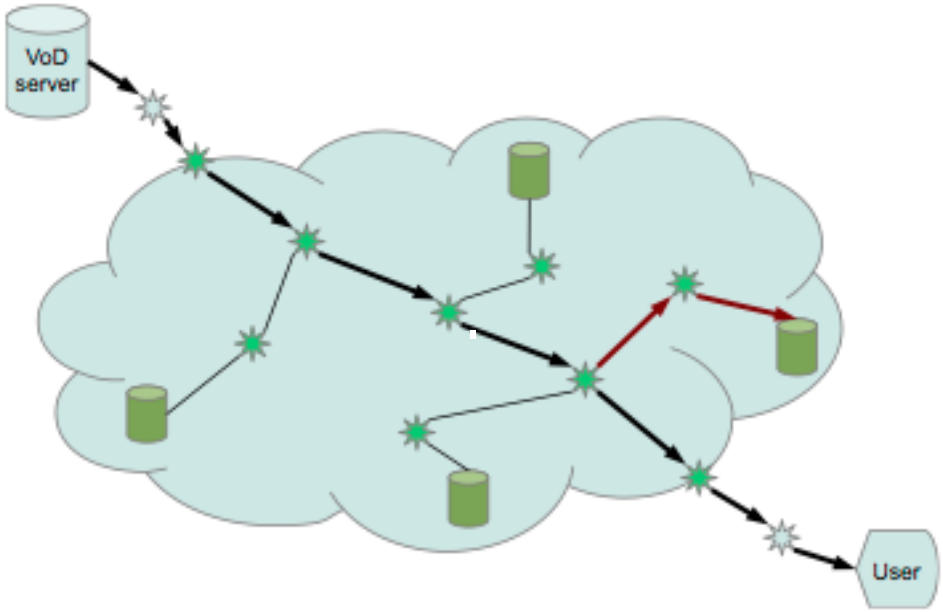
- SDN/OpenFlow is the **tool** ; not the solution !
  - It is not a panacea
- But :
  - Provides **network abstraction** (e.g. topology, links & network stats)
  - Provides **open interfaces** to monitor/manage/administer the network equipment easier and more efficiently
  - **Programmable hooks** to the network without access to the particular devices
  - Allows easier and simpler solutions to be deployed on a network
  - Easier innovation (even on production networks)
  - Open Source
  - Cross vendor support (hardware independent)

# Video-on-Demand Content Caching with SDN



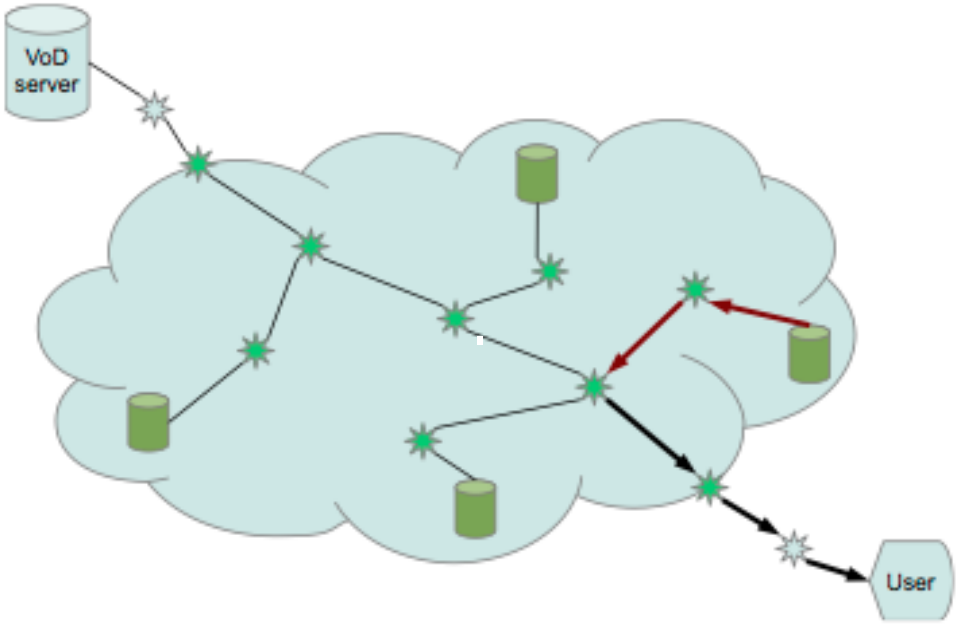

An OpenFlow network with peripheral content caches

# Video-on-Demand Content Caching with SDN




First interaction: Content silently copied to cache

# Video-on-Demand Content Caching with SDN




Later interactions: Content retrieved from cache

# Caching Requirements (1)

An **OpenFlow-based content caching** architecture should satisfy the following **functional requirements** :

1. Should identify cacheable content without any significant impact on the user's request
2. Should cache content transparently to the user
3. Should deliver content transparently to the user
4. Should retain the underlying content delivery mechanism to avoid fundamental changes to the service
5. Should be content agnostic
6. Should be easily integrated in a production network
7. Should be able to use multiple cache instances
8. Should be able to add or remove cache instances without service interruption

Worth thinking :
How could we do the above without SDN?

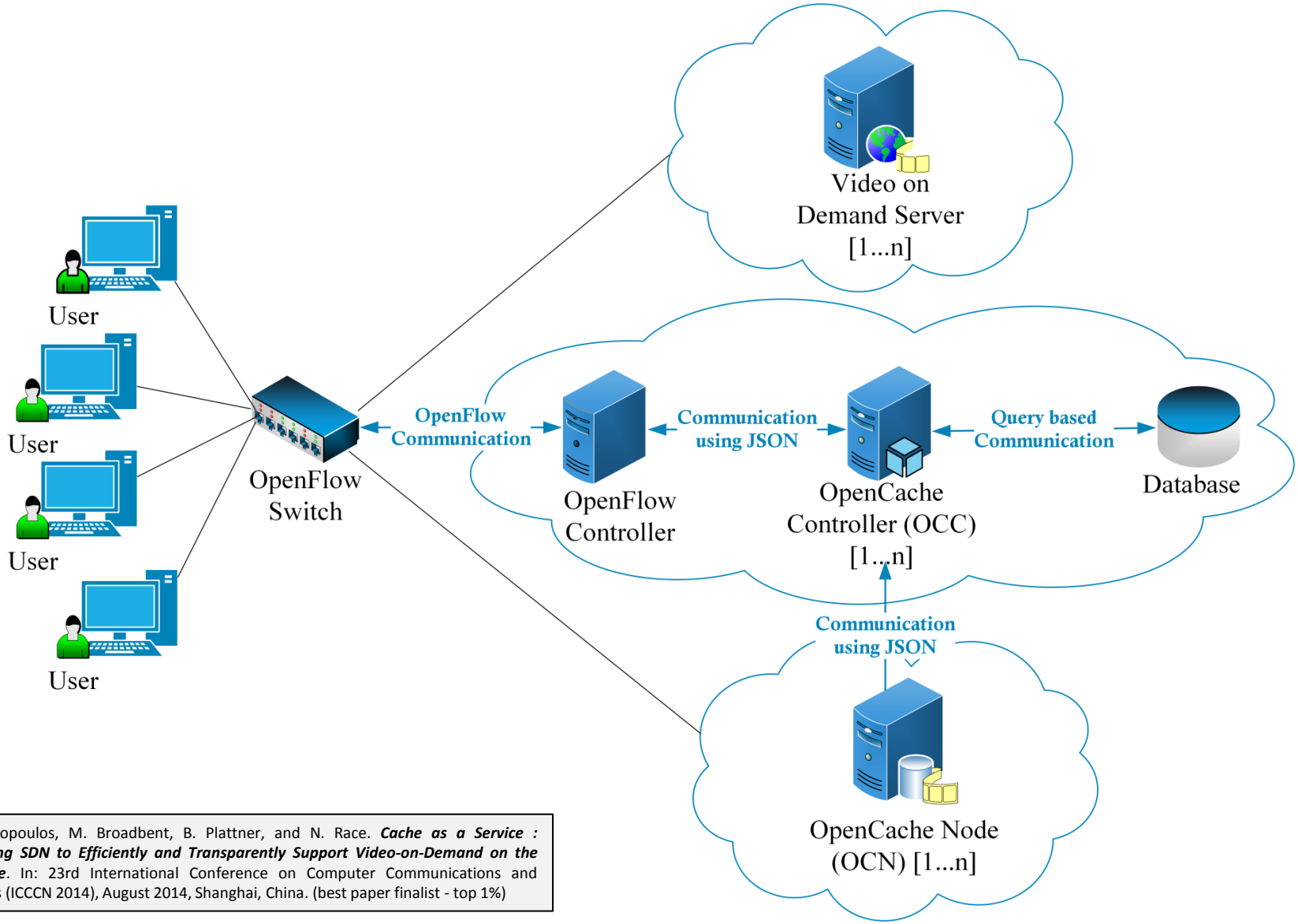
# Caching Requirements (2)

An **OpenFlow-based content caching** should satisfy the following **non-functional requirements** :

1. Should optimize network utilization. For example, it should not unreasonably cache content that is infrequently requested and thus increase the network utilisation unnecessarily
2. Should adjust its run-time functionality and improve the users' QoE by maintaining a high level view of the network based on run-time metrics (e.g. buffering times etc.)
3. Should support load balancing between carefully and strategically located in-network caches

Worth thinking :
How could we do the above without SDN?

# **OpenCache** : OpenFlow-based In-network Caching Service




P. Georgopoulos, M. Broadbent, B. Plattner, and N. Race. ***Cache as a Service : Leveraging SDN to Efficiently and Transparently Support Video-on-Demand on the Last Mile***. In: 23rd International Conference on Computer Communications and Networks (ICCCN 2014), August 2014, Shanghai, China. (best paper finalist - top 1%)

# Entities

- Any hardware or software OpenFlow Switch
  - Must be able to communicate with the VoD server, the OCN(s) and the OpenFlow controller, but not necessarily directly


- Primary source for the video assets
  - Could be located anywhere on the Internet (reachable by IP)


- Any kind of OpenFlow Controller (e.g. Floodlight, NOX, POX)
  - Should be reachable by the OpenFlow Switch
  - Runs L2 learning switch : allows the switch to forward on MAC-to-Port pairing
  - Exposes a JSON-RPC Flow Pusher interface to OpenCache Controller

# Entities : OpenCache Controller (OCC)


- Orchestrator of in-network caching functionality
  1. Provides a JSON-RPC interface to retrieve requests for content to be cached in a highly flexible and configurable fashion
     - Used by network administrator or even content providers or CDNs (via SLAs)
     - Supports regular expressions to fine tune requests for content e.g. particular video, all videos from a domain, a type of video from any domain (n.b. with later versions of OpenFlow)

| METHOD | PARAMETERS | RESULT |
|---|---|---|
| start | { ("expr" : <expr>), ("node" : <node-id>) } | <boolean> |
| stop | { ("expr" : <expr>), ("node" : <node-id>) } | <boolean> |
| pause | { ("expr" : <expr>), ("node" : <node-id>) } | <boolean> |
| fetch | { ("expr" : <expr>), ("node" : <node-id>) } | <boolean> |
| seed | { ("expr" : <expr>), ("node" : <node-id>) } | <boolean> |
| refresh | { ("expr" : <expr>), ("node" : <node-id>) } | <boolean> |
| stat | { ("expr" : <expr>), ("node" : <node-id>) } | [<cache_hit>, <cache_miss>... ] |

  2. Implements the caching logic : what should be cached where at each point in time
     - Enhanced to support resource monitoring and load-balancing

# Entities : OpenCache Controller (OCC)


- Orchestrator of in-network caching functionality
  3. Manages the resources of the available caches in the network via a JSON-RPC interface : Handles addition/removal of caches at run-time

| METHOD | PARAMETERS | RESULT |
|---|---|---|
| hello | { "host" : <host>, "port" : <port> } | <node-id> |
| Keep-alive | { "node-id" : <node-id> } | <boolean> |
| goodbye | { "node-id" : <node-id> } | <boolean> |

  4. Interacts with the OpenFlow switches of the network via the Controller
     - Adding/removing flows to switches via the Flow Pusher API of the controller so that users' requests are served appropriately

| URI | DESCRIPTION | ARGUMENTS |
|---|---|---|
| /wm/staticflowentrypusher/json | Add/Delete static flow | HTTP POST data (add flow), HTTP DELETE (for deletion) |

# Entities

- Database to maintain a list of :
  - All names of videos that have been requested for caching
  - Videos that have been cached and where
  - Status of OCN (online/offline, reachable etc.), their location and resources


- **OpenCache Node (OCN)**
  - Multiple OCN instances in the network, possibly connected directly to the switch and consequently to the user : Lower latency and faster response times (high QoE)
  - Three operations :
    1. Communicate its status to the OCC
    2. Caching content that is requested from the user
    3. Stream content that is being already cached

# Metrics/statistics related to caching

| FIELD | NOTE |
|---|---|
| start | Number of cache instances in “start” state |
| stop | Number of cache instances in “stop” state |
| pause | Number of cache instances in “paused” state |
| cache_miss | Number of cache miss (content not found in cache) events (one per request) |
| cache_miss_size | Number of bytes served whilst handling cache miss (content not found in cache) events |
| cache_hit | Number of cache hit (content already found in cache) events (one per request) |
| cache_hit_size | Number of bytes served whilst handling cache hit (content already found in cache) events |
| cache_object | Number of objects currently stored by the cache |
| cache_object_size | Number of bytes for the cached objects on disk (actual) |
| total_node_id_count | Number of unique node IDs present in results |
| total_expr_count | Number of unique expressions present in results |
| total_response_count | Number of unique responses seen |
| node_id_seen | List of those node IDs present in results |
| expr_seen | List of those expressions present in results |
| node_expr_pairs_seen | Pairs of nodes and expressions present in results, including current status and average load |

OpenCache Controller (OCC)

OpenCache Node (OCN)

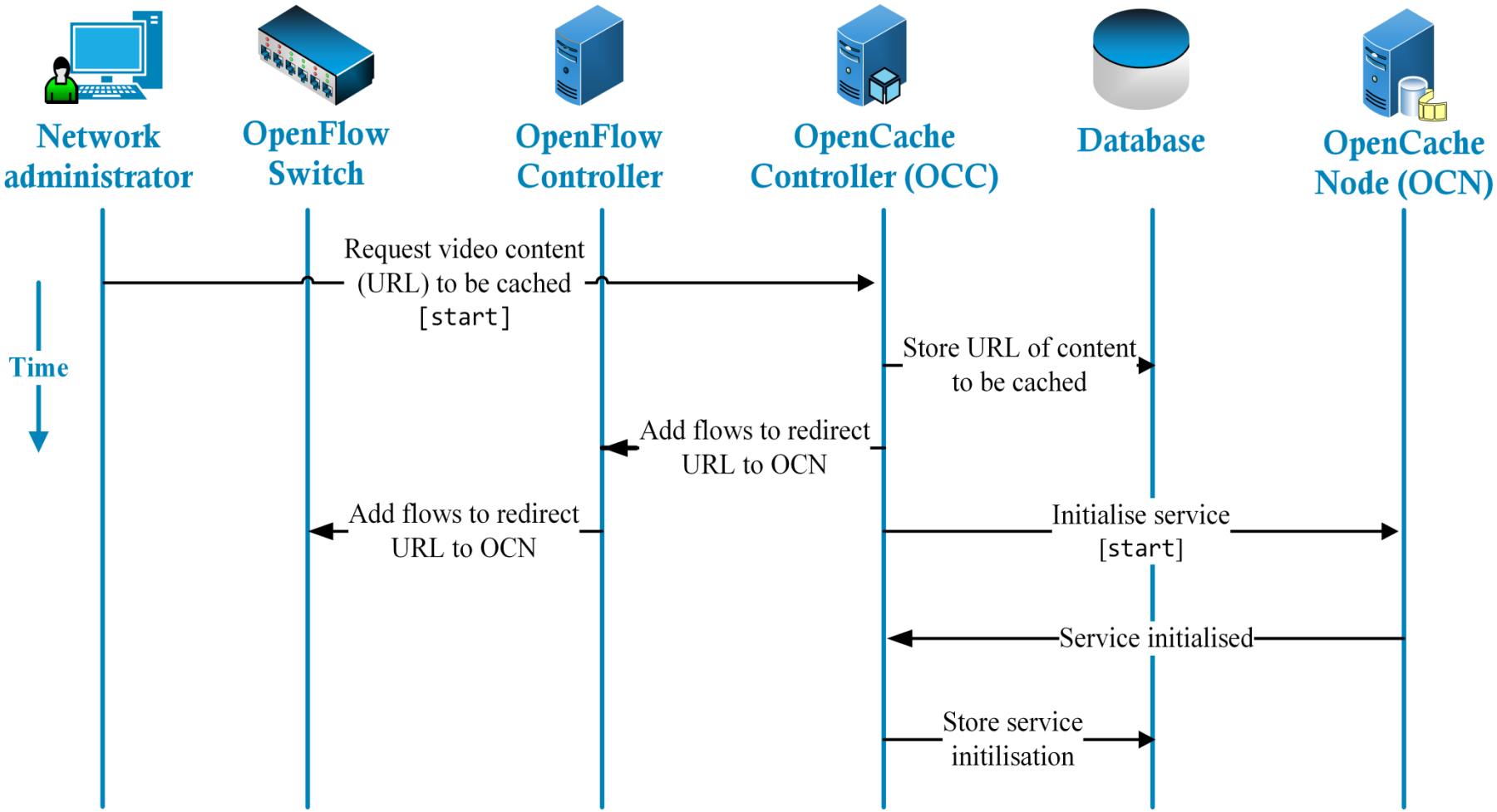
# OpenCache Supports Three Essential Operations

1. Handle **requests** for **content to be cached**
   - From network admins/content providers

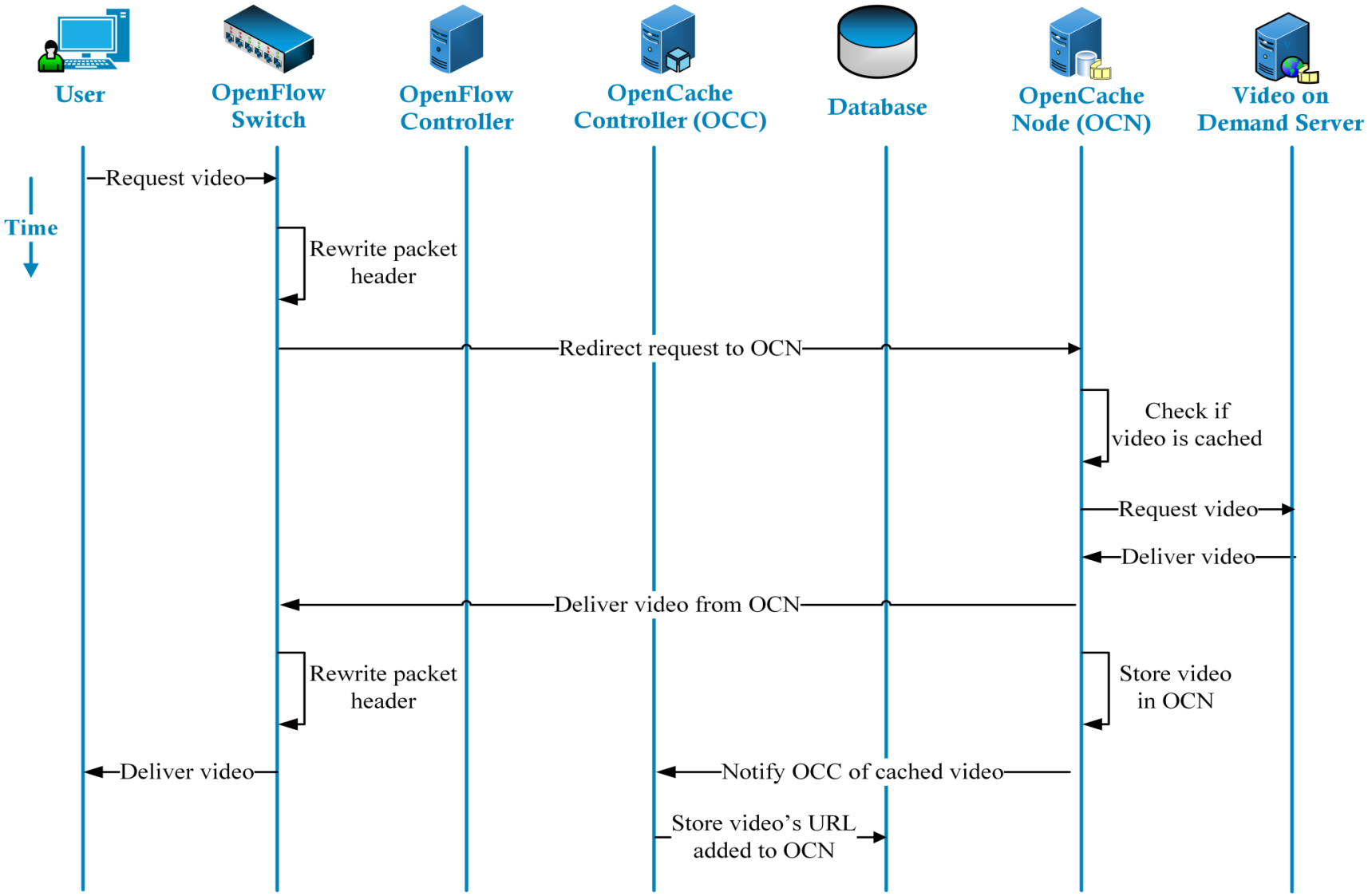
2. **Serve user requests** for content that has **not been cached yet** (**cache-miss**)
   - Fetch content, serve user and cache content for future use

3. **Serve user requests** for content that is in a **network's cache** (**cache-hit**)

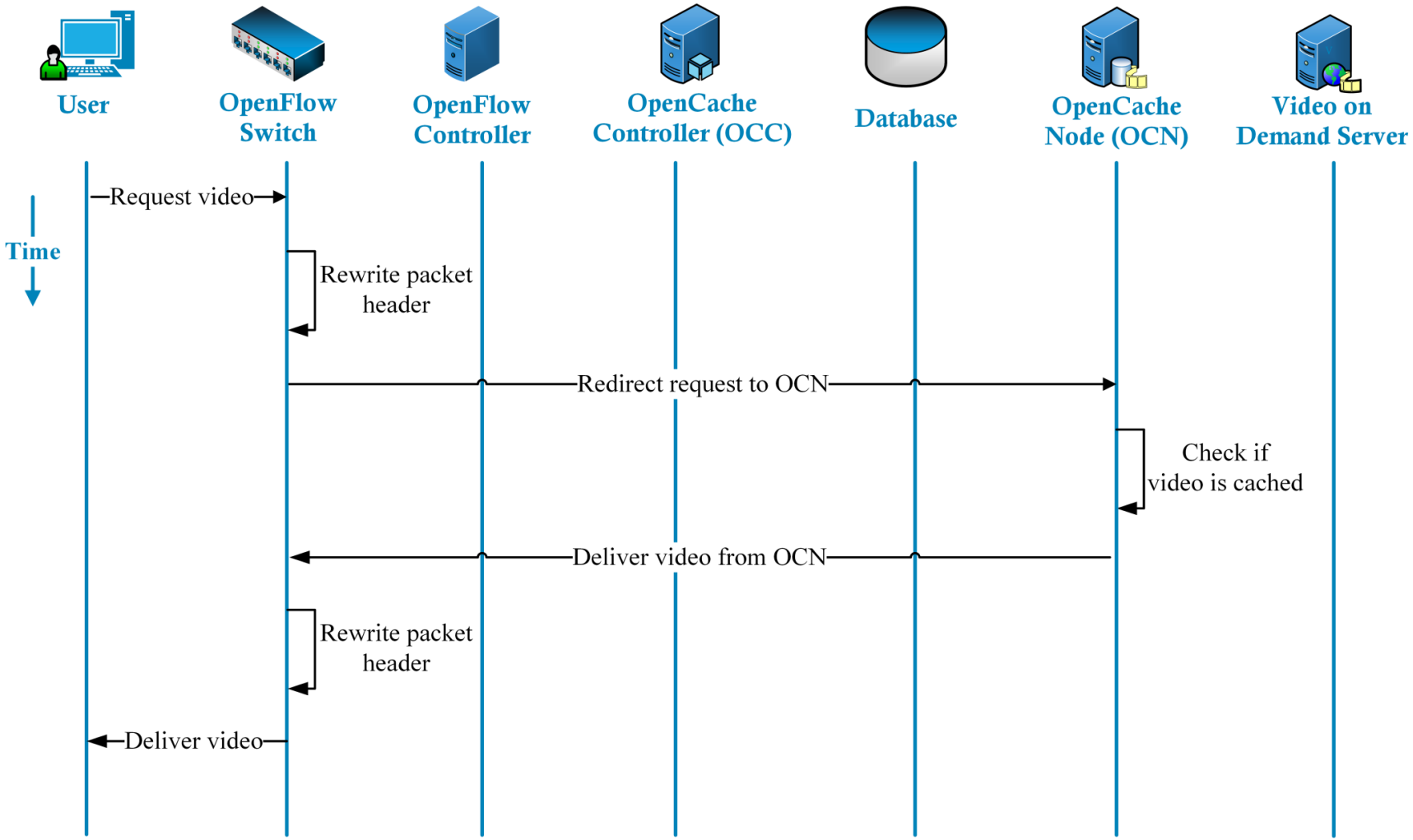
# Handle Requests for Content to be Cached



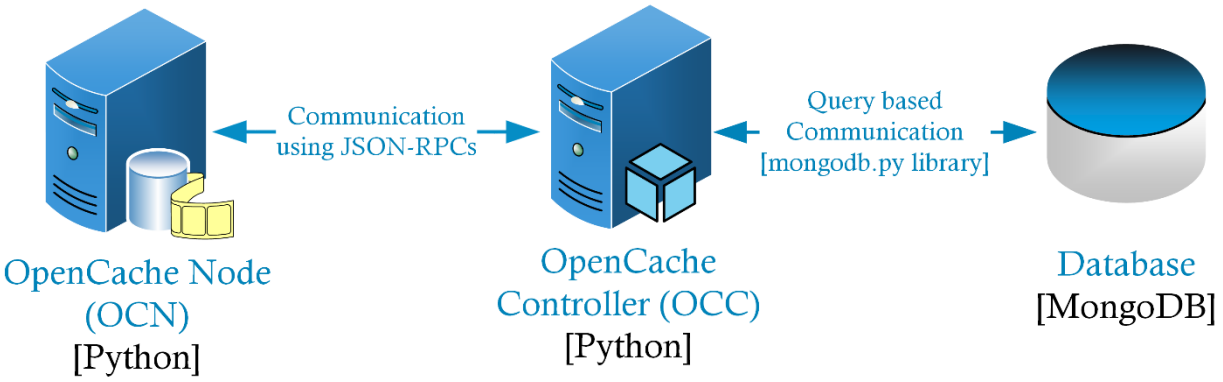
# Serve User Requests for Content that has not been Cached yet (cache-miss)



# Serve User Requests for Content that is in the Network's Cache (cache-hit)

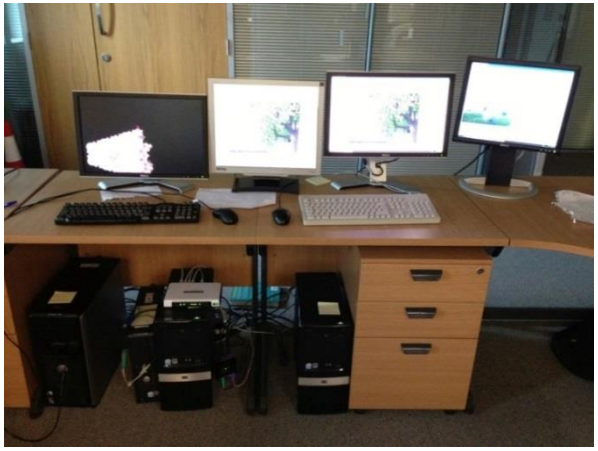


# Implementation (1)




- Python based Implementation : using MongoDB, Floodlight Controller
- OpenCache is open-source and available at https://github.com/broadbent/opencache

- Video Content :
  - Video files are big ; we need chunk based video files that provide flexibility & scalability
  - MP4 chunks don't work well ; either web browsers don't play them properly or have to load the full video before start playing it ☹



# Implementation (2) : MPEG-DASH

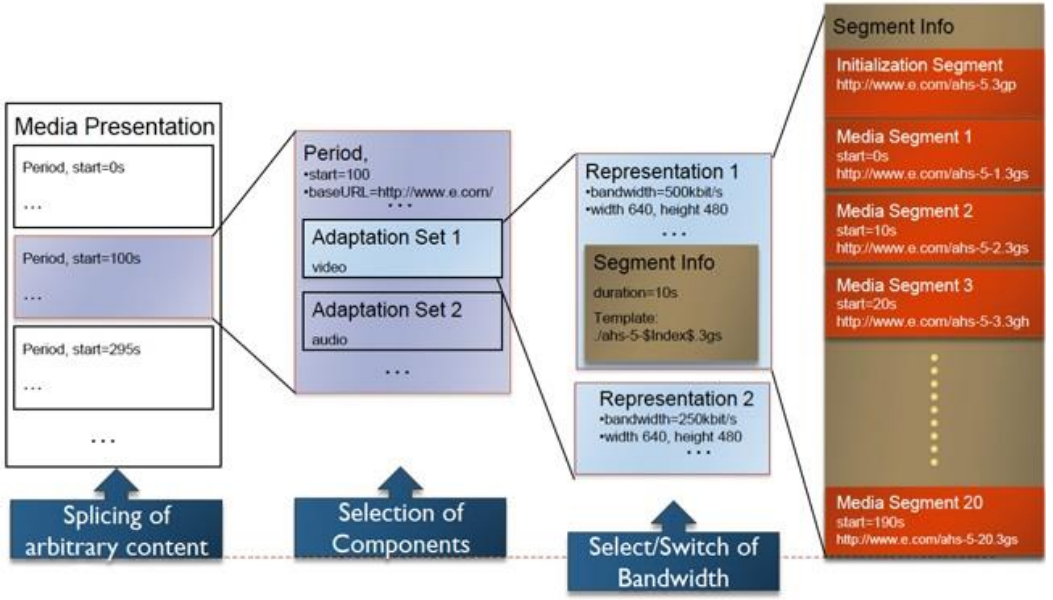
- **DASH: Dynamic Adaptive Streaming over HTTP**
  - Audio/video agnostic
  - Chunked media facilitates swapping between bitrates
  - Adaptive to network bandwidth
  - Can be delivered using conventional HTTP servers
  - Standardised and has support from industry

Chunks

Fetch from different caches

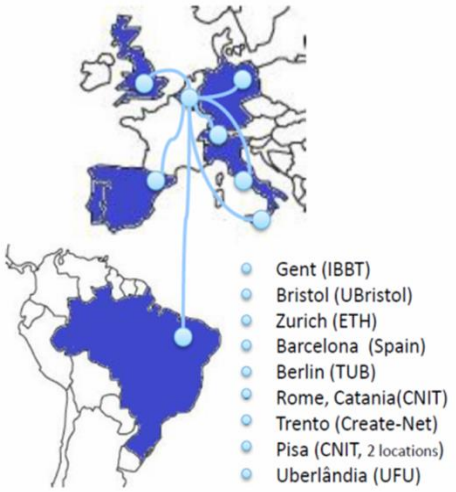
Increase QoE

- Uses a **media presentation description (MPD)** describes segments information :
  - Timing, URL, media characteristics such as video resolution and bit rates



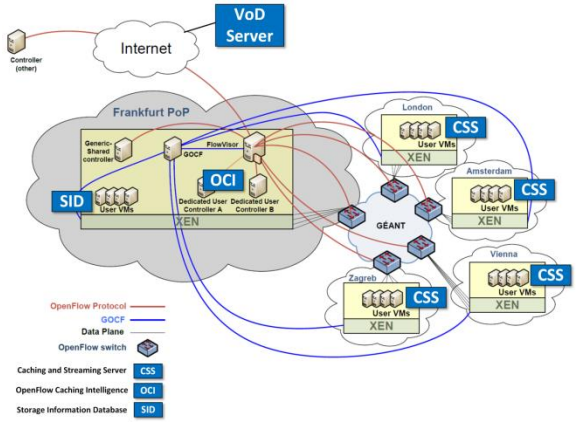

Thomas Stockhammer , Qualcomm Incorporated

# SDN Testbed Experimentation in EU projects




FELIA

- Sep 2010 – Sep 2013 : 3 years, 17 Partners
- First OpenFlow Testbed across Europe (10 federated islands)
- Joined on 2nd Open Call : Video-on-Demand use case




GÉANT

- GN3plus : Apr 2013 – Mar 2015 : 2 years, 41+ Partners
- GN3Plus : Extend/expand GEANT's network across EU
- Joined on 1st Open Call : Cross-site extension and evaluation of our OpenFlow-assisted VoD service on an OpenFlow testbed

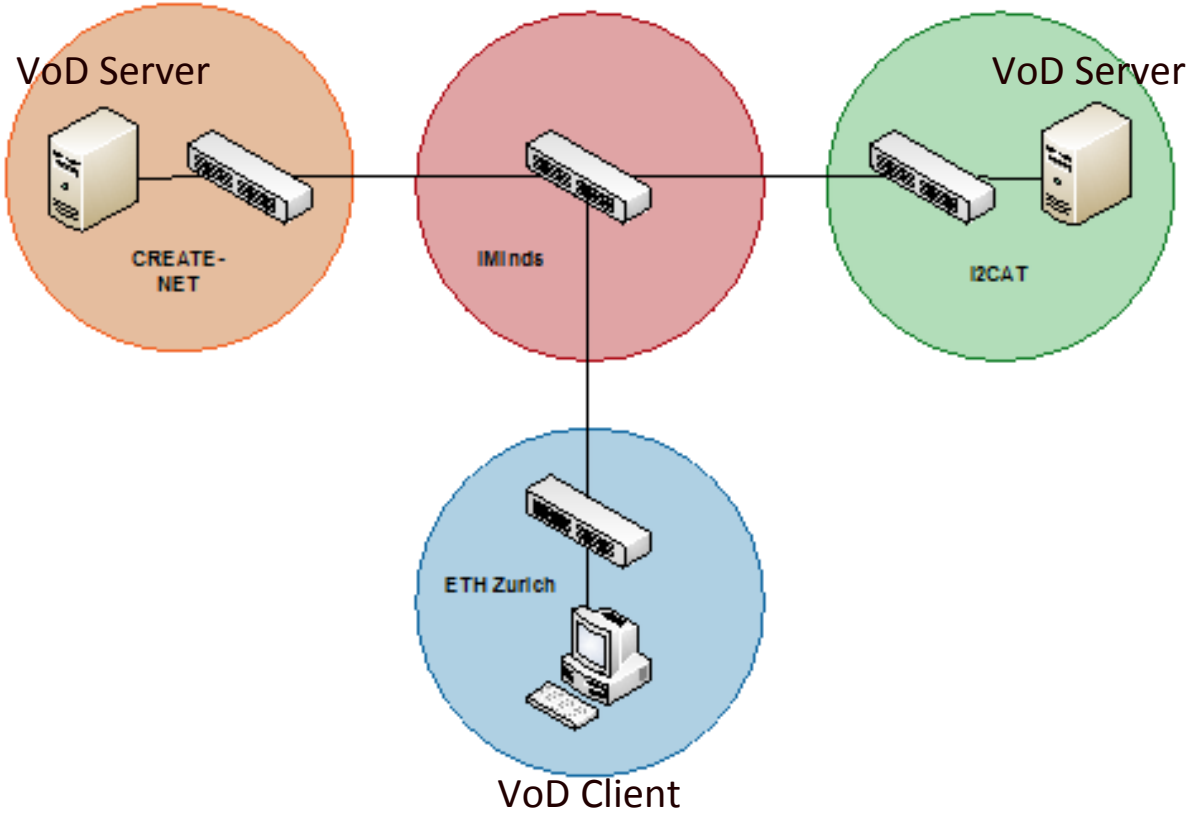
FED4FIRE

- Oct 2012 – Nov 2016 : 4 years, 17+ partners
- Provide a common federation framework for Future Internet Research and Experimentation facilities
- Joined on 1st Open Call : Multi-testbed Experimentation of a VoD service on islands providing a variety of technologies/services

# Evaluation of OpenCache on OFELIA

- **OFELIA** is a large-scale pan-European OpenFlow experimentation testbed
- **Topology :** Deployed OpenCache on three sites distributed geographically
  - Switzerland : ETH Zurich
  - Italy : Create-NET
  - Spain : i2CAT
  - [Belgium : iMinds (hub)]
- Over 120 inter-island (federated) video streaming experiments

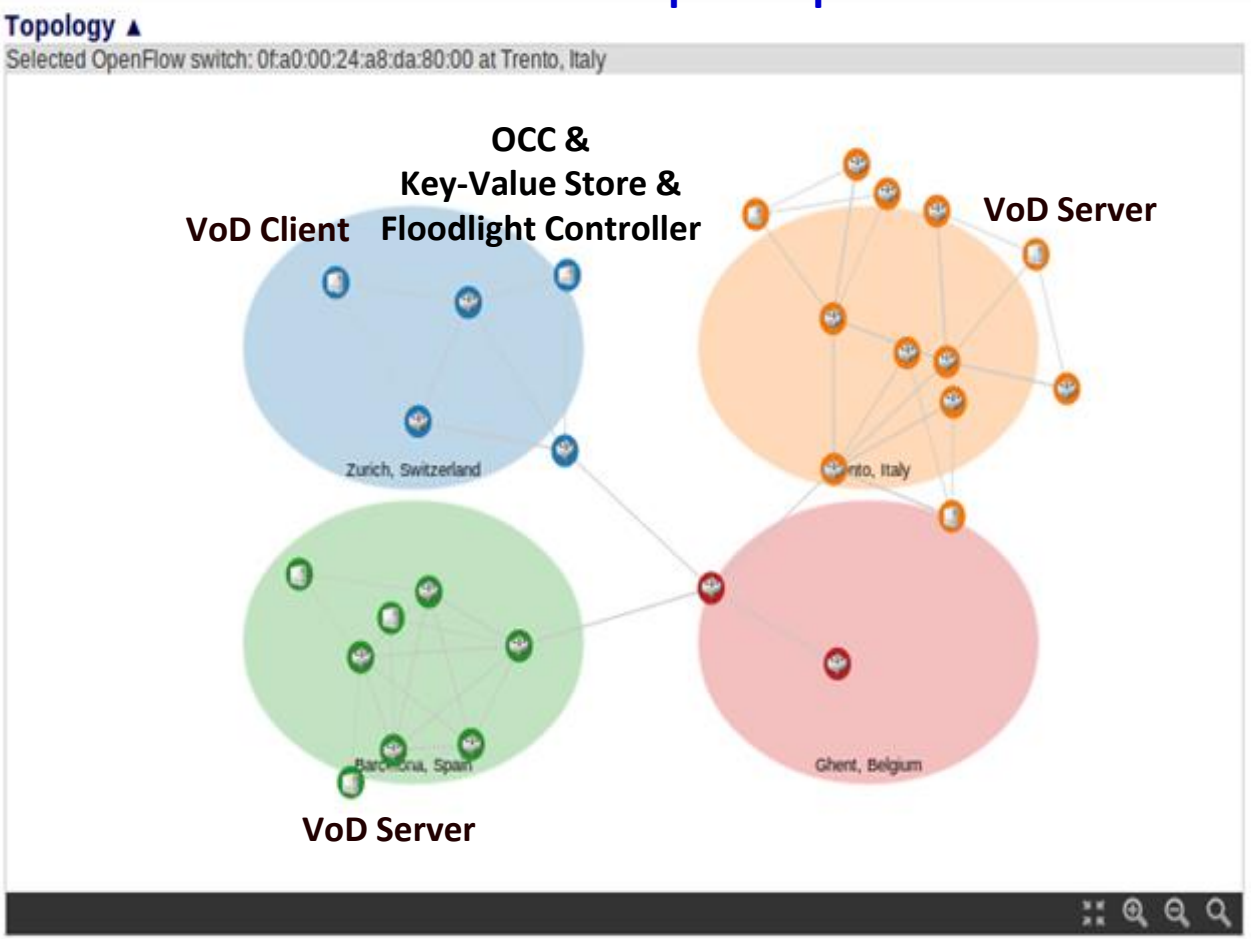
**Conceptual Evaluation Setup**



# Evaluation

- **Three Scenarios :**
  - Without cache (baseline)
  - With cache (cache-miss)
  - With cache (cache-hit)
- **Experiments**
  - Big Buck Bunny : ~10min. reference video using adaptive video streaming technology (MPEG-DASH)
  - 20 VoD requests of each scenario with both VoD servers

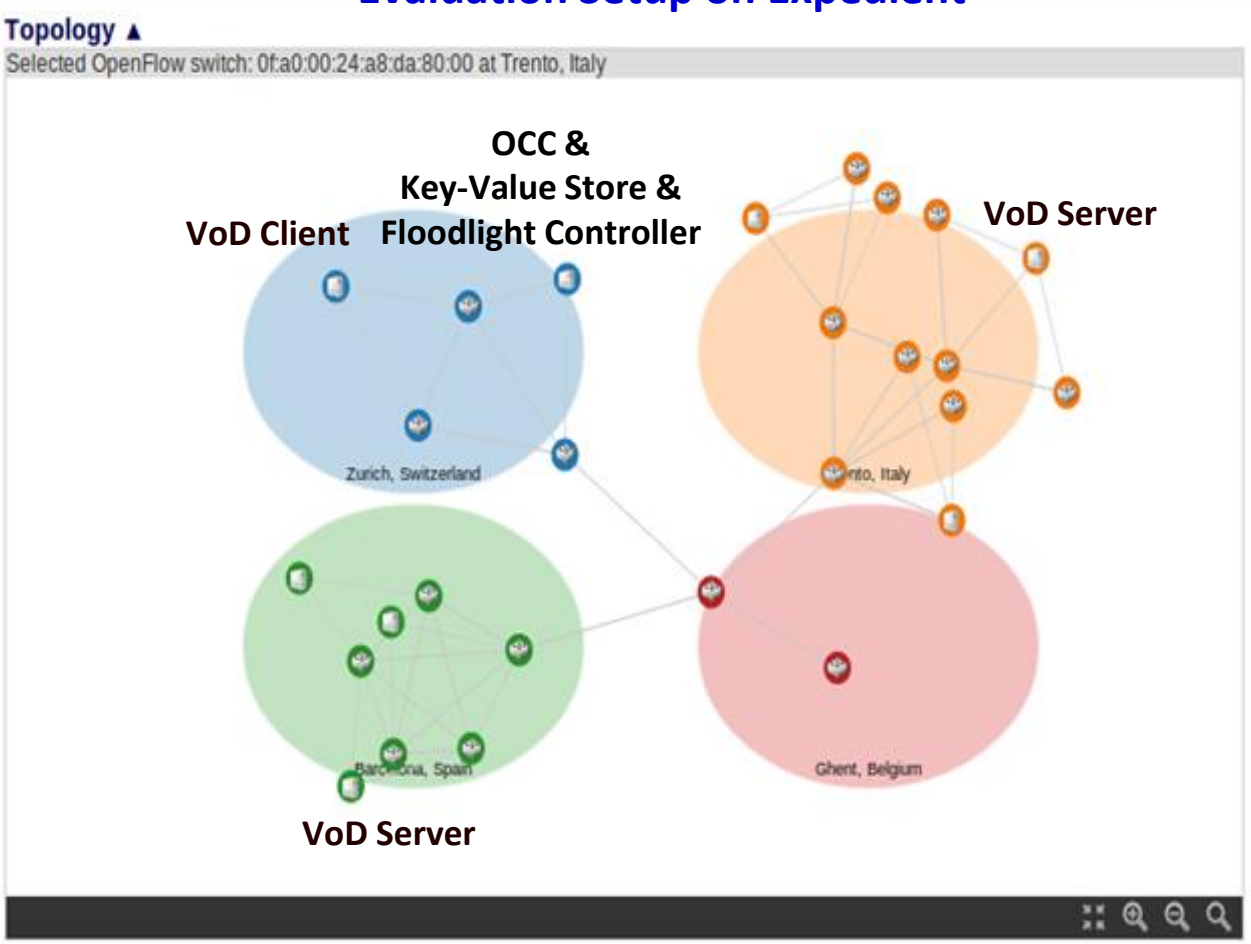
## Evaluation Setup on Expedient



# Evaluation

- **Evaluation Criteria** :
  1. Startup delay (QoE metric)
  2. External link network utilisation (content fetched from cache)
  3. Video quality (bitrate) requested (QoE metric)

## Evaluation Setup on Expedient



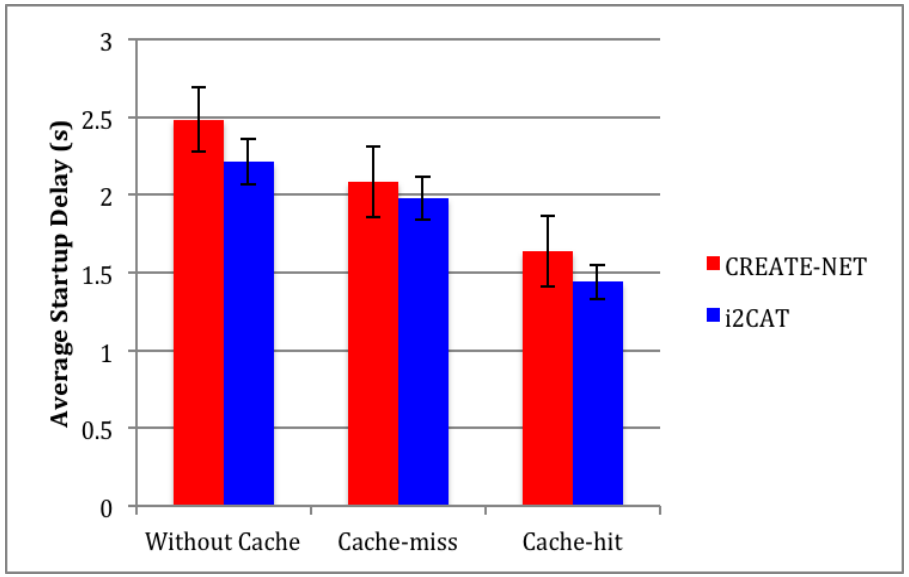
# Results

| | CREATE-NET (Italy) | | | i2CAT (Spain) | | |
|---|---|---|---|---|---|---|
| | **Without Cache** | **Cache-miss** | **Cache-hit** | **Without Cache** | **Cache-miss** | **Cache-hit** |
| Average Startup Delay (s) | 2.484 | 2.088 | 1.639 | 2.212 | 1.982 | 1.441 |
| Improvement over Baseline (%) | - | 16.02 | 34.02 | - | 10.40 | 34.85 |
| Standard Deviation (σ) | 0.208 | 0.225 | 0.226 | 0.145 | 0.138 | 0.109 |
| External Link Usage (Bytes) | 105,734,144 | 105,827,872 | 0 | 105,734,144 | 105,827,872 | 0 |

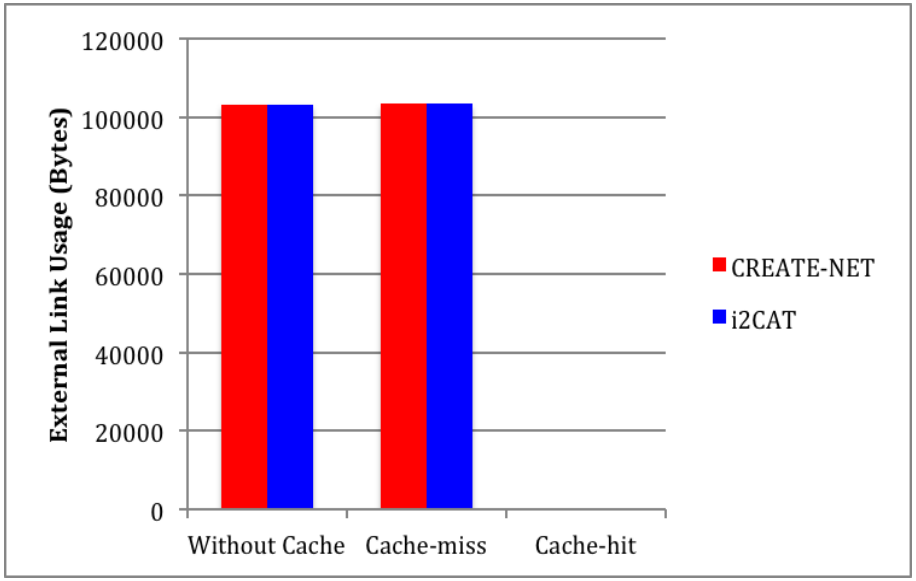
- **Key results :**
  - In tests over both islands we **reduced the startup delay** up to **35% -> increased QoE for end-user**
  - External **link utilisation reduced to virtually zero** (only background traffic remained)
    - Indicatively, the full streaming of our ~10min video saved ~100MBytes for just one client session

# Results

## Average Startup Delay



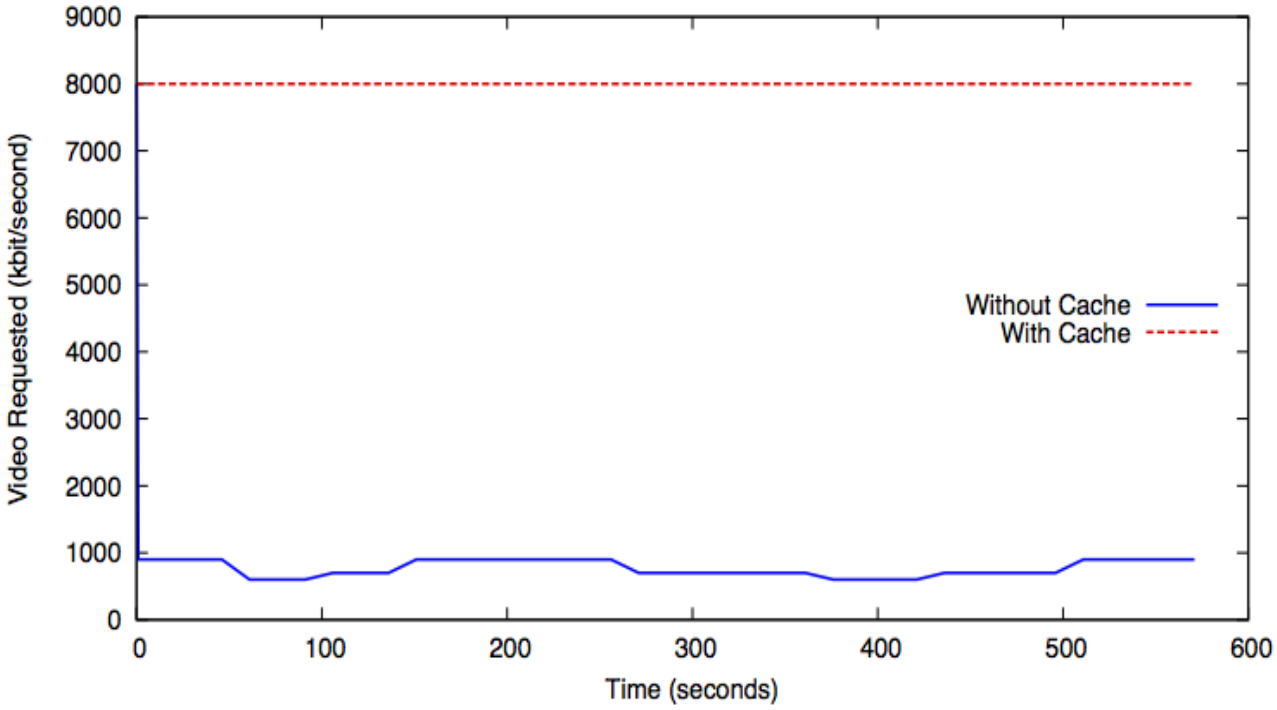

## External Link Usage



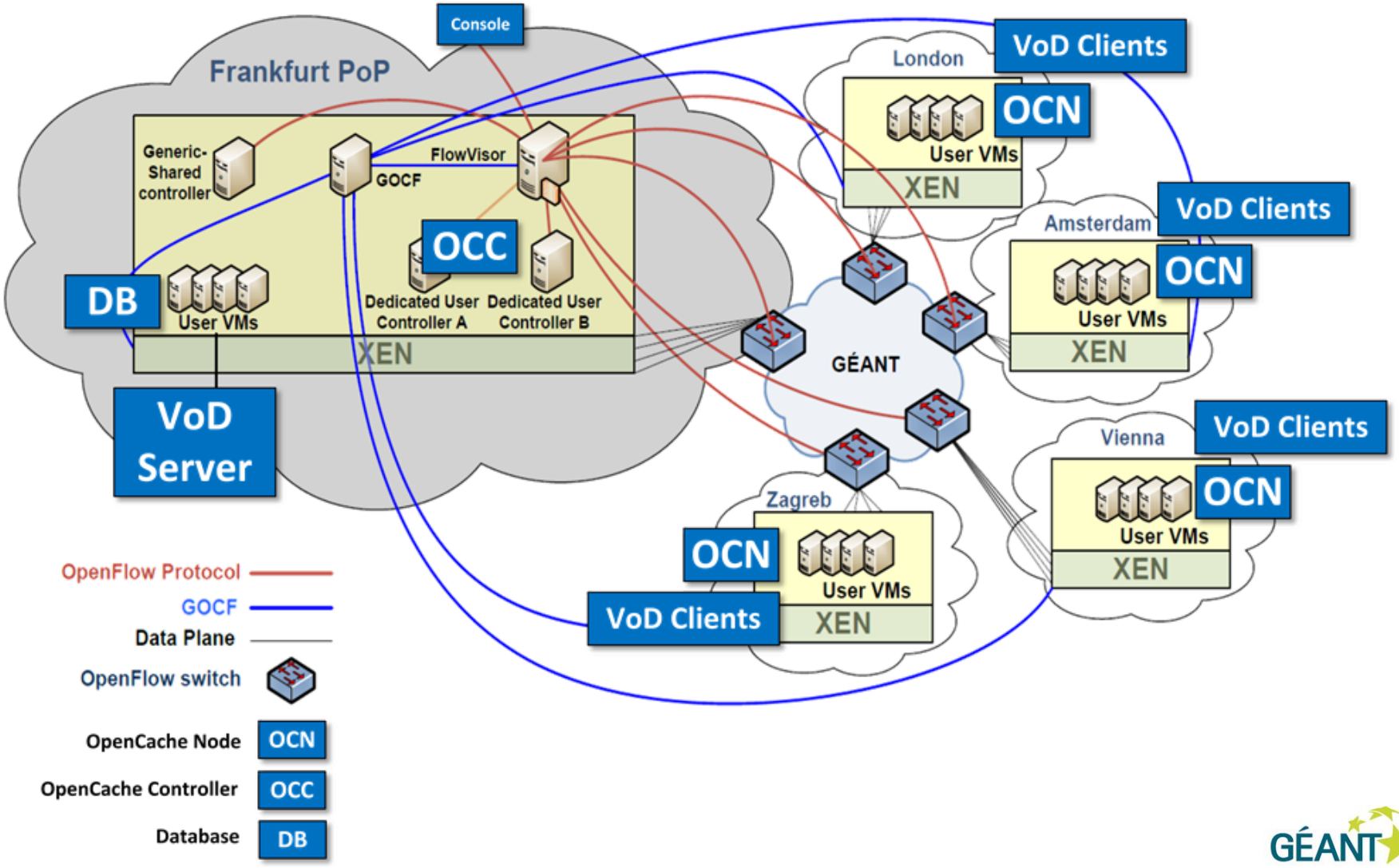

- 35% Improvement even in a bandwidth rich environment (OFELIA testbed)
  - Reinforced by relatively low standard deviation values
- Greater improvements would be possible on next generation OpenFlow switches (better hardware or software OpenFlow switches (OVS) running on x86 CPUs)
  - Currently carrying out tests on EU GN3plus SDN testbed

# Results

- **OpenCache** moves content as close to the user as possible and thus **increased video quality**
  - Client requested bitrate 8 times higher : 8Mbits (highest quality available) vs less than 1Mbit without cache -> **Increased QoE for end-user**



# Evaluation of OpenCache on GN3plus



# Evaluation Tests

- **Two tests**

| | Link Configuration | Description |
|---|---|---|
| **Test1** | Default Link Characteristics | No additional link latency or packet loss is added to the testbed links. Indicatively, VoD Clients experience on average ~30ms RTT delay when communicating with the VoD Server. |
| **Test2** | Emulated Link Characteristics | The clients' site link characteristics fall into the following three categories at each point in time: 45% have default link characteristics, 45% have additional 50ms RTT and 0.1% packet loss, and 10% have additional 150ms RTT and 0.1% packet loss. |

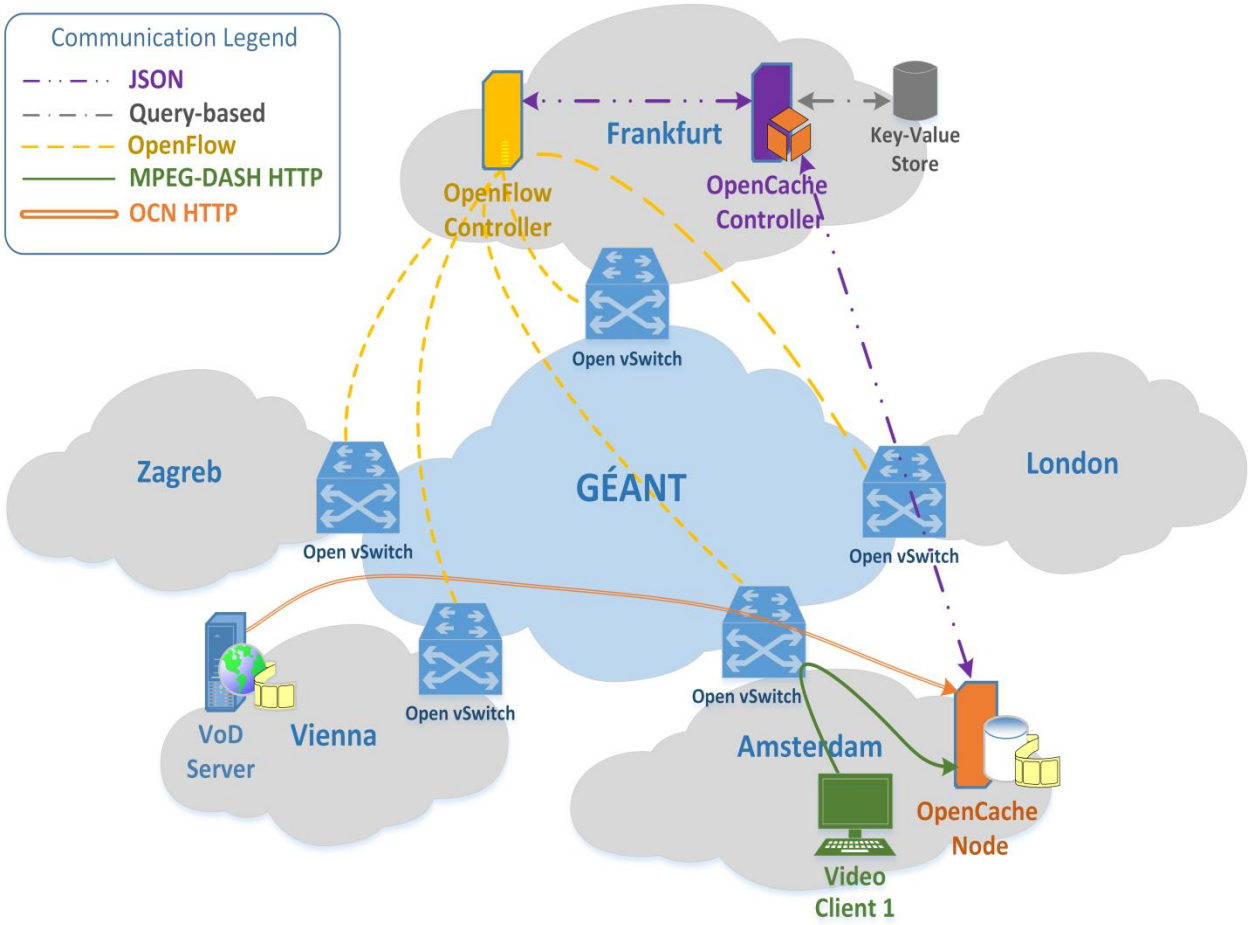
- **Two scenarios in each Test :**
  - Single video client (baseline) -> direct with VoD server, cache-miss, cache-hit
  - Multiple video clients -> how what has already been requested/cached affects QoE
- **Video : Big Buck Bunny**
  - Duration : 9:56 seconds
  - 15 second chunks
  - 20 video quality representations from 50Kbps up to 8000Kbps

# Evaluation Metrics

| Metric | Definitions |
|---|---|
| **Startup Time** | The time it takes a VoD client to start playback from requesting the content. |
| **Video Bitrate Changes** | The number of times a VoD client has to change the video streaming bitrate during playback. |
| **Weighted Average Video Bitrate** | The average video bitrate experienced by a VoD client weighted by its duration during playback. |
| **Minimum Video Bitrate** | The minimum video bitrate a VoD client experienced during playback. |

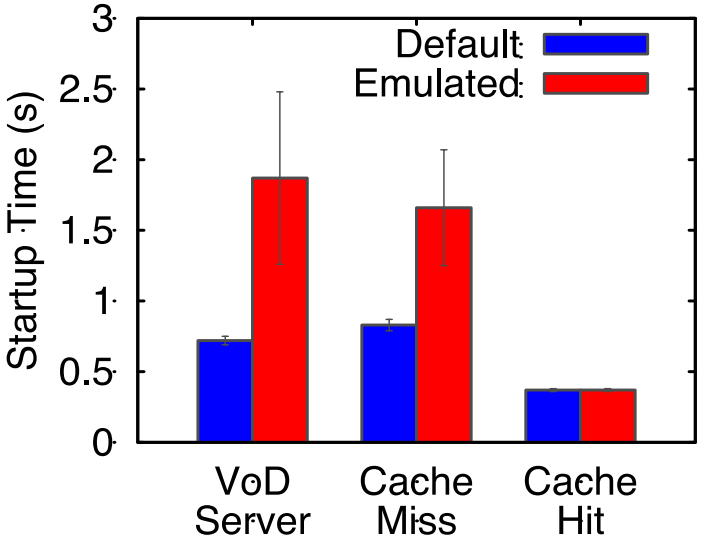
- **Developed Scootplayer** :
  - Open-source video playback tool (http://github.com/broadbent/Scootplayer)
  - Logs a number of video streaming metrics as experienced during playback on VoD clients
  - Compatible with the MPEG-DASH manifest file, and can be used to create realistic HTTP adaptive streaming traffic in a network
  - To help experimenters better understand the effect of network conditions and their relationship with the end-users' QoE

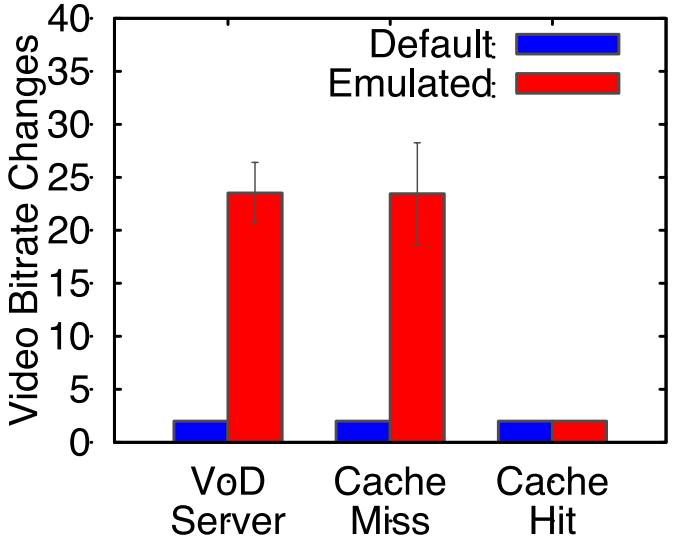
# Single Client Evaluation

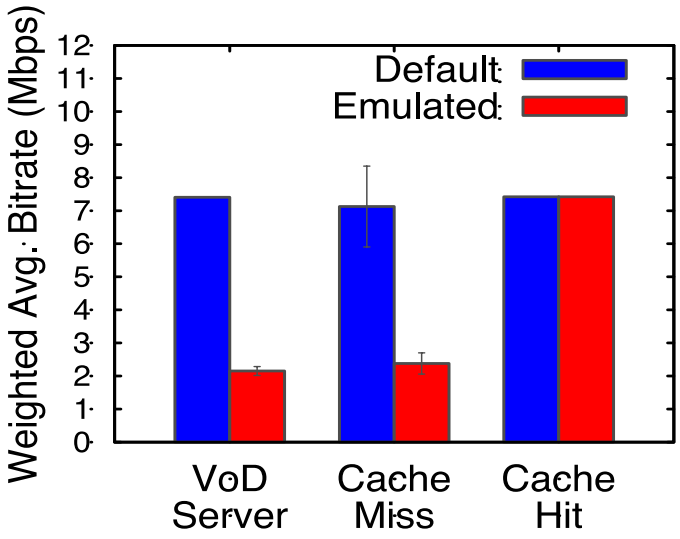


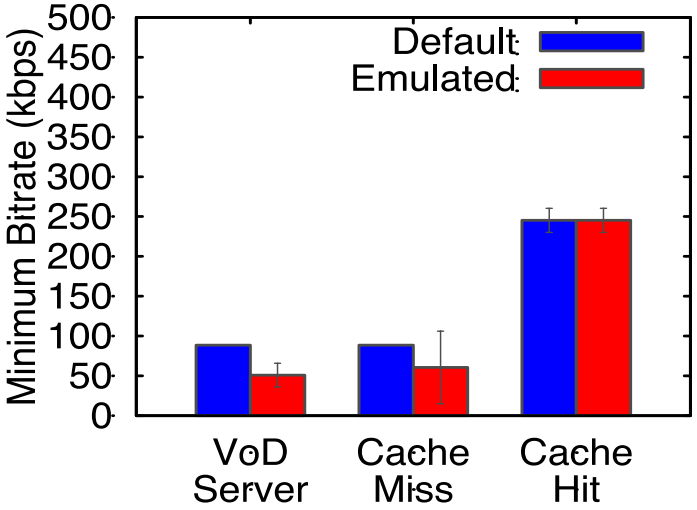

One client plays the video with OpenCache present

# Single Client Evaluation Results

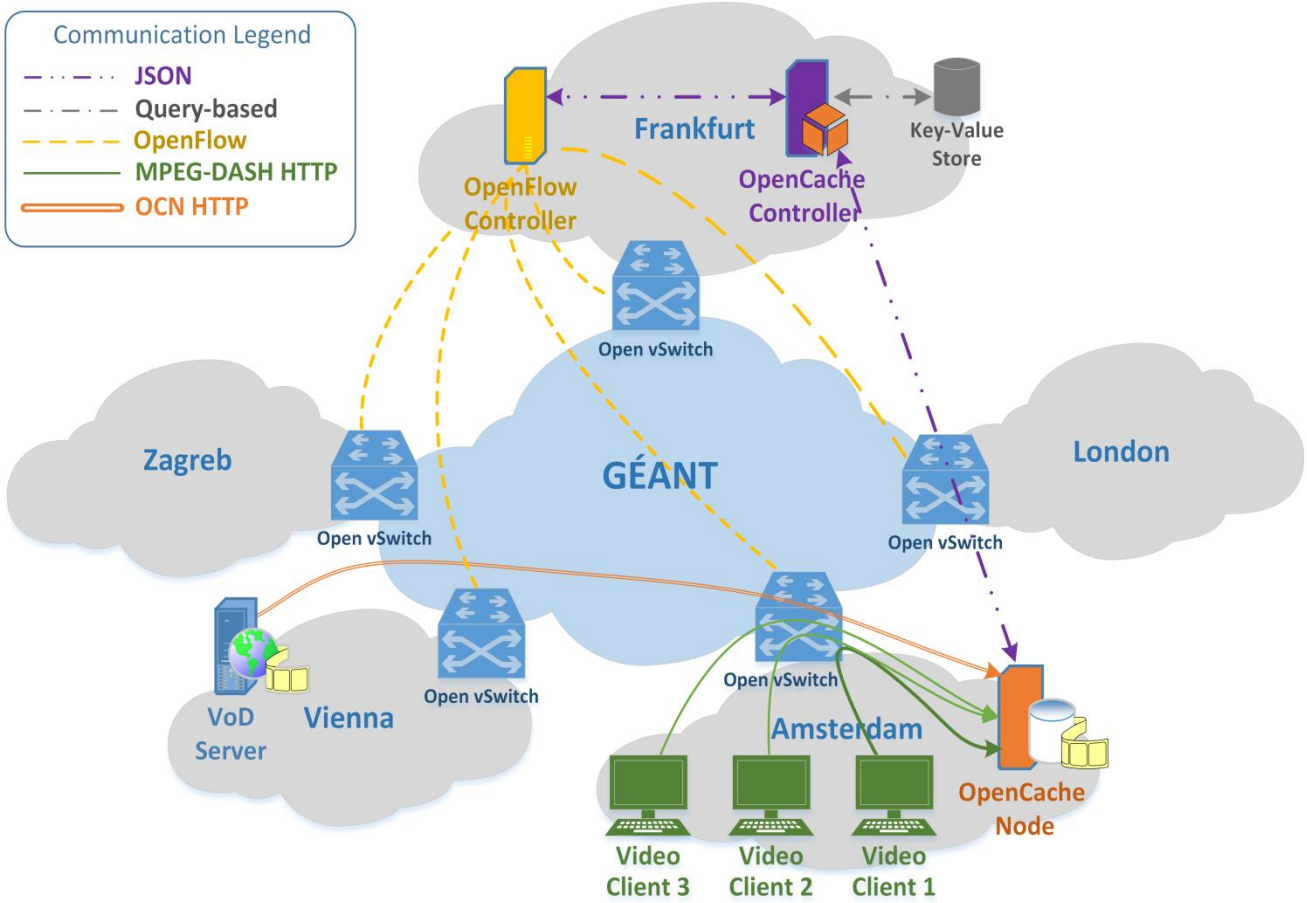


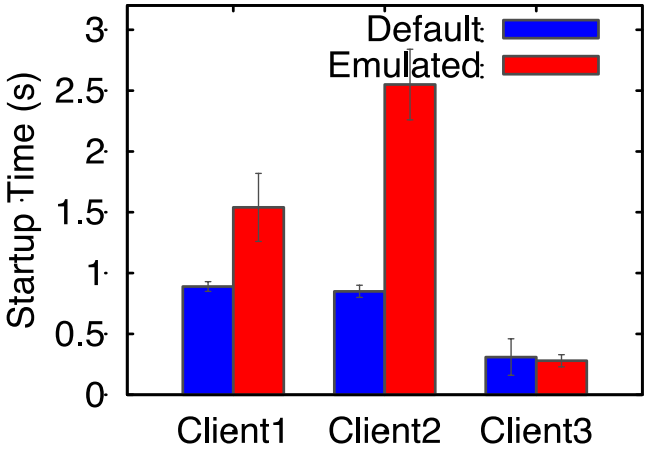



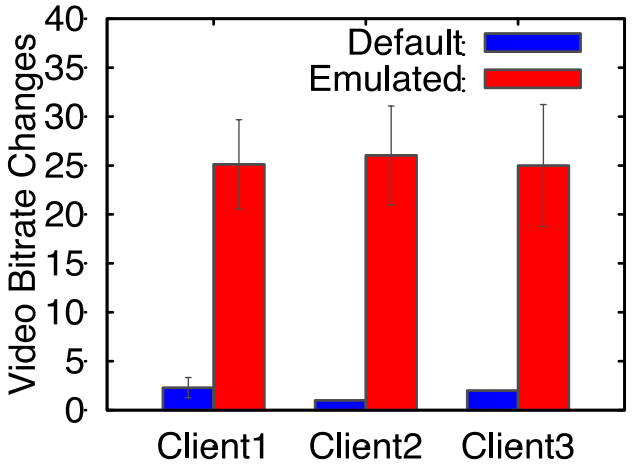
# Multiple Client Evaluation

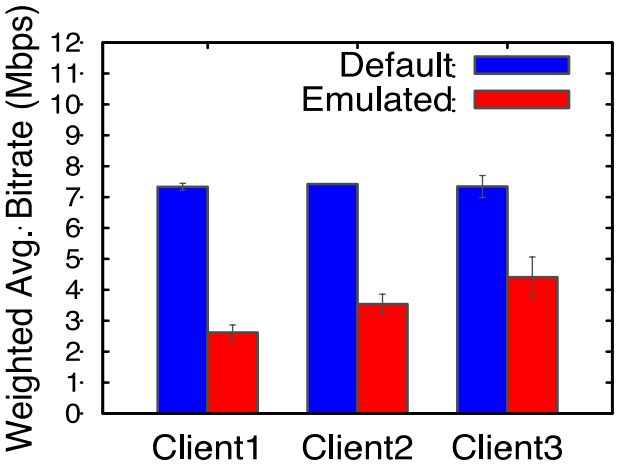


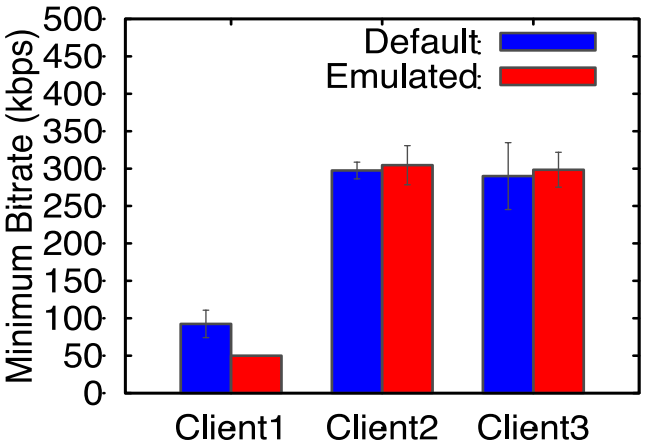

Three video clients requesting the same video at 0, 30 and 90 seconds respectively

# Multiple Client Evaluation Results



# Summary : Advantages of OpenCache

1. Provides **cache as a service for the last mile** by offering an **interface for cacheable content** in an **open**, **highly configurable, controllable** and **flexible** manner

2. **Supports centrally controlled caching** : efficient load balancing, allows pre-caching of frequent content

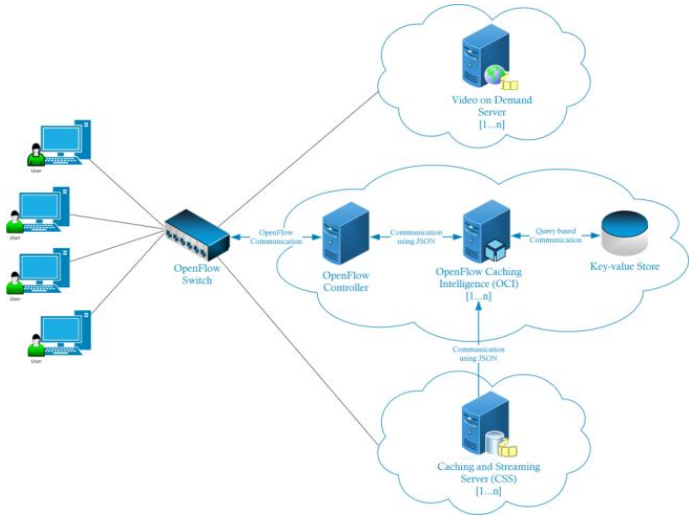
3. Is **easily deployable in a production network** : the underlying delivery video mechanism will remain the same in an OpenFlow network

4. Is fully **transparent to the user** : no need to install any extra software or have to sacrifice any of his local network or storage to be able to stream HD content with high efficiency.

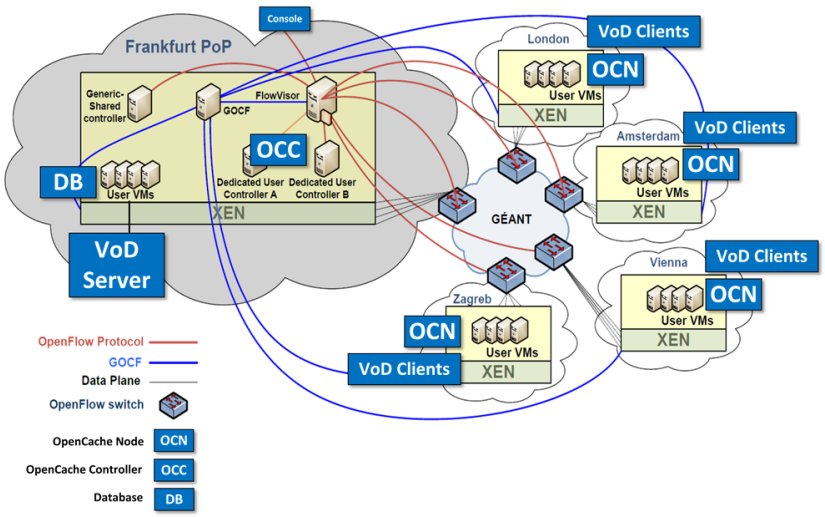
5. **Caching very close to the user** :
   a) **Reduces network utilisation** as requests are served locally : minimize the amount of packets that are required to traverse the network from the source media provider to the user
   b) The **video QoE of the end-user will improve**, as the user will experience lower latency, higher throughput, smaller buffering times and higher video quality as content is now located locally

# Summary of Part A for VoD

1. Designed and implemented OpenCache : an **OpenFlow-assisted Video-on-Demand** service based on efficient, transparent and highly configurable caching




2. Evaluated and demonstrated the benefits of OpenFlow on a VoD service by running inter-island experiments over the OFELIA and GN3plus SDN testbeds across Europe
   - Improved both **network utilisation** and **user experience**



# How to provide a user centric, but network-wide, Quality of Experience (QoE) Fairness on Adaptive Video Streaming ?

**Live Video Traffic**

Panagiotis Georgopoulos, Yehia Elkhatib, Matthew Broadbent, Mu Mu, and Nicholas Race. ***Towards Network-wide QoE Fairness using OpenFlow-assisted Adaptive Video Streaming***. In: ACM SIGCOMM 2013 Workshop on Future Human-Centric Multimedia Networking (FhMN), 16 August, 2013, Hong Kong, China.

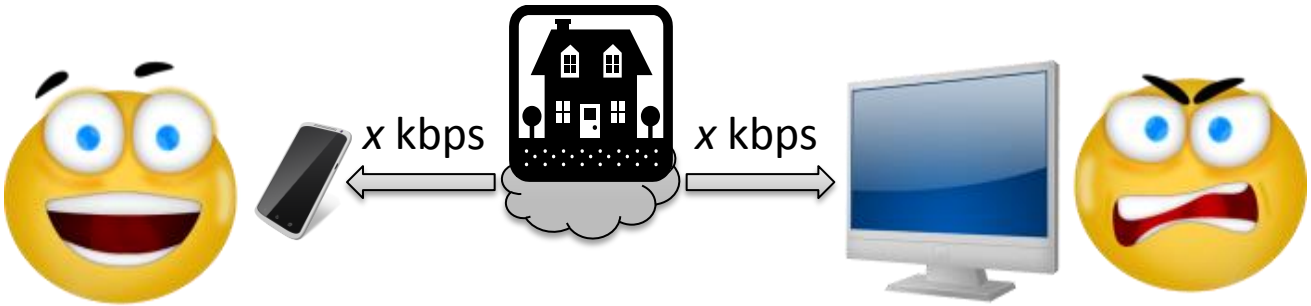
# The Problem

- Adaptive Video Streaming (e.g. MPEG-DASH) aims to increase QoE and maximise connection utilisation (supporting chunks encoded at different bitrates)
- Many implementations are bursty and unstable in nature and naively estimate available bandwidth from a one-sided client perspective
  - No account of other devices in the network
  - Results in unfairness ; video streams fight over link's capacity which causes network congestion (video quality degradation, frame freezing etc.) and potentially lowers QoE for all clients
- **Counter productive!**

# Potential Solution

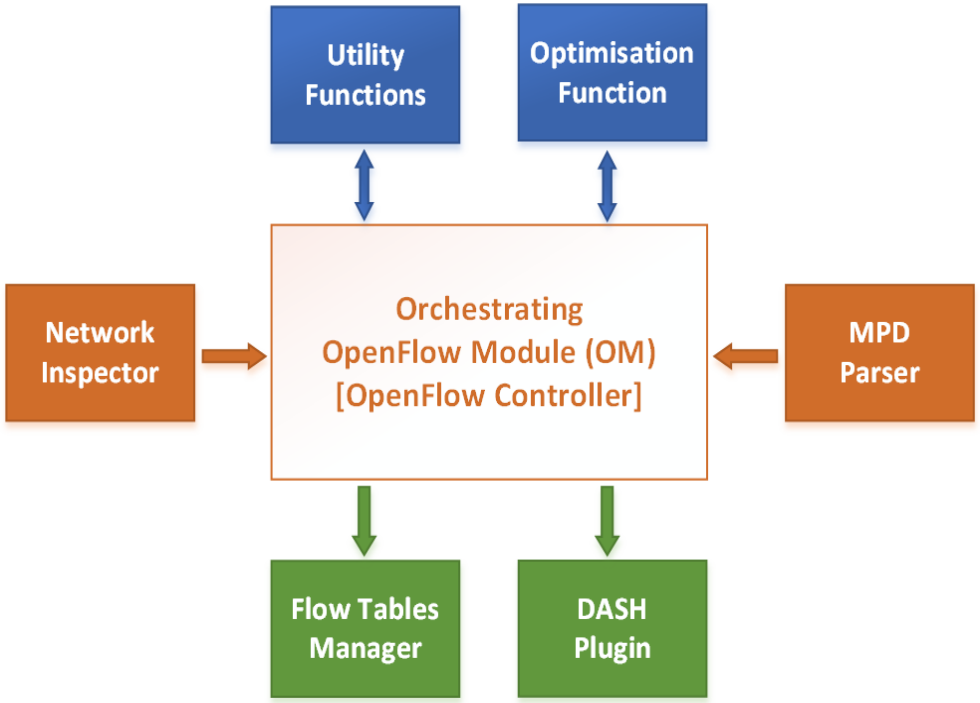
- Split available bandwidth to current users on the network ?

- But **naïve network resource fairness** (equal split) is **unfair** :
  - You could easily satisfy a user watching a video on his smartphone, but it is much harder for an HD TV

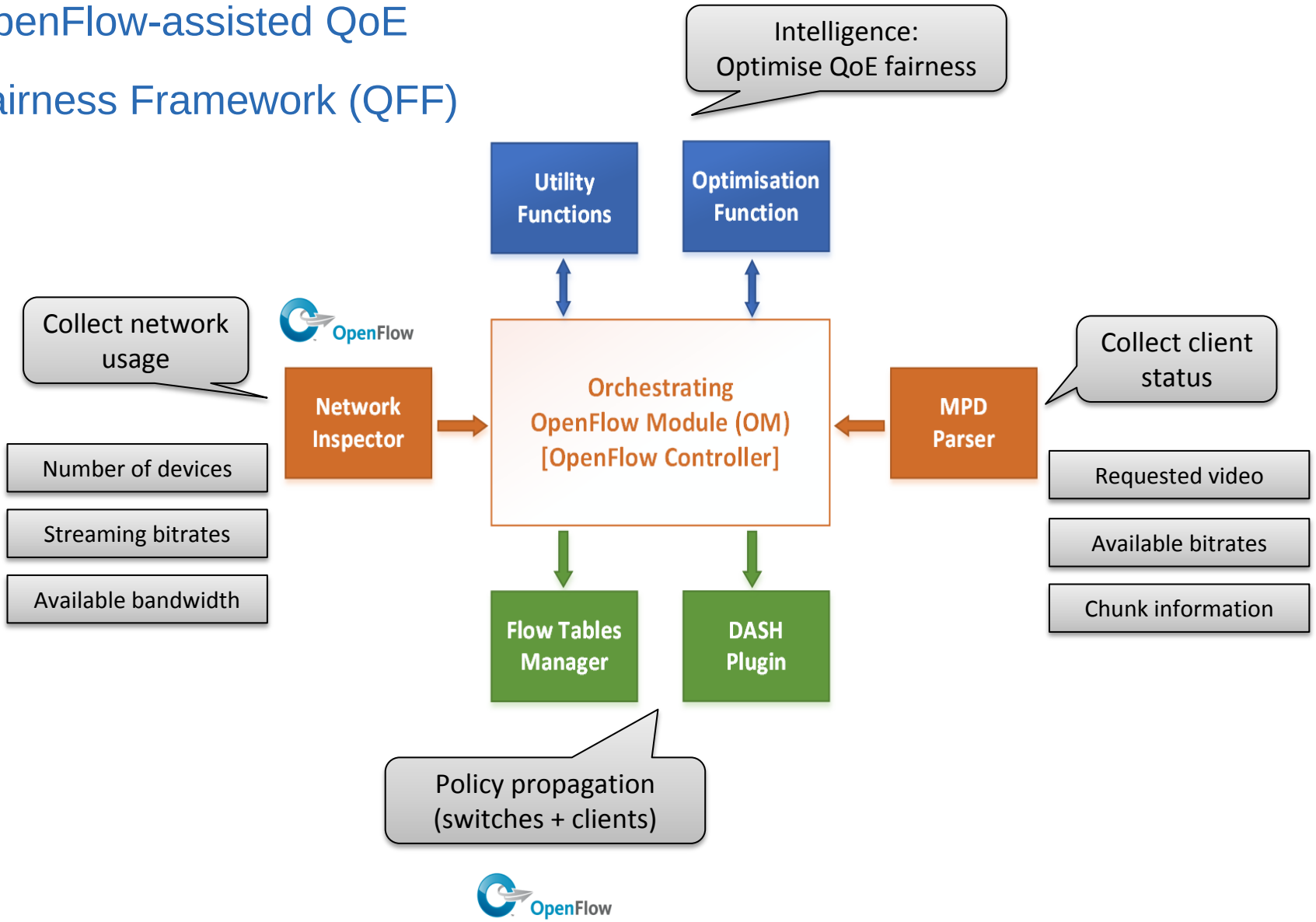


# Our Solution : OpenFlow-assisted QoE Fairness Framework (QFF)

- Aims to provide a user-centric fair-share of network resources and fairly maximise the QoE of multiple competing clients in a shared network environment
  - QFF monitors video streams of all clients in a network and dynamically allocates network resources to each device. Avoid user-agnostic decisions ; no blindly dividing bandwidth between active users
  - Use of SDN to provide the network-wide view and the control plane to orchestrate this functionality



# OpenFlow-assisted QoE Fairness Framework (QFF)

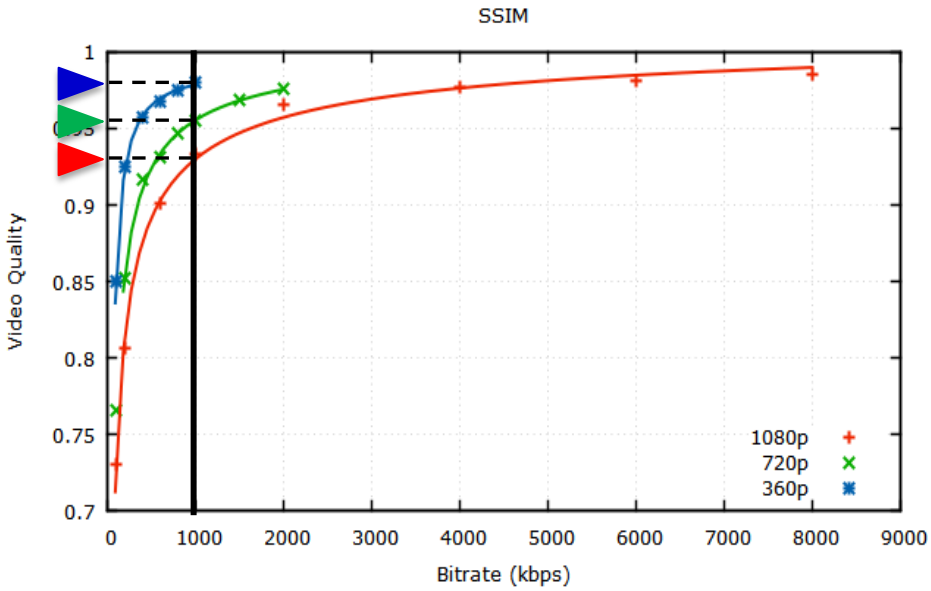


# QFF Core Intelligence : Utility Function

- Utility Function provides a model that maps the bitrate of a particular video to the QoE delivered on that specific device
  - We obtained QoE for each video sequence using objective video quality assessment that employ a functional model of the human visual system (Structural Similarity Index (SSIM), Video Quality Metric (VQM))

| Resolution | Video Bitrate (kbps) |
|---|---|
| 1080p | 100, 200, 600, 1000, 2000, 4000, 6000, 8000 |
| 720p | 100, 200, 400, 600, 800, 1000, 1500, 2000 |
| 360p | 100, 200, 400, 600, 800, 1000 |

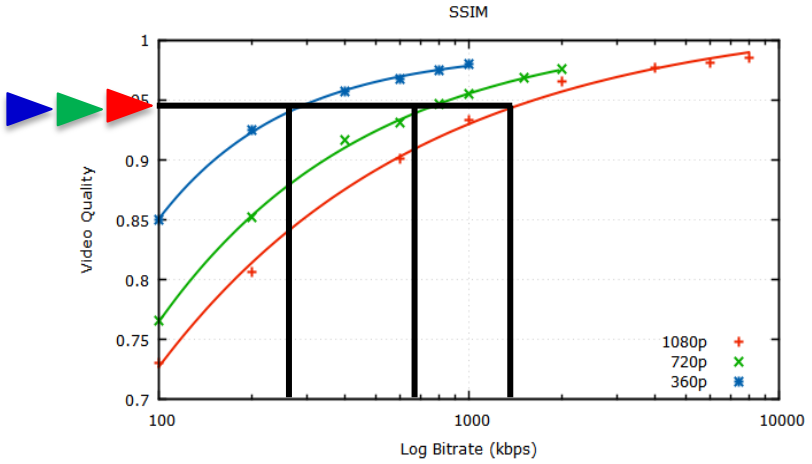
- Utility Function proved that :
  - Relationship between bitrate and perceptual quality is not linear
  - Equal division of bandwidth between different resolutions results in QoE unfairness



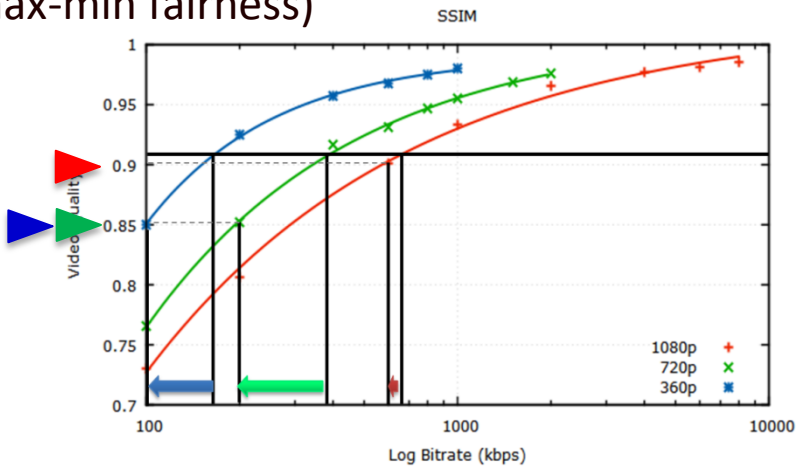

Scatter Plot and Derived Utility Function

# QFF Core Intelligence : Optimisation Function

- Optimisation Function finds the optimum bitrate for each streaming video device in the network that results in equivalent QoE levels for all devices
  - But the utility functions are not continuous, i.e. we don't have available encodings for all possible bitrates

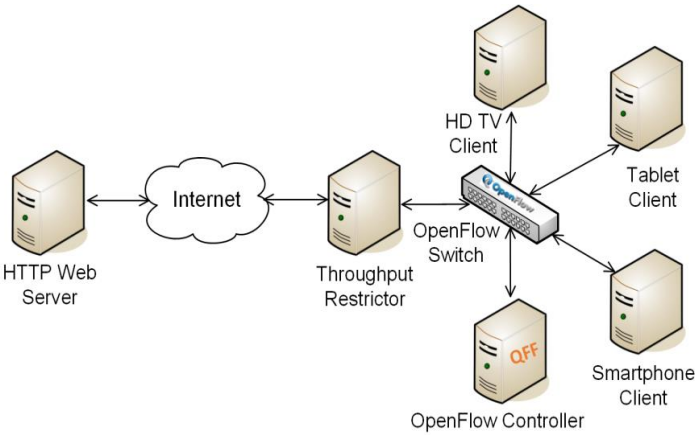



- Implemented branch and bound optimisation algorithm that downgrade all clients to the maximum feasible bitrate (max-min fairness)
  - Very modest computational overhead < 0.3sec for optimising 100 Utility Functions with 10 different bitrates each

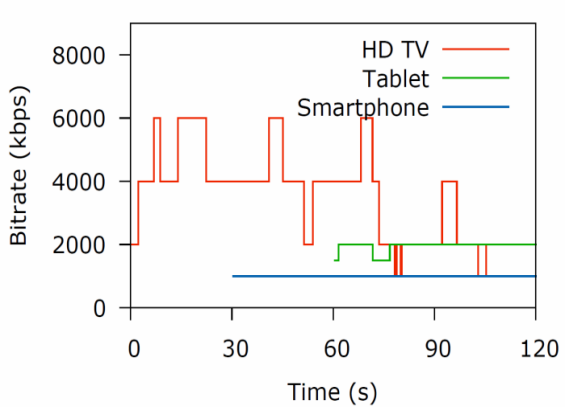


# Proof of Concept Evaluation

- Around a home networking scenario (transferable to bigger networks)
- Three different DASH-enabled devices : smartphone (360p), Tablet (720p), HDTV (1080p)



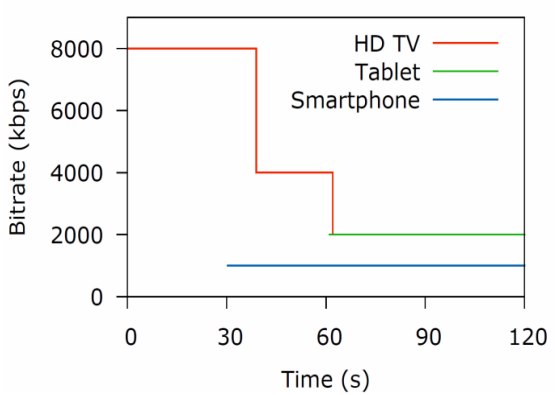

## DASH-JS




Network instability :

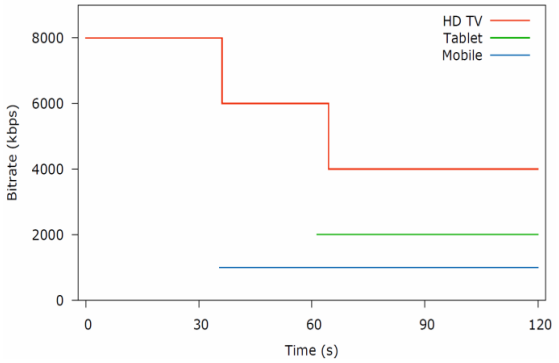
Bitrate changes : 18-31 (av.23)

## EQUAL B/W (control)




Network stability: Bitrate changes : 2, but HDTV gets penalized (lower QoE)

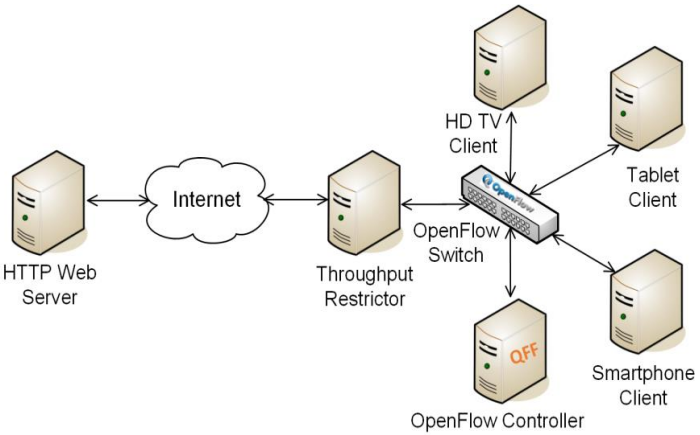
## QFF



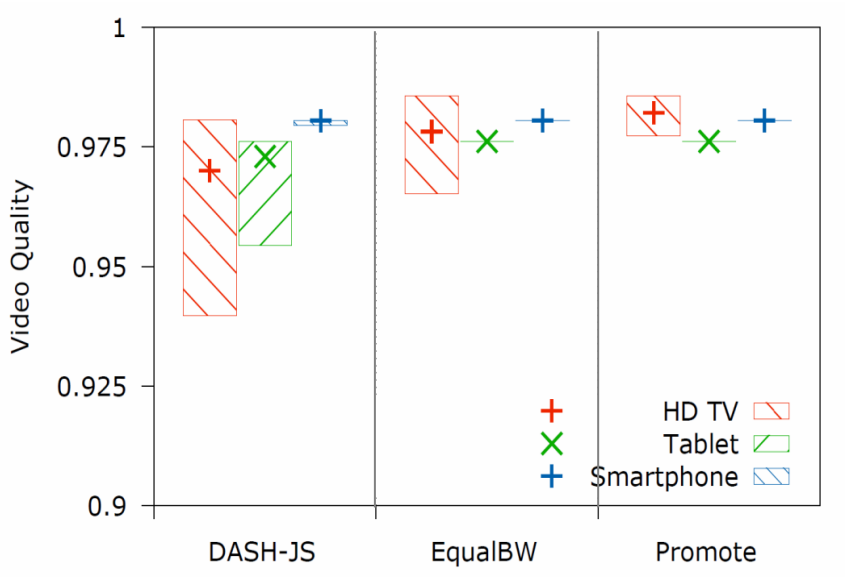

Network stability & QoE fairness across devices

# Proof of Concept Evaluation

- Around a home networking scenario (transferable to bigger networks)
- Three different DASH-enabled devices : smartphone (360p), Tablet (720p), HDTV (1080p)




- QFF produces
  - increased mean QoE
  - reduced QoE variance (particularly for the HDTV)

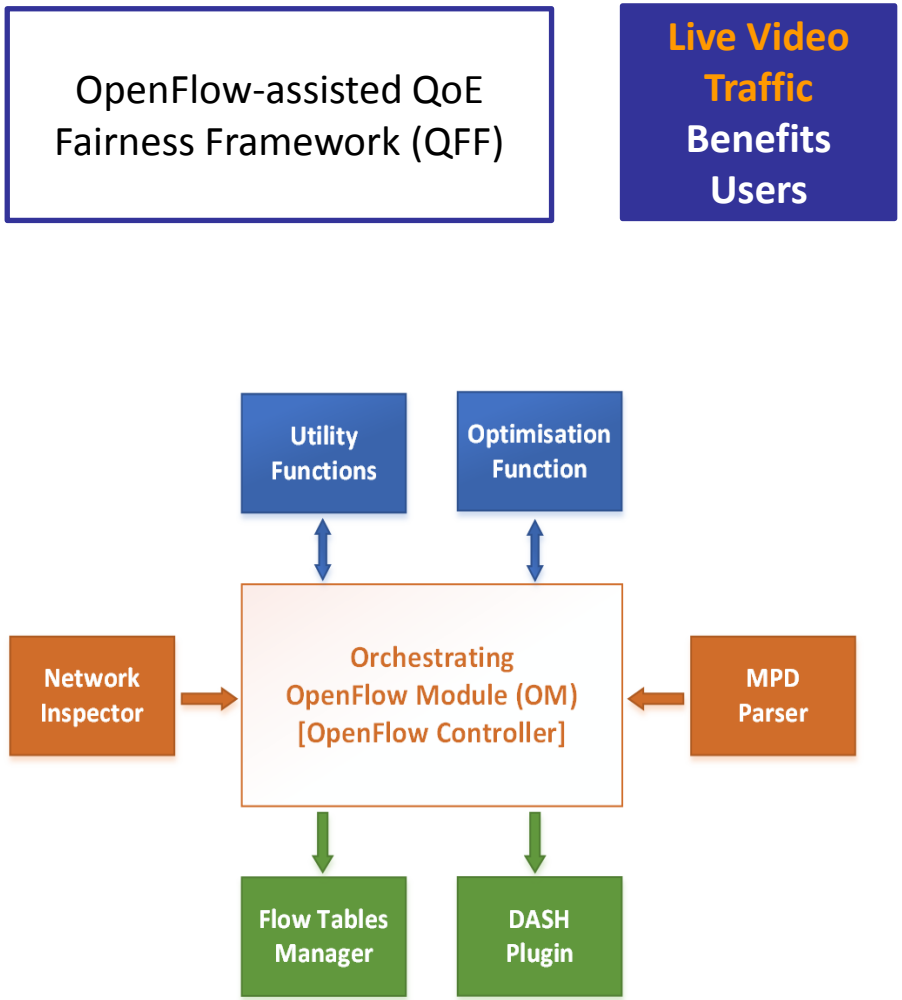



*Mean and variance of QoE*

# Summary of Part B for Live Video

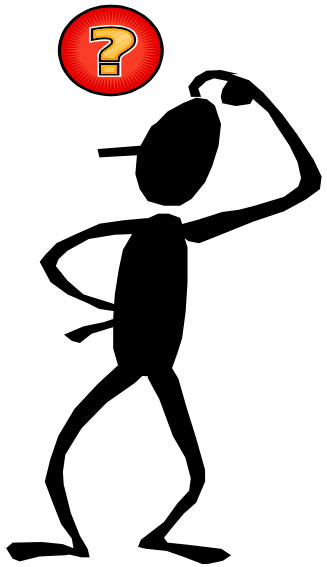
- Aims to provide a user-centric fair-share of network resources and fairly maximise the QoE of multiple competing clients in a shared network environment

- SDN to provided the network-wide view and the control plane to orchestrate this functionality



# Part C :

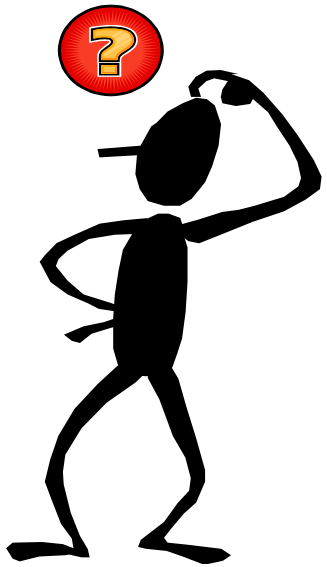
## What problems do you experience as end-users when streaming video (live or on-demand) over the Internet?



Part C :

What problems do you experience as end-users when streaming video (live or on-demand) over the Internet?

**Can SDN alleviate those? How?**



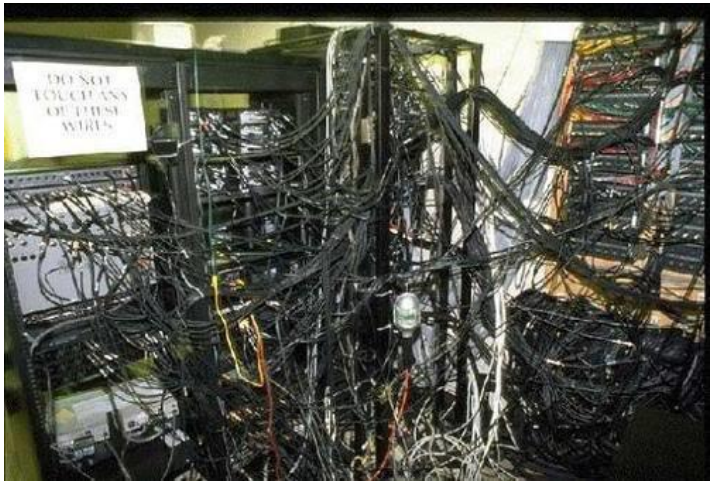
# Part D:

# More SDN-assisted Video Content Distribution projects

# -work in progress-

# SDN-assisted Video Content Distribution Projects (1)

- **Software Defined Audio* Networking**
  - MSc project : Remo Balaguer
  - Cooperation with Studer Harman Inc.
  - With Vasileios Kotronis and Bernhard Plattner

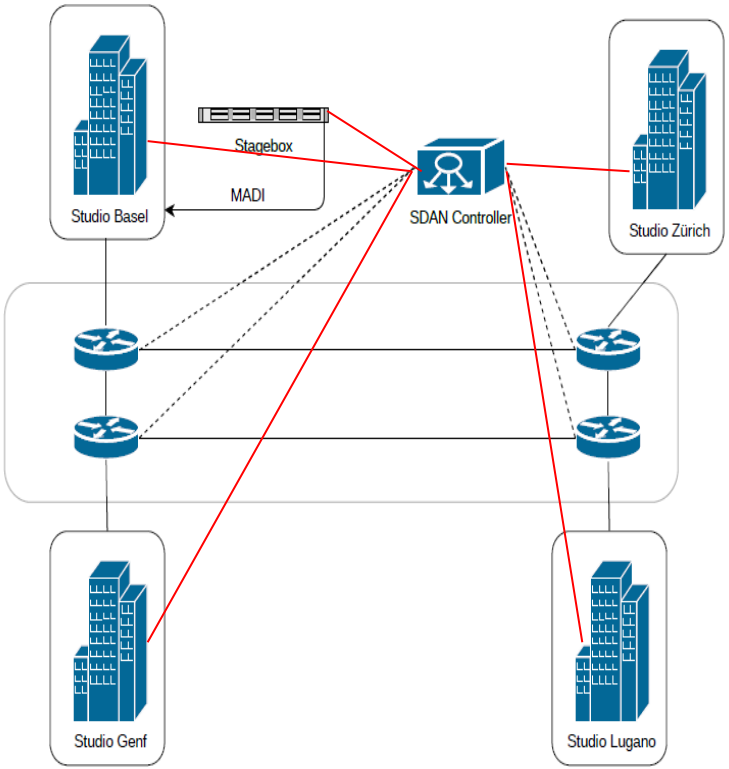


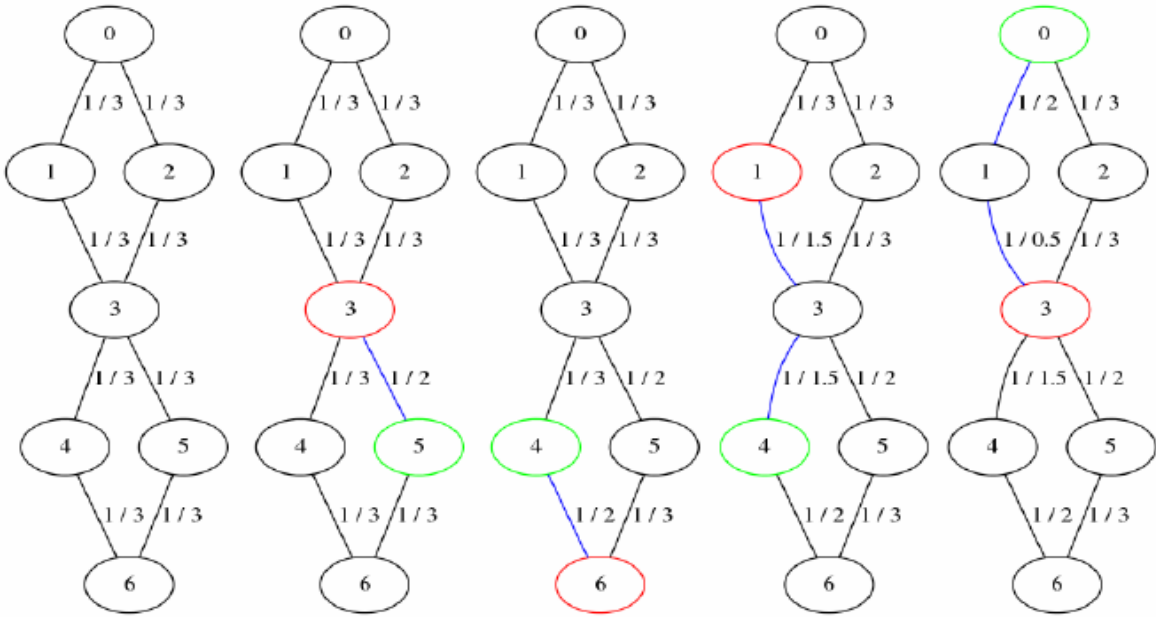

- Connections between many media (audio/video) sources and many sinks
- Point-point or multichannel links
- Industry wants to move to Audio over IP (AOIP) solutions (AES 67)
- SDAN : Use Controller to embed audio requests *optimally* in a network
  - Online vs offline, priority, group requests, minimise latency end-to-end

*Audio ≈ Video : we are solving the problem in a generic way

# SDN-assisted Video Content Distribution Projects (1)

- **Software Defined Audio Networking**



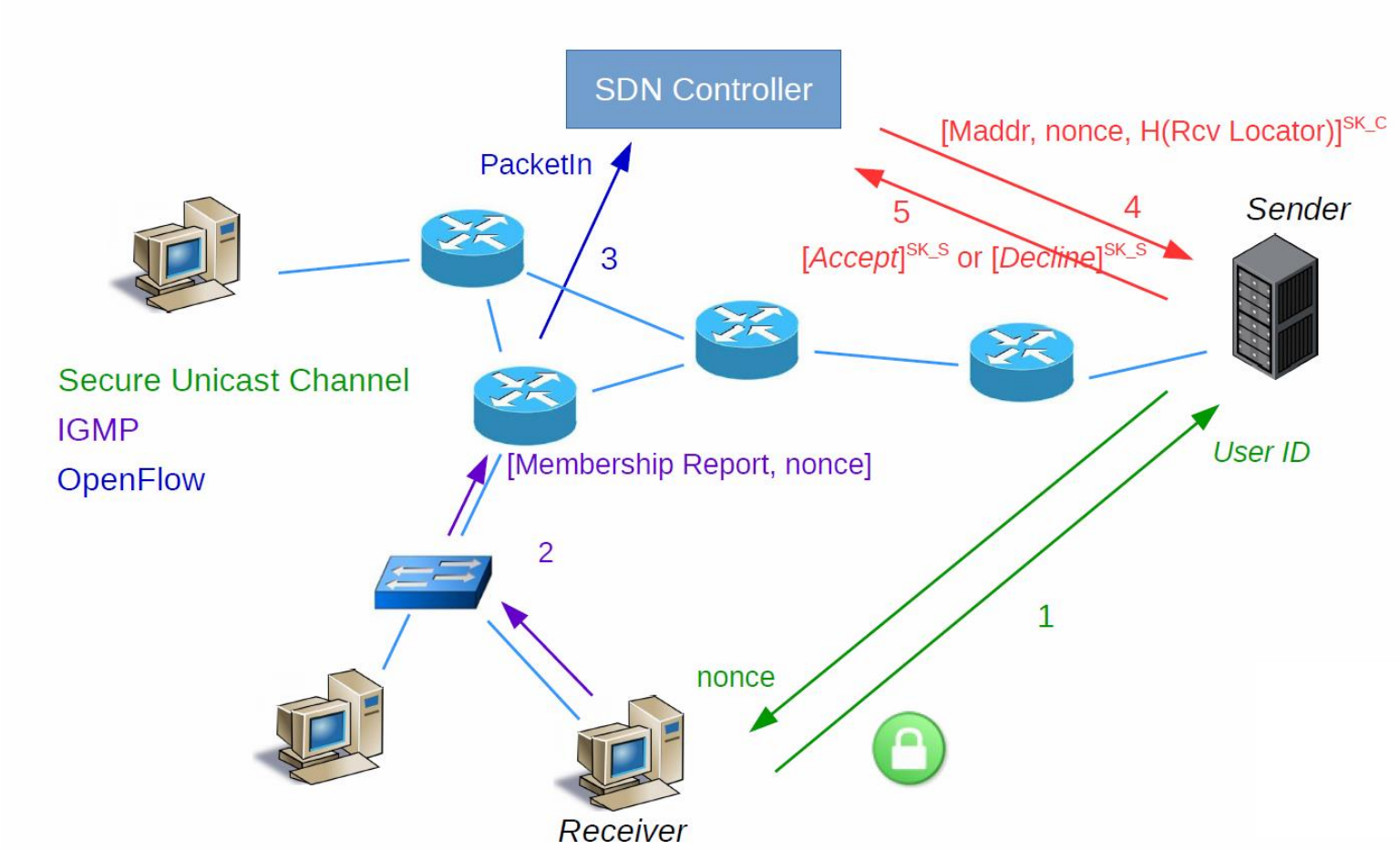



# SDN-assisted Video Content Distribution Projects (2)

- **SDN-assisted access control for IP Multicast**
  - Semester project : Patrick Leu
  - With Bernhard Ager and Bernhard Plattner
- IP Multicast has not see global deployment
  - Lack of receiver authentication
- Provide an authentication scheme for IP multicast receivers
  - Use SDN Controller's central viewpoint
  - Design the authentication scheme
  - Requirements (backwards compatible? transparent?)
  - Security threats

# SDN-assisted Video Content Distribution Projects (2)

- **SDN-assisted access control for IP Multicast**



# SDN-assisted Video Content Distribution Projects (3)

- **SDN-supported Live Video Streaming**
  - PhD project : Haiyan Ma
  - With Jinyao Yan (CUC)
- Live Video Streaming : minimize end-to-end delay
  1. Profile delay in the network for end-to-end scenario
     - How much delay we can tolerate without video breaking up?
  2. Build a use case :
     - Which video characteristic(s) predicts/infers video breaking up (buffer occupancy?) and its relationship to QoE
     - How can the OpenFlow controller help?
     - Control/manage queues on SDN switches

# SDN-assisted Video Content Distribution Projects (4)

- **Provide QoE as a service**
  - PhD project : Matthew Broadbent (Lancaster University)
  - With Arsham Farshad, Nicholas Race (Lancaster University)

- Define QoE related metrics that we can measure in-network using the SDN control plane during playback
- Provide framework that analyses them and defines their relationship to QoE
- Use SDN Controller's view to provide network-wide QoE as a service
- React and improve QoE from within network : e.g. with intelligent caching policies

## One final thought…

**Could we have done all this without SDN** 

**Thank you !**

**Any questions ?**

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# Τέλος Ενότητας

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ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

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