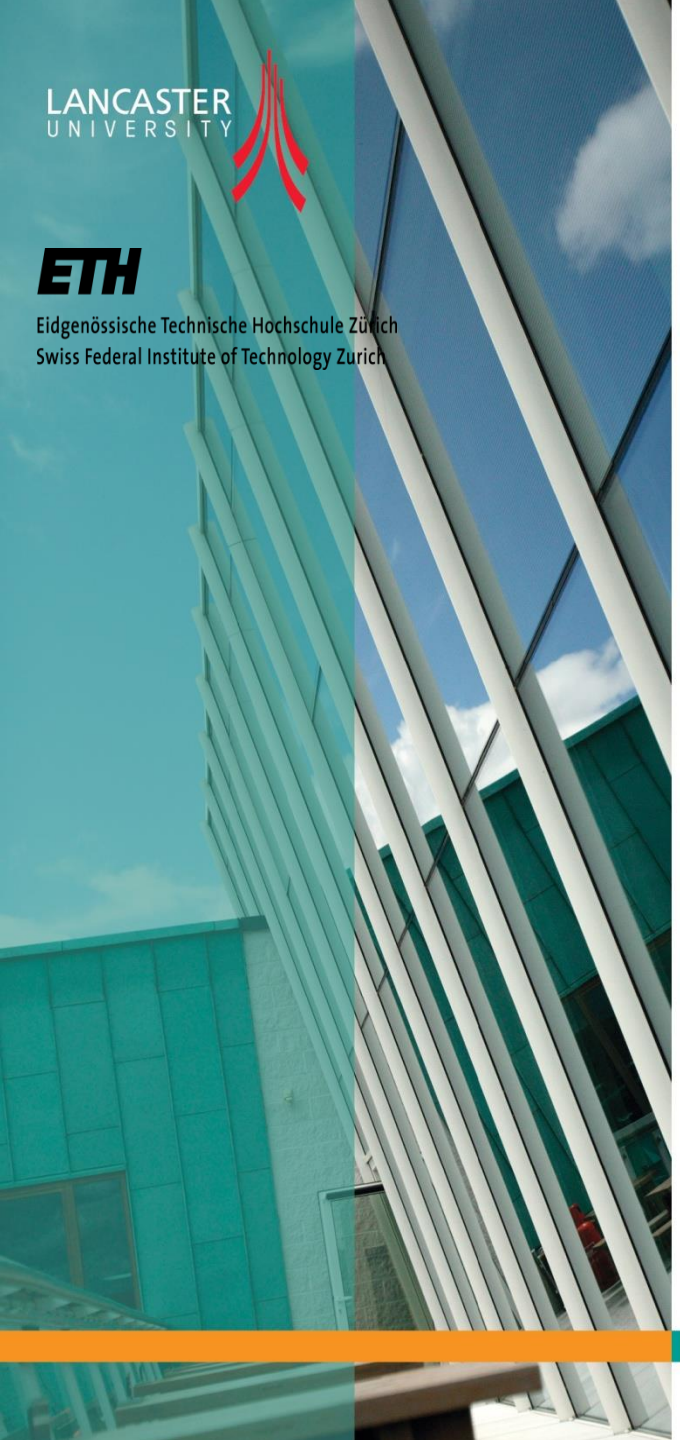

Leveraging SDN for Video Content Distribution

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People Involved

- **Prof. David Hutchinson**
- **Prof. Nicholas Race**
- **Dr. Mu Mu**
- **Dr. Yehia El-Khatib**
- **Matthew Broadbent**
- **Prof. Bernhard Plattner**
- **Vasileios Kotronis**







Overview

Theme : How can we leverage SDN for Video Content Distribution

- Why ?
- What is it?
- Design & Implementation
- Evaluation results

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

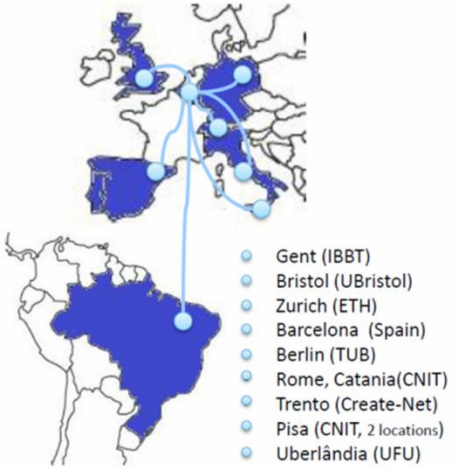
VoD Traffic Benefits Network and Users

OpenFlow-assisted QoE Fairness Framework (QFF)

Live Video Traffic Benefits Users

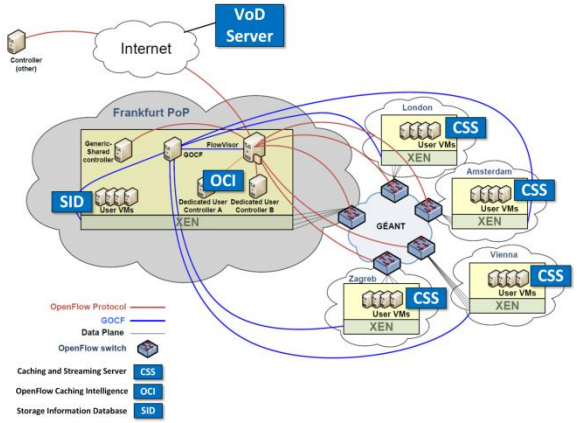
- *"Disclaimer" : work in progress*

SDN Experimentation in EU projects



OFELIA

- 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

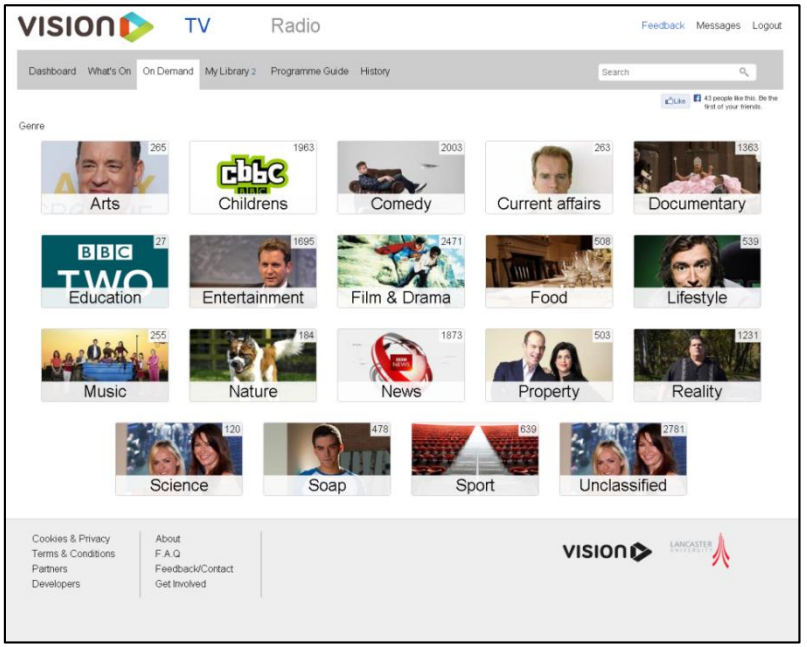
- Oct 2012 – Nov 2016 : 4 years, 17+ partners
- Provide a common federation framework for Future Internet Research and Experimentation facilities
- Joined on 1st Open Call : Multi-testbed Experimentation of a VoD service on islands providing a variety of technologies/services

Experimental Video-on-Demand Use Case

- **Goals :**

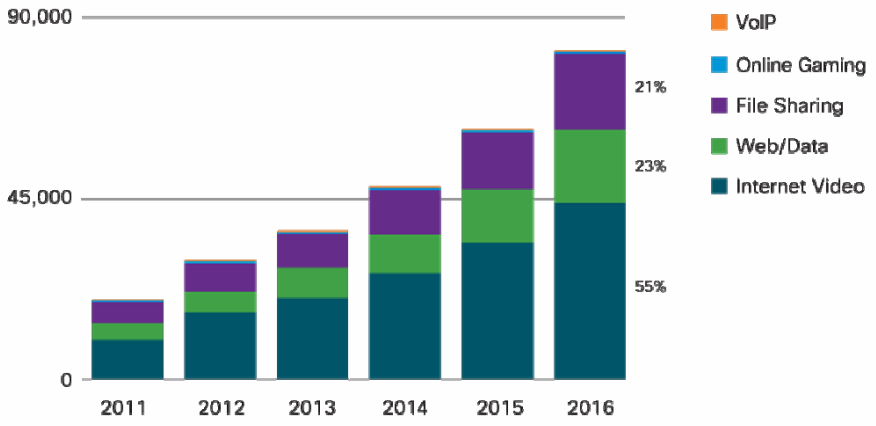
1) Design and implement an OpenFlow-assisted Video-on-Demand service based on transparent caching

2) Evaluate and demonstrate the benefits of OpenFlow on a VoD service by running inter-island experiments over the OFELIA/GN3plus/Fed4FIRE testbeds across Europe
   - Consider both Network & User perspectives



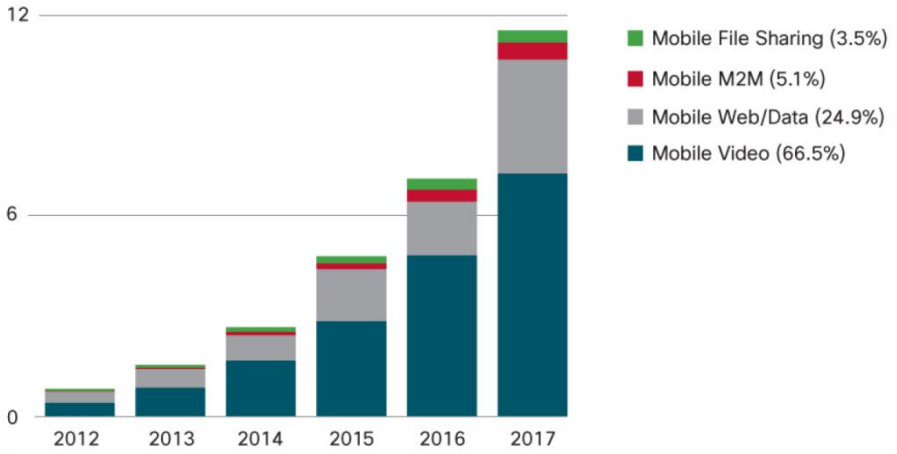
Motivation : Why Video?

- In the UK visits to online video sites have **grown by 36%** in one year (Sept 2010 - Sept 2011) [1]
- Globally, **Internet video traffic was 57% of all consumer Internet traffic** in 2012 and will be 69% in 2017 [2]



Global consumer Internet traffic in Petabytes per month [2]

- **Mobile video traffic** exceeded 50% for the first time in 2012 [3]
- Mobile video will increase 16-fold between 2012 and 2017
- Two-thirds (~66%) of the world's mobile data traffic will be video by 2017



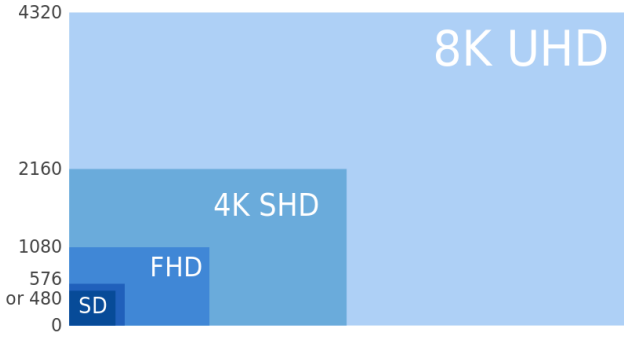
Mobile consumer Internet traffic in Exabytes per month [3]

[1] Hitwise (2011)
[2] Cisco VNI Global Forecast (2012)
[3] Cisco VNI Mobile Forecast (2013)

Motivation : Why Video-on-Demand (VoD)?

- With a **VoD service** (e.g. BBC iPlayer, Netflix, Amazon's LOVEFiLM) 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]

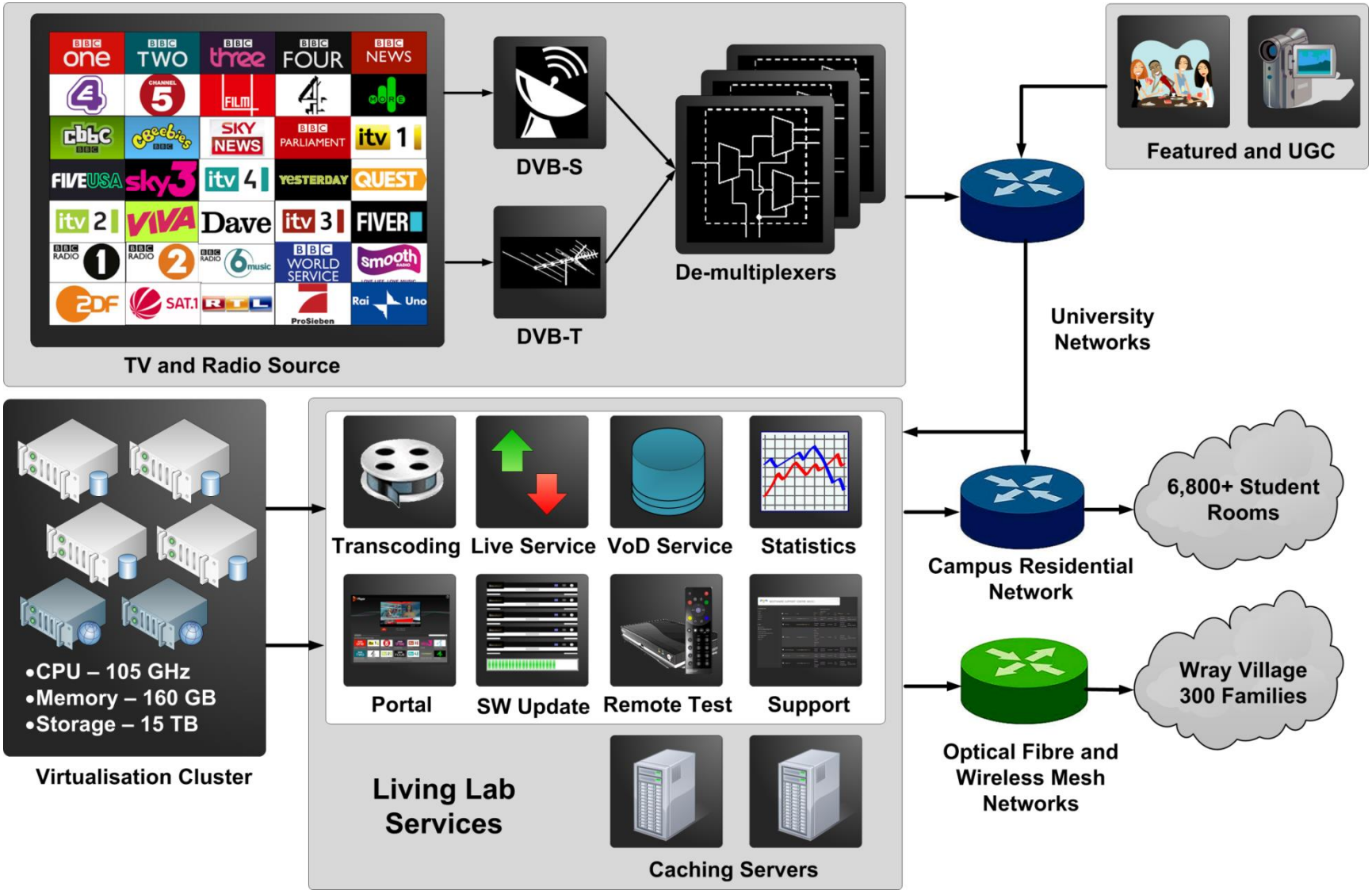


Evolution of video resolution for online streaming

- On one hand ; **Video-on-Demand is fast becoming an essential part of consumers' lives**
- On the other hand ; **a huge strain on the underlying network infrastructure to transfer an enormous amount of data end-to-end**

[1] Cisco VNI Forecast 2012

IPTV Living Lab Infrastructure at Lancaster University



Quick Live Overview of Vision IPTV

VISION TV Radio

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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

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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** 15:00 - 15:45 | Duration 45 mins 6/25. John Barrowman hosts the quiz where two teams compete in a series of head-to-head games. Also in HD. [S] Watch Live Save for Me	 **Paul Hollywood's Pies & Puds** 15:45 - 16:30 | Duration 45 mins 6/20. Paul uses cheese from Yorkshire, lavender from Kent and chocolate from Paul A Young. Also in HD. [S] Save for Me
BBC TWO	 **Cagney and Lacey** 15:00 - 15:45 | Duration 45 mins 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] Watch Live Save for Me	 **Are You Being Served?** 15:45 - 16:15 | Duration 45 mins 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] Save for Me
itv	 **The Alan Titchmarsh Show** 15:00 - 16:00 | Duration 60 mins Teatime chat and music with Alan Titchmarsh. [S] Watch Live Save for Me	 **Tipping Point: Lucky Stars** 16:00 - 17:00 | Duration 60 mins 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] Save for Me
4	 **Countdown** 15:10 - 16:00 | Duration 50 mins 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] Watch Live Save for Me	 **Deal or No Deal** 16:00 - 17:00 | Duration 50 mins 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] Save for Me
5	 **Mary Higgins-Clark's Remember Me** 15:10 - 17:00 | Duration 110 mins 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] Watch Live Save for Me	**5 News at 5** 17:00 - 17:30 | Duration 110 mins International and national news update. [S] Save for Me
itv2	 **The Jeremy Kyle Show** 15:05 - 16:10 | Duration 65 mins Jeremy Kyle deals with more dilemmas, fiery confrontations and topical issues all in front of a studio audience. [S]	 **Real Housewives of Orange County** 16:10 - 17:05 | Duration 65 mins Are You In or Out?: Reality show. The drama intensifies at Heather's opulent party. Brooks instigates an explosive fight between Vicki and

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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 in Video-on-Demand (aka the Problem)

VoD 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

- What is NOT a solution :
  - Multicast : VoD requests are not for the same content at the same time
  - Peer-to-Peer : Limited storage and uplink resources on user devices (peers) – cannot guarantee high QoE for the users

Key Characteristics of Video-on-Demand

- 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
- 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

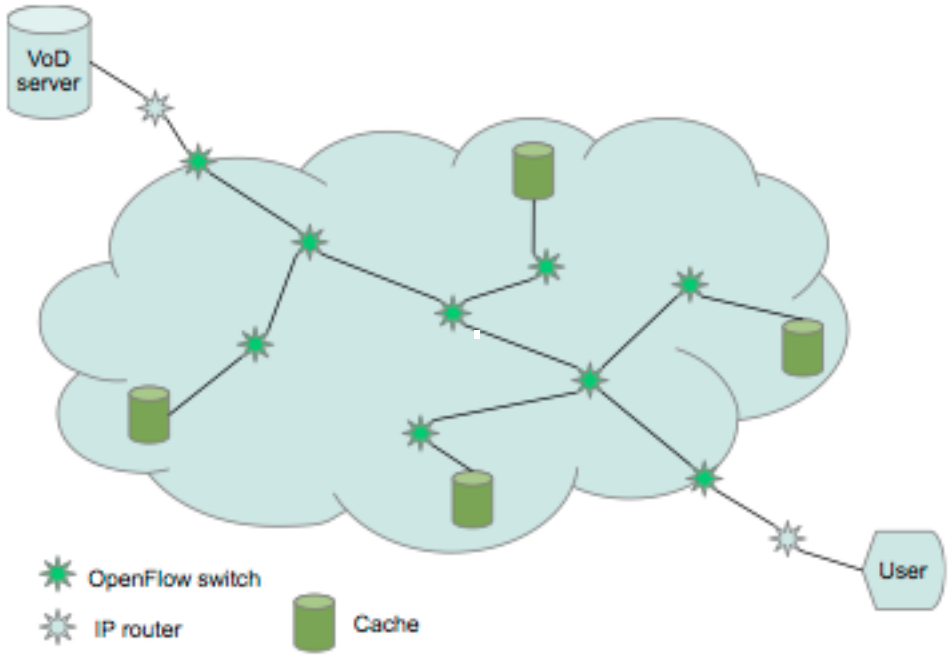
Distance (Server to User)	Network RTT	Typical Packet Loss	Throughput	4GB DVD Download Time
Local: <100 mi.	1.6 ms	0.6%	44 Mbps (high quality HDTV)	12 min.
Regional: 500–1,000 mi.	16 ms	0.7%	4 Mbps (basic HDTV)	2.2 hrs.
Cross-continent: ~3,000 mi.	48 ms	1.0%	1 Mbps (SD TV)	8.2 hrs.
Multi-continent: ~6,000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

Effect of Distance on Throughput and Download Time [1]

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

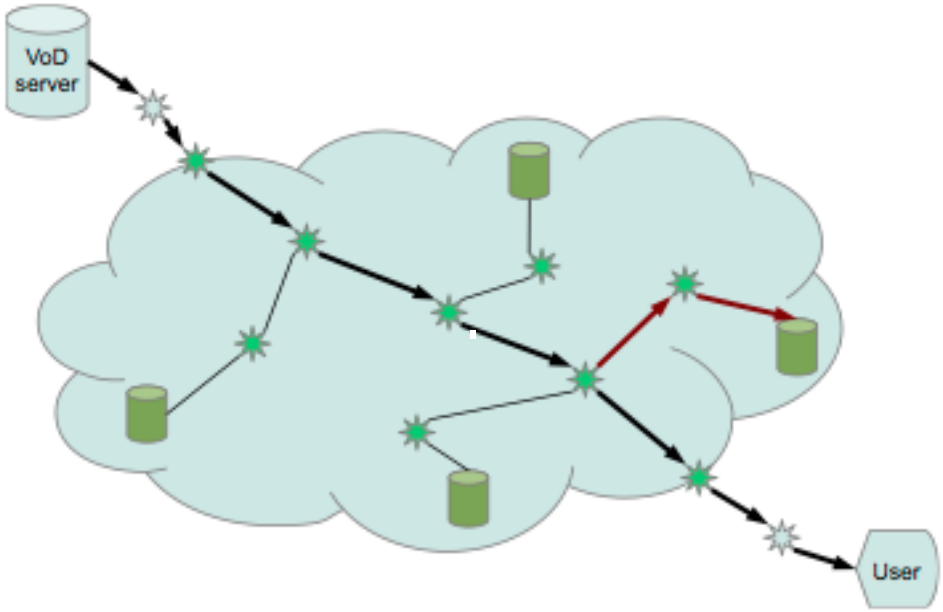
[1] E. Nygren, R. K. Sitaraman, and J. Sun. The Akamai Network: a Platform for High-Performance Internet Applications. SIGOPS Oper. Syst. Rev., 44(3):2–19, 2010.

Video-on-Demand Content Caching with Openflow



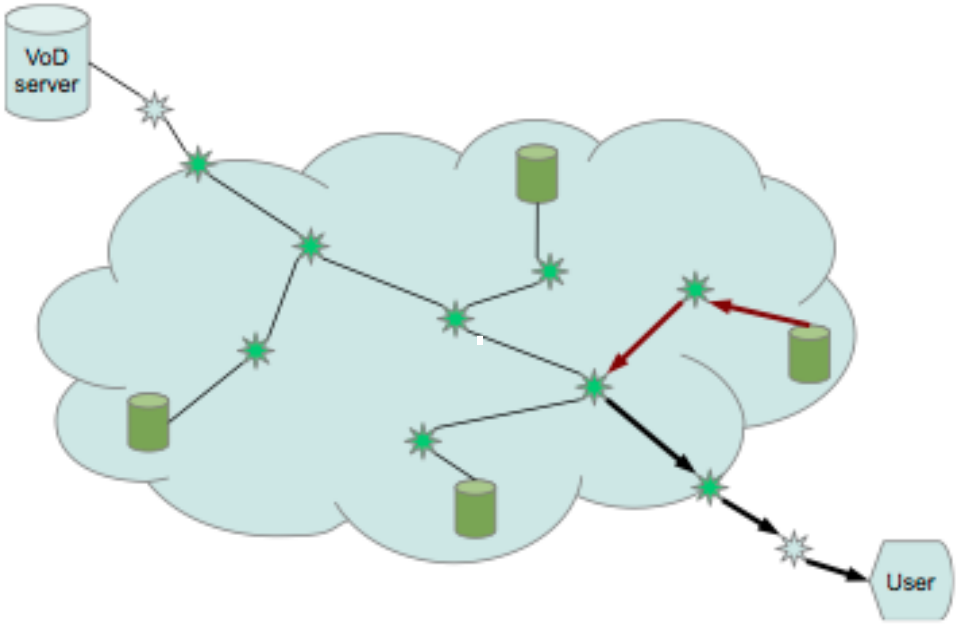
An OpenFlow network with peripheral content caches

Video-on-Demand Content Caching with Openflow



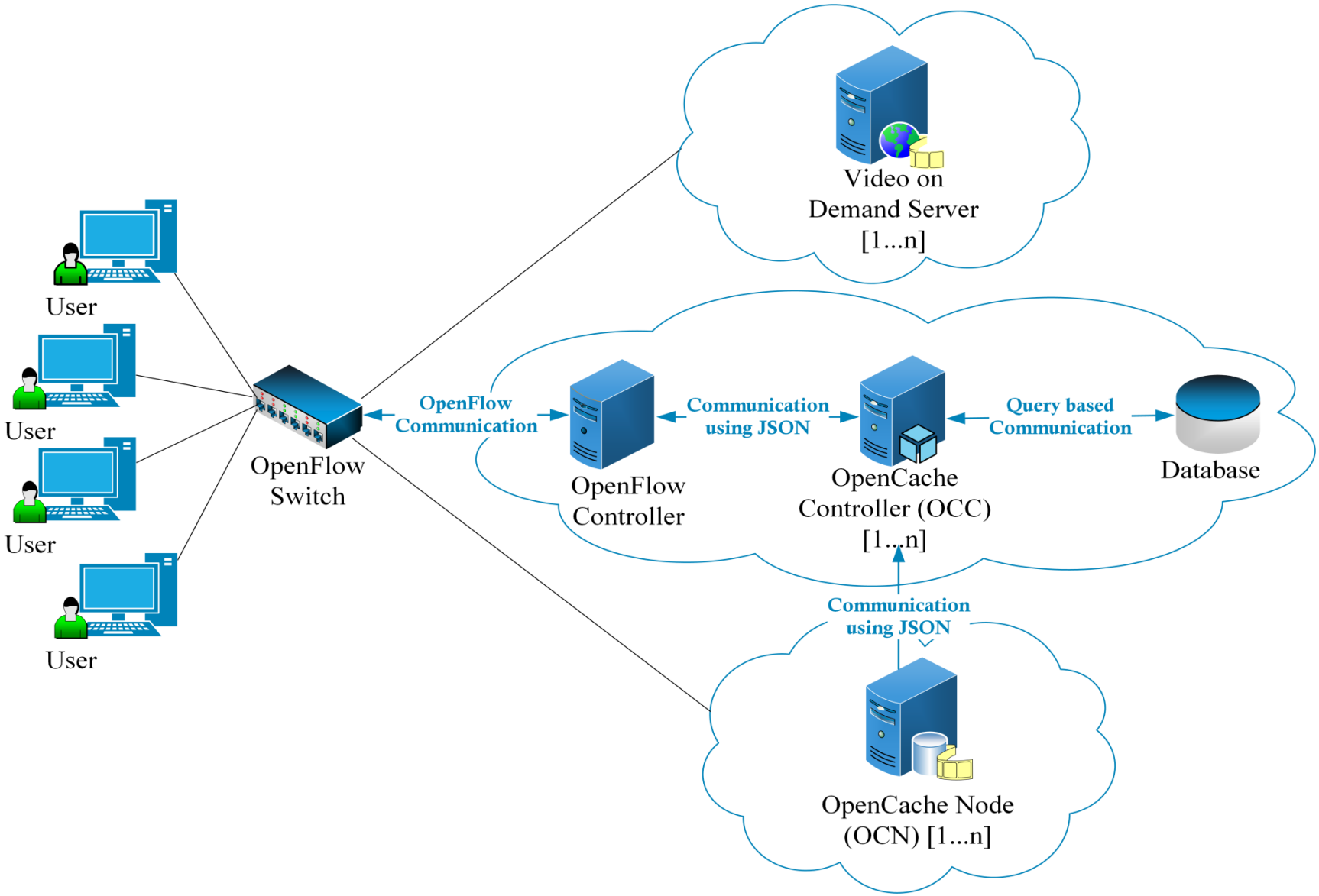
First interaction: Content silently copied to cache

Video-on-Demand Content Caching with Openflow



Later interactions: Content retrieved from cache

OpenCache : OpenFlow-based In-network Caching Service



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

OpenFlow Switch

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

Video on Demand Server

- 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 OCC

OpenFlow 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 (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 version of OpenFlow)

METHOD	PARAMETERS	RESULT
start-expr	{ "expr" : <expr> }	<boolean>
stop-expr	{ "expr" : <expr> }	<boolean>
list-expr-all	None	[{'expr': <expr>, 'port': <port>}, ...]

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

OpenCache Controller (OCC)

3. Provides a JSON-RPC interface to manage the resources of the available cacl in the network : 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. Manages 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

Database

- **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

OpenCache Node (OCN)

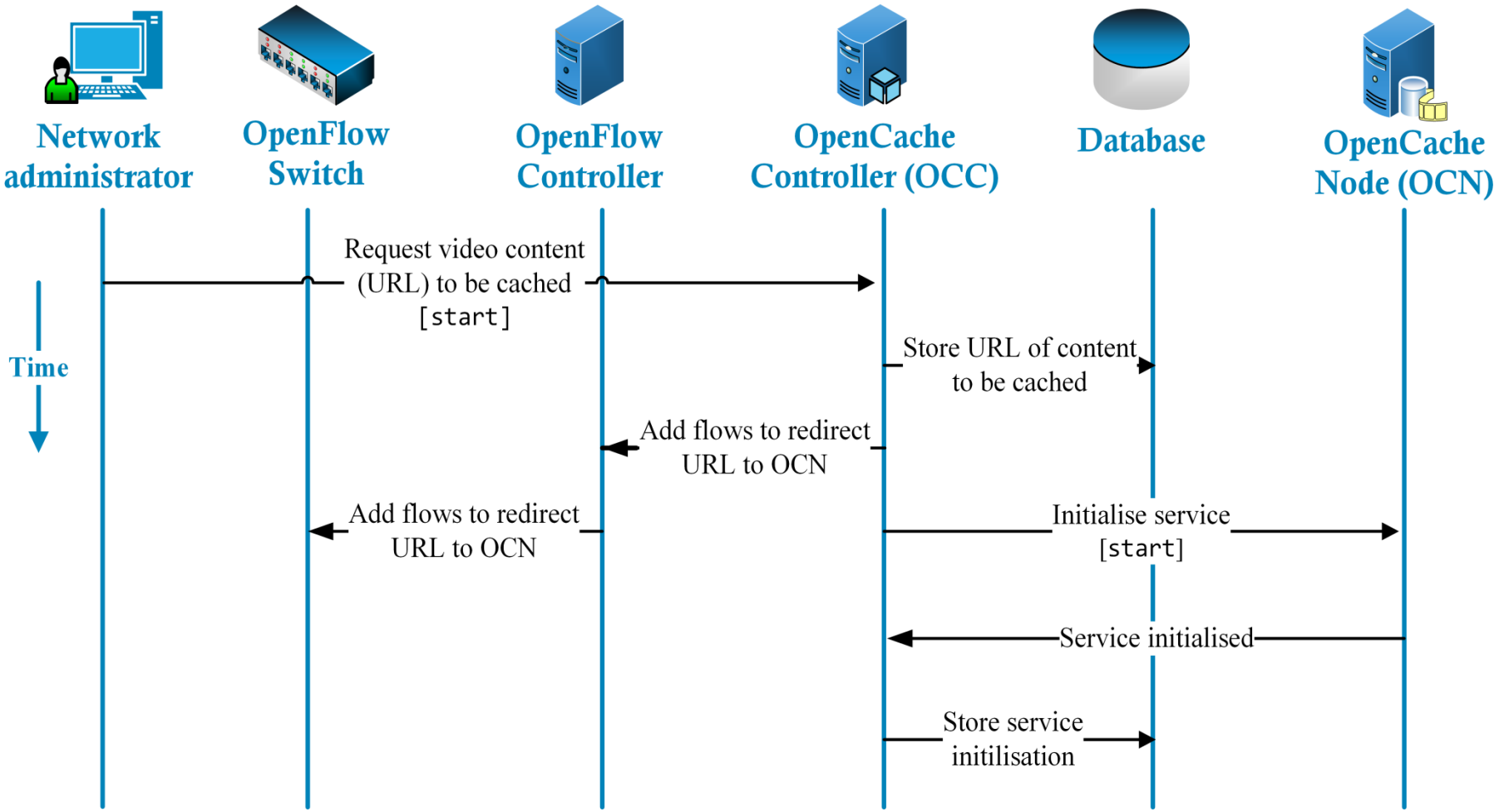
OpenCache Supports Three Essential Operations

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

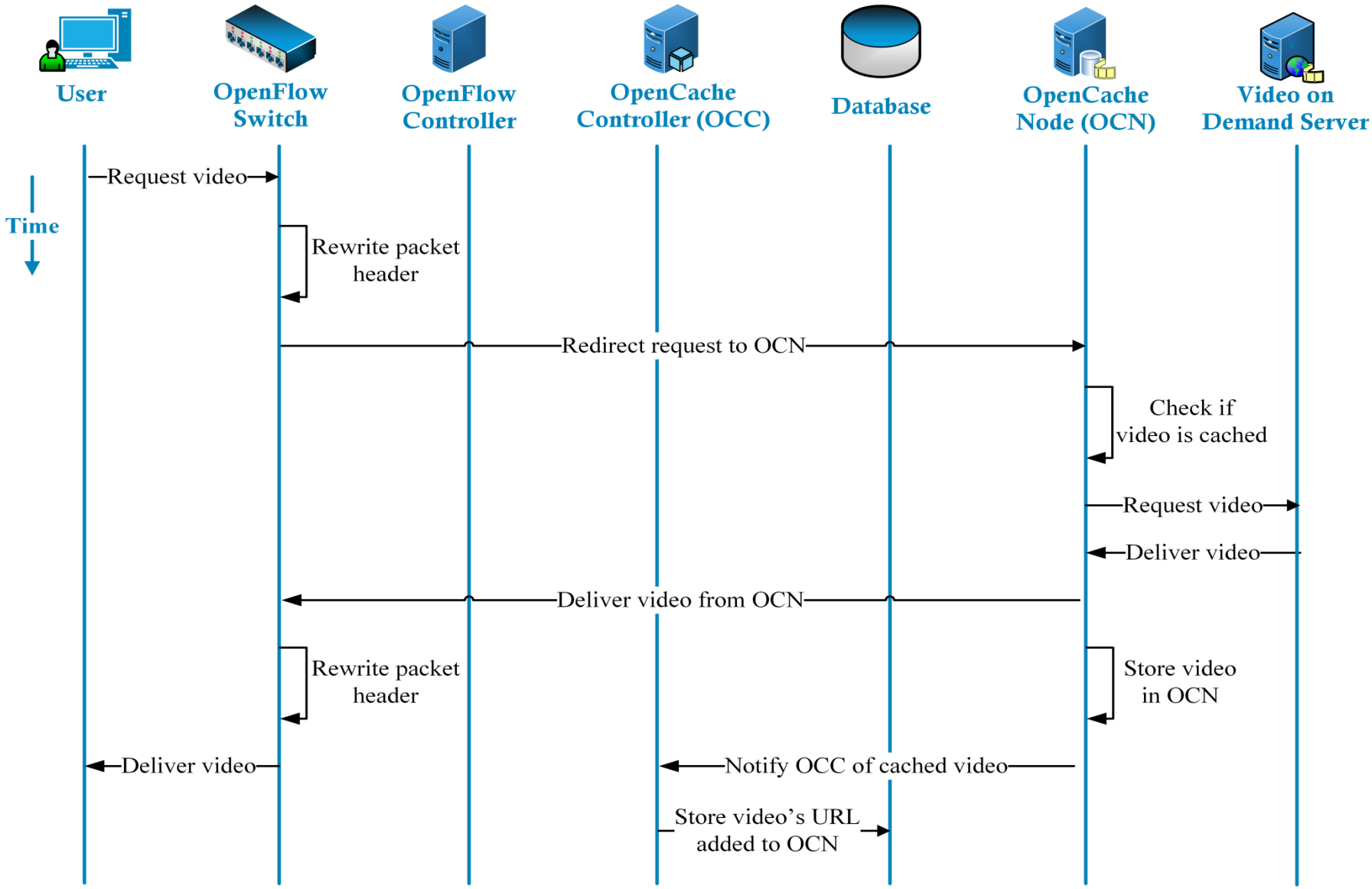
2. Serve user requests for content that has not been cached yet (**cache-miss**)
   - Fetch content, serve user and cache content for future use

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

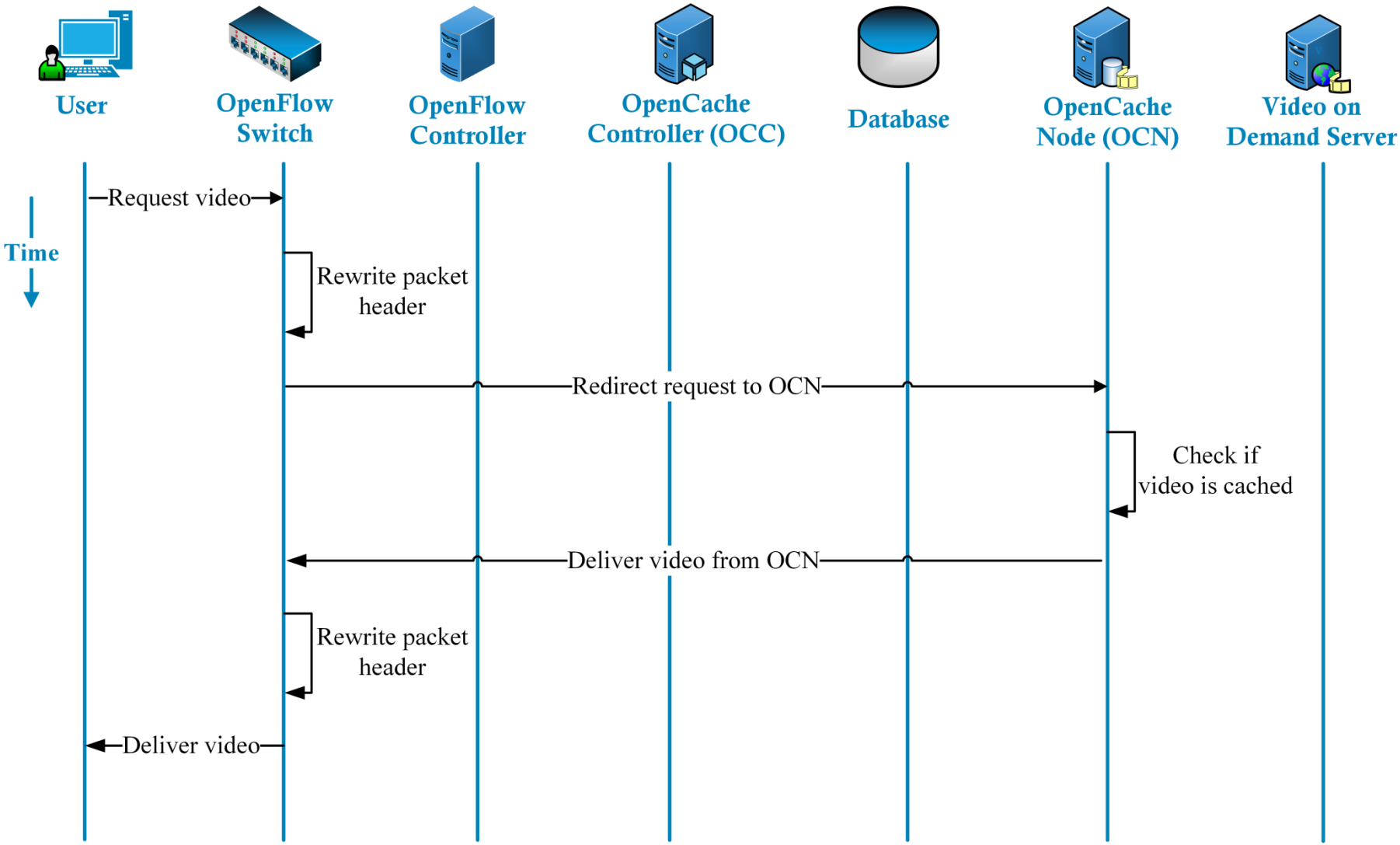
Handle Requests for Content to be Cached



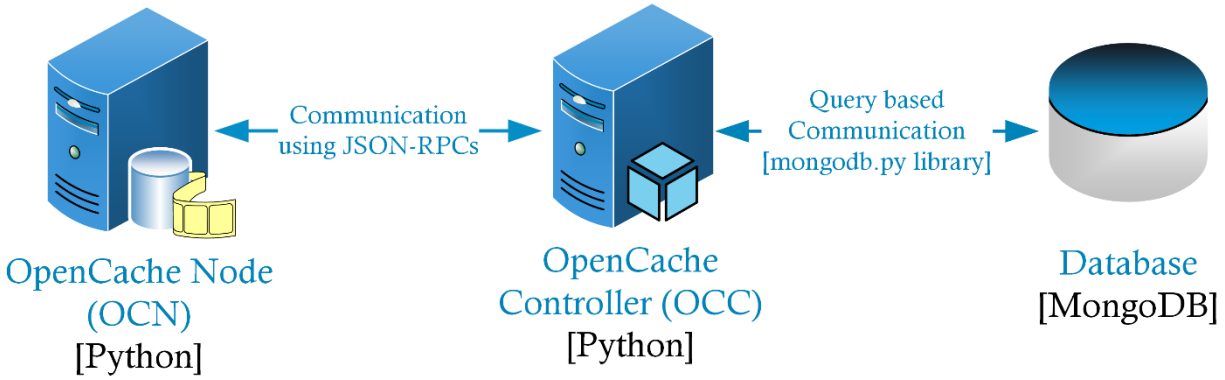
Serve User Requests for Content that has not been Cached yet (cache-miss)



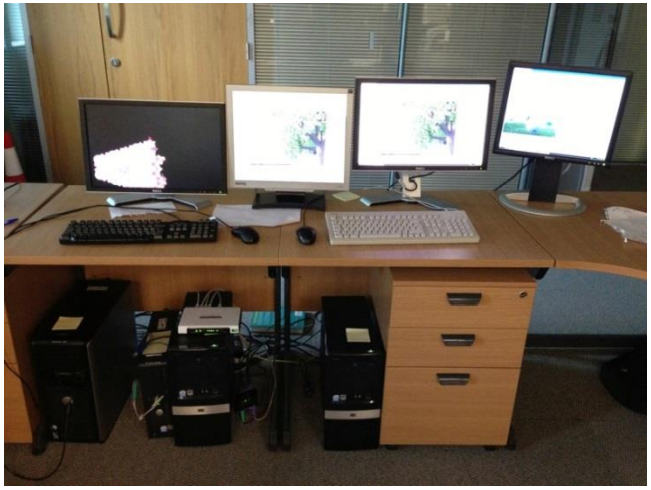
Serve User Requests for Content that is in the Network's Cache (cache-hit)



Implementation



- Python based Implementation : using MongoDB, Floodlight Controller
- OpenCache is open-source and available at https://github.com/broadbent/opencache
- Using MPEG-DASH for video content: Dynamic Adaptive video streaming over HTTP
  - Adaptive to network bandwidth
  - Chunked media facilitates swapping between bitrates
  - Can be delivered using conventional HTTP servers
  - Standardised & Industry-support

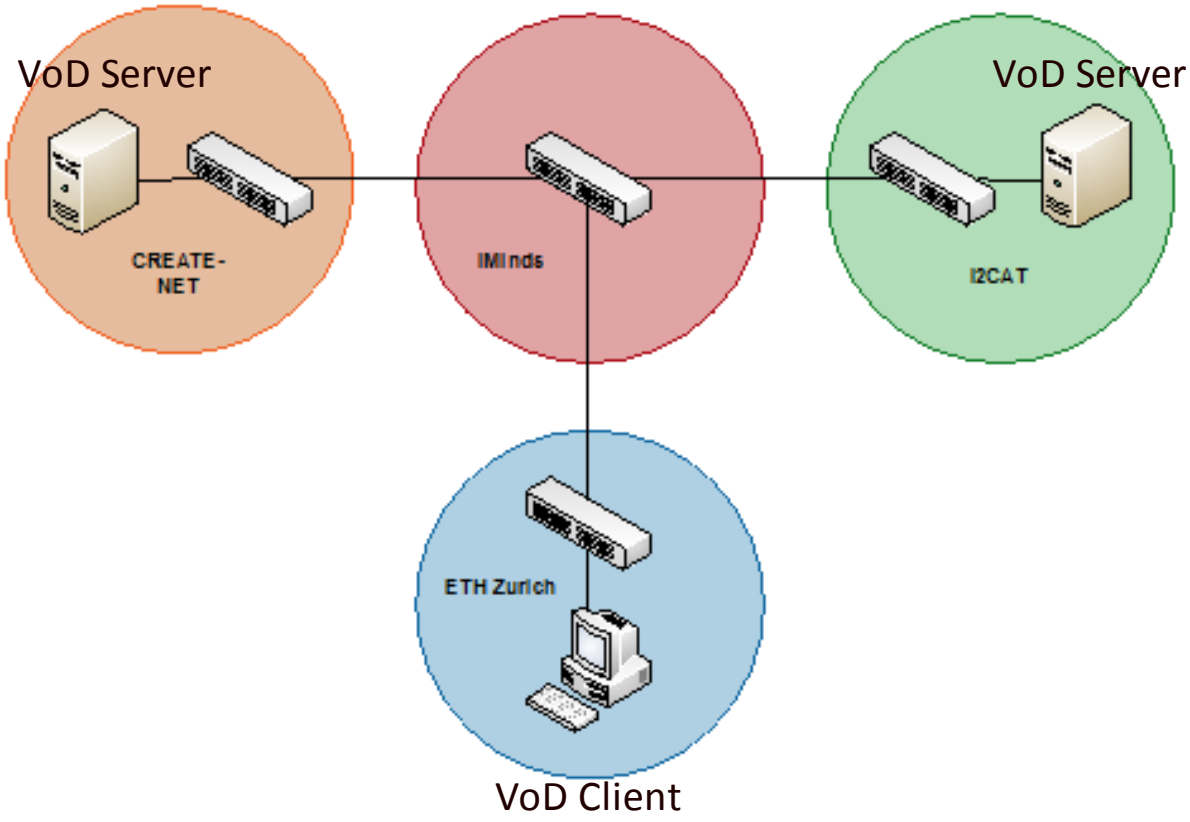


Evaluation on the OFELIA testbed

- **Topology :** Deployed OpenCache on three OFELIA islands distributed geographically
  - Switzerland : ETH Zurich
  - Italy : Create-NET
  - Spain : i2CAT

- Over 120 inter-island (federated) experiments over the OFELIA testbed

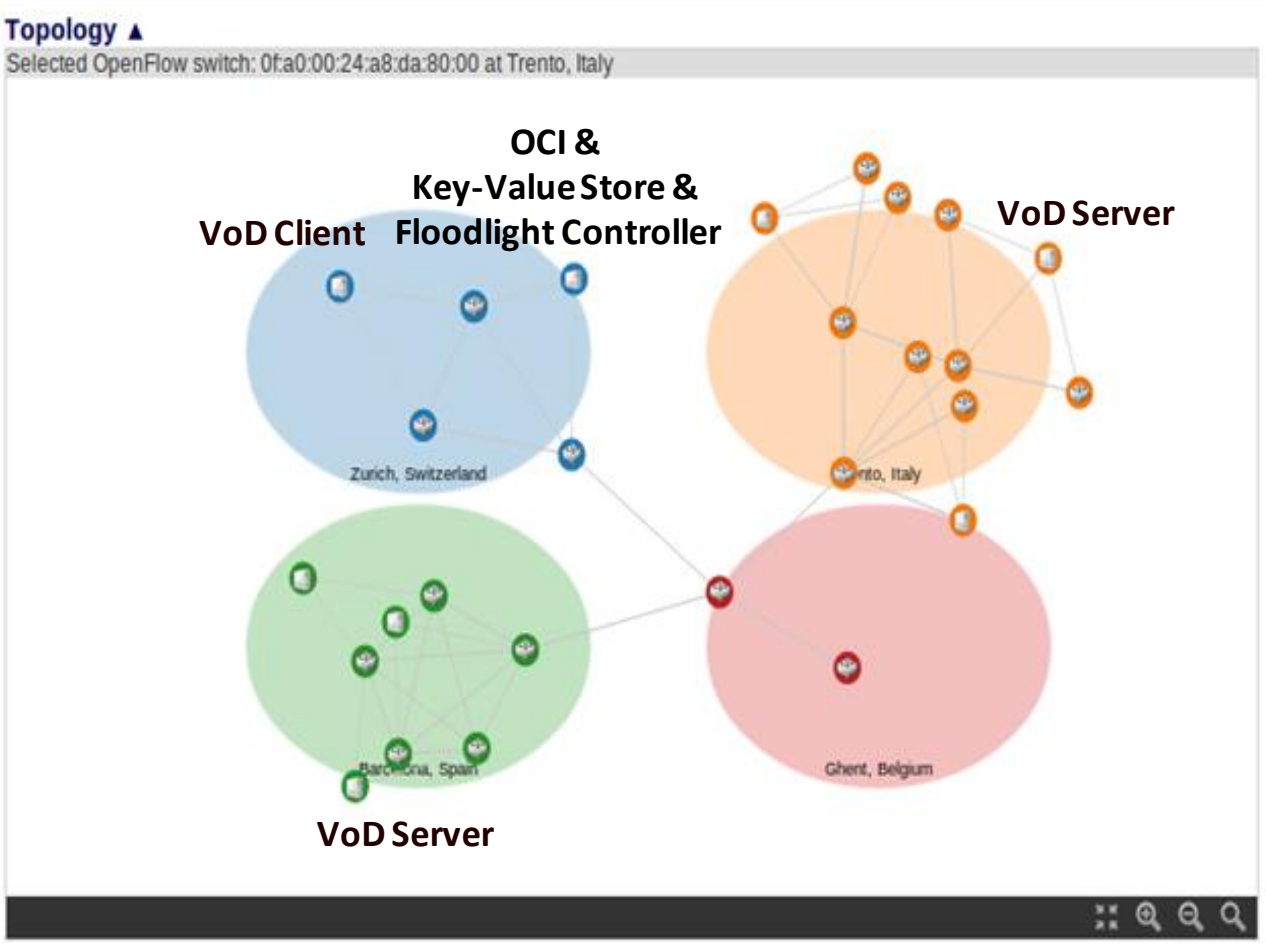
Conceptual Evaluation Setup



Evaluation on the OFELIA testbed

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

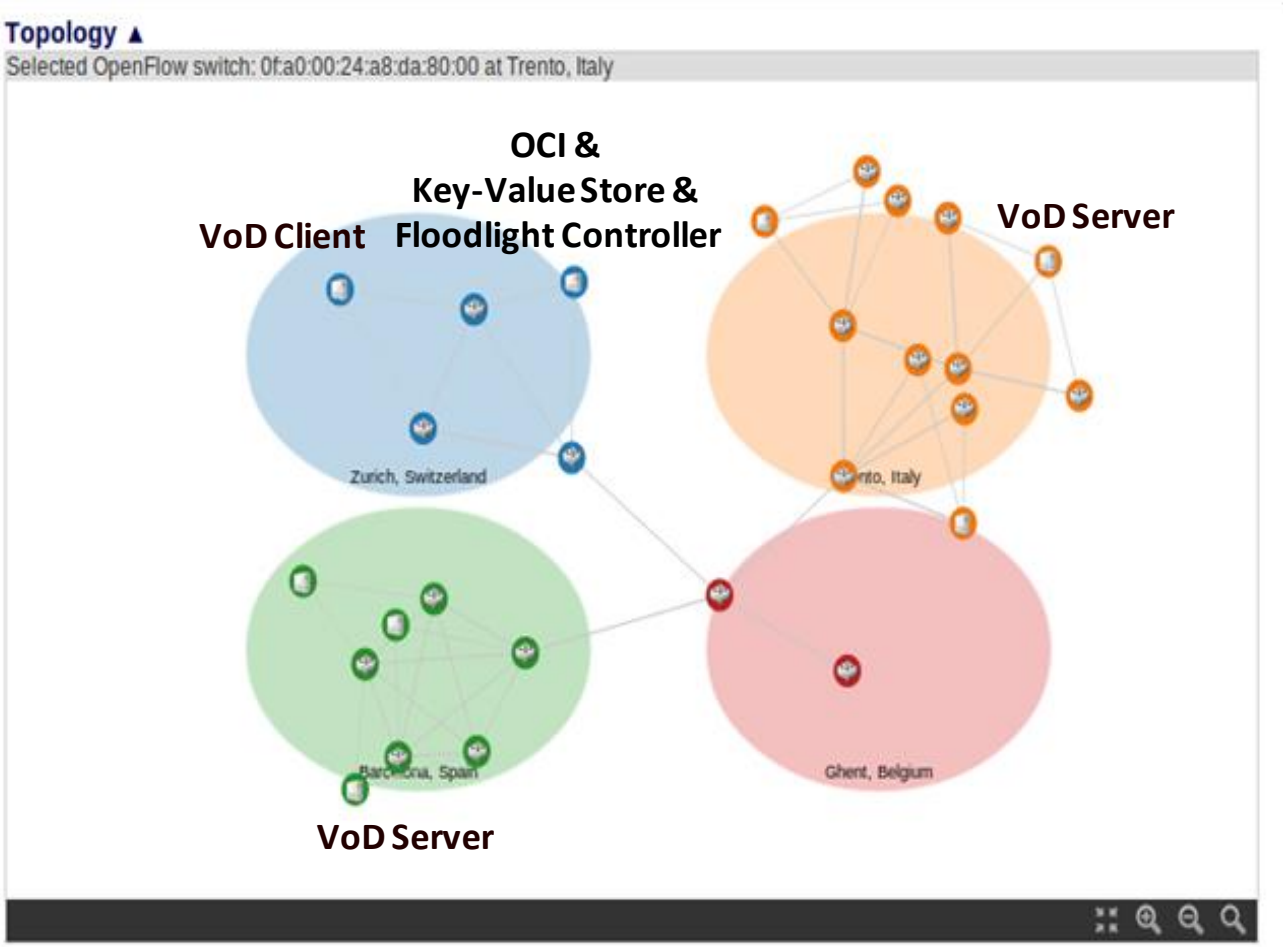
Evaluation Setup on Expedient



Evaluation on the OFELIA testbed

- **Evaluation Criteria** :
  - Startup delay (QoE metric)
  - External link network utilisation (content fetched from cache)
  - Caching hits/miss

Evaluation Setup on Expedient



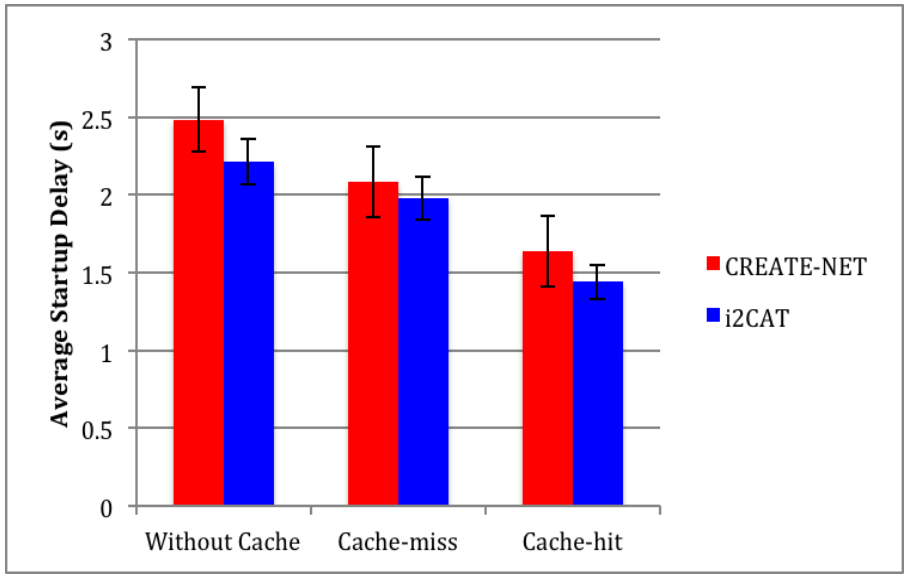
Results

	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

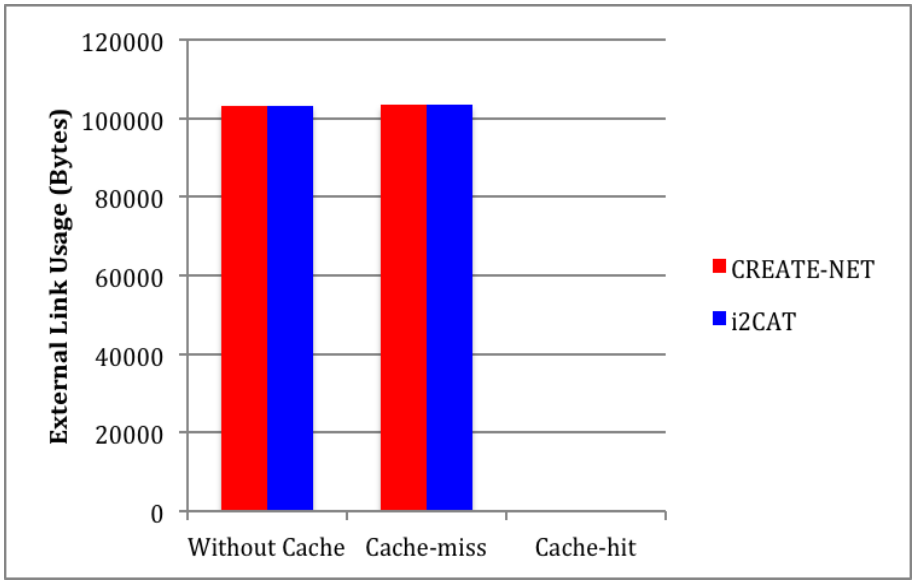
- **Key results :**
  - In tests over both islands we **reduced the startup delay** up to **35% -> increased QoE for end-user**
  - External **link utilisation reduced to virtually zero** (only background traffic remained)
    - Indicatively, the full streaming of our ~10min video saved ~100MBytes for 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 where packet processing will take place on the hardware path

Advantages of OpenCache

Demonstrated OpenCache at INFOCOM 2014

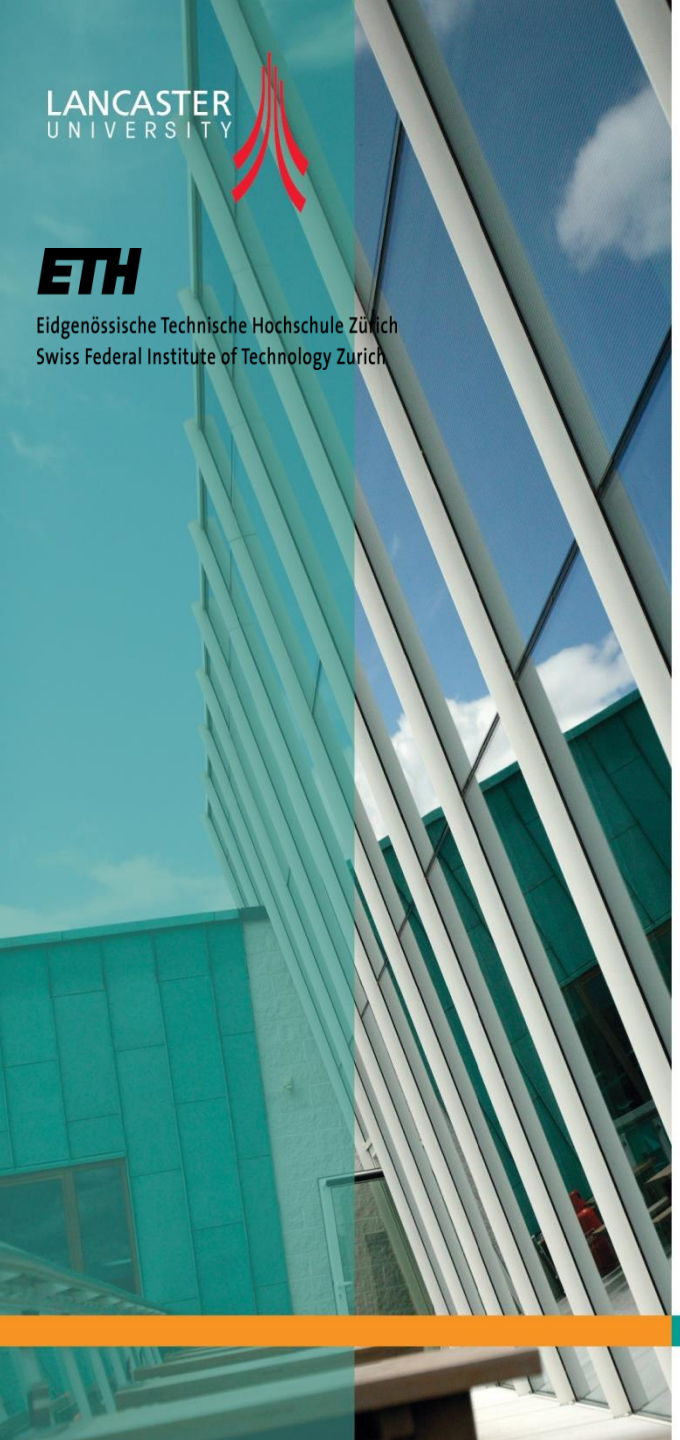
1. Provides an **interface for cacheable content** in an "**open**", **highly-configurable, controllable** and **flexible** manner ≈ *cache as a service*

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

3. **Easily deployable in a production network** : the underlying delivery video mechanism will remain the same in an OpenFlow network (existing hardware and software can be retained, no fundamental changes in service)

4. 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, smaller buffering times and higher video quality as content is now located locally



Live Video Traffic

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

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.

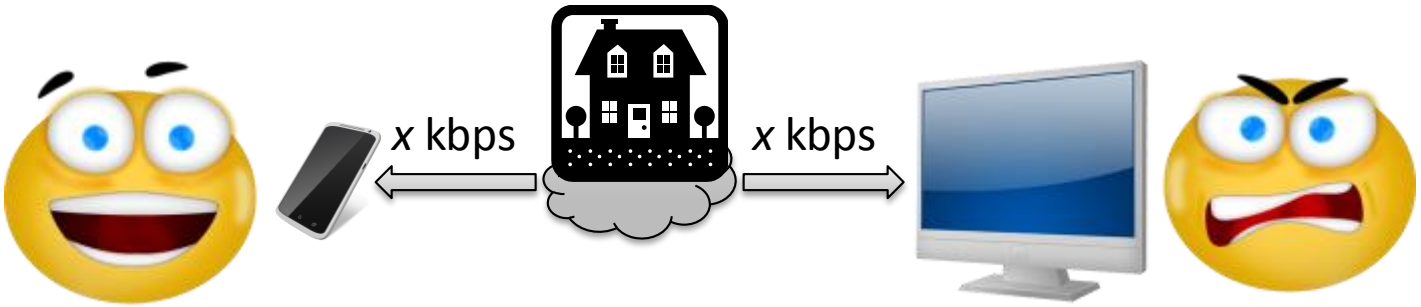
The Problem

- 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

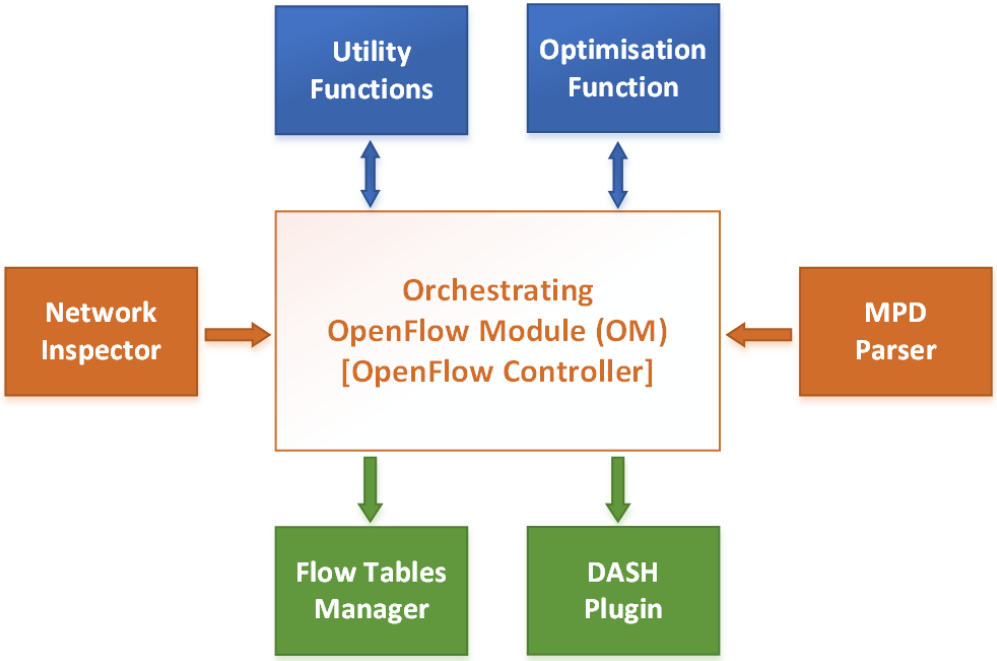
- Split available bandwidth to current users on the network ?

- 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

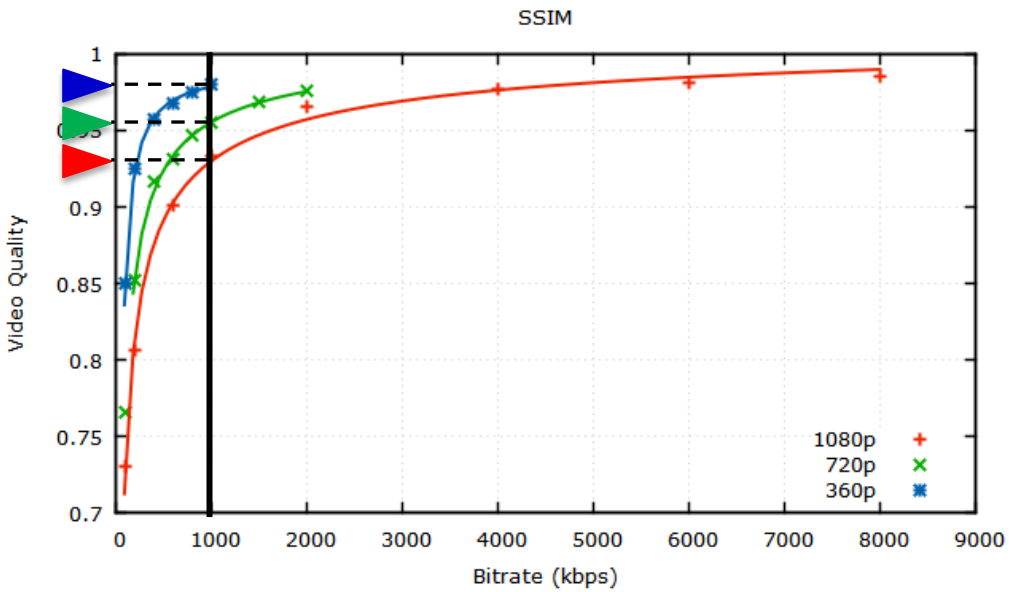


QFF's Core Intelligence : Utility Function

- 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

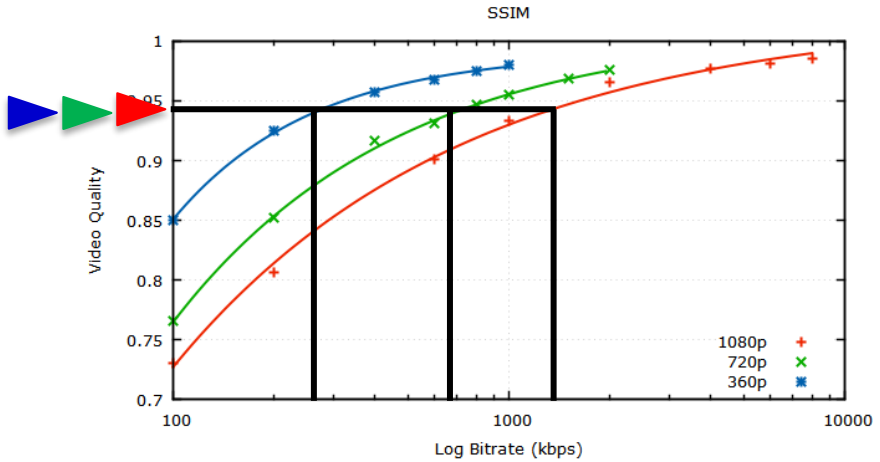
- Utility Function proved that :
  - Relationship between bitrate and perceptual quality is not linear
  - Equal division of bandwidth between different resolutions results in QoE unfairness



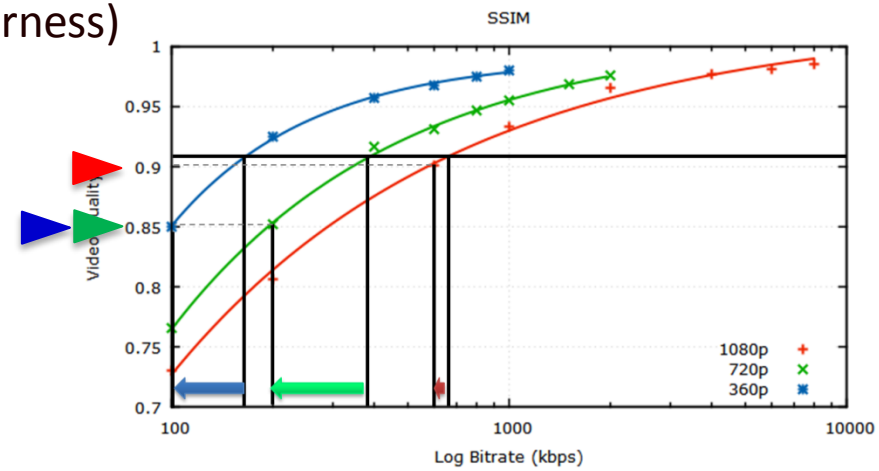
Scatter Plot and Derived Utility Function

QFF's 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

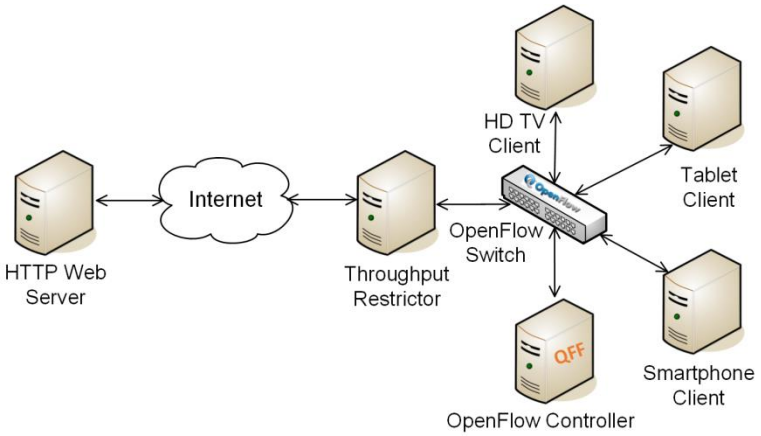


- Implemented branch and bound optimisation algorithm that downgrade all clients to the maximum feasible bitrate (max-min fairness)
  - Very modest computational overhead < 0.3sec for optimising 100 Utility Functions with 10 different bitrates each

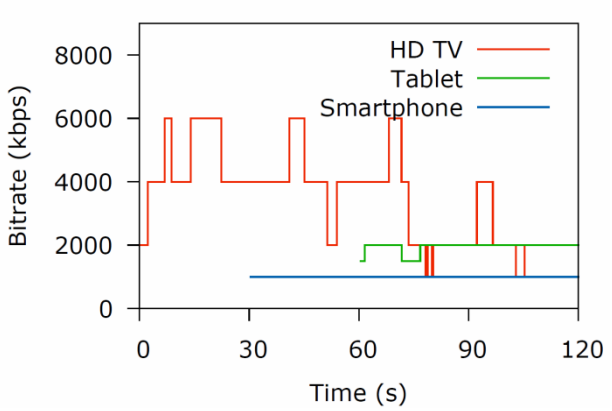


Proof-of-concept Evaluation

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



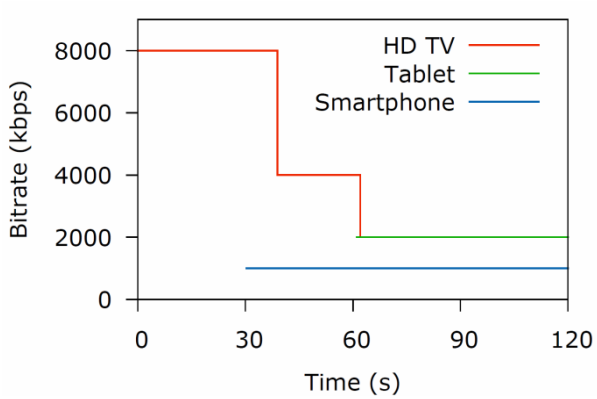
DASH-JS



Network instability :

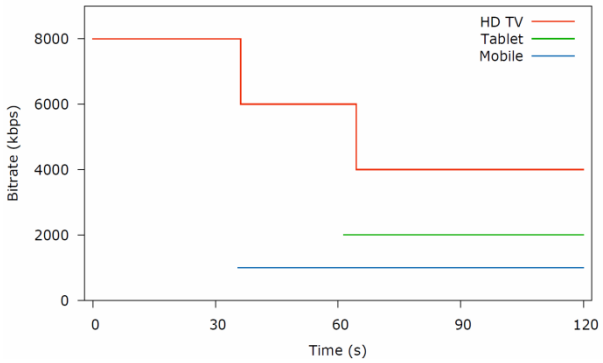
Bitrate changes : 18-31 (av.23)

EQUAL B/W (control)



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

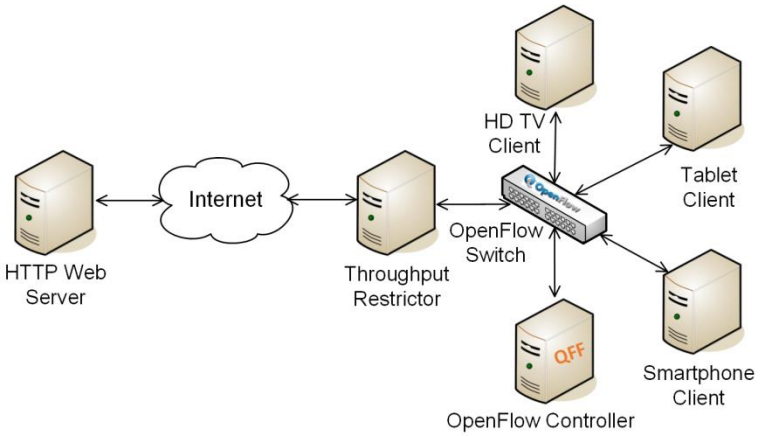
QFF



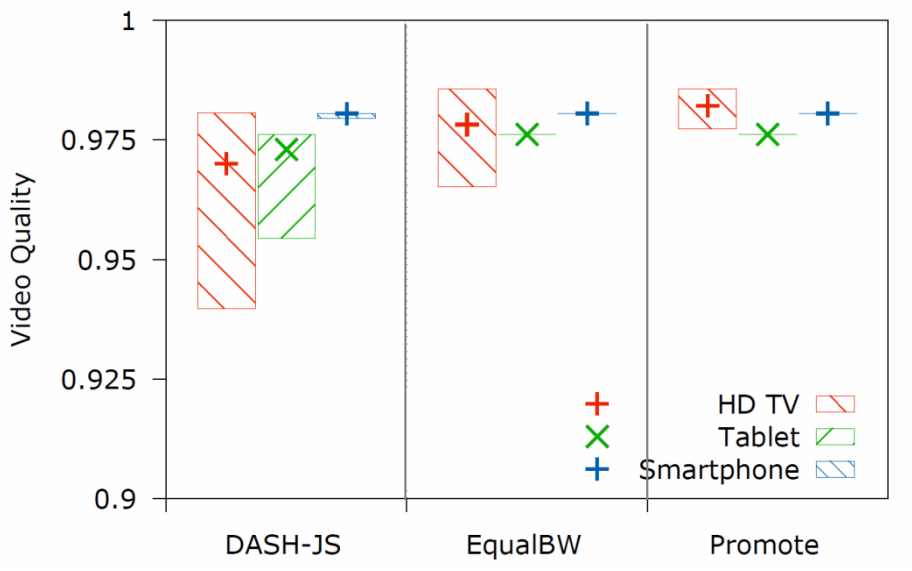
Network stability & QoE fairness across devices

Proof-of-concept Evaluation

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



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



Mean and variance of QoE

Summary

Theme : How can we leverage SDN for Video Content Distribution

- Aims to optimise network utilization and increase user's QoE by reducing start up and buffering times and increasing video quality levels

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

VoD Traffic Benefits Network and Users

- 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

OpenFlow-assisted QoE Fairness Framework (QFF)

Live Video Traffic Benefits Users

Thanks!

Questions?

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