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A Context-Adaptive Content Ecosystem Under Uncertainty (CONCERT)

Topic: Context- and Content-aware, Communication Networks (C3N)

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concert

Project start date: 1st January 2014

Outline

- Scientific background
- Key challenges and potential impact of the project
- Project consortium
- Main scientific results, dissemination and other output
- Sustainability/valorisation

Scientific Background

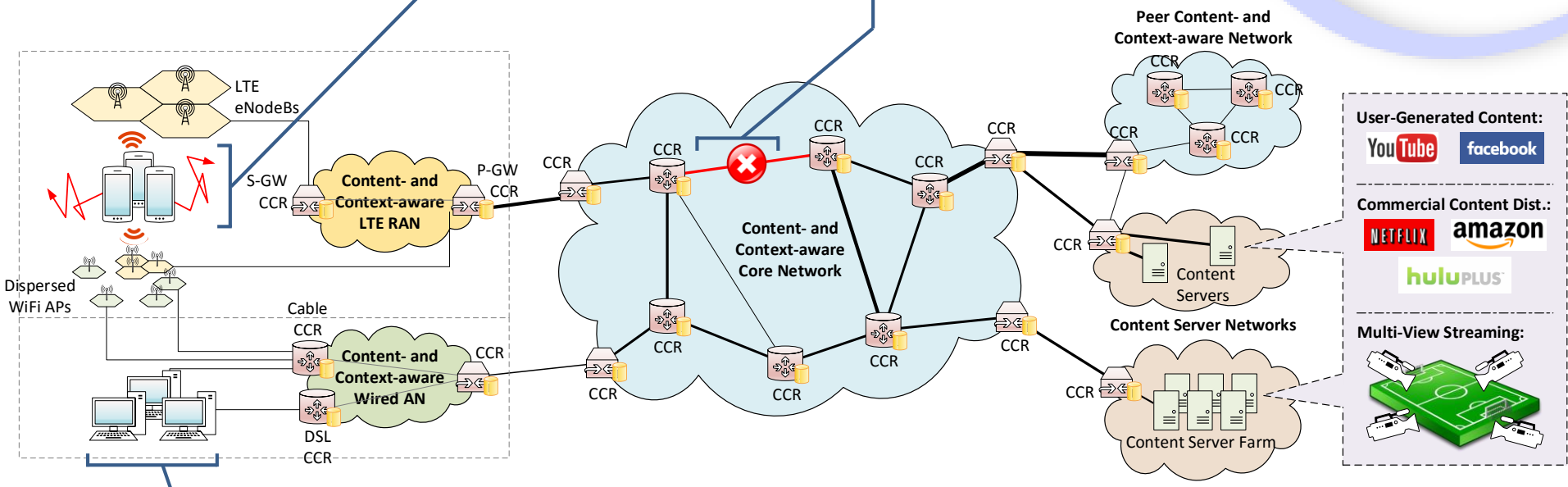
- Heterogeneity of content ecosystem
  - Increasing content volume and formats
  - Diverse user requirements
  - Dynamic and varied network capabilities and operating conditions
  - Increasing number of connected devices with different constraints
  - Emerging service and applications
- Internet **NOT** designed to operate in such conditions and for such purposes.

Overall objective: to devise and evaluate a context-aware content ecosystem to holistically manage and exploit uncertainties in future, dynamic, content-oriented network environments.

- This ecosystem will be based on information-centric networking (ICN).
  - Centered on information (*what*) instead of host locations (*where*)
  - Content-based resolution and delivery based on names
  - Support intrinsic in-network content manipulation (data caching/storage and processing)

Scientific Background

Threats:
Network anomalies disrupting content service performance

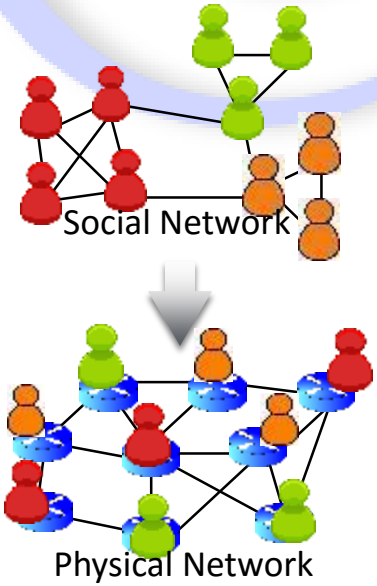


Requirements:
Heterogeneous and changing service requirements by end users

Opportunities:
Exploitation of opportunities for cost reduction or performance enhancements

Uncertainties and Challenges

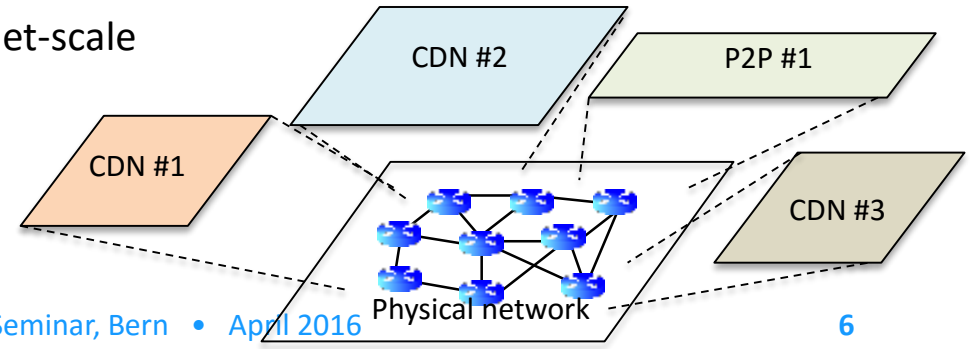
- Scenario #1: User generated content (UGC) on social media
  - Uncertainties
    - User behaviour (user interactivity, sharing and social connections)
    - Content popularity evolution and access patterns (e.g., viral content)
    - User mobility
    - Limitations to access devices



  - Challenges
    - Collection and dissemination of (social) context information
    - Coordination of user connections and video distribution
    - Network adaptivity to users interactivity and social connections
    - Delay tolerant user-generated content (UGC) applications based on UGC pushing
    - Exploiting (mobile) user terminals with caching capabilities to achieve controlled epidemic spray of UGC to interested consumers

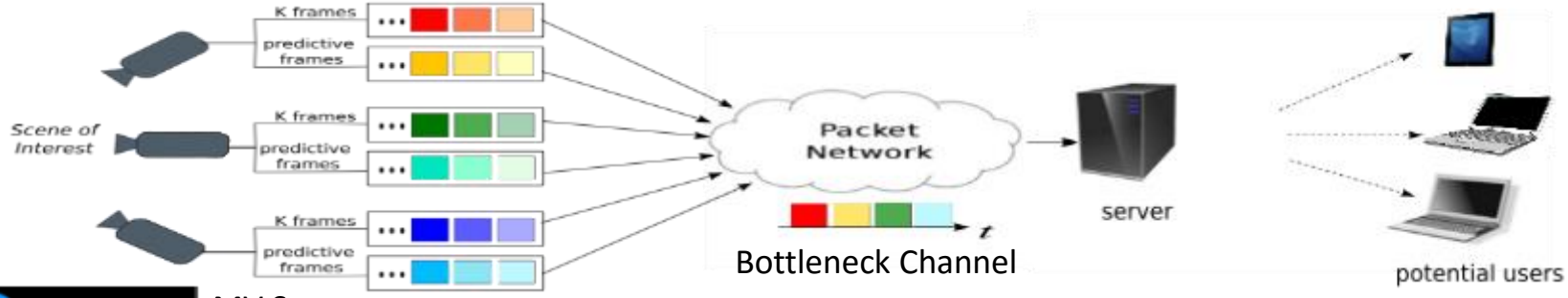
Uncertainties and Challenges

- Scenario #2: Commercial content distribution (COM)
  - Uncertainties
    - User requirements, preferences and mobility
    - Network capability and conditions
    - Content publication and resolution
    - Content popularity evolution and access patterns
    - Content characteristics (VoD, live streaming etc.)
  - Challenges
    - Collection and dissemination of context information
    - Network adaptivity to content access patterns (e.g., flash crowd)
    - On/off-path content caching / adaptation problem
    - On-time delivery of content on Internet-scale



Uncertainties and Challenges

- Scenario #3: Multi-view video Streaming (MV)
  - Uncertainties
    - Source correlation: Sources acquired by multiple cameras are highly correlated but highly varied and evolve over time.
    - Network resources: Limited network resources and variable bandwidth availability
    - User uncertainty: users not passively download content, but dynamically select the content they are interested.
  - Challenges
    - Optimal exploitation of source correlation among neighboring cameras
    - Enabling free-navigation of the 3D scene from the users
    - Modelling of dynamic behavior by properly learning from past requests



Potential Impact

- Collaborations between ICN/networking and multimedia communication research communities
- Theoretical
  - Development of learning strategies for adaptive resource allocation in networks
  - Design of methods for modelling information diffusion in networks in general
- Multimedia and ICN Communications:
  - Development of ICN-based in-network mechanisms with context-awareness
  - Design of adaptive and interactive multimedia systems
  - Development of cost-effective streaming solutions in heterogeneous user populations
  - Multimedia services in ICN networks

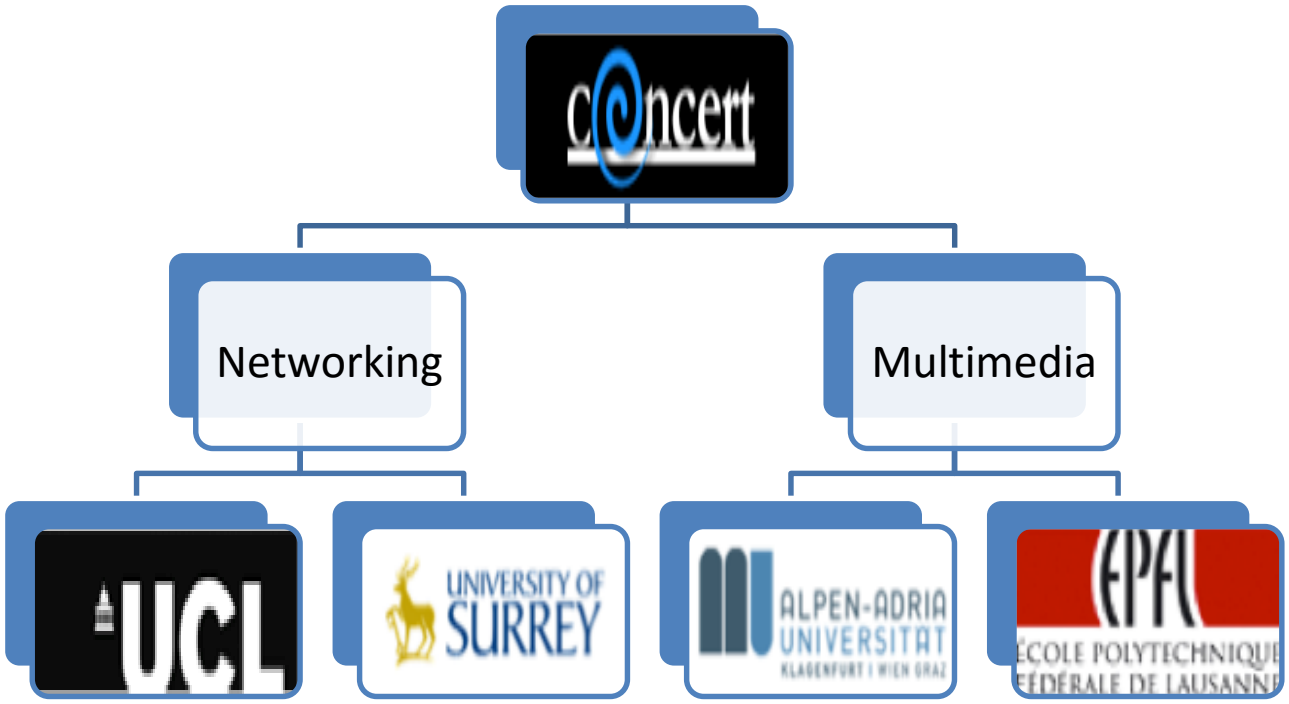
Project Consortium

Project Commencement: **1st January 2014**

Project Duration: **3 years**

Partners	Country	Sponsor
Project Coordinator University College London (UCL) • George Pavlou, Wei Koong Chai	UK	EPSRC
University of Surrey (UniS) • Ning Wang, George Kamel	UK	EPSRC
AAU Klagenfurt (AAU) • Hermann Hellwagner, Benjamin Rainer, Christian Kreuzberger, Daniel Posch	Austria	FWF
École Polytechnique Fédérale de Lausanne (EPFL) • Pascal Frossard, Laura Toni	Switzerland	SNSF

Partners' Background



Partners' Background

UCL:

- Information-centric networking (ICN)
- Information/Content caching and dissemination
- Service differentiation and Quality of Service (QoS)
- Network and service management
- Epidemic theory

AAU:

- Video content adaptation in distributed multimedia systems
- Event detection using machine learning / data mining techniques
- Active contributor to multimedia content standards (e.g., MPEG-21, MPEG-DASH)
- Multimedia communication and networking

UniS:

- Content and Information-centric networking
- Routing and Quality of Service
- Virtual and overlay networks
- Mobile networking technologies

EPFL:

- Image coding and communications
- Network coding for video streaming
- Adaptive multimedia streaming
- Distributed content delivery systems

Main Scientific Results

- A universal **path-based information spreading** modelling framework
- Feasibility study of **Internet-wide content name resolution** systems
- **Location-independent** context dissemination and content resolution strategy for ICN
- **Stochastic Adaptive Forwarding (SAF)** strategy for Interests in **Named Data Networks (NDN)**
- Performance analyses and upper bounds for **multimedia streaming performance in NDN** using **dynamic adaptive streaming,** considering different Interest forwarding and content caching strategies

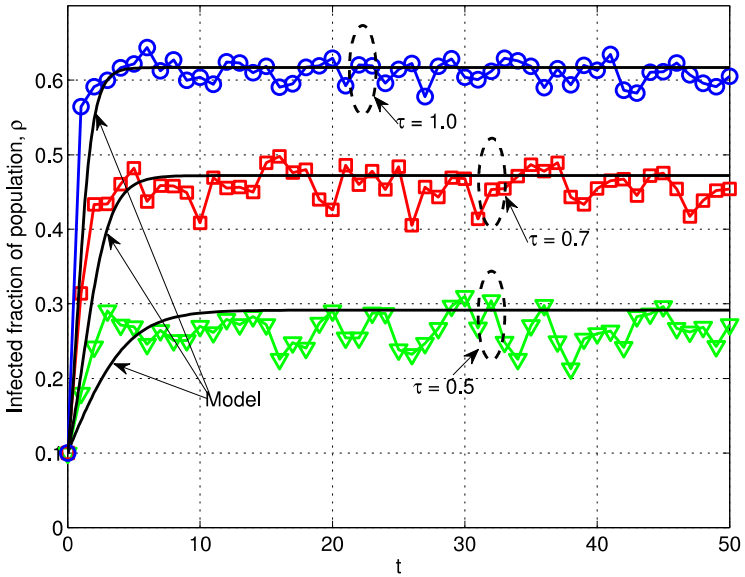
Main Scientific Results (cont'd)

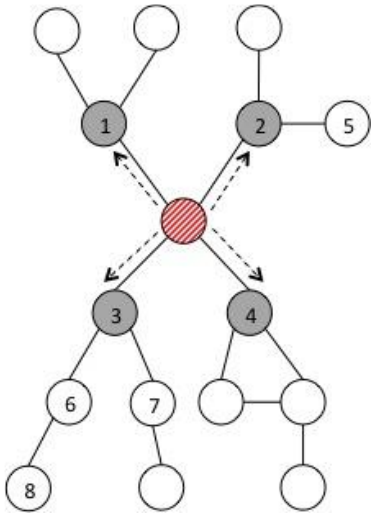
- Adaptation and scheduling strategy for **simultaneous multi-RAT video streaming**
- Optimal design of context-aware multi-players distributed transmission strategies
- **Learning adaptation logic for DASH** systems to adapt each agent's video requests to the perceived context and predict ecosystem dynamics
- Optimization algorithm for organizing the source in MV streaming when sent to multiple and heterogeneous players
- **In-network multiview processing** that adapts to the context to obviate for ecosystems with limited network resources
- Low-cost **ICN testbed** using Banana Pi routers

Path-based Information Spreading

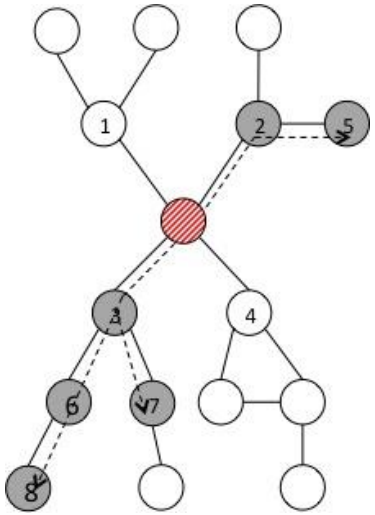
A novel universal **path-based information spreading** modelling framework.

- Considers: routing protocol, traffic intensity and distribution and network topology
- Identification of an epidemic survival threshold, $\tau_c = \frac{\beta}{\delta} \leq \frac{1}{\mu^C_{max}}$
  - *C* is the **infection characterization matrix**





Contact-based

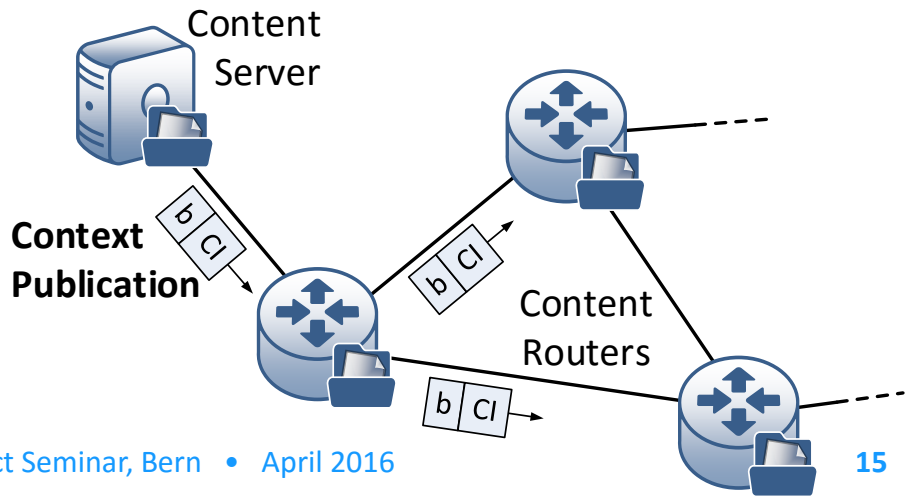


Path-based

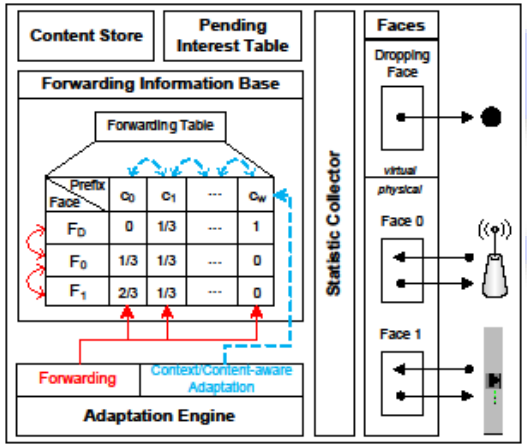
Initial infected node
Susceptible nodes

Context Dissemination and Content Resolution Strategy for ICN

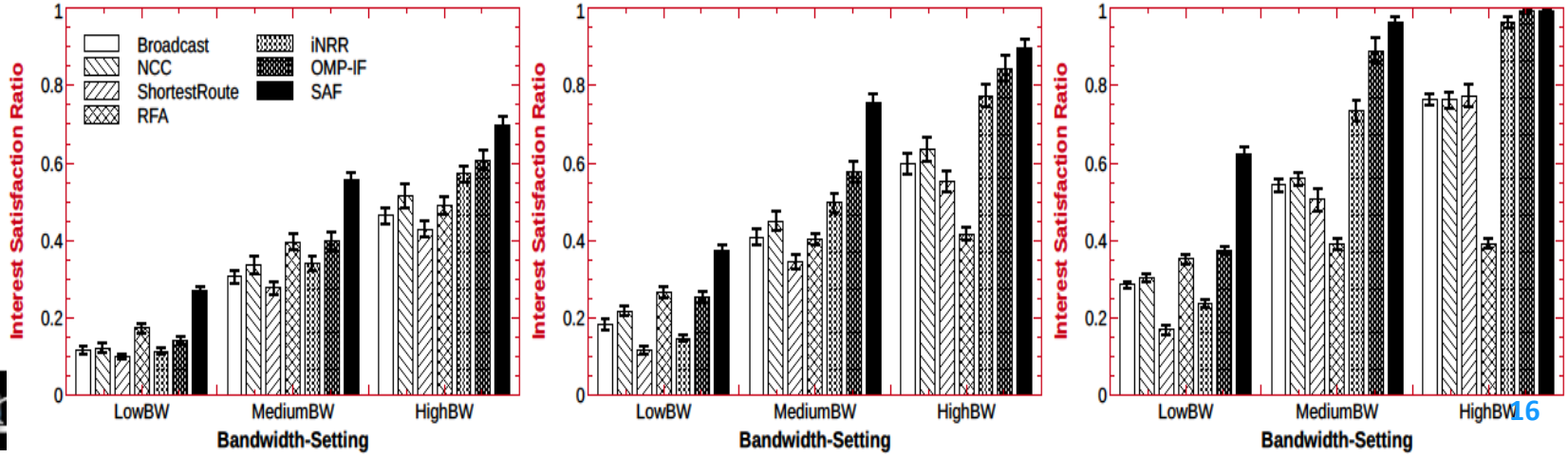
- Novel Bloom-filter-based scheme to disseminate context information associated directly to content
  - Host information not exposed to the network
  - Some support for in-network cached content
- Scheme increases the balance of load across links and improves the cache hit ratio compared to the host-based approach



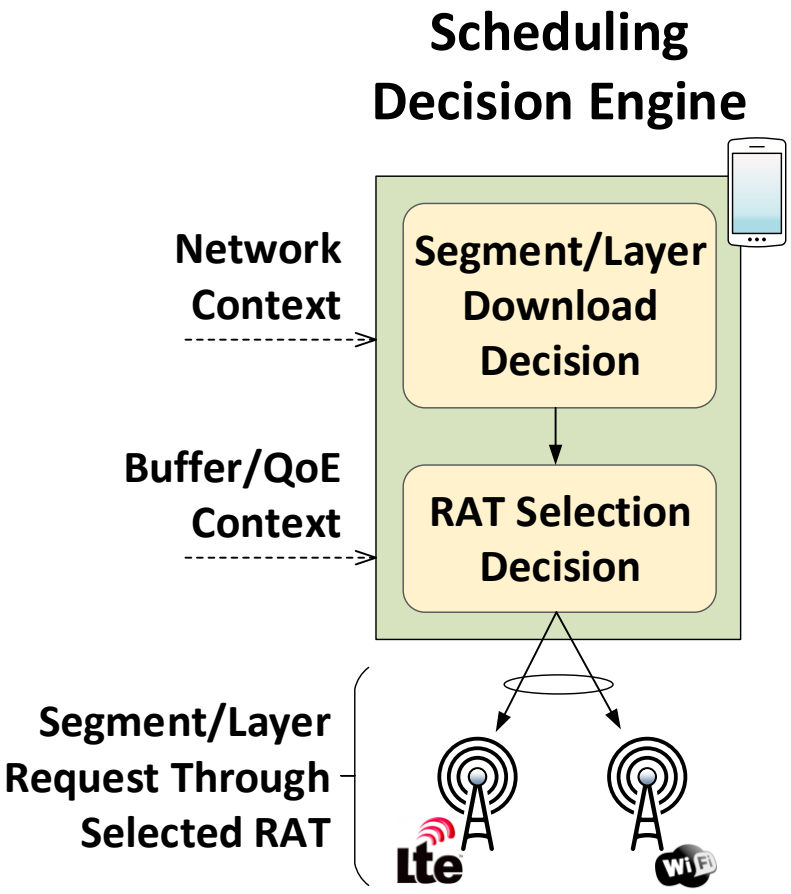
Stochastic Adaptive Forwarding (SAF)



- Novel strategy to forward Interest packets in NDN
- NDN router learns network status upstream (i.e., builds context) by observing Data packets that return/do not return in response to Interests
- Router forwards further Interests probabilistically on promising path(s) based on these findings
- Exploits multi-path transmission in NDN and circumvents potential congestion and link failures
- In most cases outperforms other forwarding strategies



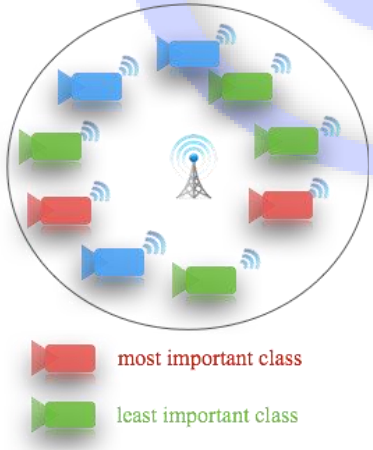
Multi-RAT Video Streaming



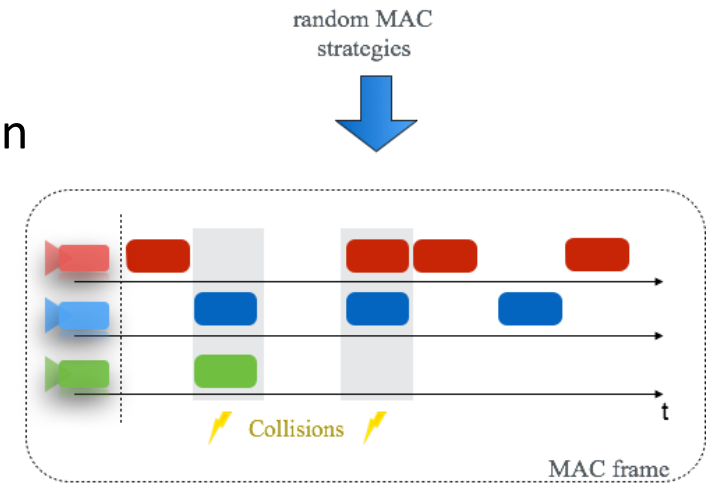
- Novel adaptation and scheduling strategy for concurrent multi-RAT streaming to benefit from combined network resources
  - Increases video quality and quality stability
  - Reduces buffer stalling
  - Improves network efficiency
- Takes both network and buffer context into account

Context-aware multi-players distributed transmission strategies.

Context-aware multi-players transmission schemes able to adapt to the experienced state of the ecosystem.



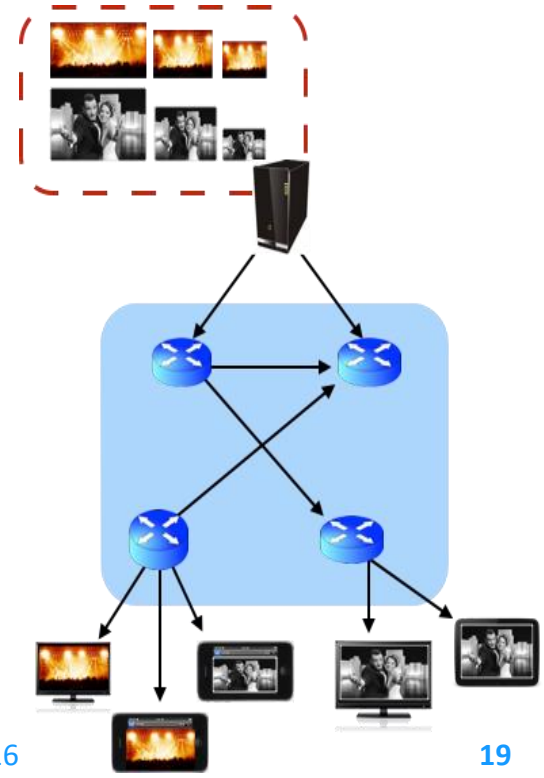
- Novel adaptive scheme to optimize **prioritized transmission strategies** for **large-scale ecosystems.**
- **Theoretical study** of the collision recovery probability for multi-class of players used then in the transmission scheme optimization.
- **Heuristic solving method** able to reach performance close to the optimal ones.



Learning adaptation logic for DASH systems

Adaptation logic for adaptive streaming that **learns** each agent's video best request based on both the **perceived context and the predicted ecosystem dynamics.**

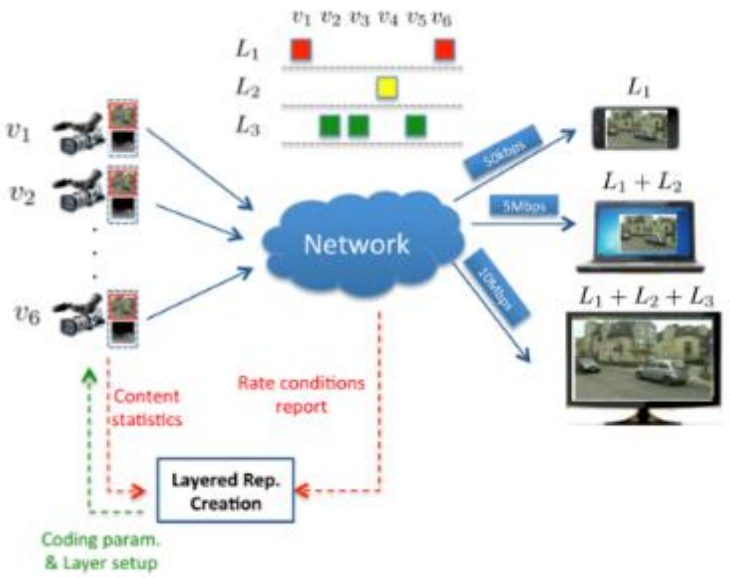
- Novel **reinforcement learning-based DASH** controller for each agent video requests aimed at optimizing both the **quality** and the **quality fluctuations.**
- Novel learning algorithm is implemented to **speed-up the learning process** without losing in accuracy
- Performance **results for different ecosystem dynamics** to validate the proposed learning system.



Context-Aware In-Network Multiview Processing

Novel adaptive **layered multiview representation** for progressive transmissions in multi-player heterogeneous ecosystem

- **Novel problem formulation** to optimally organize the source content into layered subsets that **obviate for context uncertainty and heterogeneity.**
- **Optimal and sub-optimal** (at a reduced computational complexity) solving methods **based on dynamic-programming**.
- Evaluation of the **gain of the layered structure** compared to a baseline algorithms

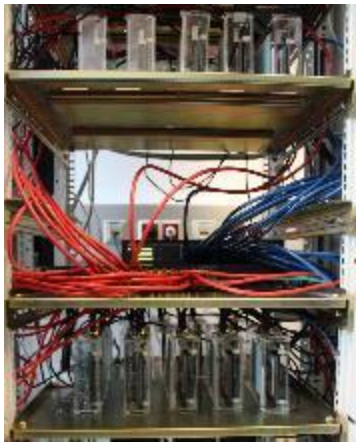


Context-Aware In-Network Multiview Processing

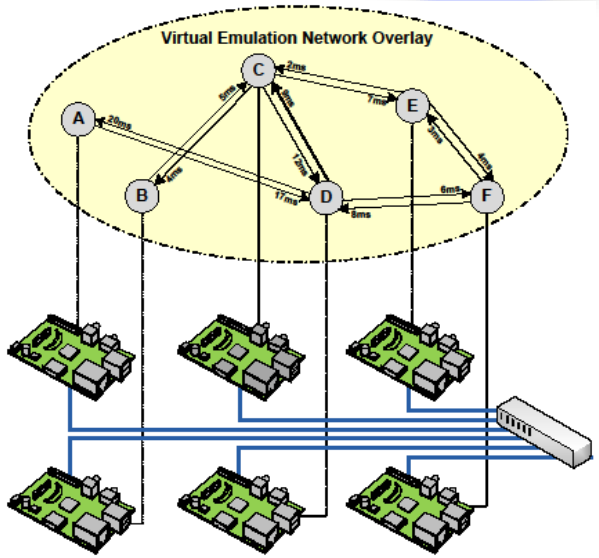
Novel **in-network views re-sampling** method that adapts to the perceived context to obviate for limited network resources

- Novel paradigm of **in-network views re-sampling** (synthesizing novel virtual views in the cloudlets that are transmitted as new references to the decoder)
- Definition of the optimal **resampling problem formulation**, proofing that is a NP-hard problem.
- Derivation of a **dynamic programming (DP) solution** based on generic assumption on the view synthesis distortion
- Evaluation of the **gain compared to mere subsampling** of the original set of **camera views**

Low-cost ICN Testbed



- Banana Pi Router
  - System on a Chip (SoC)
    - CPU: ARM Cortex A7
    - GPU: Mali-400
- Software
  - Linux BananaPi (Bananian)
  - Networking Forwarding Daemon



- Testbed consists of two physical networks
  - Emulation network, where any topology can be deployed
  - Management network, for gathering statistics and instructing the PIs

Dissemination

- Scientific Publications
  - This year: 5 journal papers; 7 conference papers
  - Overall: 6 journal papers; 11 conference papers
- Deliverables
  - CONCERT consortium, “D2.2: Learning and Decision-Making Methodologies and Interim CONCERT Architecture and Framework”.
  - CONCERT consortium, “D3.1: Interim Specification of Context-Aware Content Adaptation”.
  - CONCERT consortium, “D4.1: Interim Specification of Context-Aware Network Adaptation”.
  - CONCERT consortium, “D6.2: Year 2 Project Dissemination Report”.

Dissemination

- Workshop Organization
  - International **Workshop on Multimedia Streaming in Information-Centric Networks (MuSIC'2016)** at San Francisco, USA, 11th April 2016 in conjunction with IEEE INFOCOM 2016.
- Miscellaneous
  - CONCERT at http://www.concert-project.org

Sustainability/Valorisation

- Foster collaborations and interactions between ICN/networking and multimedia communication research communities
  - Workshops: http://music2015.itec.aau.at/ and http://music2016.itec.aau.at/
- Open access to AAU ICN research (results)
  - Publicly available at http://icn.itec.aau.at

Thank you

www.concert-project.org