FUTEBOL

Objectives
Experiments
Control framework
Numbers

Title	Federated Union of Telecommunications Research Facilities for an EU-Brazil Open Laboratory
Acronym	FUTEBOL
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Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

UFRGS

imec

Universidade Federal do Ceará

it
instituto de telecomunicações

VTT

UFES
Universidade Federal do Espírito Santo

intel

UNICAMP

UFMG

University of Bristol

Digitel

Description

The main goal of FUTEBOL is to develop and deploy research infrastructure and an associated control framework for experimentation in Europe and Brazil, that enables experimental research at the convergence point between optical and wireless networks.

Great progress has been made in the past few years on the development of federated telecommunications research infrastructure in Europe, through the Fed4FIRE program. More recently, the FIBRE project enabled optical fiber interconnection of research facilities in Europe and Brazil. The needs of future telecommunication systems, be it from high data rate applications in smart mobile devices, machine-type communications and the Internet of things (IoT), or backhaul requirements brought about from cell densification, require the co-design of the wireless access and the optical backhaul and backbone. FUTEBOL aims at developing a converged control framework for experimentation on wireless and optical networks and to deploy this framework in federated research facilities on both sides of the Atlantic Ocean.

Description

To deploy facilities in Europe and Brazil that can be accessed by external experimenters for experimentation that requires integration of wireless and optical technologies.

- Three testbeds in Europe and three testbeds in Brazil are enabled for use by external experimenters working on research topics dealing with the convergence of wireless and optical networks.
- Testbeds federated with functionality created in the Fed4FIRE project.

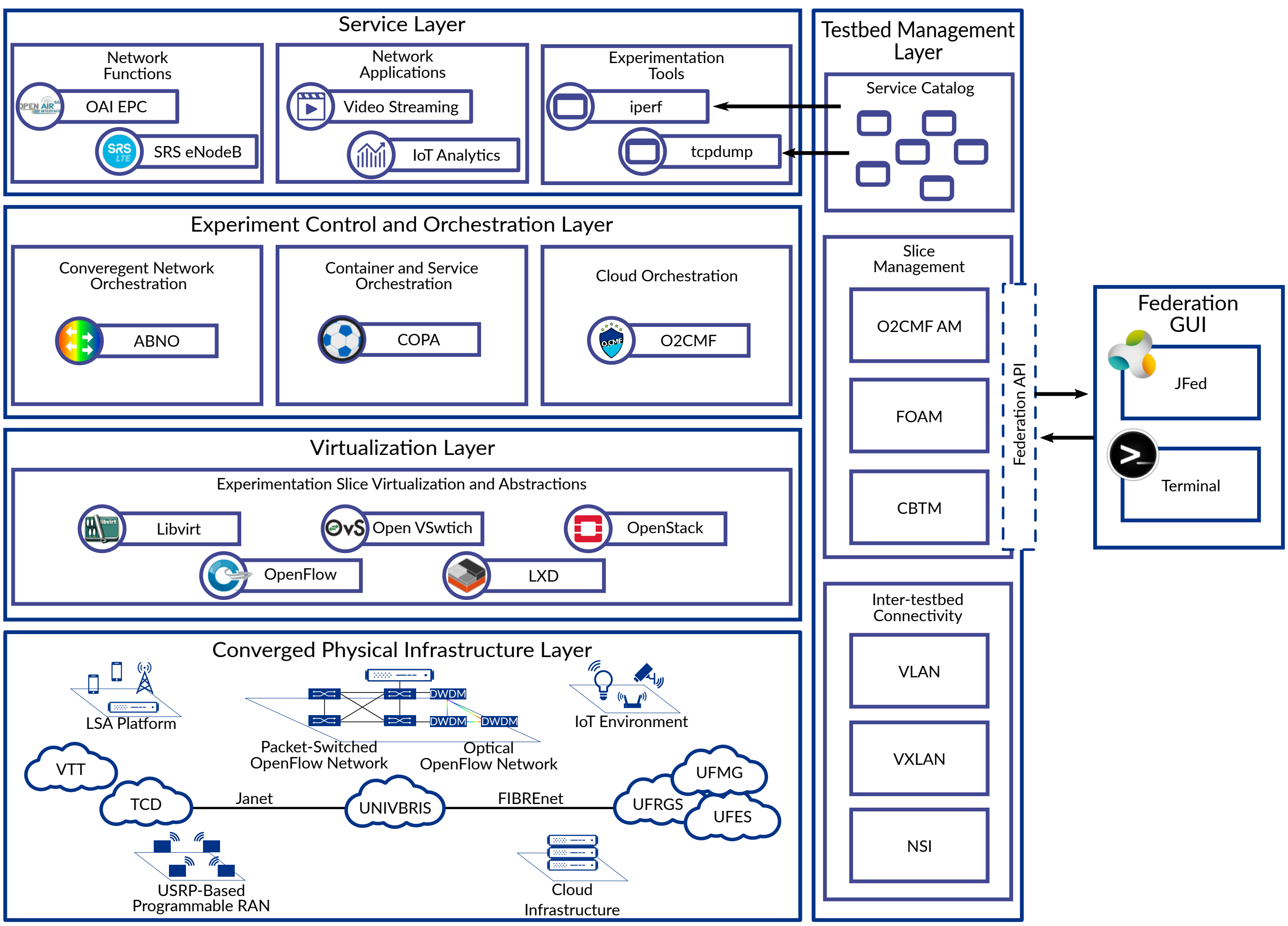
Control framework

Description

To develop and deploy a converged control framework for experimentation at the wireless/optical boundary, currently missing in Fed4FIRE and FIBRE research infrastructure.

The FUTEBOL control framework allows experimenters to easily reserve and deploy complex experiments along with multiple network domains, including resources from testbeds in Europe and Brazil. The combination of all the layers that comprise the FUTEBOL control framework provides to the experimenter the control over multiple network domains, and from physical infrastructure to service management.

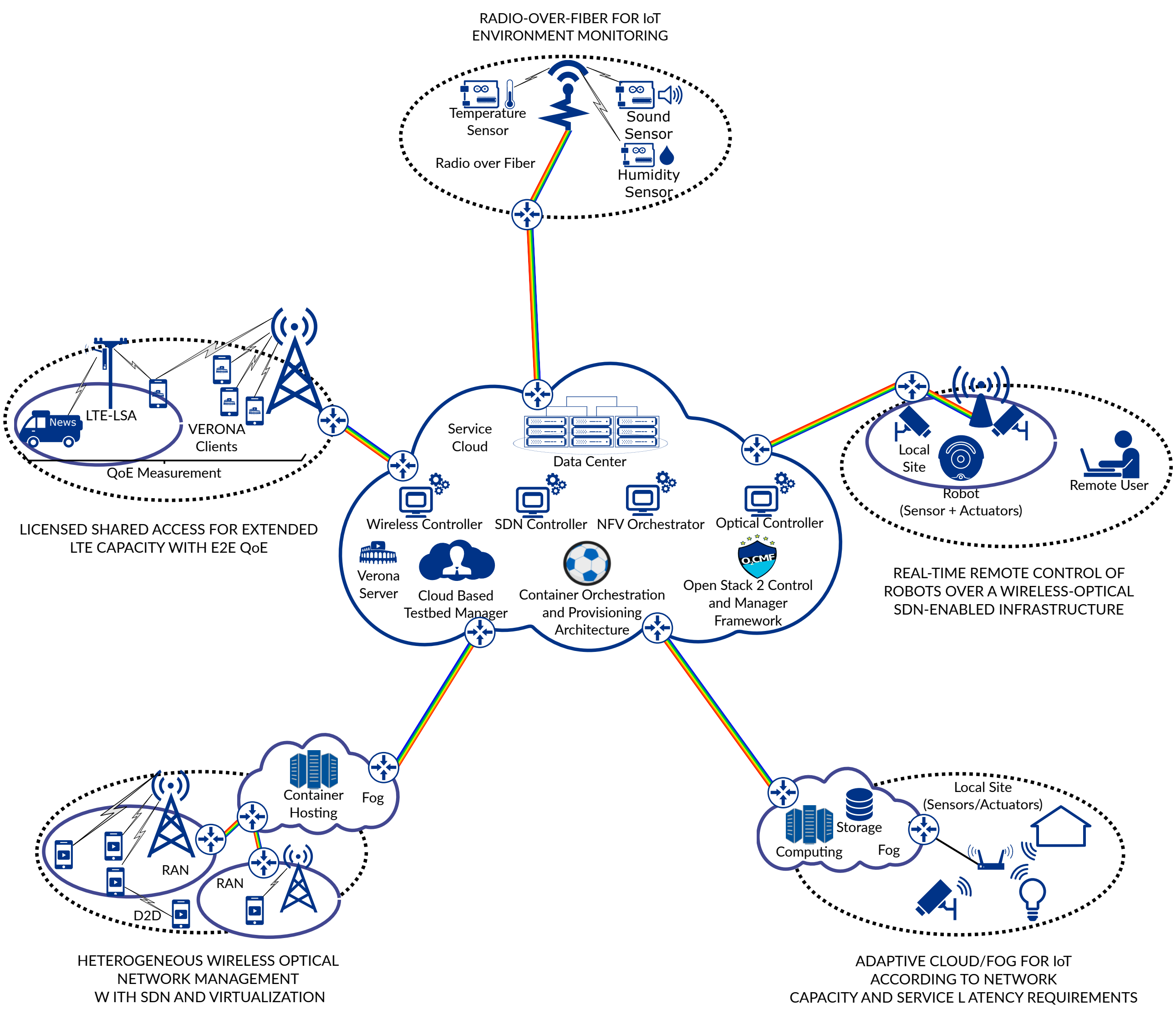
- The converged control framework was demonstrated by partners both in Europe and Brazil.
- The control framework is openly available for adoption by other experimental facilities not in the consortium.



Description

To conduct industry-informed research using the optical/wireless facilities.

- Demonstration of five showcase experiments that addressed problems of wireless/optical convergence and that involve a partnership between Brazil and Europe.
- Demonstration of showcase experiments that made a combined use of the federated testbeds.



Collaborative research and partnerships

Description

To create a sustainable ecosystem of collaborative research and industrial/academic partnerships between Brazil and Europe.

- Testbeds are available to the general public with access free for researchers, companies, and educators.
- Five proposals were selected in an open call for using the methodologies and tools that have been developed within the FUTEBOL project.

Description

To create education and outreach materials for a broad audience interested in experimental issues in wireless and optical networks.

- Video lectures on topics related experimentation using FUTEBOL research infrastructure available on the project website and YouTube channel.
- Four meetings with the Brazilian regulatory agency (ANATEL) provided an overview of the main FUTEBOL results that may impact on telecommunications regulation, managing radiofrequency spectrum, and digital inclusion.

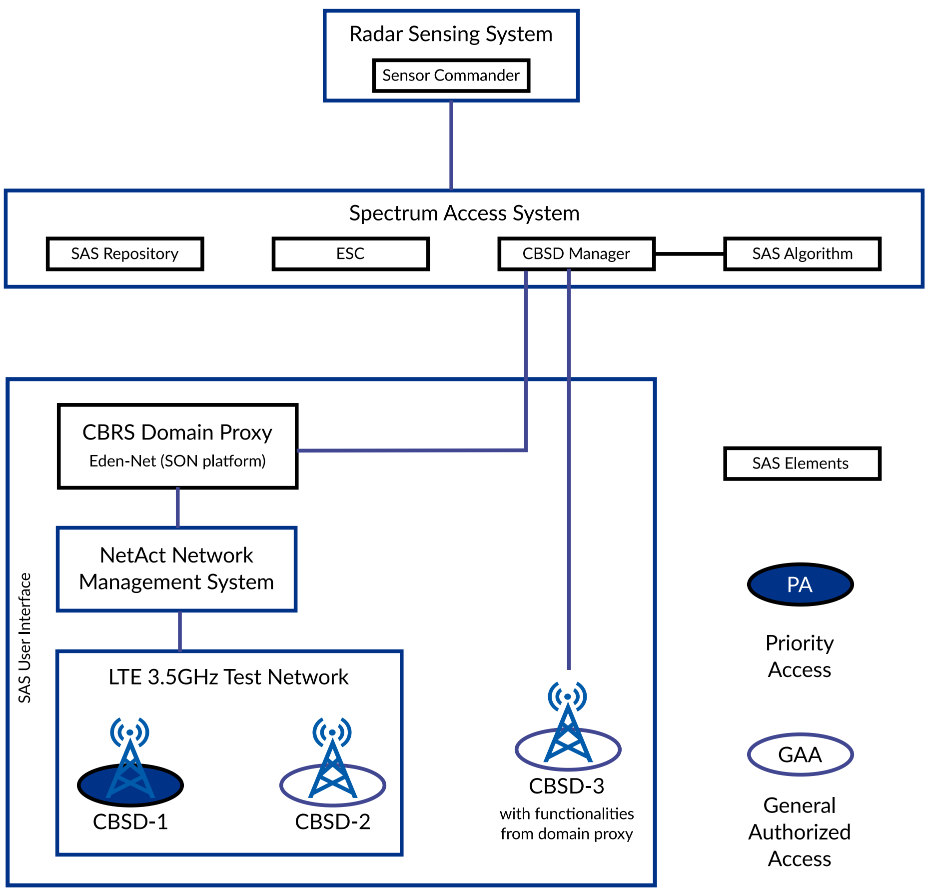
LSA/SAS for extended LTE capacity with E2E QoE

The concept

- To meet the growing demand for mobile broadband services, Long Term Evolution-Advanced (LTE-A) and future fifth generation (5G) networks will need more radio spectrum. Licensed shared access (LSA) and spectrum access system (SAS) are promising mechanisms for expanding the capacity of wireless networks without incurring infrastructure costs, which is of high relevance to operators and regulators.
- Experimentation is important to build up the trust in shared spectrum technologies, demonstrating no interference with incumbents and at the same time ensuring the quality of service (QoS) for the licensees.

Demo setup

- Environmental sensing capability (ESC) sensors.
- Citizens broadband radio service device (CBSD).
- Commercial Long Term Evolution (LTE) small cells.
- 3rd Generation Partnership Project (3GPP) band 42 (3550 to 3700 MHz).



LSA/SAS for extended LTE capacity with E2E QoE

The goals

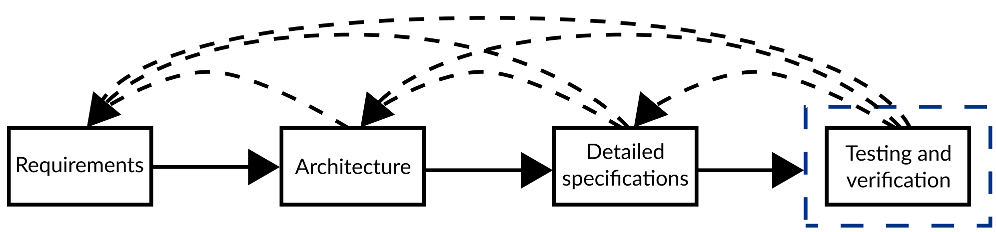
1. Test the feasibility of spectrum sharing regimes LSA and SAS and quantify its performance in terms of end-to-end (E2E) quality of experience (QoE).
2. Focus on the measurement of the evacuation time of the shared spectrum band using commercial LTE equipment and the approved LSA/SAS standards.
3. Disseminate the results to the Agência Nacional de Telecomunicações (ANATEL).

Challenges

- Measurements of the SAS protocol have shown that it takes from a sensing alert until the eNodeB's frequency change process is completed on average around 3 min and 30 s.
- FUTEBOL proposes a modification in the SAS architecture that includes a distributed SAS controller (DLC) to locally control spectrum sharing operations, decreasing the overall configuration and evacuation time to less than 1 min.

Results

- This experiment has contributed to the technical and regulatory discussion in Brazil regarding spectrum sharing. The results were presented to ANATEL, showing the feasibility of LSA/SAS in the 2.3 and 3.5 GHz bands when using commercially available mobile networks equipment and user equipment (UE).
- Special interest was given to the 3.5 GHz band which has been considered a 5G candidate band in Brazil but where there are coexistence challenges with TV receive-only services (TVROs).



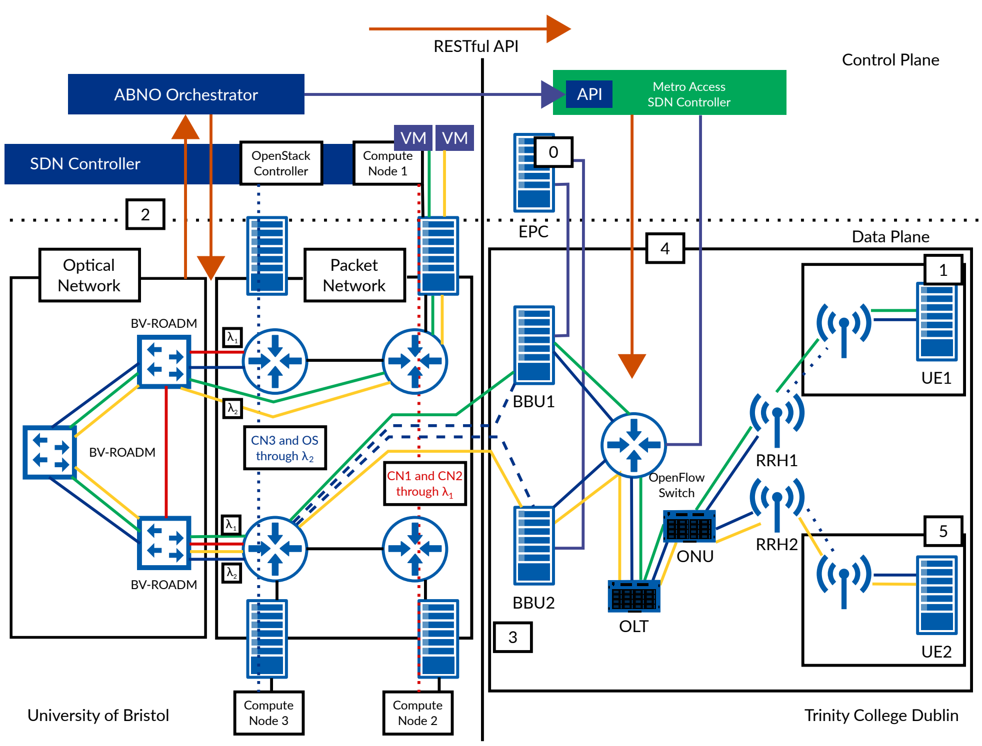
SDN-controlled multi-cell resource allocation in converged LTE-over-PON and optical core

The concept

- This experiment represents an operator in Bristol, serving different contents providers. The contents providers (A and B) decide they want to access the Irish market and ask Bristol to provide access to wireless users in Ireland. Bristol thus leases wireless capacity from TCD (which owns the license in Ireland), but it wants to minimize its leasing cost, therefore only makes use of the wireless spectrum and fixed network capacity required explicitly by each content provider.
- We show coordination of wireless spectrum and passive optical network (PON) capacity allocation to small cells using the concept developed at TCD of variable-rate fronthaul.
- We reproduce a scenario where two mobile users, UE1 and UE2, are served respectively by content providers A and B. UE1 and UE2 are in adjacent cells and are each allocated bandwidth depending on their demand. The cells use a PON as a common fronthaul. The demo starts with both users UE1 and UE2 running at low capacity and develops in two further steps: a) UE1 needs more capacity as it starts to get content from provider A: the orchestrator assigns more network and computing resources through the core and edge network towards UE1. b) UE1 stops using content from provider A and the orchestrator releases the network and computing resources including the mobile bandwidth towards that cell. The additional capacity available over the PON can be reassigned to the cell for UE2, together with the freed spectrum resources.

Demo setup

- Setup replicates an optical core and optical-wireless edge network, with data transmitted to clients on the LTE network from a data center on the far side of the core network.
- Application-based network operations (ABNO), located at Bristol side, orchestrates the provision of the optical-packet path, and computing resources, across a meshed optical and OpenFlow network located at Bristol and a wireless optical network at TCD.
- The optical-wireless software-defined network (SDN) controller at TCD coordinates the capacity adaptation between the base-band unit (BBU), the remote radio head (RRH), and the PON and spectrum reuse across multiple adjacent cells.



The goals

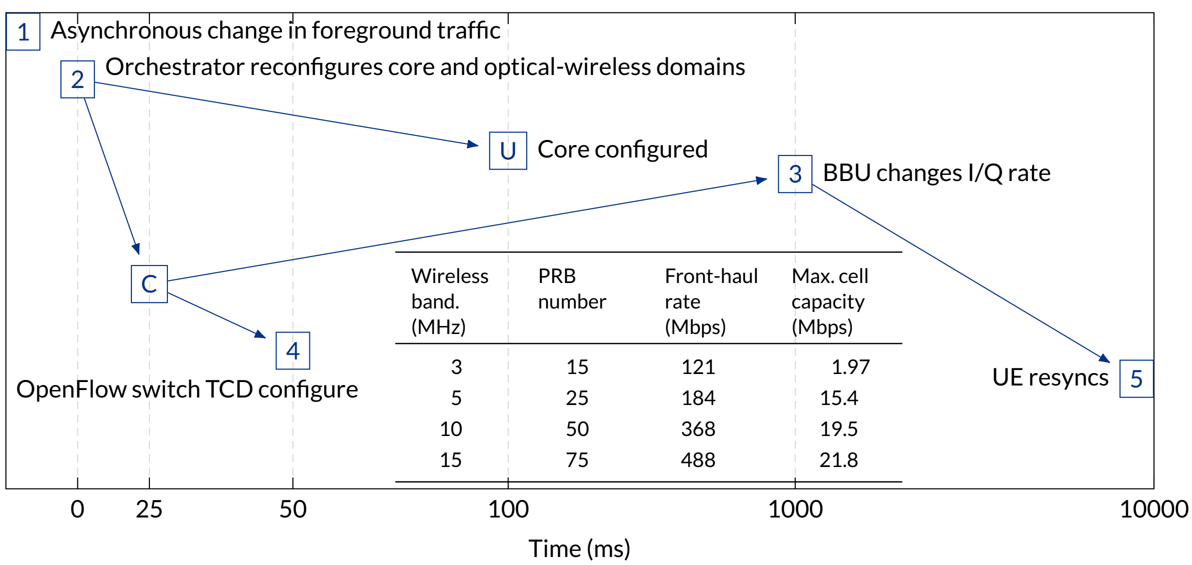
- Demonstrate the performance of multi-cell resource allocation using a testbed facility that converges cloud radio access network (C-RAN), LTE and PON technologies with a software-defined optical-packet-cloud core between different testbeds.
- Demonstrate the concept of spectrum reuse across multiple adjacent cells and variable-rate fronthaul enabled by SDN and statistical time division multiplexing (TDM).

Challenges

- Use the full-stack LTE system, including the medium access control (MAC), enabling full E2E communication.
- eNodeBs are modified to allow dynamic reconfiguration of the number of physical resource blocks (PRBs) of both the physical downlink shared channel (PDSCH). This affects the bandwidth, sampling rate, fast Fourier transform (FFT) size and other signal processing blocks.

Results

We derive a relationship between channel bandwidth, fronthaul rate, and cell capacity.



Wireless band. (MHz)	PRB number	Front-haul rate (Mbps)	Max. cell capacity (Mbps)
3	15	121	1.97
5	25	184	15.4
10	50	368	19.5
15	75	488	21.8

Dynamic fixed-mobile network capacity is reconfigured in seconds, although the control plane is capable of reconfiguring the system in sub-second time.

- When user UE1 starts using a higher bandwidth service (event 1), the core controller, detects the increase in capacity at the BBU side (event 2) and instructs the optical-wireless controller (event C) to increase the core capacity and mobile capacity through the Restful application program interface (API).
- The optical-wireless controller instructs the BBU to change the PRBs (event 3) and reconfigures the OpenFlow switch to guarantee capacity to the fronthaul link over the PON (event 4). The core network at Bristol is configured within 100 ms (event U).
- When the BBU updates its wireless bandwidth, it resets the physical channel with the UE, which synchronizes to the new sampling rate, FFT size (event 5).

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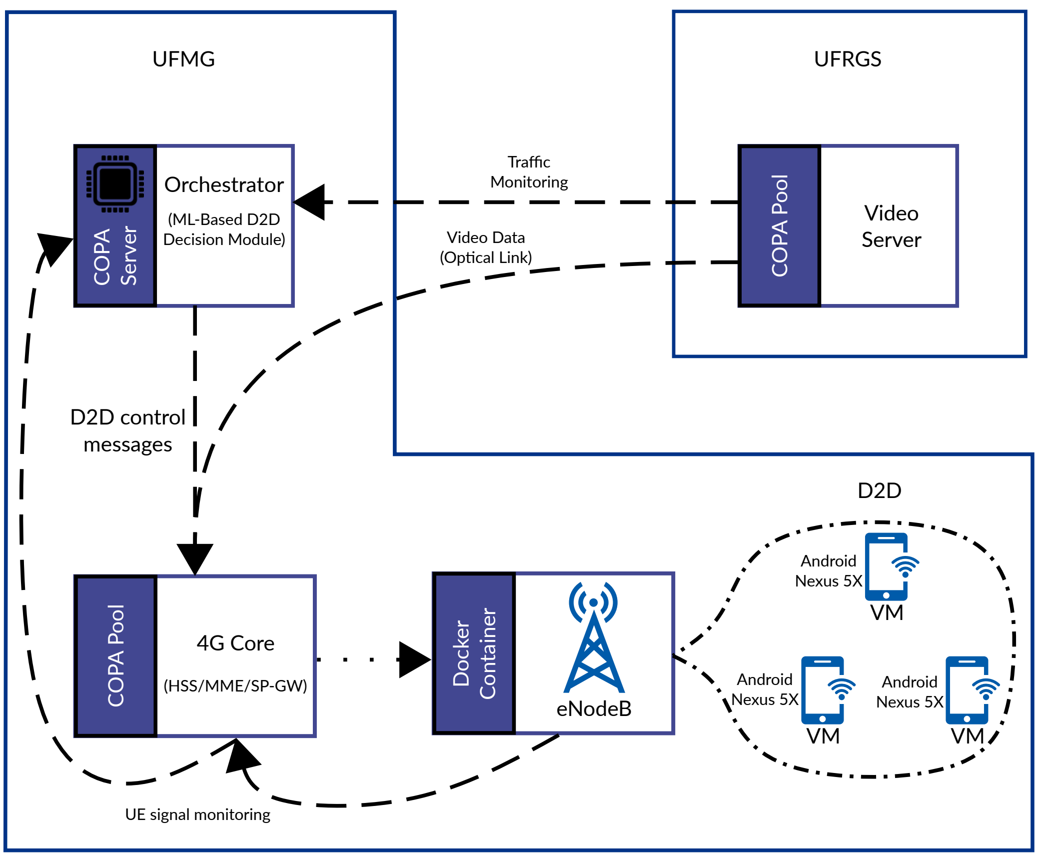
Using D2D and machine learning to improve cellular users' QoE for video streaming

The concept

- Development of mechanisms to reduce traffic demand at the optical infrastructure and improve the QoE delivered to a UE, which request multiple videos to an external server, through optical infrastructure.
- Users who request the same video content will download it through the device-to-device (D2D) connection from another UE, thus removing the same multiple requests to the video server, contributing to increase the mean video resolution (QoE metric) and reducing traffic on optical infrastructure.

Demo setup

- The video server runs at UFGRS FUTEBOL testbed and is connected to UFMG FUTEBOL testbed by an optical link.
- The Android Nexus 5X smartphones requesting video are connected on fourth generation (4G) cellular network, which is emulated at UFMG FUTEBOL testbed.
- The machine learning (ML)-based orchestrator monitors the traffic generated by the video server and monitors UEUE signal data recorded at the eNodeB: it is the D2D decision module.
- When the creation of a D2D group improves UEUE QoE, the D2D decision module defines one UE as the group owner (GO) and the other UEUE as D2D clients.



The goals

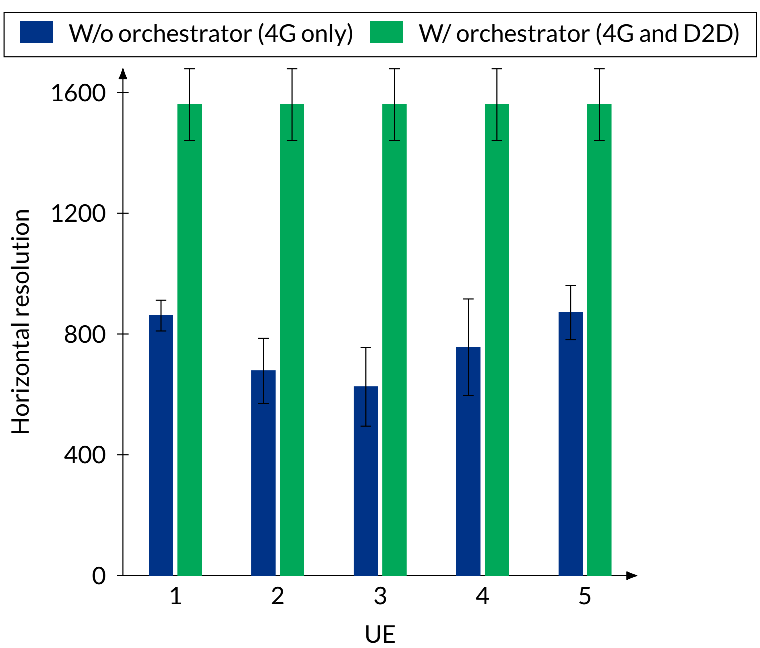
1. Improve UEUE mean video resolution with the use of D2D, *i.e.*, improve UEUE QoE.
2. Reduce the traffic load on the optical infrastructure.

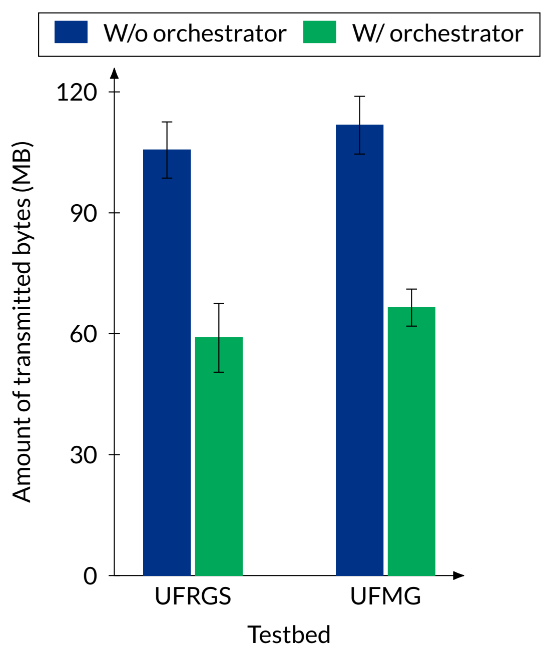
Challenges

- Create an ML-based orchestration module to decide on the creation of D2D groups, by means of monitoring the video server traffic at the optical infrastructure, as well as the UEUE signal data measured by the eNodeB.
- A UE GO acts as a cache and the other UEUE download, through D2D, the same video from it.

Results

- The use of an ML-based orchestrator reduces video traffic demand at the optical infrastructure by about 38 %.
- The QoE is increased by around 150 %, regarding the UEUE mean video resolution. Regarding the number of resolution changes, the impact on QoE is decreased by about 90 %.





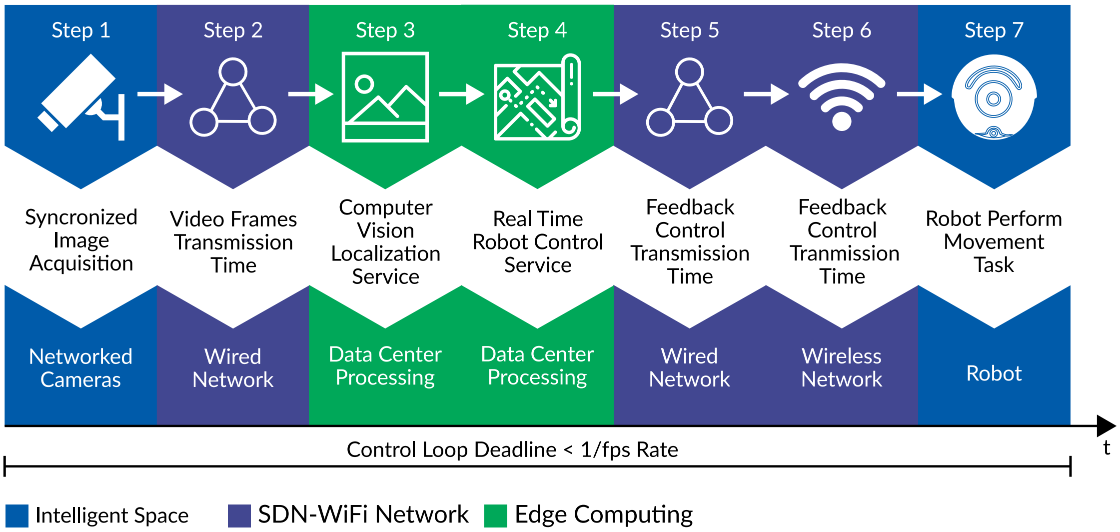
Real-time remote control of robots over a wireless-optical SDN-enabled infrastructure

The concept

This experiment integrates SDN and cloud computing techniques to leverage latency bounds, communication, and computation resources to enable the so-called cloud robotics paradigm in an "intelligent space". The robot task is to complete a trajectory with a pre-set number of laps in a pre-set time, doing it with the lowest possible trajectory error.

Demo setup

The FUTEBOL testbed at UFES has an "intelligent space" with four cameras, a wirelessly commanded mobile robot unit, and an SDN switch connecting the "intelligent space" to a data center via a wired optical network.



The robot has limited onboard computation capabilities and memory, being commanded by remotely generated control signals. The cloud computing facilities (*i.e.*, data center) are responsible for receiving video images, processing data, and generating control commands back to the robot. These tasks need to be completed before the control loop deadline.

The goals

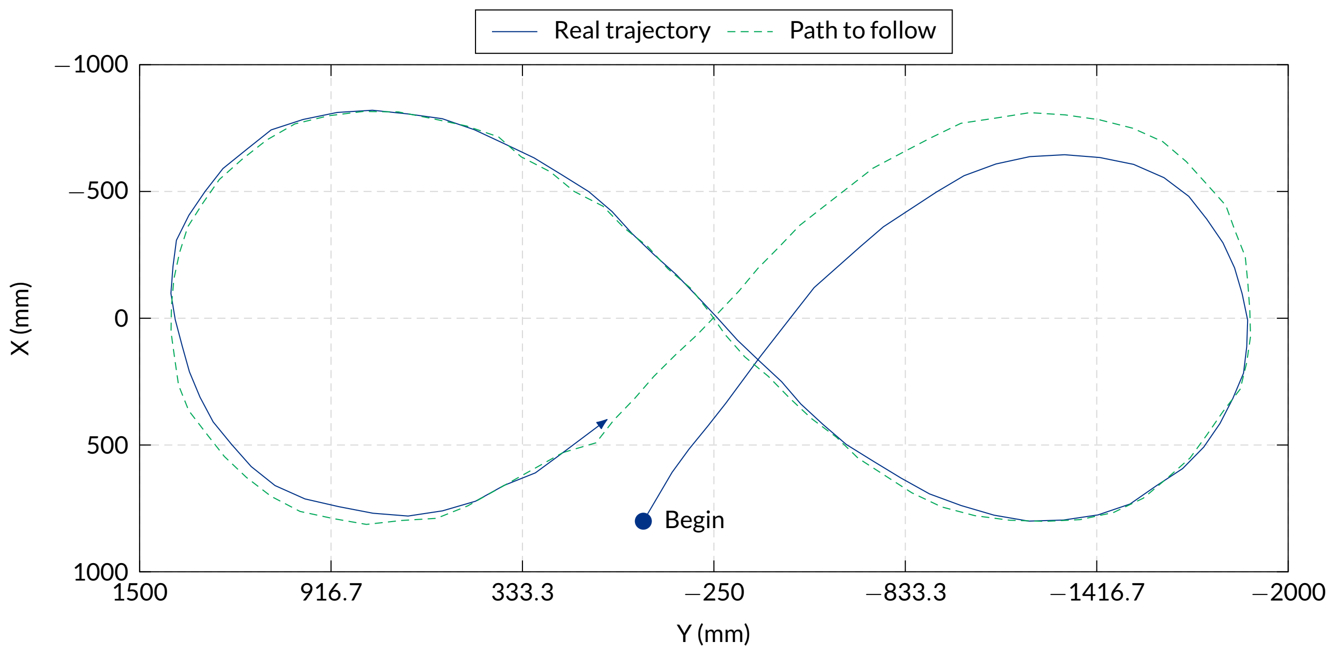
1. Reduce the trajectory error of the robot in the "intelligent space" by combining virtual network function (VNF) and network orchestration.
2. Achieve seamlessly communication during robot mobility and handover, delivering packets within the deadline window with similar performance to a no handover baseline scenario using a wireless SDN controller.

Challenges

- To obtain the stringent processing requirements of real-time remote control of robots applications.
- To achieve the low latency, high reliability, and high bandwidth requirements of these applications.

Results

The figure shows the trajectory error of the robot when using the highest frames per second (fps) rate (15 fps) remotely controlled by the cloud orchestrator and wireless SDN solution.



We can state that there is a clear need to orchestrate the computational resources available in the cloud to obtain the best possible results.

Adaptive cloud/fog for IoT according to network capacity and service latency requirements

The concept

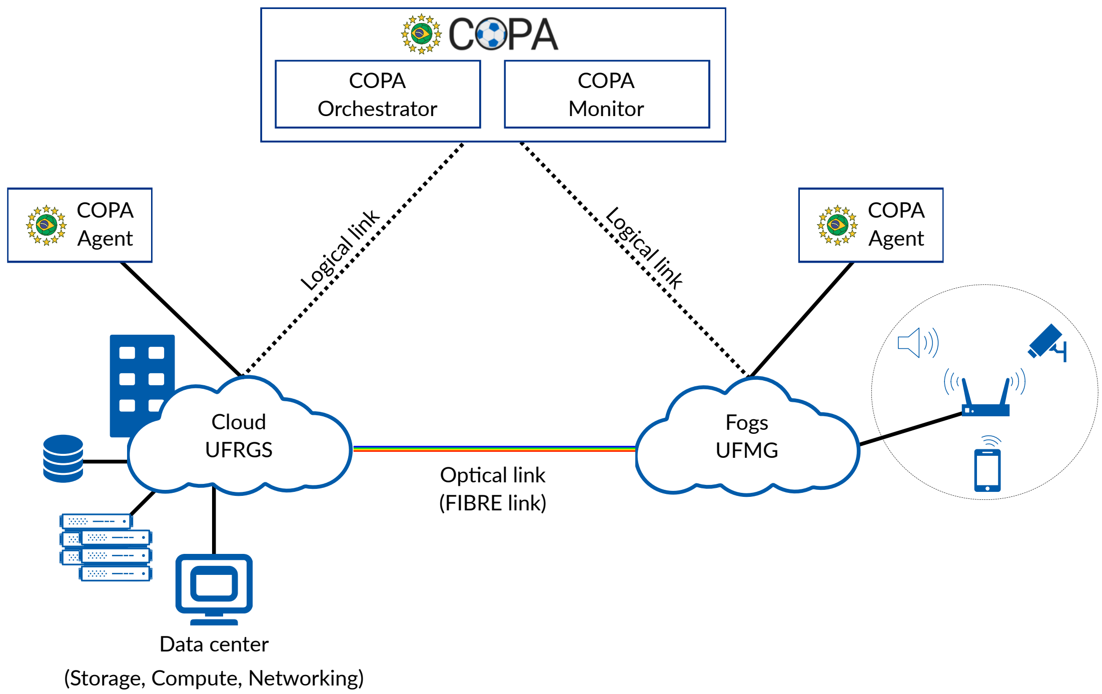
This experiment researches the interplay between wireless and optical networks for the IoT. The convergence among optical and wireless infrastructures will be part of future computer networks and will enable the creation of new applications for several research areas, such as healthcare and home automation. These areas utilize IoT devices that most of the time are resource constrained and may not be able to process heavy loads of data, storage much information, and must save as much energy as possible.

To assess those limitations, paradigms such as cloud and fog computing enable remote data processing and storage which are not available in a regular device. These computing paradigms unified with a wireless/optical infrastructure can provide to new applications high data processing and ample storage together with mobility and low network latency.

Demo setup

The experimental scenario is composed of two tiers of processing. The first and nearer to the user is the fog and the second is the cloud which has higher processing power than the fog. The main idea of this scenario is to monitor the quality of the wireless and optical networks and computational resources among servers host and the client application, and compare the deployment and migration behavior of remote applications in such situations. The tools utilized in this scenario were:

- Resources monitoring and container orchestration (COPA): a control framework application provided by FUTEBOL.
- IoT application: image capture and object identification software, which is similar to a surveillance application in smart cities.



The goals

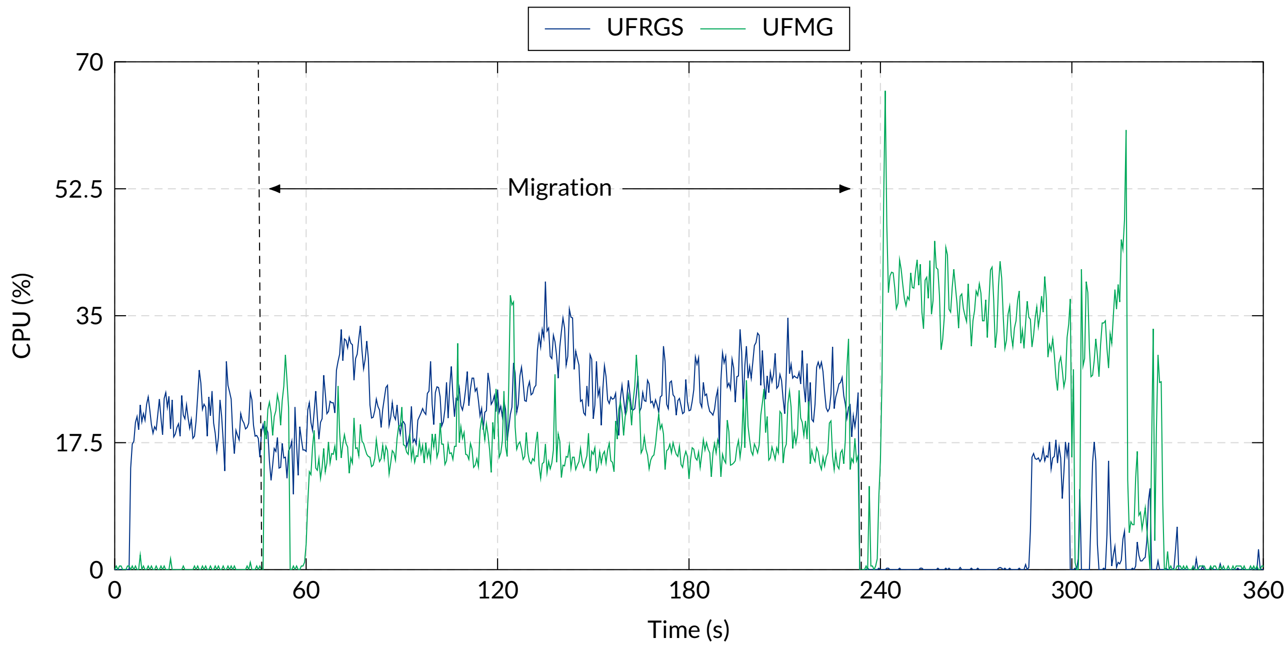
1. Define how much the migration of this application stress the computational and network resources, affecting the QoS of other services.
2. Train an intelligent orchestration system and study how automation can enhance the overall quality of the applications.

Challenges

- Set up a cloud/fog like scenario between two different testbeds.
- Evaluate which metrics are relevant for the intelligent orchestration system decision-making.

Results

- The development of the COPA graphic tool for live container migration.
- The proposal of an ML algorithm to automatically orchestrate the migration of IoT applications among servers scattered in a wide area network (WAN).
- Performance results related to the live migrating containers across wide area networks.



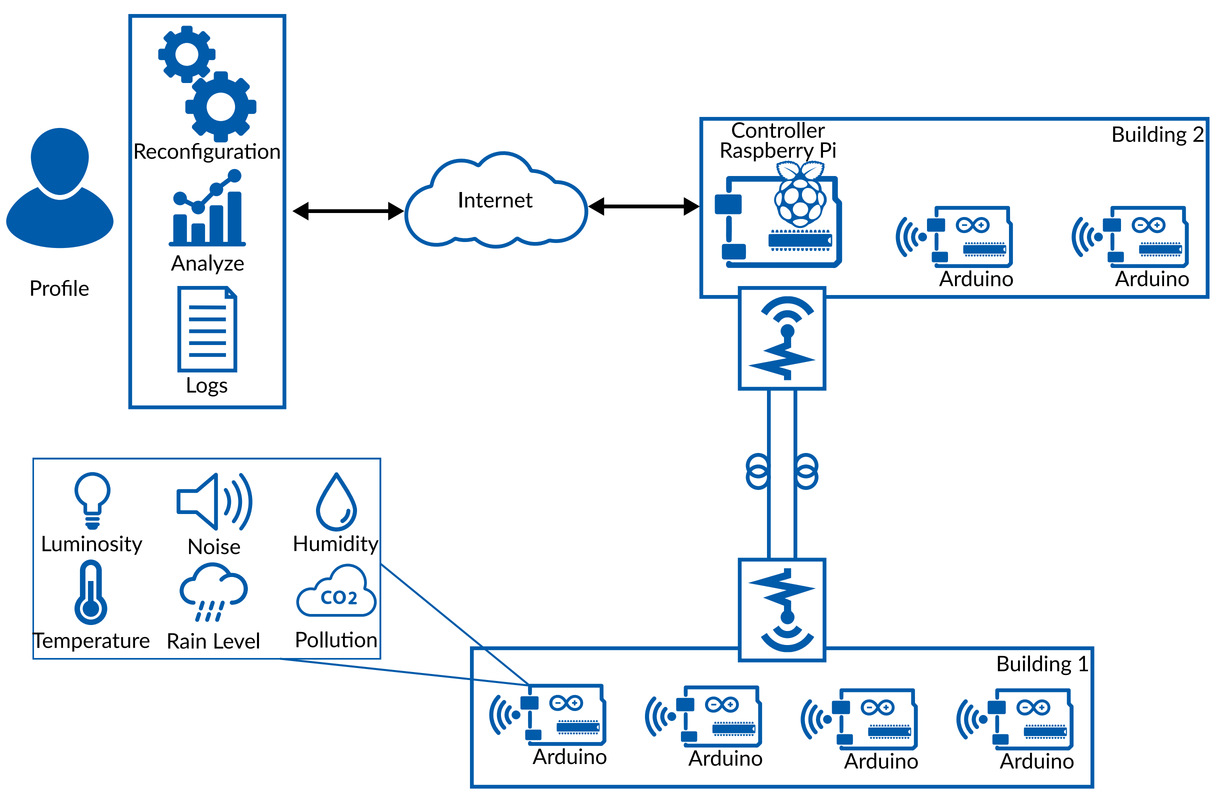
Radio over fiber for IoT environment monitoring

The concept

- Implementation of an infrastructure based on the radio over fiber (RoF) to support communication of diverse IoT devices.
- Proposal of network architectures for IoT monitoring based on RoF technology.
- Study how the RoF system can impact the IoT network operation.
- Deployment of indoor and outdoor IoT nodes in a real campus environment.

Demo setup

- IEEE 802.15.4 IoT network employing:
  - Centralized RoF-based architecture: IoT sensor nodes in one site with remote centralized processing.
  - Extended-coverage RoF-based architecture: IoT sensor nodes in two different sites with a centralized processing.
- Three different scenarios:
  - Single channel: just one IEEE 802.15.4 channel used in the whole IoT network.
  - Two channels: two channels used by IoT devices in the whole network.
  - Separated channels: different channels used in each site.
- Sensor nodes transmitting different sensor data (*e.g.*, temperature and humidity) to an IoT application.
- The network load is varied by modifying the reporting periodicity at the application level.



The goals

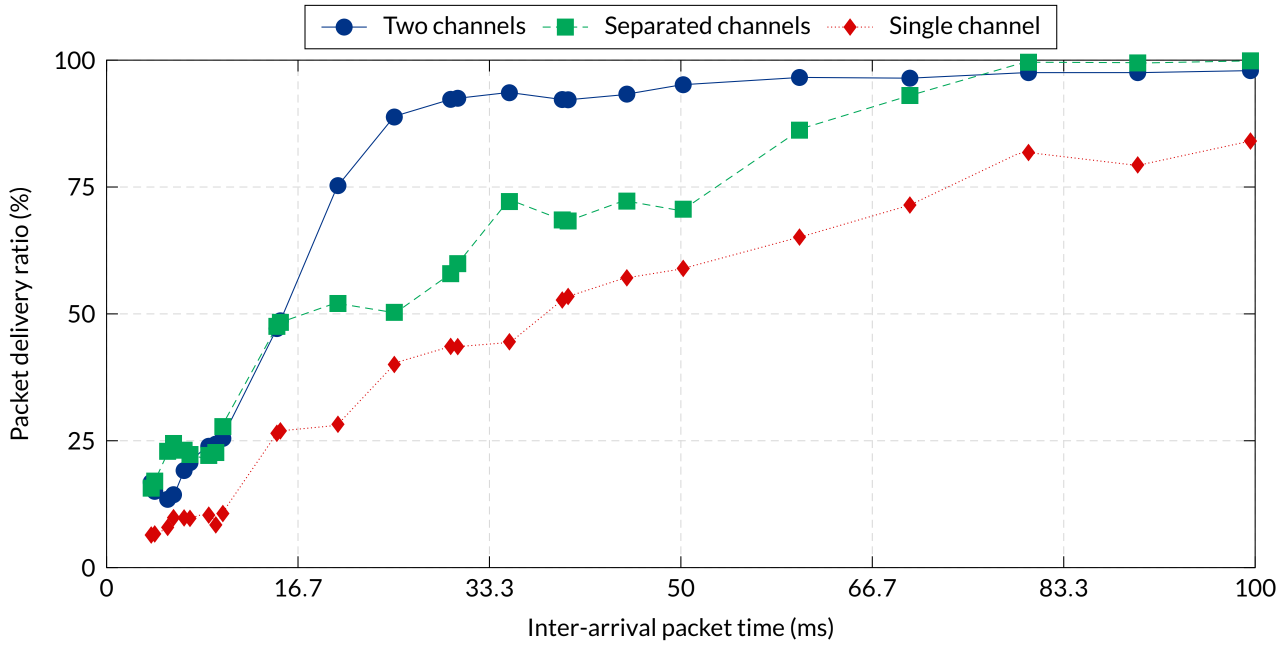
1. Demonstrate the suitability and impact of RoF technology for IoT applications.
2. Investigate potential improvements on network performance under massive IoT accesses of the RoF-based network architectures.

Challenges

- The access of several IoT devices puts a lot of pressure in the IoT access network.
- Create a testbed for RoF-based IoT monitoring application.

Results

- Increased packet delivery ratio.
- Decreased channel contention.
- Provisioning of flexibility and scalability for supporting the increase in the demand.



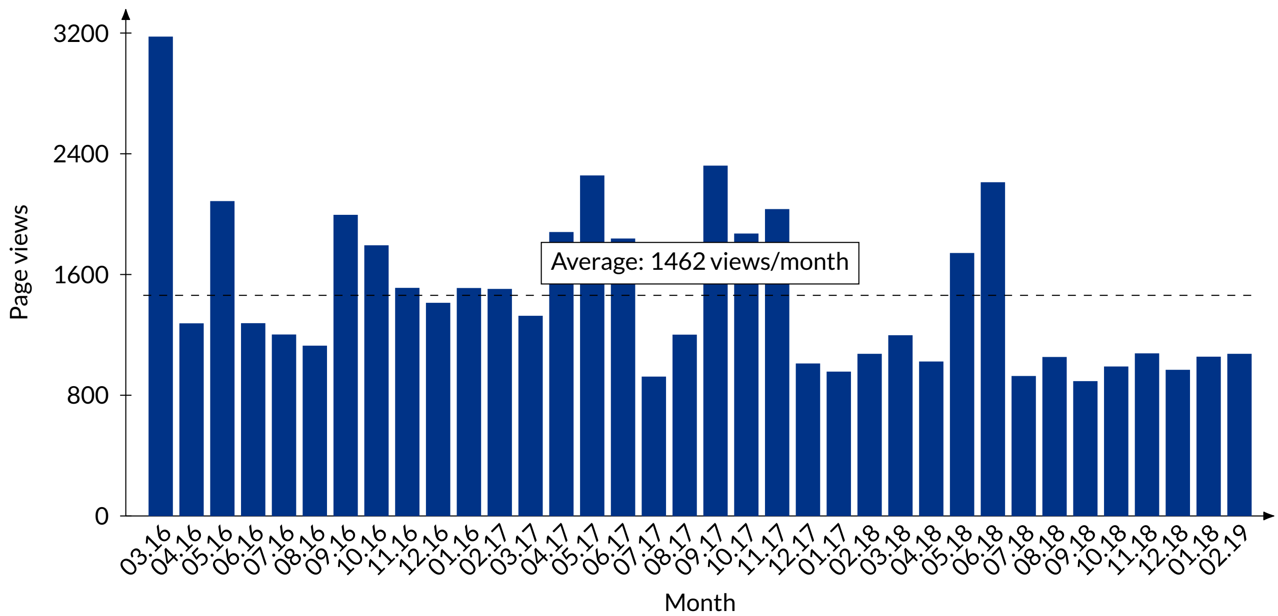
General and open-call KPIs

	Promissed	Achieved
Number of peer-reviewed publications in leading telecommunication journals and conferences	30	76
Number of jointly authored, peer-reviewed publications in leading telecommunications journals and conferences including at least one European and one Brazilian author	15	20
Number of ETSI technical committee meetings attended by Brazilian partners, contributing results from FUTEBOL experiments	2	0
Number of research groups in Latin America, outside of Brazil, involved in FUTEBOL experimentation	1	2
Number of video lectures, in both English and Portuguese, based on FUTEBOL results	3	24
Meetings with ANATEL	2	4
Number of FUTEBOL promotional events held in conjunction with major international events	2	9
On a scale of 1–5, what is the probability that you would give positive references for the FUTEBOL testbeds?	4	4.4
Number of external institutions using FUTEBOL control framework and/or infrastructure	8	8
Number of publications submitted by external experimenters	3	1

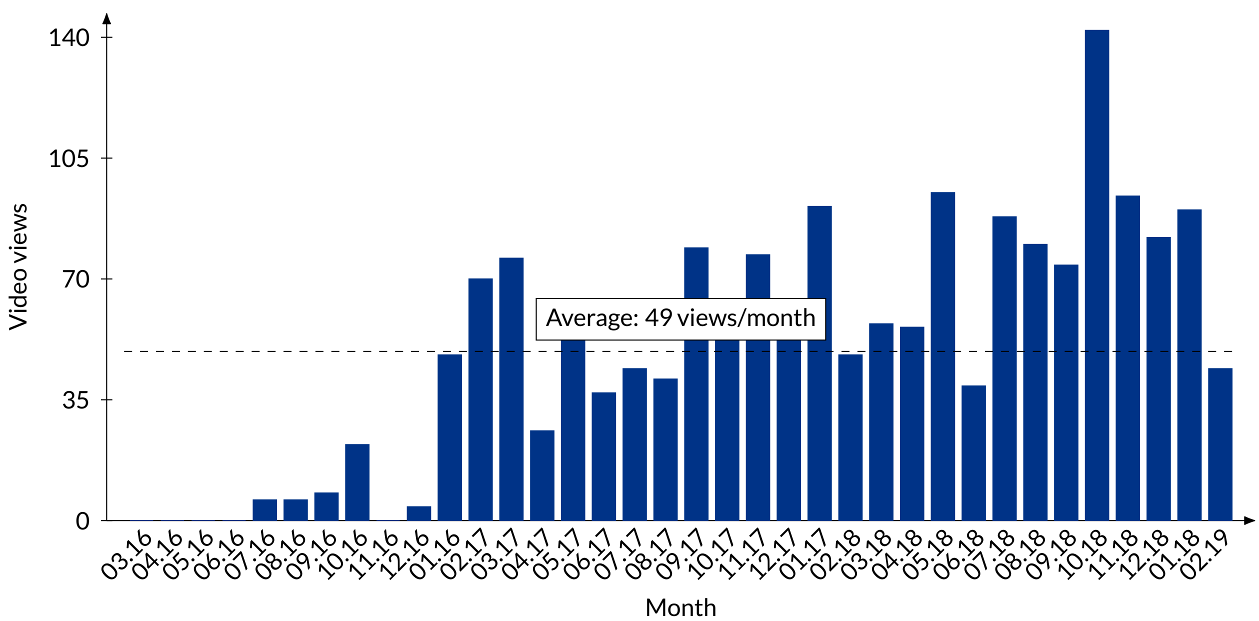
Summary

	Phase 1 (1.5 years)	Phase 2 (1.5 years)	Total
Peer-reviewed publications	39	37	76
Jointly peer-reviewed publications	9	11	20
Invited talks	16	11	27
Workshops/demonstrations	2	7	9
Standardization activities	1	1	2
Regulatory activities	3	4	7
YouTube channel videos	10	20	30
Newsletters	2	4	6

Website page views per month



YouTube channel video views per month



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3GPP	3rd Generation Partnership Project
4G	fourth generation
5G	fifth generation
ABNO	application-based network operations
ANATEL	Agência Nacional de Telecomunicações
API	application program interface
BBU	base-band unit
C-RAN	cloud radio access network
CBSD	citizens broadband radio service device
COPA	resources monitoring and container orchestration
D2D	device-to-device
DLC	distributed SAS controller
E2E	end-to-end
ESC	environmental sensing capability
ETSI	European Telecommunications Standards Institute
FFT	fast Fourier transform
fps	frames per second
GO	group owner
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of things
KPI	key performance indicator
LSA	licensed shared access
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MAC	medium access control
ML	machine learning
PDSCH	physical downlink shared channel
PON	passive optical network
PRB	physical resource block
QoE	quality of experience
QoS	quality of service
RoF	radio over fiber
RRH	remote radio head
SAS	spectrum access system
SDN	software-defined network
TDM	time division multiplexing
TV	television
TVRO	TV receive-only service
UE	user equipment
VNF	virtual network function
WAN	wide area network

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