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Understanding the Challenges in the Optical/Wireless Converged Communications

Federated Union of Telecommunications Research Facilities for an EU-Brazil Open Laboratory (FUTEBOL)[1]

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Abstract

Current wireless trends (cell densification, coordinated communication, massive MIMO) pose a new set of challenges that require the joint consideration of optical and wireless network architectures. These problems are of direct impact to emerging economies such as Brazil, with highly heterogeneous infrastructure capabilities and demand, as well as to more established markets such as the EU, which aims to regain its leadership in the next generation

[1]www.ict-futebol.eu

of telecommunication technologies. FUTEBOL composes a federation of research infrastructure in Europe and Brazil, develops a supporting control framework, and conducts experimentation-based research in order to advance the state of telecommunications through the investigation of converged optical/ wireless networks. Also FUTEBOL establishes the research infrastructure to address these research challenges through innovation over this infrastructure, with a consortium of leading industrial and academic telecommunications institutions.

Keywords: Wireless, Optical, Converged Networks.

25.1 Introduction

There have been approaches to improve telecommunications by linking up wireless networks with optical ones, such as Radio over Fiber solutions. However, it is still a fact that wireless and optical network research problems are often treated in isolation of each other [Beas13, Saskar07]. Current wireless trends (cell densification, coordinated communication, massive MIMO, millimetre-wave) pose a new set of challenges that require the joint consideration of optical and wireless network architectures. These problems are of direct impact to emerging economies such as Brazil, with highly heterogeneous infrastructure capabilities and demand, as well as to more established markets such as the European Union, which aims to regain its leadership in the next generation of telecommunication technologies. The Federated Union of Telecommunications Research Facilities for an EU-Brazil Open Laboratory FUTEBOL project develops the research infrastructure to address these research challenges and conducts research over this infrastructure.

Europe and Brazil have a long research cooperation tradition in the area of Science & Technology culminating in the signing in 2004 of the Agreement for Scientific and Technological Cooperation[2]. The Agreement identifies some priority areas for future cooperation including Information and Communications Technology (ICT). EU-Brazil research cooperation in the area of ICT has been developing since the launch of the first coordinated call in 2011 and addresses some topics dealing with Future Internet, micro-electronics and micro-systems, cloud computing, technologies and applications for a smarter

[2] http://ec.europa.eu/world/agreements/prepareCreateTreatiesWorkspace/treatiesGeneralData.do?step=0&redirect=true&treatyId=2041

society and e-infrastructures. It is supported by an EU-Brazil Dialogue on Information Society with specific working groups in some areas addressing not only research and innovation matters but also ICT policy and regulatory aspects. EU-Brazil research cooperation in the area of ICT, including cloud computing, is also regarded as having a crucial strategic value and high societal impact. The current call further realises some of the objectives of the cooperation agreement by focusing on Advanced CyberInfrastructure including **Experimental Platforms** federating network resources in Europe and Brazil building on FIRE (Future Internet) and FIBRE (Future Internet Brazilian Environment for Experimentation) developments. Joint work on the areas above is expected to be continued in the work-programme 2016–17 of Horizon 2020.

The overall objective of the FUTEBOL project 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**.

Considerable progress has been made in the past few years on the development of federated telecommunications research infrastructure in Europe, through the FIRE[3] program. More recently, the FIBRE project enabled optical fibre interconnection of research facilities in Europe and Brazil. However, telecommunications research remains largely segregated between optical networks and wireless systems and rarely do researchers cross the boundary between the two. We argue that the needs of future telecommunication systems, be it for 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.

Within this chapter we present an overview of the research targeted by the FUTEBOL project. FUTEBOL is in an early stage of execution, and the research questions regarding optical/wireless converged networks are starting to be answered by understanding the challenges the such networks. However, the approach to tackle such challenges is described along this chapter.

[3]http://www.ict-fire.eu

25.2 Problem Statement

As of May 2014, Brazil was one of the largest internet markets in the world. Recent industry data projects the current online penetration rate of 49.3 percent to grow to 59.5 percent in 2017, which at that point will equal more than 123 million internet users across all online devices. Recent statistics suggest that out of the current 84 million internet users, 43 million are mobile internet users, 41 million of these accessing the internet via a mobile phone. The strong presence of mobile internet correlates with a recent Brazilian survey stating that 52 percent of Brazilian consumers do not have any internet access at home[4]. It is also estimated that in Brazil there may be up to ten times more mobile phones per base station than in Europe[5]. Notably, Brazil is characterized by enormous environmental diversity, ranging from mega-cities to wide expanses of low population density; this creates challenges to providing high level of communication services to all citizens. The lack of investment in research infrastructure is a limiting factor for digital inclusion in Brazil, relevant to democratize quality access to a broad range of internet-enabled services.

From the European mobile operator point of view, a key requirement of future mobile networks is that significant additional network capacity has to be added at lowest possible cost, to combat the current trend of stagnant revenues while traffic grows exponentially. Approximately 24% of a network operator's costs come from OPEX, including the cost of network operation and maintenance, training and support, energy, site rental. The experimental research infrastructure enabled by FUTEBOL will demonstrate how wireless/optical convergence will support future traffic growth and new mobile services, while limiting the CAPEX/OPEX required to deploy and maintain the network.

FUTEBOL's focus is on converged optical/wireless experimentation. On the wireless side, new spectrum access modalities such as Licensed Shared Access (LSA) will soon open new bands for mobile broadband, and more spectrum also means that less investment in infrastructure would be needed. The proliferation of small cells increases frequency reuse and is responsible for a major proportion of the gains in mobile network capacity. On the optical network side, network function virtualization and the concept of software defined networks are revolutionizing the way that network resources are managed. We view virtualization on the optical side and densification

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[4]http://www.statista.com/topics/2045/internet-usage-in-brazil

[5]http://wireless.ictp.it/tvws/book/5.pdf

and capacity increase on the wireless access as major game changers in future networks that should be co-designed and experimented with together. FUTEBOL creates the infrastructure that enables academic and industrial researchers in Europe and Brazil to experiment at the convergence points between wireless and optical networks.

25.3 Background and State-of-the-Art

Converged wireless-optical network architectures started to appear in the second half of the last decade. Due to the high cost of developing a highly capillary fibre access network, these solutions considered increasing the broadband coverage by deploying a wireless network, mainly in dense urban areas, backhauled by a fibre access networks, typically implemented as a Passive Optical Network (PON). Typically the wireless access network was implemented as a mesh of WiFi enabled nodes. Architectures such as those dubbed CROWN [Kazowsky07], MARIN [Shaw07], or WOBAN [Sakar07] were developed to address the challenge of optical/wireless integration. All such models employed the PON as a mechanism to backhaul the wireless network, i.e. providing connectivity to the general Internet, while also integrating dynamic routing in the wireless mesh.

Example challenges addressed by prior architectures include: load balancing both on the wireless mesh and PON access points, and integrated routing algorithms between the wireless mesh and a multi-wavelength PON network. In particular the WOBAN architecture addressed additional issues such as optimization of node location and fault tolerance while also providing an implementation of a laboratory prototype [Chowdhury09], where a number of Optical Line Terminals (OLTs), Optical Network Units (ONUs), and WiFi access points were interconnected in order to measure their overall integrated performance. As the first highly integrated optical-wireless prototype, WOBAN allowed the authors of [Chowdhury09] to measure throughput, packet loss, and jitter of the integrated system in various applications, such as file transfer or VoIP, under varying background load conditions.

Over time, as LTE started being developed together with concepts of small and femtocells, the attention moved towards integration of optical access and mobile networks. Due to the increasing number of mobile cells in a small or femtocell deployment, current practice of backhauling a base station with point-to-point fibre links becomes highly uneconomical, as the cost of the backhaul network can easily exceed that of the mobile infrastructure. Backhauling base stations with a Passive Optical Network becomes thus an interesting alternative, as the infrastructure cost can be shared with other services, such as residential broadband.

In [Milosavljevic13], a novel network architecture has been proposed that addresses the challenges posed by the emergence of mobile cloud computing. A comprehensive solution of optical-wireless convergence has been described, that takes into consideration not only the aggregated bandwidth of the ONU/eNBs, but also the individual bandwidth requirements of wireless users, allowing better resource management, reduced delay, and scalable optical links. This is achieved via long-reach TDWM-PON, as well as a combination of centralized and decentralized backhauls. The solution tackles bandwidth outage with dynamic routing at the intersection of the presented heterogeneous backhaul networks (CRAN and IP backhauling), as well as with redundant links. These links are also considered in order to provide path for transmission in case of fibre failure. The proposed solution is able to constantly adjust to the conditions of the RAN in terms of channel estimation, as well as bandwidth demands; the network becomes aware of the conditions that are static throughout time in its coverage (e.g. buildings and terrain anomalies), in addition to those that are dynamic (e.g. congestion in specific areas during specific hours of the day).

Access networks are responsible for a significant part of overall telecom network energy consumption, and their demand for energy also increases rapidly with the ever-growing traffic volume they carry. Sustainability necessitates energy conserving solutions which also carefully limit the negative effects on other system qualities. It is expected that future access networks are based on a converged optical/wireless architecture. The work in [Ladanyi14] examines a hybrid small cell LTE and PON network. The authors analyse the impact of serving the user population with a reduced number of active cells, either due to failure or selective switch-off of chosen cells. Multiple optical topologies are considered for connecting the cells of the wireless network. Extensive simulations are used to quantify the interdependence of energy consumption, network availability and the QoS experienced by the consumer. In [Ladanyi14b] one investigates the trade-off between serving the user population with a reduced number of active cells and the quality of network services.

The transmission of a 3GPP LTE signal over a seamlessly integrated radio-over-fibre and millimetre-wave wireless link at 90-GHz band has been theoretically analysed and experimentally demonstrated in [Dat13]; one successfully transmitted and demodulated all the test signal models defined by 3GPP for LTE eNB over the proposed system. The measured error vector magnitude for all test signal transmission is well under the limit threshold defined by the standard. The proposed system can be realized as an attractive means for a high capacity backhauling network for high speed mobile networks using small cell and/or carrier frequency at millimetre-wave.

In [Vall-llosera14] the authors have discussed a strategy for increased capacity based on improving macro cells, increasing density of the macro layer, and adding small cells for indoor users. The authors show the differences between 3GPP RoF solutions and WiFi and conclude that a 3GPP coordinated indoor small cell is the best solution to provide the best mobile broadband experience. One has shown a new architectural all-optical solution, the fibre radio-dot, that brings the macro layer indoors. This solution is an upgrade of the current radio dot system (a radio dot system is an alternative macro base station architecture based on detaching the antenna radio head from the radio units), and uses logical point-to-point connections to the antenna, therefore enabling higher bandwidths and no eavesdropping. Because it is a macro cell solution it offers frequency reuse, low latency, interference management, cell selection and network management, features that non-coordinated solutions cannot provide. The authors have tested a full fibre radio-dot system in the lab, and concluded that their analogue radio over fibre solution meets mobile broadband requirements while using a cost-effective link technology.

The work in [Yamada14] proposes a new type of wireless network named Virtual Single Cell (VSC) network. The VSC network is a small cell network which allows smooth packet transfer to moving terminals as if they stayed in a single cell. Each terminal is closed in an LMC (Logical Macro Cell) which consists of a few numbers of adjacent cells around the cell with the target terminal, and LMC is handed over to follow the moving terminal. If the interruption due to cell to cell move in an LMC is small enough, the total network can be a virtual single cell. The authors of [Yamada14] examine the 3G-LTE based handover procedures for the small cell network under the conditions that the total network is synchronously operated considering the cell size is very small, and cells are contiguously placed. PON with multicast functionality contributes to configuring LMC.

A number of solutions have specifically targeted machine type communications (MTC) communications and the Internet of Things (IoT), where a multitude of heterogeneous access networks are emerging and the integration of them in a single platform ensuring seamless data-exchange with Data-Centres is of major importance. In [Orphanoudakis14] one describes HYDRA (HYbriD long-Reach fibre Access network), a novel network architecture that overcomes the limitations of both long-reach PONs as well as mobile backhauling schemes, leading to significantly improved cost and power consumption figures. The key concept is the introduction of an Active Remote Node (ARN) that interfaces to end-users by means of the lowest cost/power consumption technology (short-range xPON, wireless, etc.) whilst on the core network side it employs adaptive ultra-long reach links to bypass the Metropolitan Area Network. The proposed architecture can enhance performance while supporting network virtualization and efficient resource orchestration based on Software Defined Networking (SDN) principles and open access networking models.

From an optical transmission perspective backhauling solutions are categorized into:

- Pure Backhauling, where the signal is processed entirely at the base station and cells connected at an IP level.
- Radio-over-Fibre (RoF), where the optical carrier is modulated by the RF signal.
- Fronthauling, where the RF signal is sampled and the I/Q samples transmitted digitally over fibre.

There has been over the past few years, in the research community, a trend of moving from backhauling towards fronthauling solutions, as this enables better efficiency and cost reduction from a mobile network perspective. Fronthauling allows reducing processing equipment at each mobile site and centralizing it in one location that can handle all processing required for a number of base stations. Besides enabling lower power consumption and better sharing of processing resources it is also more suitable to implement advanced functionalities such as Coordinated Multi-Point (CoMP) or Inter Cell Interference Coordination (ICIC).

Although fronthauling does have clear advantages from a mobile network viewpoint it does bring some important issue from an optical transport perspective [Pizzinat15], as it poses very strict requirements on the maximum latency budget (lower than 400 μs) and it increases the required capacity by over an order of magnitude compared to backhauling (the typical increase being a factor of 16). While studies have attempted to reduce the capacity requirement by adopting compression techniques [Park14], [Lorca13], and cope with the latency requirements [Tashiro14], it is uncertain whether such technology will prove adequate. The fact that the optical access network needs to be carefully design to accommodate the fronthauling requirements could largely increase its cost and thus offset many of the economic advantages it brings on from a mobile network perspective.

Recently a new research area, dubbed Split Base Station Processing aiming at harnessing benefits from both backhauling and fronthauling has emerged, looking at intermediate solution between the two. The idea is to add some additional signal processing at the base station, compared to the fronthauling solution, to relax latency requirements and reduce capacity occupation. The authors of [Dotsch13] provide an excellent study of different processing splitting options, highlighting benefits and constraints.

From the work carried out over the past decade it is clear that there is much to gain in integrating the mobile and optical access domains and large economic benefits can be achieved by converging multiple services on top of the same optical access infrastructure. There are however challenges to be overcome in assuring tight integration between the two worlds in order to maintain low latency and end-to-end high quality of service, across the two domains.

FUTEBOL is exploring these aspects of network convergence enabling easy access to integrated optical/wireless research infrastructures.

Notable European projects in this domain include: the FP7 project COMBO constructing a fixed-mobile convergence testbed, looking at LTE as mobile technology [Baldo14]; the FP7 project ACCORDANCE which investigates the introduction of OFDMA into a PON architecture offering optical backhauling for wireless and copper based networking[6]; the FP7 project iJOIN which designs an open access and backhaul network architecture for small cells based on cloud networks[7].

25.4 FUTEBOL Approach

The infrastructure and control framework created in FUTEBOL is being federated according to principles developed in the FIRE program and facilities in the two continents interconnected through infrastructure deployed by the FIBRE project, as shown in Figure 25.1.

As mentioned before the main goal of FUTEBOL is is to enable experimental research at the convergence point between optical and wireless networks through the development of research infrastructure between Europe and Brazil. Nevertheless, the following objectives will be also addressed during the project's lifespan:

[6]www.ict-accordance.eu
[7]www.ict-ijoin.eu

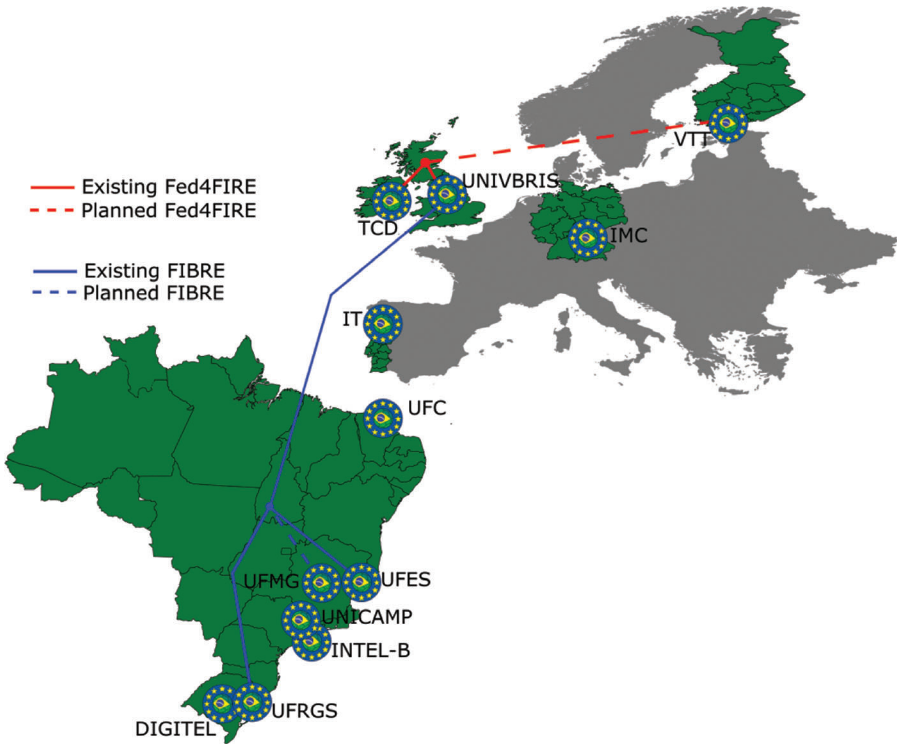

Figure 25.1 FUTEBOL consortium geographically distributed in Brazil and Europe.

- To deploy facilities in Europe and Brazil that can be accessed by external experimenters for experimentation that requires integration of wireless and optical technologies.
- To develop and deploy a converged control framework for experimentation at the optical/wireless boundary, currently missing in FIRE and FIBRE research infrastructure.
- To conduct industry-informed experimental research using the optical/wireless facilities.
- To create a sustainable ecosystem of collaborative research and industrial/academic partnerships between Brazil and Europe.
- To create education and outreach materials for a broad audience interested in experimental issues in wireless and optical networks.

In order to reach the above objectives, FUTEBOL composes a federation of research infrastructure, develops a supporting control framework, and conducts experimentation-based research advancing the state of telecommunications through the investigation of the optical/wireless boundary of networks. Figure 25.2 illustrates the layer natured of FUTEBOL: the end-user driven advancement of telecommunications relies on the development of the FUTEBOL converged control framework, which, in turn, requires the composition of federated research infrastructure. Through this approach,

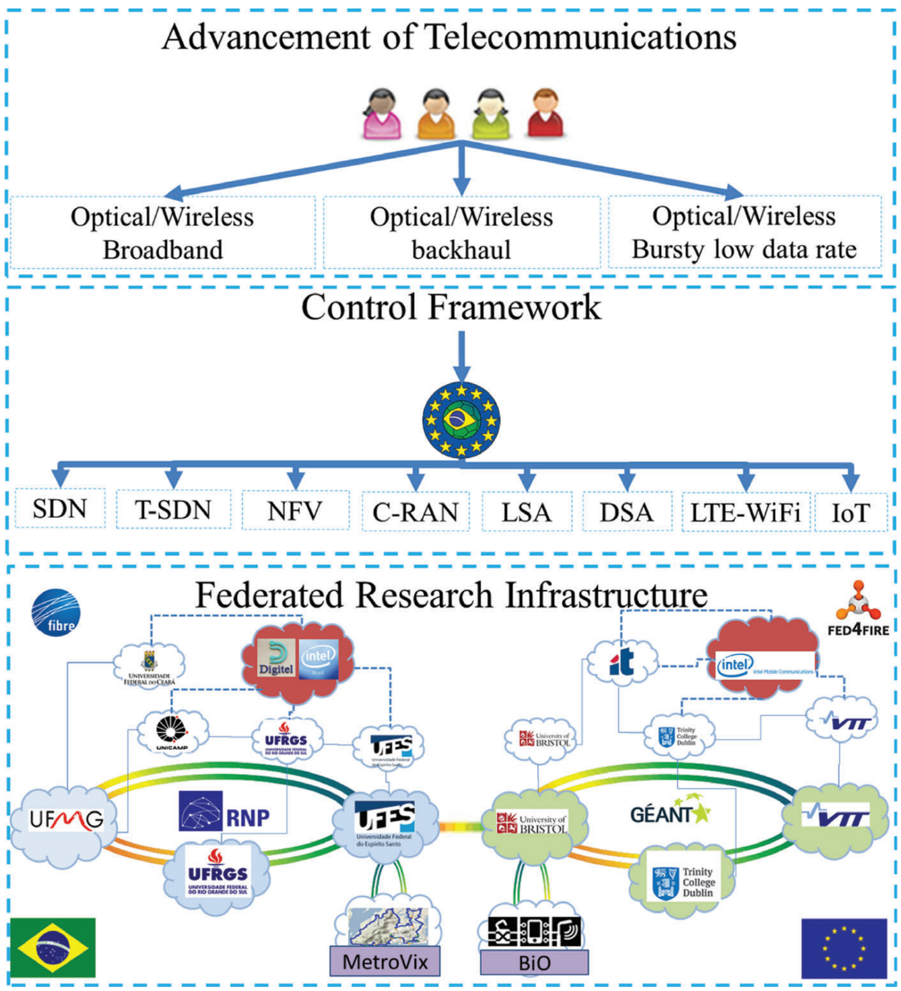

Figure 25.2 FUTEBOL approach.

FUTEBOL provides a complete, top-down development of research infrastructure, tailored to the needs of end-users throughout Brazil and Europe. Moreover, the combination of leading academic and industrial partners within the FUTEBOL consortium provides the key ingredients required to connect the broader telecommunications community to the advancements achieved through research.

European partners, Trinity College Dublin (TCD), University of Bristol (UNIVBRIS), and Teknologian Tutkimuskeskus VTT Oy (VTT), bring to the project mature, proven optical and wireless research infrastructure. While these facilities provide advanced capabilities in both optical and wireless experimentation, there is no converged control framework that enables integrated experimentation at the optical/wireless boundary. FUTEBOL is providing such a framework, federate these facilities with tools derived from the Fed4FIRE[8] project, and open this framework to external experimenters. Brazilian partners, Universidade Federal do Rio Grande do Sul (UFRGS) and Universidade Federal do Espírito Santo (UFES), bring to the project existing FIBRE[9] islands, as a foundation for further expansion through FUTEBOL. Universidade Federal de Minas Gerais (UFMG) will deploy such an island through their involvement in the project. All three of these partners will adopt and deploy the converged control framework developed within FUTEBOL.

25.5 Pushing the Status Quo of Optical/Wireless Solutions

FUTEBOL project envisions three main use cases related to the new requirements faced by the optical network to support substantial changes in the wireless service requirements. Through such showcases, FUTEBOL will be able to push further the current status of the converged solutions.

25.5.1 Licensed Shared Access for 4G Mobile Networks with QoE Support

The cost of network infrastructure is a limiting factor for digital inclusion in Brazil. More available spectrum means less investment in infrastructure which can be a relevant factor to decrease costs and democratize quality access to the

[8]www.fed4fire.eu
[9]www.fibre.org.br

internet in Brazil. Licensed Shared Access (LSA) is becoming an emerging model in Europe that promises to open new spectrum for mobile operators. In European, a 100 MHz frequency band in 2.3–2.4 GHz are expected for LSA to be used by cellular stakeholders on a shared basis. In this context, this experiment will exploit the 4G/LTE LSA trial environment developed by VTT in Finland to demonstrate the viability of LSA as a way to increase capacity with limited infrastructure investment in spectrum bands of common interest for Brazil and Europe.

It is expected that use of LSA will provide more spectrum bandwidth capacity to support a larger number of end-users in certain areas. However, the use of LSA will also increase the network handovers for entering and vacating the LSA band. In this sense, is required to evaluate the impact of LSA on the end-users Quality of Experience (QoE). The performance impact of using LSA will be assessed concerning how it affects the QoE for end-users on the shared spectrum. Additionally, this experiment will evaluate the system performance, functionality and incumbent characteristic of LSA under the latest ETSI specifications.

The main aim of this experiment is to evaluate the latest ETSI specifications about LSA and quantify its performance regarding QoE. Further, this experiment will demonstrate the wireless/optical co-work, through the dynamic reconfiguration of the optical backhaul to deal the rapid increase of wireless capacity due to the use of LSA spectrum opportunities in small cell scenarios.

25.5.2 The Design of Optical Backhaul for Next-Generation Wireless

Extreme cell densification and data rates expected in wireless networks create unprecedented demand on the optical backhaul both in terms of delivering capacity to the appropriate point in the network and in support tight delay constraints for applications reliant on the tactile internet. Following such trends, it becomes apparent that convergence among wireless and optical networks needs to be considered throughout the communications protocol stack, from the physical layer to the network layer and the interface with the service layer. In fact, operators in Europe and Brazil are currently struggling to satisfy the requirements for the 4G wireless access networks using advanced front-/back-hauling techniques. Their first approach was to keep existing wireline and wireless architectures as unchanged as possible. Wireless base-stations have been connected to the core network exclusively via IP. So, in this case, the backhauling network simply needs to provision for tunnels for transporting S1 (i.e. LTE protocol between the base-station and the core-network) and X2 (i.e. LTE protocol for connecting base-stations) packets. The second approach emerged with the cloud radio access network (C-RAN) concept, embedding the wireless subsystem into the wireline network. An architecture capable of supporting the massive deployment of remote radio heads, while providing different degrees of centralized processing, allows for the development of more advanced virtualization solutions at the access segment. A hyper dense deployment of radio elements will open up new research challenges in terms of interference management and mobility and will fundamentally change the needed point of attachment for the fibre optical infrastructure. From the mobile operator point of view, a key requirement of future mobile networks is that this additional network capacity has to be added at the lowest possible cost, in contrast to the current trend of decoupling revenues and traffic. C-RAN will allow for a significant reduction of costs for operators, because part of the RAN computation complexity is moved to the cloud infrastructure.

25.5.3 The Interplay between Bursty, Low Data Rate Wireless and Optical Network Architectures

Machine Type Communication (MTC) is a use case mainly characterized by a very large number of connected devices that typically transmit relatively low volume of data. Most of these services are non-delay-sensitive (e.g., utility metering). Devices are required to be simple and cheap, and have a very long battery life. This use case addresses the needs of a massive deployment of ubiquitous machine-to-machine communication, involving devices ranging from low complexity to those that are more advanced. Ubiquitous devices will sometimes communicate in a local context, which means that the traffic pattern and routes may be different than in cloud or traditional human-centred communication. To integrate the ubiquity of communication in a unified optical/wireless network is a challenge e.g. for applications combining information from different types of sources. Another challenge lies in how to manage the signalling overhead created by the high number of devices. Many devices frequently exchange short bursts of data with their network-side application. When there are no other communication needs, the devices have only a small amount of data to send but nevertheless have to go through a full signalling procedure to transmit the data. This wastes battery life, spectrum and network capacity. To handle this type of transaction more efficiently, the network needs to support a truly connectionless mode of operation, where devices can simply wake up and send a short burst of data. Upon reception of the short burst, device and application-related state information can be retrieved from a controller function and resources to handle the packet allocated accordingly.

25.6 Conclusions

The experimental research infrastructure enabled by FUTEBOL will demonstrate how wireless/optical convergence will support future traffic growth and new mobile services, while limiting the CAPEX/OPEX required to deploy and maintain the network. Moreover, FUTEBOL envisages the creation of a federated control framework to integrate testbeds from Europe and Brazil for network researchers form academia/industry with unprecedented features. Our major goal is to allow the access to advanced experimental facilities in Europe and Brazil for research and education across the wireless and optical domains. To accomplish this goal, we are developing a converged control framework to support optical/wireless experimentation on the federated research infrastructure from all associated partners/institutions. This way, industry-driven use cases can be deployed to produce advances in research at the optical/wireless boundary.

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