

# On Building a Distributed Antenna System with Joint Signal Processing for Next-Generation Wireless Access Networks: The FUTON Approach

Sílvia Pato<sup>†§</sup>, João Pedro<sup>†¶</sup>, João Santos<sup>†¶</sup>, Artur Arsénio<sup>†§</sup>, Pedro Inácio<sup>†¶</sup>, Paulo Monteiro<sup>†§</sup>

<sup>†</sup> Nokia Siemens Networks Portugal S.A., Rua Irmãos Siemens 1, 2720-093 Amadora, Portugal

<sup>§</sup> Instituto de Telecomunicações, Departamento de Engenharia Electrotécnica e de Computadores, Universidade de Coimbra, Pólo II, 3030-290 Coimbra, Portugal

<sup>¶</sup> Instituto de Telecomunicações, Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal

<sup>§</sup> Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal

<sup>¶</sup> IT-Grupo de Redes e Multimédia, Departamento de Informática, Universidade da Beira Interior, Rua Marquês de Ávila e Bolama, 6201-001 Covilhã, Portugal

<sup>§</sup> Instituto de Telecomunicações, Campus Universitário de Santiago, Universidade de Aveiro, 3810-391 Aveiro, Portugal  
Phone: +351-214167471, Fax: +351-214242082, e-mail: [silvia.pato@nsn.com](mailto:silvia.pato@nsn.com)

**Abstract** — The growing relevance of wireless communications in our daily lives has been driving the research and development of advanced network architectures to enable the cost-effective support of a large numbers of users at very high data rates. In this context, the FUTON project aims to fulfil the objectives of the so-called 4<sup>th</sup> Generation (4G) systems, developing and validating an innovative Distributed Antenna System (DAS) with centralized signal processing. FUTON also accounts for the support of legacy systems and for the coexistence of multiple Radio Access Technologies (RATs) over a single optical fibre infrastructure, which reduces the operational expenditures of network operators when upgrading their wireless systems.

## I. INTRODUCTION

This paper focuses on the main contributions provided in the scope of the FUTON project. In this context, the founding motivations and intentions driving the project are introduced and clarified. Therefore, the most relevant challenges imposed by the approaches proposed in FUTON are also presented and described in detail.

The remainder of the paper is organized as follows. Section II introduces the motivation behind FUTON. Section III gives an overview of the FUTON approach, whereas section IV identifies its main challenges. Finally, section V presents some final remarks.

## II. MOTIVATION

### A. Requirements of Future Wireless Systems

The main goal of the *information society* is to provide broadband services to everyone. Reaching such goal has been often promised through the deployment of optical fibre in the form of Fibre-to-the-Curb (FTTC) and Fibre-to-the-Home (FTTH) implementations. However, the impact of wireless

telephony and wireless LANs in society has been of such magnitude that the liberation of a wired connection created in the end user a sense of autonomy that he/she is compelled to preserve. In fact, being able to benefit from the high capacities envisioned for next-generation fixed access networks, while keeping the abovementioned autonomy, would certainly represent the most desirable scenario from an end user point of view. This is one of the objectives addressed by the International Mobile Telecommunications-Advanced (IMT-A) systems, which go beyond the capabilities of IMT-2000. In particular, it specifies data rates of up to 1 Gb/s for low mobility users (e.g. pedestrians) and up to 100 Mb/s for high mobility users (e.g. travelling by car or train) [2]. Clearly, attaining these values in a cost-effective manner an important technical challenge.

### B. Distributed Antenna System

Future wireless systems, namely the ones targeting the demanding IMT-A objectives, may be implemented with a Distributed Antenna System (DAS). In theory, DAS provides a number of advantages over the conventional systems, such as lower cost, increased flexibility, improved performance and capacity. DAS consists of spatially separated antennas, which are connected to a Central Unit (CU) via a transmission medium, like coaxial cable or optical fibre. The immediate advantage over a conventional single antenna system is that the same area can be covered with less power and improved reliability, because line-of-sight is present more frequently and power losses from penetration and shadowing can be more easily reduced. As described in the next section, FUTON exploits DAS in several ways.

## III. FUTON APPROACH

The FUTON project [1] aims to develop a hybrid fibre-radio network that interconnects multiple Remote Antenna Units (RAUs), transparently carrying radio signals to/from a CU, where joint processing takes place. The objectives of this project are aligned with the specifications of 4<sup>th</sup> Generation (4G) wireless networks.

The generic architecture of FUTON is intended to cover a geographical area that is divided into several serving areas, where the multifrequency RAUs are located. These RAUs

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This work was supported in part by the European Commission, in the context of the project FUTON “Fibre Optic Networks for Distributed, Extendible Heterogeneous Radio Architectures and Service Provisioning”, grant agreement FP7 ICT-2007-215533, and by *Fundação para a Ciência e a Tecnologia* (FCT), under the research grants SFRH/BDE/15652/2007 and SFRH/BDE/15643/2006.

are linked to a CU, using a transparent optical fibre system, and can send/receive signals from different wireless systems.

The processing tasks concerning all communications within a serving area are performed at the correspondent CU. For distributed wireless systems, the availability of the radio signals at a common location allows the joint processing of the signals from different RAUs, enabling the development of virtual Multiple-Input Multiple-Output (MIMO) concepts for broadband wireless transmission and also inter-cell interference cancellation. In addition, heterogeneous wireless systems can be co-localized, which allows the use of a common management platform. In this context, cross-layer algorithms may be developed to optimize the usage of the radio resources, and may be generalized to cross-system model, enabling the development of efficient Common Radio Resource Management (CRRM) algorithms. Fig. 1 depicts the FUTON scenario where several systems coexist in the same serving area, representing also the main modules of the CU to which all of those systems are connected.

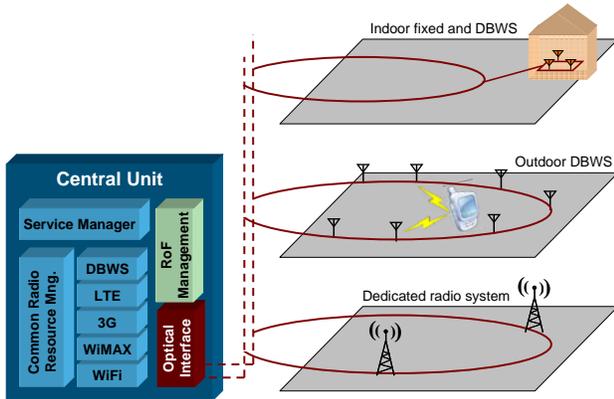


Fig. 1. FUTON generic architecture.

From a practical point of view, FUTON consists of a fixed infrastructure that provides enough flexibility to share its resources by a wide range of wireless systems and by fixed optical connections, instead of being dedicated to a single system. The supported systems should include, among others, outdoor Distributed Broadband Wireless Systems (DBWS), where the infrastructure acts as a virtual MIMO enabler to achieve the target high bit rates, indoor distributed broadband systems, and also the remote control of dedicated radio systems. DBWS is the technology envisioned within the scope of FUTON to cope with the IMT-A requirements. Its operational model includes functionalities of the three bottom layers of the OSI model.

#### IV. MAIN CHALLENGES OF FUTON

In view of the innovative steps behind it, the achievements proposed in the FUTON project comprise a collection of technical challenges that require proper understanding. These challenges include the definition of the fibre optic

architecture used to transport and distribute the wireless signals between CUs and RAUs, the specification of the Radio-over-Fibre (RoF) manager entity that controls the optical infrastructure, the conception of fixed-wireless convergence scenarios enabling the coexistence of a plurality of communication technologies, and the implementation of the CRRM functions for improving the RAT actions and interoperability.

#### A. Fibre optic architectures

The FUTON optical-radio infrastructure should provide reliability and flexibility, and the most effective way to achieve these goals is to use a combination of Radio Frequency (RF) translation with Sub-Carrier Multiplexing (SCM) over Wavelength Division Multiplexing (WDM). The combination of these techniques allows one to maximize the infrastructure transparency, making it future-proof. However, the coarser form of WDM, Coarse WDM (CWDM), may be the most appealing one, as it enables using less-expensive and uncooled electro-optical components. In this scenario, each RAU is assigned unique wavelengths and the different antenna elements within the same RAU (or associated with different wireless systems) are separated using SCM.

Regarding the topology, a passive tree-and-branch layout should be preferably used in the connection between the CU and the RAUs. This topology is preferred over others because it simultaneously enables the minimization of the fibre layout and the optimization of resource sharing. Moreover, passive architectures are preferred over active deployments for FUTON systems due to their lower CAPEX and OPEX. This argument can also be supported by the standardized Passive Optical Network (PON) concepts and deployments.

Several deployment schemes and technologies may be envisioned, depending on the implementation scenario and target network cost. The one selected as the most adequate to the FUTON requirements uses a single CDWM mux/demux placed in a splitting point near the area comprising the set of RAUs connected to that CU. In this architecture, represented in Fig. 2, each RAU is served by a unique uplink and downlink wavelengths. If no Space Division Multiplexing (SDM) is used, up to 8 RAUs may be supported (considering the 16 CWDM channels available), but this architecture was proven to be less-expensive than others, since it uses CWDM low-cost optical equipment both in the network ends and within the fibre plant.

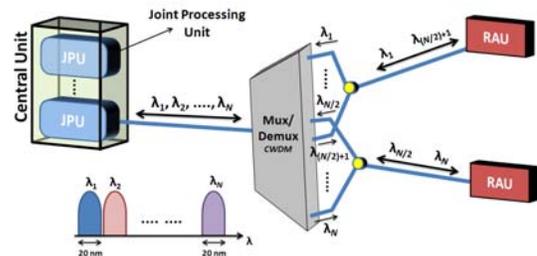


Fig. 2. CWDM architecture selected for FUTON.

Independently of the architecture, a monitoring channel is necessary by the Middleware and Network Manager components, to manage the RoF infrastructure. It is expected to be implemented as a low data rate digital channel, supported in baseband or as an additional sub-carrier.

### *B. RoF Manager*

The RoF Network Manager is expected to manage the network equipment and the communication links, while enabling end-to-end service problem resolution and service quality management by the FUTON Middleware (this is depicted in Fig. 1).

As previously mentioned, FUTON optical infrastructure will carry radio information from/to the wireless infrastructure. Therefore, both optical components (as well as other hardware at the CU, System Database, Firewalls) and RAUs (including also antenna elements) will have to be properly monitored and configured. RoF Management functions are hence tightly correlated with the definition of the radio and optical interface, physical layer algorithms in place, and radio resource management algorithms proposed and evaluated in the project, and which have to be integrated and cooperating with the RoF Manager entity.

The new FUTON optical-radio architecture brings new challenges regarding the network management, fostered from the use of multiple technologies derived from heterogeneous wireless access networks. Hence, FUTON aims at technology agnostic, multi-layer services management, in order for the management of deployed services to become independent of the underlying technology. Improved scalability will imply the possibility to manage more resources over more technology-diverse networks.

The objectives of FUTON Network Management System (NMS) are hence aligned with the NMS specifications for Next-Generation Networks (NGN). The RoF Manager architecture includes cooperative RoF Manager instances per CU to manage a multitude of network domains over different technologies. The management solution must therefore cope with the provisioning, connection outage, and performance management of the RoF infrastructure through re-usable components that may be applied in all network management sub-systems.

A telecommunication network gathers long logging entries into their databases, being this data periodically collected, or event-triggered, from the network. The amount of such measurements, which are statistically treated, are growing very rapidly, as well as the underlying monitored sub-systems complexity. This data may contain alarms associated to system faults, or else performance bottleneck indicators, to which the network management system has to react very rapidly. One current challenge within such systems is to reduce the amount of alarms and indicators displayed to a human operator (since the amount of variables monitored may reach the hundreds), by correlating these to eliminate the most redundant ones. A scenario to be investigated relates

therefore to fault propagation, which is especially important on RoF scenarios, in which certain faults might only be detected at the Central Unit where data is processed, while the origin of the problem may be on the optical link, at the Optical Network Terminal or even at the RAU.

On the other hand, fault propagation over multiple technologies brings as well new challenges: the correct identification of the faulty source, the impact on deployed services of such faults or performance impairments, and assurance of service levels over FUTON heterogeneous mobile networks.

Through Artificial Intelligence (AI) techniques such as data mining, the RoF Manager should also be able to act proactively to solve potential faulty or performance bottleneck problems before they occur. Data mining techniques can therefore be used to predict network behaviour and to detect deteriorating network conditions and ultimately prevent network outages through faults. Network models created during a learning phase, using collected measurements of various aspects of network performance, can alert administrators to impending problems so that counteractive measures can be taken. Offline operation of this mechanism should also be useful, for instance to estimate how network growth may affect performance metrics.

A last challenge concerns multi-layer resilience, flexibility, reconfigurability and upgradeability of the RoF network management system.

### *C. Fixed-wireless convergence*

From a deployment perspective, the simultaneous support of both wired and wireless/mobile communication technologies over the same access infrastructure creates the opportunity for increasing the OPEX and CAPEX savings. In the current telecommunication landscape, there is a clear differentiation between both: wireless systems are connected through leased line services (such as E1/T1) transmitted over copper (most common solution) or fibre, or microwave-based point-to-point links; wired systems typically rely on the reuse of the Public Switched Telephone Network (PSTN) copper plant, or the Hybrid Fiber-Coaxial (HFC) network initially devised for analog TV broadcasting or, more recently, in optical fibre generally applied in PON implementations.

Presently, the remarkable widespread adoption of broadband connectivity services (in both wireless and wired flavors) is pushing service providers and network operators into renovating their physical structures. For the fixed network case, the most future-proof option is to replace physically stressed copper and coaxial cables with fibre lines. This has boosted the deployment of several PON systems, such as the Gigabit-PON (GPON) and the Ethernet-PON (EPON). PON technology uses fibre-based passive tree-and-branch topologies for the delivery of data rates ranging from 1 Gb/s from to 2.5 Gb/s. These bit rates are time-shared by the active users whereas only two wavelength channels (one for the downlink and another for the uplink) are reserved.

The attention gathered around xPONs has been such that both ITU-T and IEEE standardization bodies felt compelled to start the specification of next-generation 10 Gb/s xPON systems. In the wireless perspective, the revolution has been mainly centered on innovative radio protocols and transmission techniques (e.g. Orthogonal Frequency-Division Multiplexing, OFDM). While current packet-based technologies, such as High-Speed Packet Access (HSPA), are already consuming most of the available base-station capacity, it is foreseen that future technologies, namely the most recent Long Term Evolution (LTE) specification, will surely surpass the network resources. Hence, it becomes evident that both wired and wireless operators require higher bandwidth capacities to satisfy the end-user demands.

In this view, joint efforts from both telecommunication industry branches can be undertaken to exploit the virtually-infinite bandwidth capabilities of the optical fibre. This engagement is perfectly aligned with the FUTON propositions since the RAT diversity can be allied with the coexistence of fixed services over the same physical medium. In fact, by using fibre to distribute the RoF signals between the CU and the RAUs, the remnant optical spectrum can be exploited to carry fixed-based digital communications, such as xPON, Ethernet, etc. An example of such scenario is illustrated in Fig. 3. In the case depicted, the CU that manages the RAUs can be installed in the Central Office or Distribution Node enclosures.

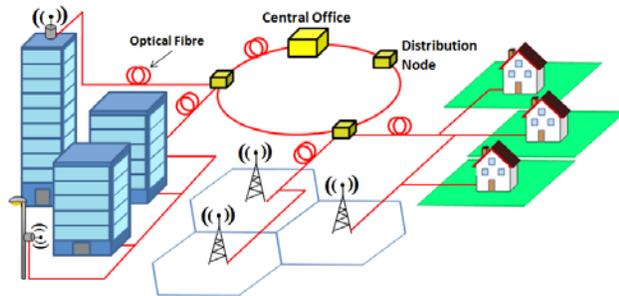


Fig. 3. Fixed-wireless network convergence scenario.

#### D. CRRM Architecture

A very important part of the FUTON project concerns the architecture of the CRRM, whose delineation draws on the combination of DAS with centralized processing. The CRRM of FUTON addresses not only the resources allocation schemes for the several Radio Access Technologies (RATs), as the interference mitigation solutions, which benefit from the centralization of the resource management. Since the CRRM plane has the highest perspective of the entire DAS, it should enable, together with the RoF Manager, seamless and heterogeneous service provisioning to an end-user, while simplifying and reducing management costs for network operators. Vertical handover of users between several RATs is leveraged in such systems, and enables the overall network to balance loads, serve more users, increase the Quality of

Service (QoS) and, potentially, increase the coverage area (via interference reduction).

The FUTON CRRM functional model is inspired in the reciprocal model of the 3<sup>rd</sup> Generation Partnership Project (3GPP), which divides the set of radio resources into radio resources pools. Each pool is then of the responsibility of Local Radio Resource Management (LRRM) entities, which report and receive assignments from the CRRM. In a FUTON implementation, the LRRMs are proposed to be modules of the CU. The functionalities of LRRMs are confined to Power Control, Packet Scheduling and Horizontal Handover (handover within the same resource pool); while the CRRM functionalities include Admission Control, Load/Congestion Control, Vertical Handovers and Policies Definition. The fact all entities are at the same site results in smaller decision delays and in bandwidth savings.

In order to completely exploit DAS, the CRRM entity has to be envisioned to interact with the DBWS, which presumes that the former has access to network state information with a high degree of granularity. This interaction enables implementation of dynamic resource allocation schemes, packet scheduling algorithms and selection diversity mechanisms for reduction of interference or signal recovery.

#### V. CONCLUSIONS

The FUTON project elaborates on the combination of DAS with centralized processing to cope with the expectations of wireless technology users. The attractiveness of the solution lies in the advantages of carrying the radio signals to a central unit in a technology agnostic manner, and on the centralized management of the resources of the network. The cost of deployment is reduced, since the physical space to install FUTON compatible antenna units is smaller than for typical base stations. Simplified vertical handover enables the system to switch users between several technologies conditioned by QoS and load balancing requirements, instead of forced by service continuity requirement or coverage issues.

#### REFERENCES

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- [2] ITU-R Rec. M.1645, "Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000", 2003.