

The FUTON Prototype: Proof of Concept for Coordinated Multi-Point in Conjunction with a Novel Integrated Wireless/Optical Architecture

Fabian Diehm, Patrick Marsch, Gerhard Fettweis

Vodafone Chair Mobile Communications Systems

Technische Universität Dresden, Germany

Email: {fabian.diehm, marsch, fettweis}@ifn.et.tu-dresden.de

Abstract—The growing relevance of wireless communications has been driving the research and development to enable cost-efficient support of very high data rates to be delivered to a large number of users. The high bandwidth targets for future networks are reflected in the ITU's call for IMT-Advanced. As interference poses the main limitation in today's networks, cooperative signal processing (often referred to as coordinated multi-point, CoMP) is seen as a key enabler to achieve these targets. However, cooperation among base stations in traditional cellular infrastructures is problematic because interconnections (referred to as backhaul) are often very limited in capacity and investigations on more flexible and cost-efficient future architectures are being undertaken. A promising concept was proposed in the European research project FUTON. It is based on the use of radio-over-fiber (RoF) technology to create a distributed antenna system (DAS) that is capable of supporting the high requirements of future wireless networks. Currently, a prototype FUTON system is being built as a proof of concept. In this contribution, we describe the FUTON architecture and give insights into the demonstration that is being prepared. Results from trials with the planned setup will follow.

Index Terms—FUTON, optical/wireless integration, RoF, distributed antenna systems

I. INTRODUCTION

The rapid growth of mobile communications has led to a highly increasing demand for wideband high data rate services. Many services enabled by wired networks are now pushing into the wireless domain and are generally characterized by high quality of service requirements like high bandwidth and low latency. Examples of such sophisticated services are video streaming and video conferencing. The provision of these services to a large number of users is currently the main driver for research and development of advanced network technologies. While the industry is trying to meet the increasing user demands, it is simultaneously facing diminishing revenues, as users become more and more accustomed to the cheap availability of wireless services. Thus, from an economical perspective, next generation systems are required to meet the

high user demands, while keeping the total cost of ownership (TCO) of the networks as low as possible.

The objective of true mobile broadband wireless access has also been addressed by the ITU in their call for IMT-Advanced (IMT-A). In particular, IMT-A specifies data rates of up to 1Gbps for low mobility users (e.g. pedestrians) and up to 100Mbps for high mobility users (e.g. traveling by car or train) [1]. The considered technologies (LTE and WiMAX) for the succession of the currently deployed third generation wireless cellular networks will not be able to meet the IMT-A requirements yet. Steps towards a radio access technology (RAT) that is able to realize the targets of IMT-A are now being undertaken with the definition of LTE-Advanced.

Since spectrum is a scarce resource, the IMT-A requirements can only be met if spectral efficiency is significantly increased. As high spectral efficiency requires high degrees of spectrum reuse in cellular systems, interference strongly increases and puts a tight cap on the achievable system capacity. To overcome this limitation, cooperative signal processing is seen as a key technology for LTE-Advanced. In cooperative networks, signals transmitted by or received from spatially separated antenna sites are jointly processed, enabling so called coordinated multi-point (CoMP) techniques. These techniques allow for mitigating interference or even exploiting it for gains in spectral efficiency (e.g. through the use of multi-user MIMO). However, in traditional cellular systems cooperation is difficult to realize, as backhaul capacity is often scarce. Thus, new architectures are of interest to support the requirements of future wireless technologies.

In the wired domain, optical fibers play a vital role in delivering high bandwidth data services. While the core and metro networks already fully rely on optical links, traditional copper-lines to the subscriber premises are gradually being replaced by deployments of Fiber-To-The-Curb (FTTC), Fiber-To-The-Building (FTTB) or even Fiber-To-The-Home (FTTH). The triumph of optical fibers in many segments of telecommunication originates from its ability to support very high data rates in a cost efficient manner. This is mainly due to the medium's inherent broadband and low-attenuation characteristics, which allow the transportation of data over large distances.

Within the European research project FUTON (Fiber Optic

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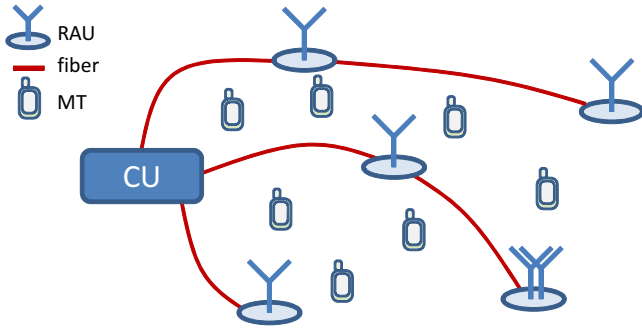


Fig. 1. System architecture

Networks for Distributed, Extendible, Heterogeneous Radio Architectures and Service Provisioning) a novel integrated wireless/optical system architecture was developed that enables wireless services to meet the IMT-A requirements in a cost-efficient manner. The FUTON consortium is comprised of 16 partners from industry and academia from various European countries, bringing together strong expertise in both, wireless and optical technology [2]. In the proposed architecture, low complexity antenna units are transparently connected via optical fibers to a central processing unit (CU), which performs joint signal processing and resource management. Thus, CoMP techniques can easily be applied. Throughout its development, economic viability has been one of the focus areas of the concept. It is delivered through low complexity hardware, great flexibility and compatibility to existing radio access technologies. Also, the possible convergence of wireless and wired services that can capitalize on the increasing penetration of fibers for fixed access services is a viable prospect to cut the network TCO. To demonstrate the capabilities and the feasibility of the FUTON architecture, a prototype is currently being built to deliver a proof of concept.

In the following, we describe the FUTON architecture in more detail and give an overview of the demonstration setup and planned measurements. Finally, the paper is concluded with an outlook. First measurement results from this proof of concept will be presented at the workshop.

II. THE FUTON ARCHITECTURE

In the FUTON architecture, low complexity remote antenna units (RAUs) are transparently connected via optical links to a central unit (CU), where joint signal processing and resource management is performed. Figure 1 depicts the system architecture. As the RAUs form a distributed antenna system (DAS), this infrastructure allows to employ various CoMP techniques such as multi-user MIMO to greatly enhance throughput and coverage in the service area. Furthermore, the architecture is not specific to a certain radio access technology (RAT) so that multiple wireless standards can make use of the infrastructure. This not only enables efficient cross-layer algorithms to be implemented at the CU, but also cross-system algorithms and mechanisms for vertical handovers between the systems. The support of legacy systems also make the concept

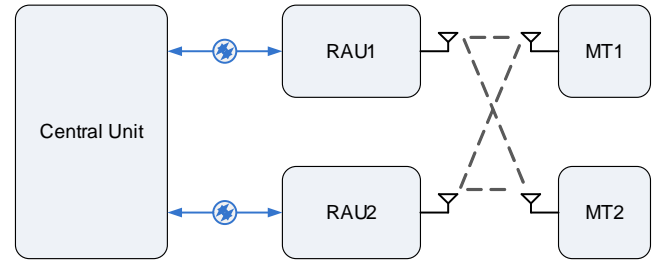


Fig. 2. Demonstration scenario

very attractive from a TCO point of view. The broadband RAT that utilizes the FUTON architecture to achieve the IMT-A targets is referred to as Distributed Broadband Wireless System (DBWS) and is in the focus of the demonstration.

Outside the FUTON project, the concept of remote radio heads (RRHs) has already experienced much attention. As it allows for flexible deployments and great CAPEX and OPEX savings due to low complexity hardware and low site acquisition costs, it has found widespread adaption. In this context, two specifications have emerged recently. Namely, Common Public Radio Interface (CPRI) [3] and Open Base Station Architecture Initiative (OBSAI) [4]. They specify a digitized and serial interface between the RRHs and a digital base station (DBS) containing the baseband processing functions of traditional base stations. Currently, the specifications cover UMTS, WiMAX and LTE. The links between the DBSs and the RRHs use digital optical transmission. However, current standards do not make use of the increased degrees of freedom offered by distributed antennas.

Unlike these concepts, the RAUs in the FUTON architecture are connected to the CU via Radio-over-Fiber (RoF) technology, where the light in the fibers is modulated by the analog radio signals. The advantages of analog fiber transmissions are that they support higher bandwidths and are much more cost-efficient [5]. Signals from the CU to different antennas of a site and to different RAUs can be multiplexed onto the same optical fiber by employing Wavelength Division Multiplexing (WDM) and Subcarrier-Multiplexing (SCM). Another advantage of RoF technology is that it shifts complexity from the RAUs to the CU, as digital-to-analog conversion (DAC) and IQ-modulation components are not required at the RAUs [5]. On the downside, analog optical transmission limits the achievable dynamic range performance in wideband systems and non-linear distortions degrade the signal quality. However, dynamic range requirements can be reduced through uplink power control and automatic gain control [5] and the nonlinear distortions can be compensated in the digital baseband as e.g. described in [6].

For more details on the FUTON architecture and the FUTON project, please refer to [2], [7], [8].

III. THE FUTON PROTOTYPE

The DBWS that was specified as part of the FUTON project comprises a collection of MAC-, PHY- and cross-layer

unit at the MT, analog radio signals are exchanged on a frequency of 50MHz.

- 5) **Reference Generator:** The reference signal generator ensures synchronous transmission and reception on the CU side. This is especially important to guarantee that the employed oscillators are not impaired by different phase noise processes, which can lead to severe performance degradations.

IV. PLANNED MEASUREMENT AND EVALUATION

As stated in the last section, the demonstration setup will comprise one CU with two single-antenna RAUs jointly transmitting to two MTs. In the planned trials, the terminals will be moved in such a way that a variety of different interference scenarios is generated - from symmetric cell-edge or cell-center scenarios to asymmetric interference scenarios. In each location, the MTs will further be moved on a small-scale (translation on the order of a few centimeters as well as rotation), to assure that for each large-scale fading realization the MTs are subject to a representative number of fast fading realizations. The quantities measured will be

- **SINR values with and without CoMP.** In our setup, it is possible to apply CoMP to some OFDM subcarriers used for transmission, while conventional non-cooperative transmission is performed on others. This way, the gain of CoMP can be measured explicitly through an increase in signal-to-interference-and-noise-ratio (SINR) on corresponding subcarriers.
- **Achievable data rates with and without CoMP.** By transmitting reoccurring sequences of modulation and coding schemes (MCS) that represent different data rates and evaluating the decoding success, it is possible to observe the rates that can be achieved with or without the usage of CoMP.

One main intention of the FUTON demonstration is to prove the concept of RAUs connected to a CU via RoF, as an enabler of CoMP. However, the optical links are not completely transparent as transmitted signals are subject to degradation due to non-linear fiber characteristics. We intend to use different lengths of fiber-optic cables in the demonstration setup to evaluate how cable length affects the CoMP performance. In the context of OFDMA systems, it is particularly interesting to observe asymmetrical RoF scenarios, where the two RAUs experience a significant difference in RoF propagation delay, as this can lead to inter-symbol interference (ISI) that requires more complex baseband equalization [12].

V. OUTLOOK

The novel hybrid optical/wireless infrastructure proposed in the FUTON project has a lot of potential to meet the requirements of future networks and service demands, since RoF is a very promising technology to facilitate CoMP. However, as the replacement of all legacy infrastructure by fiber is a big undertaking, it is unlikely that RoF will be used as the sole technology to facilitate CoMP in the near future. Instead, we can expect to find heterogeneous infrastructures,

where microwave links or other legacy infrastructure are used to connect RAUs in addition to RoF. Also, decentralized approaches are currently being investigated, that facilitate more limited CoMP techniques under the constraints of today's infrastructure (i.e. mainly strong backhaul limitations). In [10], [11] it is e.g. shown that decentralized interference cancellation or avoidance schemes in uplink or downlink, respectively, can be very backhaul efficient. The proposed schemes are based on the exchange of data bits between cooperating base stations rather than an exchange of modulated signals. Thus, an interesting future research topic is the determination of most suitable cooperation strategies and RoF/backhaul deployments for particular signal propagation scenarios.

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