

# Coordinated fibre and wireless spectrum allocation in SDN-controlled wireless-optical-cloud converged architecture

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**Abstract** We provide an experimental demonstration of LTE multi-cell resource allocation in a converged LTE-over-PON architecture. Our SDN controller dynamically adjusts the wireless bandwidth of each cell, according to their demand, jointly with their fronthaul rate and reserved PON capacity.

## Introduction

In next-generation mobile networks, Cloud Radio Access Network (C-RAN) is a promising solution for massive cell densification<sup>1</sup>. One main advantage of C-RAN is the simplification of the Remote Radio Head (RRH) functionality, which decreases its size, power consumption and overall cost. Another advantage is the centralization of Baseband Unit (BBU) processing through BBU pooling, which enables resource sharing and raises advanced options of joint inter-cell and multi-user coordination such as Coordinated Multi Point transmission and reception (CoMP), enhanced Inter-Cell Interference Coordination (eICIC) or multi-cell packet scheduling, etc. C-RAN can adopt different types of functional splits which separate the signal processing and protocol functionality between the RRH and the BBU<sup>2</sup> in different ways. The type of functional split used has a direct impact on the resource and performance requirements for the link between RRHs and BBUs<sup>3</sup>.

Fronthaul (also called split 8) typically refers to a complete centralized functional split where the RRH performs only RF signal up-/down-conversion, digital-/analogue-conversion, and basic signal conditioning. All the baseband processing is carried out at the BBU pool, thus maximising the amount of shared infrastructure and minimising energy consumption. It is envisaged that in the future it will coexist with other functional splits<sup>3</sup>. In the split 8 the BBU-RRH link exchanges pure or compressed I/Q-data under a conventionally fixed data rate, independent of the actual demand of the mobile subscriber. This approach accounts for the maximum potential demand, which translates into a maximum transmission rate. While Passive Optical Networks

(PONs) could in principle provide cost-effective fronthaul to multiple RRHs<sup>4</sup>, by multiplexing multiple cells over each wavelength channel, the fixed fronthaul rate highly reduces such advantages, as it eliminates the ability to statistically multiplex across the fronthaul streams.

In<sup>5</sup>, we demonstrated the concept of adaptive variable-rate fronthaul, which is enabled by Software Defined Network (SDN) and statistical Time Division Multiplexing (TDM). There, the SDN controller interacted with the BBU to monitor the cell usage, and in response adapted the cell wireless bandwidth. In our solution, a reduction in the wireless bandwidth requirement triggered a reduction of the fronthaul sampling rate, which in turn reduced the required capacity over the PON. The SDN controller coordinated the capacity adaptation between the BBU, the RRH, and the PON, so that any freed-up capacity could then be re-used by other lower-priority services.

In this paper we propose a demonstration that extends our adaptive variable-rate fronthaul idea to a multi-cell scenario, where we carry out joint coordination of optical and wireless bandwidth. The demonstration has been developed within the European H2020 collaborative project FUTE-BOL as part of one of the experimental use cases, involving multiple partner sites. On the University of Bristol side (UnivBris), ABNO Orchestrator (application-based network operations) is in charge to orchestrate the provision of service across a core network domain located at UnivBris and a metro access network domain placed at Trinity College Dublin (TCD). The core network at UnivBris is a meshed optical and OpenFlow network that provides a route from hosts in the cloud layer to the access port which gives access to inter-testbed communication. Further, ABNO

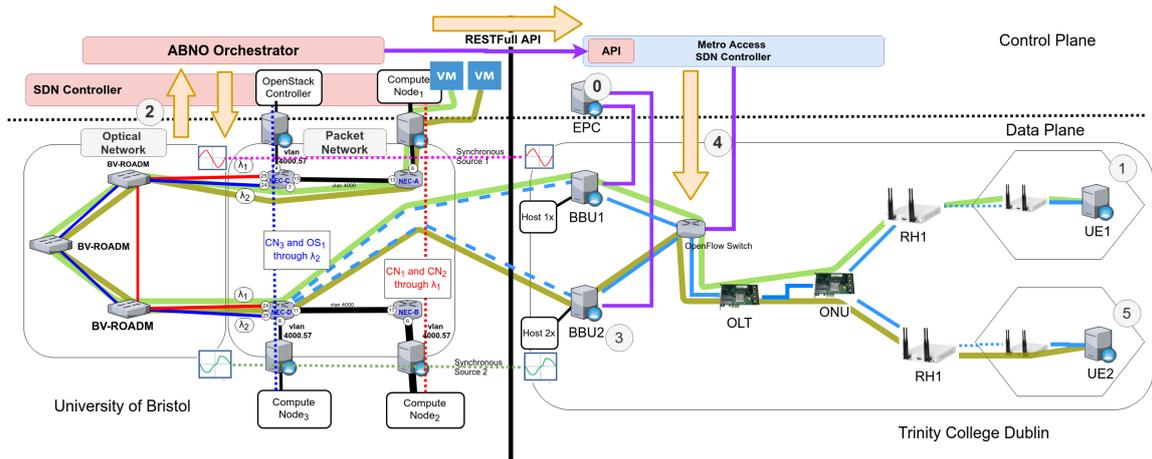


Fig. 1: Experimental setup

can access the SDN controller located at TCD through the control plane channel to configure the fronthaul rate of each cell, so enabling dynamic physical resources configuration at TCD from UnivBris. On the TCD side, the SDN controller in the metro access domain coordinates spectrum reuse across multiple adjacent cells. The cell bandwidth will be dynamically modified as users move across the cells so that higher bandwidth sets to cells with higher demand. It enables efficient frequency reuse across adjacent cells, especially at the cell edges. In addition, and this is the main advantage of our proposal, since the fronthaul rate of each cell over the PON is proportional to the cell bandwidth, by increasing/reducing a cell bandwidth, we also increase/reduce the cell fronthaul rate, thus the PON capacity is also dynamically redirected towards the cell with higher bandwidth. This synergy across the optical and wireless bandwidth allocation greatly improves the statistical multiplexing properties of the entire optical-wireless system.

In summary, we demonstrate the performance of multi-cell resource allocation using a testbed facility that converges C-RAN, LTE and PON technologies with a software defined optical core. Our experiment results show that we can achieve dynamic fixed-mobile network capacity reconfiguration in seconds (although the control plane is capable of reconfiguring the system in sub-second time). To the best of our knowledge, our demonstration is the first multi-cell dynamic resource allocation experiment for a LTE-PON integration with open-source LTE software.

### Experimental Setup

Our testbed setup is shown in Fig. 1. The PON system provides shared downstream connectivity to two fronthaul links. The two ONUs are mul-

tiplexed into one physical FPGA device, where each is assigned to a different 10G Ethernet port. A Metro-Access switch (Pronto 3270 Openflow) separates the two links logically via VLAN tags, before aggregating them for transmission. In this experimental setup, while the upstream link is active, the main traffic flows operate downstream. While fronthaul-over-PON is challenging in upstream, its feasibility has been demonstrated in<sup>6</sup>, where the PON DBA is coordinated with the BBU scheduler. The PON OLTs and ONUs are built on Xilinx FPGA development boards VC709<sup>7</sup> and have been implemented following the ITU-T XGSPON standard in most parts<sup>8</sup>.

The BBU part of the wireless LTE system is implemented through the open source srsLTE library<sup>9</sup>, which provides the building blocks for implementing LTE prototypes in SDR. In our previous publication<sup>5</sup> we only made use of the LTE physical layer, because the MAC layer had not yet been released as open source. In this current experiment, we make use of the full-stack LTE system, e.g., including the MAC, enabling full end-to-end communication. We have modified the implementation of the eNodeBs, to allow dynamic reconfiguration of bandwidth of both the Physical Downstream Shared Channel (PDSCH) and the Physical Upstream Channel. This is achieved by reconfiguring the number of Physical Resource Blocks (PRBs) used by the signal, which affects the bandwidth, sampling rate, FFT size and other signal processing blocks.

The RRH part is implemented using the USRP X310 reconfigurable radio device, which directly connects to the ONU through a 10G Ethernet interface. In the downstream direction, the BBU sends I/Q samples over the PON towards the USRP board, which operates digital-to-analogue conversion and upconverts the signal to the 2.5

GHz ISM band. The LTE user equipment (UE) is implemented through a USRP B210 radio device, linked to a server implementing the full-stack LTE UE (also open-source from srsLTE). In our setup, the Core domain controller collects flow statistics for both channels of the mobile network load.

With reference to Fig. 1, we reproduce a scenario where there are two mobile users, UE1 and UE2, each assigned a basic bandwidth allocation that is sufficient to conduct low bit rate communications, for instance sending e-mail or browsing. In the figure, event 0 relates to the identification and authentication of the UE devices by the EPC (Evolved Packet Core) MME (Mobile Management Entity) and HSS (Home Subscriber Server). When user A starts using a higher bandwidth service (Event 1), the increase in capacity at the BBU side is detected by the Core domain controller (Event 2), which increases the mobile capacity by sending instruction through the restful API to Metro-Access Controller (implemented in RYU<sup>10</sup>), which in turn instructs the BBU to change the PRBs (Event 3) and reconfigures the Openflow switch to guarantee capacity to the front-haul link over the PON (Event 4). We use Table 1, empirically derived in our previous experiment<sup>5</sup>, and revalidated in this experiment, to correlate the relationship between channel bandwidth, front-haul rate and cell capacity. Once the data stream terminates, the Core domain controller detects a cell load that is below the current cell capacity and it triggers the reduction of the mobile bandwidth for that cell. The additional capacity available over the PON can thus be reassigned to the other cells, together with the freed spectrum resources.

When the BBU updates its wireless bandwidth, it resets the physical channel with the UE which synchronises to the new sampling rate, FFT size, etc. (Event 5). The combined downstream flows of I/Q (In-phase and Quadrature) samples from both streams are fed from the Openflow switch to the OLT. The switch separates these links logically via VLAN tags. In the OLT, those VLAN tags are then translated into the XGS-PON addressing format XGEM. At the ONU, the XGEM ports are configured to route traffic to the 10G Ethernet port connected to either of the RRHs.

## Demonstration

For the demonstration, the Optical Wireless equipment will be located on site, while the ABNO controller and the Optical core will be located at the University of Bristol. The two systems will be

Tab. 1: Bandwidth to I/Q and application rate mapping

| Bandwidth | Fronthaul Rate | Max Cell Capacity |
|-----------|----------------|-------------------|
| 3 MHz     | 121 Mbps       | 1.97 Mbps         |
| 5 MHz     | 184 Mbps       | 15.4 Mbps         |
| 10 MHz    | 368 Mbps       | 19.5 Mbps         |
| 15 MHz    | 488 Mbps       | 21.8 Mbps         |

connected live at the control plane level.

Our demonstration shows the practical feasibility of synchronising dynamic resource allocation across a mobile LTE and a fixed PON system, as well as its benefit for improving the Quality of Service (QoS) of the UEs when high bandwidth-demand applications and services are provided.

During the demonstration, we will show how the controller firstly receives a report of low load and sets the number of PRBs to 15 (corresponding to a 3 MHz wireless bandwidth). Then, after the start of the video application (event 1 in Fig. 2), the controller sets the number of PRBs to the higher rate 25 (5 MHz) and reconfigures the Committed Information Rate (CIR) of the switch to cope with the extra load. We will also provide

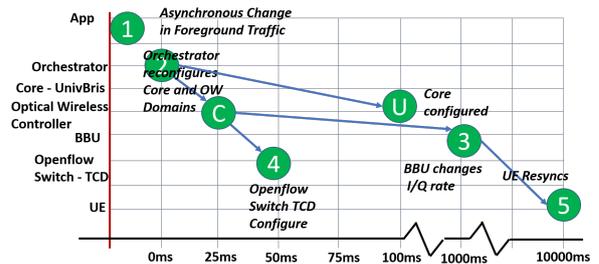


Fig. 2: Timing Results

insight into the end-to-end reconfiguration time of our implementation. Typically, the BBU changes the I/Q rate in 1 second and the UE resets and synchronises within 10 seconds. At this point, the LTE capacity is increased towards the UE and is made available at the application level. Indicatively, most of the reconfiguration time is spent in the reset of the data plane, due to the re-set of the PRB numbers of eNodeBs.

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