

DESIGNING THE NEW BACKHAUL FOR 5G HETEROGENEOUS NETWORK BASED ON CONVERGED OPTICAL INFRASTRUCTURE

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ABSTRACT

In this paper, a new flexible backhaul design is proposed based on the time-frequency resource grid. The advantage of proposed approach is in the fine granularity bandwidth allocation. Proposed approach allows tunneling of Cloud-RAN modulated radio signals between baseband processing unit and remote radio head within the same resource blocks. In addition, new handover mechanism has been introduced to reduce the handover overhead in the backhaul network. The main idea of the proposed handover mechanism is in multicast data transmission to both involved eNodeBs by joint assignment of the resource elements for multiple cells during handover that allows to decrease the amount of backhaul traffic over X2 interface by 20%.

Keywords: 5G, optical backhaul, OLT, ONU, handover, C-RAN

1. INTRODUCTION

Modern cellular networks are rapidly evolving towards 5G paradigm. 5G imposes new challenges regarding significant improvement of user experience and overall network capacity increasing by thousand times [1], [2]. Upcoming 5G era enables more diverse use cases and applications including Internet of Things, tactile internet, industry 4.0, etc. [3] [4].

Therefore, emerging systems will need to be agile and flexible enough in order to support the diversity of applications without increasing the network management complexity [5]. Since different services are targeting different KPIs (Key Performance Indicators), the network has to be able to allocate resources on the run and based on real time information.

To ensure such a flexibility of network infrastructure new concepts for network management are emerging such as software defined networks (SDN) and network functions virtualization (NFV). SDN is the concept that enables remote programming of network nodes to apply the needed changes in the network configuration [6]. SDN has been proved as an effective solution for both fixed and wireless systems to manage the quality of experience for end users. To simplify the network softwarization, NFV technology is designed to provide the end-to-end abstraction of the network resources for SDN controller.

In this article, we completely rethink the design of the network infrastructure to eliminate all bottlenecks in the pipeline between service providers and end users. We propose new converged access network that encompasses both optical backhaul and wireless access segments. Proposed network infrastructure is designed to be agnostic to radio access technologies (RATs) that allows integration of existing as well as the emerging RATs.

This paper is organized as follows. Section 2 describes the proposed design for converged network infrastructure. Section 3 provides simulation results of the network performance. Section 4 concludes the paper.

2. ARCHITECTURE OF THE CONVERGED OPTICAL NETWORK

2.1. MAC layer design for converged optical backhaul

Given the high requirements to the capacity in the 5G networks, the design paradigm is moved towards ultra-dense cells deployment with extremely high frequency reuse and system spectral efficiency. In addition, 5G is much more heterogeneous in terms of architecture and radio access technologies, comparing to existing LTE networks. Due to the denser infrastructure of 5G network, handovers become more frequent resulting in high fluctuations traffic of load in each cell [7]. This in turn, results in the load-balancing problem between neighbor cells and their corresponding backhaul links [8] [9]. Using separate wavelengths for each small cell, we can maintain enough throughput for optical backhaul. But, in this case bandwidth utilization is quite low, because most of the time traffic demand will be less than the capacity provided by backhaul. Especially, this problem occurs when neighbor cells have significantly different traffic load. This is a typical situation in the urban scenario. In this case, one backhaul channel is underutilized, while another has more packets in the queue than it can process with acceptable delay. Force handovers from the overloaded cell to any neighbor cell allows to solve the problem, by jeopardizing the quality of wireless channels. However, this is not a good option because it will lead to the worse users experience. We propose a new architecture for optical backhaul based on the next generation passive optical network (NG-PON) [10]. Our proposal is aimed to simplify traffic steering and load balancing in highly heterogeneous environment of 5G mobile network. In order to meet the new paradigm of 5G heterogeneous network design, we improve the network design by introducing a modified MAC layer [11]. The main idea of the proposed model is to split the entire bandwidth into resource blocks, which occupy 8 time slots and 8 carriers in frequency domain. Carriers separation is in frequency domain is 200 GHz that is equal to 1.6 nm interval between wavelengths in a single optical fiber. Time slot has duration of 15 us that allows fitting resource block into the 125 us

time frame of 10 GEAPON. Proposed MAC layer can allocate any throughput for the small cell in a range between 1.25 Gbit/s and 80 Gbit/s. For cells with very high traffic load, it is also possible to aggregate 4 resource blocks in frequency domain, providing the total capacity of 320 Gbit/s within 32 wavelengths.

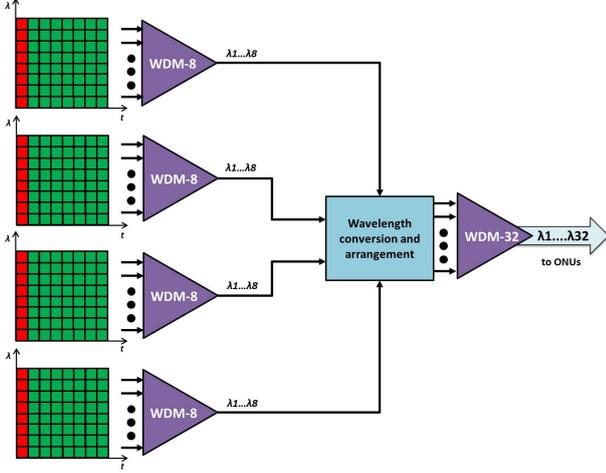


Fig. 1 Aggregation of resource blocks to provide the higher network capacity

Originally the idea of time-frequency resources allocation comes from wireless networks, such as LTE [12]. Since proposed MAC layer of optical network backhaul has similar structure to time-frequency grid of LTE network, it can be also integrated with wireless backhaul solutions for 5G small cells. The main advantages of the proposed MAC layer are that it allows to improve the performance of carrier aggregation, coordinated multipoint and handover.

2.2. Analysis of cell traffic and backhaul capacity demand

Backhaul capacity demands are dependent on the types of service, which dominates in the mobile network. In GSM network voice services require continuous guaranteed bit rate. Therefore, required backhaul capacity increases proportionally to the number of users. However, in current LTE and future 5G networks situation is very different because most of users are using packet data instead of voice calls. In addition, traffic in the cells is directly related to the SINR (signal-plus-interference-noise ratio), experienced by the users and the number of users themselves. Given 15 different CQI (channel quality indicator) values, the spectral efficiency of the wireless channels can vary from 0.15 bps/Hz to 5.55 bps/Hz, which means that total traffic in one cell, oscillates in the high range. Moreover, the amount of signaling data in wireless channels is getting higher when number of users increases. This leads to a very interesting conclusion that backhaul traffic decreases proportionally with the increasing of the number of users. Taking into account that one LTE user with CQI 15 and the lowest signaling overhead can occupy the entire capacity of the cell,

we can prove that the number of users is inversely proportional to the capacity demand for backhaul. Additional factor, considered in the proposed model is the handover execution procedure via X2 logical interface, which triggers up to 10% of additional backhaul traffic. The signaling data via S1 logical interface and packet tunneling over the transport layer are also included in the model with another 15% of the backhaul overhead. To simplify or model, we assume that spectrum splits equally among all active subscribers. In this case the total cell throughput can be calculated according to the following equation:

$$C_{cell} = \sum_{i=1}^N \frac{1}{N} \cdot W \cdot Seff_i \quad (1)$$

where N is the number of users, W is the total spectrum available for the cell, $Seff_i$ is the spectral efficiency of i -th user. Then, let's assume that uplink and downlink cell capacity are equal. The minimum allowed capacity of the backhaul network in downlink can be estimated based on the following equation:

$$C_{backhaul\ DL} = \left\lceil \frac{k_{X2} \cdot k_t \cdot cell}{ONU\ min} \right\rceil \cdot C_{ONU\ min} \quad (2)$$

where k_{X2} is the handover coefficient (usually in a range from 1.05 to 1.2), k_t is the packet tunneling overhead coefficient (usually around 1.1), $C_{ONU\ min}$ is the throughput granularity (1.25 Gbps). The minimum allowed capacity of the backhaul network in uplink can be estimated based on the following equation:

$$C_{backhaul\ UL} = \left\lceil \frac{k_{X2} \cdot cell}{ONU\ min} \right\rceil \cdot C_{ONU\ min} \quad (3)$$

2.3. Integration of the Cloud Radio Access Networks into converged optical infrastructure

Cloud Radio Access Network (CRAN) was introduced as the one of possible candidates to provide 5G capabilities. The cloud-based architecture allows to improve the spectral and energy efficiency of the mobile network. In C-RAN, the conventional cellular base station is decoupled into two entities: baseband processing unit (BBU) and remote radio head (RRH) [13]. The responsibilities of BBU are to provide necessary signal processing, functionalities of physical, MAC, and network layer, i.e. encoding, modulation, etc. RRH is a simple transceiver without any processing capabilities. The most interesting feature of C-RAN is the transmission of modulated waveforms via optical fiber link, namely fronthaul. Fronthaul interconnects the BBU and RRH, and provides transparent tunneling of radiosignals. Usually BBUs are clustered together in one big data center, and RRHs are distributed over the target coverage area. Such architecture allows to improve the flexibility of resource sharing, rapid deployment, and centralized network management. The architectural overview of the proposed converged optical network infrastructure with modified MAC layers is presented in Fig. 2.

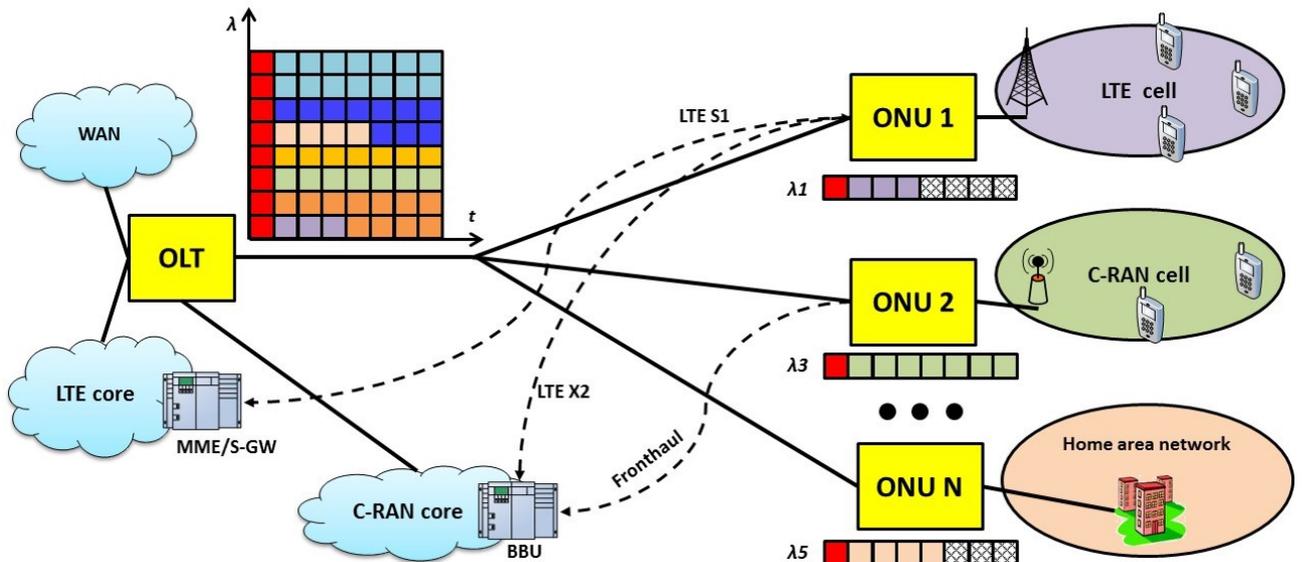


Fig. 2 Architectural overview of the proposed converged optical network infrastructure with modified MAC layers

The novelty of this model is that it allows tunneling of radio signals between baseband processing unit and remote radio head over the optical network [14]. This provides more flexibility of integration the Cloud-RAN and LTE mobile networks into converged infrastructure. As shown in Fig. 2, in our model, fronthaul network is integrated together with other optical channels, but have different resource allocation principle. If fronthaul is integrated within the same MAC layer, it occupies the wavelengths within time-frequency resource grid but does not follow the same resources granularity. In order to support effective transmission of modulated radio signals, OLT (Optical Line Terminal) provides exclusive rights to specific wavelengths for BBU according to current demand, so that it will be transmitted in parallel with conventional LTE backhaul.

2.4. Improved handover mechanism based on the proposed 5G backhaul architecture

In order to reduce the amount of traffic overhead generated by handovers, we propose an improved handover mechanism among neighbor small cells. Instead of conventional data forwarding between involved cells in existing backhaul networks, we propose the multicast data transmission to several cells simultaneously by simple association of corresponding resource elements for home eNodeB and target eNodeB. When mobility management entity (MME) receives a handover request, it tells OLT to allocate the same resource elements in the resource block for multicast transmission and sends the acknowledgement to the both eNodeBs (Fig. 3).

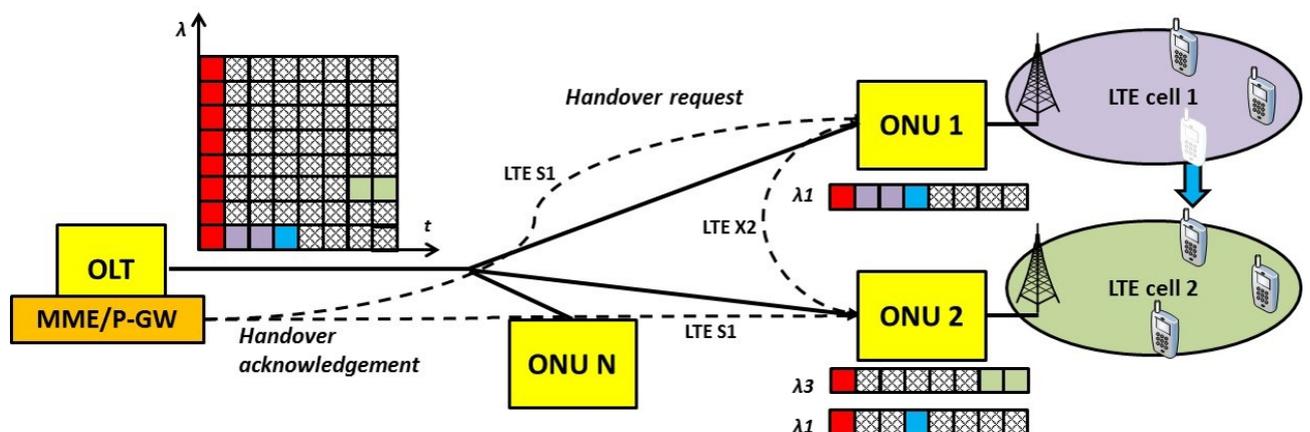


Fig. 3 Multicast data transmission in 5G backhaul during handover execution

Thus, it is not necessary to transmit data from home eNodeB to the OLT and then forward these data from OLT to the target eNodeB during handover execution, because necessary data are known in advance in the target eNodeB. Hence, we can modify the equations (2) and (3) as following:

$$C_{\text{backhaul UL}} = \left\lceil \frac{C_{\text{cell}}}{\text{ONU min}} \right\rceil \cdot C_{\text{ONU min}} \quad (4)$$

$$C_{\text{backhaul DL}} = \left\lceil \frac{k_t \cdot C_{\text{cell}}}{\text{ONU min}} \right\rceil \cdot C_{\text{ONU min}} \quad (5)$$

The sequence of the proposed handover execution algorithm is explained below. 1. The home eNodeB sends a request to the MME via the S1 interface. 2. MME determines the target base station and informs both involved stations about handover acknowledgement. 3. If both stations are served by the same OLT, the same resource elements are allocated for both eNodeBs in the resource block. 4. Target eNodeB received the same data as the home eNodeB, so it is not necessary to forward these data again between involved cells through OLT.

3. SIMULATION RESULTS AND DISCUSSION

To prove the theoretical expectations we have conducted the simulations of the backhaul capacity for two cases: existing handover mechanism and proposed handover mechanism with multicast data transmission. Results are shown in Fig. 4.

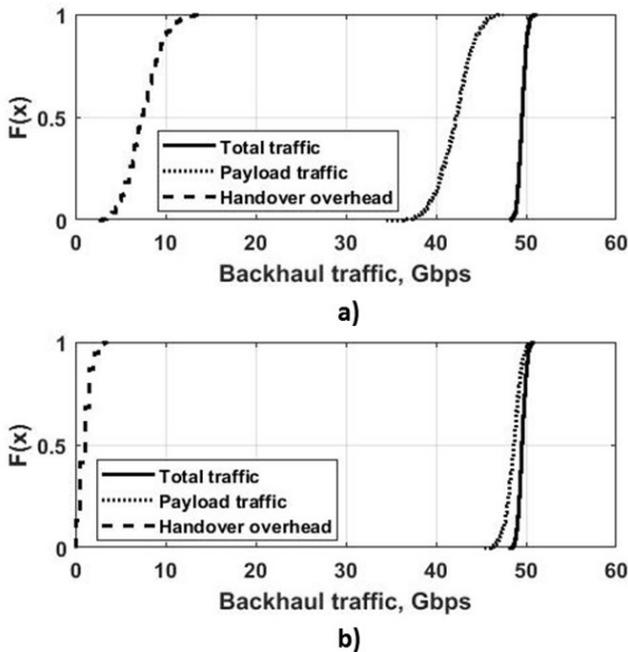


Fig. 4 Simulation results of the backhaul capacity

Simulation results show that in the case of conventional handover algorithm, traffic overhead is 3 and 12 Gbps (Fig. 4a). Proposed handover algorithm decreases the amount of handover overhead to 1-3 Gbps, while increasing the payload traffic by 5-10 Gbps.

4. CONCLUSIONS

In this paper, a new approach for 5G backhaul design is proposed based on the converged optical infrastructure. The main novelty of the proposed approach is in the time-frequency resource grid. Based on the proposed backhaul, we have designed a new handover mechanism to decrease the amount of overhead during handover execution. Simulation results show the advantage of the proposed solution over the existing ones.

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