Experiments on Cloud-RAN Wireless Handover using Optical Switching in a Dense Urban Testbed

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Abstract: We investigate dynamic network resource allocation using software-defined networking optical controller with software-defined radios on the COSMOS testbed. 10 Gb/s capacity, deterministic low latency are maintained through user equipment wireless handover via optical switching.

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1. Introduction

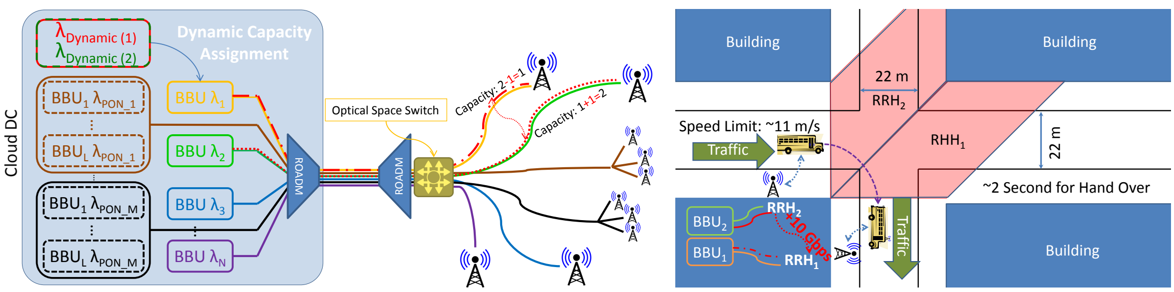
Compared to 4G, 5G wireless technology is designed to provide significantly higher bandwidth with lower latency. As traffic increases, cell sizes are shrinking, dramatically augmenting the number of cell sites and their capacity. This motivates the development of Cloud Radio Access Networks (C-RANs), where BaseBand processing Units (BBUs) will be moved to a centralized location to allow sharing (possibly heterogeneous) computing resources among multiple Remote Radio Heads (RRHs) and mobile networks.

Deploying sufficient optical front-haul bandwidth between the RRHs and the BBUs located on Edge Cloud (EC) is costly in physical equipment and energy efficiency. Streaming RF signals using optical fibers (radio-over-fiber, [ROF]) between the RRHs and the BBUs requires significant optical bandwidth. For example, a 10 Gb/s wireless link would require over 150 Gb/s of capacity in the optical front-haul [1], requiring new types of optical networks for efficient resource allocation (e.g., time slotted optical switching networks [2]). On the other hand, an intelligent software-defined optical network can allocate the required front-haul bandwidth to each RRH depending on the wireless bandwidth requirements. Optical reconfiguration based on cellular network requirements can be based on long-term trends [3], or on short-term windows for specific users that have intensive wireless requirements. Short-term user mobility prediction models can monitor mobile users that require significant bandwidth and relay this to the optical network management plane. To overcome this challenge, one can also opt for using Wavelength Division Multiplexing (WDM) in the front-haul network [1]. In addition, to realize the benefit of the optical equipment, such networks require new advances in intelligent network management.

In this paper, we develop a scheme and optical control algorithms to efficiently control optical front-haul for remote baseband processing. We implement and experimentally evaluate the scheme using the city-scale COSMOS advanced wireless testbed [4] deployed in a dense urban area of New York City.

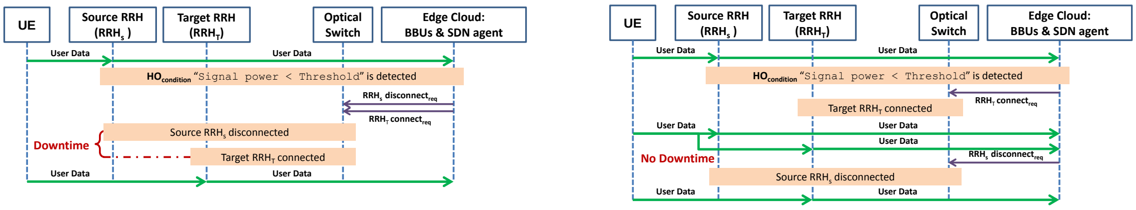
2. Dynamically Reconfigurable C-RAN and Its Use for Wireless Handover Functionality

The use of WDM in front-haul networks suggests adopting multiple wavelength-specific Passive Optical Networks (PONs), connecting BBUs and RRHs. Moreover, WDM can be used for dedicated point-to-point, wavelength-specific links and not just for PONs. These links are provisioned for each RRH requiring high capacity (cf.



(a) (b)

Fig. 1. (a) The WDM/PON reconfigurable C-RANs where dynamic capacities can be allocated on each link depending on the bandwidth requirement. (b) The handover (HO) scheme where a vehicle taking a turn at an intersection receives services from two RRHs through dynamic optical switching and wavelength re-allocation.



(a) (b)

Fig. 2. The considered handover (HO) modes signaling flow: (a) *hard HO* ("break before make"), the new connection to the target RRH is made *after* the connection to the source RRH is broken; (b) *soft HO* ("make before break"), the new connection to the target RRH is made *before* the connection to the source RRH is broken.

Fig. 1(a)) [1], and can be dynamically reconfigured by Software Defined Network (SDN) controller as part of the back/mid/back-haul networks.

We investigate optical/wireless links' *dynamic capacity allocation*, to support varying network bandwidth demands. Particularly, we consider the application of wireless HandOver (HO) between a RRH and a User Equipment (UE) that requires exceptionally large capacity with deterministic low latency. For example, when the UE is moving from the "service area" of one RRH to another, the capacity of the optical link is *dynamically* re-allocated. A channel on a dedicated wavelength is *optically switched* from one link towards another by either Reconfigurable Optical Add and Drop Multiplexers (ROADMs), or by the Optical Space Switch (OSS) with links leading to RRHs. The reconfiguration of such network elements can be done by an SDN controller [5].

The use of optical networks and functionalities in order to facilitate HO of wireless signals has been investigated before. Mukhopadhyay et al. [6] proposed to reduce the HO latency by forming a ring-based PON, a concept that can be extended to form dynamically changing PON networks. Similar concepts were studied by Wang et al. [7] who proposed to dynamically form wavelength-specific Virtual PONs (VPON) that would merge RRHs to groups. Such groups would be assigned a wavelength and set of radio-frequencies. If a UE would pass from one cell to another still served by one radio frequency, then HO will not happen, using Time Division Multiplexing features employed by PON. However, the practical proof wasn't provided.

In this work, we explore a concept similar to [7] but with the application to larger traffic to/from a UE and assigning to a UE a wavelength-specific point-to-point link instead of a wavelength-specific VPON, as shown in Fig. 1(b). Going away from VPON would allow networks to more efficiently use the total wavelength resources and deliver higher bandwidth to the UE. We study this concept on the example of wireless HO via optical switching by experimentation. All decisions are made at the EC combining BBUs with an SDN controller. We consider only upstream traffic from the UE. We illustrate the signaling exchanges in Fig. 2, where a signal-power-switching-threshold based decision is implemented via either a *hard HO* ("Break Before Make" mode), or a *soft HO* ("Make Before Break" mode). In particular:

- *Hard HO* suggests that SDN can assign to the UE only one wavelength, that would "follow" the UE from RRH to RRH. The switching consists of changing the OSS configuration, always keeping one port connected to the link leading to the EC and changing ports with the link leading to the RRHs. A downtime period exists during the hard HO process, in which the UE is not connected to any RRH due to "Break Before Make" mode nature.
- *Soft HO* uses a "Make Before Break" mode, meaning that at least two wavelengths or at least independent fiber channels are required at the time of HO. Specifically, new connections from the EC to a RRH are made before breaking the old ones. As a result, soft HO is free from downtime, but at the cost of network resources.

3. COSMOS Testbed Configuration

We implement and evaluate the wireless signal HO via optical switching in the case presented in Fig. 1(b) using the COSMOS advanced optical-wireless testbed [4]. Fig. 3 shows our experimental setup, which involves two RRHs (RRH_1 and RRH_2) located on two sides of the CEPSR Building at Columbia University. We use two USRP software-definde radios (SDRs) to emulate one RRH_i ($i = 1, 2$), with one assigned a *fixed* capacity ($\text{USRP}_{i,\text{fix}}$) and one assigned a *dynamic* capacity ($\text{USRP}_{i,\text{dyn}}$). The link between $\text{USRP}_{i,\text{fix}}$ and the EC is always live, whereas the link between $\text{USRP}_{i,\text{dyn}}$ and the EC can be dynamically allocated (i.e., switched). All USRPs are connected to a top-of-rack (ToR) Pica8 switch located in the same building using 1 Gb/s Ethernet. The Pica8 switch has 4 optical bi-directional transceivers (tunable C-Band SFPs of 1/10 Gb/s) towards the central Calient S320 OSS located in the Columbia data center. Three ports are used for hard HO, while using of 4th is required by soft HO.

The Calient S320 OSS has 4 connections to the ToR leading through 25 Gb/s of available bandwidth to the EC server, the latter running a customized GNU Radio script. The script runs wireless signal processing (BBUs), and executes the SDN controller for optical switching. In particular, the script sends commands over an out of band control channel (not shown here) to the Calient S320 OSS to implement the hard HO or soft HO as shown in Fig. 3.

We use a USB-powered USRP B205-mini as the UE, which transmits a tone at 900 MHz carrier frequency. The RRHs are receiving radio-signals and transmitting I/Q samples to the EC server, which measures the signal

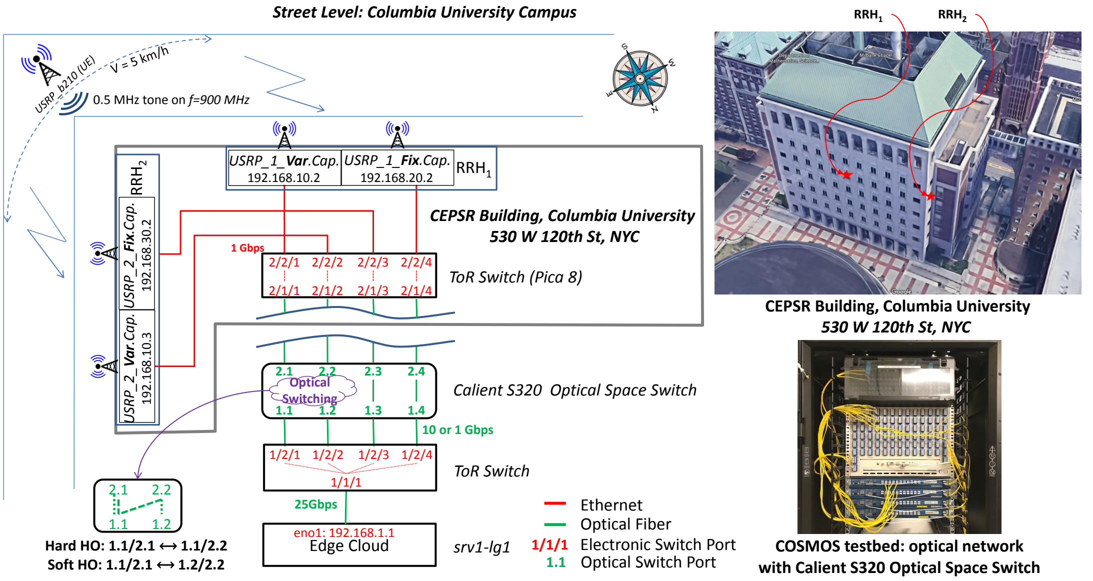


Fig. 3. Experimental setup: Two RRHs on each side of the CEPSR Building at Columbia University, with each composed of 2 USRPs. One USRP has a dedicated channel with *fixed* capacity through an optical link, another USRP has *dynamic* channel allocated by an SDN controller via OSS optical switching when wireless HO is underway. The UE moves around the building corner, passing from one RRH to another, invoking HO.

strength at $\text{USRP}_{i,\text{fix}}$. If the threshold ($-57$ dBm) is passed the switching/handover is triggered, disconnecting $\text{USRP}_{i,\text{dyn}}$ and connecting other $\text{USRP}_{j,\text{dyn}}$.

4. Handover Operation and Measurements Results

We consider two performance metrics: (i) *HO time*, which is the time duration between the triggering and completion of the HO event, and (ii) *downtime*, which is the duration in which no $\text{USRP}_{j,\text{dyn}}$ is connected. We tested 10 Gb/s optical links between EC and USRPs on the experimental setup (cf. Fig. 3), with 15 valid attempts for hard HO and 14 trials for soft HO; We tested 1 Gb/s links in an indoor setup, artificially creating HO conditions.

Our experimental results show that the average switching time for **hard HO is 0.957/1.830 s with 1/10 Gb/s** links, respectively, where the resulting **downtime is 0.914/1.647 s**. Similarly, the average switching time for **soft HO is 0.724/1.614 s with 1/10 Gb/s** links, respectively, with **no downtime**. The HO switching time is limited by the time it takes for the optical transceivers to establish the link connections, which is at the order of seconds [8]. We confirmed this hypothesis by WireShark measurement of an optical link recovery time, by changing the OSS port configurations from state ON to OFF and then immediately from OFF to ON, which takes <50 ms (set by the OSS switching time). The time difference between 1 Gb/s and 10 Gb/s is due to the fact that the 1 Gb/s links are with a fixed rate, and thus no rate-negotiation phase is needed during the link establishment. Long HO times can be reduced by using burst-mode transceivers in future experiments.

5. Conclusion

We experimentally investigated wireless signal HO via optical switching in the COSMOS testbed. HOs are implemented using an OSS controlled through an SDN controller and support two different handover mechanisms. Long transceiver signal recovery times are overcome using a make before break handover, ensuring a 10 Gb/s throughput throughout the process.

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