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A SDN Controller Architecture for Small Cell Wireless Backhaul using a LTE Control Channel

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Abstract—Future Access and Backhaul Networks need to significantly carry more data traffic, which calls for network densification. However, when many small cells are densely deployed, the backhaul network might become the bottleneck, as it is economically infeasible to wire every small cell or power them on constantly. Therefore, an effective configuration of a Small Cell Wireless Backhaul Network is important due to its multi-hop operation, possibly operating in mmWave bands. In this paper, we propose to use Software-Defined Networking for the Operation and Management of Small Cell Wireless Backhaul Networks. A SDN controller based in OpenDaylight is in charge of adaptively powering on/off Small Cells and reconfiguring the backhaul forwarding topology, according to traffic demands. The SDN controller uses an optimizer module which can be configured with different policies in order to minimize the energy cost or optimize capacity or latency. We extend OpenFlow in order to gather wireless and power consumption statistics, which are exchanged between Controller and Small Cell Backhaul nodes using a LTE Out-Of-Band Control Channel.

Index Terms—Software-defined networking, wireless backhaul, small cell networks, mmWave network, 5G.

I. INTRODUCTION

With the increase of the number of mobile devices and related data traffic requirements [1], the standards of future wireless networks must support higher transfer rates. Key to those data rates relies in a better spatial reuse, leading to small cells (SC) and cell densification. However, a massive deployment of SC requires a wireless backhaul (BH) infrastructure with high capacity, contrary to optical-based connection approaches (e.g. LTEHaul [2]), because we cannot economically wire thousands of SC. Here, mmWave bands are specially interesting because they offer several GHz free spectrum, leading to several Gbps wireless links [3]. Also, such SC infrastructure should be operated in an energy efficient way, powering on SC only when needed based, on localised traffic demands. This leads to a so called Heterogeneous Network (HetNet) infrastructure, where a dense SC network co-exists with an overlay of LTE eNodeBs providing the basic coverage.

In such deployment, traffic from user equipments (UE) are forwarded from the entry SC node over (multiple) wireless BH links to a gateway node, which is typically co-located at the eNodeB. Consequently, in a multi-hop deployment, routing and forwarding are crucial aspects to consider, since they might have to cope with dynamically powered on and off nodes, according to traffic demand changes.

With Software-Defined Networking (SDN), packet forwarding can be handled by a centralized controller entity, in a flexible and effective way. Adding device configuration capabilities

to this kind of architecture allows a wireless network to be fully managed. However, in a typical SDN based architecture, the SDN controller sends OpenFlow (OF) messages that need to be routed over the wireless links towards the correct SC, leading to potentially long control latency.

The key contribution of this paper is a SDN-based network architecture for SC BH operation and management. Based on the HetNets concept, we propose that the SDN controller sends OF messages via LTE control channels directly to SC nodes. We sketch extensions for the OpenDaylight (ODL) controller, in order to provide the necessary resilient routing infrastructure for a SC BH operation. A Backhaul Orchestrator is dynamically optimizing the SC BH, regarding energy efficiency and configuration of low latency and high capacity BH paths.

II. SDN FOR SMALL CELL BACKHAUL

In this section, we summarise important issues a SDN architecture for SC Wireless BH Networks should consider.

A. Out-of-band Controller connectivity

A SDN enabled SC BH node needs to maintain a communication channel with the controller in order to be able to exchange control plane messages. This communication channel can be established in the same network interface as the one used for the data plane (in-band connectivity) [4] or in a different interface (out-of-band) [5]. With in-band connectivity, the infrastructure costs are reduced, but if link failure occurs, the node loses the connection with the controller. Out-of-band control plane connectivity requires an additional NIC in the managed devices. We propose to use a LTE interface on each SDN enabled SC BH node for SDN control plane connectivity, in order to provide a robust control channel and reduce SDN control latency while the data plane is using the BH (multi-hop) connectivity (e.g. mmWave).

B. Energy Efficient Small Cell Backhaul Operation

With increased traffic demands, HetNets will be formed by the deployment of SC nodes. Constantly powering on all SC BH nodes will result in high energy consumption for BH operation. Consequently, we want to adaptively power on or off SC nodes to provide localized capacity when needed, according to user demands.

When SC nodes get powered off, re-routing might be required, as the given SC node might be used to relay traffic originated from other SC node. Users can be handed over from a SC towards an eNodeB if the SC is powered off and

the demand in that region is too small to justify the additional energy. This requires a trade-off to be made in terms of the BH's energy efficiency, latency of the traffic forwarding and BH capacity, given the user demand requisites. By knowing the traffic demands, power consumption profile of the SC BH nodes, as well as connectivity options, the SDN controller can orchestrate the balance between energy and performance.

C. Configurable Optimization Policies

Optimization problems with multiple variables and conflicting goals (e.g. energy versus capacity and latency) are highly complex [6]. As the SDN Controller should react fast to standard events, we outsource computationally heavy parts such as the network optimization problem to a different entity, which receives information about BH topology, traffic demands, link configurations, and energy consumption statistics. Based on configurable policies and optimization algorithms, this optimizer entity calculates a trade-off between energy and capacity/latency.

D. Resiliency for Small Cell Backhaul Forwarding

SC BH links might be subject to dynamic link outages, especially when operating at very high frequencies, where capacity requirements exist (e.g. mmWave bands) [3]. A link can temporarily go from Non-Line-of-Sight to Outage (e.g. due to blockage), leading to changes in the BH topology and consequently, in the available capacity. When such events happen, the SDN controller can perform path recalculation between the BH SC nodes, but it can take a significant amount of time. We propose to use fast failover (FF) group tables from OF to rapidly repair link failures locally. This requires the calculation a disjoint backup path towards the gateway at each SC BH node. If the failure that triggered the usage of a different network path persists, the controller can recalculate new routes, based in the current topology and previous calculated energy optimization strategy.

E. Flexible Path Calculation Strategies

With SDN it is possible to have flexible path calculation strategies in place, based on fine-grained forwarding decisions. For multi-hop SC BH networks, it will be essential to control the existing paths' latency. This requires an estimation of the delay for each link and path at the SDN controller, which can also depend on the existing queueing strategies. Consequently, some flows might be routed along low latency paths, while others to higher latency paths with high available capacity. Novel Centralized Routing Algorithms might be needed, allowing fast path calculation while supporting multiple constraints (e.g. bandwidth and latency).

III. PROPOSED ARCHITECTURE

In this section we present the SOCRA (Software Defined Small Cell Radio Access Network) architecture (Figure 1). Its core component is a SDN controller that manages the BH network by configuring the SC nodes, by managing flow rules, wireless link and power management parameters. It interacts with a Backhaul Orchestrator (BO), responsible for optimizing the BH operation.

Fig. 1. Small cell backhaul SDN architecture

A. SOCRA - A Small Cell RAN SDN Controller

The SOCRA architecture uses a SDN controller based in ODL to manage the SC BH nodes' configurations and respective data traffic handling. It implements components such as Packet Handler, Path Calculator, Neighborhood Mapper and exposes an Orchestrator interface. Additionally, it extends the Openflowplugin (OPF) and the OF 1.3 libraries (native components in ODL). This controller can control multiple eNodeBs and SC under a routing area (routing over areas where multiple controllers are involved is beyond the current scope).

- **Packet Handler** parses packets sent to the controller (e.g. for new flows when no rules are installed at the SC BH nodes). The extracted information is sent to the Path Calculator, which replies with a primary path from the source to the destination node according to a given path calculation strategy. The original packet is then sent back to the destination node.
- **Path Calculator** computes paths between the powered-on SC BH nodes and instructs the installation of new forwarding rules. It uses an auxiliary network graph that contains only the active nodes. If the FF strategy from II-D is active, a maximum disjoint path is also calculated from each intermediate node, and the required forwarding rules are installed in combination with the usage of the FF group table feature from OF.

TABLE I
WIRELESS CONFIGURATION FUNCTIONS

Function	Description
<code>setDeviceState(state)</code>	Sets the device state (e.g. Active, Sleep, Idle) to <code>state</code> . The available states are device specific.
<code>setPowerTx(interface, value)</code>	Sets the transmission power of <code>interface</code> to <code>value</code> .
<code>setChannel(interface, channel)</code>	Changes the channel of <code>interface</code> to <code>channel</code> .

- **Neighborhood Mapper** infers the neighborhood and interference graph for each node/link from the existing topology. Similar to [7], SC BH nodes send out periodic beacons to neighbors. The collected information statistics are sent to the controller, which are used to augment existing data from the BH links.
- **Wireless Configuration Service (WCS)** sends wireless specific configuration requests to the managed SC BH nodes through an OF protocol extension. An initial specification of the commands can be found in Table I.
- **Wireless Statistics Manager** collects wireless related statistics from the managed SC BH nodes through an extension of the Statistics Manager component from the OFP. The requests and statistics can have different types, which are specified by a bit mask field in the request body, similarly to the mechanisms used in [8].
- **Orchestrator Interface** is used to communicate with the BO in order to perform the reconfiguration of the SC BH network. Additionally, this configuration can be triggered by the BO through this REST API. The new configurations are pushed to the WCS and new paths are requested to the Path Calculator.
- **Metrics Collector** is responsible for obtaining network performance metrics that cannot be directly retrieved through OF (e.g. link or path delay [9]). The calculated data is merged into the available statistics and can be used by every other controller component.

B. Backhaul Orchestrator

The Backhaul Orchestrator (BO) is responsible for interacting with SDN controllers regarding the configuration of their respective BH networks. It obtains information from the topology, traffic demands, and statistics concerning interference and power consumption for the managed wireless SC BH nodes. Additionally, it can receive notifications sent by a controller (e.g. when a new SC BH node connects to the network, or if a link is carrying traffic over/under a configurable capacity threshold), that may trigger a network reconfiguration.

The BO periodically calculates a new BH network configuration through the usage of an Optimizer Module (OM) using an configurable optimization policy. Such policy may aim towards an energy efficient optimization strategy that minimizes the total SC BH network power consumption while maximizing the throughput of existing latency-sensitive flows. The new BH network configuration is then sent to the SDN

controller, which is responsible for making the required adjustments in the managed network (e.g. power down some nodes, reroute the traffic or adjusting transmissions powers as required).

C. Optimizer Module

The OM computes a new BH network configuration when triggered by BO. The information sent to the OM includes wireless statistics, neighborhood and interference related information, as well as power consumption statistics. By using a customizable optimization policy, the network can be optimized for different operational states (e.g. power efficient vs. optimal capacity,) while using different heuristics. The OM exposes a REST API, possibly residing on a machine with high processing power, in order to provide fast solutions, suitable for online optimization.

IV. CONCLUSIONS

We presented an overview of the SOCRA architecture, which combines SDN with a SC BH network. We consider important aspects for SC BH optimization, such as energy efficient operation, resilient BH forwarding infrastructure configuration or an LTE based control channel between the SDN controller and the SC BH nodes. The SOCRA controller collects power consumption, traffic, interference and neighborhood statistics data from the network. A Backhaul Orchestrator uses an Optimizer Module, which dynamically powers up/down the nodes and configures the forwarding paths and nodes. While we are currently implementing the architecture using OpenDaylight, a challenge is the development of heuristics for online optimization according to a given policy.

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