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Experimental evaluation of self-organized backpressure routing in a wireless mesh backhaul of small cells ☆

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ABSTRACT

Small cells (SC) are low-power base stations designed to cope with the anticipated huge traffic growth of mobile communications. These increasing capacity requirements require the corresponding backhaul capacity to transport traffic from/to the core network. Since it is unlikely that fiber reaches every SC, a wireless mesh backhaul amongst SCs is expected to become popular. These low-cost deployments require to balance resource consumption amongst SCs, however, current routing protocols were not designed to fulfill this requirement. To tackle this challenge, we presented and developed with ns-3 a self-organized backpressure routing protocol (BP), designed to make the most out of the backhaul resources. This paper provides the evaluation of BP exploiting built in ns-3 emulation features to allow rapid prototyping under real-world conditions and through controlled ns-3 simulations. Through a novel evaluation methodology based on ns-3 emulation, we evaluate BP in a 12 SC indoor wireless mesh backhaul testbed under different wireless link rates and topologies, showing Packet Delivery Ratio (PDR) gains of up to 50% with respect to shortest path (SP). Through simulations, we show BP scalability properties with both the size of the backhaul and the number of backhaul radios per SC. Results in single- and multi-radio deployments show TCP traffic gains with BP of up to 79% and 95% compared to SP in terms of throughput and latency, respectively.

1. Introduction

The ever increasing demand for wireless data services has given a starring role to dense deployments of low-power base stations referred to as small cell (SCs), as increasing frequency re-use by reducing cell size has historically been the most effective and simple way to increase capacity. Such densification entails challenges at the Transport Network Layer (TNL), since hard-wired backhaul deployments of SCs prove to be cost-prohibitive and inflexible. The main challenge is to provide cost-effective and dynamic TNL solutions for dense and semi-planned SC deployments. An approach to decrease costs and augment the dynamicity at the TNL is the creation of a wireless mesh network [1] amongst SCs to carry control and data plane traffic to/from the core network [2].

A wireless mesh backhaul requires of practical routing schemes realizing an even resource consumption to ease the mentioned capacity crunch. An identified requirement when steering traffic is to dynamically grow or shrink the pool of SC resources according to network conditions, thus, exploiting the capacity offered by the wireless mesh backhaul. However, the IEEE 802.11s [3] mesh standard specifies Hybrid Wireless Mesh Protocol (HWMP) (see Section 2), tree-based protocol oriented to provide network

☆ Fully documented templates are available in the elsarticle package on CTAN.

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[1] Since 1880.

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connectivity rather than the exploitation of resources. Aiming for capacity, the original centralized backpressure algorithm [4] proved to be throughput optimal in theory. However, its implementation under real-world conditions showed scalability problems with the number of flows and forces the wireless network to operate on a Time Division Multiple Access (TDMA) MAC [5]. To counteract these issues, in [6,7], we presented and evaluated through ns-3 simulations [8] a self-organized backpressure routing protocol (BP) for the TNL that dynamically grows or shrinks SC resources according to network conditions (see Section 2). Specifically [6] focuses on multi-gateway SC deployments, whereas in [7] the focus is on sparse wireless mesh backhaul deployments. Additionally, in [9] we presented the integration details and preliminary experimental results of our scheme using ns-3 emulation features (see Section 2). However, the evaluation in [6] was merely based on simulations in a single-radio single-channel backhaul deployments, and the experimental evaluation in [9] was scarce.

The contribution of this paper is twofold. First, we detail the configuration of the experimental platform (see Section 3) using ns-3 emulation composed by 12 SCs endowed with 3G for the Radio Access Network (RAN), and an additional WiFi card to form a WiFi-based mesh backhaul amongst them (see Fig. 1), thus, forming an all-wireless Network of SCs (NoS). Prior to the evaluation of BP, we characterize the NoS testbed by analyzing the quality of the backhaul WiFi links composing the prototype. Additionally, we revealed that the ns-3 emulation rolled out in each SC does not introduce performance degradation in terms of throughput by showing that it can saturate the WiFi cards underneath (see Section 4).

Second, we tested BP in a wide variety of realistic wireless mesh backhaul conditions (see Section 5). In particular, using ns-3 emulation we demonstrate the operation of BP under different wireless link configurations (wireless link rate, ambient noise reduction techniques) and showed how by switching on and off SCs in the testbed, BP adapts to dynamic wireless mesh backhaul deployments. We observed gains of around 50% in terms of PDR with regards to a shortest path (SP) routing policy. Additionally, we demonstrated through ns-3 simulations the scalability of BP with both the number of SCs, and the number of backhaul radios per SC forming a multi-radio multi-channel wireless mesh network. We provide first simulation results of BP with TCP traffic showing promising advantages. In particular, BP showed significant gains over SP of up to 79% and 95% in terms of throughput and latency, respectively, with respect to SP routing.

We conclude the paper and provide future possibilities with Section 6.

2. Background and related work

2.1. Emulation

Fall [10] classifies emulation into two types. In environment emulation, an implementation environment is built so that real protocol implementations can be executed in a simulator, whilst in network emulation simulated components interact with real world implementations. As for the former, Network Simulation Cradle (NSC) [11] is a pioneer of introducing real stacks into network simulators. Recently, in [12] a framework for executing Linux kernel

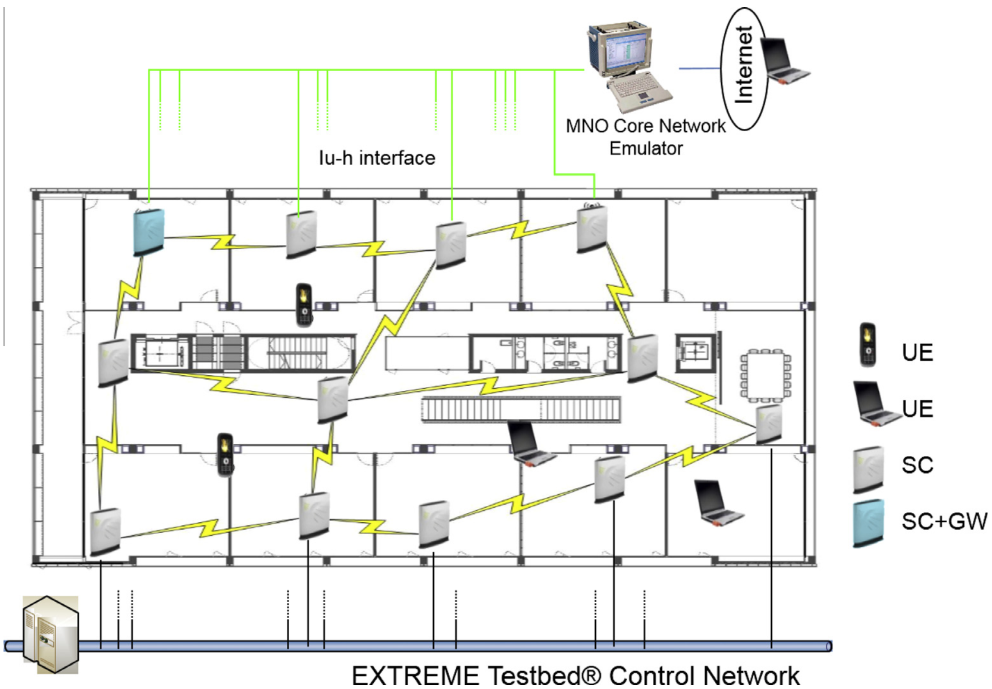

Fig. 1. Architecture of the NoS testbed.