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A self-organized backpressure routing scheme for dynamic small cell deployments

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ABSTRACT

The increase of demand for mobile data services requires a massive network densification. A cost-effective solution to this problem is to reduce cell size by deploying a low-cost all-wireless Network of Small Cells (NoS). These hyper-dense deployments create a wireless mesh backhaul among Small Cells (SCs) to transport control and data plane traffic. The semi-planned nature of SCs can often lead to dynamic wireless mesh backhaul topologies.

This paper presents a self-organized backpressure routing scheme for dynamic SC deployments (BS) that combines queue backlog and geographic information to route traffic in dynamic NoS deployments. BS aims at relieving network congestion, while having a low routing stretch (i.e., the ratio of the hop count of the selected paths to that of the shortest path). Evaluation results show that, under uncongested conditions, BS shows similar performance to that of an Idealized Shortest PAth routing protocol (ISPA), while outperforming Greedy Perimeter Stateless Routing (GPSR), a state of the art geographic routing scheme. Under more severe traffic conditions, BS outperforms both GPSR and ISPA in terms of average latency by up to a 85% and 70%, respectively. We conducted ns-3 simulations in a wide range of sparse NoS deployments and workloads to support these performance claims.

1. Introduction

The ever increasing demand for wireless data services has given a starring role to dense small cell (SC) deployments, as increasing frequency re-use by reducing cell size has historically been the most effective and simple way to increase capacity [1]. Such densification, particularly substantial in densely populated areas, entails several challenges, both at the mobile network layer (MNL), specified by 3GPP, and at the underlying transport network layer (TNL). As for the former, the idea of Network of Small Cells (NoS) has been proposed to confine control plane and data plane traffic in the local environment [2]. As for the latter, Fig. 1 reveals how SCs, equipped with an additional wireless radio, can create a wireless mesh backhaul to direct control and data plane traffic between them or towards the core network (Evolved Packet Core, or EPC, for LTE networks). The resulting deployment yields improvements in terms of cost, coverage, ease of deployment, and capacity.

However, such deployments imply several challenges at the TNL level. On the one hand, the semi-planned and low-cost nature of the NoS placements will inevitably lead to irregular (or sparse) topologies, SC failures, or disconnection due to obstacles (e.g., wireless link among SC_1 and SC_2 in Fig. 1), wireless link variability (e.g., due to adverse weather conditions), or vandalism. On the other hand, the wireless backhaul is subject to traffic dynamics. The study in [3] shows that a large fraction of mobile subscribers generate traffic only a few days a week and a few hours during the day. The activation of all SCs when a low fraction of

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mobile subscribers are using the network results in unnecessary resource consumption and interference. In an hyper-dense SC environment, a possibility is to power off some SCs (e.g., SC_4 and SC_8 in Fig. 1) selectively during low load conditions (e.g., at night), while still being able to serve all the traffic. Despite energy efficiency gains, these opportunistic SCs [4] could substantially alter the wireless backhaul topology.

The dynamicity of the above context may render transport protocols such as MPLS-TP [5], traditionally used in wired TNLs, unsuitable for an all-wireless NoS. A challenge for the TNL is to design a dynamic routing protocol that operates efficiently in large-scale and changing SC topologies, while meeting mobile traffic demands. A strategy to tackle large-scale multi-hop wireless topologies is geographic routing [6]. A well known problem of geographic routing is how to react when packets get trapped in a dead-end/local minimum (i.e., when there is not any neighboring node closer to the packet destination). In such situations, most geographic routing protocols have their own recovery methods to find a detour path when they reach a local minimum [7]. However, these strategies entail a substantial increase in control overhead as well as an increment of the per-node routing state, required to build alternative routes, hence compromising their scalability in sparse deployments. Further, despite eventually circumventing network voids, geographic routing can lead to network congestion due to a misuse of network resources, and a high routing stretch (i.e., the ratio of the hop count of the selected paths to that of the shortest path) due to the lack of flexibility of the route recovery method.

To address these problems, we present backpressure routing for dynamic Small cell deployments (BS), a self-organized routing scheme for the TNL to route traffic in dynamic and often sparse NoS deployments. Our previous work on backpressure routing [8,9] helped us to evaluate the potential of combining geographic and backpressure routing when applied to regular (i.e., grid-like) wireless mesh networks. This approach relied on two routing components, namely, backpressure and geographic routing, and the variable V algorithm to trade-off the importance of backpressure and geographic routing. Such a scheme showed potential to perform routing under dynamic SC deployments due mostly to the backpressure routing and V algorithm components, as explained in the preliminary extended abstract of this paper [10]. Thus, we inherit the backpressure routing and the variable V algorithm components from the previous work to tackle dynamic NoS deployments.

The novelty in this paper resides, first, in presenting a new geographic routing component to alleviate the identified inefficiencies of our previous approach in dynamic NoS deployments. Second, BS with the new geographic routing component exhibits self-organization, decentralization, scalability, low-overhead, and (quasi-) statelessness in dynamic NoS deployments. Unlike geographic routing schemes designed for dynamic deployments, BS neither requires complex and resource consuming routing recovery methods nor incrementing the per-node state to dynamically adapt to the current topology. And third, the validation of BS in a wide range of dynamic NoS deployments.

Extensive ns-3 [11] simulations results validate the robustness of BS under a wide variety of wireless mesh deployments and workloads. Under uncongested traffic demands, BS showed a latency and routing stretch performance close to an Idealized Shortest PAth routing protocol (ISPA), which is aware of the global current network topology without consuming air resources. ISPA is taken as an abstraction of traditional TNL protocols of core networks and wired mobile backhauls (e.g., MPLS-TP [5]). In turn, BS improved the latency results obtained by GPSR [12], taken in general as benchmark for comparison against geographic routing featuring void circumvention mechanisms. In the case of more severe traffic conditions, BS outperforms both GPSR and ISPA showing a reduction in terms of average latency of up to a 85% and 70%, respectively, due to its inherent load balancing capabilities while serving the offered load and maintaining a low routing stretch. Note also that, aside from the NoS previously described, our approach is generic enough to be applied to other dynamic scenarios such as the Internet of Things (IoT) [13].

The remainder of this paper is organized as follows. The related work in Section 2 is followed by a description of the backpressure routing protocol and its limitations to be tackled in sparse SC deployments in Section 3. The details

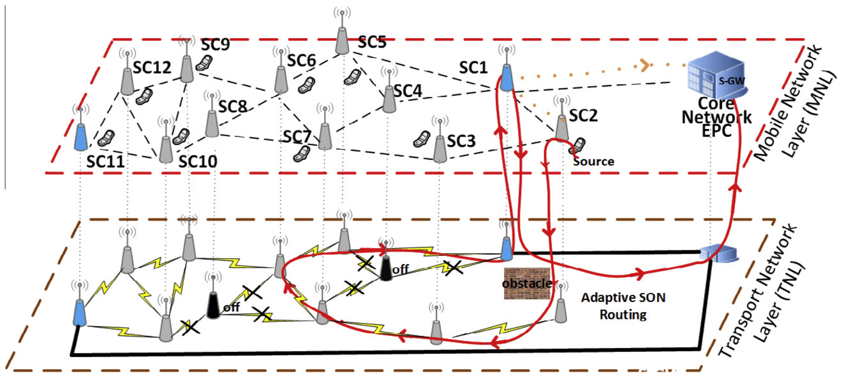

Fig. 1. Portion of an all-wireless semi-planed and hyper-dense yet irregular NoS deployment due to obstacles and SCs powered off opportunistically.