Providing Ubiquitous Wireless Connectivity in Smart Cities through Dense Small Cell Deployment

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Abstract—**Information and Communication Technologies are a key enabler for the realization of future Smart Cities. These technologies can provide pervasive and ubiquitous wireless connectivity to citizens, thanks to which citizens will be able to contribute to the improvement of several urban services. Such connectivity is generally realized through mobile broadband wireless devices, such as smart phones and tablets. However, the severe increase in mobile subscriptions and data usage, pose severe challenges to mobile network operators in meeting the growing demand, without creating new network complexity. Small cell networks have been proposed as a viable solution to offload the macrocell network. However, the wide spread adoption of dense small cell networks is challenging, due to potential interference and increased energy consumption, that may prevent to achieve the potential benefits of this technology. This paper describes the challenges and overviews a framework to enable dense deployments of small cell networks. The framework includes techniques for selective activation, inference prediction, energy harvesting and computation offloading, with the ultimate goal of providing user efficient and pervasive connectivity to meet the demand of future Smart Cities.**

I. Introduction

Information and Communication Technologies (ICT) are widely recognized to be a key enabler in the development of future Smart Cities [1], [2]. In particular, the use of such technologies to provide pervasive and ubiquitous wireless connectivity to citizens is at the basis of the Smart City paradigm. Thanks to this connectivity, citizens will be able to positively contribute to the information feedback loop to improve several urban services such as transportation, traffic management, energy, health care, etc. Such user connectivity is generally realized through mobile broadband wireless devices, such as smart phones and tablets. The use of such devices is experiencing an explosive growth. According to recent studies [3], global mobile broadband subscriptions will reach 4.4 billion by 2016, and global mobile data traffic has been growing at a rate of 150% yearly. Additionally, it has also been shown that once users get accustomed to LTE's faster speeds, their data usage can increase up to ten times more than 3G users' [4]. Such an increase in users and data usage, pose severe challenges to mobile network operators to meet the growing demand, without creating new network complexity.

Small cell networks, including femtocells, picocells and microcells, have been proposed as a solution to offload the macrocell network. Small cell networks are based on the idea of delivering the mobile signal closer to the user, and often indoors, hence overcoming the crucial signal-loss ratio from outdoor to indoor. The small cell architecture exploits the wired broadband connection to backhaul the traffic towards the mobile core network, offloading the cellular network.

Small cell networks are a promising technology to provide the ubiquitous connectivity required by Smart Cities. As an example, small cells can be used to provide services in public places where the macro cell network is not available, such as subway stations, or public places such as airport gates and stadiums which are characterized by a highly dense and variable concentration of users over time.

However, the adoption of small cells in these scenarios is challenging. The relatively limited capacity of such devices requires them to be *densely deployed* to meet the users' demand. On the one hand, such dense deployments may result in a high communication interference, in fact preventing the improvement of the quality of service provided to the users. On the other hand, densely deploying small cell networks would significantly increase the network energy consumption, representing an additional cost for the network operators.

This position paper describes the challenges and overviews a framework to enable dense deployments of small cell networks, and ultimately provide the pervasive wireless connectivity at the basis of the Smart City paradigm.

II. Challenges and State of the Art

This sections describes the main challenges of small cell network deployment , as well as state of the art solutions.

Interference Management. Small cells may generate interference between themselves and with the macro cell network. Several previous works focus on inference management, a comprehensive survey can be found in [5]. The problem is generally modeled as a network resource allocation problem, which intends to assign the sub-bands to the macrocell and the small cells [6]–[9]. Other approaches adopt cognitive based solutions, where the macrocell is seen as the primary user, while femtocells act as secondary user [10], [11].

These works mainly consider networks composed by a single or few small cells. Conversely, the framework described in this paper adopts an inference management scheme which specifically takes into account the dense nature of the network and the possibility of turning off underutilized small cells.

Energy efficiency. An additional challenge of dense small cell deployment is the non-negligible energy consumption incurred

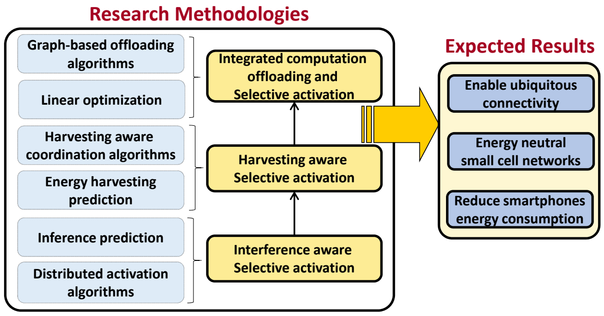

Fig. 1: Overview of the proposed framework.

by the network. As an example, assuming that small cells consume 6 W, a network of 1000 cells covering a university campus would consume more than 50 MWh/year [12]. As a result, reducing the energy consumption of such networks is of primary importance to enable their adoption.

Previous works design power control schemes based on game theory, to adjust the transmission power [13], and Pareto optimal power control and scheduling algorithms, to improve the spectral efficiency [14]. These works are perpendicular to ours, and could be integrated in our framework to further reduce the energy consumption.

III. A Framework for Dense Small Cell Deployment in Smart Cities

Figure 1 shows a block diagram of the proposed framework, the underlying research methodologies, and the expected results. The main components of the framework are described in the following.

Selective Activation. Our preliminary experiments on real small cell devices show that the energy consumption of small cells is dominated by the internal hardware, and only marginally by the traffic load [12]. Based on these findings, the proposed framework provides distributed selective activation algorithms, that exploit local coordination among small cells, and the typical fluctuations of users and traffic. The goal is to keep active only a minimal subset of the available small cells, thus reducing the energy consumption, while meeting the users' quality of service requirements.

Interference Prediction. An inference prediction mechanism aims at autonomously creating a knowledge base, that relates a given selective activation pattern to the actual quality of service perceived by the user. This knowledge is build by periodic observations, filtered using regressograms, linear interpolation and statistical change detection tests to take into account inaccuracies and environmental changes over time.

Energy Harvesting. Energy harvesting technologies, such as solar panels, can be used to further reduce the energy consumption of the network and potentially realize *energy neutral* small cell networks, where all the energy consumed is from renewable resources. To this purpose, our framework combines energy harvesting prediction techniques with distributed optimization algorithms. The goal is to concentrate the traffic where most likely renewable energy will be available.

Computation Offloading. Smart phones and tablets are responsible for a significant amount of energy expenditure in a cellular network. To reduce their energy consumption, in our framework we consider small cells endowed with computational capabilities. This transforms the network in a distributed computational infrastructure, which can be used to offload the computation from user devices to the network. The framework provides graph based optimization strategies that consider different types of applications, and take offloading decision based on the status of the network, the user mobility and the user quality requirements. The goal is to minimize the smart phone energy consumption while meeting the users' quality requirements.

IV. Conclusions

This paper describes the challenges and overviews a framework to enable dense deployments of small cell networks. The framework includes techniques for small cell selective activation, inference prediction, energy harvesting and computation offloading. The framework contributes to the realization of the ICT infrastructure of future Smart Cities. The goal is to provide efficient and pervasive communication to users, and allow them to positively contribute to the information feedback loop at the basis of the Smart Cities paradigm.

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