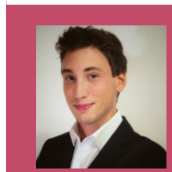

Nicola Piovesan received the B.Sc. degree in Information Engineering and the M.Sc. in Telecommunication Engineering from the University of Padova, Italy, in 2013 and 2016, respectively. Currently, he is pursuing a Ph.D. at the department of Network Engineering of the Universitat Politècnica de Catalunya (UPC), Spain. From September 2016 to September 2019, he was an Assistant Researcher at the Mobile Networks Department of the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), where he worked as European Commission's Marie Skłodowska-Curie fellow in the EU H2020 MSCA SCAVENGE (Sustainable Cellular Networks Harvesting Ambient Energy) project. In 2019, he was at Nokia Bell Labs as a visiting student in the Small Cells Research Department.

Abstract

During the last decades, mobile network operators have witnessed an exponential increase in the traffic demand, mainly due to the high request of services from a huge amount of users. The trend is of a further increase in both the traffic demand and the number of connected devices over the next years. The traffic load is expected to have an annual growth rate of 53% for the mobile network alone, and the upcoming industrial era, which will connect different types of devices to the mobile infrastructure including human and machine type communications, will definitely exacerbate such an increasing trend.

The current directions anticipate that future mobile networks will be composed of ultra dense deployments of heterogeneous Base Stations (BSs), where BSs using different transmission powers coexist. Accordingly, the traditional Macro BSs layer will be complemented or replaced with multiple overlapping tiers of small BSs (SBSs), which will allow extending the system capacity. However, the massive use of Information and Communication Technology (ICT) and the dense deployment of network elements is going to increase the level of energy consumed by the telecommunication infrastructure and its carbon footprint on the environment.

Current estimations indicates that 10% of the worldwide electricity generation is due to the ICT industry and this value is forecasted to reach 51% by 2030, which imply that 23% of the carbon footprint by human activity will be due to ICT. Environmental sustainability is thus a key requirement for designing next generation mobile networks.

Recently, the use of Renewable Energy Sources (RESs) for supplying network elements has attracted the attention of the research community, where the interest is driven by the increased efficiency and the reduced costs of energy harvesters and storage devices, specially when installed to supply SBSs. Such a solution has been demonstrated to be environmentally and economically sustainable in both rural and urban areas. However, RESs will entail a higher management complexity. In fact, environmental energy is inherently erratic and intermittent, which may cause a fluctuating energy inflow and produce service outage. A proper control of how the energy is drained and balanced across network elements is therefore necessary for a self-sustainable network design.

In this dissertation, we focus on energy harvested through solar panels that is deemed the most appropriate due to the good efficiency of commercial photovoltaic panels as well as the wide availability of the solar source for typical installations. The characteristics of this energy source are analyzed in the first technical part of the dissertation, by considering an approach based on the extraction of features from collected data of solar energy radiation.

In the second technical part of the thesis we introduce our proposed scenario. A federation of BSs together with the distributed harvesters and storage devices at the SBS sites form a micro-grid, whose operations are managed by an energy management system in charge of controlling the intermittent and erratic energy budget from the RESs. We consider load control (i.e., enabling sleep mode in the SBSs) as a method to properly manage energy inflow and spending, based on the traffic demand. Moreover, in the third technical part, we introduce the possibility of improving the network energy efficiency by sharing the exceeding energy that may be available at some BS sites within the micro-grid.

Finally, centralized controller implementations based on supervised and reinforcement learning are proposed in the last technical part of the dissertation. The controller is in charge of opportunistically operating the network to achieve efficient utilization of the harvested energy and prevent SBSs blackout.

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Network Resource Allocation Policies with Energy Transfer Capabilities

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MARIE CURIE ACTIONS