PhD Dissertation title:

DESIGN AND OPTIMIZATIONS TOWARD SMART GRID CONNECTED GREEN FUTURE COMMUNICATION NETWORKS

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Abstract:

Green networking solution is a major theme in the upcoming 6G communications. The rising proliferation of the Internet of Things alongside evolving communication technology towards sixth generation (6G) communication networks is estimated to significantly increase the quality of service (QoS) requirements of the network devices. 6G communications-based technologies like autonomous vehicles, metaverse, virtual reality, and ultra reliable low latency use cases are expected to enhance the user quality of experience (QoE). To meet the rising QoS/QoE requirements, mobile network operators are expected to densify the deployment of base stations (BSs) in the network, resulting in a potential rise in network energy consumption and thereby carbon footprint. In addition to mitigating network carbon footprint generation, cost incurred to the mobile network operator in network deployment and operations also requires to be considered while network designing, to realize scalable networks. The main objective of this dissertation is to design energy efficient and cost optimal, self-sustainable scalable future networks.

To realize energy and cost-efficient networks, the BSs are provisioned with renewable energy power supply in addition to the traditional power grid connectivity. With the BSs being spatially distributed in a geographical area, designing grid connected and energy harvesting powered networks is challenging due to the stochastic variation of green energy harvest and BS load, leading to Spatio-temporal traffic-energy imbalances across the network. By modelling the degree of skewness of these imbalances, the first topic of dissertation presents a cooperative coverage adjustment based analytical framework to mitigate the effect of these imbalances on user QoS and operator revenue. Considering the network traffic profile to be heterogeneous, i.e., have delay-constrained as well as delay-tolerant traffic, a tractable lower bound on the rate requirement of a user is derived in this work as a function of QoS parameters defined by 3GPP. The revenue earned by the network operator is mathematically formulated and is observed to be a non-deterministic polynomial-time (NP) hard problem, with the revenue function depending on the number of users in the network and green energy allocated. The optimization problem is algorithmically solved for both these decision variables.

The second topic of the dissertation presents an analytical study wherein the power grid infrastructure is leveraged through cooperative energy transfer, by exploiting the traffic-energy imbalances, to improve the temporal network energy utilization without compromising the user QoS. The cooperative energy transfer framework is designed and optimized independently from two diverging objectives, carbon footprint minimization and operator revenue maximization. The problems are reformulated as convex optimization problem and optimal values are derived. As a carbon-free mode of network operation, “energy-producer” mode of network operation is proposed wherein the BSs act as distributed energy sources to the power grid, realizing a self-sustainable communication network. From the operator perspective, “energy-prosumer” mode of operation involving flexibility of energy purchase from the grid in addition to energy selling and transfer is proposed. The proposed strategies are evaluated and compared with the state-of-the-art.

The third part of the dissertation extends the cooperative energy transfer framework and studies the prospect of designing self-sustainable and self-organizing BS clusters from an energy perspective. The study first analyses a standalone grid connected and solar powered BS system by modelling the BS green energy storage as a three-state discrete time Markov chain (DTMC). This work studies the computational overhead required in a grid connected and solar powered communication system to compute the energy outage and compares the exisiting literature with the proposed DTMC based framework. For a multi-BS framework, a computationally efficient distributed energy bank-based energy cooperation strategy is proposed, wherein the system of BSs is modelled as a two state DTMC. The capital expenditure is optimized by jointly optimizing the solar provisioning in addition to the BS cluster size, towards attaining self-sustainability.

The fourth part of the thesis involves joint traffic-energy management in grid connected and solar powered systems. The study motivates the need for a joint analysis, thereby improving the user QoS in addition to improving the network green energy utilization. Taking the system constraints into consideration, the proposed cooperative coverage adjustment and sharing of energy (CASE) framework is proposed. The CASE framework is mathematically simulated and compared with the competitive state-of-the-art. The proposed joint CASE framework provides superior network QoS and operator profit gains over the state of art, in addition to realizing self-sustainable BS clusters at a much-reduced CAPEX.

The final part of the thesis explores the possibility of integrating the existing grid connected and solar powered terrestrial networks with aerial communication technologies. Specifically, through the dissertation, a High Altitude Platform Station (HAPS) aided and power grid connected communication framework is explored. The proposed framework aims to offload excess users with the solar powered terrestrial macro base station (tMBS) to the HAPS mounted MBS (hMBS) in the event of high traffic or low energy harvest. The solar powered tMBS utilizes the power grid connectivity purely for energy selling rather than energy procurement. The inherent communication and energy networks in the proposed system are studied and modeled jointly as a six state DTMC. The paper also provides analytical bounds on the solar provisioning required at the hMBS for radio access network functions. The proposed framework is compared with a without offloading and grid energy procurement based competitive state of art, in terms of network QoS and annual operator profit. Our simulation-based performance studies demonstrate that the proposed framework under limited hMBS offloading capability offers gains compared to the competitive state of the art, up to 21% enhanced network QoS and 64% increased operator profit.

The communication network frameworks discussed in the dissertation are expected to realize energy sustainable and cost-profitable networks, incentivizing the telecommunication service providers to move towards green future networks.

Keywords: Networked energy systems, energy sustainability, smart grid networks, green communication, telecommunication operator revenue analysis