Design and Optimizations Toward Cost Aware Green Future Networks

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***Abstract*—Achieving energy sustainable networks has been a key challenge in the upcoming sixth generation communication technologies. In addition to energy sustainability, cost/revenue aspects to the mobile operator also require to be incorporated in the system design analysis, so as to achieve scalability. In a grid connected and renewable energy harvesting enabled network, we study various network operation frameworks involving traffic management (TM), energy management (EM), intelligent solar provisioning, and further analyze the prospect of joint traffic and energy management (JTEM). First, we outlay the challenges and physical limits involved in optimizing a grid connected and renewable energy powered cellular network framework. Next, we discuss the system design objectives showcasing the evolution of grid connected and renewable energy powered networks. The key design objectives include achieving self-sustainability (i.e., carbon free networks), cost profitability to the operator, in addition to realizing sustainable network clusters. Simulation results demonstrate the superior gain in user quality of service and operator profit obtained through the JTEM framework over other state of art. The article concludes presenting some open issues associated with grid connected sustainable networks.**

***Index Terms*—Green networks, smart grid, traffic energy imbalances, sustainability, operator profit**

I. Introduction

Achieving greenness through network energy savings is one of the key objectives of upcoming sixth generation (6G) communications [1]. The Information and Communication Technology (ICT) sector currently consumes roughly around 10% of global electricity [2]. The rapid evolution of the Internet of Things (IoT) alongside advent of 6G based future networks is estimated to significantly increase the number of mobile subscribers by around 13% in the upcoming years [3]. Significant research has been conducted at the user end, pertaining around the study of energy efficiency-spectral efficiency tradeoff [4]. In addition to energy efficiency, deployment and operational cost incurred to the mobile network operator also requires to be studied from a network perspective, so as to bring scalability to the network. In this paper, we showcase that fully utilizing the green energy potential by joint traffic and green energy management (JTEM) in grid connected and renewable energy powered communication networks, can provide significant gains in user quality of service (QoS) and profit gains to mobile operator.

A. State of art and motivation

A wireless communication system consists of network devices, base station (BS), and the core network. The BS is the most energy intensive entity, taking up to 58% of the energy consumed by a communication system [5]. Recent studies have shown that a standalone diesel powered BS is estimated to consume about 1500 liters of diesel per month, generating around 4000 Kg of CO_2. With continually increasing user QoS demands, the number of BSs in the network is expected to grow, resulting in an estimated increase in network energy consumption by 170% in the coming years [6]. Hence, there is a growing need to analyse energy efficiency from a network perspective, rather than at the user end.

Apart from energy efficiency, cost expenditure incurred to the mobile network operator has emerged as a crucial parameter for system design [7]. Various costs borne by the mobile service provider include initial network deployment costs (termed as capital expenditure, CAPEX) and operational costs required to manage daily network operations (termed as operational expenditure, OPEX). There is a urgent need to realize operator cost aware system solutions taking the operator cost also into account in addition to the energy considerations, so that the solutions can be readily accepted and deployed by the industry [2]. Hence, scalability of the system solution has become equally pertinent as energy efficiency.

Integrating renewable energy sources (e.g., solar) with the smart grid connected communication network is a potent system solution to mitigate carbon footprint besides offering cost benefits to the operator [8]. Grid connected and renewable energy powered communication networks are becoming increasingly attractive as the power grid connectivity can be leveraged to realize energy and cost profitability. The spatially distributed BSs can be networked leveraging the grid infrastructure, and can be intelligently controlled to transfer green energy among other networked BSs or trade energy (i.e., sell or procure) with the grid. These grid connected and ambient powered networks are prone to stochastic space-time variation of green energy harvest and BS load with varying degrees of skewness, resulting in traffic-energy imbalances across the network. Taking the system design constraints into account, in this work we study various network operation strategies in a grid connected and solar powered setting, and compare them with a joint traffic and green energy management (JTEM) framework. The competitive state of art frameworks include: green energy aware traffic management (TM) [7], [9], traffic aware green energy management (EM) [10], [11], and a without traffic and green energy management (wTEM) framework. The frameworks are compared w.r.t. network QoS perspective (i.e., user perspective), as well as mobile operator profit gains.

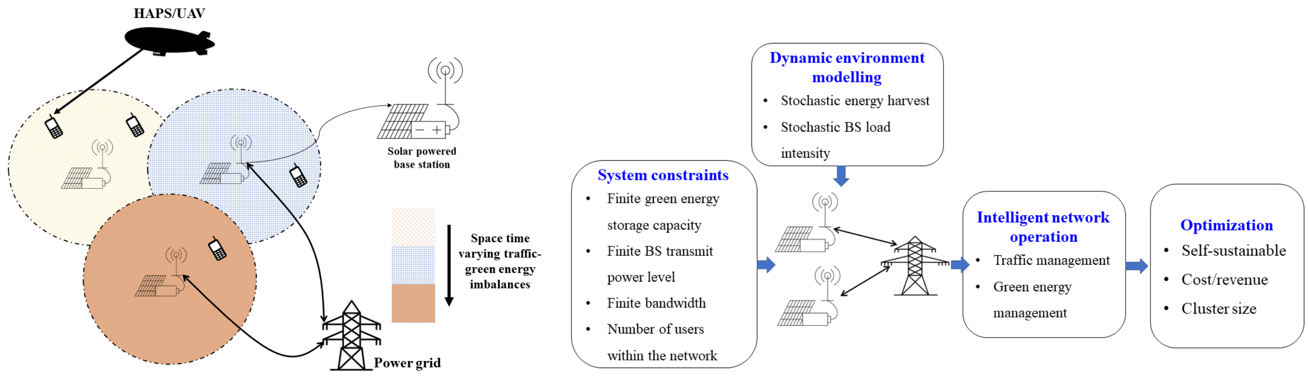

Figure 1: Illustrating (a) space-time varying traffic-energy imbalance prone, grid connected, multi tier, green communication network. (b) overview of the system design framework.

The frameworks are based on dynamic adjustment of space-time traffic inhomogeneities and provisioning of green energy transfer across the BSs by leveraging the grid connectivity.

II. Grid Connected and Solar Powered Communication Network

The communication network comprises of solar powered and grid connected BSs as shown in Fig. 1(a). Being solar powered, the BSs are equipped with solar harvesting photo voltaic (PV) panels and storage batteries. The BSs are connected to core network via optic fiber backhaul links. The system can be expanded to incorporate multi-tier network involving aerial and satellite networks. We discuss the design constraints and objectives in the upcoming subsections.

A. Design constraints and challenges

An overview of the system design framework is shown in Fig. 1(b). In the current 6G technology, the BS generally has access to the entire bandwidth (full frequency reuse) and is prone to co-channel interference from the other networked BSs. The system is also constrained by finite green energy harvesting and storage capacity with each BS. To prevent harmful effects of radio waves to mankind, the BSs radiate power up to a certain transmit level as mandated by the federal communications commission (FCC) guidelines [12].

To study a system in the long run, it is assumed that there are finite number of mobile subscribers in the network such that they can displace within the network. Additionally the green energy harvest on a BS is also stochastic. Hence, grid connected solar powered networks experience space-time varying stochastic behaviour of BS load and energy harvest, resulting in inhomogeneous traffic-energy imbalances throughout the network. Therefore, it is extremely pertinent to capture the effects of the space-time varying traffic-energy imbalances on network energy efficiency and cost performance to the mobile operator. The effect of the traffic-energy imbalances on network performance depends on the degree of skewness of these imbalances on a BS in the network. A BS is termed to be subjected to skewed (or imbalanced) traffic if it experiences inhomogeneous traffic relative to balanced load scenario. In the upcoming subsection, we discuss the objectives associated with system design.

B. Design objectives

The grid connected and renewable powered system can be optimized from multiple objectives namely, carbon emission minimization and network operator revenue maximization. Carbon emission minimization involves maximizing the network green energy utilization or minimizing the grid energy procurement. The system if optimized from this perspective results in the design of grid energy procurement independent system or a carbon-free system. To ensure that the network is scalable, it requires to be cost-effective from an mobile operator's perspective. The operator revenue maximization and carbon emission minimization are diverging objectives and cannot be met together. It is a tradeoff and depends on the CAPEX provisioning and OPEX which are borne by the operator. Another design objective can be to compute the optimal BS cluster size at which the network becomes self-sustainable, upon being subjected to traffic-energy imbalances of varying levels. Hence, while designing grid connected and renewable powered networks, it is extremely pertinent to account for the physical constraints and stochastic challenges listed in Section II-A, depending on the system objective.

III. Novel Network Operation Frameworks

Depending on the objectives, the system designing also involves a careful understanding of the cost metrics which can influence the end result in addition to intelligently selecting the network operation strategies as discussed in the next section.

A. Cost metrics involved in system design

In this subsection we first discuss the cost metrics involved in the design of a grid connected and renewable powered network, which will be followed by the possible BS operations.

1) CAPEX: It is the initial cost incurred to the mobile service provider in installing the communication system. It involves the cost of installing BSs and solar provisioning (includes PV panels and storage batteries) at each BS.

2) OPEX: It includes the cost incurred to the operator in daily operations of the network. OPEX includes the cost incurred to the BSs in procuring energy from the power grid and the cost of energy sharing among the BSs using the grid infrastructure (proposed to be borne by the operator towards power grid maintenance).
3) Revenue earned from serving users: It is the basic revenue paid to the operator by users in the network, towards QoS satisfaction. The operator aims to serve all active users through the BSs and earn higher revenue.
4) Revenue earned by selling energy: The operator can earn additional revenue by selling temporally unutilized excess energy present with other networked BSs.

Next, we enlist possible BS operations in system design.

B. Network operations

Traditionally, the BSs do not have the flexibility of traffic management or green energy management via energy transfer to the other BSs. Below, we list the possible BS operations.

1) Traffic management among BSs: It involves cooperative coverage adjustment among the neighboring BSs, enhancing the network service prospects. As the BSs are geographically distributed, there might be a possibility that in the event of inhomogeneous network traffic, some BS might still be energy starved. TM frameworks are limited by FCC guidelines on antenna power radiation.
2) Green energy management among BSs: It involves cooperative energy sharing among the networked BSs using the power grid infrastructure. EM frameworks are limited due to finite CAPEX provisioning with each BS, resulting in finite energy storage capabilities.
3) Energy trade with power grid: It involves selling energy back to the power grid (if battery overflow) or purchasing energy from the power grid (if BS is still energy starved despite TM and EM).

We discuss key results in the upcoming section.

IV. Key Results and Discussion

We study the effect of relative traffic skewness on operator revenue and user QoS in a grid connected and solar powered communication system. The frameworks evaluated are : green energy aware TM framework [7], traffic aware EM framework [10], without traffic energy management based (wTEM) framework, and joint traffic energy management (JTEM) framework. In Fig. 2(a) we observe that the traffic management based JTEM and TM frameworks result in much significant user QoS over non TM based frameworks like EM and wTEM. From Fig. 2(b) it is observed that the JTEM framework results in significant operator profit compared to other competitive frameworks. These results showcase the significance of fully utilizing the green energy potential in the network though traffic and green energy management jointly.

V. Conclusion and Future Works

The paper has studied various network operation frameworks in a grid connected and solar powered communication

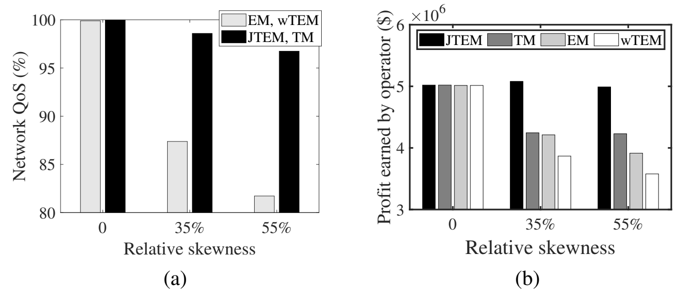

Figure 2: Variation of network QoS and operator profit.

framework, and has evaluated these frameworks with respect to user QoS and operator revenue. The research has identified various challenges, constraints, and operator revenue factors involved in optimal system design. Simulation results have demonstrated that full utilization of green energy potential of the network via JTEM framework can provide superior gains in user QoS and operator profit.

Further research directions in grid connected solar powered communication networks include designing secure grid networks, in addition to using artificial intelligence to make the system design more robust and self-organized.

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References

[1] W. Chen, et al., "5G-Advanced Toward 6G: Past, Present, and Future," *IEEE J. Sel. Areas Commun.*, vol. 41, no. 6, pp. 1592–1619, 2023.
[2] Ericsson: On the road to breaking the energy curve. [Online]. Available: https://www.ericsson.com/en/about-us/sustainability-and-corporate-responsibility/environment/product-energy-performance
[3] GSMA Research: The Mobile Economy 2022. [Online]. Available: https://www.gsma.com/mobileeconomy/
[4] T. Hossfeld, et al., "A Greener Experience: Trade-offs between QoE and CO2 Emissions in Today's and 6G Networks," *IEEE Commun. Mag.*, pp. 1–7, 2023.
[5] C. Han, et al., "Green radio: radio techniques to enable energy-efficient wireless networks," *IEEE Commun. Mag.*, vol. 49, pp. 46–54, 2011.
[6] J. G. Andrews, et al., "What Will 5G Be?" *IEEE J. Sel. Areas Commun.*, vol. 32, no. 6, pp. 1065–1082, 2014.
[7] A. Balakrishnan, S. De, and L.-C. Wang, "Network Operator Revenue Maximization in Dual Powered Green Cellular Networks," *IEEE Trans. Green Commun. Netw.*, vol. 5, no. 4, pp. 1791–1805, 2021.
[8] A. Balakrishnan, et al., "Toward Green Residential Systems: Is Cooperation The Way Forward?" in *Proc. IEEE GLOBECOM*, Dec. 2022.
[9] A. Balakrishnan, S. De, and L.-C. Wang, "Traffic Skewness-Aware Performance Analysis of Dual-Powered Green Cellular Networks," in *in Proc. IEEE GLOBECOM*, Taipei, Taiwan, Dec. 2020.
[10] A. Balakrishnan, S. De, and L.-C. Wang, "Networked Energy Cooperation in Dual Powered Green Cellular Networks," *IEEE Trans. Commun.*, vol. 70, no. 10, pp. 6977–6991, 2022.
[11] A. Balakrishnan, S. De, and L.-C. Wang, "Energy Sharing based Cooperative Dual-powered Green Cellular Networks," in *Proc. IEEE GLOBECOM*, Madrid, Spain, Dec. 2021.
[12] G. Auer, et al., "How Much Energy is Needed To Run A Wireless Network?" *IEEE Wireless Commun.*, vol. 18, no. 5, pp. 40–49, 2011.