Green 6G: Energy Awareness in Design

Rashmi Kamran*, Shwetha Kiran*, Pranav Jha*, Abhay Karandikar*†, Prasanna Chaporkar*

Department of Electrical Engineering, Indian Institute of Technology Bombay, India*

Secretary to the Government of India, Department of Science & Technology, New Delhi, India†

Email: rashmi.kamran@iitb.ac.in*, shwethak@iitb.ac.in*, pranavjha@ee.iitb.ac.in*,
karandi@ee.iitb.ac.in*, chaporkar@ee.iitb.ac.in*

Abstract—Usage and application trends for Sixth Generation (6G) networks (based on ITU's IMT-2030 framework) include immersive multimedia and multi-sensory interactions, digital twin and virtual world, smart industries, digital health and well-being, integration of sensing and communication along with ubiquitous connectivity, intelligence, and computing. 6G technology to support such diverse and demanding use case scenarios is also expected to result in minimized and efficient usage of energy. 6G networks designed to address the challenge of environmental sustainability in addition to serving the above use case scenarios can be named "Green 6G". In Green 6G, the proposal is to include energy awareness in its design along with energy usage optimization at the network level. Users can be provided with information on service-level energy usage in the network including the source of energy (renewable or non-renewable sources), and their (user's) choice should be taken into consideration for service delivery in the network. In this context, there are various ongoing activities in standardization bodies to bring energy awareness into network design. We summarize these standardization initiatives and identify aspects which remain unaddressed in the existing mobile networks. Further, we present the required features of Green 6G design for future networks and highlight associated challenges. We also provide a design perspective for Green 6G architecture as a step towards this direction.

Index Terms—Green 6G, Energy efficiency, Energy aware services, Energy utilization, 6G networks

I. INTRODUCTION

Speedy digitization and rising demand for communications services is resulting in continued increase in energy consumption in cellular networks. GSMA in its 2019 report estimates that cellular networks contribute to total annual emissions of approximately 220 $MtCO_2e^3$ in global emissions, which may double by 2025 [1]. Usage of Artificial Intelligence (AI)-Machine Learning (ML) may further increase energy consumption in cellular networks. To reduce the energy-consumption of future mobile networks, the upcoming Sixth Generation (6G) system can be designed as a "Green 6G" system, with energy awareness built into its design, which is the need of the hour. A "Green 6G" system is also imperative due to the impact of climate change and global energy shortage. Additionally, 6G has an explicit requirement of "ubiquitous connectivity" as per IMT-2030 framework [2]. Hence, a Green 6G system with reduced carbon footprint may enable connectivity to areas with limited energy resources available to its disposal and thereby support the vision of "connectivity for all and everywhere". Another motivation for Green 6G is that today users are more aware and sensitive towards creating a green environment and may want to reduce their carbon footprint while availing compute and communication services from the cellular networks. To this end, a Green 6G system needs to have a coordinated solution at both user and operator levels from the perspective of energy consumption.

There have been numerous efforts by the research community, standardization bodies, equipment manufacturers, and telecom operators to reduce carbon footprint and improve energy efficiency in cellular networks. Some solutions, like Discontinuous Transmission (DTX), have been applied to reduce energy consumption at the Radio Access Network (RAN) level [3]. Deployment of Intelligent Reflecting Surfaces is being considered to reduce transmit power consumption of micro base stations [4]. AI-ML based energy optimization algorithms are being explored to reduce end-to-end energy usage in future networks [5]. In other work, reasonable cost of learning (in some network scenarios) is analyzed to minimize energy consumption in proposed AI native 6G networks [6]. Renewable energy-based solutions for sustainable base stations are being researched [7]. Energy cost is considered as a goal for inference capabilities of Multi-access edge infrastructure [8]. Joint optimization of energy consumption and spectral efficiency is proposed (in [9]) considering various channel conditions. The concept of harvesting energy (for network components) from the environment is also being evaluated for deployment feasibility in real-world scenarios [10].

Above-discussed ongoing research for energy saving in cellular networks is mainly focused on sustainable implementation (in RAN) and AI-ML based energy optimization solutions aimed towards satisfying user experience and achieving energy efficiency, but do not consider/discuss inclusion for "Energy monitoring and exposure" and "user choice from energy perspective". There is still scope to explore following directions: monitoring and exposure of service/user-specific energy usage; inclusion of energy consumption as a performance criterion, e.g., Quality of Service (QoS) parameters like bit rate and latency; and exposure of energy resource type information (renewable or non-renewable) to verticals or users. In this context, this review paper provides a perspective of energy awareness in mobile networks highlighting relevant Third Generation Partnership Project (3GPP) standardization activities and some unaddressed aspects. We propose some new features and design ideas for Green 6G system. Some of the associated challenges are also discussed to conclude the proposal.

II. Energy awareness in cellular networks: Standardization initiatives and uncovered aspects

A few standardization initiatives and outcomes in 3GPP related to energy efficiency and energy awareness in the Fifth Generation (5G) system are listed in Table II. A study report from Release 15 specifies system-wide energy-related Key Performance Indicators (KPIs) and support of energy-saving control with associated management in 3GPP standards [11]. It also highlights architectural requirements to support energy-saving capabilities at network and equipment level. Key issues related to energy efficiency KPIs for RAN, Core, network slice types, network functions' energy consumption estimations, and energy control framework are discussed in [12] with some proposed solutions. Further, 3GPP Release 18 details out data collection requirements and procedures for management and orchestration of energy efficient system [13]. In addition, energy saving state is also defined in which some functional entities in a cell or network functions are powered down [13]. Another report from Release 18 [14], investigates gains and impact of energy-saving techniques in time, frequency, spatial, and power domains by considering other KPIs such as spectral efficiency, capacity, latency, etc. As a result, 5G system requirements in [15] include a clause on "energy efficiency as a service" defining requirements related to energy as service criteria, defining energy states, energy consumption monitoring and information exposure. A recent report in 3GPP is available as TR 22.882 for Release 19 [16], it provides new use case scenarios and identifies new requirements related to energy efficiency as service criteria.

TABLE I
STANDARDIZATION INITIATIVES

Technical Specifications	Title
3GPP TR 22.882 V19.1.0 (2023-09) [16]	Study on Energy Efficiency as a service criteria (Release 19)
3GPP TS 22.261 V19.4.0 (2023-09) Clause 6.15 [15]	Service requirements for the 5G system; Stage 1 (Release 19)
3GPP TR 38.864 V18.1.0 (2023-03) [14]	Study on network energy savings for NR (Release 18)
3GPP TS 28.310 V18.3.0 (2023-09) [13]	Management and orchestration; Energy efficiency of 5G (Release 18)
3GPP TR 28.813 V17.0.0 (2021-12) [12]	Management and orchestration; Study on new aspects of Energy Efficiency (EE) for 5G (Release 17)
3GPP TR 21.866 V15.0.0 (2017-06) [11]	Study on Energy Efficiency Aspects of 3GPP Standards (Release 15)

Although there have been many initiatives and outcomes in standardization communities towards energy efficient networks, there is scope for additional features to be considered for designing a Green cellular network. Following limitations are identified in existing cellular networks:

- Energy-related parameters such as energy consumption, and energy state are not included as performance criteria (E.g., QoS parameters like bit rate and latency) for network services.
- There is no provision for exposing energy-usage related information to verticals and users.

- There is no exposure of energy resource type information (renewable or non-renewable) to verticals or users so they are aware of the availability of renewable energy resources. To include energy source awareness in energy optimization algorithms, methods need to be developed/deployed to predict the availability and types of energy sources.
- There is no provision for energy-consumption based charging, as energy consumption monitoring at a granular level in the network is not provisioned and implemented yet.
- Energy-saving modes are limited to network-level, mainly aiming for reduction of energy consumption at the RAN level (using deployed solutions, like cell on/off feature).
- Partial support for monitoring of Energy consumption and efficiency is feasible through Operations, Administration, and Maintenance (OAM) procedures to execute AI/ML based algorithms/operations for energy efficiency optimization.
- RAT selection mechanisms (in multi-RAT networks) do not include any energy-related information as a deciding factor. Hence energy-aware resource allocation algorithms can be a way forward for energy-efficient RAT selection.

To address some of the above-listed aspects, we propose some new features for Green 6G in the next section.

III. Proposed features for Green 6G

Considering global energy constraints, a Green 6G system needs to have an energy-aware solution at both the user and operator level by considering the availability of multiple and renewable energy sources, availability of energy-saving hardware (e.g., zero-energy devices), along with user awareness about the effects of climate change. On a broader level, we propose to include service-level energy usage exposure to users including the information on energy sources that can facilitate provisioning of energy-aware services based on user choice. In the context of the above-mentioned objective, following are proposed features for Green 6G:

A. Energy consumption granularity

Energy consumption monitoring at a granular level i.e., per slice, per service, per user along with the ability to identify energy source(s) used (including information on renewable and non-renewable energy sources used along with their ratio in the mix) is illustrated in Figure 1.
Green 6G needs to implement granularity in monitoring features to facilitate energy exposure at various levels of the network.

B. Energy exposure at service level

Figure 2 shows a broad-level concept of providing service choices to the user in Green 6G based on energy usage as well as other service parameters. Green 6G users must be free to choose a green service while knowing about the tradeoff in terms of QoS. There can be various options of services
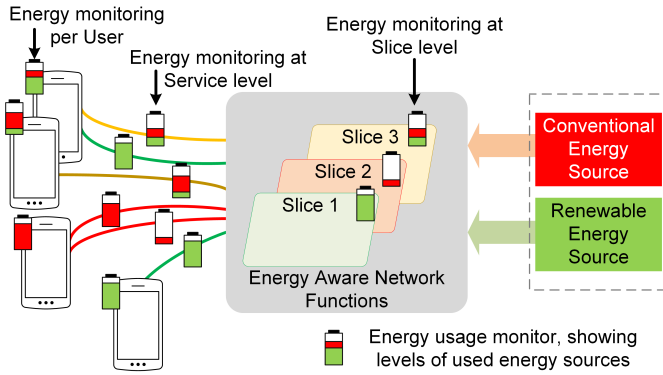
Fig. 1. Energy monitoring with granularity.

based on energy usage and energy resource type used (for that service) as shown in Figure 3. This service level energy usage and energy source type can be exposed to verticals and users. It can be the choice of users/verticals to select an option from available energy-aware services. For example, an environmentally friendly user chooses a green service (low energy, low QoS, provided by renewable energy sources only) over a red service (high energy usage, high QoS, provided by conventional energy sources) by choice.
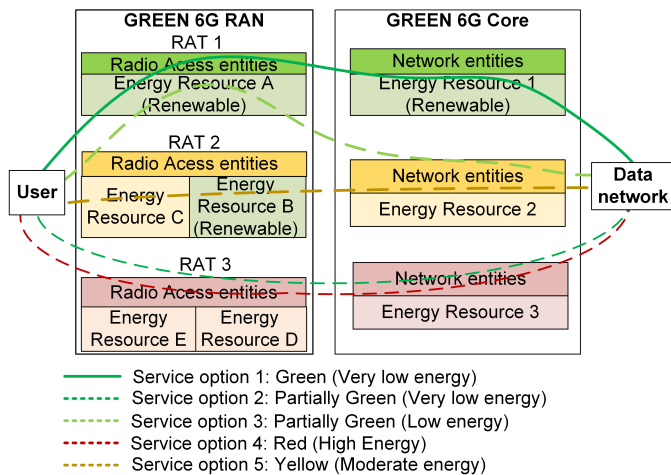

— Service option 1: Green (Very low energy)
····· Service option 2: Partially Green (Very low energy)
····· Service option 3: Partially Green (Low energy)
····· Service option 4: Red (High Energy)
····· Service option 5: Yellow (Moderate energy)

Fig. 2. Energy-aware services.

Subscription choices	Energy usage	Renewable energy sources	Non-renewable energy sources	QoS
Green Services	Very low	√	X	Very low
Partially Green Services	Very low	X	√	Very low
	Low	√	√	Low
Red services	High	X	√	High
Yellow services (Combination of Green and Red services)	Moderate	√	√	Moderate

Fig. 3. Energy based subscriptions.

C. Energy based subscriptions

Feasibility of service subscriptions for users with multiple levels of energy and QoS mapping can introduce openness in energy-based network exposure. Energy consumption/energy credits-based charging can encourage users to opt for green services even with low QoS. The inclusion of energy consumption as a performance criterion like bit rate, and latency is the first step towards designing energy-aware service and subscriptions.

D. Green optimization

AI/ML based optimization algorithms are continuously being evolved for various functions of the network like resource allocation, load balancing, resource usage optimization, energy efficiency maximization, interference management, and positioning. There is now a new concern, increased energy utilization of compute resources due to AI/ML algorithms. Energy utilization by the compute resources and related network entities can be taken as input parameters while designing the algorithm. Such designing of energy-aware algorithms for AI/ML enabled services in the network can be a solution to resolve this concern (as illustrated in Figure 4). Such AI/ML provisioning can result in green optimization in the network.
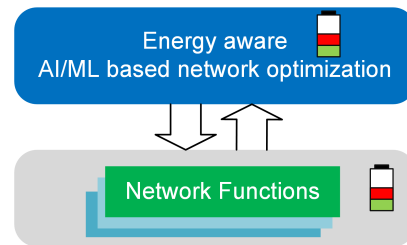

Fig. 4. Green optimization using energy-aware algorithms.

IV. A DESIGN PERSPECTIVE FOR GREEN 6G ARCHITECTURE

A design concept towards coordinating energy awareness in the Green 6G architecture is shown in Figure 5. This architecture is a conceptual view to facilitate energy-aware service to a user/vertical in Green 6G.
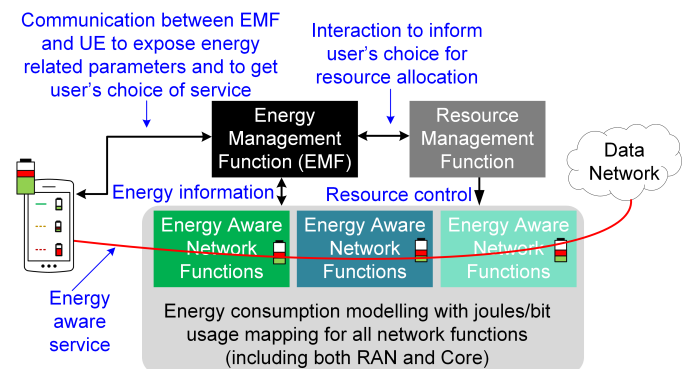

Fig. 5. A design perspective for Green 6G architecture.

A dedicated Energy Management Function (EMF) is introduced to coordinate user requirements and the selection of

network functions based on energy information (for example energy usage, energy credits, etc.). EMF collects granular-level energy information from all network entities. It exposes this information to other entities and also to users based on its service requirements. It also interacts with Resource Management Functions (RMFs) and provides information regarding service-wise energy utilization by network resources and also the user's choice of energy-aware service. RMFs can utilize this information for energy-aware resource allocation. EMF also maps energy information at the service level along with associated QoS and this mapping is exposed to user/verticals as per their choices. Energy consumption using joules/bit modeling can be explored for usage mapping for all network entities (including RAN and core).

V. GREEN 6G CHALLENGES

Above mentioned features and design idea for Green 6G is a revolutionary step towards controlling the carbon footprint of the network while at the same time satisfying service requirements. However, these features may lead to some challenges listed below which need to be discussed and addressed:

- Consent and coordination between all stakeholders is necessary to move forward.
- Coordination and interaction related to energy information between various elements need to be addressed in the network design.
- Dynamic changes in the availability of energy sources (especially renewable energy resources) can make its usage prediction and exposure challenging.
- Agreement of support for the exposure of energy resource types from energy providers (suppliers) is also a coordination challenge for this design.

VI. CONCLUSION

Integration of energy-saving solutions at all levels in 6G design and exposure of energy-related information to verticals and users is essential for minimizing energy usage in the 6G system. Hence, we should take these requirements and challenges into consideration while working on 6G design so that 6G can become "Green 6G". The proposed approach can encourage lower energy consumption and increased utilization of renewable energy. Although there can be a trade-off between the quality of service and energy consumption, it can be an open choice for the user.

REFERENCES

[1] GSMA, "The Enablement Effect: The impact of mobile communications technologies on carbon emission reductions," *Report*, 2019.
[2] ITU-R M.[IMT.FRAMEWORK FOR 2030 AND BEYOND], "Framework and overall objectives of the future development of IMT for 2030 and beyond," *Draft new recommendation*, 2023.
[3] P. Lähdekorpi, M. Hronec, P. Jolma, and J. Moilanen, "Energy efficiency of 5G mobile networks with base station sleep modes," in *IEEE Conference on Standards for Communications and Networking (CSCN)*, 2017, pp. 163–168.
[4] M. Mahbub and R. M. Shubair, "Energy Efficient Maximization of User Association Employing IRS in mmWave Multi-Tier 6G Networks," in *IEEE International Conference on Sensing, Communication, and Networking (SECON Workshops)*, 2022, pp. 25–30.

[5] B. Mao, F. Tang, Y. Kawamoto, and N. Kato, "AI Models for Green Communications Towards 6G," *IEEE Communications Surveys Tutorials*, vol. 24, no. 1, pp. 210–247, 2022.
[6] B. Zhao, Q. Cui, S. Liang, J. Zhai, Y. Hou, X. Huang, M. Pan, and X. Tao, "Green concerns in federated learning over 6G," *China Communications*, vol. 19, no. 3, pp. 50–69, 2022.
[7] H. Yuan, G. Tang, D. Guo, K. Wu, X. Shao, K. Yu, and W. Wei, "BESS Aided Renewable Energy Supply Using Deep Reinforcement Learning for 5G and Beyond," *IEEE Transactions on Green Communications and Networking*, vol. 6, no. 2, pp. 669–684, 2022.
[8] M. Merluzzi, M. C. Filippou, L. G. Baltar, and E. C. Strinati, "Effective Goal-oriented 6G Communications: the Energy-aware Edge Inferencing Case," in *Joint European Conference on Networks and Communications 6G Summit (EuCNC/6G Summit)*, 2022, pp. 457–462.
[9] M. Younes and Y. Louet, "Joint optimization of energy consumption and spectral efficiency for 5G/6G point-to-point networks," in *3rd URSI Atlantic and Asia Pacific Radio Science Meeting (AT-AP-RASC)*, 2022, pp. 1–4.
[10] A. D. Ijala, S. Thomas, and B. B. Adetokun, "The Role Of Energy Harvesting In 5G Wireless Networks Connectivity," in *IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON)*, 2022, pp. 1–5.
[11] 3GPP TR 21.866 V15.0.0 (2017-06), "Study on Energy Efficiency Aspects of 3GPP Standards (Release 15)," *Technical Report*, 2017.
[12] 3GPP TR 28.813 V17.0.0 (2021-12), "Management and orchestration; Study on new aspects of Energy Efficiency (EE) for 5G (Release 17)," *Technical Report*, 2021.
[13] 3GPP TS 28.310 V18.3.0 (2023-09), "Management and orchestration; Energy efficiency of 5G (Release 18)," *Technical Specification*, 2023.
[14] 3GPP TR 38.864 V18.1.0 (2023-03), "Study on network energy savings for NR (Release 18)," *Technical Report*, 2023.
[15] 3GPP TS 22.261 V19.4.0 (2023-09), "Service requirements for the 5G system; Stage 1 (Release 19)," *Technical Specification*, 2023.
[16] 3GPP TR 22.882 V19.1.0 (2023-09), "Study on Energy Efficiency as a service criteria (Release 19)," *Technical Report*, 2023.