A Review of Energy Information Collection and Exposure in 3GPP Mobile Networks

Rashmi Kamran*, Pranav Jha*, Shwetha Kiran*, Pradnya Taksande*, Prasanna Chaporkar *
Abhay Karandikar*†, Manjesh Hanawal ‡
Department of Electrical Engineering, Indian Institute of Technology Bombay, India*
Secretary to the Government of India, Department of Science & Technology, New Delhi, India†
Department of Industrial Engineering and Operations Research, Indian Institute of Technology Bombay, India ‡

Email: rashmi.kamran@iitb.ac.in*, pranavjha@ee.iitb.ac.in*, shwethak@iitb.ac.in*, 20001816@iitb.ac.in*,
chaporkar@ee.iitb.ac.in*, karandi@ee.iitb.ac.in*, mhanawal@iitb.ac.in‡

***Abstract*—International Telecommunication Union identifies sustainability as a key capability of the future 6th Generation (6G) mobile communication system. To move towards a sustainable mobile network design in future, monitoring of energy consumption and energy efficiency in user service delivery is being discussed as a part of the 5th Generation (5G) mobile communication system standards. Several ongoing activities in Release 19 and 20 of the 3rd Generation Partnership Project (3GPP) are focused on an energy-aware mobile network design. Energy awareness in 3GPP 5G and 6G network is envisaged to be supported by: (a) collecting energy-related information, e.g. energy consumption of the network functions, (b) exposing the information to users/third parties (application service providers), and (c) dynamically adjusting the quality of service to reduce energy consumption in networks. In this context, we review the latest standardization efforts in 3GPP on energy-aware mobile network design. Our main contribution is to highlight the challenges and open problems of an energy-aware mobile network design, and to propose a novel policy update mechanism.**

***Index Terms*—Energy awareness, Energy information exposure, Energy efficient networks, Sustainable network design, Policy update**

I. Introduction

Rising demand for communication services by ever-growing number of users is increasing energy consumption in mobile networks. The 5th Generation (5G) system is expected to serve 6.3 billion subscriptions globally by 2030 [1]. Resulting mobile data growth will lead to a significant increase in the network's overall energy consumption and also impact energy costs [2]. Taking cognizance of this issue and also acknowledging the growing importance of sustainable system design as highlighted by the International Telecommunication Union (ITU) in its framework and overall objectives for the 6th Generation (6G) mobile communication system [3], 3rd Generation Partnership Project (3GPP) has started working on an energy-aware network design as part of its Release 19 specifications for the 5G mobile network. This ongoing Release 19 and recently initiated Release 20 work in 3GPP, emphasizes energy awareness in mobile networks by collecting energy-related information from network functions, exposing it securely to users and third parties (application service providers), and adjusting the Quality of Service (QoS) for data flows based on energy-related information [4]–[6]. Here, energy-related information includes per slice and user (subscriber) energy usage information for network functions and the ratio of the type of energy resources, conventional or renewable, used to serve a user. This information can also be shared with third parties (application providers). Following are the highlights of some requirements from 3GPP TS 22.261 [7], pertaining to energy information monitoring/collection, energy information exposure, and associated policy configuration and service update in 3GPP 5G System (5GS):

A. Energy Consumption Monitoring and Collection

- The 5GS supports monitoring of energy consumption per network slice and per subscriber level. The monitoring could be based on a statistical model of energy consumption and not necessarily done in real-time. The 5GS also supports monitoring energy consumption for serving a 3rd party, which may relate to energy consumption by network resources of a network slice, a Non-Public Network (NPN) etc.

B. Energy Information Exposure

- The 5GS allows exposure of energy consumption information to external entities (e.g., 3rd party Application server). The energy information may be related to network resources of a slice, NPN etc. It can include information on carbon emissions or renewable energy ratio and energy credit limit, e.g., if energy consumption for the services to the subscriber is nearing its energy credit limit.
- The 5GS supports exposure of performance statistics information of the network also, e.g., the data rate, the packet delay, and the packet loss along with the energy consumption information to external entities. It helps correlate energy consumption with the QoS supplied.

C. Policy configuration and service modification

- The 5GS supports subscription policies with an energy credit limit for best-effort service. It also supports a

mechanism to perform energy consumption credit limit control and enforce limits on energy consumption for such services, i.e., the maximum quantity of energy that can be consumed over a specific period of time.
- The 5GS allows modification of a communication service based on energy information in accordance with user subscription policies.
- Further, Release 20 of the 3GPP standards proposes to dynamically adjust the QoS of a data flow (service) considering energy constraints.

It is evident from the above requirements that significant enhancements are needed to collect and expose energy information within the network. Further, it will require considerable data exchange, leading to increased overhead and may exacerbate the network's overall energy consumption, the very problem it intends to solve. The requirement to modify the service or adjust the service quality based on energy-related information may require periodic collection and analysis. In this article, we present the ongoing standardization activities under 3GPP and highlight the need for a detailed evaluation of all energy-related information exchange from the perspective of overhead, user consent (user privacy) and implementation feasibility at granular level. In addition, we propose a policy update solution based on energy information collection.

II. Ongoing study items (SIs)/work items (WIs) on energy saving in 3GPP

This section summarizes the scope of ongoing SIs/WIs on energy efficiency and energy saving in SA1, SA2, SA3, and SA5 groups of 3GPP.

A. SA1 - 3GPP TR 22.883 Study on Energy Efficiency as service criteria Ph 2 (Release 20) [5]

This study aims to explore new use cases and potential requirements to address improvements in end-to-end energy saving and energy efficiency. It includes additional functional requirements related to exposure of energy-related parameters (i.e., energy consumption, energy supply mix, carbon footprint, energy capacity, and availability conditions) to the users and third parties. Further, it also delves into use cases for dynamically adjusting service performance based on energy information analysis. This work is an extension of 3GPP TR 22.882 titled 'Study on Energy Efficiency as a service criteria' [4].

B. SA2 - 3GPP TR 23.700-66 Study on Energy Efficiency and Energy Saving (Release 19) [6]

The study identifies and evaluates new solutions for energy information collection, exposure, subscription and policy control, and service modification to fulfill the above-mentioned requirements related to energy efficiency and energy saving in the 5G network. This study is concluded, and normative work has started [8]. Based on conclusions from the recent SA2 meeting #165, a new Network Function (NF) called 'Energy Information Function (EIF)' was defined to support energy efficiency and energy saving in the 5G system. Details of the agreed content are available in approved contributions S2-2411073 [9] and S2-2411074 [10], which will be integrated into 3GPP TS 23.501 [11].

C. SA3 - 3GPP TR 33.766 Study on security aspects of energy savings in 5G (Release 19) [12]

The objective of the study is to identify issues related to security and privacy of collection and exposure of energy-related information for a user. The study also explores if existing security mechanisms will suffice for energy information collection and exposure or if new security mechanisms/solutions are needed. It should be noted that per-user energy information, e.g., user-specific energy consumption data, is private to a user. Therefore, user consent may be required before the data can be shared with third parties. In addition, authorization, authentication of the data consumer, and data protection are other key security aspects.

D. SA5 - 3GPP TR 28.880 Study on energy efficiency and energy saving aspects of 5G networks and services (Release 19) [13]

There are many Key Performance Indicators (KPIs) related to energy efficiency in the existing 5G framework [14]. However, additional KPIs for energy consumption and efficiency may be required to fulfill new use cases and requirements on energy-related information (e.g. renewable energy factor, carbon emission), energy consumption, energy efficiency, and energy saving. The study aims to identify new use cases and KPIs for the 5G system.

III. Energy information collection and exposure

As discussed in the previous section, additional use cases and KPIs are being considered for energy efficiency and energy-saving related requirements even though there already is some provision for collecting and analyzing energy-related information from the Network Functions (NFs), as detailed in [14]. Energy-related KPIs cover a significant part of end-to-end KPIs in the 5G network [14]; some of them are as follows:

- Next Generation - Radio Access Network (NG-RAN) data Energy Efficiency (EE)
- Generic network slice EE KPI
  - Energy efficiency of Enhanced Mobile Broadband (eMBB) network slice
  - Energy efficiency of Ultra-Reliable and Low Latency Communications (URLLC) network slice (based on latency of the network slice, based on both latency and Data Volume (DV) of the network slice)
  - Energy efficiency of Massive Internet of Things (MIoT) network slice (based on the number of registered subscribers of the network slice, based on the number of active UEs in the network slice)
- Estimated Virtualized Network Function (VNF) energy consumption
  - Estimated VNF Component energy consumption

- Estimated virtual compute resource instance energy consumption based on mean vCPU usage
- Estimated virtual compute resource instance energy consumption based on mean vMemory usage
- Estimated virtual compute resource instance energy consumption based on mean vDisk usage
- Estimated virtual compute resource instance energy consumption based on I/O traffic volume

- 5G Core (5GC) Energy Consumption (EC)
- Network Slice EC
- NG-RAN EC
- Generic 5GC EE KPI
- Energy Efficiency of 5GC based on the useful output of 5GC user plane

In addition to the above existing energy-related KPIs exchanged with Operations, Administration and Maintenance (OAM), there is a possibility for including new energy-related KPIs in future specifications as per the latest objectives and requirements (discussed and detailed in [13]).

- Energy consumption of 5GC NFs based on containerized VNF/VNF Components
- Carbon emission related information per 5GC NF
- Carbon emission related information per NG-RAN node
- Averaged NG-RAN energy consumption per UE
- Energy efficiency based on network data traffic
- Energy efficiency based on network availability
- Energy efficiency based on network quality.
- Renewable energy consumption information of 5GC NFs

Other than energy-related information, network functions may need to share additional information with consumer functions, e.g., Application Function (AF), to support energy calculation at a granular level. Some of these information parameters (for example, NF load information from Network Repository Function (NRF), and the number of the QoS flow per PDU session collected from Session Management Function (SMF)) are detailed in Solution 12 of [6]. The energy-related information (including energy KPIs and other relevant non-energy KPIs) also needs to be exchanged among NFs and analyzed within the network for energy-aware network decisions (for example, to adjust QoS for services) as per the service requirements and subscription policies. A specific part of energy information can also be exposed to third parties and users for some use cases, such as '*Use case on exposing subscriber carbon footprint information*' [5]. In this context, Figure 1 shows collection and analysis of energy information in the network through EIF (based on approved contributions from SA2#165 [9] [10]). Further, it can expose this information to the user or third party or be used to adjust the service performance dynamically.

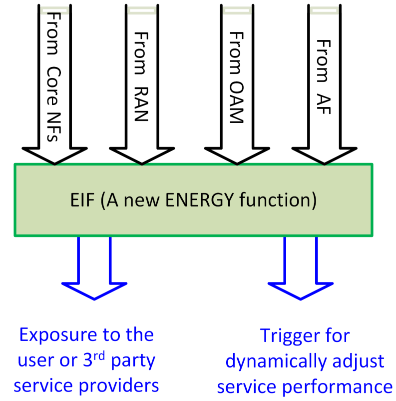

Fig. 1. Collection and exposure of energy information in the network through a new energy function EIF.

IV. Policy Update Based on Energy Information

In [5], clauses '*5.7 Use case on tolerance to QoS degradation due to network energy saving*' and '*5.4 Use case on supporting information exposure and service adjustment based on energy supply mix*' support dynamic adjustment of service performance based on energy information. For example, using renewable energy in mobile network may trigger QoS adjustment due to time-varying characteristics of energy sources. Since clean energy sources are dependent on environmental conditions (e.g., solar and wind), the energy supply available from the grid may not always be from renewable sources. Depending on the energy supply mix (combination of renewable and non-renewable), service QoS levels can be dynamically adjusted in the network to optimize performance. To dynamically adjust service performance in the network, a policy update is triggered by EIF in the network.

Figure 2 shows our proposed solution for policy update based on energy information in the network. Description of the high level information flow is as follows:

1) User subscribes to the energy-saving service, providing its energy consumption threshold values as part of the subscription. 5GS ensures that the UE's energy consumption threshold values are met. Such subscription related data, including multiple energy-saving profiles per service, are maintained in the network by Unified Data Management (UDM) & Unified Data Repository (UDR) Functions.
2) AF shares different QoS profiles for the services, it offers, say Q1, Q2, Q3, ... with the 5GS's Network Exposure Function (NEF).
3) NEF sends these QoS profiles to the Policy Control Function (PCF).
4) According to the mapping of profiles at PCF, a particular QoS profile, say Q1, is selected and used for the data session with the UE.
5) The new energy function (EIF) collects the energy information parameters like energy consumption information, from different NFs in the 5GS as well as from NG-RAN. These functions share details of the energy consumed in the particular data flow (associated with QoS profile Q1) with the EIF.
6) PCF sends the set of QoS profiles to the EIF.
7) Based on the mapping of QoS profiles (received from PCF in the previous step) to energy profiles and energy thresholds provided by the user in step 1 (EIF gets this

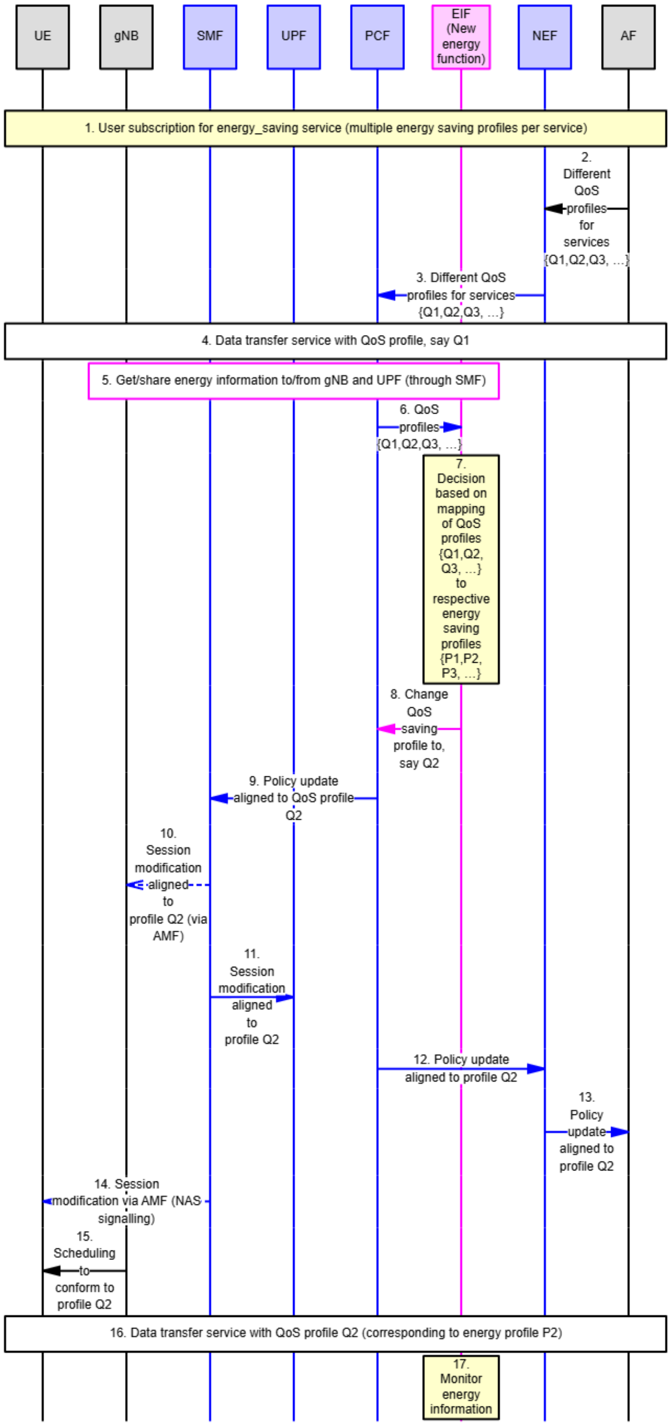

Fig. 2. High level flow for policy updates in the network based on energy information.

information from the UDM), EIF takes the decision to change the energy profile from P1 to, say, P2 for saving energy.

8) EIF requests the PCF to switch the QoS profile to Q2, which corresponds to energy profile P2.
9) PCF updates the policies upon receiving a trigger from the EIF and sends policy update information to the SMF so the session can be modified accordingly for the UE based on the policy updates. Policy updates can be periodic based on service level agreements with user consent.
10) Consequently SMF sends the session modification message for the particular data session to the NG-RAN node, via the Access and Mobility Management Function (AMF).
11) SMF sends the session modification message also to the User Plane Function (UPF).
12) PCF sends policy update message aligned with QoS profile Q2 to NEF.
13) NEF further shares the update with the AF. This enables the AF to modify the data flow according to updated QoS profile.
14) SMF sends the session modification message to the UE, via the AMF (Non Access Stratum (NAS) signalling).
15) NG-RAN changes the scheduling of UE to conform to the policy updates.
16) Ongoing data session of the UE is modified to align with the QoS profile Q2.
17) EIF continually monitors energy information related to the ongoing data sessions for a user and adjusts the QoS parameters as needed.

In a similar way, energy exposure service can be provided in the network upon receiving a request from an authorized AF.

V. Challenges and Open Problems

Key issues and objectives covered in the scope of ongoing 3GPP studies mainly focus on secure collection of energy information within the network, secure exposure of this information through NEF to the AF, and using this information for policy and QoS updates according to the subscription. However, there are a few additional aspects that need consideration, as highlighted in Figure 3. The first issue is the implementation overhead regarding additional signaling, data exchange, and analysis related to energy, as it includes the calculation for per UE/service/slice granular level energy information. Besides, real-time data collection and prediction may not be possible in all scenarios, especially when time-varying characteristics depend on environmental situations (for example, energy supply mix from renewable and non-renewable energy sources). Further, there is higher implementation complexity in network decision making, e.g., resource allocation, due to the additional requirement to use energy information. Another issue is the increase in energy consumption (say, ‘energy utilization overhead’) due to additional data transfer in collecting and exposing energy-related information, aggravating the very problem it intends to solve. And last but not the least, in these new enhancements and procedures, a lot of UE-specific information, such as identifiers, location, etc., is proposed to be shared, which may impinge on user privacy.

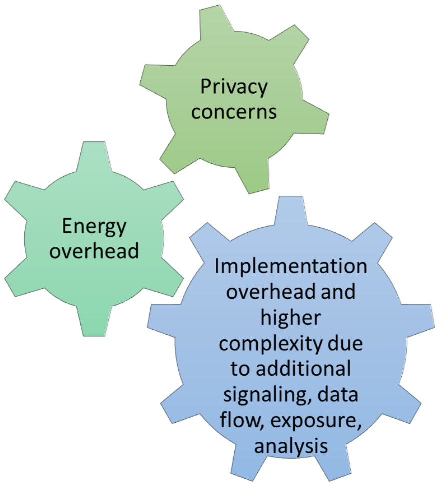

Fig. 3. Challenges related to energy saving enhancements in the mobile network

A. *Questions to be addressed for future sustainable networks*

We understand that new requirements, enhancements, and KPIs related to energy information collection and exposure are included in the recent energy related proposals from 3GPP with the aim of saving energy. However, it's important to be aware of the challenges these new developments bring towards implementation complexity including the complexity of procedures, energy consumption overhead (due to energy information exposure), and privacy concerns etc. so as to address them. In this context, we highlight a few questions for consideration in standardization fora:

- **Should new solutions be considered for reducing overhead of energy information exposure, as this can also be one of the factors contributing to growing energy consumption?**
- **Should existing security mechanisms be used to secure energy information exchange, or can a new mechanism satisfy its security needs, minimize security overhead, and therefore save energy?**
- **From a broader perspective, can there be a way to simplify energy-related procedures, for example, a centralized intelligent energy controller that controls energy consumption by all components?**
- **Should user consent-related mechanisms be introduced in these enhancements to support user privacy in case of direct and indirect UE related exposure and collection?**
- **Should careful scrutiny be done regularly about which parameters are important in energy information metrics that can contribute to substantial end-to-end energy saving?**
- **Should Machine Learning based approach be considered for energy information collection, and information exchange be prioritized based on network resource availability in order to reduce the impact of energy data collection?**

VI. Conclusion

This review paper presents learnings from the ongoing work on energy efficiency in 3GPP Releases 19 and 20. We review the latest standardization efforts in 3GPP on energy-aware mobile network design and provide insights into some missing aspects therein. We also highlight the challenges and open problems of an energy-aware mobile network design especially the issues of implementation complexity, overheads to support a sustainable energy-efficient network, and user privacy. We emphasize rethinking the 'Minimization of complexity in procedures due to energy information collection, exposure and analysis' along with the issue of 'User consent for UE level information collection and exposure'.

Acknowledgment

We thank the Ministry of Electronics and Information Technology (MeitY), Government of India for supporting our work.

References

[1] Ericsson, "Ericsson Mobility Report ," Report, November, 2024.
[2] 5G Americas, "Becoming 5G Advanced: the 3GPP 2025 Roadmap," White Paper, 2022.
[3] 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.
[4] 3GPP TR 22.882 V19.3.0 (2024-03), "Study on Energy Efficiency as a service criteria (Release 19)," Technical Report, 2024.
[5] 3GPP TR 22.883 V0.2.0 (2024-08), "Study on Energy Efficiency as service criteria Ph 2 (Release 20)," Technical Report, 2024.
[6] 3GPP TR 23.700-66 V19.0.0 (2024-09), "Study on Energy Efficiency and Energy Saving (Release 19)," Technical Report, 2024.
[7] 3GPP TS 22.261 V19.8.0 (2024-09), "Service requirements for the 5G system; Stage 1 (Release 19)," Technical Specification, 2024.
[8] 3GPP SA Plenary, "SP-241388 New WID on Energy Efficiency and Energy Saving," 3GPP Agreed Contribution, 2024.
[9] 3GPP SA2, "S2-2411073 Functional Description of Energy Efficiency Control Functionality," 3GPP Agreed Contribution, 2024.
[10] 3GPP_SA2, "S2-2411074 Introduction of new network function for energy related information, its definition and corresponding Architecture Reference Model," 3GPP Agreed Contribution, 2024.
[11] 3GPP TS 23.501 V19.1.0 (2024-09), "System architecture for the 5G System (5GS); Stage 2 (Release 19) ," Technical Specification, 2024.
[12] 3GPP TR 33.766 V0.3.0 (2024-08), "Study on security aspects of energy savings in 5G (Release 19)," Technical Report, 2024.
[13] 3GPP TR 28.880 V1.1.0 (2024-10), "Study on energy efficiency and energy saving aspects of 5G networks and services (Release 19)," Technical Report, 2024.
[14] 3GPP TS 28.554 V19.1.0 (2024-09), "Management and orchestration; 5G end to end Key Performance Indicators (KPI (Release 19)," Technical Specification, 2024.