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Review and Syncretization of Energy Optimization for 5G/6G Networks

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Abstract : Pruning energy consumption has gained momentumrecently, mainly due to its impact on the environment and business operational costs. In response, researchers have proposed various methodologies, some of which have been adopted by standards development organizations (SDOs) to pave the way for sustainable future networks. This paper aims to synergize these optimization techniques and enhance their pertinence by leveraging their complementary capabilities. Existing approaches are often inhibited by specific components, protocols, layers, or applications. To enhance their utility, these methods could be expanded and integrated to enhance the energy efficiency of other components as well. The paper is concluded by highlighting the accuracy impact of these optimizations on the network ecosystem,along with future directions for research in this critical area.

IndexTerms - *Energy saving and optimization, Green Computing, Resilient Network, 5G, 6G network*

I. Introduction

With the ongoing deployment of 5G, researcher and standards have started formulating the requirements and objectives of 6th Generation network. As an initiative International Telecommunication Union (ITU) has set six usage requirements along with sustainability and security. These requirement are taken as a dawn for standardization in 3rd Generation Partnership Project (3GPP). [1]. Sustainability became a focal point due to two major reasons - first is the environmental impacts which is being observed by United Nations and the Paris agreement [2], [3], second it the contribution of energy in the operational cost for the network deployment. [4], [5] With the extreme requirement and aspirations towards 6G, 10^{-9} packet error rate, that is 1000 times more reliable, peak data rate 1 Tbps which was 20 Gbps in 5G, immersive and seamless data rate of 1000 Gbps which was limited to 0.1Gbps [6] set very high goals to achieve by 2030. At this point of time if the energy efficacy is not incorporated in the network then it would impact our surrounding and health and also the profit figures would decrease for network operators and industry. The agenda of 6G is to be more human centric and natively intelligent which involves massive computation. Synchronization would be a major player for example for a live concert, haptic communication the synchronization of each sense is required to provide immersive experience without motion sickness. Beyond its own optimization, the future network is expected to act as a catalyst for sustainable industry 5.0. Furthermore the integration of terrestrial and non-terrestrial/satellite network for seamless connectivity even in remote areas would exponentially increase the resilience requirement.If not planned properly, during critical applications such as public safety the energy consumption would be huge. This behavior shows a tangential path for 6G usage scenario and sustainability. The efforts to make the future generation network energy efficient rooted in the LTE-Advanced. The 5G network was designed to consume less energy, but as soon as 5G picked up momentum higher requirements of data rates, exponential increase in the number of subscriber overshadow this achievement. [5] The locus of this paper is to synergize sustainability and energy efficiency of the network. Before attempting to reinvent the wheel for 6G, it is essential to explore whether existing optimization techniques can be integrated to achieve more efficient outcomes. There are various optimization methodologies but the fault management or accuracy of these techniques plays a vital role such as error in enabling sleep modes, resource allocation could impact the system reliability specifically in time-critical scenarios. Similarly, the service degradation is widely discussed but how to substantiate this degradation and the key performance indicators (KPI) tradeoff with energy cannot be generic. The structure of this paper could be defined as: Section II provides a review of ongoing work in 5G. Section 3 provides a brief overview of Synergy of Energy Optimization Techniques. Section IV concludes the paper by summarizing the work and suggesting future directions.

II. ONGOING RESEARCH BY VARIOUS RESEARCHERS AND SDOS

2.1 Slice-level Energy Optimization

A network slice is a logical network that provides specific network capabilities and network characteristics, supporting various service properties for network slice customers.[7] The 5G uses (ETSI) Network Function Virtualization (NFV) Management and Orchestration (MANO) framework[8] for the deployment of Network Slices (NSs). 3GPP has defined Network Slice Selection Function (NSSF), Network Slice Admission Control Function (NSACF) and Network Slice-specific and SNPN Authentication and Authorization Function (NSSAAF) in [9] to apply and manage network slicing in the 5G Core Network. The optimization through Network Slicing majorly focused on

- Quality of Service (QoS) and Resource Allocation in Mobile Network - RAN, Core and End to End
- Proper isolation of affected network in case of fault.
- Integrating Smart Grid/Power System with 5G network[10–12]

Most of the features of the fifth-generation (5G), such as network slicing, spectrum sharing, and federated learning, rely on a centralized authority[13, 14] highlighted the requirement of QoS and resource optimization virtualization Plane or Hypervisor Plane (H- Plane) by dynamic Virtualized Network Function sharing over multiple Service Function Chains (SFC), considering the flow requests of SFC for individual Network Slice. [15] proposes a 5G network slice resource orchestration and mapping method based on power service which covers End-to-End Network with graph theory depth-first search (GDFS) algorithm. [16]propose the iterative Joint Radio and Core Resource Allocation (JRCRA) method. For RAN slicing, the sub-channel and power are allocated to users of different slices, and in Core Network, processing, and networking resources are allocated to users' data packets. An AI-Assisted Network Slicing Framework for 5G-and-Beyond Networks proposed in [17] based on resource allocation schemes to enable high-quality selection of radio points of access, Virtual Network Function (VNF) placement and data routing, data compression ratios, from the end users to the cloud.

2.2 Micro service based Energy Optimization

The microservices are decomposition of several inter-dependent services which are loosely coupled into modules.Even though microservices have numerous advantages, one of the shortcomings from monolithic architecture is substantial energy demands to meet the desired standards of performance and availability. Gabriel el at. In [18] conducted a systematic review of Energy Consumption in microservice base architecture based on various criteria, including metrics, evaluation methodologies, and architectural typologies, thus uncovering research gaps and emerging trends. Taking that reference as a benchmark we tried to uncover the research which is applicable or can be reused for 5G Network. The 5G Core Network is based on Service Based Architecture (SBA) [9].The major contributions of energy optimization in micro-services could be categorized as

- Scaling of Micro-service
- Fault Detection and Optimization
- Power Monitoring and simulators for Micro-service to promote R&D
- Placement of Network Function Components and its impacts
- Load balancing
- Inter-service Communication

For Auto-scaling of micro-services various methodologies proposed by researchers such as Monitor-Analyze-Plan-Execute over a shared Knowledge (MAPE-K) [19], workload Prediction in Cloud-Edge Collaboration Environment[20], Geo-Scale [21], Smart-HPA(Horizontal Pod Autoscaler) [22] etc. A review conducted in [23] which classified existing autoscalers dealing with containers in microservice and provided a future roadmap. Resilience is one of the main concerns for sustainability. Faults in the system adds an extra header on the energy consumption of the system and hence decreases its efficiency. Various research has been conducted on Fault Management of Microservices based architecture which includes but not limited to [24–26].For load balancing [27] evaluated the XDP-Monitoring Energy-Adaptive Network Functions(X-MAN) framework for managing the CPU operational states (P-states) so as to reduce the power consumption while prioritizing low-latency service. [28] provided a review which covers some selected load balancing techniques. Also these microservices need to communicate with each other on a requirement basis including synchronization. [29] The primary challenge in Micro-services architecture lies in software performance degradation, specifically in terms of response time and throughput, due to inter-service communication over the network.To mitiigate the challenges, which uses a request response-based steam Transport Control Protocol (TCP) communication strategy for inter-service communication in both on-premise and cloud-native environments. [30] proposed Energy-Aware HTTP Protocol to increase energy efficiency in HTTP based communication.L.D.S.B Weerasinghe el at. has taken an experimental methodology in [31] to compare and contrast the most trending inter-service communication mechanisms such as Hypertext Transfer Protocol(HTTP), (google Remote Procedure Call) gRPC etc and suggested that gRPC protocol performs well in terms of response time and throughput.

2.3 AI based Network Energy Optimization

The introduction of Network Data Analytics Function (NWDAF), Data Collection Coordination Function(DCCF) and Analytics Data Repository Function(ADRF) [9] opens the road map for integration of AI in 5G Core Network. NWDAF supports various services for providing insights of the current network and prediction for future to enhance user experience, has potential to foster the sustainability. Lot of research activity going in AI to develop a sustainable future network such as [32] highlighted the potential of Generative AI for addressing various challenges in network optimization, organization and resource management which includes enhancing ML algorithms using Generative AI, predicting user requirement for different resources, Generating synthetic call records which can be used as training data for ML algorithms that powers Self Organized Network and adaptability of algorithms to changes in network conditions, Network Traffic Analysis etc. [33] highlights the management of Energy Mix using Responsible AI and the future challenges in realization in deployment setup. In addition to that [34] proposed ML model is presented, combining Multi-layer Perceptron (MLP), and Support Vector Regression (SVR) to predict energy consumption from renewable sources. [35] highlights the bottleneck of a common management plane for all Network Slices (NS) – scalability and resilience and proposed automated and distributed hierarchical management plane which is easily scalable and secured which also helps vendor and/or operators for accountability. [36] suggested recurrent neural network (RNN) controller to realize accurate load balancing for efficient utilization of network slices and slice failure conditions. A green business model proposed in [37] promotes behaviors (e.g.

consuming resources as-a-Service). [17] proposed an AI assisted slicing framework to enable high-quality selection of radio points of access, Virtual Network Function placement and data routing, as well as data compression ratios, from the end users to the cloud. [38] proposed Explainable AI (XAI) method to enhance the transparency of the black-box AI decision-making process.[39] highlighted the importance of freshness of dataset for Machine Learning based optimization and also coined Age of Information (AoI) metric to represent Data Set Freshness. Similarly [40] proposed Green Energy Quotient a metric to measure the greenness during different phases of AI life-cycle and generates recommendations for best practice to adopt, ease of adoption etc. [41]. Major trends in machine learning approaches that can address the sustainability problem of AI have been reviewed in [42]. Similarly, [43] employs mathematical expressions to quantify the environmental benefits of AI integration, including algorithms that optimize resource use and reduce carbon footprints and questioned companies view and trust in AI, Power requirement Prediction, Cost Prediction, etc

2.4 Placement of Network Component

While edge has tremendous advantages, the deployment in edge and in-Network devices is costlier than compared to cloud. The exponential increase of users accessing wireless networks has gradually highlighted the importance of proper placement of microservices.[44] Efficient placement also ensures the reduction of energy consumption. The concept of "Edge Agility" proposed in [45] enables the foundation of stateless 5G Network Function (NFs) to accommodate runtime relocation of microservices based on events and/or forecasting end-users behavior like mobility, traffic intensity pattern etc. It can be based on external factors such as availability of renewable energy, weather forecasting etc. [46] proposed Components-aware microservices placement with focus on fault management, database for each microservice etc. Another work proposed in [47] to reduce the deployment cost by co-locating the microservices with a shareable common layers.

2.5 Use of Energy Mix

Energy Mix implies the how we can integrate renewable sources of energy as energy supply for telecommunication network.The challenges faced in integrating 5G network with energy mix are mentioned below.

- To find sustainable alternative to non-renewable energy sources - Photovoltaic (PV), Wind, Biomass [48]
- To measure efficiency and storage of these energy sources.
- To integrate with the existing communication protocol such as Stream Control Transport Protocol (SCTP) [49], Next Generation Application Protocol (NGAP) etc.
- To add autonomy to the network to dynamically manage the energy supply with fault management. [50] [51]

2.6 Self Organized Network

Features like flexibility, agility and configurablity, leveraged the Software, while the hardware has always played the role of physical infrastructure, to make such software executable[52].As we are moving towards autonomous network the concept of Self organized network is blooming and evolving towards Self Healing Network [53].[54] proposed a self-sustained RAN slicing framework, which integrates the self-management of network resources framework which hierarchically structured, and decomposes the RAN slicing control into three levels, i.e.,Network Level, RAN Level and Packet Scheduling level to achieve an adaptive control strategy under unplanned network conditions which can be further evaluated to End-to-End Network Slicing. Operational and Management (O&M) also collects energy consumption statistics from the network at various levels- per NF Level, per UE Level, per QoS level and per slice level. While the former calculates the energy consumption and manage the system accordingly.This information could also exposed to Application Function and User for taking informative decisions.This is commonly know as Energy as a Service [55][56]. The use of relay for energy consumption and enhanced coverage is another dimension in this domain.[57]

III. SYNERGY OF ENERGY OPTIMIZATION TECHNIQUES

The eco-optimization methodologies enables the sustainable development. The widely accepted optimization which is applicable throughout the network is sleep mode, AI which could be integrated with almost all the other methodologies such as energy mix, network placement, relays, Reflective Intelligent Surface, energy harvesting, energy efficient protocols etc. Some of the identified applications are listed below

3.1 Sleep/Deactivation and AI

In a network density of 107 devices/kilometer2, the likelihood of a network element or function being in an idle state is inherently constrained. This can be further optimized through the integration of AI/ML-based mechanisms that predict time-space probabilities, enabling location-based, time-based, orhybrid sleep scheduling. Moreover the sleep modes varies based on requirement similarly the threshold for these sleep cycles could be dynamic based AI/ML predictions. In addition, the prediction process itself could be designed as a scheduled operation, negating the need for continuous activation as shown in Figure 1. AI/ML components could similarly operate within defined activation and deactivation cycles. This approach is further justified when deviations from predicted outcomes are minimal, or the results consistently align with predictions, reducing the necessity for perpetual activity.

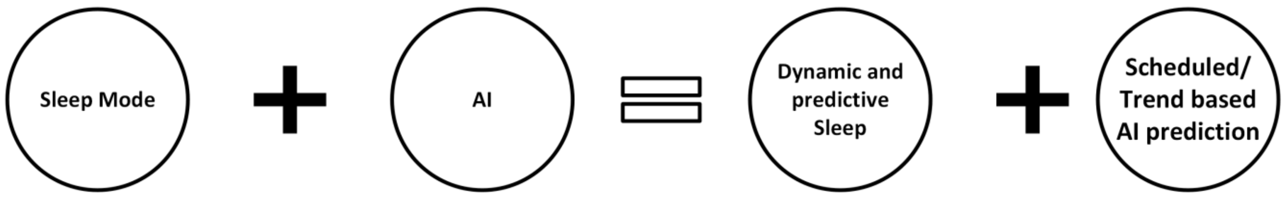

Fig 1: Hybrid AI and Sleep Mode

3.2 Sleep and Placement of Network Function

Network functions or elements that are moderately active—neither highly utilized nor idle—can be placed away from the edge, similar work has been proposed in [58] for virtual machines. This relocation aligns them with energysources having the lowest carbon emissions. It reduces reliance on fossil fuels at the edge, reserving it for critical, high-performance tasks.

3.3 Sleep/Deactivation and Log Management

The sleep or deactivation are scheduled based on a certain threshold, if a network element is not active but not crossing the threshold could decrease the log level to reduce the power utilization. The combination of sleep/Deactivation, log management can be shown in Figure 2 where T1, T2 , T3 and T4 are threshold for log level disablement, sleep mode, deep sleep and de-activation**.**

3.4 AI and Placement of Network Function

The network function could be placed in advanced at edge/cloud/fog based on the traffic prediction by AI model. This could also helps in network planning. Similarly AI model might not always need to be placed near the edge and could be placed near high renewable energy source supply. AI could help in application based network deployment planning also based on UE's data/application consumption pattern analysis. [59] proposed Multi-edge intelligence placement where the access point (AP) places the most up-to-date AI program at user devices to enable local computing/task execution at the user side. [60] provide a comprehensive review for AI enable resource management in fog computing.

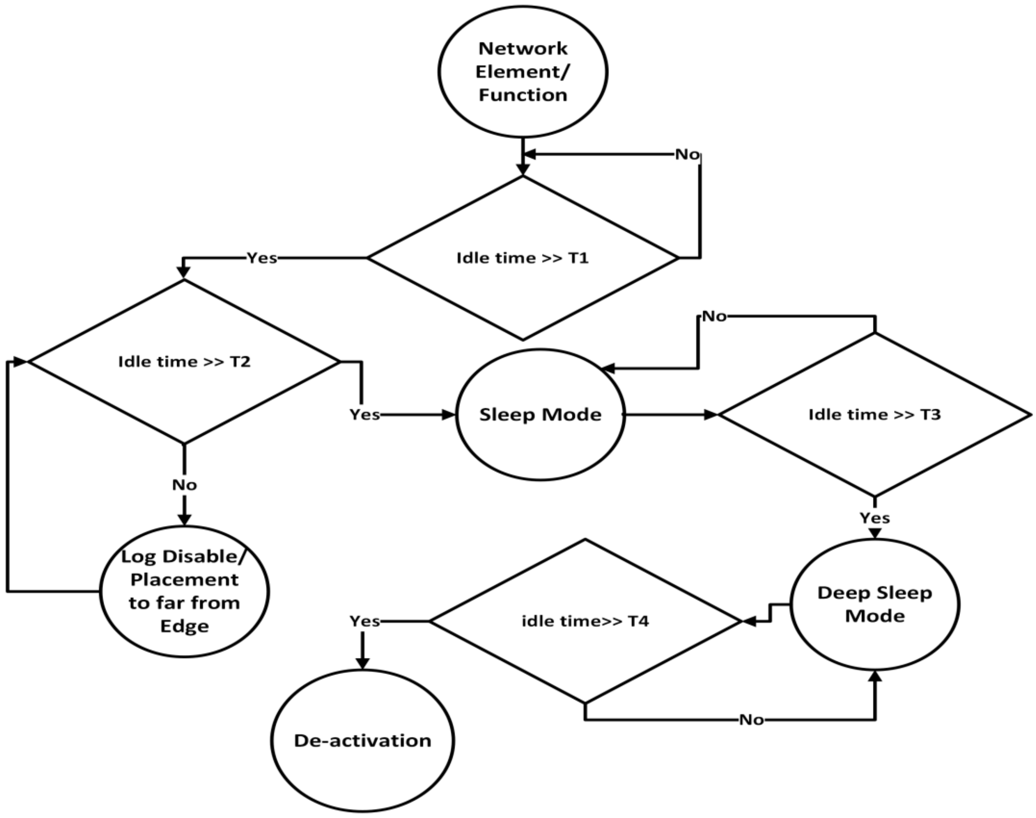

Fig 2: Hybrid Sleep, Log Management and Placement

3.5 Energy Efficient Protocol with all other optimization Mechanisms

Energy optimization involves adding an extra header to network elements [61]. To enable signaling for energy efficiency, the use of an energy-efficient protocol is essential, further enhancing the optimization process. Similarly, leveraging AI predictions, dynamic protocols can be employed, adapting in real-time to meet specific application or user requirements, thereby optimizing overall network performance.

3.6 AI, Log Management, Fault Management

The AI system can dynamically adjust the log level based on network traffic patterns, optimizing data logging for current conditions. Additionally, it can proactively relocate historical log data to a different location as part of network pre-planning. By analyzing fault predictions or resilience trends, the AI algorithm ensures log levels adapt in real time to enhance network performance and reliability. Upto a certain level of log analysis could be provided by AI/ML itself to speed up the fault management process as shown in Figure 3

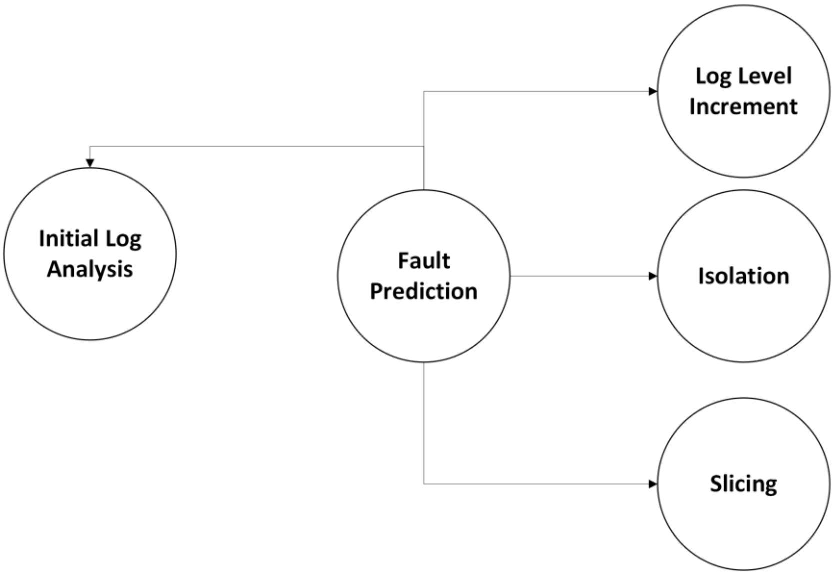

Fig 3: AI enabled - Fault Management and Log Management

3.7 AI and Energy Mix

The scheduling of AI training and inference tasks can be optimized based on the energy supply mix of the network, ensuring efficient energy utilization. Furthermore, AI can play a pivotal role in location-specific predictions and the strategic planning of energy supply mixes, including the anticipation and management of power outages. Another potential avenue for optimization involves leveraging AI's prediction accuracy to conduct intra-network analyses, thereby enhancing the alignment between energy supply and demand within the system. Another issue is planning the most feasible timing for energy source switching to reduce the latency impacts on user experience.

3.8 AI/ML and Circular Optimization

While significant focus has been placed on energy reduction, other optimization strategies, such as reuse and refurbishment, also play a crucial role. AI and machine learning can predict and enhance the effectiveness of these optimizations by determining which strategies are most suitable for a given context. This could be applicable for generic context based optimization selection based on AI/ML.

3.9 AI, Energy Harvesting and Reflective Intelligent Surface (RIS)

[62] proposed a deep reinforcement learning (DRL)-based algorithm is developed to improve the proposed EH-RIS scheme for guaranteeing the quality of service (QoS) under dynamic wireless environments. Energy harvested from the environment (e.g., RF signals or solar power) can be used to power the RIS elements themselves, ensuring that the system operates with minimal external energy inputs. In scenarios like mobile networks, where the network conditions may constantly change, or in remote locations where power supply is unreliable, the combination of EH and RIS offers a resilient solution. Energy harvesting can ensure continuous operation while RIS adapts to the changing conditions to maintain network performance.

3.10 Relay and Reflective Intelligent Surface (RIS)

[63] propose a hybrid relay-reflecting intelligent surface (HR-RIS) architecture, in which a single or few elements serve as active relays, while the remaining only reflect the incident signals which could be fixed or dynamic HR-RIS. This was lateutilized to enhance the performance of Integrated Sensing and Communication (ISAC) in [64]. Environmental monitoring through ISAC could be used as a feedback for the network.

3.11 Relay, RIS, AI and Placement

Placement plays a crucial role based on AI the deployment requirements could be predicted and the placement of the relays, RIS or hybid could be explored.

3.12 Advanced Materialization with AI and Network Placement

Hardware plays a pivitol role energy utilization in the sources of material and availability could be pre-defined. This could be enhanced further by futuristic planning of the placement requirement specifically for the installation which could be added with environmental awareness using ISAC capabilities. Similarly a hologram could add more clear picture to make a robust system.

3.13 Network Slicing and AI

Slicing could help in fault isolation and AI in fault prediction combining these together would enhance the reliability of the network and reduce the downtime.

3.14 Network slicing and sleep mode

The potential network component before reaching the cut-off threshold for sleep mode could be transferred to a separate slice with lower priority and resources.

IV. Conclusion and Future Work

With advanced research in sustainability and cross-domain applicability it is required to provide the big picture of optimization carried out in 5G system before taking next step towards future generation that is 6G. Its a time to re-examine the current optimization techniques and to synergies their capabilities to provide multiplied enhancements. This paper examined 14 combinations at high level and provided a roadmap for further additions to these approaches. The outcome of this study was to appreciate the role of Sleep mechanism and Artificial Intelligence which collaborate with almost every domain to increase the efficiency of the system as well as energy. This paper would help researcher to visualize a holistic view of how the network intelligence would enable sustainability. Going forward each algorithms in these areas could be evaluated.

References

[1] 3rd Generation Partnership Project, "Study on 6g use cases and service requirements," 3rd Generation Partnership Project, Tech. Rep., 2024, status: Draft.

[2] International Telecommunication Union, "Framework and overall objectives of the future development of imt for 2030 and beyond," ITU Radiocommunication Sector, Tech. Rep., 2023, accessed: 2024-08-27.

[3] P. Agreement, "United nations," United Nations treaty collect, pp. 1-27,2015.

[4] R. Bolla, R. Bruschi, F. Davoli, L. Ivaldi, C. Lombardo, and B. Siccardi, "An ai framework for fostering 6g towards energy efficiency," in 2022 61st FITCE International Congress Future Telecommunications: Infrastructure and Sustainability (FITCE), 2022, pp. 1–6.

[5] VIAVI Solutions, "What is 5g energy consumption?" accessed: 2024-11-20. [Online]. Available: https://www.viavisolutions.com/en-us/resources/learning-center/what-5g-energy-consumption

[6] R. Kumar, S. K. Gupta, H.-C. Wang, C. S. Kumari, and S. S. V. P.Korlam, "From efficiency to sustainability: Exploring the potential of 6g for a greener future," Sustainability, vol. 15, no. 23, 2023. [Online]. Available: https://www.mdpi.com/2071-1050/15/23/16387

[7] 3GPP: 5G Network Slice Management. Accessed: 2024-09-16 (2024). https://www.3gpp.org/technologies/slice-management

[8] NFV, E.I.S.G.I.: Network Functions Virtualisation (NFV); Management and Orchestration; Report on Architectural Options. Technical Report ETSI GR NFV-MAN 001 V1.2.1, European Telecommunications Standards Institute (ETSI) (2016). Accessed: 2024-09-07. https://www.etsi.org/deliver/etsigr/NFV-MAN/001099/001/01.02.0160/grNFV-MAN001v010201p.pdf

[9] 3rd Generation Partnership Project (3GPP): 5G System; System Architecture for the 5G System (Release 19). Technical Specification TS 23.501, 3GPP (June 2024). [Online]. https://www.3gpp.org/ftp/Specs/archive/23 series/23.501/23501-j00.zip

[10] Li, L., Zeng, Y., Feng, B.: An end-to-end deterministic network architecture for electricity-energy internet. In: 2023 IEEE International Conferences on Internet of Things (iThings) and IEEE Green Computing & Communications (GreenCom) and IEEE Cyber, Physical & Social Computing (CPSCom) and IEEE Smart Data (SmartData) and IEEE Congress on Cybermatics (Cybermatics), pp. 102–108 (2023). https://doi.org/10.1109/iThings-GreenCom-CPSCom-SmartData-Cybermatics60724.2023.00041

[11] Zhou, X., Hu, C., Wang, W., Yang, Y., Lv, S., Rao, W., Zhou, Z., Tang, Y., Luo, X., Cheng, B., Chen, Y., Chen, L.: Application of 5g short slice in self-healing distribution network automation. In: 2023 IEEE 6th International Electrical and Energy Conference (CIEEC), pp. 2008–2012 (2023). https://doi.org/10.1109/CIEEC58067.2023.1016594019

[12] Yan, J., Dong, M., Lv, S., Wang, B., Zong, Y.: Research on 5g network architecture for smart pumped storage power station. In: 2022 4th International Conference on Intelligent Control, Measurement and Signal Processing (ICMSP), pp. 1122–1125 (2022). https://doi.org/10.1109/ICMSP55950.2022.9859105

[13] Taskou, S.K., Rasti, M., Nardelli, P.H.J.: Blockchain function virtualization: A new approach for mobile networks beyond 5g. IEEE Network 36(6), 134–141 (2022) https://doi.org/10.1109/MNET.009.2100473

[14] Basu, D., Jain, A., Ghosh, U., Datta, R.: Qos-aware dynamic network slicing and vnf embedding in softwarized 5g networks. In: 2022 National Conference on Communications (NCC), pp. 100–105 (2022). https://doi.org/10.1109/NCC55593.2022.9806465

[15] Zhao, Y., Shen, J., Qi, X., Wang, X., Zhao, X., Yao, J.: A 5g network slice resource orchestration and mapping method based on power service. In: 2022 IEEE 6th Information Technology and Mechatronics Engineering Conference (ITOEC), vol. 6, pp. 1419–1422 (2022). https://doi.org/10.1109/ITOEC53115.2022.9734573

[16] Taskou, S.K., Rasti, M., Hossain, E.: End-to-end resource slicing for coexistence of embb and urllc services in 5g-advanced/6g networks. IEEE Transactions on Mobile Computing 23(7), 8015–8032 (2024) https://doi.org/10.1109/TMC.2023.3341810

[17] Awad Abdellatif, A., Abo-Eleneen, A., Mohamed, A., Erbad, A., Navkar, N.V.,Guizani, M.: Intelligent-slicing: An ai-assisted network slicing framework for 5g-and-beyond networks. IEEE Transactions on Network and Service Management 20(2), 1024–1039 (2023) https://doi.org/10.1109/TNSM.2023.3274236

[18] Ara´ujo, G., Barbosa, V., Lima, L.N., Sabino, A., Brito, C., F´e, I., Rego, P., Choi, E., Min, D., Nguyen, T.A., Silva, F.A.: Energy consumption in microservices architectures: A systematic literature review. IEEE Access, 1–1 (2024) https://doi.org/10.1109/ACCESS.2024.3389064

[19] Bucchiarone, A., Guidi, C., Lanese, I., Bencomo, N., Spillner, J.: A mape-k approach to autonomic microservices. In: 2022 IEEE 19th International Conference on Software Architecture Companion (ICSA-C), pp. 100–103 (2022). https://doi.org/10.1109/ICSA-C54293.2022.00025

[20] Peng, Z., Tang, B., Xu, W., Yang, Q., Hussaini, E., Xiao, Y., Li, H.: Microservice auto-scaling algorithm based on workload prediction in cloud-edge collaboration environment. In: 2023 IEEE International Conferences on Internet of Things (iThings) and IEEE Green Computing & Communications (GreenCom) and IEEE Cyber, Physical & Social Computing (CPSCom) and IEEE Smart Data (SmartData) and IEEE Congress on Cybermatics (Cybermatics), pp. 608–615 (2023). https://doi.org/10.1109/iThings-GreenCom-CPSCom-SmartData-Cybermatics60724.2023.00112

[21] Cheng, K., Zhang, S., Liu, M., Gu, Y., Wei, L., Cheng, H., Liu, K., Song, Y., Shi, X., Zhu, A., Tang, L.: Geoscale: Microservice autoscaling with cost budget in geo-distributed edge clouds. IEEE Transactions on Parallel and Distributed Systems 35(4), 646–662 (2024) https://doi.org/10.1109/TPDS.2024.3366533

[22] Ahmad, H., Treude, C., Wagner, M., Szabo, C.: Smart hpa: A resource-efficient horizontal pod auto-scaler for microservice architectures. In: 2024 IEEE 21st International Conference on Software Architecture (ICSA). IEEE,(2024). https://doi.org/10.1109/icsa59870.2024.00013

[23] Fourati, M.H., Marzouk, S., Jmaiel, M.: Towards microservices-aware autoscaling: A review. In: 2023 IEEE Symposium on Computers and Communications (ISCC), pp. 1080–1083 (2023). https://doi.org/10.1109/ISCC58397.2023.10218213

[24] Rios, J., Jha, S., Shwartz, L.: Localizing and explaining faults in microservices using distributed tracing. In: 2022 IEEE 15th International Conference on Cloud Computing (CLOUD), pp. 489–499 (2022). https://doi.org/10.1109/CLOUD55607.2022.00072

[25] Rangaiyengar, R., Komondoor, R., Medicherla, R.K.: Multi-layer observability for fault localization in microservices based systems. In: 2023 IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER), pp. 733–737 (2023). https://doi.org/10.1109/SANER56733.2023.00081

[26] Sarda, K.: Leveraging large language models for auto-remediation in microservices architecture. In: 2023 IEEE International Conference on Autonomic Computing and Self-Organizing Systems Companion (ACSOS-C), pp. 16–18 (2023). https://doi.org/10.1109/ACSOS-C58168.2023.00025

[27] Xiang, Z., H¨oweler, M., You, D., Reisslein, M., Fitzek, F.H.P.: X-man: A non-intrusive power manager for energy-adaptive cloud-native network functions. IEEE Transactions on Network and Service Management 19(2), 1017–1035 (2022) https://doi.org/10.1109/TNSM.2021.3126822

[28] Saxena, D., Bhowmik, B.: Analysis of selected load balancing algorithms in containerized cloud environment for microservices. In: 2024 IEEE 4th International Conference on VLSI Systems, Architecture, Technology and Applications (VLSI SATA), pp. 1–6 (2024). https://doi.org/10.1109/VLSISATA61709.2024.10560139

[29] Weerasinghe, L.D.S.B., Perera, I.: Reference architecture for microservices with an optimized inter-service communication strategy. In: 2024 International Research Conference on Smart Computing and Systems Engineering (SCSE), vol. 7, pp. 1–6 (2024). https://doi.org/10.1109/SCSE61872.2024.10550466

[30] Alan, I., Kosar, T.: Energy-aware http data transfers. In: 2016 IEEE 36th International Conference on Distributed Computing Systems Workshops (ICDCSW), pp. 37–42 (2016). https://doi.org/10.1109/ICDCSW.2016.26

[31] Weerasinghe, L.D.S.B., Perera, I.: Evaluating the inter-service communication on microservice architecture. In: 2022 7th International Conference on Information Technology Research (ICITR), pp. 1–6 (2022). https://doi.org/10.1109/ICITR57877.2022.9992918

[32] Celik, A., Eltawil, A.M.: At the dawn of generative ai era: A tutorial-cum-survey on new frontiers in 6g wireless intelligence. IEEE Open Journal of the Communications Society 5, 2433–2489 (2024) https://doi.org/10.1109/OJCOMS.2024.3362271

[33] Xue, M., Nepal, S., Liu, L., Sethuvenkatraman, S., Yuan, X., Rudolph, C., Sun, R., Eisenhauer, G.: Rai4ioe: Responsible ai for enabling the internet of energy. In: 2023 5th IEEE International Conference on Trust, Privacy and Security in Intelligent Systems and Applications (TPS-ISA), pp. 13–22 (2023). https://doi.org/10.1109/TPS-ISA58951.2023.00012

[34] Zolfaghari, F., Alharasees, O., Kale, U.: Ai-powered prediction drives hungarian renewable energy integration. In: 2024 6th Global Power, Energy and Communication Conference (GPECOM), pp. 641–646 (2024). https://doi.org/10.1109/GPECOM61896.2024.10582633

[35] Blanco, L., Kukli´nski, S., Zeydan, E., Rezazadeh, F., Chawla, A., Zanzi, L.,Devoti, F., Kolakowski, R., Vlahodimitropoulou, V., Chochliouros, I., Bosneag, A.-M., Cherrared, S., Garrido, L.A., Barrachina-Mu˜noz, S., Mangues, J.: Ai-driven framework for scalable management of network slices. IEEE Communications Magazine 61(11), 216–222 (2023) https://doi.org/10.1109/MCOM.005.2300147

[36] Soud, N.S., Al-Jamali, N.A.S., Al-Raweshidy, H.S.: Moderately multispike return neural network for sdn accurate traffic awareness in effective 5g network slicing. IEEE Access 10, 73378–73387 (2022) https://doi.org/10.1109/ACCESS.2022.3189354

[37] Bolla, R., Bruschi, R., Davoli, F., Ivaldi, L., Lombardo, C., Siccardi, B.: An ai framework for fostering 6g towards energy efficiency. In: 2022 61st FITCE International Congress Future Telecommunications: Infrastructure and Sustainability (FITCE), pp. 1–6 (2022). https://doi.org/10.23919/FITCE56290.2022.9934697

[38] Wang, S., Qureshi, M.A., Miralles-Pechu´an, L., Huynh-The, T., Gadekallu, T.R., Liyanage, M.: Explainable ai for 6g use cases: Technical aspects and research challenges. IEEE Open Journal of the Communications Society 5, 2490–2540 (2024) https://doi.org/10.1109/OJCOMS.2024.3386872

[39] Al-Quraan, M., Mohjazi, L., Bariah, L., Centeno, A., Zoha, A., Arshad, K.,Assaleh, K., Muhaidat, S., Debbah, M., Imran, M.A.: Edge-native intelligence for 6g communications driven by federated learning: A survey of trends and challenges. IEEE Transactions on Emerging Topics in Computational Intelligence 7(3), 957–979 (2023) https://doi.org/10.1109/TETCI.2023.3251404

[40] Sikand, S., Sharma, V.S., Kaulgud, V., Podder, S.: Green ai quotient: Assessing greenness of ai-based software and the way forward. In: 2023 38th IEEE/ACM International Conference on Automated Software Engineering (ASE), pp. 1828–1833 (2023). https://doi.org/10.1109/ASE56229.2023.00115

[41] Sabella, D., Nardini, G., Demestichas, P., Barmpounakis, S., Phan-Huy, D.-T.,Merluzzi, M., Gamazo, E.G., Ramos, A., Landi, G., Leinonen, M.E., P¨arssinen, A., Wolfgang, A.: Innovation management in 6g research: The case of hexa-x project. IEEE Communications Magazine 62(2), 142–149 (2024) https://doi.org/10.1109/MCOM.018.2300040

[42] Chen, Z., Wu, M., Chan, A., Li, X., Ong, Y.-S.: Survey on ai sustainability:Emerging trends on learning algorithms and research challenges [review article]. IEEE Computational Intelligence Magazine 18(2), 60–77 (2023) https://doi.org/10.1109/MCI.2023.3245733

[43] Nosirov, I., Yormatov, I., Yuldasheva, N., Avulchayeva, F.: Ai and corporate sustainability: Exploring the environmental and social impacts of ai integration. In: 2024 International Conference on Knowledge Engineering and Communication Systems (ICKECS), vol. 1, pp. 1–7 (2024). https://doi.org/10.1109/ICKECS61492.2024.10617421

[44] Su, X., Tolba, A., Lu, Y., Tan, L., Wang, J., Zhang, P.: An attention mechanism-based microservice placement scheme for on-star edge computing nodes. IEEE Access 11, 114341–114351 (2023) https://doi.org/10.1109/ACCESS.2023.3324222

[45] Bolla, R., Bruschi, R., Lombardo, C., Siccardi, B.: 6g enablers for zero-carbon network slices and vertical edge services. IEEE Networking Letters 5(3), 173–176 (2023) https://doi.org/10.1109/LNET.2023.3262861

[46] Ali, S.O., Elbiaze, H., Glitho, R., Ajib, W.: Camp-inc: Components-aware microservices placement for in-network computing cloud-edge continuum. In: GLOBECOM 2022 - 2022 IEEE Global Communications Conference, pp. 2116–2121 (2022). https://doi.org/10.1109/GLOBECOM48099.2022.10000936

[47] Bouaouda, A., Afdel, K., Abounacer, R.: Forecasting the energy consumption of cloud data centers based on container placement with ant colony optimization and bin packing. In: 2022 5th Conference on Cloud and Internet of Things (CioT), pp. 150–157 (2022). https://doi.org/10.1109/CIoT53061.2022.9766522

[48] Rabetanetiarimanana, J.C.I., Ayagapin, L., Morau, D., Praene, J.P.: Biomass-based scenario to achieve the electricity sustainability: the case of reunion island. In: 2022 7th International Conference on Environment Friendly Energies and Applications (EFEA), pp. 1–6 (2022). https://doi.org/10.1109/EFEA56675.2022.10063740 . IEEE

[49] Aljanah, A., Alowaidi, M., Yu, R.: Green cellular networks with renewable energy resources using stream control transmission protocol (sctp). In: 2015 IEEE Canada International Humanitarian Technology Conference (IHTC2015), pp. 1–4 (2015). https://doi.org/10.1109/IHTC.2015.7238066

[50] Lin, H., Wang, W., Zou, Y., Liu, Y.: A method for identifying abnormal energy consumption in multi-energy system. In: 2023 2nd Asian Conference on Frontiers of Power and Energy (ACFPE), pp. 205–209 (2023). https://doi.org/10.1109/ACFPE59335.2023.10455178

[51] Zhang, S., Deng, W., Yang, X., Liu, J., Yu, M., Li, Z., Bi, C.: Research on the overall architecture and key technologies of information energy network integration. In: 2023 IEEE 23rd International Conference on Communication Technology (ICCT), pp. 1526–1532 (2023). https://doi.org/10.1109/ICCT59356.2023.10419615

[52] Iannacci, J.: Towards future 6g from the hardware components perspective – a focus on the hardware-software divide, its limiting factors and the envisioned benefits in going beyond it. In: 2021 IEEE 4th 5G World Forum (5GWF), pp. 1–6 (2021). https://doi.org/10.1109/5GWF52925.2021.00008

[53] Iannacci, J., Poor, H.V.: A vision of 6g from the perspective of low-complexity hardware micro/nano components. In: 2022 International Symposium on Networks, Computers and Communications (ISNCC), pp. 1–5 (2022). https://doi.org/10.1109/ISNCC55209.2022.9851736

[54] Mei, J., Wang, X., Zheng, K.: An intelligent self-sustained ran slicing framework for diverse service provisioning in 5g-beyond and 6g networks. Intelligent and Converged Networks 1(3), 281–294 (2020) https://doi.org/10.23919/ICN.2020.0019

[55] 3rd Generation Partnership Project (3GPP): Study on energy efficiency as a service criteria. Technical Report 22.882, 3rd Generation Partnership Project (3GPP) (March 2024). https://www.3gpp.org/ftp/Specs/archive/22 series/22.882/22882-j30.zip

[56] 3rd Generation Partnership Project (3GPP): Study on energy efficiency as service criteria ph 2. Technical Report TR 22.883 V0.1.0, 3rd Generation Partnership Project (3GPP) (June 2024). Version 0.1.0. https://www.3gpp.org/ftp/Specs/archive/22 series/22.883/22883-0.1.0.pdf

[57] 3rd Generation Partnership Project (3GPP): Enhanced relays for energy efficiency and extensive coverage. Technical Report TR 22.866 V17.1.0, 3rd Generation Partnership Project (3GPP) (December 2019). Version 17.1.0. https://www.3gpp.org/ftp/Specs/archive/22 series/22.866/22866-1710.zip

[58] N. Patel and H. Patel, "Energy efficient strategy for placement of virtual machines selected from underloaded servers in compute cloud," Journal of King Saud University - Computer and Information Sciences, vol. 32, no. 6, pp. 700–708, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1319157817302288

[59] Z. Lin, S. Bi, and Y.-J. A. Zhang, "Optimizing ai service placement and resource allocation in mobile edge intelligence systems," IEEE Transactions on Wireless Communications, vol. 20, no. 11, pp. 7257–7271, 2021.

[60] D. Alsadie, "A comprehensive review of ai techniques for resource management in fog computing: Trends, challenges, and future directions,"IEEE Access, vol. 12, pp. 118 007–118 059, 2024.

[61] 3rd Generation Partnership Project (3GPP), "Study on Energy Efficiency Aspects of 3GPP Standards," 3GPP, Technical Report TR 21.866, Jun. 2017, [Online].

[62] H. Peng and L.-C. Wang, "Energy harvesting reconfigurable intelligent surface for uav based on robust deep reinforcement learning," IEEE Transactions on Wireless Communications, vol. 22, no. 10, pp. 6826–6838, 2023.

[63] N. T. Nguyen, Q.-D. Vu, K. Lee, and M. Juntti, "Hybrid relay-reflecting intelligent surface-assisted wireless communications," IEEE Transactions on Vehicular Technology, vol. 71, no. 6, pp. 6228–6244, 2022.

[64] J. Zhang, S. Wang, Z. Zheng, Z. Fei, H. Yu, Q. Zhang, and Z. Han, "Enhancing performance of integrated sensing and communication via joint optimization of hybrid and passive reconfigurable intelligent surfaces," IEEE Internet of Things Journal, vol. 11, no. 19, pp. 32 041–32 054,2024.