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COMPONENT ANALYSIS FOR ENERGY-EFFICIENT MULTIMEDIA NETWORKS UTILIZING 5G RADIO ACCESS TECHNOLOGIES

The object of the research is the energy-efficient multimedia networks based on 5G wireless access technologies.

The research is aimed at developing energy-efficient multimedia networks based on 5G wireless access technologies, considering the increasing importance of information and communication technologies (ICT) in modern society. With the proliferation of wireless access networks and the advancement of fifth-generation mobile networks (5G), there is a need to assess and reduce the environmental impact of ICT. The article specifically focuses on the challenges related to energy consumption and CO_2 emissions in radio access networks, highlighting the responsibility to balance technological advancements with environmental concerns.

The paper examines various components and technologies necessary for enhancing energy efficiency in multimedia networks. It discusses the concept of multimedia, including digital storage, data processing, and interactive elements. Statistical data is provided to underscore the significant energy consumption and carbon footprint of the ICT industry, with an emphasis on radio access networks. Heterogeneous networks, non-orthogonal multiple access (NOMA) technologies, and multiple-input multiple-output (MIMO) technologies are identified as key components for achieving energy efficiency. The importance of reducing the distance between transmitters and receivers in heterogeneous networks is emphasized, as well as the use of energy-saving strategies such as putting small base stations into sleep mode during low network loads. Special attention is given to the role of green data centers in reducing CO_2 emissions and optimizing the use of green energy in high-performance networks. Proposed methods include leveraging renewable energy sources, improving hardware energy efficiency, and implementing energy-efficient routing.

The findings offer valuable insights for the development and implementation of energy-efficient multimedia networks, particularly in the context of 5G networks. The interdisciplinary approach advocated in the conclusion emphasizes the collective efforts needed to address environmental challenges in the field of information and communication technologies. The combination of these technologies ensures efficient resource utilization and reduced environmental impact compared to similar known approaches.

Keywords: *multimedia technologies, energy-efficient multimedia networks, 5G radio access technologies, heterogeneous networks.*

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1. Introduction

In the contemporary landscape, society is undergoing a profound shift towards an information society, marked by intricate socio-cultural and economic connections. At the forefront of this transformation is multimedia technology [1].

Central to the modern multimedia user is their inherent mobility, intricately tied to wireless access networks. The prospect of elevating the presence of fifth-generation mobile networks, commonly recognized as 5G networks, emerges as a pivotal stride in the evolution of information and communication technologies (ICT). Distinguished from its predecessors, 5G networks offer low-latency, highly reliable connectivity, advanced mobile broadband capabilities, and support for machine-type connectivity. The primary objective of 5G communication systems is a perpetual enhancement of the «quality of experience» (QoE) and an augmentation of data rates.

While multimedia communication unfolds a spectrum of possibilities, it also ushers in a responsibility to scrutinize the environmental impact of associated technologies. This entails addressing emerging challenges and embracing a judicious utilization of available resources.

Multimedia encompasses the intricate manipulation of information presented in the form of continuous media data. Continuous media data, characterized by its time-dependent nature in multimedia systems (e. g., audio and video data), undergoes systematic manipulation within defined

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segments over a specified time interval, adhering to established norms [2]. The distinction between multimedia and non-multimedia resources is evident on multiple fronts [1]:

– digital storage and processing through computer technology are integral;
– data comprises one or more components, such as text, photos, audio, or video information; interactivity plays a pivotal role, involving active engagement among resources, programs, services, and individuals; incorporates hypertext.

Consequently, «multimedia communications» pertains to the transmission, protocols, services, and mechanisms governing both discrete and continuous media across digital networks. It's imperative to clarify that, for instance, the transmission of digital video via a specific dedicated television network does not qualify as multimedia data if it lacks the capability to additionally transmit a specific type of discrete media data [2].

The Information and Communication Technology (ICT) industry operates within a notably energy-intensive framework. Current statistics reveal that this sector accounts for approximately 2–10 % of global energy consumption and contributes to 2 % of CO_2 emissions. Significantly, radio access networks shoulder 60 % of the documented energy consumption and environmental impact [3].

The dynamic nature of networks mirrors a living organism, characterized by constant growth and evolution. The integration of intelligent devices is on the rise, encompassing an expanding array of user devices, interconnected vehicles, and household appliances. This proliferation extends to the enhancement of services within the network, including but not limited to remote monitoring, road safety initiatives, real-time management, and the development of concepts like the Internet of Things (IoT) [4]. Consequently, the trajectory of data traffic and network expansion is anticipated to follow an exponential growth pattern. So, *the aim of the research* is to identify the impact of 5G mobile networks on the development of modern information society and to establish patterns of their functioning in relation to economic and sociocultural changes. It is expected that the research results will enable optimization of multimedia network operations based on 5G technologies, leading to improved service quality and ensuring more efficient resource utilization.

2. Materials and Methods

Reviewing the literature reveals that addressing the escalating energy consumption and expanding carbon footprint of cellular networks has prompted continual exploration of «green» solutions by researchers, governmental bodies, and particularly telecommunication providers. Beyond its environmental significance, the objective of energy efficiency (EE) extends to curbing the operational costs of mobile network operators and enhancing user satisfaction by prolonging the battery life of their devices. Consequently, energy efficiency stands as an integral facet of the next generation of networks.

In delineating an energy-efficient network, the focus is on the radio interface technology's capacity to minimize energy consumption within the access network relative to traffic bandwidth. An energy-efficient (EE) device refers to one that can minimize the power consumed by its modem, contingent on specific traffic characteristics. This definition equally applies to user equipment, which should uphold mobile broadband data speed while mitigating power consumption. Overall, these devices must align with the criteria outlined in ITU-R M.2410-0 (Minimum requirements related to technical performance for IMT-2020 radio interface(s)) [5].

The typical mobile network comprises base stations and access points facilitating interaction between mobile terminals and the network core. Base stations, in the realm of mobile communications, stand out as the primary contributors to energy consumption. The present reality underscores that 5G New Radio consumes three times more energy than equivalent LTE base stations, while achieving only 10 % of their energy efficiency.

When discussing the energy efficiency indicators of base stations, certain metrics are used. The most commonly used efficiency metric is bit/joule. Therefore, the basic value of EE [6]: EE (bit/joule) = (Data rate)/(Energy consumption).

3. Results and Discussion

One approach to curbing consumption involves deactivating components of base stations (BSs) that are unnecessary or inactive during specific periods. In terms of hardware resource utilization, various paradigms come into play, namely – resource consolidation, virtualization, selective connection, and proportional computing [7]. These encompass the following:

– resource consolidation entails regrouping underutilized resources. The network infrastructure experiences varying loads at different times, contingent upon specific traffic patterns. Consequently, equipment designed for peak loads may not be essential during particular periods;
– distributed selective connection mechanisms enable individual components at the network's edge to remain in standby mode for as long as possible, abstaining from supporting network connection tasks openly to the rest of the network;
– virtualization facilitates the effective operation of more than one service within a single physical environment. This proves efficient because, for instance, one heavily loaded computer can consume less energy than several lightly loaded computers;
– the paradigm of proportional calculations aligns the amount of work performed with the energy consumed by the device, as described in [7]. This strategy ensures a proportional relationship between energy consumption and the workload executed by the device.

The imperative for technology to be environmentally conscious has given rise to the concept of «green radio» in the realm of wireless networks. This term has firmly established itself in both academia and industry, serving as a guiding principle for research and development in wireless networks, with a focus on achieving high energy efficiency [8]. Different components within wireless networks exhibit varying energy consumption percentages, as illustrated in Fig. 1, portraying the power consumption profile of a typical wireless network. Clearly, enhancing the energy efficiency of base stations and access points is essential.

Particular emphasis is placed on augmenting the energy efficiency percentage in networks featuring a multitude of heterogeneous base stations, all without compromising bandwidth. Studies are underway to strike a balance between energy, spectral efficiency (SE), and the sustainability of 5G networks. In this context, three primary objectives have been outlined. Firstly, leveraging unused spectrum, especially unlicensed spectrum. Secondly, reducing the distance between receivers and transmitters while enhancing frequency reuse. And thirdly, amplifying spectral efficiency through the extensive deployment of structures. Technologies aligned with these goals contribute to an overall increase in system throughput.

To minimize the separation between the receiver and transmitter, the utilization of heterogeneous networks (HetNETs) is proposed. A heterogeneous wireless network incorporates diverse connectivity technologies, forming subnets with varied technologies that collectively constitute a unified, seamlessly integrated environment. This integration ensures a transition from one subnet to another that is imperceptible to the user. Within the access network, a macrocell is accompanied by several small cells, such as microcells, picocells, or femtocells. The backhaul network is established by connecting the base station through a hybrid architecture, encompassing both wired and wireless elements. Fig. 2 illustrates an example of a heterogeneous network [9].

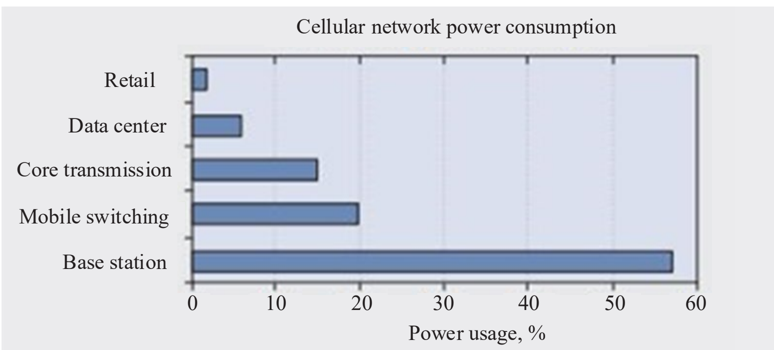

Fig. 1. Power consumption of a typical wireless cellular network [8]

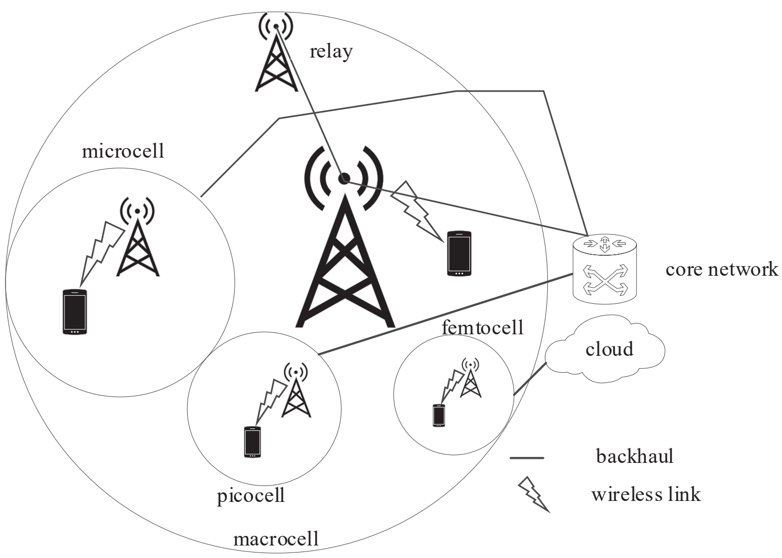

Fig. 2. Network architecture of a 5G HetNets [9]

While macrocells wield potent radio beams and boast extensive coverage, they may at times envelop areas, a majority of which remain unoccupied, lacking users. Consequently, the power exerted can be excessive and squandered. Femptocells, on the other hand, allocate power precisely where needed. Their proximity to users necessitates less radio frequency (RF) power for achieving high bandwidth. Femptocells also offer energy-efficient attributes, including more comprehensive user coverage, enhanced Quality of Service (QoS) capabilities, and prolonged battery life. Moreover, the ability to place small cells in sleep mode when the network experiences low or no load is crucial [10]. Integrating femtocells into macrocells allows for the creation of varied and necessary combinations, contributing to more effective network planning.

HetNETs play a pivotal role in bringing end users closer to network access, leading to improved signal-to-noise ratios and facilitating more efficient frequency reuse [9].

When referring to the transition of cells into sleep mode, it denotes a long-standing system employed in mobile transmitters to prolong battery life. The Discontinuous Transmission (DT) system enables transmissions only when necessary; otherwise, the transmitter enters a low-power state. This technology, applied to the entire cell, is termed cell DT and relies on hardware shutdown functions to maintain low power levels. Two modes, fast-cell DT and long-cell DT, delineate its operation. In fast-cell DT, the radio within the cell may enter a microsleep state at intervals when user data is not being transmitted. Conversely, long-cell DT operates at a slower pace and falls under the mode of low cell activity, akin to a cellular «sleep» characterized by reduced power consumption.

To enhance spectral efficiency and promote improved frequency reuse, heterogeneous networks integrate the technology of Non-Orthogonal Multiple Access (NOMA). NOMA facilitates multiple users operating within the same spectrum concurrently, distinguished by varying power levels. Employing superposition coding, the transmitter ensures that the receiver, equipped with a Successive Interference Cancellation (SIC) unit, can segregate users in both the uplink and downlink channels. In SIC, the receiver decodes packets received simultaneously by first decoding the stronger signal, subtracting it from the composite signal, and subsequently decoding the remaining difference as a weaker signal (Fig. 3) [11]. Consequently, the integration of NOMA into the small cells of heterogeneous networks, coupled with the well-established Multiple Input Multiple Output (MIMO) technology, caters to serving multiple users (N) efficiently, striking a balance between bandwidth utilization and energy efficiency [12].

Moreover, a pivotal technology essential for crafting efficient wireless networks is Multiple-Input, Multiple-Output (MIMO) technology. This technology has been successfully deployed in preceding generation networks, encompassing both Time-Division Duplex (TDD) and Frequency Division Duplex (FDD).

Within the realm of 5G networks, particularly at frequencies below 6 GHz, MIMO technology stands as one of the instrumental mechanisms enabling high-speed data transmission with heightened spectral and energy efficiency [13]. Its functionality spans two levels: at a macro level in the microwave bands for executing control signals and at a micro level in mm wave bands for facilitating user traffic transfer. Massive MIMO proves to be efficient in high-frequency bands, offering substantial antenna array gain to mitigate path losses and furnish spatial diversity. MIMO stands out as a pivotal tool influencing various facets of wireless communication, playing a crucial role in 5G technology and shaping users' everyday interactions with these technologies. The impact encompasses elevated network capacities, broader coverage, and an enhanced user experience (UX).

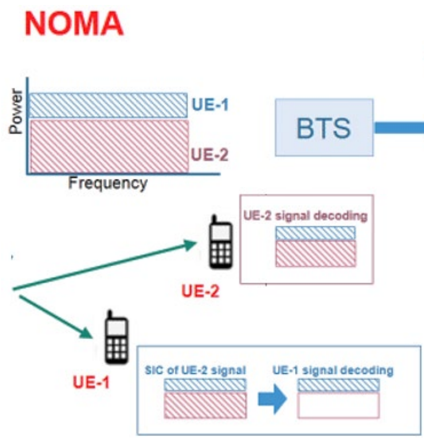

Fig. 3. Non-orthogonal multiple access technology (NOMA)

Wireless sensor networks (WSNs) are intricately connected to the Internet of Things (IoT) concept, particularly emphasizing the use of sensors in the context of the Industrial Internet of Things (IIoT). Sensors of diverse types, coupled with wireless communication, coalesce to form what is termed as wireless sensor networks. In the contemporary landscape, WSNs serve as the backbone of IIoT networks and constitute a primary contributor to energy consumption. Within the IoT paradigm, WSNs are instrumental for object monitoring, environmental surveillance, threat identification, and more. Comprising sensors and base stations, WSNs autonomously distribute sensors to monitor the physical conditions of the environment. Given the anticipated growth of this network, proactive efforts are imperative to develop an ecologically sustainable WSN, aiming to enhance autonomy and resource utilization efficiency [14].

To achieve this aim, several strategies can be employed:
– activate sensor units only when necessary;
– implement wireless charging and incorporate mechanisms for harnessing solar, kinetic, and vibration energy;
– utilize energy-efficient (EE) optimization methods, encompassing transmitter power control, modulation optimization, cooperative communication, directional antennas, and cognitive radio (CR);
– adopt judicious routing schemes to curtail energy consumption;
– through the optimization of scanning, processing, and connectivity processes in the WSN network, a gradual reduction in required energy can be achieved.

This optimized architecture can be categorized into three layers: a sensor layer, a gateway layer, and a control layer.

Green data centers, pivotal to every high-performance network, are continually evolving to reduce CO_2 emissions, optimize the utilization of green energy, and minimize electricity costs. Various strategies can be employed to enhance energy efficiency (EE) in environmental data centers, including the following methods [4]:
– utilizing renewable/green energy sources such as wind, water, solar energy, and heat pumps;
– increasing the operation of hardware in energy-efficient modes;
– implementing EE routing to ensure the optimal utilization of hardware;
– developing accurate power models for data centers;
– establishing a clear relationship between data centers and wireless networks to coordinate actions effectively.

The technologies, systems, and algorithms discussed above contribute to the understanding of smart grids and grid communications (SGGCs), aiming to provide novel insights for the design of computer and communication systems. These systems oversee a plethora of sensors, meters, etc., accumulating substantial data for optimization and self-improvement. Interconnected systems, with a focus on environmental considerations, offer valuable services globally, including transportation, healthcare, utilities, and more, in an efficient and energy-conscious manner.

The results obtained during the *research can be applied* in various practical scenarios. For example, the implementation of resource consolidation, virtualization, selective connection, and proportional computing techniques can significantly enhance the energy efficiency of wireless networks, leading to reduced operational costs and environmental impact, which may be of interest to commercial entities, such as cellular operators. Moreover, the integration of green radio concepts and technologies can promote sustainable practices in wireless network design and operation, benefiting both academia and industry.

Despite the potential benefits, there are certain *limitations* to consider when applying the research results in practice. For example, the deployment of energy-efficient techniques may require substantial initial investments in infrastructure upgrades and technology implementation. Moreover, the effectiveness of these techniques may vary depending on the specific characteristics of the network and the deployment environment. *Further research* is needed to address these limitations and optimize the implementation of energy-efficient solutions in real-world scenarios. It is also important to consider *the impact of the state of war* on the research process itself, as well as its prospects. Due to the state of war, there have been restrictions on access to certain electronic and statistical data, as well as changes in the operation mode of mobile networks, such as reduced usage of some base stations and implementation of energy-saving measures, such as the change and utilization of battery packs. Additionally, the conditions of war have compelled telecommunication operators to review their network development strategies and investment priorities, which already affects the pace of implementing new technologies and approaches to reducing energy consumption.

4. Conclusions

The urgency of our current era emphasizes the vital importance of preserving the environment, elevating it from a mere preference to an absolute necessity. The evolution of 5G wireless networks seamlessly aligns with the advancements in green energy technologies. Researchers face challenges as they navigate the complexities of future telecommunications systems. Addressing these challenges effectively requires collaborative interdisciplinary efforts across various domains, including networks, power systems, devices, end-users, and corporations.

The unique characteristics of 5G networks, marked by minimal latency and highly reliable connectivity, herald a new era of mobile broadband and machine-type communication. While these advancements expand possibilities, they also heighten expectations for data rates, spectrum efficiency, bandwidth, and coverage density, thereby influencing energy efficiency.

In this context, integrating state-of-the-art technologies with optimal performance necessitates the development of systems and models capable of efficiently allocating available resources. These systems and models have become essential components of contemporary mobile multimedia communication systems, ensuring the seamless integration of advanced technologies while maximizing performance.

The research findings encompass an analysis of energy-efficient techniques for wireless networks, including resource consolidation, virtualization, and selective connectivity. It has been demonstrated that these techniques significantly enhance network energy efficiency, leading to cost reduction and mitigating environmental impact. Additionally, the integration of «green radio» concepts and technologies can contribute to the sustainable development of wireless networks. These results suggest that implementing energy-efficient techniques can help curb energy consumption in wireless networks, which is crucial for sustainable development. Leveraging «green radio» integration can further enhance network energy efficiency and foster sustainable practices in network design and operation. The insights gained from this research have theoretical and practical implications, serving as a foundation for further scientific inquiry and the development of new technologies in the wireless network domain. Their practical application can result in reduced energy costs and lessened environmental impact, benefiting both commercial entities and society as a whole.

Conflict of interest

The authors declare that they have no conflict of interest concerning this research, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

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Data availability

The paper has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating this work.

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