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AN OVERVIEW OF COMPONENTS FOR ENERGY EFFICIENT MULTIMEDIA NETWORKS BASED ON 5G RADIO ACCESS TECHNOLOGIES

Modern society is actively transitioning into an information-based one, and multimedia technologies have become an integral part of this process. Thanks to the proliferation of wireless access networks, users are becoming more mobile, and the development of the fifth generation of mobile networks, known as 5G, is a significant step in the advancement of information and communication technologies. 5G networks offer low latency and reliable connectivity, expanding the capabilities of mobile internet and machine communication. However, along with the opportunities provided by multimedia communication, there is a responsibility to consider the impact of associated technologies on the environment, as well as to address new challenges and the need for prudent resource utilization.

The article defines the concept of "multimedia" and discusses various aspects of this concept, including digital storage and processing of information, components (text, photos, audio, and video), interactivity, and hypertextuality. It is noted that the transmission of multimedia data and the use of information technologies are closely linked to wireless access networks.

The authors discuss challenges and solutions in the field of energy efficiency for networks. They provide statistics indicating that the information and communication technology (ICT) industry is responsible for a significant portion of global energy consumption and CO2 emissions, with radio access networks being a major contributor. Various components and technologies that can contribute to the development of energy-efficient multimedia networks based on 5G radio access technologies are examined. Specifically, heterogeneous networks, non-orthogonal multiple access (NOMA) technologies, and multiple-input multiple-output (MIMO) technologies are highlighted as key components for achieving energy efficiency.

The importance of using heterogeneous networks to reduce the distance between transmitters and receivers is emphasized, along with the possibility of putting small base stations into sleep mode when there is no network load. Technologies like NOMA and MIMO are discussed as crucial components for achieving spectral efficiency and energy efficiency.

Additionally, the article focuses on wireless sensor networks (WSNs) and suggests ways to optimize them for energy efficiency. This includes operating sensor units only when necessary, implementing wireless charging, using energy-efficient optimization methods, and applying efficient routing schemes.

The authors also highlight the role of green data centers in reducing CO2 emissions and optimizing the use of green energy in high-performance networks. Methods such as using renewable energy sources, increasing the energy efficiency of hardware, and implementing energy-efficient routing are discussed.

In conclusion, the article underscores the importance of energy efficiency and reduced CO2 emissions in modern multimedia networks, particularly in the context of 5G networks. It calls for interdisciplinary efforts to address these critical challenges in the field of information and communication technologies.

Key words: multimedia, energy-efficient, WSN, 5G, HetNet.

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ОГЛЯД КОМПОНЕНТІВ ДЛЯ ЕНЕРГОЕФЕКТИВНИХ МУЛЬТИМЕДІЙНИХ МЕРЕЖ НА ОСНОВІ ТЕХНОЛОГІЙ РАДІОДОСТУПУ 5G

У сучасне суспільство перебуває в активному переході до інформаційного типу, а технології мультимедіа вже невід'ємна частина цього процесу. Завдяки поширенню бездротових мереж доступу, користувачі стають більш мобільними, і розвиток п'ятого покоління мобільних мереж, відомих як 5G, виявляється важливим кроком у розвитку інформаційно-комунікаційних технологій. Мережі 5G надають низьку затримку та надійний зв'язок, розширюють можливості мобільного інтернету та машинного зв'язку. Однак разом з можливостями мультимедійного зв'язку приходить відповідальність за вплив супутніх технологій на навколишнє середовище, а також нові виклики і потреба раціонально використовувати наявні ресурси.

У статті визначається поняття "мультимедіа" та розглядаються різні аспекти цього поняття, включаючи цифрове зберігання та обробку інформації, складові (текст, фото, аудіо та відео), можливість інтерактивної взаємодії та гіпертекстовий характер. Зазначається, що передача мультимедійних даних та використання інформаційних технологій тісно пов'язані з бездротовими мережами доступу.

Автори обговорюють виклики та рішення в галузі енергоефективності мереж. Вони наводять статистику, згідно з якою інформаційно-комунікаційна галузь відповідає за значну частку споживаної енергії та викидів CO2, і звертають увагу на те, що мережі радіодоступу є основним джерелом споживання енергії та забруднення навколишнього середовища в цій галузі. Далі у статті розглядаються різні компоненти та технології, які можуть сприяти створенню енергоефективних мультимедійних мереж на базі технологій радіодоступу 5G. Зокрема, розглядаються гетерогенні мережі, технології неортогонального множинного доступу та технології MIMO.

Автори обговорюють важливість використання гетерогенних мереж для зменшення відстані між передавачем та приймачем, а також можливість використання режиму сну для малих базових станцій. Технології неортогонального множинного доступу (NOMA) та множинного введення-множинного виведення (MIMO) також розглядаються як ключові компоненти для досягнення спектральної ефективності та підвищення енергоефективності.

Додатково, стаття звертає увагу на бездротові сенсорні мережі (WSN) та пропонує шляхи для їхньої оптимізації в напрямку енергоефективності. Також обговорюються можливості використання зелених дата-центрів для зменшення викидів CO2 в інформаційно-комунікаційних технологіях.

У висновку, стаття підкреслює важливість енергоефективності та зменшення викидів CO2 в сучасних мультимедійних мережах, особливо в контексті мереж 5G, та закликає до міждисциплінарних зусиль для розв'язання цих важливих завдань у галузі інформаційно-комунікаційних технологій.

Ключові слова: мультимедіа, енергоефективність, WSN, 5G, HetNet.

Introduction

Modern society is shaping its socio-cultural and economic ties, effectively transforming itself into an information society. The modern technological form of the information society is multimedia technology [1].

The modern user of multimedia and information technology is a "mobile" user. Mobility is inextricably linked to wireless access networks. In particular, it is promising to increase the share of fifth-generation mobile networks, widely known as 5G networks, which is an important step in the development of information and communication technologies (ICT). 5G networks stand out from previous generations, providing low-latency and ultra-reliable connectivity, advanced mobile broadband and machine-type connectivity. 5G communication systems are aimed at continuously improving the "quality of experience (impressions)" (quality of experience, QoE), and increasing data rates.

Along with the opportunities provided by multimedia communication, comes the responsibility for the impact of related technologies on the environment, as well as new challenges and the need to use available resources wisely.

Multimedia

"Multimedia" refers to the complex manipulation of at least some of the information presented as continuous media data. Continuous media data means time-dependent data in multimedia systems (eg, audio and video data), which are manipulated in clearly defined parts over a time interval in accordance with established norms [2]. Thus, the multimedia resource is distinguished from the non-multimedia on several grounds [1]:

•Data is stored and processed digitally by using computer technology;

•Data consist of one or more components, such as text, photo, audio or video information;

•Interactivity, active interaction of resources, programs, services and people, etc;

•Contains hypertext.

Thus, “multimedia communications” refers to the transmission, protocols, services and mechanisms for discrete and continuous media over digital networks. But it is important to clarify that, for example, the transmission of digital video over a certain dedicated television network, is not multimedia data, if it is not possible to additionally transmit a certain type of discrete media data [2].

Challenges and solutions

The ICT industry is quite an energy-intensive environment. According to statistics, this industry is responsible for about 2-10% of world energy consumption and 2% of CO_2 emissions. It is important that radio access networks are responsible for 60% of the reported consumption and pollution [3]. The network does not stand still and constantly growing like a living organism. Intelligent devices are connected, and, in particular, the number of user devices is increased, cars, household appliances, etc. are connected. The number and quality of services provided in the network is growing, such as remote monitoring, road safety, real-time management, virtual, augmented reality and the development of the concept of the Internet of Things, etc. [4]. As a result, data traffic and networks' growth are expected to continue to grow exponentially.

Literature review

Increasing energy consumption and growing carbon footprint from cellular networks have led to constant offers of "green" solutions from researchers, governments, and in particular telecommunications providers. In addition to its environmental value, the goal of energy efficiency (EE) is also to reduce the operating costs of mobile network operators and increase user satisfaction by increasing the battery life of their devices. Thus, energy efficiency is an integral part of the new generation of networks. To control energy consumption, the need for efficient allocation of resources, optimal network planning, and the use of renewable sources has been identified. The challenge is to keep energy consumption at the same level, or even reduce it, against the background of increasing data transmission, along with an increase in the number of base stations (BS).

When describing an energy efficient network, it means the ability of radio interface technology to minimize energy consumption by the access network, relative to traffic bandwidth. An EE device is a device that can minimize the power consumed by its device modem, depending on specific traffic characteristics. The same definition applies to user equipment, which should support the speed of mobile broadband data while reducing power consumption. In general, the devices must meet the requirements set out in ITU-R M.2410-0 (Minimum requirements related to technical performance for IMT-2020 radio interface (s))[5].

In general, the mobile network consists of base stations and access points that allow mobile terminals to interact with the network core. In mobile communications, base stations are the main source of energy consumption. The reality of today's, is that 5G New Radio consume three times more energy than the base stations of the same LTE and use 10% of their energy efficiency.

Methodology

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*).

One method to reduce consumption is to turn off BSs' components that they do not need or use during this period of time. From the point of view of the use of hardware resources, there are several paradigms, namely - resource consolidation, virtualization, selective connection and proportional calculations [7]. These include the following:

•Resource consolidation involves the regrouping of underutilized resources. At different times, network infrastructure resources are loaded differently, depending on the specific traffic. Thus, all equipment that is designed for peak loads may not be needed at a particular time.

•Distributed selective connection mechanisms allow individual components on the edge of the network to stand for as long as possible, staying in standby mode, avoiding supporting network connection tasks in an open environment to the rest of the network.

•Virtualization allows more than one service to operate effectively within a single physical environment. This is effective because, for example, one heavily loaded computer can consume less than a few lightly loaded computers.

•The paradigm of proportional calculations is based on the correspondence of the amount of work performed to the amount of energy consumed by the device, described by Prem et al. [7].

The environmental friendliness of technology has become a must for wireless networks. Researchers talk about environmentally friendly "green radio". This term is firmly entrenched in academia and industry as a guideline in research and development of wireless networks, on the way to high energy efficiency [8]. Different elements of wireless networks consume different percentages of energy. Figure 1 shows an example of the power consumption of a typical wireless network. It is clear that it is necessary to increase the energy efficiency of base stations and access points. It is extremely important to increase the percentage of EE in networks with a large number of heterogeneous BS, without loss of bandwidth. Studies are being conducted to balance energy, spectral efficiency (SE) and sustainability of the 5G network. From this point of view, three goals were set: first, to use unused spectrum, in particular unlicensed spectrum; second, to reduce the distance between receiver and transmitter, and to improve the frequency reuse; to increase spectral efficiency by deploying structures in large numbers. The technologies that achieve these goals increase system throughput.

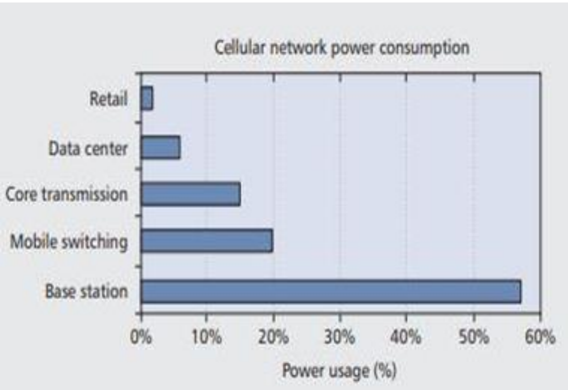

Fig. 1. Power consumption of a typical wireless cellular network [8].

HetNet. To reduce the distance between the receiver and the transmitter, it is proposed to use so-called heterogeneous networks (HetNETs). A heterogeneous wireless network uses a variety of connectivity technologies. That is, a heterogeneous network consists of subnets, with different technologies, and they all form a single integrated environment, which provides a seamless invisible to the user transition from one subnet to another. An access network consists of a macrocell and several small cells, such as a microcell, a picocell, or a femtocell. The backhaul network is formed by connecting the base station using a mixed, wired or wireless architecture. An example of a heterogeneous network is shown in Figure 2 [9].

Although macrocells control powerful radio beams and have a large coverage area, they can sometimes cover areas, most of which may be empty, i.e. without users. Thus, the power can be excessive and used in vain. Femptocells provide power where needed. Because they are closer to the user, they need less RF power for high bandwidth. The femtocell also offers EE features such as denser user coverage, better QoS capabilities, and longer battery life. Also, it is important that it is possible to put small cells in sleep mode, in the absence of load on the network [10]. It is important to be able to integrate femtocells into macrocells, creating different, necessary combinations for more efficient network planning.

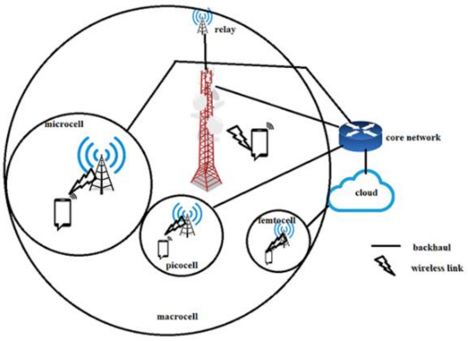

Fig. 2. Network Architecture of a 5G HetNets [9].

Thus, HetNETs bring end users closer to network access, thus improving the signal-to-noise ratio as well as more efficient reuse of frequencies [9].

When describing the transfer of cells to sleep mode, it means a system that has been used in mobile transmitters in order to save battery life for a long time. The discontinuous transmission (DT) system makes it possible to transmit only when the need arises, otherwise the transmitter enters a low power state. As for the cell as a whole, this technology is already called cell DT and is based on hardware shutdown functions to ensure low power levels. There are two modes, fast-cell DT and long-cell DT. In the case of a fast-cell DT radio in the cell, may be in a microsleep state at intervals when user data is not transmitted. Long-cell DT works slower and belongs to the mode of low cell activity, this condition can be considered a cellular "sleep" with lower power consumption.

NOMA and MIMO. To achieve spectral efficiency and better frequency reuse, heterogeneous networks incorporate NOMA non-orthogonal multiple access technology. In NOMA, multiple users can operate in the same range simultaneously, being divided by power levels. The transmitter uses superposition coding so that the receiver, using a successive interference cancellation (SIC) unit, can separate users in both uplink and downlink lines. In SIC, decoding of simultaneously received packets is achieved by the receiver decoding first the stronger signal, subtracting it from the combined signal, and then decoding the difference as a weaker signal (fig.3) [11]. Thus, the incorporation of NOMA into small cells of heterogeneous networks using the well-known Multiple Input Multiple Output technology to serve N number of users, enabling efficient use of bandwidth and finding a trade-off between bandwidth and energy efficiency [12].

Also, a critical technology for building efficient wireless networks is multiple-input, multiple-output (MIMO) technology, which has already been successfully deployed in previous generation networks, both for time-division duplex (TDD) and for frequency distribution division duplex) (FDD). This technology is one of the mechanisms that allow achieving high speeds for data transmission with high spectral and energy efficiency in 5 G networks, at frequencies below 6 GHz [13]. It provides work at two levels: a macro level in the microwave bands for the implementation of control signals and a micro level in the bands mmWave for the transfer of user traffic. Massive MIMO is efficient in high-frequency bands and provides high antenna array gain, covering path losses and providing spatial diversity. MIMO is a key tool for promoting all aspects of wireless communication. It plays an important role in 5G technology and influences how users interact with these technologies on a daily basis. These effects include the following:

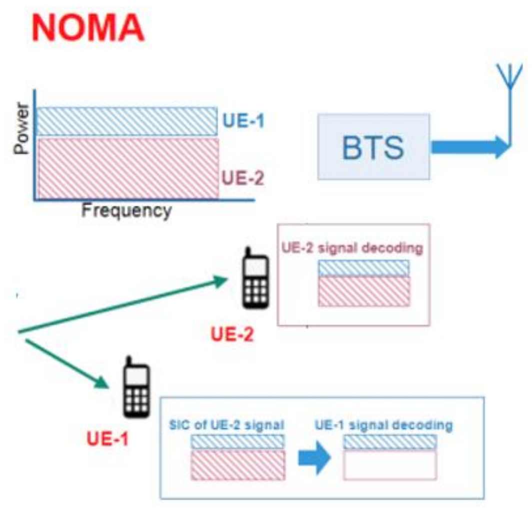

Fig.-3. Non-orthogonal multiple access technology (NOMA).

•High network capacities;
•More coverage;
•Better user experience (UX).

Wireless sensor networks. Wireless networks are inextricably linked to the concept of the Internet of Things, which uses sensors, particularly for the industrial Internet of Things (IIoT). Sensors of various types in combination with wireless communication form the so-called wireless sensor networks (WSNs). Today, WSNs are the core of IIoT networks and are the main source of energy consumption. In the IoT, it is used to monitor objects, monitor the environment, identify threats, and more. WSN consists of sensors and base stations, the sensors in turn are distributed autonomously, monitoring the physical conditions of the environment. As this network will only grow, it is necessary to work in advance towards an ecological WSN, in order to improve the autonomy and efficient use of resources [14].

•Sensor units should be operated only when necessary;

•Applicate a wireless charging, introduce mechanisms for collecting solar, kinetic, vibration energy;

•Use EE optimization methods (transmitter power control, modulation optimization, cooperative communication, directional antennas, cognitive radio(CR)).

•Apply rational routing schemes to reduce energy consumption;

Thus, by optimizing the processes of scanning, processing and connection in the WSN network, it is possible to gradually move to reduce the required energy. This optimized architecture can be divided into three layers, a sensor layer, a gateway layer, and a control layer.

Green data centers. Each high-performance network is based on data centers (DC). Improvements are also being made in this direction in order to reduce CO2 emissions, optimize the use of green energy, and reduce electricity costs. To improve the EE in the environmental data center, the following methods can be used [4].

•Use renewable / green energy sources (wind, water, solar energy, heat pumps, etc.);

•Increasing the hardware operating in EE modes;

•Introduction of EE routing, in order to use the appropriate number of hardware;

•Build accurate DC power models;

•Establish a clear relationship between DC and wireless networks, in order to coordinate actions;

The technologies, systems, and algorithms discussed above lead to an understanding of smart grid and grid communications (SGGCs) designed to promote new insights that contribute to the design of computer and communication systems. Such systems control a large number of sensors, meters, etc., and accumulate a large amount of data for optimization and self-development. Several environmentally interconnected systems provide valuable services to people around the world, such as transportation, health care, utilities, and more, and can do so efficiently and energy-efficiently.

Conclusion

The realities of today are that protecting the environment is not a whim, but an extreme necessity. 5G wireless networks are evolving in conjunction with green energy technologies. There are a large number of tasks facing researchers. The issues facing the future telecommunications systems require interdisciplinary efforts from diverse networks, power systems, devices, customers, and corporations to address them.

5G networks stand out in previous generations, creating low-latency and ultra-reliable connectivity, expanding mobile broadband, and providing machine-type connectivity. Such advantages simultaneously expand the scope and set higher requirements for data rate, spectrum efficiency, bandwidth, coverage density, which in turn affects energy efficiency.

Thus, to ensure the integration of advanced technologies with maximum performance, systems, and models that allow the allocation of available resources efficiently and effectively, have become a new integral part of mobile multimedia communication systems.

References

1. Volynets V. Multimedia: concept, essence and scope // International Bulletin: Culturology. Philology. Musicology. 2016. Vip. 1. pp. 98–102.
2. Cvetković D. Interactive Multimedia - Multimedia Production and Digital Storytelling, ch 1, 2019, DOI: 10.5772/intechopen.85904.
3. Y.Li, et al.(2017), Green heterogeneous cloud radio access networks: Potential techniques, performance trade-offs and challenges,1–7. doi: 10.1109/MCOM.2017.1600807.
4. C. Zhu, et al (2015)., Green Internet of Things for Smart World, IEEE Access, vol.3. 2151 2162.
5. International Telecommunication Union (2017). Minimum requirements related to technical performance for IMT-2020 radio interface(s). Retrieved 07 May 2021 from https://www.itu.int/pub/R-REP-M.2410-2017.
6. E. Björnson. How Energy-Efficient Can a Wireless Communication System Become?. Björnson .E, G. Larsson E. pp.1–5, 2019. Retrieved 07 May 2021 from https://arxiv.org/pdf/1812.01688.pdf.
7. Prem Aruna & Rougier Jean-Louis & Rossi Dario & Chaudet Claude (2012). A Survey of Green Networking Research. IEEE Communications Surveys & Tutorials, 1-19.
8. C.Han, et al.(2011), Green radio: Radio techniques to enable energy efficient wireless networks, IEEE Communication Magazine, vol.49, no.6,.46–54.
9. Malik Nabeel & Ur Rehman Masood (2017). Green Communications: Techniques and Challenges. EAI Endorsed Transactions on Energy Web. , vol 4, 1-6. doi: 10.4108/eai.4-10-2017.153162.
10. Lee Woongsup & Jung Bang Chul. (2016). Improving Energy Efficiency of Cooperative Femtocell Networks via Base Station Switching Off. Mobile Information Systems. pp 1-6, 2016. doi: 10.1155/2016/3073184.

11. R.C. Kizilirmak. Non-Orthogonal Multiple Access (NOMA) for 5G Networks. doi 10.5772/66048. Retrieved 07 May 2021 from https://www.intechopen.com/books/towards-5g-wireless-networks-a-physical-layer-perspective/non-orthogonal-multiple-access-noma-for-5g-networks.
12. Z. Ding & F. Adachi & H. V. Poor (2016). The Application of MIMO to Non-Orthogonal Multiple Access. IEEE Transactions on Wireless Communications. vol.15, no.1, 537–552
13. Haralabos Papadopoulos, Chenwei Wang, Ozgun Bursalioglu, Xiaolin Hou. 2016. Massive MIMO Technologies and Challenges towards 5G. DOI:10.1587/transcom.2015EBI0002
14. Albreem Mahmoud & El-Saleh Ayman, Isa Muzamir & Salah Wael & Jusoh Muzammil. (2017). Green internet of things (IoT): An overview. 10.1109/ICSIMA.2017.8312021.