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Energy Proficient Strategies and Future Challenges in 5G Networks in Pakistan

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Abstract *To meet the extraordinary subscribers' requests in near future, 5G wireless cellular networks are developing. With the arrival of 5th generation (5G), millions of new Base Stations (BS) and billions of associated gadgets will also be increased which require the extra power. More power utilization will result in an ascent in the CO2 discharge into the atmosphere, which may cause various human diseases. To meet the requests of an expanded limit, an enhanced data rate, and a superior nature of the service of the up-coming generation systems, there is a dire need to embrace energy proficient models, which consume less power. This manuscript gives an overview of energy proficient strategies and future challenges in 5G networks, which will be helpful for research scholars and organizations for future exploration of power optimization in 5G networks.*

Key Words: Energy Efficiency, Power Optimization, Green Communication, Wireless Communication

Introduction

There is an enormous development in the use of mobile phones and the number of their clients. Mobile phones and tablets have turned out to be extremely helpful and are accessible to nearly everybody, which means its area expands from towns to small villages. There has been a massive development in the figures of mobile phone subscribers which require high data rates and in addition expedient web for speedier browsing. Similarly, social media like Facebook, Twitter, Whatsapp, etc. also require high data rates.

It is expected that there will be in excess of 50 billion connected devices by 2020 (approximate 6 connected devices per individual). The basic purpose is to have an associated civilization in which autos, sensors, medical, drones, and other wearable gadgets will all utilize wireless systems to connect with each other, cooperating with human end-clients to give a progression of inventive administrations, for example, smart cars, smart cities, urban areas, and strong security. Obviously, with a specific end goal to serve such countless, future systems should significantly maximize the provided limit as compared to the existing models. The utilization of energy has become an indispensable worry in the Devise and task of wireless communication frameworks. Surely, communication networks have been mostly devised with the point of streamlining execution measurements, for example, the throughput, latency, data rate, and so forth. In the current decade, energy proficiency has developed as an important figure of authority because of operational, financial, and natural challenges. To be sure, 5G frameworks will serve a remarkable number of gadgets, giving pervasive availability, and creative services.

Energy proficiency of the wireless network can be enhanced by diminishing the power consumption. Energy productivity is also important from the client's point of view. To fulfill the clients' request for battery life, energy effectiveness in wireless communication is necessary. There is another factor under thought is the health issue of the client. High power transmitted by mobile phone while being used tends to hurt the client in nearness. The requirement for embracing green communication has been acknowledged around the world.

System energy utilization quickly increments when excessive quantities of Base Stations are installed to give the requested services to each client. During satisfying the data traffic and to oblige each subscriber with adequate

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quality of service, mobile operators mostly left the energy utilization issue at the backend. So, in order to supply the high data rate to subscribers, service providers maximize the number of BS. With the increase in Base Stations, power consumption has also increased which results in the emission of carbon dioxide in large amount which is very harmful to living human being.

So, the power efficiency can be obtained by different ways, such as by improving the execution of various hardware parts, the organization of proficient heterogeneous systems, utilizing normal energy resources and turning off selectively base station parts. Another source of power consumption in a base station is power amplifiers, therefore, power consumption can be minimized by increasing the performance of power amplifiers. However, in order to achieve the energy proficient networks, other strategies can also be utilized.

This manuscript is arranged as follows: Section II explains the knowledge obtained from the literature review, problem statement defines in Section III, Section IV explains the growth of wireless communication, Section V portrays the energy constraints in wireless sensor networks. Section VI expose the energy proficiency metric, Section VII explain the energy proficient strategies, Section VIII describes the future challenges for 5G networks and Section IX provides the final conclusion of this research.

Literature Review

Abrol et al (2016) have examined the developing requirements for energy production in the next generation networks i.e. 5G and investigated the style in the field of wireless communications in the most recent decade that demonstrated a move towards pursuing green communication [1]. They also discussed the importance of suitable energy proficiency metric and different methods, which can be utilized in future for upgrading the intensity of the system and the exhibited a synopsis of the work that has just been done to enhance energy productivity of system utilizing these strategies. They demonstrate a framework for energy efficiency improvement with the utilization of relay selection. Various energy efficient techniques like SWIPT, Massive MIMO and C-RAN have also joined into it. Furthermore, various difficulties for future research for enhancing energy efficiency of wireless system have also been described.

Authors described that the demand for data rate maximizes with the increase in a number of customers [2]. They proposed a scheme (normal traffic mode and the peak traffic mode) which gives the valuable results when plotted for the normal traffic mode in the decline of the average energy expenditure of all the BSs. Authors adopting the Millimeter-Wave and Massive MIMO technologies to analyze the power consumption of Base Stations for 5G small cell network [3]. Obtained simulation results reflected that the computation power of Base Stations maximizes with the increase in bandwidth and quantity of antennas. They concluded that the energy proficiency optimization of 5G small cell networks must mutually consider the transmission power and computation. However, to join the transmission power and computation to increase the EE of 5G networks is an open challenge.

Obeid et al (2018) have given an outline of the power limitations in wireless sensor networks and the energy administration techniques utilized in the writing to accumulate the energy as power efficiency has been taken as the most difficult issue in wireless sensor networks [4]. Moreover, they presented the versatile frameworks as an effective answer to handle the non-predictable and changing application requirements. They also displayed their new adoption strategy to accomplish performance and proficiency.

Buzzi et al conducted a survey of power proficiency methods for fifth generation wireless networks and its future problems [5]. They described that the policy, business, and technical challenges are still standing and required to be addressed in order to achieve the improvement goal of energy efficiency.

For multimedia communication, 3rd generation (3G) cellular systems are developed whereas, 4th generation (4G) provides the ultra-broadband access for mobile phones [6]. In order to face the challenges of huge costs, connectivity and flexibility, the fifth generation (5G) utilize the SDN, NFV, and mobile clouds. Authors described the various security mechanisms for these challenges [7].

Gandotra et al (2017) conducted a thorough survey on green communication and discussed the protection issues faced by fifth generation wireless networks [8]. They described that an extreme increase in the number of consumers will also maximize the power consumption which consequence in acceleration in the quantity of CO_2 released in the surroundings which are very harmful. They proposed 3-layers architecture for increasing the battery life of consumers by utilizing the relays as a substitute for direct transmission of data. Authors proposed a remote multimedia communication autonomous green resources administration method and its design for resolution of hindrance and multimedia server surplus issues in huge parallel multimedia streaming [9]. According to the authors, this architecture can efficiently balance the resources of wireless multimedia service.

Problem Statement

Although, noteworthy efforts have already been made by a number of researchers and organizations in power optimization of 5G networks; however, various energy efficiency challenges of 5G networks encourages the industrialists and research scholars to do more in this domain to achieve the intelligent power saving mechanism which is a step towards green communication and it will also maximize the interest of users on 5G networks.

Growth of Wireless Communication

The growth of wireless communication from first generation to fifth generation is discussed as under:

1st Generation (1G)

In1980's, analog cellular systems has come into existence, which referred to as the 1st generation (1G) systems, for example, Total Access Communication System, Advance Mobile Phone Service, and Nordic Mobile Telephone. Its data rate was up to 2.4kbps with numerous inconveniences. As it was the first framework to be planned significant concern was guaranteeing wireless connectivity and scope and no concentration was given to control advancement of the system.

2nd Generation (2G)

Second generation (2G) came into existence after about 10 years of early computerized cellular systems. These systems were developed for voice alongside power control approaches that gave a fixed data rate of around 64kbps keeping up certain Quality of Service (QoS). 2G also gives services such as email and SMS. GSM was the main standard of 2G, IS-136, IS-95. Due to low power radio signals, 2G portable handsets had longer battery life. After that 2.5G came which utilized 2G framework structure yet it applied packet switching alongside circuit switching and gave data rate up to 144kbps. That improved data rate for GSM evolution, GPRS, and CDMA 2000 are the main 2.5 G technologies, however, the power levels were similar to 2G.

3rd Generation (3G)

3rd generation systems showed up in 2000 that ensured the transmission rate up to 2 Mb/s alongside the change in Quality of Service (QoS). It depends on the wideband CDMA standard, which is called International Mobile Telecommunications 2000. Universal Partnership Project was the 3G standard that is a successor to GSM and standardized by the Third Generation Partnership Project. Different services given by the 3G included the enhanced voice quality and worldwide roaming. However, the real drawback of 3G mobile phones was that they required more power as compared to 2G mobile handsets.

4th Generation (4G)

4th generation (4G) is referred to as the successor of 2G and 3G benchmarks. After one more decade, ITU-R group indicated the IMT-Advanced necessities for 4G benchmarks. 3GPP is standardizing LTE Advance as imminent 4G standard. As compared to the previous generations (2G and 3G), 4G provides the data, voice and multimedia services to their subscribers at any time and wherever premise at best data rates. Now, Digital Video Broadcasting, MMS, Mobile TV and Video Chats are possible in presence of 4G. In order to maximize the area coverage and more energy proficiency, the concept of multi-hop in-band and out-band relays has been presented. However, the principal inconvenience of 4th generation systems is the utilization of cell-specific reference signals that diminish the power proficiency of the system by causing unreasonable overhead.

5th Generation (5G)

To meet the expanding demands of high data rate, the fourth generation (4G) will be upgraded by the next generation i.e. 5G. To take care of the demand of the subscribers, change in the energy proficiency of the next generation systems is of utmost importance, so, the Green Communication will play a vital role in this field. With the increase of frequency in use, the power requirement of the system also increases. To amplify the proficiency of future frameworks, proper planning of time and occurrence resources should be synchronized with the energy enhancement methods. The future systems giving much more data rate will also need additional power saving procedures.

Energy Constraints In Wireless Sensor Networks

Battery Lifetime

The resourceful utilization of battery energy of a node is a valuable attention to avoid the malfunction of the node process due to limited and not replaceable power sources of sensors nodes in wireless sensors networks. Generally, replacement of power battery in remote or difficult-to-access wireless sensor networks is extremely troublesome in specific cases including ecological checking, response to an emergent situation, military tracking and environment checking. Consequently, battery productivity is among the most significant research issues in wireless sensors networks.

Radio Communication

Between the sensor nodes, radio communication is power costly. It significantly spends energy by putting forward not interested or tedious information. It is the fact that the sensor hubs are utilized just to capture information that is later evaluated in more influential entrance node which necessitates a nonstop communication which spent energy not just at the sensor nodes stage yet additionally at the general system stage.

Static Configurations

A conventional sensor node is committed for the utilization of a prearranged application, which means that the gadget is planned after the description and the advancement of the application necessities. However, when operation or functionality change, the sensor node should work diversely in the light of these configurations, hence, it is difficult to set static designs. Therefore, the sensor node should persistently deal with its energy utilization regarding its accessible resources and in addition, the application necessities change to draw out its lifetime. In this way, the power administration techniques show up as a proficient solution leading to the enhanced performances and modern applications.

Power Proficiency Metric

A relating prerequisite for improvement in energy utilization is growing with the advancement of communication technology. As per a review, the mobile operators are among the best energy customers and in addition, their utilization is growing at a quick rate particularly with the deployment of 4G innovation. The BS devours a large piece of the energy, which results in an increase of electricity bills. So, energy has considerable economic values from the operators' as well as customers' point of view. It likewise has awesome environmental advantages and represents social duty in battling environmental change [10]. In this way, there is a critical need to pursue energy productivity alongside ideal limit and spectral proficiency when designing the wireless systems.

Energy proficiency in wireless communication is of utmost importance from the user's point of view. The requirement for energy efficient transmission begins with energy constraints systems such as ad-hoc systems where wireless gadgets are battery controlled so energy utilization must be limited [11]. Therefore, the cellular frameworks must be energy production, particularly with the ongoing developing interest in mobile media communication that has made the battery constraints a noteworthy problem.

The significance of energy proficiency for wireless communication has been acknowledged much more with the appearance of 5G technology. The real concern is to enhance the energy proficiency without compromising on client experience. Hence, the choice of adequate energy productivity metric is of utmost significance before analyzing a power-optimized system. Conventionally, energy proficiency is described as the evaluation of the number of bits transmitted per joule of energy devoured [12]. Because all broadcasting data is not a genuine data, thus, must not be incorporated into throughput.

The energy expended relies upon the kind of the BS and has two sections, such as dynamic and static. Conventional power advancement strategies consider just transmit power yet it just makes sense if transmit control has significantly bigger extent in complete power utilization. Therefore, decent energy proficiency metric must consider circuit and transmission power and spare in one of them must not be balanced by an increment in another for getting an energy proficient system. So, there is a dire need to concentrate on energy proficiency improvement in cellular networks.

Energy Proficient Strategies

Energy proficient architecture, radio technologies, and resource management are the few techniques to make the network energy proficient [1].

Simultaneous Wireless Information and Power Transfer (SWIPT)

Due to prominent demand of EE in wireless communication, the interest of integrating energy reaping innovations in the wireless communication system has been increased. WPT is an upcoming technology in which hubs charge their batteries from electromagnetic radiations [1]. Solid signals increment power transfer; however, in the meantime, they additionally increment the obstruction. This method can be most valuable on account of sensor node or for the novel innovation of IoT in which access points will be charged with the help of control signals. The up camping networks will redress these problems of path loss with the utilization of small cell, millimeter waves, and MIMO. The component utilized for this design is a Rectenna that change microwave energy to direct current and this could be possible by splitting of the received signals to 2 orthogonal signals. Synchronized wireless information and power shift includes the adjustment in the present communication framework [13].

SWIPT can be utilized in 3 scenarios, such as near field scenario, far-field scenario, and far-field low power scenario. In far field scenario, the power signal got is split up into two signals, one for power yield and the other is utilized for information decoding [14]. To accomplish this, some techniques, such as Time Switching, Receiving Wire Switching, Power Splitting and Spatial Switching are utilized.

Millimeter Waves (MM Waves)

The MM waves are required to be a standout amongst the most encouraging innovation of 5G. For speedier delivery of high-quality videos and multimedia contents, it relied on that the issue of bandwidth allocation can be solved. With the development of remote industry, the demands of the customer are expanding day by day, which may create the issue of blockage of the system by 2020. So, in order to beat this challenge in the fifth generation, the wireless signals are being shifted to an elevated recurrence band working at millimeter wavelength between 30 GHz to 300 GHz on the radio band. Therefore, in future, the data rates are maximized to multi-gigabit/sec but there will be high signal attenuation and path loss, which can result in inadequate communication range. Because the MM range wavelength is little, so spatial multiplexing strategies for both reception and transmission will be used.

Small Cells

They are utilized for administrator controlled, low-fueled and low-cost base stations working in the authorized range which can be deployed to ensure high data rates. Small cells can be of various sizes, such as Femto Cell, Pico Cell, and Micro Cells. Figure 1 shows the comparison of these cells deployment in term of their cell capacity and coverage area.

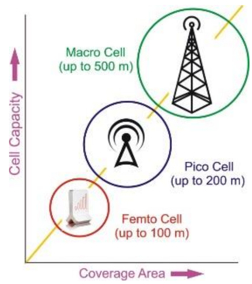

Figure 1: Coverage area Vs Cell capacity

Small cells can have a concentrated BS or wireless radio heads which can be wired or wireless with a center system. They diminish the separation between the client and base station consequently likewise lessening the transmit control required to defeat the pathless, particularly in the indoor condition thus enhancing the energy proficiency of both uplink and downlink communication. The basic access techniques are shown in Figure 2.

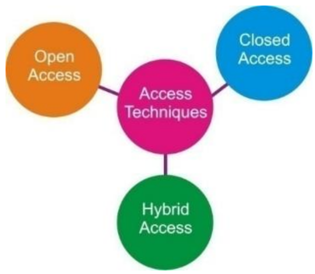

Figure 2: Access Techniques

The Mobile Stations (MS) situated inside the building will just need to communicate to the SCA and not to the far found BS consequently diminishing both the load and power requirements. So, consumer's battery utilization can be saved by the deployment of small cells that require least changes in the present standard.

Massive MIMO

MIMO is the key innovation used to expand network limit in 4G systems which gives both decent varieties pick up by sending similar signals through various ways amongst transmitter and receiver antennas and in addition multiplexing pick up by transmitting free signals in parallel via spatial channels. Authors proposed an algorithm for a virtual MIMO framework utilizing sharp antennas for energy productivity change [15]. Reference signals are utilized to decrease performance debasement for supporting 8 x 8 MIMO because of mistakes in channel evaluation. For this purpose, LTE utilizes steady reference signals. In any case, its fundamental detriment is that it makes excessively overhead and leads to diminish in the energy efficiency of the system [16].

In fifth generation networks, Massive MIMO is proposed in which a lot of antennas are used at BS. By utilizing this technology, the BS can communicate with various consumers concurrently in the same frequency band, which ensures the high multiplexing and array gain as well. According to the authors, massive MIMO technology is energy efficient and spectrum efficient [17] which, depicts that broadcast power is diminished by the number of antennas. Clearly, there are a substantial number of antennas in Massive MIMO, which expend high circuit control thus causing extensive diminishment in energy proficiency. A strategy of turning off a portion of BS antennas is proposed like MIMO to enhance the energy proficiency of the framework. Numerous different methods can be utilized to enhance the energy proficiency.

Wireless Relays

In the wireless framework, a wireless relay is considered as an "agent" of BS outside its cell scope territory, which enables the mobile terminals to assist in transmits of information when they are neither the source nor the goal of the data included. Use of relay is of utmost importance to enhance the energy proficiency of a wireless system. However, the allocation of resources is another confrontation in relay networks for maximizing energy proficiency of the network. The selection of the finest relay node and the best allocation of resources channel state information is crucial.

The major relaying schemes are, Amplify-and-Forward, Compress-and-Forward, and Decode-and-Forward. AF requires minimum delay as compared to the other relaying schemes because of this relay node function time-slot by time-slot and also needs minimum computing power.

Future Challenges For 5G Networks

Some future challenges for 5G networks are described as under:

The Requirement for a Holistic Approach

Most of the researches have been directed towards a different examination and utilization of the distinctive energy proficient advances. Energy reaping and exchange, deployment and arranging strategies and resource allocation have been frequently examined individually but there is no single approach which has the capacity to accomplish the desired requirement of energy proficiency. Therefore, there is a dire need of holistic approach in which all energy proficient techniques are joined. Various researchers have an underlying end-to-end point of view for the appraisal of the network power effectiveness and power utilization but extra work is required to comprehend the relative effect and the joined advantages of new innovations, designs, and calculations being produced.

Dealing with Interference

Lamentably, 5G systems will be interference-limited because symmetrical transmission plans, as well as linear interference balance strategies, are not pragmatic because of the huge number of nodes to be provided [5]. Therefore, the possibilities of fractional programming should be expanded. A talented answer is spoken to by the structure of consecutive fractional programming that gives an orderly way to deal with stretch out partial programming to interference-limited systems with reasonable unpredictability. Successive partial programming has been appeared to be compelling in maximizing the energy effectiveness of various applicant advancements for 5G, for example, device-to-device framework, multi-cell framework, multi-bearer transmissions, multi-cell massive MIMO frameworks, full duplex systems, C-RAN, CoMP and heterogeneous relay-helped interference systems.

Managing Arbitrariness

Randomness will affect the traffic evolution, energy availability and network topologies. The energy proficiency plan of systems with such an exceptional intensity of haphazardness needs the improvement of fresh arithmetical models that can catch the normal or constraining conduct of arbitrarily advancing systems. Stochastic geometry and random matrix theory show up as reasonable apparatuses towards this end, yet most examinations utilizing these procedures have been worried about conventional execution measurement, whereas a careful examination of their effect on the energy effectiveness of Communication frameworks is as yet absent. Another approach lies in the utilization of knowledge strategies, which manage arbitrariness by giving the gadgets a chance to acquire from history perception of their backgrounds and react as suitable in a self-sorting out the mold. Only a few research efforts have given the directions towards thoughtful contact of this method on power proficient network plan.

Developing Methods and Novel Energy Models

As far as lessening energy utilization is concerned, new rising advancement can also be utilized for power productive functions, specifically, storing and mobile computing has demonstrated noteworthy potential. By a smart dissemination of often-accessed contents over the system nodes, storing eases the requirement for backhaul transmissions that brings the decrease utilization of energy. Rather, mobile computing is not straightforwardly decreasing the power utilization but rather, also to wireless energy exchange, it can draw out the lifespan of nodes, which are low on battery power. However, it is important to create novel energy utilization models.

Conclusion

Wireless communications are experiencing a quick advancement, in which the journey for new applications and services drives for the quick preface of new engineering into the market. 5G demos and models are being pronounced and mobile operators have already started to deploy Long-Term Evaluation (LTE) networks to ensure the elevated speed wireless communication. In addition, the wireless communication industry has started to plan for energy proficiency. In this paper, growth of wireless communication, energy constraints in wireless communication, significance of selecting the appropriate energy proficiency metric, various energy proficient strategies that can be utilized for optimizing the power of the network and some future challenges in 5G networks are discussed at length. It will be supportive for intellectuals and developing organizations to produce the new energy proficient architecture to redress the energy consumption problem.

References

Abrol, A., & Jha, R. K. (2016). Power optimization in 5G networks: A step towards GrEEn communication. *IEEE Access*, *4*, 1355-1374

Ahmad, I., Kumar, T., Liyanage, M., Okwuibe, J., Ylianttila, M., & Gurtov, A. (2017, September). 5G security: Analysis of threats and solutions. In *2017 IEEE Conference on Standards for Communications and Networking (CSCN)* (pp. 193-199). IEEE.

Buzzi, S., Chih-Lin, I., Klein, T. E., Poor, H. V., Yang, C., & Zappone, A. (2016). A survey of energy-efficient techniques for 5G networks and challenges ahead. *IEEE Journal on Selected Areas in Communications*, *34*(4), 697-709

D. Feng, C. Jiang, G. Lim, L. J. Cimini, G. Feng and G. Y. Li, "A survey of energy-efficient wireless communications,", *IEEE Communication Survey & Tutorials,* vol. 15, no. 1, pp. 167-178, 2013.

Gandotra, P., & Jha, R. K. (2017). A survey on green communication and security challenges in 5G wireless communication networks. *Journal of Network and Computer Applications*, *96*, 39-61.

Ge, X., Yang, J., Gharavi, H., & Sun, Y. (2017). Energy efficiency challenges of 5G small cell networks. *IEEE Communications Magazine*, *55*(5), 184-191

H. Q. Ngo, E. G. Larsson and T. L. Marzetta, "Energy and spectral efficiency and very large multiuser MIMO systems," *IEEE Transactions on Communications*, vol. 61, no. 4, pp. 1436-1449, April 2013.

Hossain, E., Rasti, M., Tabassum, H., & Abdelnasser, A. (2014). Evolution towards 5G multi-tier cellular wireless networks: An interference management perspective. *arXiv preprint arXiv:1401.5530*.

Huang, K. & Larsson, E. (2013) "Simultaneous Information on Power Transfer for Broadband Wireless Systems," *IEEE Transactions on Signal Processing, 61*(23), 5972-5986.

Jiang, Y. (2019). Wireless resource management mechanism with green communication for multimedia streaming. *Multimedia Tools and Applications*, *78*(7), 8699-8710.

Krikidis, I., Timotheou, S., Nikolaou, S., Zheng, G., Ng, D. W. K., & Schober, R. (2014). Simultaneous wireless information and power transfer in modern communication systems. *IEEE Communications Magazine*, *52*(11), 104-110.

M. Azhar, M., & A. Shabbir. (2018) "5G Networks: Challenges and Technologies for Energy Efficiency," *Engineering, Technology & Applied Science Research*, *8*(2), 2864-2868.

Mishra, S., & Singh, M. (2017). Research Challenges and Opportunities in 5G Network. *International Journal of Future Generation Communication and Networking*, *10*(6), 13-21.

Ngo, H. Q., Larsson, E. G., & Marzetta, T. L. (2013). Energy and spectral efficiency of very large multiuser MIMO systems. *IEEE Transactions on Communications*, *61*(4), 1436-1449.

Obeid, A. M., Atitallah, N., Loukil, K., Abid, M., & Bensalah, M. (2018). A survey on efficient power consumption in adaptive wireless sensor networks. *Wireless Personal Communications*, *101*(1), 101-117.

T. T. Tran, Y. Shin and O. S. Shin, "Overview of enabling technologies for 3GPP LTE-advanced," *EURASIP Journal on Wireless Communication and Networking,* pp. 1-12, Feb. 2012.

Tran, T. T., Shin, Y., & Shin, O. S. (2012). Overview of enabling technologies for 3GPP LTE-advanced. *EURASIP Journal on Wireless Communications and Networking*, *2012*(1), 54.

Wan, L., Han, G., Rodrigues, J. J., Si, W., & Feng, N. (2015). An energy efficient DOA estimation algorithm for uncorrelated and coherent signals in virtual MIMO systems. *Telecommunication Systems*, *59*(1), 93-110.

Wu, G., Yang, C., Li, S., & Li, G. Y. (2015). Recent advances in energy-efficient networks and their application in 5G systems. *IEEE Wireless Communications*, *22*(2), 145-151.