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Optimization Techniques for the Energy Efficiency of Wireless Networks

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TITLE

Optimization techniques for the energy efficiency of wireless networks

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Abstract

This paper aims to study the energy efficiency optimization techniques applied to the design and architecture of wireless cellular networks to achieve the reduction of gas emissions in the environment and the improvement of the energy efficiency of mobile networks. The urgent need to reduce energy consumption and protect the environment have now oriented research into new techniques for optimizing the energy efficiency of wireless networks and are a key factor in their design and implementation

Additional Keywords and Phrases: Hetnets, mmWave technology, massive MIMO, Sleep Mode, Alternative Energy sources, Harvesting energy, Radio signals

Introduction

As observed in recent decades, the explosive growth of mobile telephony combined with the rapid evolution of wireless communication to cope with the ever-increasing number of users and the introduction of new higher-rate data services has led the wireless communication industry to significantly enhance its speed data transmission rate, but also the capacity and reliability of the network.

It has achieved this with an unprecedented expansion and density of wireless networks which, however, emit high concentrations of carbon dioxide into the atmosphere in such quantities that the earth does not have the capacity to integrate it into the cycles of energy and matter flow. The enormous consumption of energy causes many effects on the environment and the economy where these lead to an urgent need to reduce gas emissions as well as to improve the energy efficiency of wireless networks.

Optimization techniques for the energy efficiency

It has been observed that most of the energy consumption for cellular networks comes from the radio frequency access part, i.e. the energy of mobile networks, which is consumed mainly in base stations, thus ranking them in the most energy-intensive part of the mobile network.

It has been noted that the percentage of energy spent on the operation of the CN backbone network amounts to around 10-20% of the total amount of energy compared to the percentage of 50-90% of the total network power consumed by the base stations and which it depends on the type of station, the topology and technology of the access network, but also on the data transmission rate used.

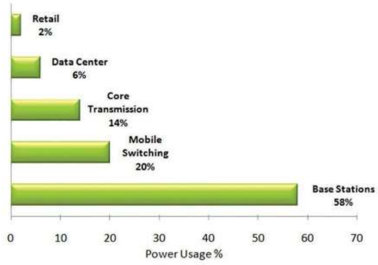

Figure 1: Power consumption of a typical wireless cellular network. (via reasearchgate.com)

Addressing all these problems lead to various energy efficiency techniques concerning the access network, which is the most energy-intensive part of the wireless mobile network, and these are presented below:

Heterogeneous Networks (HetNets)

The networks are configured to efficiently serve the demands of high traffic loads but also to operate statically at their peak performance resulting in energy wastage during low load conditions. In addition, the diversity of Radio Access networks created by the different air interface technologies, the different cell sizes, the different services provided over the same areas, but also the diversity in coverage and ownership lead to the development of HetNets (Heterogeneous Networks -) multi-level.

The development of HetNets supports a flexible cellular network architecture that combines a wide variety of wireless access technologies and protocols, different cell types as well as applications and services with different QoS requirements. In addition, the concept of "green" is added to energy efficiency, which refers to that part of the wireless access system that not only improves the quality of its services but also utilizes the various fluctuations to optimize the energy efficiency of the network ("energy efficiency optimization"). With the implementation of the heterogeneous networks, in addition to addressing the problem of signal quality degradation at the cell boundaries (better coverage) and lightening the telecommunications load at high demand points, a noticeable reduction in energy consumption in the network is also observed [1].

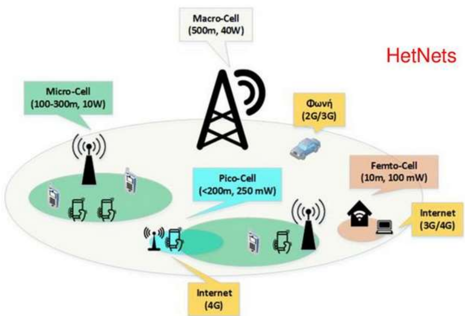

Figure 2: Heterogeneous networks of various radio technologies (2G, 3G, 4G) with various types of antennas (Macro, Micro, Pico, Femto (via reasearchgate.com)

As we know for cellular systems, telecommunication traffic is defined as the total number and duration of calls from and to mobile terminals, carried out through a number of radio paths. However, the different telecommunication traffic in the various areas of the cellular communication networks changes the specifications regarding their design, resulting in the use of different types of cells, regarding the size and shape in order to meet the capacity requirements, but always in combination with the economic cost.

In addition, the types of cells and by extension the base stations act in combination and cooperatively for different profiles of coverage and telecommunication demand, simultaneously utilizing studies for alternative radio-access infrastructures. The size of the cells is determined by the power used in the antenna system as higher power means a larger cell size (coverage area). In the original cellular infrastructure of the 4G network users are served by a base station that covers a wide area, while in dense heterogeneous networks the network consists of a long-range (Macro) cell covered by a central base station and smaller cells located inside of and which are served by a smaller base station of lower power [2].

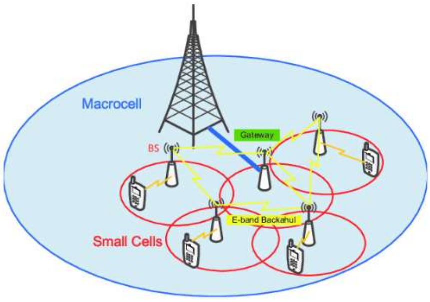

Figure 3: Integration of micro-cells (small-cells) in macro-cellular infrastructures (Heterogeneous network of two levels). (via link.springer.com)

With the introduction of a new mobile phone station, a new coverage area is created resulting from the subdivision of the area covered by the pre-existing stations and this implies a reduction in their transmission power and consequently a reduction in the total radiation in the wider area. The three categories of Small Cells depending on the distance they cover and the energy they consume are the following: Micro, Pico and Femto-cells. By densifying the network through the use of UDNs (Ultra Dense Network) technologies, small, densely placed cells manage the majority of telecommunication traffic.

Two-layer heterogeneous network

An example of the use of small cells is implemented indoors or outdoors, in hot spots where there is high demand from UE users (user equipment) and in areas not covered by the macro network. This has the effect of reducing traffic on macro systems and improving network performance and quality of service as they provide the user with additional resources when needed. In the network design of the image below there is a Macro Cell Base Station (MBS) that uses the entire spectrum band for communications and can be powered by both renewable energy sources and the traditional power grid due to the high-power consumption required for operation of. On the other hand, each Small Cell Base Station (SBS) through OFDMA wireless access technology provides high-level multimedia services to users within its coverage area [3].

A system with a Micro station - a micro cell - can be located in a house or an office building where solar panels or wind turbines will be installed to harvest energy from the environment. In a high-density HetNet, a wireless user may be in the coverage areas of several SBSs, so he has the ability to choose the nearest MicroStation and also the one that according to the automatic transmit power control has the best signal quality. On the other hand, if no small cell has sufficient network resources to successfully enter the user then there is the option of Macrocell Base Station [4].

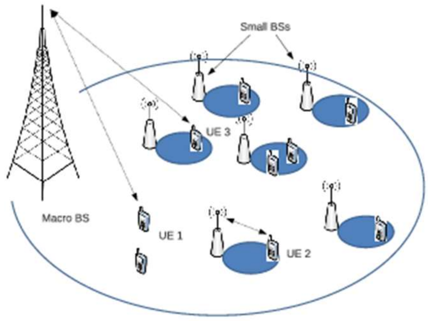

Figure 4: HetNet scenario with macro cell as baseline and small cells as capacity or coverage cells (via reasearchgate.com)

In conclusion, reducing the distance between the transmitter and the receiver improves the spectral performance, frees up radio resources in the access network and this leads to better mobility management and consequently to better energy efficiency since the power of the wireless links is limited.

A Femtocell which is the smallest cell, with coverage reaching up to 50m low power with features such as good internal signal quality combined with the small number of users (maximum number of 16 users) for simultaneous connection are a benefit for optimization techniques for wireless communication on many levels. Femtocells are a good solution for indoor spaces as the transmission leakages to the interior are much smaller due to the walls but also because their distance to the terminal equipment is reduced, as a result the mobile device transmits at lower power levels i.e. they achieve energy savings at the terminals. Femtocells are grouped into four categories depending on their use cases:

- Individual Femtocells: located in private homes with a backhaul connection that can be wired or wireless.
- Femtocells networks: These femtocells are deployed in enterprises or commercial centers with large numbers of users with a wired backhaul connection to the network.
- Fixed Relay Femtocells: external femtocell networks are used to improve coverage and capacity in areas where the macrocell network is insufficient.
- Mobile Femtocells: used in vehicles such as trains to provide services for mobile users and require a wireless backhaul connection.

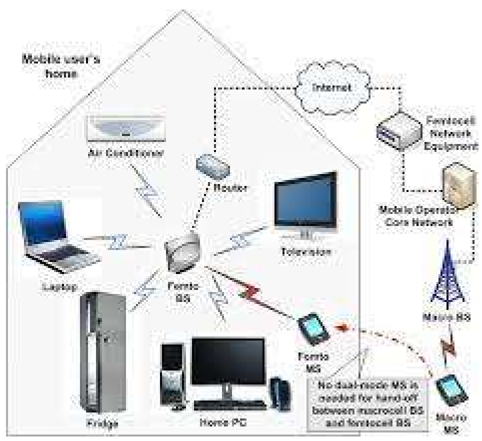

Figure 5: Femtocell deployment at homes (via reasearchgate.com)

The femtocell is an independent base station and can be connected to the provider's network using an IP address and with the possibility of three different implementation methods: open, closed and hybrid access. It is estimated that in the future Femtocells will be the key element in mobile communications [5].

Millimeter Wave - mmWave technology

A key technology that 5G systems are going to leverage is mmWave technology which has 30 to 300 GHz bandwidths available. Millimeter radio waves are electromagnetic waves typically defined as being within the 30–300 GHz frequency range between microwaves and infrared waves, and this spectrum can be used for high-speed wireless communications.

Radio waves in the Extremely High Frequency Band EHF (Extremely high frequency) have wavelengths from 1 to 10 mm, and this short wavelength gives them the name millimeter wave band. They have a short range (about one kilometer) so they are used for short range applications but they can be used in frequency reuse and interference management.

The application in wireless communication systems of the Ultra High Frequency band promises a rapid and promising development for cellular communications with the characteristics of high quality and high data transmission rate, but at the same time it is also a solution for improving energy efficiency, as long as some obstacles are overcome problems in both the integrated circuits and the design of this equipment. This technology forms the basis for the next technology below, that of Massive MIMO [6]

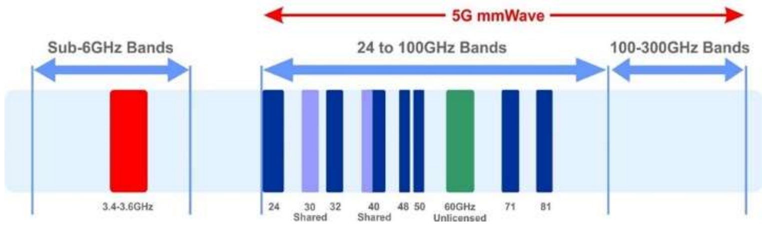

Figure 6: 5G mmWave Bands (via moniem-tech.com)

The Massive MIMO technology

MIMO (Multiple Input Multiple Output) technology initially worked for simultaneous data transfer to multiple users from a wireless router or access point, (by increasing the number of antennas) for one stream for each of them. On the side of the wireless devices (smartphone, tablet or laptop) they had to take turns sending data to the wireless router or access point. Later with MU-MIMO technology as multiple antennas are used on both the transmitter and receiver, data can be simultaneously transmitted to multiple users, be it one or multiple streams for each of them, thus increasing the capacity for each receiver but also the possibility of communication between several users at the same time.

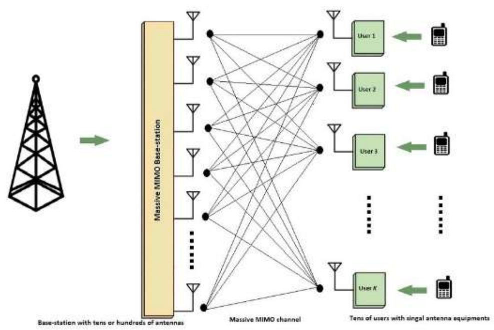

Figure 7: Massive MIMO Architecture (via researchgate.com)

This is achieved by OFDMA multiple access techniques of reusing the same time period and frequency resource to send and receive more than one independent and separately coded data signals ("streams") simultaneously over the same radio channel. Massive-MIMO is essentially a MU-MIMO with a fairly large number of antennas and finds application in fifth generation wireless communications where it improves the spectral efficiency of the system. The word "Massive" does not refer to the physical size of the antenna, but to the number of elements it consists of as it increases due to the reduction in distance between these elements. The very short wavelengths at mmWave frequencies enabled antennas with smaller dimensions and this resulted in the expansion of the MIMO antenna size and the creation of Massive MIMO. 3GPP has specified 32T32R (32 x 32 MIMO) increasing to 64T64R and beyond [7].

Massive MIMO is a set of multiple-input, multiple-output technologies for multipath wireless communication, where multiple terminal equipment, each emitting radio signals on one or more antennas, communicate with each other. It uses multiple antenna arrays and spatial multiplexing (Orthogonal Frequency Division Multiple Access, OFDMA) to transmit independent and separately coded data signals, known as "streams" (one stream per antenna) that can be focused by accuracy. These allow simultaneous communication with multiple user equipment (UE) during the same time period and with the same frequency resources. Massive-MIMO technology: uses multiple antennas in both the transmitter and receiver, but the number of antennas in the base station will be significantly greater than that of the users.

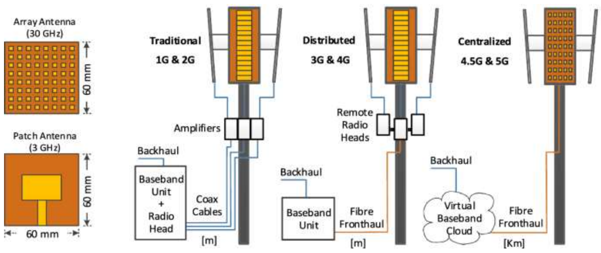

Figure 8: Antenna array for mm-Wave frequencies and the cellular infrastructure evolution (via link.springer.com)

The spatial diversity of Massive-MIMO is achieved by transmitting the radio signal to multiple antennas, with each antenna sending modified versions of the signal, thereby increasing the reliability of the radio link. Spatial multiplexing increases the capacity of the radio link by using the multiple hops as additional channels to send multiple, unique data streams between the transmitter and the receiver. Combined with the Beamforming technique (which uses advanced antenna technologies to direct a wireless signal in a specific direction, instead of radiating in all directions, i.e. over a wide area), interference between beams directed at different directions, thus allowing the deployment of larger antenna arrays. But also on the user side with the deployment of multiple receive antennas, each antenna receives a slightly different version of the signal, which can be mathematically combined to improve the quality of the transmitted signal. This implies the reduction of the user's individual exposure to radiation as the better the radio communication, the lower the mobile phone's transmission power. Combined with the automatic power control systems of mobile phones, they limit the radiation to the extent that it is possible to communicate with the base station [8].

Summarizing the above, the large number of antennas in the base stations implies a reduction in transmission power, as they direct the energy specifically to the mobile users and concentrate the radiation in very small areas of space, thus making the future 5G networks faster and serving more users with greater reliability and increased energy efficiency

Network management

The management of the network which integrates functions and technologies to achieve energy efficiency, combined with the development of resource management algorithms is an important factor both in the optimal operation of the network and in saving energy.

The use of radio resource management algorithms (RRM - Radio Resources Management Techniques) always combined with the limitation of network resources and the fluctuations of the telecommunication demand makes them necessary to maximize the capacity of the network, to optimize QoS services and to minimize the transmitted power. This is achieved by correlating quantities such as exchanging spectral efficiency with energy efficiency, energy saving with transmission delay, but also shaping wireless signals according to the load of telecommunication demand.

Sleep Mode

Modern cellular networks are active 24 hours a day - "always - on" - and consume a significant amount of power, regardless of network traffic demands.

One approach aimed at reducing energy consumption in the mobile network access network is to turn off active cells during periods when network traffic is low. The sleep mode function in base stations reduces the number of active cells when they are not needed due to low traffic in the network and for certain periods of time puts them in a low power state. This is achieved by CPU mechanisms that turn off the power of certain subsystems but continue supplying the RAM with the necessary power to maintain its data [9].

To reduce the number of base stations without degrading the quality of services, a distance-aware algorithm is used, which decides to deactivate the base station not because of its traffic load, but because of the average distance of its users. With this method, a 29% reduction in the consumption of the total energy required for the operation of the network is achieved. In particular, we use the sleep mode function in the structure of femtocell networks when they do not serve any mobile device as most of the femtocell components are dormant except those that manage the back-haul network connection and those that detect user activity.

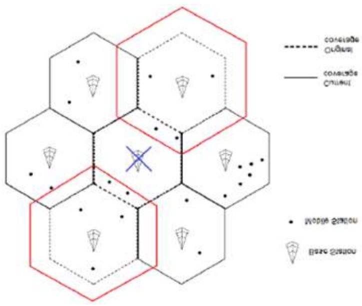

Figure 9: Combination of cell zooming and sleep mode. (via research-gate.com)

In addition, with the use of the two energy-saving protocols, the discontinuous reception (DRX) and the discontinuous transmission (DTX), the terminal devices remain connected to the network with a reduced transmission rate. The DRX non-continuous reception method saves energy from the user equipment by turning off the terminal device receiver and entering a low-power state for one DRX cycle when there is no packet to receive from a base station (eNodeB). The DRX settings are very sensitive, as it can cause severe QoS degradation, (packet delay or even packet loss) in the event that the mobile device is in standby mode while the eNodeB is planning to transmit data to the device. Discontinuous transmission (DTX) is a method of temporarily disabling or muting a mobile equipment when there is no voice input to the device as the use of the mobile for telephony may be less than 50 percent of the time. This improves the overall performance of the mobile system as the DTX circuit uses Voice Activity Detection (VAD) algorithm in the speech codec. keeps the transmitter signal on only during voice signal periods. This provides an advantage as in combination with time division multiplexing (TDM) the extra available bandwidth that is freed up is given to be exploited by the other signals.

We conclude that the combination of techniques to disable the operation of the components of the mobile device when they are not in use, or to cut off their supply when this is possible, is an effective way to reduce the energy consumption of mobile devices.

Alternative Energy Sources at the base station

An important factor in improving energy efficiency is the use of alternative energy sources such as wind and solar to power base stations over conventional energy sources and also to power those remote base stations that do not have access to an electrical source energy.

The collection of solar energy through the use of Photovoltaics and the conversion into electricity is an energy pumping solution for the wireless mobile network. The energy also produced by exploiting the wind through a wind turbine and converting it from mechanical to electrical is a renewable source of energy which, however, depends on the size and location of the wind turbine as well as the intensity of the wind. Of course, the combination of a wind turbine and solar panels can serve remote base stations for continuous energy supply [10].

The hydrogen base station produces electricity through specific processes-reactions of oxygen and hydrogen and minimizes the emission of harmful gases into the environment. Different fluctuations in environmental conditions result in the interruption of energy collection from some renewable source. To deal with this problem, a hybrid energy supply system can be designed which collects energy from the various natural sources and then converts it into electricity.

In addition, the model of the existence of several units that draw energy from the environment and then through a suitable system distribute this energy to neighboring base stations can also be applied.

Harvesting energy from the radio signals themselves

A promising technique is Wireless Energy Transfer (WET) and powering small mobile devices through the received radio signal. In the Wireless Powered Communication Network WPCNs architecture, the base station sends a radio signal that contains both the transmitted information and a part required for energy collection. Then the user's wireless equipment with appropriate techniques and mechanisms must separate the radio signal into these two parts, one for collecting the energy and the other for decoding the information. This architecture can be applied to dense wireless networks, Massive MIMO systems, and EHF Ultra High Frequency Band networks as long as some challenges such as system performance degradation due to radio signal decay at the receiver are overcome.

But the research interest has turned to Wireless Charging Communication Networks as the possibility of powering a telecommunications network from a node - which has excess energy

- is being studied through the emission of a radio frequency signal. In this way, the possibility is provided by the nodes of the network which are in the phase of wireless charging, after drawing and collecting the energy to use it later to transmit a signal containing information [12].

It should be noted that the station's transmission power is properly calculated to satisfy each user separately, even the most demanding within its range, so that there is a quality of service, and this has to do with maximizing the user's energy efficiency as a function of their utility. In addition, the energy that is not consumed can be stored in the users' batteries for future transmission of information.

Conclusion

In this paper we presented some techniques such as the densification of network cells achieved by a combination of the Orthogonal Frequency Division Multiple Access (OFDMA) technique, the use of radio waves in the EHF Ultra High Frequency Band and Massive MIMO technology where ever larger antenna arrays become possible as they operate at frequencies mmWave, it is possible to increase the capacity and performance of the network but also to reduce the consumed energy as the size of the base stations decreases.

In addition to the energy efficiency optimization techniques applied to the design and architecture of wireless cellular networks and presented in this paper, the reduction of gas emissions into the environment and the improvement of the energy efficiency of mobile networks are achieved.

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