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Energy Efficient Modeling of MIMO-OFDM in 4G Networks

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***Abstract*—With the ubiquitous proliferation of mobile broadband and its widespread usage, the energy consumption of mobile devices has increased tenfold times as compared to a decade ago. It is a well-known fact that the mobile communication capability has escalated, and its service provisioning is approaching those achieved by fixed line connections. Driven by the demand to cater to the upwardly mobile user and a desire to outcompete current service providers, the mobile industry is surging ahead with an exponential pace leveraging new technologies and applications. However, this race for envisioning the communication paradigm has taken its toll on the environment with excessive greenhouse gas emission, due to enormous energy expended by the mobile networks. With almost half of the globe population consuming mobile services, it is imperative to leverage such technologies that optimize the Energy Efficiency of mobile networks. 3GPP Release 10 provided a framework for the LTE-Advanced standard, targeted to fulfill as well as exceed the requirements of IMT-Advanced defined by ITU. LTE-Advanced has evolved from LTE and is backward compatible with legacy systems. Coupled with the ability to use a maximum bandwidth of 100 MHz along with scalable OFDM as the multiple access technology, LTE has emerged as the fastest growing mobile standard. Also, the LTE-Advanced networks deploy Carrier aggregation, Advanced MIMO technologies, support of Het-Nets and Coordinated multi-points for cell edge users, to achieve the target specifications of IMT-Advanced. MIMO-OFDM is the air interface of choice for 4G Networks. This paper highlights the key technologies in LTE-Advanced framed in 3GPP Release 12, which attempt to reduce energy consumption, ushering LTE towards Green Communication, an environment-friendly paradigm. An Energy Efficient model of MIMO-OFDM is proposed to advocate the role of this technology to boost Energy Efficiency in Wireless Networks.**

***Index Terms*— Energy Efficiency, Green communication, LTE-Advanced, MIMO, OFDM.**

I. INTRODUCTION

With the ubiquitous proliferation of mobile communication, half the earth's human population is actively using this technology. 3GPPs Long Term Evolution (LTE) is declared as the fastest growing system in the history of mobile technology[1]. By the year 2017, half the world's population is expected to be covered by LTE network[2]. With this phenomenal growth in the number of subscribers, the energy consumption has increased manifold times along with the emission of greenhouse gasses such as Carbon dioxide(CO_2). Thus, Mobile operators face the challenge of optimizing Energy Efficiency and at the same time, keeping a check on operational cost [3]. Although the energy consumption at the user terminal is optimal due to limited

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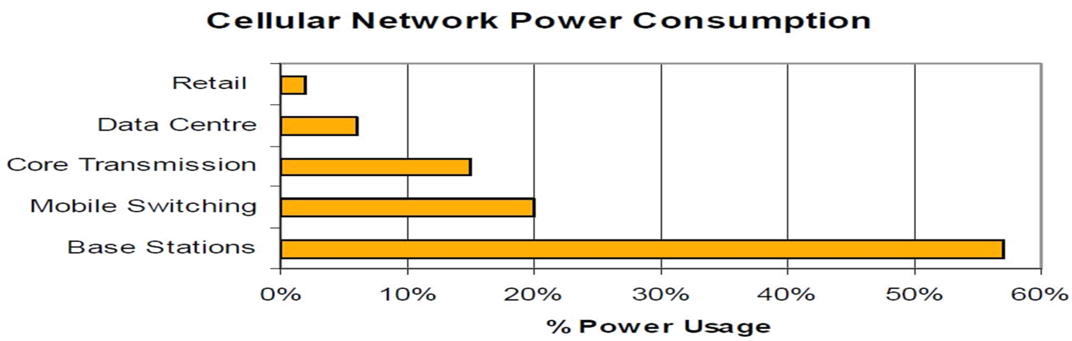

Figure 1. Cellular Network Power Consumption scenario

resources, the energy consumption at the network side needs to be minimized. Fig. 1[4] portrays a typical Cellular Network Power Consumption scenario, where it is evident that the Base stations consume a significant portion of power. The most important initiative has been taken by Alcatel-Lucent Bell Labs, who launched the Green Touch Initiative. It is a global consortium comprising of service providers and leading research organizations around the world; with a goal towards making communications networks 1000 times more energy efficient[5]. It primary objective was to bring down the energy consumption thousand-fold times by the year 2015, resulting in a reduction of millions of tons of carbon emission. The European Commission research project EARTH [6], aimed to find solutions and concepts that can reduce the energy consumption of mobile broadband systems by 50%. It proposed large-scale antenna system where concentrated beams of information are transmitted simultaneously to many users. As the number of antennas increase, the concentration of beams also increase. In this scheme, less power is required by transmitting antennas to send information. Thus, the overall reduction in energy consumption in the network is a blend of reduction of dissipated power of base station hardware components, the design of link interfaces and application of original radio transmission, energy efficient Radio Resource Management(RRM)[3]. Section II gives a brief introduction to the concept of Green Communication; Section III provides the evolution path of LTE while Section IV outlines the key technologies proposed in LTE-Advanced for enhancing the Energy Efficiency(EE). An analysis of MIMO-OFDM is presented to evaluate their role in improving EE.

II GREEN COMMUNICATION

With the demand to reduce energy consumption in wireless networks proliferating globally, the networks operators have become conscious of their role towards the environment. The EE cellular networks will lead to a Green Wireless Communication, which will operate at low operational cost while maintaining the same level of performance. Specific solutions and methods have been deployed to render these systems energy efficient. The solutions and methods to obtain EE can be grouped into three different categories based on Architecture, RRM and radio technology. Fig. 2[7] portrays a scenario on the deployment of Heterogeneous networks(Het-Nets) and Coordinated Multipoint(CoMP). Both these solutions are implemented at the architecture level to enhance the EE. In Het-Nets; macro, micro and pico cells are deployed depending on the applications while CoMP exploits the cooperative relay stations to improve their EE. The use of Femto-cells[8] in Cellular Networks has also generated interest that provide a backhaul and reduce the burden, on the whole, system. In the Energy Efficient RRM, the key technologies adopted are switching-off scheme, cell zooming and use of renewable energy. The Base stations can be conveniently switched off during idle hours by assessing their traffic load. Cell zooming is frequently employed to complement switching-off scheme to minimize energy consumption. In [9] it is emphasized that use of renewable energy is the defining criterion from an environmental point of view. Efficient RRM is another aspect of optimizing Energy consumption. Multiple Input Multiple outputs (MIMO) along with Orthogonal Frequency Division Multiplexing(OFDM) has been the air interface of choice for Cellular networks in Fourth Generation(4G)[10]. The EE of Multi-user MIMO(MU-MIMO) is highlighted in [11], where MU-MIMO offers significant advantages over Single Input Single Output(SISO) system. In [12], energy efficient OFDM relay system is analyzed, where two source nodes communicate with each other via a half-duplex amplify-and-forward relay node. By optimizing the mobile number of subcarriers along with the number of bits at each subcarrier, EE is enhanced.

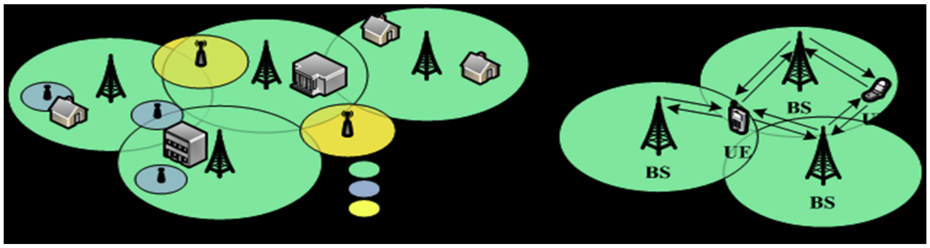

Figure 2. HetNets and CoMP to improve EE

III EVOLUTION OF LTE

Mobile data traffic has been growing exponentially and is expected to grow further by 12 times by the year 2018[2]. With LTE networks outnumbering the other competing technologies, the EE of LTE system should be optimized. Third Generation Partnership Project(3GPP) has developed the LTE system using Release 8 to 12. Release 8 and 9, known as LTE are backward compatible with Global System for Mobile Communication(GSM). However, they did not meet the requirements of International Mobile Telecommunication-Advanced(IMT-Advanced), proposed by the International Telecommunication Union(ITU) as a benchmark for 4G standard. 3GPP further proposed release 10 to 12, to meet as well as exceed the requirements of IMT-Advanced. This evolution of LTE through 3GPP release 10 to 12 is known as LTE-Advanced(LTE-A). LTE-A(3GPPP release 10) is known as IMT-Advanced technology, and it satisfies the criterion laid down by IMT-Advanced[13]. Table I summarizes the key technological innovations in 3GPP release 8 to 12. Release 8 was a significant landmark as it marked the advent of LTE, which offered enhanced capacity improvement over existing Third Generation(3G) Technologies like Universal Mobile Telecommunication services(UMTS) and High-Speed Packet Access(HSPA). LTE exploits the robustness of OFDM against frequency selective fading and combines it with MIMO to boost capacity. Release 9 was an interim release that employs evolved Multimedia Broadcast/ Multicast service(MBMS) and enabled dual stream beamforming to enhance the downlink performance for the user equipment(UE) specific reference signal. Release 10 marks a significant milestone in the evolution of LTE systems where they can meet the IMT-Advanced requirements. Major technological upgrades in Release 10 are the inclusion of carrier aggregation and enhanced MIMO in the form of Multi-user MIMO(MU-MIMO). OFDMA employs bandwidth of 1.4, 3, 5, 10,15 and 20 MHz. A maximum of five of these bandwidths known as the component carrier(CC) can be aggregated to yield a maximum bandwidth of 100 MHz. Enhanced MIMO employs 8 Downlink(DL) and 4 Uplink(UL) layers to enhance peak data rate and capacity. 3GPP Release 11 incorporates the transmission and reception through CoMP along with additional support for Het-Nets. Het-Nets aim for network densification, where small low power nodes are deployed under the umbrella of low power nodes to achieve enhanced local area access. 3GPP Release 12 is a major release that was introduced in December 2014 and finalized in March 2015. The prime focus areas of Release 12 are increased support for local area access, multi-antenna enhancement, device-to-device communication and better support for machine type communication(MTC)[15].

TABLE I. 3GPP RELEASE 8 TO 13[14]

3GPP Release	Year	Technological Innovation	Standard
Release 8	March 2009	MIMO/OFDMA Flexible bandwidth	LTE
Release 9	March 2010	Evolved MBMS dual stream beam-forming	LTE
Release 10	Sep 2011	Carrier aggregation Enhanced MIMO	LTE-A
Release 11	Jun 2013	DL and UL CoMP In-device co-existence	LTE-A
Release 12	March 2015	Small cell enhancement Lean Carrier	LTE-A
Release 13	March 2016 (expected)	MTC, D2D	LTE-B

IV Energy Efficient LTE

A. Technology Areas for LTE

Fig. 3[15] portrays the major specialized areas which have been identified in the evolution of LTE. As is evident, the 3GPP Release 12 has the prime focus on Network EE. A new carrier type known as Lean carrier has been proposed[16] to address this issue. In this scheme, a user can simultaneously transmit on two carriers; one is the primary carrier based on legacy LTE carrier, and the other is a lean carrier. Fig. 4[7] shows small cell scenario where the terminal is connected to a macro node using legacy LTE connection as well as to low power node using a lean carrier. Using this dual connectivity, the legacy connection can be used for system information and control signaling while the lean carrier connection is used for high rate data transmission. Thus, it aims to reduce the control channel and signal overhead, resulting in better spectral efficiency and reduction of energy consumption. Ref [17] quantifies the energy saving 20% for the macro node at low loads. This energy saving stems from the fact that the base station can go to micro sleep more frequently due to the lesser number of mandatory transmissions on the lean carrier. Another factor responsible for energy saving is the higher throughput of the lean carrier which enables the base stations to sleep for a longer time since they empty the terminal buffer in a brief span. The other focus areas of 3GPP release 12 are network capacity, cell edge performance along with spectrum utilization and carrier aggregation. To augment network capacity relay nodes are deployed which enhance the EE of the system as well[18]. In [19] an efficient power management scheme for Het-Nets is proposed where a quantized channel quality indicator is proposed as the input and Quality of service(QoS) parameters are also considered. The simulation results demonstrate the power efficiency of the scheme for Het-nets.[20] highlights the energy saving capabilities of Self-Organizing Networks(SON). SON can dynamically switch on and off the base stations for maximum energy consumption. The deployment of CoMP and relay along with massive MIMO aid LTE-A in achieving high EE. Further, the use of scalable OFDMA along with power and resource also helps in improving EE by optimizing the number of sub-carriers. Table II summarizes the different approaches to improving EE in LTE-A networks. The technologies outlined in Table II are incorporated in Release 12 of LTE-A, thus providing the capability to be EE. However, these different approaches need to be combined in a holistic manner so as to provide a green environment. [21] provides the future directions of green wireless communications and outlines the need for standardizing of benchmarks so that they are compatible globally. The emergence of agile radios in the form of Software Defined Radio(SDR) in LTE systems will augment spectrum flexibility and improve EE. However, the reduction in power at Base stations will significantly improve the network EE as the Base stations consume 60% of the system power.

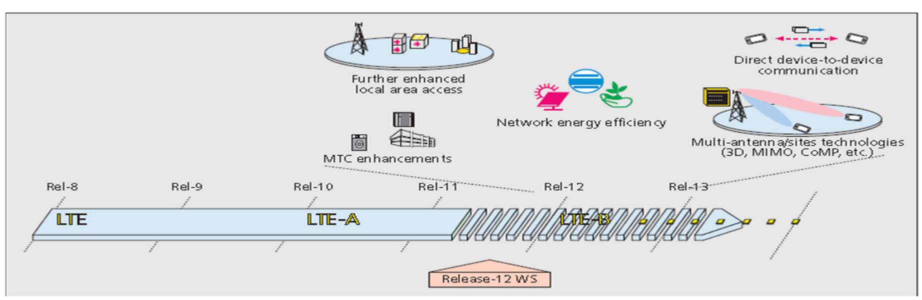

Figure 3. Technology areas for LTE evolution

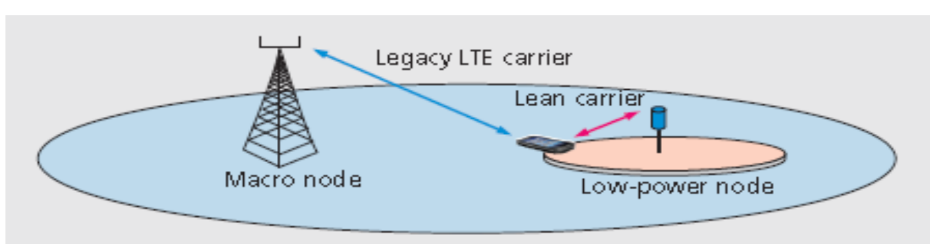

Figure 4. A scenario where the terminal is connected to legacy as well as lean carrier

TABLE II. ENERGY EFFICIENT TECHNOLOGIES FOR LTE-A

Technology	Implementation level	Benefits
Het-Nets	Architecture	Increase of throughput and low cost and improves *EE*
CoMP	Architecture	Boost capacity and *EE*
SON	RRM	Improves operational cost and *EE*
Renewable energy such as wind or solar	RRM	Cuts the operational cost and provides green communication
New carrier type known as 'Lean Carrier'	Radio access technology	Improves spectral efficiency, network *EE* Improves support of Het-Nets and spectrum flexibility
Optimized OFDMA	Radio access technology	Improves Spectrum flexibility and *EE*
Massive MIMO extending upto 64 transmit antennas	Radio access technology	Boost capacity and performance along with network *EE*

B. Energy Efficient modeling of MIMO-OFDM for LTE-Advanced

MIMO-OFDM is the radio interface technology over the physical channel for LTE/LTE-Advanced. Ref [22] analyzes the Energy Efficiency(EE) of cellular networks for spatially distributed load. There exists a trade-off between EE and Spectral Efficiency(SE) in the cellular network[23-26]. Hence, the modeling of Energy efficient radio interface has to be done without compromising the SE. In [27] an energy-efficiency optimized power allocation (EEOPA) algorithm is proposed to improve the energy efficiency of MIMO-OFDM mobile multimedia communication systems. Through simulation comparisons, the author(s) validate that the proposed EEOPA algorithm can guarantee the required Quality of Service(QoS) with high energy efficiency in MIMO-OFDM. In [28] the problem of designing efficient scheme for reducing the power consumption and hardware cost in MIMO system has been addressed by spectrum sensing scheme designed for MIMO-OFDM based Cognitive Radio network. In [29] a comprehensive analysis of fundamental trade-off between SE and EE, deployment efficiency and EE is provided. In [30] it is shown that by transmitting and receiving information jointly, for transmission distance larger than a given threshold, energy saving is possible to a large extent. Ref [11] demonstrates the improvement of energy efficiency by using a combination of adaptive overall transmit power and its allocation. This adaptation is according to the channel states and the circuit power consumed. In [31] it is argued that conventional MIMO is not suitable for implementation to improve EE. Instead virtual MIMO, also known as Multi-user MIMO(MU-MIMO) is proposed to improve EE. In MU-MIMO, multiple users co-operate for distributed transmission and information processing. Due to high Circuit power consumption in Single user MIMO(SU-MIMO), MU-MIMO is better suited for improving EE. Fig. 5 depicts an MU-MIMO system where each user often receives data intended for another user. OFDMA offers flexibility to LTE system. Hence, adaptive resource allocation can be deployed to improve EE. In [32] a cross-layer optimization is proposed to improve EE. In the current work, we have endeavored to envisage an energy efficient model for a LTE-Advanced network that focuses on the physical layer. The proposed model deploys MU-MIMO and adaptive OFDMA to enhance EE. The simulation work needs to be carried out, and we optimistically await the results to verify the efficacy of the model.

V. CONCLUSIONS

The rising energy costs and carbon footprint of operating cellular networks have led to a trend in addressing energy-efficiency amongst the network operators and regulatory bodies such as 3GPP and ITU. However

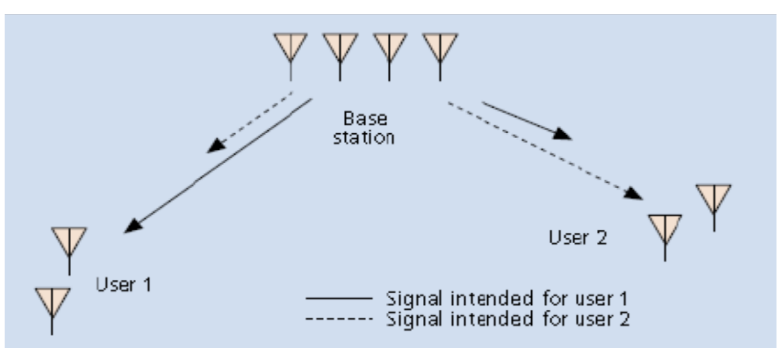

Figure 5. Multi-user MIMO for improving EE

with the exponential increase of mobile traffic at high data rates, the task of designing Energy Efficient systems becomes more challenging. The major component in LTE release 12 'Lean Carrier' offers multiple advantages and is a step towards Green communication. It provides 70% cell edge user throughput gain along with 20% reduction in energy consumption of macro nodes. Other approaches to augment EE are also briefly discussed. However realizing an energy efficient wireless network is the subject of extensive research that encompasses various layers of the protocol stack and system architectures. In this paper, physical layer optimization is proposed to reduce EE. However, a holistic approach is required to address this critical issue of Energy Efficient new communication. The need of the hour is that all regulatory bodies and service providers should collaborate further while providing guidelines for eco-friendly cellular communication.

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