World Journal of Engineering Research and Technology

WJERT

www.wjert.org

Impact Factor Value: 5.924

FUTURE WIRELESS NETWORKS AND ENERGY EFFICIENCY: A COMPREHENSIVE SURVEY

Pahalson C. A. D.*[1] and Davou Gyang[2]

[1]Dept of Science, Plateau State Polytechnic, Barkin Ladi. Jos, Nigeria.

[2]Dept of Electrical/Electronics Engineering, Plateau State Polytechnic, Barkin Ladi. Jos, Nigeria.

Article Received on 22/10/2020 **Article Revised on 12/11/2020** **Article Accepted on 02/12/2020**

***Corresponding Author**
Pahalson C. A. D.
Dept of Science, Plateau State Polytechnic, Barkin Ladi. Jos, Nigeria.

ABSTRACT

This paper brings forward some of the new and emerging wireless communication technologies. It also discusses some of the new wireless technologies that can be expected to materialize in the future due to the demand from the end users, and hence the advances in the research of new technology. Emerging 5G technologies, various infrastructure improvements and new innovations were discussed.

KEYWORDS: Energy, Efficiency, Energy-efficiency, Wireless, Networks, 3G, 4G, 5G, LTE, *Wi-Fi, WDC, WMN, Green,and Mobile.*

INTRODUCTION

5G (also known as the 5th generation wireless systems, or beyond 4G, or beyond 2020 mobile communications technologies) is one of the upcoming buzzwords for the future's mobile communication world. It can be seen as a user-centric network, as opposed to the operator centric approach seen in 3G and the service-centric in 4G. 5G is not yet detailed in any particular specification in any official document by any telecommunication standardization body. However, the 5G terminals are expected be software defined radios that are able to utilize access to different wireless networks simultaneously. They are expected to be capable to download and incorporate new modulation schemes and error-control schemes into use, and they should also be able to join different data-flows together from different technologies (so called multi-mode MTs). The network is going to be the party responsible for handling the user-mobility, while the MT will make the final choice among different wireless network providers for a given service (Janevski, 2009). Also, greater wireless spectrum allocations, highly directional beamforming antennas at both the MT and BS, longer battery life, lower network outage probability, much higher bit rates in larger portions of the wireless coverage area, lower infrastructure costs, and higher aggregate capacity for many simultaneous users in both licensed and in unlicensed spectrum (Wi-Fi and cellular) are expected from 5G in an article by (Li *et al*., 2009). The article also predicted, that the backbone networks of 5G will move from copper and fiber to millimetre-wave wireless connections.

At the moment the entire wireless spectrum available for mobile communications is over 1.1GHz, and in addition to that, a large amount (about 500 MHz) is reserved for unlicensed spectrum at the 2.4 GHz and the 5 GHz ISM-bands (Industrial, Scientific and Medical (ISM) bands refer to the operation of equipment or appliances designed to generate and use local RF-energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunications). By the year 2020 the amount of wireless spectrum available for mobile broadband may increase by up to 10 times, therefore global coordination work will be required to achieve that target. The next major technology step in the wireless interface will be LTE-Advanced, which is expected to raise the spectral efficiency and thus offer peak transfer rates of over 1 Gbit/s. The wireless evolution will not however stop with LTE-Advanced. Digital processing power will continue to grow to meet the increasing data rates in the MTs. RF-technologies will continue supporting wider bandwidth, and wider optical fiber deployments will continue providing faster connections to the BSs (‘10 x 10 x 10 the formula for beyond 4G’ 2012). More densely deployed BSs will result in HetNets with radio nodes varying from stand-alone BSs to systems with centralized processing, which is why so many diverse RATs, including LTE, HSPA+, Wi-Fi and "Beyond 4G", will have to be integrated flexibly. In addition to that, the available wireless spectrum will be more fragmented than ever and may even be shared among the operators according to new network leasing models. The diverseness of the wireless equipment in the HetNets will have a wide range of unique performance demands.

Cognitive radio networks will play a vital in this because they will enable flexible wireless spectrum management, D2D (device-to-device) networking and wideband software defined radio (‘10 x 10 x 10 the formula for beyond 4G’ 2012).

Surveys regarding the concepts and contents for what functionality is expected to be included into 5G and how the future's networks ought to be powered, have been brought up by the authors of (Gohil *et al.*, 2013) and (Wang and Rangapillai, 2012), in which the authors also considered the greenness of 5G technology to some extent). The latter article also reasoned that to improve the performance of 5G networks over the existing 4G networks, multiple standards in a single device and single platform must be implemented, with a hybrid multiple access scheme along with the use of CDMA-OFDMA.

Authors of (Li *et al.*, 2009) proposed a model for a multi-network data path for 5G networks, in which the data is sent to and from the MTs sporadically via different paths. To corroborate the presented theoretical models and claims of the article, the authors also ran simulations for evaluating the performance of the multi-network data-path scheme. Millimetre-wave frequencies, due to their much smaller wavelength and the size of the antennas, may exploit polarization and new spatial processing techniques, such as massive MIMO and adaptive beamforming (Rusek *et al*., 2013).

Although the underlying MIMO theoretic concepts are well understood, cooperative systems are still in their infancy, and much further research is still required in order to be able to fully understand these systems and to be able to achieve the full benefits from multi-base cooperation. Unlike in standard MIMO systems, where the cost of multi-antenna processing lies in the extra hardware and software at each device, cooperative MIMO techniques do not necessarily require any extra antennas. Rather, the cost in cooperative MIMO lies in the additional exchange of information (i.e. user data and channel state) between the devices engaged in the cooperation, or between the devices and the central controller in a centralized architecture. Furthermore, the information exchange is subject to tight delay constraints, which can be difficult to meet over a large wireless network (Gesbert *et al*., 2010).

The future wireless communication systems face several key challenges that must be addressed in order to maintain an acceptable level of energy efficiency and affordability – the most influential being (Baldemair *et al.*, 2013):

- The large growth in the traffic volume

The traffic volume has grown tremendously in recent years, fueled primarily by an enormous uptake in the use of mobile broadband – it can be safely expected that this trend will also continue in the future. Just by straightforward extrapolation, one may expect a several hundred-fold traffic increase within the next ten years, and even further growth beyond that. This traffic increase will to a large extent be driven by further increase in mobile-broadband usage.

- Growth in number of connected devices with diverse requirements.

In the future, the human-centric connected MTs are expected to be surpassed tenfold by wireless devices related to communicating machines, including surveillance cameras, smart-home and smart-grid devices, connected sensors, etc.

- Differing requirements and characteristics for the future wireless systems.

While mobile-broadband access still remains as the dominant application for future wireless systems, a major difference is that ever higher data rates should be available essentially anywhere and anytime, and very high bit-rates should also be supported as needed. Additionally, applications where wireless machines communicate with other machines are expected to become more popular (e.g. safety or control mechanisms in process industry, remote cameras or smart-grid products).

- Affordability and Sustainability

Cost of wireless communications will remain a key factor in the future, along with the way the energy for the communications is produced.

To match the above challenges, new advances in technology components are required, either in the form of evolved versions of already existing wireless technologies, or as building blocks for new 5G wireless access technologies for specific scenarios and use cases. In the article (Rappaport *et al.*, 2013) the authors discussed the motivation for new mm-wave cellular systems for 5G, their methodology and hardware, and offered suggestions for the applicable frequencies for the new wireless systems. The authors noted an interesting point, that the today's cellular systems are limited to a carrier frequency spectrum ranging only between 700 MHz and 2.6 GHz and of that range, only 780 MHz is actually reserved for the worldwide wireless spectrum bandwidth allocation for all cellular technologies combined.

Being able to serve both the legacy users with older and often hence energy-wise inefficient cellphones, as well as the customers with the cutting edge newest smartphones, requires simultaneous management of multiple technologies in the same bandwidth-limited wireless spectrum – from energy efficiency standpoint, this is not the optimal or desired situation. The authors also conducted extensive real-world measurements of the propagation characteristics of 28 and 38 GHz wireless signals in urban areas. Their studies conducted at 28 and 38 GHz showed that consistent coverage can be achieved by having BSs with a cell-radius of 200 metres.

In the article (Khan *et al.*, 2012) the authors proposed a millimetre-wave mobile broadband system for 5G systems between 3 . . . 300 GHz, and discussed the advantages of millimetre waves in general, such as vast spectrum availability and large beamforming gain in small form factors. The authors also ran simulations for their implementation of a mm-wave mobile broadband-system, and noted, that with their configuration it is possible to achieve a 10-100 times cell throughput and cell-edge throughput improvement over the existing 4G systems. The gain happened to be in line with the increased system bandwidth used in their mm-wave mobile broadband-system (500 MHz – which is 25 times more bandwidth compared to the 20 MHz in LTE).

The radio is only one small part of today's smartphones. The next generation wireless devices will have a built-in support for a vast array of user services accompanied with a powerful operating system and a complex communications engine. Ubiquitous network access will be essential in supporting these new applications and services with optimal energy efficiency overall ('10 x 10 x 10 the formula for beyond 4G' 2012).

In future wireless networks, the radio resources will be distributed intelligently to achieve the lowest energy consumption possible. Hence, instead of offering a uniform radio access with varying delivery capabilities, services could be delivered more intelligently to take into account the operational environment as well. Context sensitive variables could include for instance the existence of other access networks, the availability of radio bandwidth, the radio propagation environment, user mobility patterns and cost. Additionally, the quality of the wireless connections could be set according to available network and air interface resources.

It is also expected, that the radios in the MT will be able to perform local RRM and assist with network resource management. Figure 1 illustrates the major architectural differences in the existing wireless technologies compared to LTE-Advanced ('2020: Beyond 4G Radio Evolution for the Gigabit Experience' 2011).

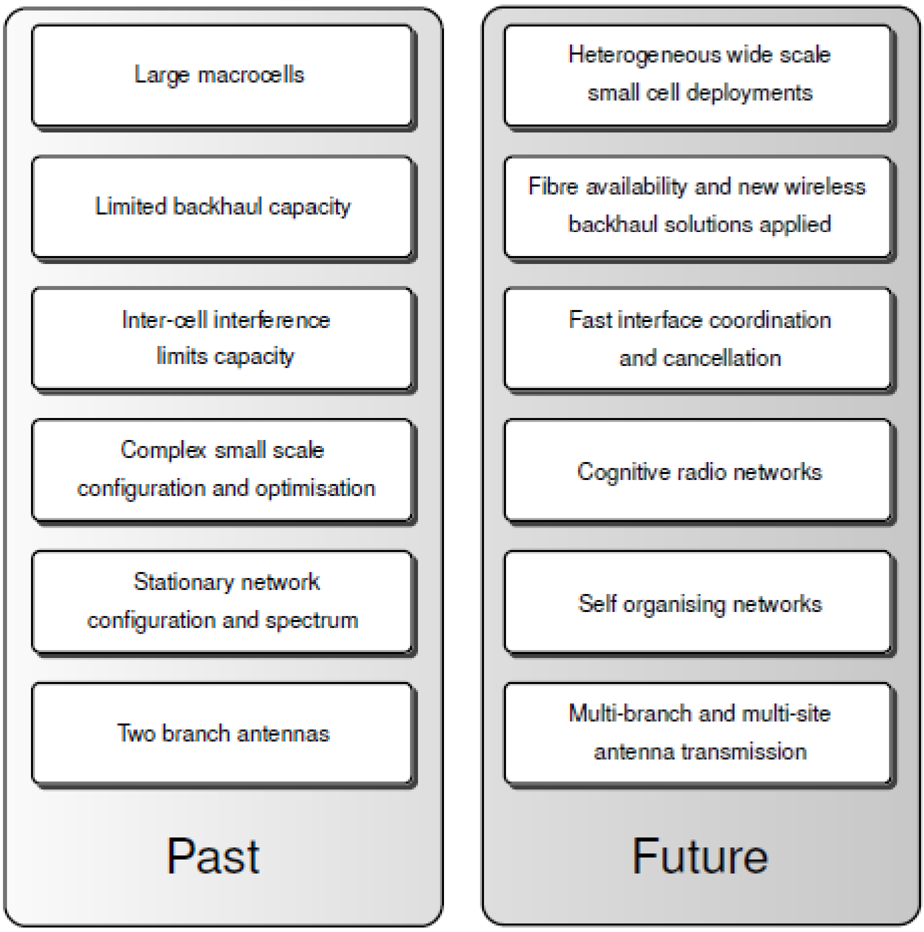

Figure 1: Advances in LTE-A compared to existing technologies.

Infrastructure improvements and new innovations

In the article (Tomba *et al.*, 2011) the authors analyzed the design limitations for future very-high-capacity wireless access systems, as well as their impact on the overall system architecture. The traditional mobile systems have primarily been limited by the available bandwidth, but for the future, the high-capacity data systems are going to be increasingly constrained by the energy and the infrastructure costs.

Some fundamental assumptions and expectations for future wireless infrastructures can be summarized as (Tombaz *et al.*, 2011):

- It's not only the energy cost, but also the total access network cost, that are heavily influenced by the number of network BSs. If the energy cost is high, the total cost will be minimized for dense BS deployments.
- In high-density scenarios, the idle power of the BSs as well as in the backhaul as a significant factor.

- The cost of energy is also strongly reliant on the amount of available spectrum. Significant cost savings in both energy and infrastructure can be made if more spectrum can be brought available.

The optimization of the MT's power consumption is vital in current devices, and will also remain as a key factor in the future as well, due to the fact that the battery technologies improve very slowly compared to the evolution of other technologies.

For MTs that use the Internet to a great degree, improvements in web caching techniques can also bring significant energy savings due to the decreased need to access the network (Sailhan and Issarny, 2002). An alternative solution to relying to BSs for accessing the Internet is to use so called ad-hoc networking, where the WLAN hotspot is reached in multiple hops as opposed to direct access. There are also proposals for concepts where the web content is being shared and cached between those ad-hoc nodes so as to make the web access seem ever faster.

There are also ways to implement optimized task schedulers for MTs, which aim to meet the deadline for the time limited task in hand by calculating the correct CPU voltage (DVS), and speed for the processor to compute the task, and to make the task's deadline (Limin and Deyu, 2006). Energy is of course also consumed for example in the display, loudspeaker and the device's CPU, but those were selected to be omitted in this thesis in order to better focus on the network issues.

The potential for very long standby and call times of the MTs today have been made possible by employing schemes like discontinuous transmission (DTX), and discontinuous reception (DRX). DTX in essence just periodically creates time-slots in the transmission protocol, during which the power consuming components in the device can be switched off. DTX is not however feasible (nor supported) in the BSs (in WCDMA/HSPA specifications), as it needs continuous pilot signal transmission. This limitation has already been improved to a certain degree in LTE, due to the fact that the cell specific reference signals are no longer being transmitted continuously – although frequent transmission of synchronization signals and the DRX has similarly the potential for power consumption reduction in the MTs by shutting down most of the MT's radio circuitry if there aren't any packets to be transmitted or received.

While shut down, the MT only listens to the downlink channel occasionally and may not even keep in sync with the uplink transmissions. Also, the MT will need to scan the neighboring eNodeBs to detect any signal quality degradation compared to the serving eNodeB. Should the signal quality of the serving eNodeB prove to be inferior compared to a neighboring eNodeB, the MT would have to either momentarily exit the DRX mode to perform a handover into the superior eNodeB, or perform a cell reselection, after which the DRX may recommence. The MT's battery savings depend on the DRX parameter settings. On the other hand, as the energy savings gained from DRX build up, so do the packet delays of the MTs engaging in DRX, which can translate to incompatibilities with some time sensitive applications (Bontu and Illidge, 2009).

In the article (Cui, Luo, and Huang, 2011), the authors brought up a joint power allocation scheme and proposed an algorithm called Joint Minimization Power Consumption Algorithm (JMPC-PA). In JMPC-PA multiple transmitters are collaboratively able to select the optimal transmission power with which data can be transmitted over to the users using multiple orthogonal sub-channels. Their optimal power allocation -scheme takes advantage of the good channel conditions in such a way that, upon good channel conditions, more power with a higher data rate is sent over the channel. Should the channel deteriorate again, less power could be sent over the channel.

The basic idea of such cooperative communications is that the nodes in wireless networks can help each other to coordinately transmit the signals, so as to be able to jointly achieve better quality links, or even higher data rates. One typical such technology is called Coordinated Multi-Point (CoMP) transmission, which has been considered as an effective tool to improve the coverage of high data rates and the cell-edge throughput of LTE-Advanced (3GPP 2013a) and (Cui *et al.*, 2011). Essentially two coordinated transmission points jointly transmit using their constrained power to the users over multiple orthogonal sub-channels by exchanging the channel state information (Luo *et al*., 2010). CoMP is considered for LTE-Advanced as a way to enhance the coverage area of high data rate communications, the cell-edge throughput for the MTs, and as a way to increase the system throughput in varying load conditions. CoMP is used to coordinate the transmissions with several cells and to reduce the interference from neighboring cells and thus reducing the power required to hold a certain QoS.

In the article (Cao *et al*., 2010), the authors analyzed the energy saving performance by turning off certain BSs with average outage constraint in three typical cooperation schemes:

single BS transmission, BS cooperation and wireless relaying. They also investigated the effect of the system parameters (traffic intensity and network density) on the energy efficiency performance.

In (Ismail and Zhuang, 2011), both network cooperation for large and small-scale traffic fluctuation was modelled and analyzed. For large-scale fluctuation, the networks with overlapped coverage could alternately switch their BSs on or off according to the long-term fluctuations in the traffic load. On a small scale, each active BS can switch its wireless channels on and off according to the short-term traffic load fluctuations. WMNs are also developing rapidly, and they are expected to resolve the limitations of ad-hoc networks, WLANs, WPANs and WMANs, as well as to crucially enhance their performance. WMNs are able to deliver a wide variety of wireless applications in everyday life in public and in private use. Even with all of the recent developments, much work still remains to be done in the various WMN protocol layers. Due to the possibility to deploy WMNs over the existing wireless technologies, some companies have already launched their rather pioneering WMN products for sale.

Practical experience however tells that WMNs can, and ought to be improved in several areas, as researched by the authors of (Akyildiz *et al.*, 2005) and (Benyamina *et al.*, 2012):

- Scalability

The overall network performance indicators (throughput, end-to-end delay and fairness) are not scalable with the number of nodes or the network hops. The issue can be eased somewhat by increasing the capacity in the network nodes, for instance by utilizing multiple radios or channels in a cations speeds. These enhancements will not however completely solve the problems the relative performance over the increased network capacity is not affected. New MAC, routing and transmission protocols however will.

- Self-organisation and self-configuration

These imply that all of the WMN protocols were fully distributive and collaborative –this is not however currently true.

- Security

Current security procedures leave WMNs partially unprotected against security attacks in different protocol layers.

- Network integration

WMNs are currently fairly limited in their capability in integrating heterogeneous wireless networks, due to the problems in incorporating multiple wireless interfaces and their corresponding gateway/bridge functions in the same WMN router. Software radios may be the answer to this issue.

- Performance

WMNs still lag behind wired networks in terms of throughput and delays.

The most apparent reason for low performance in WMNs (e.g. poor throughput, high network latency), is mainly due to the insufficiently planned wireless networks. Some research work has been done in (Qiu *et al.,* 2006) to diagnose the performance bottlenecks and problems in WMNs, such as:

- Multi-path interference
- Link slow down because of congestion or voluntary or involuntary packet dropping
- Large co-channel interference
- External RF noise
- Misconfigurations
- Hardware or software bugs in clients or in the

The article also proposed an efficient troubleshooting system that is able to detect and diagnose faults in a WMN system. In spite of the mentioned shortcomings, WMNs are still a promising emerging technology for the future's wireless networks. Despite needing a cross-layer overhaul, redesign and further research to mend the current bottlenecks, it still has several advantages and applications in several different scenarios.

There have been articles describing the potential of using higher wireless transmission frequencies (e.g. SHF and EHF) to improve the capacity- and energy efficiency of the future wireless systems (most notably in satellite communications so far) (Cianca *et al.,* 2011) and (Schiavone and Hendry, 2011). Frequency multipliers remain the most effective means of generating terahertz radiation, particularly if the operating frequency is greater than 100 GHz (Xiao *et al*., 2007) and (Li *et al*., 2012).

Frequency bands are regulated by channel plan recommendations from international organizations such as CEPT/ECC and ITU-R, and they span a vast range of frequencies

(Hansryd and Edstam, 2011), and hence some next-gen microwave backbone-in-the-air or fiber through-the-air technology communications services have been proposed and researched to reach the next-generation digital communication services, often characterized by high-speed and stringent QoS requirements.

Higher frequencies won't however solve all of the capacity, performance or energy efficiency issues in wireless communications – they can instead introduce whole new kinds of questions, such as how to combat the ever decreasing cell radius, precipitation susceptibility resistance, or the absorption spectra of various elements in the air, which can limit the usable frequency bands (e.g. oxygen, water, or other molecules). Due to this, the higher frequency bands are thus more suitable for short hops up to a few kilometers in range (Hansryd and Edstam, 2011). UWB radio is another candidate technology for future wireless communications. UWB uses very short pulses, so that the spectrum of the emitted signals may spread over several GHz (Elbahhar *et al*., 2005).

Recently work has been done towards a concept, where a picocell head unit contains both the picocell, as well as many of the functions found normally on the BSC and the MSC. This type of a picocell is sometimes referred to as an access point base station (AP-BS), or an enterprise femtocell. An enterprise femtocell unit contains all the complete functionality required to connect directly to the Internet, but without the need for the full BSC/MSC infrastructure. This type of approach can be thus seen as a more cost effective solution.

There are also enterprise femtocell implementations (Ubee-Air Walk, 2013), where the cells have so called self-organizing functionality, so that the cells can work together to form a grid with handover between them (UBIQUISYS, 2013) and (Tecore, 2013).

Having realized that the CRs have the potential to utilize the underused bands without causing too much of an interference, the FCC released a Notice of Proposed Rule Making, essentially allowing the CRs to operate in the unused bands (in the U.S.). There is also an IEEE 802.22 working group formed in November 2004 with the task of defining a CR-based IEEE 802.22 (WRAN) -air-interface for use in spectrum allocated for TV service (Cordeiro *et al*., 2005).

The article assessed the achievements of the work group and predicted that the WRANs might hold good potential for more efficient use of the wireless spectrum sometime in the future, especially in the rural areas.

The community responsible for designing mobile devices is playing a bigger and bigger role in reducing the CO_2 emissions emanating from the manufacturing and operation of mobile equipment. When it comes to energy consumption, the term always connected can also be understood as always drained. As the future handsets become more and more (computationally) powerful, they will also inevitably consume more and more energy. In the future, it can be expected that power increase will doubtlessly continue to walk somewhat hand in hand with the energy efficiency as well, but the advances in those technologies are unfortunately not developing linearly.

The MTs are gradually becoming increasingly constrained to the power outlet to provide them with more energy, and to recharge the battery more often. It can be said that the battery technology used in the MTs is lagging behind the advances in communication technologies.

Unless any new approaches for energy efficiency are developed, the 4G MT users will soon have to be continuously on the lookout for any available power outlets, rather than any available network AP. They are thus becoming once again increasingly bound to a single location– akin to the legacy landline phones. This scenario is known as the 4G energy trap. This dilemma leads one of the leading design challenges with the 4G MTs – how to better manage the energy efficiency whilst maintaining the current data transmission bandwidth (Radwan and Rodriguez, 2012).

In trying to keep up with the increasing energy requirements in the MTs, many different approaches have been developed by the manufacturers. One option is to use a synchronous sleep mode scheduling in the transceivers to time the transmissions happening at certain time slots only to minimize the power wasted while keeping the radios listening for sporadic incoming transmissions.

Another approach in IEEE 802.11 was defined by implementing a Power Save Mode (PSM), which is meant for nodes existing in infrastructure-based WLANs. Quite like in synchronous sleep mode, the idea behind PSM is to synchronize the sleep for all of the radios in the network, such that at all times only one of the radios is active (besides the one in the AP of course), and only utilize the radios at the time the AP notifies them individually (via a beacon message). AP buffers packets for each wireless PSM node, and only sends data to a node when it is scheduled to be active. PSM has its drawbacks mostly in poor QoS sensitivity and is thus poorly suitable for applications like VoIP. Wi-Fi Alliance developed a piece of technology called WMM (Wi-Fi Multimedia) Power Save to address this QoS issue (Alliance, 2005).

For future wireless innovation development, IEEE has also set up a IEEE P802.15 Wireless Next Generation Standing Committee (SCwng) to facilitate and stimulate presentations and discussions on new wireless related technologies within the defined scope, that may be subject for new 802.15 standardization projects.

Some research efforts have been made on investigating the energy savings using short-range (SR) multi-hop communications, instead of long-range (LR) communications. In an article by (Fitzek *et al.*, 2011), the authors ran a comparison between data transfer either in a WLAN in ad-hoc -mode, or communicating using an overlay cellular network, and showed that the energy efficiency can be enhanced by using SR multi-hop communications. The authors also noted that there are some practical limits on the number of relays that can be used to maintain a positive energy- (6 relays), and time- (50 relays) savings compared to the overlay network. Through the knowledge that SR communications typically have a higher bandwidth and smaller energy footprint than LR communications, it can be noted that by combining SR technology with LR technology, positive energy savings can be achieved by relying on cooperative communication. A Persistent Relay Carrier Sensing Multiple Access (PRCSMA) MAC protocol to lessen the need for LR communications in favor of cooperative SR-cluster communications has also been discussed in (Alonso-Zárate *et al.*, 2008).

ODMA (Opportunity Driven Multiple Access) is another wireless technology option fairly similar to using relays. In ODMA, the coverage area of the BS is divided into two regions, the high bit-rate and the low bit-rate regions. In ODMA the path between the BS and the MT who is at the low bit-rate region is broken down into a number of smaller radio-hops by relying on other MTs in the cell to relay the signal. The optimal routing between the nodes is calculated using intelligence in the MTs and in the BS to try and achieve the minimum total path loss for the transmission (Rouse *et al.*, 2001) and (Rouse *et al.*, 2002). The authors of the article (Lin, Lai, and Gan, 2004) evaluated the performance of ODMA and compared it to a non-ODMA network. The authors noted in the article, that ODMA significantly improves the average transmission rates especially in low traffic load conditions.

In an article by (Radwan and Rodriguez, 2012), the authors brought up the concept of selling and buying transmission credits between the network nodes. A MT with a low battery, or a poor connection to a remote LR AP, might opt to use its transmission credits to buy a more energy efficient LR connection link to the LR AP via another SR node's LR link, assuming of course that a seller node within a sufficiently good radio connection to the AP is found (i.e. one that obviously has a higher energy efficiency -link), and it is willing to sacrifice some of its own energy resources for the buyer. Notwithstanding the fact, that the cooperation requires SR communication between the two nodes, as well as LR communication for the other node, and in addition some cooperation overhead between the two nodes, this type of a collaborative network concept still yields higher overall energy efficiency from cooperative SR-cluster communication.

The mentioned overheads could include, inter alia:

- Node discovery
- Context gathering, -maintenance and –distribution
- Cluster formation and maintenance.

The energy consumption savings in SR-LR cooperation depends chiefly on the achieved data link rates on different channels (both in LR and SR), as well as the total power consumption based on the active interfaces. Using the mentioned cooperation, the total transmission time is decreased, and hence the sleep time in the nodes is increased. Keeping the nodes inactive and thus in their sleep mode as frequently as possible, helps reducing the overall energy consumption. This cooperation technique doesn't necessarily produce any network-wide energy efficiency improvements per se, but it's mainly aimed rather for improving the energy efficiency in an individual node only.

The authors of (Radwan and Rodriguez, 2012) also ran some simulations with different combinations of radio technologies, and found that using WiMedia as SR and Wi-Fi as LR yields the best possible energy efficiency in the network. It is also worth mentioning, that the Wi-Fi-technology they used in their experiments was the rather old and comparably slow IEEE 802.11g (54 Mbit/s max. throughput) – more modern and faster Wi-Fi technologies

(IEEE 802.11n or IEEE 802.11ad for instance) might have resulted in different outcome in the simulation.

In future networks, the RF complexity in the devices will grow with the need to support multiple new wireless bands and duplexing methods, carrier aggregation and heterogeneous network operation. Just like some wireless technologies today, future devices will also be able to optimize their performance by using radio sensing to capture and assess the RF environment. RF sensing uses advanced technologies for new and existing radios to sense the wireless environment and provide new applications and services, such as indoor positioning and mobile radar ('10 x 10 x 10 the formula for beyond 4G' 2012).

More advanced beamforming schemes to support SDMA, and to increase the channel capacity, such as closed-loop beamforming (Jiang *et al.*, 2012) and multi-dimensional beamforming (Gheryani,Wu, and Shayan, 2009) have also been proposed to increase the energy efficiency of the future's wireless communication systems. Additionally, location-based beam-forming (e.g. GPS) that the authors of (Maiberger, Ezri, and Erlihson, 2010) discussed can be seen as one candidate for eliminating the need for precoding specific signaling or feedback in many common scenarios.

In an article (Al-Kanj and Dawy, 2012), the authors devised a method for a BS to multicast the content over a cellular network to a selected set of MTs, who in turn multicast the content over to other MTs in their vicinity, which leads to the formation of cooperative groups. The results of the (two) formulated optimization algorithms presented in the paper demonstrate notable energy efficiency improvements in various wireless scenarios. Their formulated problem, its solution, and the simplified multicasting formulation are generic, and can as a consequence of this be applied to a wide range of network scenarios with different geographical topologies, channel models, and wireless technologies.

Recent similar work has also been done by (Chang and Ristaniemi, 2013), where the authors introduced a scheme with which the MTs in a wireless network can form a distributed mobile cloud (DMC). In a DMC the MTs will collaborate using SR links, and the idea is that they share the data gathered from a remote AP with each other to save energy by avoiding the use of *energy-wise* costly LR communication link with the AP. The idea is to exploit the fast and low-energy SR communications link within the cloud instead of only using the relatively slow and potentially high power and lossy LR link. The article also analyzed (amongst other things) the possible energy efficiency gains achieved with this method, and estimated the maximum number of distances between the SR links, and compared the energy efficiency vs. the inter-device distance with a set number of MTs.

CONCLUSION

As the wireless data traffic demand increases, the homogeneous cellular systems are not anymore able to provide uniform throughput throughout the cells without further modernization. HetNets are one part of the cure for the poor performance of the indoor MTs, who typically suffer from penetration losses through walls. HetNets are also looking to be one of the next big technology booms for improving the coverage, energy efficiency and throughput of next-generation broadband wireless communication systems. when the wireless transmission channel conditions are good, more data with a higher data rate can be sent over the channel, and conversely, as the wireless channel quality degrades, data rate over the channel slows down.

The ever-accelerating connection speeds stress the wireless networks and push the network engineers and device manufacturers into developing more and more advanced ways to simultaneously serve the users with more reliable and faster connections, while trying to increase the energy efficiency by saving power and operating costs wheresoever possible.

The accelerating wireless connection speeds with the advances in the mobile applications, and especially in mobile content are the fuel that makes the mobile network advances going. The need for utilizing the often congested and limited RF-bands in the most efficient ways possible while simultaneously trying to save electricity, continuously creates newer and more advanced technologies that will eventually benefit all wireless users.

In the future, the wireless network’s energy efficiency has got to rise drastically yet again from the previous generation. The energy efficiency jump for the same level of coverage was about 60-fold when going from the legacy 2G systems to LTE (Tombaz, Västberg, and Zander, 2011), and nothing less should be anticipated from the upcoming 5G. It can also be expected that the wireless network deployment is going to rise into an even more important role.

REFERENCES

1. Alliance, Wi-Fi. *WMM Power Save for Mobile and Portable Wi-Fi CERTIFIED Devices.* White paper. Wi-Fi Alliance. http://www.wi-fi.org/sites/default/files/downloads registered/wp_12_WMM_Power_Save_White_Paper.pdf, 2005.
2. Akyildiz, Ian F., XudongWang, andWeilinWang. 'Wireless mesh networks: a survey'.*Computer Networks*, 2005; 47(4): 445–487.
3. Alonso-Zárate, Jesus, E. Kartsakli, Ch. Verikoukis, and L. Alonso. 'Persistent RCSMA: A MAC Protocol for a Distributed Cooperative ARQ Scheme in Wireless Networks'. *EURASIP Journal on Advances in Signal Processing*, 2008; 817401: 1–13. doi:10. 1155/2008/817401.
4. Baldemair, Robert, Erik Dahlman, Gabor Fodor, Gunnar Mildh, Stefan Parkvall, Yngve Selén, Hugo Tullberg, and Kumar Balachandran. 'EvolvingWireless Communications: Addressing the Challenges and Expectations of the Future'. *IEEE Vehicular Technology Magazine*, 2013; 8(1): 24–30. oi:10.1109/MVT.2012.2234051.
5. Benyamina, Djohara, Abdelhakim Hafid, and Michel Gendreau. 'Wireless Mesh Networks Design - A Survey'. *IEEE Communications Surveys & Tutorials*, 2012; 14(2): 299–310. doi:10.1109/SURV.2011.042711.00007.
6. Bontu, Chandra S., and Ed Illidge. 'DRX mechanism for power saving in LTE'. *IEEE Communications Magazine*, 2009; 47(6): 48–55. doi:10.1109/MCOM.2009.5116800. Borkar, Shekhar. 'Design Challenges of Technology Scaling'. *IEEE Micro*, 1999; 19(4): 23–29. doi:10.1109/40.782564.
7. Cao, Dongxu, Sheng Zhou, Chao Zhang, and Zhisheng Niu. 'Energy Saving Performance Comparison of Coordinated Multi-Point Transmission and Wireless Relaying'. *IEEE Global Telecommunications Conference*, 2010; 1–5. doi:10.1109/GLOCOM. 2010.5683653.
8. Chandrasekhar, Vikram, and Jeffrey G. Andrews. 'Uplink Capacity and Interference Avoidance for Two-Tier Cellular Networks'. *IEEE Global Telecommunications Conference*, 2007; 3322–3326. doi:10.1109/GLOCOM.2007.630.
9. Chang, Zheng, and Tapani Ristaniemi. 'Energy Efficiency of Collaborative OFDMA Mobile Clusters'. *IEEE Consumer Communications and Networking Conference*, 2013; 74–78. doi:10.1109/CCNC.2013.6488428.
10. Cordeiro, Carlos, Kiran Challapali, Dagnachew Birru, and Sai Shankar. 'IEEE 802.22: The First Worldwide Wireless Standard based on Cognitive Radios'. *First IEEE*

InternationalSymposium on New Frontiers in Dynamic Spectrum Access Networks, 2005; 328–337. doi:10.1109/DYSPAN.2005. 1542649.

11. Cui, Qimei, Bing Luo, and Xueqing Huang. 'Joint Power Allocation Solutions for Power Consumption Minimization in Coordinated Transmission System'. *IEEE GLOBECOM Workshops* (Beijing, China), 2011; 452–457. doi:10.1109/GLOCOMW.2011.6162490.
12. Elbahhar, F., A. Rivenq, M. Heddebaut, and J.M. Rouvaen. 'Using UWB Gaussian pulses for intervehicle communications'. *IEE Proceedings Communications*, 2005; 15(2): 229–234. doi:10.1049/ip-com:20040572.
13. Fitzek, Frank H.P., Janus Heide, Morten V. Pedersen, Gergö Ertli, and Marcos Katz. 'Multi-Hop versus Overlay Networks A Realistic Comparison Based on Energy Requirements and Latency'. *IEEE 73rd Vehicular Technology Conference* (Yokohama, Japan), 2011; 1–5. doi:10.1109/VETECS.2011.5956533.
14. Gesbert, David, Stephen Hanly, Howard Huang, Shlomo Shamai Shitz, Osvaldo Simeone, and Wei Yu. 'Multi-Cell MIMO Cooperative Networks: A New Look at Interference'. *IEEE Journal on Selected Areas in Communications*, 2010; 28(9): 1380–1408. doi:10. 1109/JSAC.2010.101202.
15. Gheryani, Mabruk, Zhiyuan Wu, and Yousef R. Shayan. 'Multi-Dimensional Beamforming for Adaptive MIMO Systems'. *4th International Symposium on Wireless Pervasive Computing*, 2009; 1–2. doi:10.1109/ISWPC.2009.4800596.
16. Gohil, Asvin, Hardik Modi, and Shobhit K Patel. '5G technology of mobile communication: A survey'. *International Conference on Intelligent Systems and Signal Processing*, 2013; 288–292. doi:10.1109/ISSP.2013.6526920.
17. Ismail, Muhammad, and Weihua Zhuang. 'Network Cooperation for Energy Saving in Green Radio Communications'. *IEEE Wireless Communications*, 2011; 18(5): 76–81. doi:10.1109/MWC.2011.6056695.
18. Janevski, Toni. '5G Mobile Phone Concept'. *6th IEEE Consumer Communications and Networking Conference, CCNC, 2009*: 1–2. doi:10.1109/CCNC.2009.4784727.
19. Jiang, Yibo, Jilei Hou, Arjun Bharadwaj, and Sharad Sambhwani. 'Design aspects of closed loop beamforming transmit diversity in HSUPA'. *IEEE International Conference on Communications*, 2012; 6061–6065. doi:10.1109/ICC.2012.6364790.
20. Al-Kanj, Lina, and Zaher Dawy. 'Optimized Energy-Aware Multicasting overWireless Cellular Networks with Multihop Cooperation'. *IEEE International Conference on Communications (ICC)*, 2012; 5243–5248. doi:10.1109/ICC.2012.6363939.

21. Kahn, Joseph M., Roy You, Pouyan Djahani, Amy G. Weisbin, Beh Kian Teik, and Andrew Tang. 'Imaging diversity receivers for high-speed infrared wireless communication'. *IEEE Communications Magazine,* 2002; 36(12): 88–94. doi:10.1109/35.735884.
22. Li, Xichun, Rosli Salleh, Abdulla Aani, and Omar Zakaria. 'Multi-network Data Path for 5G Mobile Multimedia'. *International Conference on Communication Software and Networks,* 2009; 583–587. doi:10.1109/ICCSN.2009.107.
23. Li, Hao, Bo Zhang, and Yong Fan. 'A Terahertz Frequency Tripler with Single Serial Varactor Diode'. *International Workshop on Microwave and Millimeter Wave Circuits and System Technology,* 2012; 1–4. doi:10.1109/MMWCST.2012.6238137.
24. Lin, Phone, Wei-Ru Lai, and Chai-Hien Gan. 'Modeling opportunity driven multiple access in UMTS'. *IEEE Transactions on Wireless Communications,* 2004; 3(5): 1669–1677. doi:10.1109/TWC.2004.833446.
25. Beyond 4G Radio Evolution for the Gigabit Experience'. 2011. Nokia Siemens Networks, 2020.
26. Visited on August 20, 2011. http://nsn.com/sites/default/files/document /nokia_siemens_networks_beyond_4g_white_paper_online_20082011_0.pdf.
27. '10 x 10 x 10 the formula for beyond 4G'. Nokia Solutions and Networks. Visited on September 18, 2012. http://nsn.com/news-events/publications/unitemagazine- issue-10/10-x-10-x-10-the-formula-for-beyond-4g, 2012.
28. Luo, Bing, Qimei Cui, Hui Wang, and Xiaofeng Tao. 'Optimal Joint Water-filling for OFDM Systems with Multiple Cooperative Power Sources'. *IEEE Global Telecommunications Conference* (Beijing, China), 2010; 1–5. doi:10.1109/GLOCOM.2010.5683971.
29. Maiberger, Roy, Doron Ezri, and Michael Erlihson. 'Location based beamforming'. *IEEE 26th Convention of Electrical and Electronics Engineers in Israel,* 2010; 184–187. doi:10. 1109/EEEI.2010.5661954.
30. Qiu, Lili, Paramvir Bahl, Ananth Rao, and Lidong Zhou. 'Troubleshooting Wireless Mesh Networks'. *ACM SIGCOMM Computer Communication Review,* 2006; 36(5): 17–28. doi:10.1145/1163593.1163597.
31. Radwan, Ayman, and Jonathan Rodriguez. 'Energy Saving in Multi-standard Mobile Terminals through Short-range Cooperation'. *EURASIP Journal on Wireless Communications and Networking, 2012.* doi:10.1186/1687-1499-2012-159. http://jwcn. eurasipjournals.com/content/2012/1/159.

32. Rappaport, Theodore S., Shu Sun, Rimma Mayzus, Hang Zhao, Yaniv Azar, Kevin Wang, George N. Wong, Jocelyn K. Schulz, Mathew Samimi, and Felix Gutierrez. 'Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!' *IEEE Access*, 2013; 1: 335– 349. doi:10.1109/ACCESS.2013.2260813.
33. Rouse, T., I. Band, and S. McLaughlin. 'Capacity and power investigation of opportunity driven multiple access (ODMA) networks in TDD-CDMA based systems'. *IEEE International Conference on Communications*, 2002; 5: 3202–3206. doi:10. 1109 / ICC. 2002 .997426.
34. Rouse, T., S. McLaughlin, and H. Haas. 'Coverage capacity analysis of opportunity driven multiple access (ODMA) in UTRA TDD'. *Second International Conference on 3G Mobile Communication Technologies*, 2001; 477: 252–256. doi:10.1049/cp:20010051.
35. Rusek, Fredrik, Daniel Persson, Buon Kiong Lau, Erik G. Larsson, Thomas L. Marzetta, Ove Edfors, and Fredrik Tufvesson. 'Scaling Up MIMO: Opportunities and Challenges with Very Large Arrays'. *IEEE Signal Processing Magazine*, 2013; 30(1): 40–60. doi:10. 1109/MSP.2011.2178495.
36. Schiavone, Leonard, and David Hendry. 'EHF options for contested SATCOM'. *MILITARY COMMUNICATIONS CONFERENCE*, 2011; 2292–2295. doi:10. 1109 / MILCOM .2011.6127663.
37. Tecore. 'Tecore All-In-One 3G-4G'. http: / / tecore. com / solutions / TecoreNetworks-Datasheet-All-In-One3G-4GEnterpriseFemtocellSystem. Pdf, 2013.
38. Tombaz, Sibel, Anders Västberg, and Jens Zander. 'Energy- and Cost-Efficient Ultra-High-Capacity Wireless Access'. *IEEE Wireless Communications*, 2011; 18(5): 18–24. doi:10.1109/MWC.2011.6056688.
39. Ubee-AirWalk. 'Ubee-AirWalk EdgePoint Pro'. http://www.ubeeairwalk. com/products/enterprise-femtocells.html, 2013.
40. UBIQUISYS. 'UBIQUISYS SerComm FC17xU Series'. http://www.ubiquisys. com/small-cells-femtocells-products, 2013.
41. Wang, Rui, and Yinggang Du. 'HetNet Throughput Analysis with Picocell Interference Xiao, Qun, Jeffrey L. Hesler, ThomasW. Crowe, Jr. Bascom S. Deaver, and Robert M.Weikle II. 2007. 'A 270-GHz Tuner-Less Heterostructure Barrier Varactor Frequency Tripler'. *IEEE Microwave and Wireless Components Letters*, 2011; 17(4): 241–243. doi:10.1109/ LMWC.2007.892932.