# Broadband Wireless Access and the 5th Generation of Mobile Communications

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***Abstract*— Despite the fact that 4G deployment is still at its infancy there are already many research initiatives that focus on the next generation of mobile communications. But why there is a need for a new generation to be shaped so closely to the previous one? Is it really a need behind it by the community or the companies are seeking new ways to sustain or enhance their profits. In this paper we highlight the forces that push towards the 5th generation of mobile communications and we discuss the technologies that are envisaged to make it a reality.**

***Keywords*—*Broadband Wireless Access; MU-MIMO; cognitive radio; coordination multi-point transmission; small cells***

## I. INTRODUCTION

In a recent press release the European Commission Vice President Neelie Kroes announced a €50 million grant for research to deliver 5G mobile technology by the year 2020 [1]. The ultimate goal of this initiative as communicated by the officials is to put Europe back in the lead of the global mobile industry. Of course this is good news for researchers and for companies but what about the people? Is there really a need for such an investment? In order to answer these questions let's have a look into where we are right now and what the numbers are telling us.

With the explosion of smartphone usage the biggest percentage of traffic exchanges is data and not voice. Data transfers are served for the moment by 3G networks which however see their capacity to reach its limits. This is why many times voice traffic is being directed and served by the co-existing 2G networks. To get an idea on how the mobile data is going to grow a recent report by CISCO states that a 13-fold increase is expected by the year 2017 corresponding to a 66% compound annual growth rate [2].

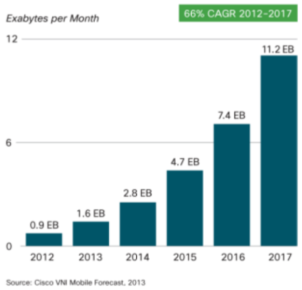


Fig. 1. Predicted annual mobile data growth [2]

This prediction is supported by the fact that the mobile cellular subscriptions are approaching the global population figures [3]. In addition the mobile-cellular penetration stands at 128% in developed countries and 89% in developing ones leading to a mean of 96%. Thus it is obvious that we are approaching a market saturation. However one of the most interesting findings reported is the fact that the mobile broadband subscriptions have grown from 268 million in 2007 to 2.1 billion in 2013.

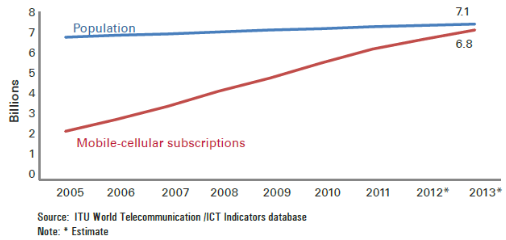


Fig. 2. World population and mobile cellular subscriptions converge [3]

In the path towards 2020 another major mobile data traffic generation source will be machine to machine (M2M) communications or Internet of Things (IoT). M2M will play a crucial role in our future everyday life since they will provide us with the ability to monitor and control numerous parameters and devices at real time. For example a heart rate monitoring sensor will gather vital data from our heart and transfer them periodically for storage in a database which is subsequently accessed by a physician. In addition our refrigerator can inform us after communicating with our smartphone regarding what should be included in our shopping list e.g. when a product is missing or it has reached a threshold of inadequate quantity. All these transactions can take place and most probably will be fulfilled wirelessly.

On the other hand, despite the fact that 4G is just around the corner, it seems that won't be able to support the forecasted growth of mobile data. Some reports state that the nominal rates of 300 Mbps are not possible in real deployments and only 50Mbps rates are achievable at the downlink. It is obvious from the above that there is really a need for technologies that will support the enormous amounts of data that will be transferred wirelessly in the near future.

The most important aspect in this direction is the air interface which is supposed to support up to 10 Gbps peak data rates with 8~10 bps/Hz/cell. Such transfer speeds may appear non pragmatic but they may not. In May 2013 Samsung has announced a successful test where a rate of 1,056 Gbps was achieved via the 28 GHz frequency band, using 64 antenna elements at a distance of 2km [4]. To make it more practical such a perspective means that real-time streaming of ultra-high definition (UHD) movies over wireless will become a commodity in the near future.

The key technologies that have been recognised as those sufficient to enable 5G include the following: Large-Scale Antenna Systems otherwise known as Massive MIMO and mmWave communications, coordination multi-point transmission (COMP) technologies, cognitive and reconfigurable wireless networking for dynamic spectrum allocation, advanced multiple access and modulation schemes, techniques for heterogeneous and cooperative communications, small cell deployments. Furthermore, energy efficiency is considered an equally important aspect that is envisaged to be fully integrated in the $5^{th}$ generation of wireless communication systems for environmental protection reasons.

The rest of this paper is structured as follows. Section II reports on Large-Scale Antenna Systems and mmWave communications. Section III on coordination multi-point transmission technologies. Section IV reviews cognitive and reconfigurable wireless networking. Section V presents the concepts of small cells and heterogeneous wireless networking and we close in section VI with concluding remarks.

## II. LARGE-SCALE ANTENNA SYSTEMS AND MMWAVE COMMUNICATIONS

Multiple Input Multiple Output (MIMO) antenna technology for wireless communications is now commercialized and has been incorporated into the latest broadband wireless standards like IEEE 802.11n and LTE. The increased number of antennas offers increased data rates and link reliability via the exploitation of multiple signal paths among the transmitter and the receiver at the cost of computational power and energy consumption. In Large-Scale Antenna Systems or massive MIMO a large number of low power antennas is being used so that it is possible to focus the radiated power in small areas. Although such deployments have been used only experimentally the number of antenna elements used varies between 32 and 128. For example the ARGOS prototype is using 64 elements while the ARGOSv2 is using 96 [5].

Building a system with such numbers of antennas serving many users in parallel is not an easy task. The most important factor that needs to be taken into account is the fast fading nature of the wireless communications channel. Since we speak about multi user MIMO (MU MIMO) the base station must have accurate channel state information (CSI) for each user in order to be able to calculate the associated precoding vectors [6]. This procedure should be done for all users within the channel's coherence time a task that it is very demanding in terms of speed for the baseband processing subsystem. Massive MIMO is the evolution of MU-MIMO with the employment of much more antennas.

The advantages of MU-MIMO can be summarized in the following: a) *increased data rates*, since more independent data streams can be sent out and more terminals can be served simultaneously. b) *enhanced reliability*, since more different propagation paths are formed by incorporating multiple antennas. c) *improved energy efficiency*, because the base station can focus its energy where the terminals are located; and d) *reduced interference* because the base station can avoid transmitting into directions where it has been identified that the interference temperature will increase. In figure 3 a sample MU-MIMO configuration is presented [7]. This would converse into massive MIMO if the antenna elements are increased. For example 128 in the base station and 16 at the terminal.

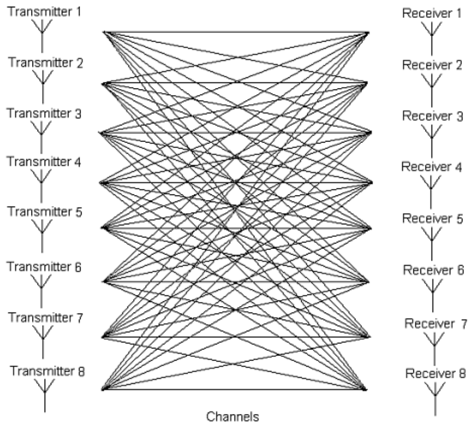


Fig. 3. Sample MU-MIMO configuration with 8 transmitters and 8 receivers [7]

Studies on massive MIMO have been carried out for both isolated and multiple cells [8]. It has been shown that in single cell configurations and under all reasonable propagation conditions, increasing the number of base station antennas permits a reduction in base station power. It is also possible to assign each terminal an orthogonal pilot sequence without the need to overtrain. On the other hand in multiple cell schemes the large number of base station antennas can eventually alleviate all noise, and eliminate both intra-cell and inter-cell interference. However since there aren't enough orthogonal pilot sequences available for every user they should be re-used.

Usage of Millimeter wave (mmWave) communications i.e. going up in the spectrum seems inevitable yet promising for future cellular systems. This is due to the fact that limited spectrum is available for commercial cellular systems. With mmWave cellular systems rates in the order of gigabit per seconf can be achieved. However in these frequencies we have to cope with the specific propagation characteristics and associated channel impairments. One of the main problems as far as propagation is concerned is the fact that free-space path loss is much larger. On the other hand scattering is not so prominent as in the legacy cellular systems leading to reduced diversity. In addition, due to the usage of larger bandwidth channels noise power is larger.

An important aspect in such deployments is to have a uniform signal-to-noise-ratio (SNR) over the complete cell's area. To achieve this outcome mmWave networks can rely on controllable directional antenna arrays with large number of elements. This is not a difficult task since due to the small wavelength employed we can fit many elements with the appropriate distance between each other in relatively small panels and provide enough array gain to overcome path loss and ensure high SNR at the receiver. This finding justifies the fact that massive MIMO and mmWave communications are considered as perfect partners for the provision of very high data rates to mobile users.

## III. Coordination multi-point transmission and reception (CoMP)

As we have seen in the previous section with massive MIMO we can cover a cell's area in a quite detailed fashion by focusing the radiated energy in smaller subareas. However when the terminals are located at the cell's edges they are bound to receive signals from the neighbouring base stations as well while the signals from the host base station will be inevitably attenuated. Thus the quality of communication and the rates achieved at the cell's edges will be lower when compared with those achieved near the base stations.

Coordination multi-point transmission and reception (CoMP) is a technique that aims to alleviate such a problem and allow mobile users to enjoy consistent performance and quality whether they are close to the center or to the edges of the cell. To achieve the required very high data rates, MIMO is of course still used in such a solution but the terminals will be able to receive signals from their neighboring sites as well. This is done under strict co-ordination in order to eliminate interference as much as possible. CoMP can be applied at both uplink and downlink. In the downlink the target maybe either interference avoidance or interference avoidance and scheduling when the same information is transmitted from multiple sites. In the uplink CoMP capitalizes on the fact that the signals of the mobile terminal are received from multiple sites a fact that can increase its performance [9].

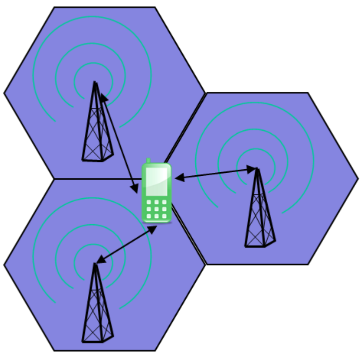

Fig. 4. Coordination multi-point transmission and reception concept

The main problem associated with CoMP is that all the required procedures should be done very quickly since it may lead to significant delays that may finally jeopardize the anticipated performance. Thus special emphasis should be put during the design phase on how the processing and the communication between the involved sites is taking place. Communication among the CoMP modules can occur either intra-site or inter-site. In the intra-site approach the coordination happens within the cell site while in the inter-site one multiple sites are involved in the decision making. In intra-site most of the information exchanges happens within the site and does not load the interconnecting links between different sites. On the opposite the inter-site approach may load the backhaul connections significantly and should be taken into account during planning.

## IV. Cognitive and reconfigurable wireless networking

Cognitive radio networks (CRNs) can enhance spectrum utilization of licensed wireless networks, also known as primary networks (PN), when certain conditions apply [10] [11]. The underutilized or unused spectrum resources can be exploited by the so called cognitive or secondary networks (SNs) as long as their operation is not harmful for the PN. CRNs are categorized either as opportunistic spectrum access (OSA) or as spectrum sharing (SS) ones [12] [13].

OSA CRNs rely on exploiting spectrum bands when they are not being used by the PN and the power level is adequate for transmission. The system model of an OSA CRN is depicted in figure 5. When a secondary user (SU) has data to transmit relies it attempts to exploit spectrum gaps being available in the PN which are recognized by the SN via spectrum sensing of the PUs' (primary users') activity.

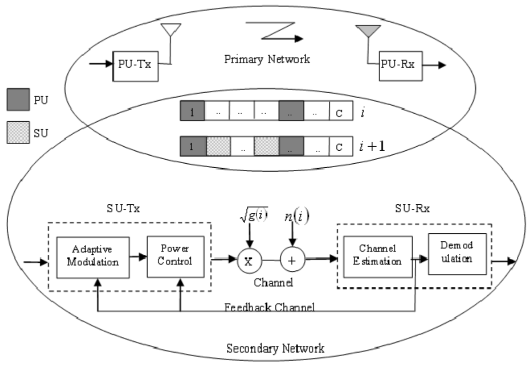


Fig. 5. System model of Opportunistic Spectrum Access CRN

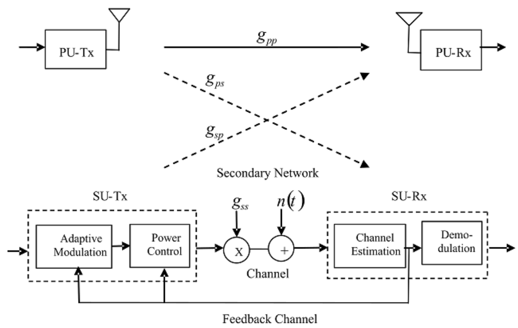


Fig. 6. System model of a Spectrum Sharing CRN

On the other hand SS CRNs rely on the co-ordinated sharing of a spectrum band among the PN and the SN. Furthermore if an SS CRN employs spectrum sensing, then it is called sensing-based spectrum sharing CRN [14]. Such a deployment is shown in figure 6.

It has been shown in various studies that CR technology can substantially improve the capacity of the secondary network and thus the overall system's throughput efficiency. A joint design of adaptive modulation and power control as well as continuous rate and discrete rate adaptive modulation for the particular CRN types is given in [15]. Closed-form expressions for the average spectral efficiency over fading channels and for the corresponding required optimal power allocation that maximizes the average spectral efficiency are derived. Furthermore numerical results highlight the networks' performance and the possible gain of implementing adaptive modulation in CRNs.

Going more practical one important application of CR technology is the exploitation of the so called TV White Space (TVWS). TVWS emerge either from the replacement of analog TV with the digital one or in places where despite the fact that there exists coverage from the TV antenna towers there are no receivers. Several regulating bodies are supporting the usage of TVWS by wireless communication systems for the efficient reuse of the unused TV spectrum, which is based on a non-interfering mode of operation. In the standardization front the IEEE 802.22 Working Group has published the IEEE 802.22-2011 standard for TVWS broadband wireless access to rural, low population density, areas thus allowing for broadband wireless access where the TV spectrum is least used [16]. IEEE 802.22 systems offer increased coverage and can provide a reliable solution for broadband access in rural areas.

In March 2013 the IEEE 802.22™ Working Group announced that it has completed and published the IEEE 802.22.2™-2012 recommended practice for installation and deployment of the IEEE 802.22-2011 standard on Wireless Regional Area Networks (WRANs) and the IEEE 802.22.1™-2010 standard [17]. Thus it is now about time to start seeing installations of this technology in real deployments. Such activities are taking place through the White Space Alliance which aims to promote the development, deployment and use of standards based products and services as a means of providing broadband capabilities via the White Space spectrum [18]

## V. Small cells and heterogeneous wireless networking

Small cells are, as the term suggests, low power base stations that operate in the licenced spectrum and aim in filling the coverage holes existing in urban environments covered only by macro cells. Small cells can be femtocells, picocells, metrocells and microcells. Apart from providing improved cellular coverage, small cells can achieve great capacity enhancements since the networking infrastructure is coming closer to the user thus allowing for improved SNR and lower delays.


Fig. 7. Small cell coverage limits [19]

With small cells we can achieve very good coverage indoors and thus the users can continue to use the cellular network without the need to switch to e.g. Wi-Fi enabled phones. This is very important for the operators since they will continue to serve their clients adequately in buildings as well so that their profits are sustained or even increased. Small cells are considered also one of the core building blocks in heterogeneous wireless networking where different networks need to cooperate. One major requirement that has to be satisfied in heterogeneous wireless networking environments is the support for real time services and applications that are becoming increasingly popular and should be effectively supported end-to-end. Obviously the diverse standards now in operation in the wireless world can be glued together if we rely on small cells.

One critical issue with small cells is the fact that their deployment is much more costly than this of macro cells. Thus there is a need to find ways that will enhance the added value of their usage. One proposal that originates from Intel is to add intelligence at the base stations so that they can run network and application services [20]. For example they can be used to run code that improves the compression and transcoding of a video stream. Trials show that such an approach reduced peak traffic loads. This result significantly improved the subscriber's experience as loading web pages and downloading videos is notably faster and reduced the required data rate of the backhaul connections something very important for service providers that lease them.

## VI. Conclusions

In this paper we reviewed the main architectural aspects and technologies that are supposed to form the 5$^{th}$ generation of mobile communications. In particular we have reported on Large-Scale Antenna Systems and mmWave communications. Then we described the coordination multi-point transmission and reception technologies. A brief outline of the main aspects related to cognitive and reconfigurable wireless networking was given next. Finally we presented the concepts of small cells and heterogeneous wireless networking. Apart from the possible benefits we outlined also the challenges that need to be addressed before making 5G a reality in our everyday activities.

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## REFERENCES

[1] http://europa.eu/rapid/press-release_IP-13-159_en.htm.

[2] http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html.

[3] The World in 2013: ICT Facts and Figures, February 2013, available at http://www.itu.int/ITU-D/ict/facts/index.html.

[4] http://global.samsungtomorrow.com/?p=24093.

[5] http://argos.rice.edu/.

[6] Spencer, Q.H.; Peel, C.B.; Swindlehurst, A.L.; Haardt, M., "An introduction to the multi-user MIMO downlink," *Communications Magazine, IEEE* , vol.42, no.10, pp.60,67, Oct. 2004.

[7] http://www.mttglobalservices.com/document/lte-advanced-45g-technology-description.

[8] T. L. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," IEEE Trans. Wireless Commun., vol. 9, no. 11, pp. 3590–3600, Nov. 2010.

[9] Juho Lee; Younsun Kim; Hyojin Lee; Boon Loong Ng; Mazzarese, D.; Jianghua Liu; Weimin Xiao; Yongxing Zhou, "Coordinated multipoint transmission and reception in LTE-advanced systems," *Communications Magazine, IEEE* , vol.50, no.11, pp.44,50, November 2012

[10] S. Haykin, "Cognitive Radio: Brain-Empowered Wireless Communications," IEEE Journal on Selected Areas in Communications, vol. 23, no. 2., pp. 201-220, February 2005.

[11] L. Khalid, A. Anpalagan, Emerging cognitive radio technology: Principles, challenges and opportunities, Computers and Electrical Engineering, Elsevier Publ., vol. 36, no 2, pp. 358-366, Mar. 2010.

[12] Q. Zhao, B. Sadler, "A survey of dynamic spectrum access," IEEE Signal Processing Magazine, vol. 24, no. 3, pp. 79-89, May 2007.

[13] B. Wang, Liu, K.J.R., "Advances in Cognitive Radio Networks: A Survey," IEEE Journal Selected Topics in Signal Processing, vol. 5, no. 1, pp. 5-23, February 2011.

[14] X. Kang, Y.-C. Liang, H. K. Garg, L. Zhang, "Sensing-based spectrum sharing in cognitive radio networks," IEEE Transaction on Vehicular Technology, vol. 58, no 8, October 2009.

[15] Foukalas, F., Karetsos, G.T., "On the performance of adaptive modulation in cognitive radio networks", (2013) Computers and Electrical Engineering, 39 (4), pp. 1260-1275.

[16] http://standards.ieee.org/about/get/802/802.22.html.

[17] http://standards.ieee.org/news/2013/802.22.2.html.

[18] http://www.whitespacealliance.org/index.html.

[19] http://www.smallcellforum.org.

[20] http://www.mobileeurope.co.uk/media/whitepapers/Intel_SmallCell_WhitePaper_327610-001.pdf.