Arguments of Innovative Antenna Design and Centralized Macro Sites for 5G

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Abstract— The Evolution of mobile networks has been extremely fast during the last decade. However, the advancements in the technological ways of improving the system capacity are not enough for the data revolution we have witnessed in the last couple of years, and for the data traffic forecast made by the professionals for the next decade. Several recent technological enhancements may double the network capacity, or may even increase the system capacity 5-10 times, but still it is far away from the expected "need for a thousandfold more capacity". The fifth Generation (5G) of mobile networks with a slogan of thousandfold more capacity has compelled the research community to think in an "Innovative Way" and to think "Outside the box". The aim of this article is first to show the limitations of recent technology solutions for the future demands, and thus to highlight the need for more innovative breakthrough solutions. The excellence of centralized macro sites is argued as a principal capacity layer instead of micro cells, small cells, or femto cells. Moreover, it is also argued that an ultimate need for innovative antenna solutions for macro sites is required instead of traditional antenna array technologies.

1 RECENT TECHNOLOGY UPDATE

A tsunami of data traffic is expected to grow rapidly in the coming years. Mobile data traffic is expected to increase a thirteen fold between 2012 and 2017 [1]. In the coming years, the number of mobile devices connected to communications networks will surpass the number of people on the planet Earth, and by the year 2017 there will be nearly 1.4 mobile devices per person [1]. New smart phones are capable of handling advanced applications with different Quality of Services (QoSs). High penetration of mobile devices and other technology gadgets with “Killer Applications” will demand a high capacity from cellular networks. Smart phones and mini tablets with a user friendly interface, high resolution camera, and high definition screens will make the “Capacity Crunch” even more severe. It is clearly evident that a traditional macro cellular network is no way near to meet the capacity requirement. Possible ways of increasing the capacity of the system are highlighted in Fig.1. Peak capacity of a traditional macro cellular network can be increased by adding more carriers (Frequency), or by network densification [2–4]. To improve the capacity, spectral efficiency and Signal-to-Interference plus Noise Ratio (SINR), an advanced antenna solutions can be employed such as spatial multiplexing through conventional Multiple Input Multiple Output (MIMO) antenna system, distributed antenna system, higher order sectorization, multiple fixed beam antennas, switch beam antennas, smart antennas for beamforming, advanced adaptive antenna [5], and massive MIMO system [6-8]. Moreover, Cooperative Multipoint Transmission (CoMP), and relay nodes are also beneficial in case of improving SINR [8-10].

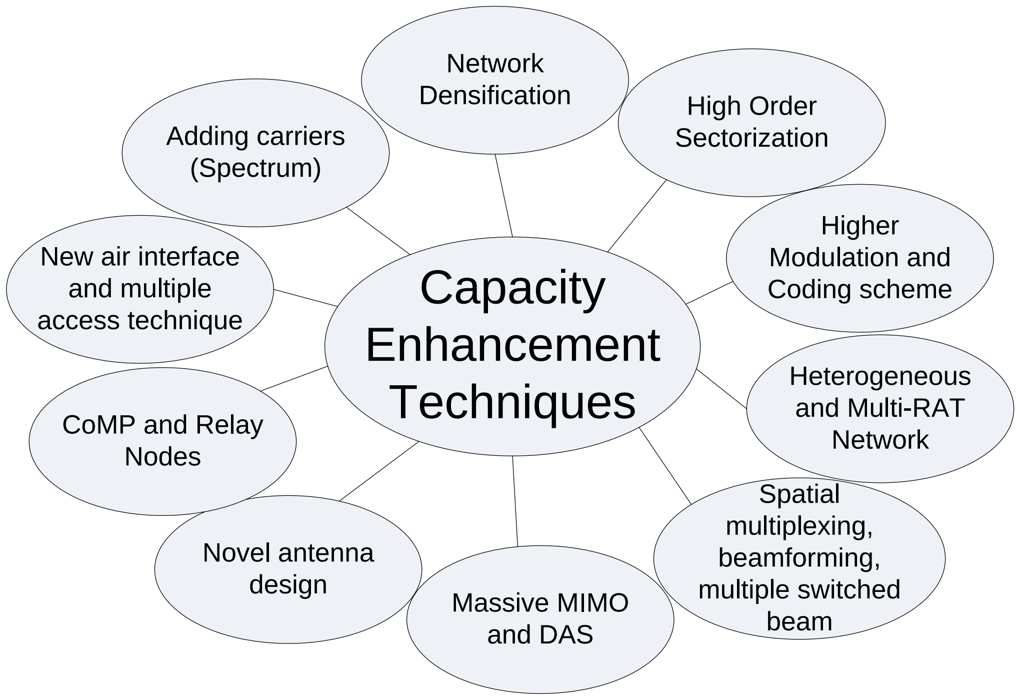

Fig.1. Overview of capacity enhancement techniques.

Frequency (Spectrum) is a scarce resource, and mobile operators have limited frequency band. Therefore, adding more carriers is not a viable solution for all of the mobile operators. This is valid for the conventional cellular network frequencies ranging from 800 MHz to 2600 MHz. However, one possibility for new cellular networks could be the utilization of even higher frequencies. Ranging from 30 GHz to 300 GHz, the so called millimetre wave (mm-Wave) communications are now considered to be used in the 5G networks. Research has been made in [11-14] to evaluate the suitability of such frequency bands for cellular network usage. While the current mobile network frequency bands are very limited, there is still a considerable amount of free bandwidth at the millimetre wave spectrum. The main problem, however, is the attenuation for long distances. Thus, even if the millimetre wave communications would be considered for 5G cellular networks, it might not be suitable for macrocellular networks, although it would most likely be suitable for microcellular environments.

Densification of cells gives higher degree of resource reuse, which results in an increased area spectral efficiency. Hence, network densification is a feasible solution for spectrum limited mobile operators. In [2-3], the performance of macrocellular network densification was compared in terms of signal coverage and quality (SINR), for the outdoor as well as for the indoor users. Network densification provides better coverage for the outdoor users at the cell edge, but indoor users at different floors have a marginal improvement. Interestingly, SINR performance degrades abruptly for the indoor users, and the most affected users are from the top floors. However, it was shown in [3] that the overall offered capacity of a cellular system tends to increase with the increase in densification of the network due to addition of new macro sites, but the improvement is not linear. The densification efficiency – also known as the cell spectral efficiency – reduces with the increase in densification of the network; due to increase in inter-cell interference.

Generally, the cellular networks are initially deployed with 3-sector sites. For mobile operators having limited spectrum, higher order sectorization is a practical solution for traffic hot spot areas. High order sectorization is a promising technique for enhancing the system capacity without building additional sites. Six-sector sites and 12-sector sites are the examples of high order sectorization. An increase in system capacity is proportional to the order of sectorization, but in [5], it is shown that by adding more sectors, capacity gain due to sectorization starts to saturate. Maximum gain of around 400% can be achieved by using 12-sector sites. A switched beam antenna is an extension of the traditional cellular sectorization approach. A multiple switched beam antenna employs slightly overlapping multiple narrow beams in fixed and predetermined directions to cover a conventional 120° wide macro sector. A switch with intelligence and processing power selects the most favourable beam to provide service to a user, avoiding interference to the other users in other cells. Thus, it helps in combating the problem of interference. The gain of a switched beam antenna depends on the beamwidth and the number of beams in a sector. The overall capacity gain of a switched beam antenna is expected to be in the range of 100% to 200%, when compared to traditional 65° wide antennas. An adaptive antenna array with a directive narrow beam (beam steering) also reduces the impact of interference, but requires complex computation and high processing power [5].

If preferred, adding new sites or cells should be avoided in order to reduce the fixed costs such as rentals, electricity, transmission etc. Spectral efficiency of a system can be increased by employing spatial multiplexing through multiple antennas i.e. sending different and independent data streams over each antenna. However, the successful reception of multiple data streams requires good and suitable channel conditions. The performance of spatial multiplexing transmission is not homogeneous over the entire cell area in the macrocellular environment, and the gain of spatial multiplexing is also not linear with the increase in the number of antennas. Massive MIMO is an advanced form of MIMO system, and offers big advantages by making use of large antenna arrays i.e. arrays with few hundred antenna elements. Massive MIMO offers all the advantages of traditional MIMO system, but on a large scale. Massive MIMO can be deployed with different configurations of antennas like linear array of antennas, rectangular array of antennas, circular array of antennas and distributed antennas as illustrated in Fig.2. Massive MIMO helps in reducing the interference by engrossing the energy into narrow regions by having narrow beams, which in turn improves the user throughput, enhances the data rates, improves the energy efficiency and enhances the reliability. But, the drawbacks of massive MIMO are the huge physical areas of the antennas, immense computational complexity, high power consumption, and the large number of pilot sequences [6-7].

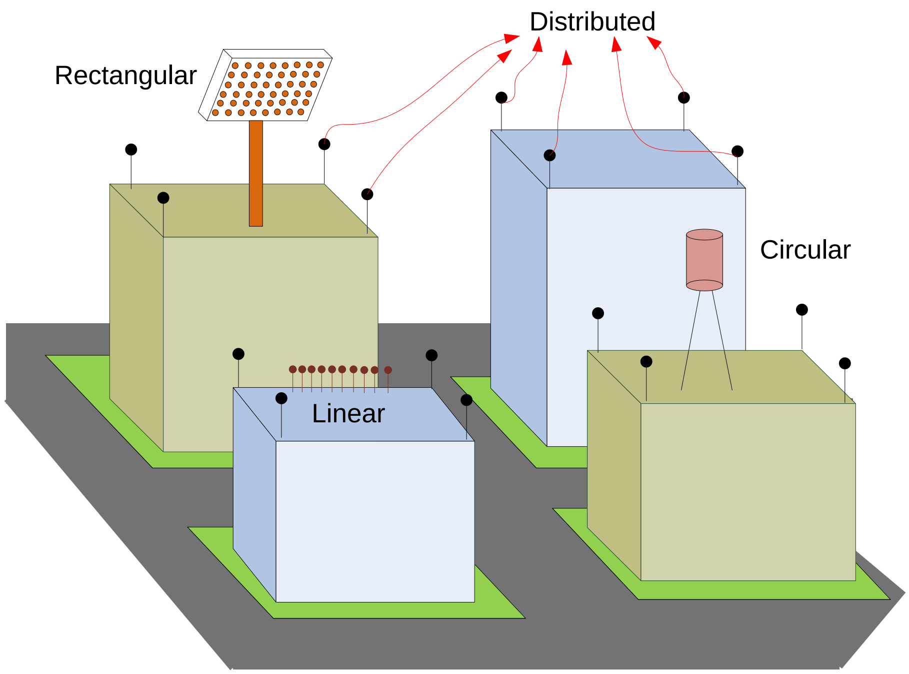

Fig.2. Different antenna configurations for massive MIMO system.

An alternative way to increase the capacity of a cellular system is to deploy a heterogeneous network i.e. introduce low power micro and femto sites along with macro sites [15-18]. These micro and femto sites are deployed in traffic hot spot areas, and generally do not provide continuous coverage. Hence, umbrella coverage is still provided by the macro layer in case of a heterogeneous network deployment.

A heterogeneous network is a blend of overlay macro cells with underlay micro, small or femto cells. Macro cells act as a coverage layer, whereas these low power micro and femto cells act as a capacity layer. Microcells are generally deployed under the rooftop level in the outdoor environment, and femto cells are used as an indoor solution for enterprises and residential areas. The performance of different types of heterogeneous network deployments was compared in [2], and it was shown that specifically the user experience for indoor users in terms of throughput and bit rates can be enhanced by deploying a considerable amount of indoor femto cells or by adding a large number of outdoor micro cells. The advantage of femto base station is that they are owned, installed and maintained by the end users, but its demerit includes the challenge of secure backhaul connection, interference to nearby macro users, and its operation in decentralized manner. Moreover, the required number of femto sites for covering a certain area is significantly high.

Finally, the expected gain from different enabling technologies is shown in Fig.3. The largest gains come from the Massive MIMO, utilizing more spectrum, the mm-Wave communications, the Macro Densification, and the Hyper Dense Heterogeneous Networks.

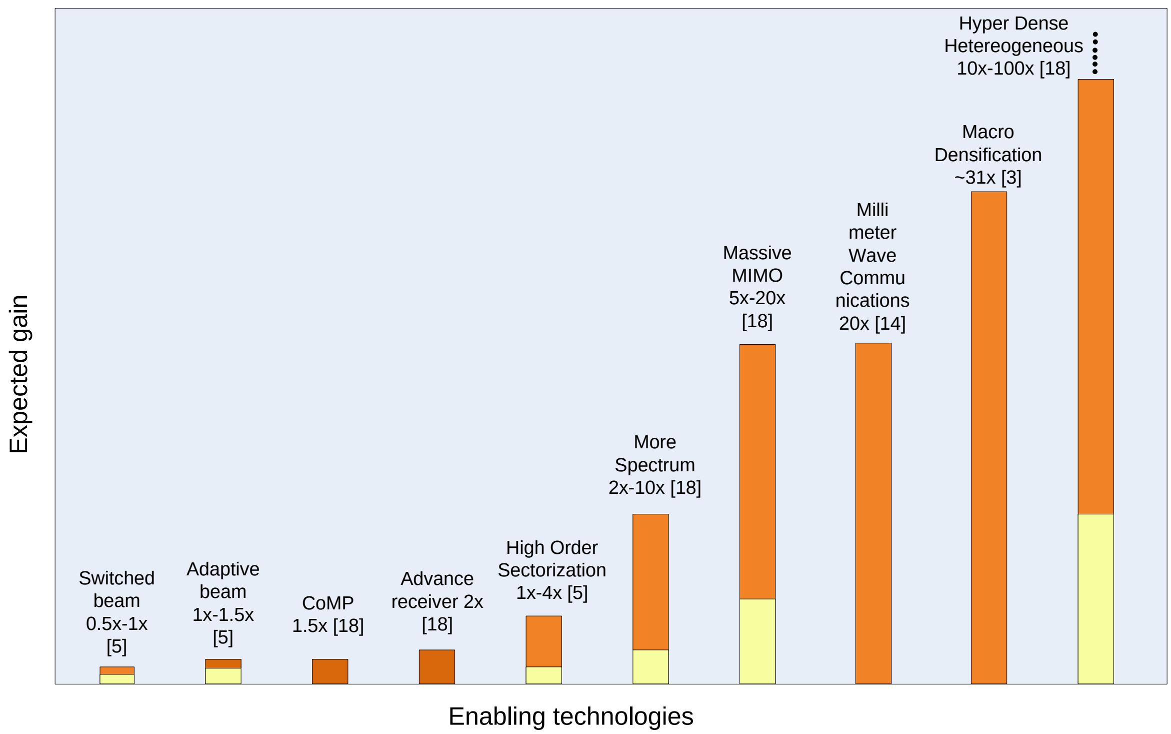

Fig.3. The gains of different enabling technologies.

2 5G EXPECTATION

5G technology is not a standardized technology yet, and currently it is in an early research phase [19-20]. Therefore, the speculation about 5G still continues as “Will 5G be an evolution of Long Term Evolution (LTE) or LTE-Advanced (LTE-A)?”, or “Will there be a giant technology leap in 5G?", which would radically and abruptly change the cellular concept, the architecture of radio access, and principles of radio network planning.

Ultimately, 5G relates to a supreme user experience that a user can even think of. It is about having a high quality of service without any interruption, a unique user experience with uniform connectivity regardless of your location. 5G wireless network is expected to offer thousand times more capacity compared to capacity offered by LTE the fourth generation of wireless network. Couple of Gbps of download speed for individual users with extremely low latency and response time is anticipated in 5G [19-23]. One can potentially expect a "Click and Bang" response from the future generation of wireless network. 5G will extend the possibilities and functionalities of any mobile application, mobile service and current mobile networks. It will offer new, innovative and smart ways for people to connect with each other and experience the prime quality of service. 5G is expected to support a vast range of capabilities from very fast moving devices to ultra-low energy sensors with high energy efficiency [24]. Essentially, 5G will show support for different kinds of network deployments and will be inter-operable with other Radio Access Technologies (RATs). It will also be able to simultaneously use multiple RATs, and will provide seamless connectivity amongst multiple RAT and different devices. 5G is supposed to use the available spectrum efficiently by utilizing the unused spectrum by adopting the cognitive radio concept. One can also expect that 5G will natively support the Device-to-Device (D2D) connectivity and the Machine-to-Machine (M2M) communication [24]. In 5G, network nodes and user devices will jointly optimize the power consumption and energy efficiency for improving their battery life and to be classified as eco-friendly technology.

Interference has always been a major issue in wireless networks. Thus, in 5G networks it is assumed that high level of interference coordination is utilized between the nodes to mitigate the problem of inter-cell interference. As a result, an advanced interference cancelling receiver architecture will be an integral part of 5G. Integration of cloud computing capability will allow a user to have unprecedented computation speed, with easy access to huge data without carrying big data storage devices. Expectations about 5G from the user's point of view are concentrated in Fig.4.

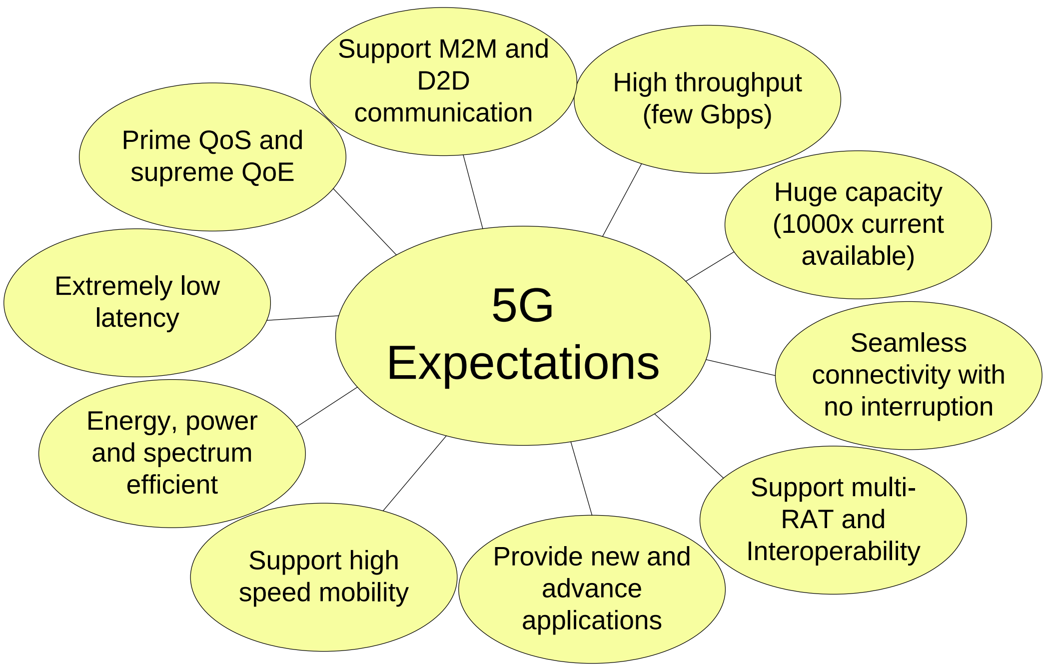

Fig.4. User's expectations about 5G.

Hence, an enormous challenge for the future 5G wireless networks is to offer a huge capacity and massive connectivity for an increasingly diverse set of applications and services with different requirements. The efficient utilization of the available non-contiguous spectrum and the confirmation of the absolute level of security and reliability will be a great challenge for 5G wireless technology. Extremely high data rates, gigantic capacity needs, much lower latency, and simple network architecture required by 5G cannot be achieved only by the evolution of the status quo mobile networks [10]. A breakthrough in wireless network innovation is definitely needed to address the requirements of 5G wireless technology.

3 BATTLE OF MACRO, MICRO AND HETEROGENEOUS NETWORK

Macro base stations have high output power e.g. typically greater than 40dBm, with antennas deployed above rooftops or mounted on cell towers in the outdoor environment. Basically, the macro layer is designed to provide umbrella coverage over a wide area. For a fixed data traffic volume, the densification of the macro layer network will reduce the average cell utilization and will also reduce the propagation path loss between the base station and the mobile user, which will in turn improve the SINR and data throughput. However, by utilizing only the macro layer, it is not possible to provide homogeneous coverage and uniform user experience for indoor users over the whole cell area, especially at the cell edge. Densification of the macro layer clearly provides improvement in the coverage and capacity of the network, but the densification gain is not linear. However, [2-3] have shown that with the densification of the macro layer the user experience for indoor users improved when moving upward in the multi-story building, whereas the outdoor users clearly showed better performance compared to indoor users.

Micro base stations have medium and relatively low base station power compared to macro base stations, with antennas below the rooftop level in the outdoor environment e.g. on building walls or on the street lamps. Usually, the system is capacity limited, not coverage limited, and low power micro sites are deployed in the capacity limited areas to offer additional capacity and to enhance achievable data rates with an improved SINR. Sometimes, it is not viable for the mobile operators to add more macro cells due to non-availability of the proposed site location e.g. a non-cooperative building or a neighbourhood owner. The micro layer generally co-exists with the macro layer. The results presented in [2] shows that the micro layer evidently offers more capacity, and clearly boosts the user throughput for the indoor users and slightly improves the outdoor user data rate at the price of more micro sites. A single micro layer deployment requires approximately 7 times more number of cells to fulfil the coverage requirement compared to the densified macro layer [2].

The world is heading for the direction of green and eco-friendly communications. Power consumption and energy efficiency have become important parameters in rating the application of technology. Energy efficiency can be defined as a power needed to cover a certain area. The components of a base station can be divided into two categories called as 1) the load dependent components e.g. a DSP, a transceiver, or a power amplifier etc., and 2) the load independent components e.g. air conditioning, a microwave link, or a rectifier. Actually, we can say that a typical macro base station and micro base station consists of almost the same load dependent power consuming components. Considering different radio access technologies, it was found that despite of higher power consumption, a macro base station is 4.4 times more energy efficient compared to a micro base station. However, a mix of macro and micro cell will further improve the power efficiency [25-27].

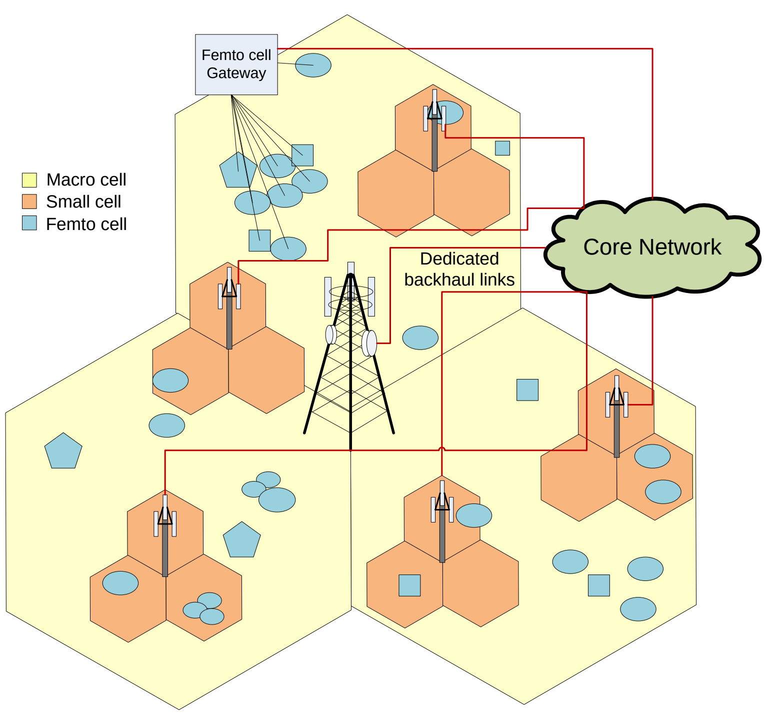

Fig.5. An overview of a heterogeneous network.

A heterogeneous network is a mix of cells with different characteristics like radio access technology, base station power, the size of the cells, the backhaul solution, the height and location of the base station antenna. An illustration of a heterogeneous network, with an overlay macro cell deployment and underlay small/femto cell base stations, is shown in Fig.5. In the current mobile market, smart cellular phones capable of handling multiple-RAT like LTE, UMTS/HSDPA, GSM/EDGE, CDMA and WiFi are already available. In 5G, it is expected that a single mobile phone will be capable of communicating with multiple protocols and RATs simultaneously, depending upon its need and type of service. A heterogeneous network has some advantages over the traditional macro cellular network like in the case of femto base stations; they are easy to deploy with an integrated feature of plug and play, maintained by the owner of the premises it is installed, inexpensive solution for the capacity limited area, and certainly offer enhanced data rates for indoor users [16-18].

However, at the same time there are also demerits of heterogeneous networks. Generally, a macro cellular network follows a network tessellation defined by a “Hexagon”, whereas there is no specific network topology, layout or tessellation for a heterogeneous network, which would define their placement and their associated coverages [16-17]. Handling of moving users is another issue in the case of heterogeneous networks, as handoffs will be more complicated for the network comprising of different tiers of macro, micro and femto layers. Radio network design engineers typically enjoy the assumption of having significant amount of processing power and a wired or wireless high-speed, high-quality backhaul connection at the macro base station. However, it is not valid for pico and femto cells. In the case of small cells, setting up a backhaul connection is a challenge, and the backhaul connection is one of the limiting factors in offering maximum capacity [18]. It is also anticipated that heterogeneous networks are largely fuelled by the unplanned and uncoordinated deployment of small cells. An unplanned deployment without much intelligence of “Self-Organizing” may cause significant problems to macro and other small cell users. In a dense heterogeneous network, mobility management through handovers is another crucial challenge. A user may expect more frequent handovers due to small cell coverage area, compared to a fairly large macro cell area. Handover performance in a heterogeneous network is found inferior to a pure macro network [18]. Also, there are many other challenges in heterogeneous networks including spectrum and interference management, and interference modelling which requires much effort from engineer’s society. Femto cells are mainly owned by the end users, and some users allow access to only a small Closed Subscriber Group (CSG) and restrict other users from accessing the cell. A femto cell with CSG does not allow a macro or micro user to camp on it, thus potentially causing severe interference to the macro and micro cell users, and vice versa. Therefore, when the number of femto cells with CSG is increased in a heterogeneous network, interference around a small cell may also significantly increase [18].

In this section, it was highlighted that the macro cell theory is far more mature, sophisticated and developed. It was also emphasized that a heterogeneous network is a temporary solution for the current capacity needs, but going in the direction of extreme heterogeneity in cellular networks requires elaborated and longstanding models.

4 EXAMPLE OF INNOVATIVE ANTENNA DESIGN FOR NOVEL MULTIPLE ACCESS TECHNIQUE

Currently, for sharing the spectrum among the multiple users, multiple access techniques like Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA), Orthogonal Frequency Division Multiple Access (OFDMA) and Space Division Multiple Access (SDMA) are already available. Considering the information given in the previous sections, the authors believe that a novel concept of Single Path Multiple Access (SPMA) for macro cell environment proposed in [28-29], or something similar can be adapted as a multiple access technique for 5G networks. SPMA is an evolved version of SDMA. Single Path Multiple Access exploits the spatial characteristics of the radio channel. In traditional cellular communications, the received power at any location is the sum of independent multipath components between the Base Station (BS) and Mobile Station (MS). Each multipath component follows a different path and experiences different number of reflections, diffractions, and losses. In case of SPMA, instead of many signal paths, only single independent multipath component is used to establish a link between a BS and MS. In SPMA, users can share the radio resources or can reuse the available spectrum at different geographical locations. In this way, the same radio and frequency resources can be reused after every few meters, which will drastically increase the capacity of the system. This approach would not only radically increase the frequency reuse for centralized macro sites; rather it will also bring a revolutionary change in the traditional/conventional cellular concept thinking.

The essence of the SPMA concept relies on the antenna ability of forming simultaneously many extremely narrow adaptive beams. In order to have narrow radiation pattern in an azimuth and elevation plane, generally, an antenna array is needed. Therefore, in order to have an extremely narrow beam, a very large antenna array is required like massive MIMO, which will make the physical size of the antenna gigantic. In contrast, a key assumption for SPMA concept is based on the expectation that new electrical materials like artificially structured meta-materials, graphene, Carbon Nanotube (CNT), Carbon Nanoribbon (CNR) etc. will be used for antenna manufacturing. Potential antenna and RF applications of graphene at microwave and terahertz frequencies are already proposed in [31], but still much advancement and hard work is required from the research and development sector to make it feasible at the cellular band. Cell area covered by a conventional wide beam antenna and with the new antenna design is shown in Fig.6a and Fig.6b, respectively (geometry is arbitrary).

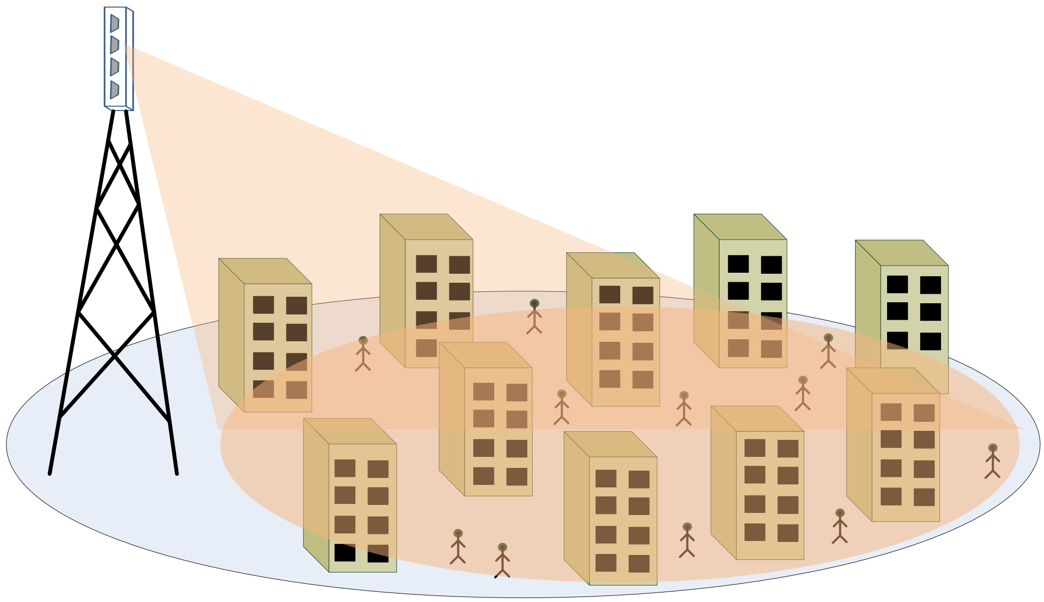

Fig.6a. Coverage of a conventional wide beam antenna.

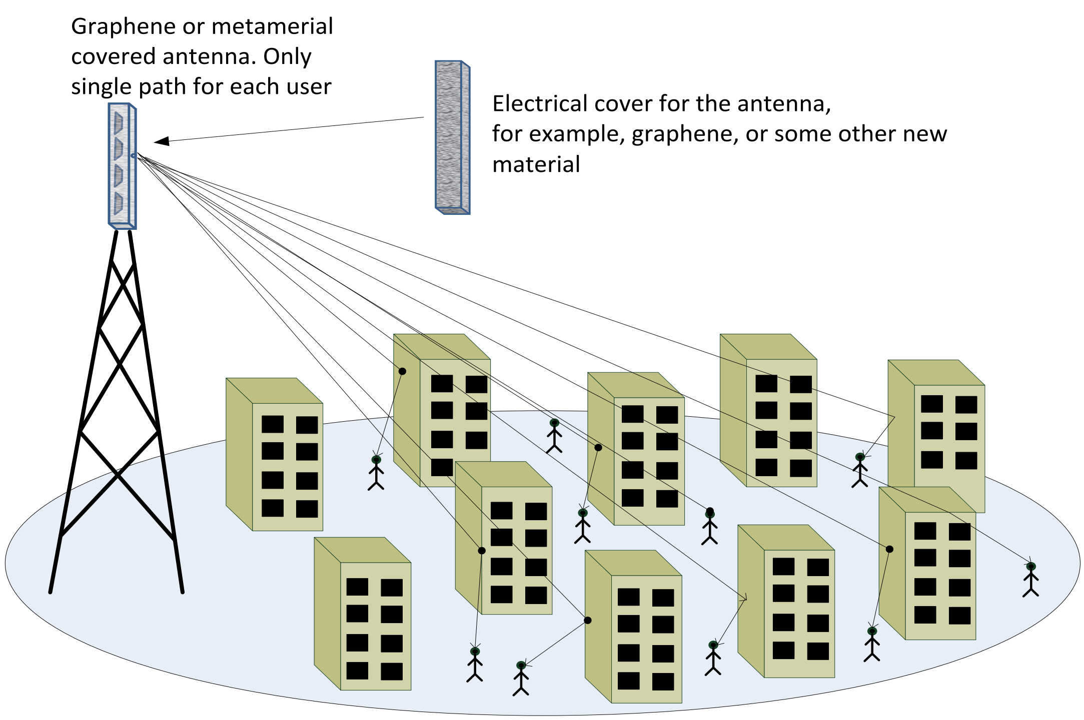

Fig.6b. Coverage of a new antenna based on artificially structured meta-material.

In [28], the antenna design requirements for the users located close to each other using SPMA in a Non-Line of Sight (NLOS) environment are discussed in detail, and the performance evaluation of SPMA in macro cell is presented in [29]. An arrangement assumed for controlling the electromagnetic radiations is similar to the approach adopted in [30], in which the antenna is covered inside a cloak. The cloak is supposed to be constructed by using artificially structured metamaterials. This new electrical material should enable the antenna to radiate in a certain direction of interest, and prevent radiation in other unwanted directions. Such a material would act as a screen for the electromagnetic (EM) radiation, restricting the propagation and creating a highly directive beam. In an ideal case, there would be a single needle beam for each user, and that single needle beam would have a flat response within the beamwidth and a zero response outside the beamwidth. Overlapping of needle beams in the azimuth or elevation plane will cause interference to other users.

This approach of innovative antenna design, based on advanced electrical materials, may lead to new possibilities to have narrow radiation patterns. It will not only reduce the size of an antenna, rather, it will also be able to serve the purpose of the SPMA concept by employing narrow beams like a “needle”.

5 Final Arguments and Recommendations

This article presented an overview of different capacity enhancement techniques available for macro cell and heterogeneous networks. Then, the expectations from the end user’s point of view about 5G were given, and the possible solutions needed for fulfilling the expectations were discussed. A brief comparison of macro, micro, femto and heterogeneous network deployments was also made. A heterogeneous network is one viable way to move forward, but it has other challenges in the coordination, topology, backhaul, mobility, and interference management.

It is emphasized that breakthroughs in the form of new radio access network, better air interface technology, novel antenna design, advanced waveform technology, along with higher modulation and coding scheme, are essential to comprehend the improvement in the spectral efficiency of the system. A giant leap is needed in the baseband and radio architecture to enable computationally intensive and adaptive air interface, and to provide a multifold increase in the capacity of the system.

A comprehensive and integrated "Single Radio" antenna design with a centralized baseband processing is needed with extraordinary computational power, which can adaptively adjust its beam with controlled emission, power, spectrum and capacity with respect to the user demand and the changing environment condition. This antenna with a complex RF processing should be able to flexibly and efficiently use the non-contiguous spectrum. Such an antenna design will not only offer a solution to the challenges faced by the 5G technology, rather, it will also bring down the capital and operational cost of the network. Authors foresee that the new antennas required for the "truly" next generation cellular systems will be complex devices, capable of controlled emission of electromagnetic radiations into many narrow beams, simultaneously. As the concept of innovative antenna design for 5G have been presented in this article, the research community should pursue with a more feasible and modernized study, along with real world verifications.

Acknowledgments

Authors would like to thank European Communications Engineering (ECE) Ltd and European Celtic-Plus project SHARING for supporting this research work.

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