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5th Generation Cellular Communication Systems Enabling Technologies and Challenges

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Abstract:

This work surveys the recent advances and key results and challenges toward the realization of the 5th generation mobile cellular communication systems. The surplus provided by The key enabling technologies for the 5th generation cellular system such as massive MIMO, signal propagations and communications at the millimeter wave band, cellular network densification, network softwarization, and interference mitigation are explicitly highlighted and explained. Furthermore, the main opportunities and the challenges toward the system design and realization are also explained for further research and scientific investigations.

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1. Introduction

Mobile cellular communications systems had seen remarkable development since its first deployment three decades ago. Developing the cellular concept, interference management and enabling handover represent the key driving ideas for the first generation system which used mostly for voice communications [1-3]. The key enabling technologies for the second generation was the making use of digital interface for voice and SMS transmission. Driven by the need for providing data communication barrier with the voice communication making use of wideband transmission and system architecture development were the main enabling technologies for the third system. In the third-generation cellular system, the problem of the wide band frequency selectivity is toggled by making use of Wideband Code Division Multiple Access (WCDMA) [4]. Furthermore, we have seen a remarkable system architecture evolution from second generation to the third generation by including additional barrier for data communication equipped with advanced communication protocols. In the 4th generation system, the problem of frequency selectivity is toggled by making use of Orthogonal Frequency Division Multiple Access (OFDMA) which provide more flexibility in resource assignment and resource scheduling [5-7]. In addition to OFDMA, the 4th generation systems make use of Multiple Input Multiple Output (MIMO) antenna technology which also adds remarkable increase in the overall system capacity [8]. Moreover, the System Architecture Evolution (SAE) developed in the 4th generation cellular systems enables the additional add up features such as reducing transmission latency and providing high data rate with multiple quality of services (QoS).

On the way to the development of the 5th generation cellular system, the main seen as enabling technologies are: Softwarization of the network, utilizing massive MIMO systems, employing and incorporating more intelligent interference reduction, power control and resource allocation algorithms, densification of the system deployment and employing wider bandwidth by making use of the millimeter wave band,. The aim of the work is to review the key enabling technologies and highlight the main challenges toward the realization of the 5th generation cellular system. The rest of the paper is organized as follows: section 2, highlights the opportunities provided by the existing technologies toward the realization of the 5th generation system features. Section 3, summarize the key challenges and research problems. And section 4, conclude the work.

2. Opportunities In the Existing Technologies

2.1. Using Millimeter –wave band

To address the growing needs in the bandwidth to connect the internet of people and the internet of things of the future, making use of the millimeter-wave at the band 30 GHz ~300 GHz is proposed[9-11]. The available spectrum in this band is 200 times greater than the entire current cellular spectrum allocated to the systems of today. This large spectrum clearly contributes to the overall system data rate, which upper bounded by the relation [12]:

$$R \le C = m(\frac{w}{n})\log_2\left(1+\frac{S}{I+N}\right) \tag{1}$$

Where: represents the cellular system upper bounded data rate, represents the system spatial multiplexing gain factor which increased by making use of multiple antennas, is the system load factor which reduced with the increase in the network densification. represents the total bandwidth or the system allocated spectrum and , , represents the desired signal power, noise power and total interference power respectively. The total system interference of the next generation cellular system will be greatly reduced with the making use of the excellent proposed intelligent power control and scheduling strategies.

Signal at the millimeter wave tend to have a reasonably small wave length, which enables deployment of larger numbers of antenna (massive MIMO) in a small area [13-15]. This feature also represents an additional surplus point in the system design according to the relation explained in equation (1). Recently, a number of specialized research groups have been working on channel characterization and developing channel models at the millimeter wave band. These groups include: METIS2020, COST IC1004, ETSI mmWave SIG, 5G mmWave Channel Model Alliance, MiWEBA, mmMagic, and NYU WIRELESS [9, 16-20]. The developed empirical models (based on extensive measurement on the millimeter wave), suggest that perfect channel path loss and shadowing parameter can be perfectly predicted. Thus, these models can be used for system design, prototyping and performance testing at this stage for the next generation system design. Also some promising results in this area shows that deployment of intelligent self-configuration algorithms can compensate the path loss and shadowing effect at high data rate[12]. The reported NYC channel models developed from the measurement data collected from the city center of New York at 28 GHz, 38 GHz, and 73 GHz show comparable pattern and characteristics [9].

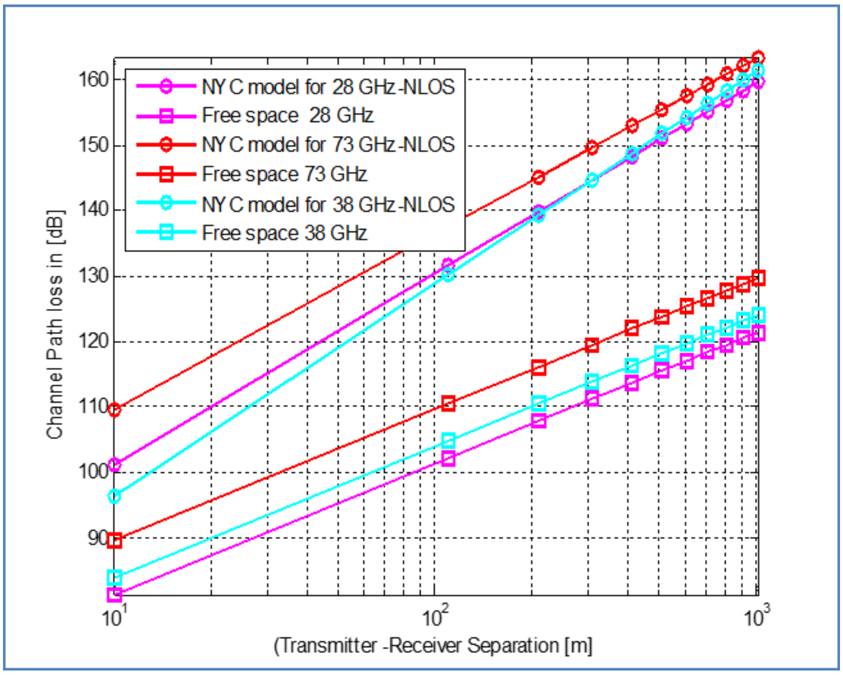

Figure 1: Channel Path loss at 28 GHz, 38 GHz and 73 GHz[21]

As shown in figure 1, the measurements also indicate that the smaller wavelengths introduce an increased sensitivity of the propagation models to the scale of the environment and show some frequency reliance of the path loss as well as increased occurrence of signal blockage. Furthermore, the penetration loss is highly dependent on the material and tends to increase with frequency. The shadowing fading and angular spread parameters are larger and the boundary between LOS transmission and NLOS transmission depends not only on antenna heights but also on the local communication environment (urbanization elements) [21, 22]. The small-scale fading characteristics of the channel such as delay spread and angular spread and the multipath richness is somewhat similar over the frequency range, which is encouraging result for enlarging the available on hand 3GPP models to the wider frequency range at the millimeter wave band[13, 19].

2.2. Making use of Massive MIMO

The primary and pioneering works reported in[23-25] shows that there is a lot of gain that can be extracted from the deployment of multi-element antennas at both communication link ends. This high predicted spectral efficiency can be extracted in terms of diversity/or spatial multiplexing gains, which are both directly related to the overall system spectral efficiency[8, 26]. The predicted additional spectral efficiency gain associated with Multiple Input Multiple Output (MIMO) channel is due to the premise that the rich scattering communication environment affords parallel independent Single Input Single Output (SISO) channel paths from the transmitter to the receiver. As a result, for any simple point-to-point MIMO channel with N_T transmit antennas and M_R receive antennas, the overall rate scales linearly with the increase in the number of antennas at the transmitter and receiver (min(N_T,M_R)) [27]. Unlike the point to point MIMO link, another advanced configuration of multi-element antennas is the multi-user multiple input multiple output (MU-MIMO) arrangement. This configuration is slightly more complex than the simple MIMO channel on the way that the MU-MIMO system makes use of the additional multi-user spatial dimension to further improve the overall system spectral efficiency.

In MU-MIMO channel configuration scenario, the Base station / or Access point is equipped with multiple antennas and concurrently communicates with a group of users. Each individual user is also equipped with multiple antennas. To maximize the MIMO channel gain utilization for single user MIMO and MU-MIMO channels, baseband signal processing techniques known as precoding is applied at the transmitter[28, 29]. With this precoding signal processing at the transmitter, the non-causal known interference is pre-subtracted or reduced, which also come with more spatial efficiency gain. Massive Multiple Input Multiple Output (MIMO)on the other hand is an emerging MIMO technology aims to scale up MIMO deployment by order of magnitude compared to what is used in the 4th generation system[14, 15]. Figure 2, shows the evaluation of channel spectral efficiency in term of (bit//sec/Hertz) vs. the SNR in atypical massive MIMO configurations. It shows clearly that massive MIMO technology will have great contribution on the 5th generation systems.

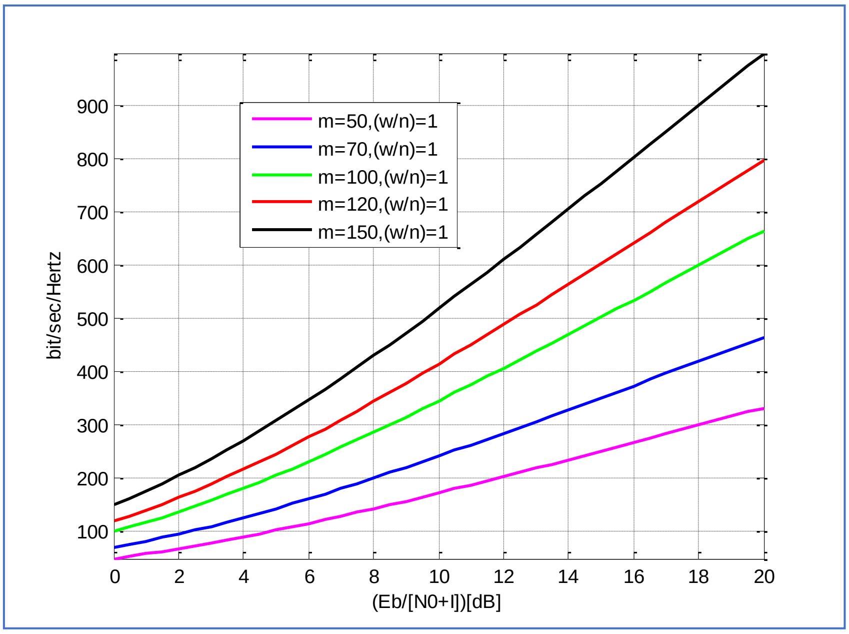

Figure 2: channel capacity increase as the number of antenna increase

2.3. Network Densification

Network densification is an increase in the number of base station/ spectrum deployed in the given geographical area. The network densification gain is an increase of the data rate relative to the increase of network density. As depicted in figure 3, network densification can be practically achieved by two ways: spatial aggregations which explicitly mean using large amount of Electromagnetic spectrum band or spatial densification which requires an increase of the factor (m/n) in equation (1)[12]. This can be achieved by an increase in the number of antennas or reduce the user served by the specific base station. In general, network densification and network throughput are related by the following relation:

$$\begin{aligned} &network\ throughput \\ &= available\ spectrum \times cell\ density \times spectral\ efficiency \end{aligned} \tag{2}$$

Where network throughput is defined in (bit/sec/km2), available spectrum is given in (Hz), cell density is defined in (cell/km2) and the spectral efficiency is given in (bits/sec/Hz/cell).

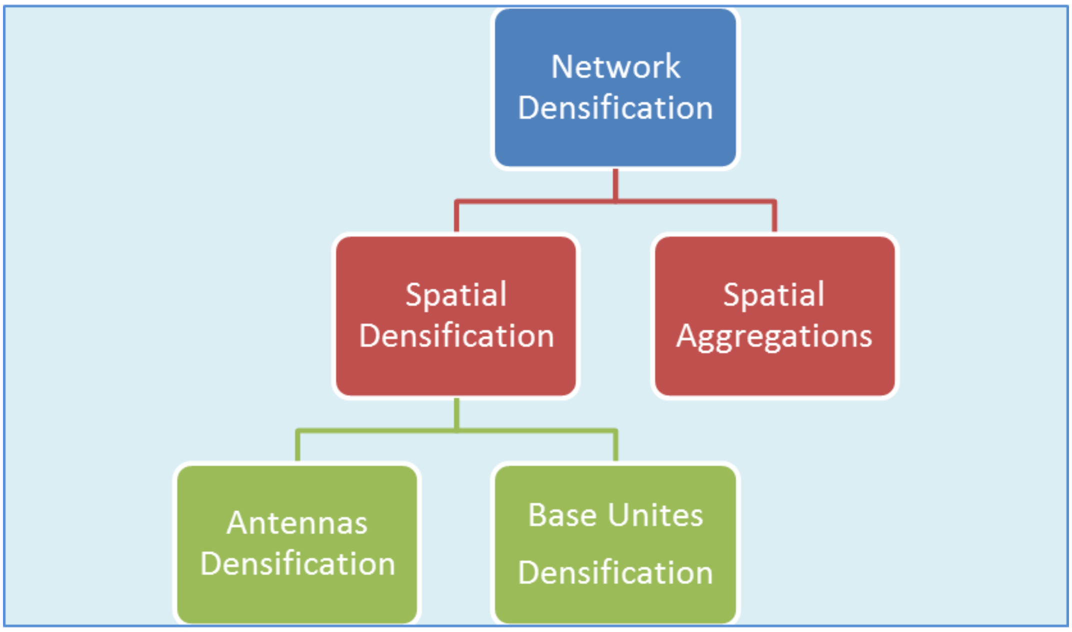

Figure 3: Network Densification Classification

The main challenges toward the realization of network densifications are the extensive need for backhaul densification, tight control of inter-cell interference and the realization of the cloud radio access network with coordinated multi-point CoMP. Given all these challenges, there are also a lot of opportunities.

2.4. Network Softwarization:

Network softwarization is an overall transformation trend of designing, implementing, deploying, managing and maintaining network by implementing of network function in software. The main objectives of network softwarization is to reduce both the capital expenditure (CAPEX) and operation expenditure (OPEX) by speeding up service creation, network deployment, service management and reducing power consumption. These objectives can be realized building following features[30]:

- System Programmability
- Network flexibility which includes reconfigurability, reusability and infrastructure sharing functions.
- Network adaptability which include self configuration, self protection, self healing and self optimization[31].
- Adding various capabilities to the network such as automatic network management and computing power.

Incorporating all these features in the 5 G network requires adding detailed system function to all 5 G network layers (Transport network, Core network, Access Network, and Mobile edge Network) as illustrated in figure 3.

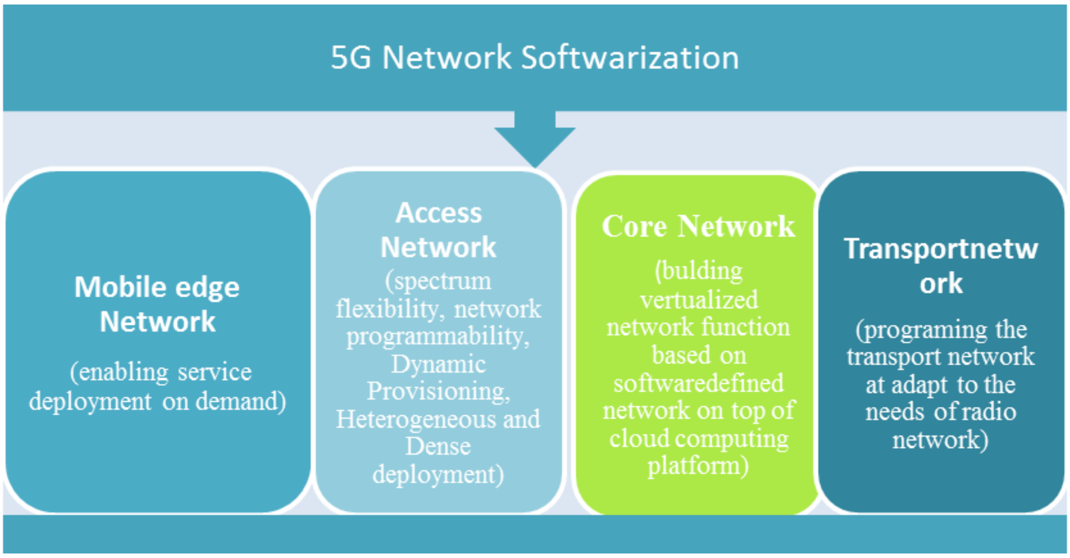

Figure 4: 5G Network Softwarization Functions

2.5. Incorporating Intelligent Interference Reduction, Power Control and Resource Allocation algorithms

Cellular communication system interference includes adjacent channel interference (ACI), coexistence interference (CEI), Co-channel interference (CCI), and Multiple access interference (MAI). ACI refers to the component of interference between links that communicate geographically close to each other using neighboring frequency bands. CEI arise in systems using the same frequency band or between adjacent frequency bands: some examples include interferences between 2nd generation and 3rd generation networks and interferences between different systems operating in the non-licensed bands. CCI is interference between links that reuse the same frequency band (channel), in cellular systems this is also known as inter-cell interference. MAI is the interference among the transmissions from multiple radios utilizing the same frequency resources to a single receiver.

In addition to the classical interference mitigation / management techniques which include various methods based on frequency reuse, there is a lot of opportunities to reduce the level of interference targeting the following objectives:

- Enhancing the cell edge user's throughput
- Enhancing the energy efficiency by switching on/off some of the base units.
- Reducing system overhead by for example clustering small cell.

These features can be brought into practical systems by developing excellent algorithms based on power controls, context awareness and optimum resource allocation. Furthermore, by making use of the self optimized network (SON), we can automate all these functions to be active at the system opera ration time.

3. Opportunities and Challenges

From all above, we can summarize the technological opportunities for the 5th generation systems in the following points

- The availability of spectrum at the conventional cellular systems band and the millimeter wave bands.
- The possibility of making use of massive MIMO technology with millimeter wave band (overcome the restriction of the size of the antenna with a wavelength which means a massive BS antenna array does not have to be physically large).
- Possibility of multi-band operation (deploying the system to operate at the conventional cellular band and millimeter wave band).
- Possibility of building advanced self optimized network software functions to automate system configurations for optimum operating conditions.
- Overall network throughput improvement.

We can summarize the technology challenges for the 5th generation systems in the following points:

- Additional channel measurement and modeling at millimeter wave band.
- Multi-band transceiver design complication issues (Amplification and Signal Processing).
- Design for large path loss range from conventional band to millimeter wave band.
- Deployment of massive MIMO in the millimeter wave band.
- Pilot contamination issue in Massive MIMO system.
- MAC layer design, power control and resource scheduling.
- Cost for network densification.
- Massive backhaul connectivity requirement.
- Signal detection and parameter estimation for massive MIMO.

4. Conclusions

This paper highlights the key benefits provided by the enabling technologies for the 5th generation cellular communications system and summarizes the main challenges and opportunities of the current researched technology. The surplus of massive MIMO systems, the possibility of making use of the millimeter wave band, network densifications, network softwarization and interference mitigation are intuitively explained in the direction to meet the requirement of the next generation cellular systems. Furthermore, the ongoing research problem in these areas was also explained to show out the way for further investigation and new research innovations.

References

[1] Rappaport, Wireless Communications: Principles and Practice: Dorling Kindersley, 2009.

[2] G. L. Stüber, Principles of Mobile Communication, Second ed.: Kluwer Academic Publishers, 2002.

[3] A. Goldsmith, Wireless Communications: Cambarge University Press, 2005.

[4] K. Fazel and S. Kaiser, Multi-Carrier and Spread Spectrum Systems, Second ed.: John Wiley and Sons, Ltd, 2008.

[5] E. Dahlman, S. Parkvall, and J. Sköld, 4G LTE/LTE-Advanced for Mobile Broadband, 1 ed.: Academic Press of Elsevier, 2011.

[6] I. F. Akyildiz, D. M. Gutierrez-Estevez, and E. C. Reyes, "The evolution to 4G cellular systems: LTE-Advanced," Physical Communication, pp. 217-244, 2010.

[7] J. Parikh and A. Basu, "LTE Advanced: The 4G Mobile Broadband Technology," International Journal of Computer Applications, vol. 13, pp. 17-21, January 2011.

[8] E. Saeid, V. Jeoti, and B. B. Samir, "On MU-MIMO Precoding Techniques for WiMAX," in Selected Topics in WiMAX, D. G. Pasolini, Ed., ed: InTech, 2013.

[9] M. R. Akdeniz, Yuanpeng Liu, M. K., Samimi, S. Sun, S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter Wave Channel Modeling and Cellular Capacity Evaluation," IEEE Journal on Selected Areas in Communications, vol. 32, pp. 1164-1179, June 2014.

[10] M. Peter, R. J. Weiler, B. s. Göktepe, W. Keusgen, and K. Sakaguchi, "Channel Measurement and Modeling for 5G Urban Microcellular Scenarios," Sensors, vol. 16, pp. 1-13, June 2016.

[11] Y. L. Yong Niu, D. Jin, L. S. , and A. V. Vasilakos, "A Survey of Millimeter Wave (mmWave) Communications for 5G: Opportunities and Challenges," 2015.

[12] N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damnjanovic, R. Teja, Sukhavasi, C. Patel, and S. Geirhofer. (2014, Feb) Network Densification: The Dominant Theme for Wireless Evolution into 5G. IEEE Communications Magazine. 82-89.

[13] S. Wu, "Massive MIMO Channel Modelling for 5G Wireless Communication Systems," PhD, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, 2015.

[14] H. Q. Ngo, "Massive MIMO: Fundamentals and System Designs," PhD, Department of Electrical Engineering, Linköping University,, Linköping 2015.

[15] E. G. Larsson, ISY, O. Edfors, F. Tufvesson, and T. L. Marzetta. (2014, Feb) Massive MIMO for Next Generation Wireless Systems. IEEE Communications Magazine. 186-196.

[16] M.-I. E. project. (2017, 27 Jan). EU project METIS-II Available: https://metis-ii.5g-ppp.eu/

[17] ETSI. (2017, 27 Jan). Millimetre Wave Transmission. Available: http://www.etsi.org/technologies-clusters/technologies/millimetre-wave-transmission

[18] NIST, "5G Millimeter Wave Channel Model Alliance," N. C. T. Laboratory, Ed., ed. U.S: NIST Wireless Networks Division,, 2015.

[19] EU, "D5.1 channel modeling and charactrization," June 2014.

[20] S. Salous, "COST IC1004 White Paper on Channel Measurements and Modeling for 5G Networks in the Frequency Bands above 6 GHz," C. IC1004, Ed., ed, 2016.

[21] E. Saeid, F. E. Ismael, and M. Ibrahim, "Evaluation of Cell Coverage Percentage of Millimeter Waves Propagation for 5th Generation System," Submitted to the international Journal of Wireless Communivations, 2017.

[22] M. K. Samimi and T. S. Rappaport, "3-D Statistical Channel Model for Millimeter-Wave Outdoor Mobile Broadband Communications," presented at the IEEE International Conference on Communications, 2015.

[23] Telatar, "Capacity of Multi-antenna Gaussian Channel," European Trans. on Telecommunications, vol. 10, pp. 585-595, October 1995.

[24] S. M. Alamouti, "A simple transmit diversity scheme for wireless communications," IEEE Journal on Selected Areas in Communications, vol. 16, pp. 1451-1458, 6 August 1998.

[25] J. Winters, "On the capacity of radio communication systems with diversity in rayleigh fading environment," IEEE Journal on Selected Areas in Communications, vol. 5, pp. 871-878, June 1987.

[26] E. Saeid, V. Jeoti, and B. B. Samir, "Precoding for Multiuser MIMO," in Developments in Wireless Network Prototyping, Design and Deployment: Future Generations", M. A. Matin, Ed., ed USA: IGI Global, 2012.

[27] E. Saeid, "Precoder Design Based On inter-antenna Leakage Minimization for MU-MIMO," PhD, Electrical and Electronic Engineering, Universiti Technology Petronas, Tronoh, Malaysia, 2013.

[28] E. Saeid, V. Jeoti, and B. B. Samir, "Efficient Per-antenna Signal to Leakage Plus noise Ratio Precoding for Multiuser Multiple Input Multiple Output System," Research Journal of Applied Sciences, Engineering and Technology, vol. 4, pp. 2489-2495,, 12 August 2012.

[29] M. Sadek and S. Assia, "Leakage Based Precoding For Multi-user MIMO-OFDM systems," IEEE Trans On wireless Comm., vol. 10, pp. 2428-2433, Aug 2011.

[30] G. P. A. W. Group, "View on 5G Architecture," 2016.

[31] J. Sánche, I. G. B. Yahia, N. Crespi, T. Rasheed, and D. Siracusa, "Softwarized 5G Networks Resiliency with Self-Healing," presented at the 1st CONFERENCE ON 5G FOR UBIQUITOUS CONNECTIVITY.