

5G Mobile Communication Systems: Innovation, Convergence and Ubiquitous Connectivity

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Abstract— Wireless technology is one industry which has seen exponential growth in data and capacity in the past decade and it still continues to grow in demand. One big challenge the mobile phones and wireless networks will face in the future is that of supporting mobile traffic efficiently for different phones requirements from diverse applications. More advanced phones will be manufactured and will be expected to properly function. Already we are seeing 4GLTE implementation and some developments of the 5G network that is presumed to be faster and more efficient than their predecessors, but the process of standard and technology ratification is still in its infancy stage. This survey paper focuses on the requirements of 5G network infrastructure and the user experiences and economic benefits that will come along with this new generation of mobile communication network. The core discussion of this paper will be centered on the main features and technological and economic characteristic of 5G mobile systems.

Keywords— Mobility; Connectivity; Quality; energy efficiency; IoT; small innovations.

I. INTRODUCTION

Just as other global organization, the recent advancement in technology has posed a great advantage and opportunity for the mobile and telecommunication company. One of the greatest revolution and response from the telecommunication industry is the implementation of network sharing strategies that have evolved from the first to the fourth generation. Even though the fourth generation (4G) telecommunication system is undergoing deployment worldwide, individuals are eyeing the development of the 5G telecommunication system, which will lead to greater opportunities from the increased efficiency and effectiveness in network access perspective. From a clear comparison of the changes in evolution between the 1G

technology and the recent 4G technology, it is clear that the changes have highly improved in speed, and reliability. The 1G technology provided access at 100 Kilobytes per second (Kbps), the 2G technology improved the speed to 270 Kbps, and the 3G came into play with an access speed of 389 Kbps, whereas the recently most used 4G network increased access to 250 Mbps [1][2]. With this trend, the 5G network technology is expected to provide a great revolution in the telecommunication network access with an access speed of approximately 10 Gbps (Gigabytes per second). This increased speed is based on the recent advancement in telecommunication technology and the urge for businesses to improve their services through enhances communication and telecommunication services [3].

Explosive growth of technology influences consumer behavior. It is estimated that by 2020, almost 80% of the global population will be utilizing mobile technology and over 60% will be using smartphones or tablets. Predictions are that there will be over 50 billion devices on the global network, out of which, mobile devices being the primarily access point for internet connection. With arrival of new 5G system, internet access will be fast and readily accessible; customers will have connections always available to them. Currently, there are over 2.7 million smart phones on the various networks, and this number will increase greatly by the time 5G will go live [4].

Businesses will have to be able to transition from existing offered products and available distribution models to a better way in order to deliver goods and services that customers want. Simpler products are always preferred – it lets consumers make informed choices. It is vital for businesses to recognize the importance of the customer relations, starting with the initial sale and continuing over the lifetime of the contract. It is vital to get customer insights and tailor the services to the individual customer rather than a group of customers.

Even with the recent efficiency status of the 4G technology, businesses have continued to look for alternatives in regards to reliable and efficient telecommunication networks. Latest developments in technology have increased the amount of consumers that are globally connected with networks; they are acutely aware of latest technological trends and attuned to changes. Brands that will respond best to what these customers require now are most likely to succeed; these demands will have to be met in the real time. When businesses will have an understanding of customer needs and wants, it will help with profit margin growth across the organizations.

If current systems make tracking of individual customers difficult, 5G systems will make it much easier. By creating custom tailored services and products based on the individual customer, it will allow businesses increase customer satisfaction and it will lead to customer loyalty. Businesses will be able to pinpoint their customers uniquely and will reward their loyalty. One of the ways to provide loyal customers with a unique option is a personalized pricing. Offered price and the discount will be based on the past history. By utilizing social media (such as Twitter, Facebook, etc.), businesses will be able to understand what kind of persons their customers are. 5G will be able to analyze customers in real time and businesses will be able to anticipate their customers' future buying plan. Keeping existing customer base is one of the main goals for any service provider; a 2% customer retention increase is equivalent to reducing the cost by 10% [5][6]. By retaining an existing customer instead of acquiring new one businesses can have a larger profit growth – by making an existing customer spend just 10% more on goods and services will produce more profit than to get a 10% growth in new customers. Businesses will be able to deliver solutions that will fulfill the needs of the customer better and offer personalized customer service. Instead of sending bulk/spam messages and emails with general information, more customized messages will be sent to the customers and that will allow better conversion rates and sales increase. Businesses should be able to respond promptly and efficiently to changing market, new customer requests and new regulations.

5G will allow a fully connected network society with unlimited access to information and data sharing anytime to anywhere to anyone. With various environments available, communication will increase exponentially. Businesses should create new services and new experiences based on all the different ways of interaction and connectivity available on the systems. 5G technology will allow brands to hop across customers' different environments using device-to-device discovery. World will become a connected place, the boundaries between developed and developing nations will dissipate.

II. MOTIVATIONS AND KEY DRIVERS OF 5G

The 5G network targets various uses including real time gaming, manufacturing or medicine and even extend to wearable technologies. For instance, in the field of medicine operations could be performed by robots which are monitored from a remote access area by a surgeon that he or she is specialized in carrying out similar type of operations

A. *When will the next higher generation (5G) of wireless network be deployed?*

Considering the statistics presented by the telecommunication network regarding the time period between the deployment of one generation to the other, it is clear that the period presents a sequential matrix whereby a period of five to six years lies between a given network generation deployment and the other. However, the 5G wireless network is expected to break the sequence and take a longer period due to the increased requirements for efficiency. Although the deployment of the 4G network is still on its final stages, operators, leading research teams, and handset developers have launched R&D initiative to develop the 5G network and to ensure that it is fully functional for commercialization by the year 2020.

The ongoing status of the 5G network for the mobile systems are on the very early stages as they underlie the changes and user response in regards to the efficiency and effectiveness of the 4G network. Most of the technological changes to be considered in the formation of the 5G network will be derived from the utilization of the 4G network, which will then be transformed to the 5G network in order to formulate a more concrete system that will be defined by increased efficiency and a positive impact to the operators and mobile industry [8]. The only issue that will lead to delayed deployment is its demanding requirements and intense check over to ensure that it meets all the user demands and transforms the globe to a technological standpoint. With this, the 5G network will not only transform the world by 2020 to a high efficient network connected globe, but also to a community that communicates and shares ideas in an efficient and effective manner.

B. *Proposed solutions to key technologies to be considered*

As indicated earlier, the development of the 5G technology will mainly lie on the changes and alterations considered after the development of the 4G network. Solutions will mainly rely on end user response and their perception of the efficiency and reliability of the 4G network. Additionally, the changes in technological advancement and consumer demands will highly influence the formation of the 5G network. A clear analysis of the recent development statistics produced by the United Nations indicate that the world will have transformed completely to a technological globe by the year 2020 whereby all nations will be united through a suitable

communication network. With this, one of the main proposed solutions would be to enhance reliability and efficiency in order to foster the development of a suitable communication network. Most organization perceives communication as the greatest managerial communication tool towards enhanced performance and productivity. The greatest urge for businesspersons is to have access to a reliable network that fosters appropriate management from appropriate communication.

Additionally, unlike the recent prototype of the 4G network, which does not enhance coverage, increased connectivity, and call frequency thus leading to underperformance, the 5G network will be expected to provide a permanent solution to these problems [9]. The deployment of the 5G network should coincide with the organizational system and become a part of the productivity enhancement strategies for any given organization. With this, the high-speed 5G technology will be expected to present a paradigm movement in the overall design of the mobile industry in order to revolutionize the entire system to encourage enhanced latency, flow, and the scalability requirements, which will be suitable to meet the overarching demands such as the trillion device connection and the augmented reality. With appropriate provision and permanent solution to these problems, the 5G technology will have taken over the business world and transformed it fully to a community defined by enhance performance and productivity.

C. Is 5G wireless mobile network an evolution or a revolution?

Through the considerations put forth as well as the expectation by the year 2020 when the 5G network will be deployed, it is clear that the invention will completely change the world to a single entity characterized by increased efficiency and reliability. With this, the worldwide transformation will define the 5G network as a revolution rather than a mere evolution. The development of the 5G network technology is expected to provide appropriate benefits that will surpass the expectation of the previous generation of network technology. Telecommunication industries are already doing away with the term World Wide Web (WWW) and coining into the term World Wide Wireless Web (WWWW), which will define the increased utilization as well as reliability in the efficiency of the 5G wireless network [1].

From an earlier analysis, it is clear that the 5G wireless network will transform the functioning of the entire globe to include the increased use of wireless network. The 5G network will easily carry over 1000 times of mobile data compared to the recent 4G prototype. This therefore indicates an increased reliance and a massive capability for increased communication, which will cater for all individual's need to access and transfer data in a quasi-instantaneous, and sensationalize in their own choice. Then 5G network will also have a direct impact on security

deployment, formation of electric transportation systems, ambient policing, and worldwide access to information. With this, the 5G network will change the entire world to a community of both similarity and togetherness, which will give the invention a revolutionary status.

D. Business opportunities from the deployment of the 5G network

The deployment of the 5G network will present great business opportunities for both the service providers and the virtual mobile network operators. With the increased agility and reliance on high-speed network, the world will have fully transformed to a technological world with great need for internet connection and network availability. Most organizations will require the installation of network for office use and downloading of business materials. Additionally, online businesses such as transaction and selling of video games and movies will present a great opportunity to the service providers and virtual mobile network operators. Additionally, security systems, tracking devices, ambient policing, internet cars, healthcare monitors, and appliances will need to transform from manual operationalization to a digital platform, which will be highly dependent on high speed network for increased efficiency and accuracy. With this, the service providers will have an increased business opportunity, as they will need to install mobile networks to the respective field. Additionally, most individuals will require high-speed network on their mobile phones in order have access to emails, games, and online transactions. This will provide an opportunity for the virtual mobile network operator to install 5G network to the respective individuals [10]. With the increased access to communication and online interactions, consumers will have a direct access to the service providers and virtual mobile network operators. As communication is a great managerial tool, the consumers will easily voice their concern for further actions, which will increase performance and productivity of the respective network provider. With this, the deployment of the 5G network will pose a great opportunity for increased business functionality and operation efficiency.

The recent technological advancements call for major consideration in the telecommunication industry in order to enhance efficiency and reliability in the general network and communication provision. Deployment of the 5G network will be considered after the complete deployment of the 4G network, as it will be a result of enhancement based on changes required and consumer reaction to the development of the 4G network. From an analysis of the changes that will be presented by the 5G network, it is clear that the invention will be a complete revolution, as it will totally transform the world to a network dependent globe. Additionally, deployment of the 5G network will unionize the world to a single entity defined by similarity and togetherness. With the increased dependence, the 5G network will also present great business opportunities, as it will lead to increased

utilization in major fields such as office management, ambient policing, security, formation of technological transport systems, and healthcare monitoring. With a clear consideration of communication efficiency and reliability, it is clear that the 5G network will provide a great platform for increased performance and productivity for the service providers and the virtual mobile network providers.

III. 5G REQUIREMENTS FRAMEWORK AND RESEARCH DIRECTION

The development of 5G technology will be helpful for executing long projects within no time and it will increase the reliability of the global networks because everyone will be connected with high speed internet. Following are the main key points which can be concluded from the research work:

- 1) It will be helpful in browsing, downloading and uploading data files from any place to anywhere.
- 2) Network energy usage will be reduced which will in turn increase the battery life of the device.
- 3) It will increase the users' density over the unit area many times which will help the users to use high bandwidth for a longer period of time.
- 4) 5G Technology will also be helpful and beneficial for the Internet to things, Machine to Machine Communication and Device to Device Communication. It will increase the object oriented works and data management.
- 5) Through the deployment of 5G technology, the users will develop frameworks to utilize machine-machine system of communication..
- 6) RF-EHN is a promising way for future 5G wireless networks.

In a nutshell, 5G technology should be developed as early as possible because of increasing technological usage of the servers and machines.

A. Vision

Any innovation is a product of a vision. The innovation of the 5G Technology is driven by three different visions [11]:

- High efficiency: The efficiency of the 5G Technology is taken as a main parameter and the innovation and design are taken forward with focus on areas like demand based networks, data rate management, etc.
- High Speed: The innovation with focus on speeds concentrates on areas like coverage, clustering of data cells, wide area mobility, dynamic spectrum, etc.
- Converged networks: The use of a joint wireless and fiber operated networks enables the new 5G Technology to be able to employ millimeter wave bands. This would facilitate the support of very high

bandwidths. This path of vision makes the emerging 5G Technology to be characterized as more of a Wi-Fi service than a mobile service

B. Goals

The main goals of the innovation of 5G technology can be broadly classified in to Flexibility and Reliability[12].

- Flexibility: 5G technology should be employable in diverse applications and services. All the needs and services required should be embedded into a single operation point. 5G service owned by a person should facilitate all the services and needs required. 5G should not be entitled as “Services” but as a “Service” which is an embodiment of all the services in one entity of service.
- Reliability: 5G is, hopefully, going to be providing the most reliable set of services the world has ever seen. Security has been taken as a prominent factor in the design of 5G services. Increase of reliability will eventually be a factor in the increase of efficiency, but an unlikely increase in prices too. The specific goals that are indicated in the deployment of the 5G technology services are:
 - High data rates owing to faster modulation and some new innovation technologies
 - Fast response times by node reduction and more intelligent components
 - Whole new and diverse services using automation, cloud and tactile internet

C. Inference to the customers

With reference to the customers, the meaning of 5G in layman's words can be indicated as the ability to download a full length HD movie to a phone in just a few seconds or the services that facilitate video chats in such a way that it may feel like the person on the other side can be touched. This is not an exaggeration, but the factual vision of the network sector. The simple goals that need to be attained by the 5G technology, according to the customers are [13]:

- Faster speeds for data
- Ultra-low latency which refers to the time it takes to send a packet of data between two devices
- Connected devices (cars, home appliances, accessories, etc.) making everything flexible
- Backward compatibility with the devices that are already owned
- Reasonable costs for the 5G services

D. Services

One of the main aspects that is needed a great deal of look up is the requirements for the 5G network, which can affect many other parameters like cost, compatibility, feasibility, standardization, etc. These requirements are subject to the forecasted services that are expected to be

fulfilled by the 5G network. Some of the services that 5G technology is needed to provide are[11]:

- Pervasive Video and high quality content
- Tactile Internet and Broad cast Services
- E – Health Services and 50 + MBPS data rate everywhere
- Internet of things and Real time data analytics
- Mobile Broad band and Smart Societies
- Smart Grids and Freight tracking
- Public safety

E. Characteristics forecast

The 5G network will be characterized by its increased power, strength, efficient, and speed, which are promising features that will take the mobile industry to the next level. With the presence of the 5G network, the mobile industry will be considered as the main key to the Internet of Things. This name is given to the act whereby every activity will be tied to the internet and mobile network. The mobile industry will lead to development of billions of sensors, door locks, smartwatches, and health monitors. Additionally, the mobile industry will be characterized with an increased scalability, flow, and latency in order to meet all its overarching demands. A consideration of these factors gives a clear look at the opportunity and efficiency that will be presented to the mobile industry by the development of the 5G network in the year 2020 and beyond. From a look at the recent occurrence after the deployment of the 3G and 4G network, It is clear that by the year 2020, the 5G network will present the with new realities, increased speed, gratification, efficiency, and lightning-fast response. The following s is some of the expected characteristics of 5G networks.

- Ultra-high capacity and Massive MIMO
- Multi hop transmission and New spectrum
- Wide area coverage and Full duplex
- Ultra-dense networks and NFV SDN
- Security and New Waveforms
- Energy Efficient
- Real time inter Machine communication
- Application Awareness and Zero Latency
- Strategy based traffic management

The following graphical representations depict the implementation of a single 5G wireless antenna to facilitate diverse applications and services.

F. Need

Demand on 5G is far more complicated and comprehensive than the previous generations of mobile communication. There is a conflict and tension between factors such as high performance requirement and availability, cost, and efficiency when it comes to only one technology for 5g systems deployment. In order to provide services with variety of requirements there need to be more than one technology implementation for 5G to meet user

experiences in terms of availability, speed, reliability and cost. Some of the predominant needs for a new generation technology in spite of already existing 4G and LTE are;

- Growing data demand – It is estimated that the data needs are intended to increase to 12 times per month compared to the data used now.
- Development of Device technologies – The upgrades and developments in technologies of the devices (Android, IOS) lead to an increased need of *coverage, data rates, low latency, etc.*
- Increased use of networks – Unlike the olden days, the use of the network services has been increasing exponentially from more than a decade. This was the main reason that leads to such a heavy innovation in the devices and network industry, which is a main point of motivation for the 5G technology.
- With respect to the 4G technology, the backlogs that provided a motivation for 5G innovation are
 - I. Limited connectivity to specific carriers and geographic regions
 - II. Limited backward compatibility
 - III. Limited network coverage
 - IV. Use of multiple transmitters and antenna leading to poor battery life

G. Technology

The radio access for the 5G Technology will be energized from the already existing technologies like the LTE, HSPA, Wi-Fi and GSM as well as the new radio access technologies which are called as RAT. A successful 5g deployment requires a comprehensive designing, simulating, emulating, calibrating and validating for a new solution.

The employment of millimeter waves (Carrier, BW, MU-MIMO) is going to be the prime supporting aspect for increased speeds, wide area coverage, and reliability. Millimeter waves also support very flexible long distant communication. This will also result in use of very less radio base stations. Millimeter waves are expected to revolutionize the latency times. It is needed that the 5G Technology provide less than 1ms latency from one end to the other. The power requirements, bandwidth standardizations and the commercialization of the millimeter waves are expected to be before the year 2020[14].

Use of bandwidths that are very unlikely to be used by other broadcast technologies (3 MHz – 300 MHz) resulting in higher speeds and capacity

The multiplexing used for the 5G transmission is under speculation. The evaluation of the 5G networks using CDMA, OFDM with respect to data rate and latency is being studied.

OFDM has always been the most preferred modulation technique right from the time of its acceptance in 4G enhanced mobile broadband accesses. In 5G as we know we need low latency, high data rates and wide channel

bandwidth along with low complexity per bit. This modulation technique is very much suitable to these specifications. OFDM has a scalable symbol duration and subcarrier spacing with low complexity receiver for wider bandwidth. This also runs efficiently with special multiplexing and multi user data SDMA. OFDM implementations make way for more number of transmissions and reception filtering based on link and adjacent channel requirements. Also RSMA waveforms have better uplink for short data bursts needed for low power internet of things devices. This supports asynchronous and synchronous contention based access [15].

Advanced technologies that could recognize the surrounding objects and more number of sensors are to be used. Also, real time rendering and hologram technologies that can revive a real image in real time in an all angle (360 degree) view are to be employed. MMT which is an acronym for MPEG Media Transport is a processing technology used to decrease the latency. With the help of MVC which is an acronym for Multi View Video Encoding high efficiency in 3D transmission can be achieved. For agility of network and cost reduction efficient control of the networks based on software and virtualization are done through an orchestration that is integrated. Finally, big data is used for the 5G technologies to compare the required existing data to the whole unstructured data in real time for Traffic analysis to equip the network with intelligence for feedback and decision making. Also, self-organized networks are also the intelligent networks that detect anomalies and take the help of big data to organize a solution.

H. Deployment

It is common expectation that the deployment of the 5G services will be prevalent in 2020. This particular year was foretold taking many surveys into consideration. The factors that led to the forecast of the year 2020 for the deployment of 5G Technology are [16]:

1. Higher number of connected devices:

It is expected that the number of connected devices using the 5G Technology should be 50 to 500 billion and depending on the present surveys it would take at least 4 to 5 years to reach the expected number from the present number (2 billion). The 5G Technology should be deployed into the practical commercial network gradually with respect to the geographical areas and then completely marketed to connect all the 5G enabled devices.

2. Energy efficiency:

The energy drain is likely to be very high with the 5G services with reference to the heavy data rates and connectivity. The use of lithium ion battery devices made a heavy impact on the battery life for the high end devices, but is analyzed to be less efficient in 5G enabled devices. This factor becomes more unsolvable for low power

devices. Hence, the research for new, high battery capacity components is also expected to come to a result by 2020.

The Increase in the use of applications on mobile computing and also user needs like portable cell phones and devices will increase the need for the mobile wireless networks in the upcoming years. Cell Phone users will assume more bandwidth and fewer amounts of delays in the cell phone network. All these expectations and assumptions will increase in the infrastructures of mobile industries which will eventually lead to the discharge or emission of carbon dioxide. We can say that by 2020, 181 Megatons of carbon dioxide are emitted by mobile networks, which is almost equal to triple [17].

High energy performance and minimizing the energy usage is the basic requirement of 5G. It reduces the ownership cost and extends the network connectivity to almost everywhere and also the network access is very bearable and very resource efficient way. The main technology to finish the ultra-lean model and separation of user's data on the radio interference, 5G is very costly when compared to other data plans. Its functioning model is different from 3G and 4G. It really plays an important role in the energy saving while the data is transmitted. The device does not transmit the data unless and until a user data transfer is going on. The main two design principles of this technology are; a) being active only when the transmission is required and b) being active only where the transmission is required.

IV. CONCLUSION

While telecommunication developers have created four generations of mobile technology, a variety of mobile technologies will be included in the 5G technology. Therefore, the 5G will be released in a couple of years, and it will comprise various features such as an increase in efficiency. Establishing the 5G of mobile technology will inevitably provide higher and higher data rate. Even more, it will meet the customers' demands since it is reliable for communication, and the capability of 5G will resist the future challenges in mobile communication.

REFERENCES

- [1] Bhalla, Mudit Ratana, and Anand Vardhan Bhalla. "Generations of mobile wireless technology: A survey." *International Journal of Computer Applications* 5.4 (2010).
- [2] Yarali, A., "The Future Connectivity and Technological Advancement in Higher Generation of Telecommunication Systems", *4G and Beyond: The Convergence of Networks, Devices and Services*, Nova Inc. Publisher, 2015.
- [3] Wang, Li-Chun, and Suresh Rangapillai. "A survey on green 5G cellular networks." *Signal Processing and Communications (SPCOM), 2012 International Conference on*. IEEE, 2012.

- [4] Yarali, A., Barrow, K., "The Road Towards Densified and HetNet Gigabit Wireless Networks", 4G and Beyond: The Convergence of Networks, Devices and Services, Nova Inc. Publisher, 2015.
- [5] <https://5g-ppp.eu/> The 5G Infrastructure Public Private Partnership, 2015
- [6] White paper, Ericsson, "5G Energy Performance", Uen 284 23-3265, April 2015
- [7] Bangerter, B., Talwar, S., Arefi, R., & Stewart, K. (2014). Networks and devices for the 5G era. *Communications Magazine, IEEE*, 52(2), 90-96.
- [8] Sharma, Pankaj. "Evolution of mobile wireless communication networks-1G to 5G as well as future prospective of next generation communication network." *International Journal of Computer Science and Mobile Computing* 2.8 (2013): 47-53.
- [9] Li, Xichun, et al. "The future of mobile wireless communication networks." *Communication Software and Networks, 2009. ICCSN'09. International Conference on*. IEEE, 2009.
- [10] Osseiran, Afif, et al. "Scenarios for 5G mobile and wireless communications: the vision of the METIS project." *Communications Magazine, IEEE* 52.5 (2014): 26-35.
- [11] "What is 5g. 5g visions." *GSM History: History of GSM, Mobile Networks, Vintage Mobiles*. 20 November 2015.
- [12] Toni Janevski (10–13 January 2009). "5G Mobile Phone Concept". Consumer Communications and Networking Conference, 2009 6th IEEE [1-4244-2308-2]. Faculty of Electrical Engineering & Information Technology, University Sv. Kiril i Metodij. Retrieved 20 November 2015.
- [13] Xichun Li; Abudulla Gani; Rosli Salleh; Omar Zakaria (February 2009). "The Future of Mobile Wireless Communication Networks" International Conference on Communication Software and Networks. Retrieved 20 November 2015.
- [14] Hoydis; S. Ten Brink; M. Debbah (February 2013). "Massive MIMO in the UL/DL of Cellular Networks: How Many Antennas Do We Need?" *IEEE Journal on Selected Areas in Communications*. vol. 31, no. 2. Bell Labs, Alcatel-Lucent. pp. 160–171. Retrieved 20 November 2015.
- [15] Akhtar, Shakil (August 2008). Pagani, Margherita, ed. *2G-5G Networks: Evolution of Technologies, Standards, and Deployment* (Second ed.). Hershey, Pennsylvania, United States: IGI Global. pp. 522–532. Retrieved 20 November 2015.
- [16] Zeadally, Sherali, Samee Ullah Khan, and Naveen Chilamkurti. "Energy-efficient Networking: Past, Present, and Future." (n.d.): n. pag. *Sameekhan.org*. Springer Science+Business Media, LLC 2011, 31 May 2011. Web. 20 Nov. 2015. <http://sameekhan.org/pub/Z_K_2011_SUPE.pdf>.
- [17] Moon, Sangwoo, and Yung Yi. "Energy-Efficient User Association in Cellular Networks: A Population Game Approach." *YouTube*. Sogang University, 25 Aug. 2015. Web. 21 Nov. 2015. <<https://www.youtube.com/watch?v=Jc2HXP5qwsY>>.