

Enhancing the IoT Efficiency Using Millimeter Wave in 5G Simulation Environment and its Comparison with Real 3G and 4G Environment

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Abstract— The enhancement of environmental connection of things through the internet is based on the efficiency of the cellular network and how much it can serve massive amount of devices. The roll of previous cellular networks in the Internet of Things (IoT) trend serves a small number of devices with limited data rates, insufficient delay and large percentage of packet loss. In this research the aim is to measure the efficiency of a real test of an IoT environment using 3G and 4G cellular network sequentially, and also testing the same network in a simulative environment and compare the outputs to the real test outputs measuring the accuracy of the simulation, then also to examine a 5G network based on the millimeter wave (mmWave) and directional antennas, from this point we can analyze the efficiency of the 5G network based on the accuracy of the simulation. Bottom line, we have achieved an overall enhancement percentage of the throughput 84% and lessened delay by 80%, but, the number of packets lost was larger due to blockage that faces the mmWave signal.

Keywords—IoT, mmWave, NS3, Wireshark, throughput, packet loss, delay.

I. Introduction

The explosive growth in the data usage rate, Redesigning architectures and protocols to address the challenges including cell design to achieve the “SMART LIVING” goal, the internet of things (IoT), as well as the limited spectrums available in both 3G and 4G that are still shared between users, are not in line with the increase in the user demands which caused a critical lack in bandwidth resulting in higher delay and low convergence speed among end users and base stations (BSs), which conflict with the major requirement of the IoT environment implementation. The promising characteristics of the upcoming generation (5G) by the year 2020 provided so many features beginning with the enhancement of the cellular system rates by addressing the throughput, delay and packet loss (three metrics) along to massive machine-type communications defining the trend IoT. To meet the requirements above an extremely high frequency signals (EHF 30-300 GHz)[1, 2], known as the Millimeter Wave

frequencies (mmWave) is used to offer high spectral efficiency. The ability of the mmWave to increase the efficiency of the IoT environment regarding the three metrics will be discussed in sequenced manner based on real values with certain accuracies.

This paper aims to study the behavior of the IoT environment in basis of 5G cellular network by collecting and processing data to actuate the impact of 3G and 4G in real life in terms of IoT, throughout the calculations of the three metrics. Then to calculate the accuracy of the NS3 simulation environment, and finally to simulate the 5G using mmWave with different antenna approaches and estimate its output metrics based upon the simulation accuracy to observe the impact of 5G in real life.

II. Related Work

A. State of art of using 3G/4G in IoT

Since cellular-based IoT applications are increasing rapidly 4G is now a day is the main driver of IoT cellular systems which has many applications requiring speed and responsiveness, thus, 4G-LTE/LTE-A, the networks are positioned to address the IoT market[3].

B. 5G Enabling technologies

There are many technologies that can be key enablers for the 5G cellular network operating relying on each other. These key enablers are tackled briefly bellow:

1. Operating frequency band (Millimeter Wave (mmWave)):

MmWave is the main key enabler for 5G cellular system establishment, operating in the 10-300GHz band, appear to be a promising candidate for next-generation cellular systems by which multiple gigabit-per-second data rates can be supported. The mmWave suffers larger propagation loss due to its

high carrier frequency band so all factors such as rain attenuation and atmospheric absorption could limit the range of the mmWave, smaller cell is applied to improve the spectral efficiency so rain attenuation and atmospheric absorption wouldn't significantly create additional path loss when using small cell size on the order of 200m[1], the free space propagation loss is proportional the square of the frequency carrier, in addition to that we should put in mind that the non-line-of-sight (NLOS) suffers higher attenuation than the line-of-sight (LOS) system[2]. More likely, directive antenna is used to steer its energy towards a certain direction achieving a high gain in this certain direction (direction of the receiving user) and very low gain in all other directions[4].

2. Antenna Design for 5G frequency Bands Massive Multi-Input Multi-Output

Its acknowledged that phased array antennas will offer advantages of conformal plan and small antenna size contrasted to fixed antenna structures, in[5], an antenna array consisting of 4, 16 and 32 elements with half wave length guard, and size ranging from 10x10mm for a 2x2 array at 30GHz or 5x5mm at 60 GHz through to 10x10mm for a 4x4 16 element array at 60 GHz, will deliver antenna gain varying between 12-14 dBi. As much the applications infrastructure gain increase larger arrays will be required. The massive MIMO will define the best phased array antennas technology. From[6], the potential of the massive MIMO for the cellular systems beyond the 4G can simplify the multiple access layers, increases the robustness against interference and reduces the latency on air interface through the usage of beam-formed antenna consistent of multiple layers at the transmitter and receiver.

3. 5G infrastructure

The wide Bandwidth of the 5G promotes high capacity and coverage as long as it's based on extensive propagation and densely deployed infrastructure. In[7], explained that the appliance of mmWave in order to have feasible and efficient cellular access have been elucidated in 28 GHz and 38 GHz bands in a small cell sizes in order of 200 m known as pico-cells. Plus, having directional antennas with pointing angles will increase the capacity gain 20 times the 4G networks. The cell search technique was tested in a network simulator NS-3 using a set of directional array antennas and compare it to Omni-directional antennas in order to have initial access(IA), it was found that omnidirectional proceeds superior in terms of quality and time. In[8], authors propose directional communication over mmWave frequencies, ending

multiple permeable sequences through narrow beams to have 360 degree area coverage, resulting in a need of large number of antenna elements at transmitter (Tx) and receiver (Rx).

Because of the huge number of users will be served by the 5G networks its proposed to use a cloud based radio access network (C-RAN) in the backhaul network for data management and signaling[2].

C. State of art of using 5G in IoT

The high throughput, low delay and optimized network infrastructure, are well achieved by the 5G networks making it the best arena to install the internet of things (IoT) technology. Totally we will have 10 billion IoT device connected over a 24 billion to 50 billion of connections by the next five years[8].

The IoT requirements to be supported by the forthcoming 5G system are[8]:

- Energy efficiency: energy efficient network is introduced by the fifth generation reducing the transmission power.
- Scalability: avoiding the congestion that will occur from the massive machine type communication which shall be accommodated in the same existing infrastructure, all that with keeping the quality of service.
- Resiliency: is to have continuity of the system also in cruel conditions, because IoT doesn't accept any connection failure, therefore IoT reliable system should have high level network recovery.
- Interoperability: managing the heterogeneity providing efficient solutions for the easy integration between different types of devices, technologies and services.
- Support the multimedia IoT: smart multimedia is required.

As application of an IoT environment using the 5G networks, is the device-to-device communications (D2D), examples for the D2D was confirmed by the mobile and wireless communication leading enablers (just like METIS European project, Network2020 platform and 5G-PPP association) is the vehicle-to-vehicle communication[8]. Third generation partnership project (3GPP) has introduced features for the machine type communication[8]. It will be confirmed that IoT trend will be more efficient supported by the fifth generation capabilities.

III. Scenarios and Results

This section of this paper mainly handles the procedure explored for enhancing the IoT

environment by providing a solid platform using the fifth generation (5G) features in simulation environment and relating it to a real test done using the 3G and 4G cellular networks. Practically the Network Simulator 3 (NS3) will be used to study the impact of the enhancements that took place throughout our subsequent flow of the methodology, the procedure was handled through three main experiments.

- Note:

Numerical calculation used for calculating the throughput, delay and packet loss are declared below in (1), (2) and (3) respectively:

$$\text{Throughput} = \frac{\text{received data} * 8}{\text{Data transmission period}} \quad (1)$$

$$\text{Average delay} = \frac{\text{Total delay}}{\text{Count}} \quad (2)$$

$$\text{Delay} = \text{receiving time}[i] - \text{sending time}[i] \quad (2.1)$$

$$\text{Total delay} = \text{Total delay} + \text{delay}[i] \quad (2.2)$$

$$\text{Packet loss} = \text{Generated Packets} - \text{Received Packets} \quad (3)$$

I. 3G and 4G cellular networks in a smart home environment

A smart home objects were interconnected to examine the efficiency of the 3G and 4G cellular networks in controlling an IoT environment (smart home). The smart home interconnection is shown in fig 2. the testing scenario was made for 5 minutes in the following sequence, the first minute from “00:00 up to 00:59” all devices were set off, 2nd minute from “01:00 up to 01:59” all devices were turned on, 3rd minute from “02:00 up to 02:59” all devices were turned off back again, in the 4th minute from “03:00 up to 03:59” all devices were turned on and the 5th minute from “4:00 up to 4:59” the devices remained on. The control over the smart home environment was made using a smart home through an application named “Home Bound”. The data traffic was captured through the all 5 minutes using *Wireshark* installed in the laptop as “file. Pcap”. This was made for the 3G and 4G separately. The captured files are then processed using SQL software as a front end and C-Sharp language as a backend to address the three metrics.

The three metrics values were calculated using (1), (2) and (3). Regarding the 3G the throughput was 37 Kbps, the average delay was 2.325 s and the packet

loss percentage showed 10.28%, as for the 4G we have obtained 765 Kbps throughput, 21.37 ms delay and 0% packet loss. The two results were compared as shown below in **fig.1**.

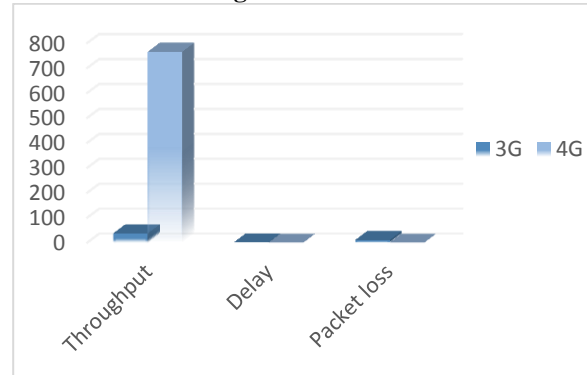


Figure 1. Comparison between the Real 3G and 4G IoT Environments

The experiment was validated using the merge software program to make sure of the two scenarios similarity in respect of running time and same environment exploration.

- Discussion:

The 4G performance as a cellular enabler for an IoT environment was much better than the 3G, but not efficient enough to support an IoT environment where a massive number of devices need to be interacting with high data rates and less delay time.

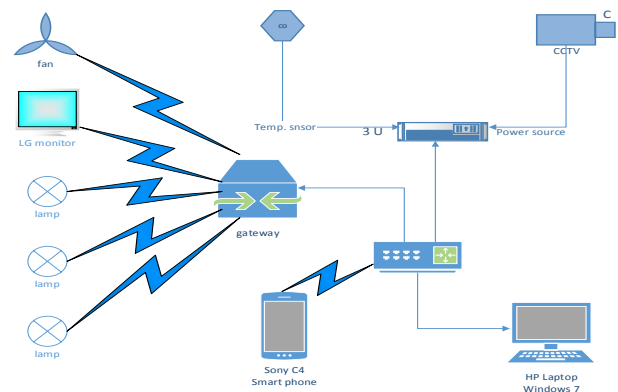


Figure 2. Real Test Environment

II. NS3 accuracy measurement based on 4G network

After the data calculated was verified, the 4G network was simulated similarly to the real 4G environment using LENA open source product-

oriented LTE/EPC that allows LTE (4G) small/macro cell vendors to be simulated.

For data capturing we have used the “lena-simple-epc” code and it was compiled via the command terminal after adding addition code lines to the original code, setting the simulation time to 30 seconds instead of 5 minutes (to avoid processor freezing of the virtual environment/NS3.) and the number of nodes to 6 nodes (same number of user ends in the real 4G test).

Data captured sequence was listed in an output trace file and analyzed using *APP-Tool-master* and *JavaScript analyzer*, 10770 packets were generated with 29.9921 s total delay. But to actuate the accuracy of the simulation with the real environment only 31 packets from 24s simulation duration were taken. calculating the three metrics it results in a throughput of 10.66 Kbps, 0.76s average delay and 0% packet loss.

From the real test made we set a target to our simulation model, by this process it was able to actuate the accuracy of the simulation environment to the real environment after matching the simulated 4G to the real 4G test made table 1. shows the accuracy of the simulation:

TABLE 1. Accuracy Measurements

Three metrics	Real LTE	Simulation LTE	Simulation accuracy
Throughput (Kbps)	7.942	10.66	74%
Average Delay (s)	0.59	0.76	77%
Packet-loss (Packets in %)	0	0	100%

We arrived at the conviction that the simulation environment is accurate enough that we can rely on it in order to simulate the 5G cellular network and enhance it.

III. Modeling the 5G cellular network in NS3

The mmWave patch was uploaded in the NS3 and modifications were carried out in the code "mmWave-epc-amc-test" for the number of nodes, simulation time and the antenna models. The experiment showed two testing scenarios based on the antenna model.

Firstly, testing the application of the mmWave with an Omni directional antenna, secondly testing again the mmWave after the enhancement applied to

the antenna model by replacing the Omni directional antenna with a beam-formed directional antenna. The two antenna models; Omni directional antenna and beam-formed antenna (directional), defined in the “mmWave-epc-amc-test” code for each scenario, were compared to deduce which antenna model serves the IoT environment more efficiently, using (1), (2) and (3) the values of the three metrics were derived respectively as declared in the below table 2, and the decision was made based on the observed enhanced percentage.

Note that the 5G testing environment was also simulated similarly to the 4G network, thus, the simulated 4G was taken as baseline.

Table 2. Comparisons between the 5G Tests before and After the Enhancement

Metrics	Omni directional antenna	Directional antenna
Throughput (Mbps)	261.005	285.392
Delay (s)	0.879534	0.879534
Number of Packet lost	122	20

IV. The expected real 5G based on enhancement of real 4G (final results)

Finally, an estimation of the real behavior of the 5G is calculated by multiplying the 5G outputs by the accuracy.

Real life implementation approach for the 5G can be carried therefore the new three metrics resulted were 211.19Mbps, 0.677s and 100% representing the throughput, delay and packet loss respectively, the final result is demonstrated in the below fig 3.

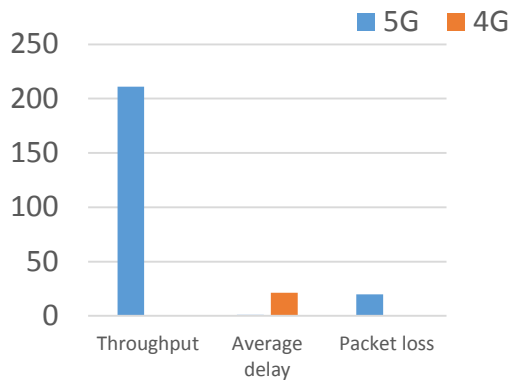


Figure 3. Expected real 5G vs. real 4G

Table 3. Real implementation approach

Metrics	Simulation accuracy	5G Output	Real 5G Output	Real 4G Output
Throughput (Mbps)	74%	285.392	211.19	0.765
Average Delay (s)	77%	0.880	0.677	21.372
Packet-loss (Packet in %)	100%	20	100%	0%

v. Conclusion

5G Simulation Model has been built whose components consist of mmWave using the Omni directional antenna and the mmWave using directional antenna. The information handling from the real environment to the simulation environment had functioned healthy on delivering the packets to

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