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Short Performance Analysis of the LTE and 5G Access Technologies in NS-3

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***Abstract*—Nowadays, the requirements for data transmission and efficiency of IoT networks are increasing. Network efficiency at all levels can be increased by using 5G networks. In this paper, we simulate and analyse the LTE, enhanced Mobile BroadBand, and enhanced Mobile BroadBand with Millimeter-wave services in scenarios with different numbers of IoT nodes and analyze the energy consumption and energy efficiency achieved results. Simulated scenarios and results were obtained using NS-3. Energy and mmWave frameworks were analyzed in this work because they were *the* main part of the research.**

***Index Terms*—Simulation, 5G, LTE, NS-3, eMBB, mmWave.**

I. Introduction

NEXT-GENERATION networks, known as 5G networks, are becoming an increasingly important part of our lives. These networks should bring improvements in various areas of data transmission, such as capacity, end-to-end latency, robustness, scalability, data transfer speed and energy efficiency.

5G enables faster, more stable, and more secure connectivity that's advancing everything from self-driving vehicles, to smart grids for renewable energy, to AI-enabled robots on factory floors. All these static and dynamic sensors acquire a large amount of IoT data, which is used to communicate and improve network efficiency.

One of the essential parameters in 5G networks and IoT (Internet of Things) is the energy efficiency and energy consumption of individual IoT devices. In addition to reducing network operating costs, the main goal of network energy efficiency is to reduce energy consumption and extend battery life in IoT end devices, such as mobile phones, laptops, drones, and the like [1].

Because LTE (Long Term Evolution) is currently the most widespread data transmission service. Therefore, in this article, we focused on comparing the achieved results of energy efficiency and energy consumption of older LTE networks with 5G network technologies in the form of enhanced Mobile BroadBand (eMBB) and millimeter waves (mmWave) [10].

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The article is divided into several parts. In the first part, we describe the implemented mmWave model in NS-3 (Network Simulator 3) used in the simulations. This part also describes the energy model with which we obtained and analyzed the results [2].

The following section describes the simulation scenarios, the used parameters, and the achieved results. The average values of energy efficiency and energy consumption of IoT nodes of LTE service were compared with the results obtained by simulation of 5G networks.

II. NS-3 frameworks

The following section describes the mmWave and energy model for the NS-3 network simulator.

A. mmWave model

The basis of the mmWave module for NS-3 is the LENA model. He is considered the most robust. It was designed to simulate complex mobile networks in the style of 3GPP (3rd Generation Partnership Project) [1]. In addition to LTE / EPC (Evolved Packet Core) protocols, it also implements its own MAC and PHY layers [2][3]. These layers have been described in detail by Rebato and Mezzavilla in their work [4][5].

The basic UML diagram of the mmWave module, which describes the relationships between classes and layers, is shown in Fig. 1. The whole diagram represents the end-to-end structure of the simulator.

The MmWaveEndNetDevice and MmWaveUeNetDevice classes have the function of radio bins for mmWave eNodeB and mmWave UE. In addition, the McUeNetDevice class ensures that a NetDevice device can connect to mmWave and LTE technologies using a dual stack.

The MAC, MmWaveEnbMac and MmWaveUeMac layer classes implement SAP (Service Access Point), user interface and LTE module for cooperation with the LTE RLC layer [6]. MAC, MmWaveMacScheduler, and derived classes implement support for classes from the RLC group, i.e. TM (Transparent Mode), UM (Unacknowledged Mode), SM (Saturation Mode) and AM (Acknowledge Mode). SAP

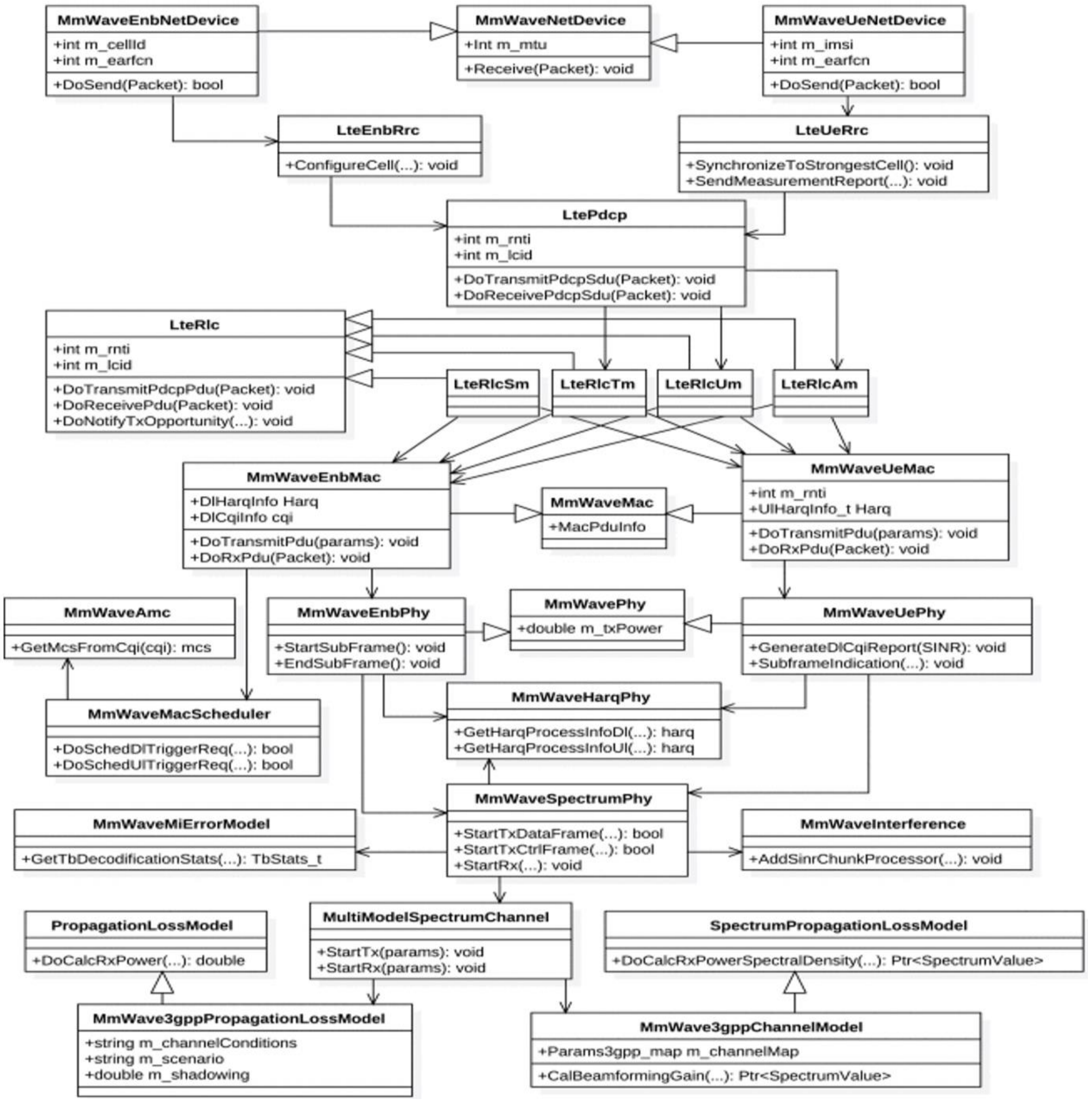

Fig. 1 UML diagram of the mmWave module [6]

is implemented in the LteEnbRrc class using a MAC scheduler due to configurations at the LTE layer of Radio Resource *Control (RRC)* [6][7].

Classes from the MmWavePhy group provide directional transmission, data reception via downlink and uplink. They also take care of channels that work on the principle of control MAC messages [1]-[3]. MmWaveSpectrumPhy class instances are used to communicate Phy class instances through SpectrumChannel [6]. The MmWaveSpectrumPhy class and its instances are shared for uplink and downlink due to the physical layer of the mmWave module, which is based on TDD (Time Division Duplexing) [8][9].

B. Energy framework

Power consumption is a crucial feature for wireless IoT nodes in mobile networks. Therefore, for research on energy consumption, and energy framework was implemented in the NS-3 simulator, using which data were obtained for further processing [11]. Energy model NS-3 consists of 3 parts:

- Energy source
- Energy model
- Energy harvester

The energy source and energy model for simulation use are described below.

The energy source in the network represents the energy source in each IoT node. Each node can be connected to multiple device energy models. If an energy source is connected to such models, the specific device will obtain energy from this source [11][12][13].

The essential function of the power source is to provide power to the node. If the energy in the nodes is depleted, the node informs neighbouring nodes that can respond to this event, obtaining information about the remaining power or the battery charge level.

To simulate power supplies, the energy source class must handle two essential effects of practical batteries:

- Rate capacity effect - Decrease of battery life when the current draw is higher than the rated value of the battery.
- Recovery effect - Increase battery life when the battery is alternating between discharge and idle states [11].

The energy source class divides a node into multiple smaller devices. Each of these devices consumes energy separately. Therefore, the energy source periodically asks for the energy consumed from all devices in the same node, from which it calculates the total energy consumption.

The model for device power consumption in IoT nodes is the device energy class. Each device has several states defined, and each state is associated with a certain value of energy consumption. If the state of the device changes, the energy model notifies the energy source class of the difference in the device's current energy consumption. Based on this, the energy source calculates the current energy consumption and updates the remaining energy value. Fig. 2 shows a block diagram of the energy model in NS-3 [10] - [13].

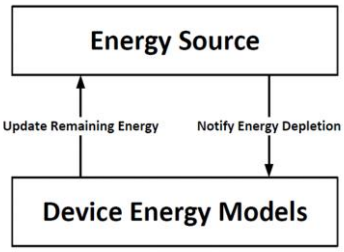

Fig. 2 Block diagram of the energy model in NS-3

III. SIMULATION PARAMETERS AND SCENARIOS

This section contains a description of the simulation parameters used, simulation scenarios and methods implemented in the NS-3 simulator.

This work focuses on simulating and comparing individual data transmission methods for research in robust data transmission using 5G networks. The work compares and analyzes the results of simulations of LTE, eMBB and eMBB with mmWave transmission methods in terms of energy efficiency and energy consumption of the network in different types of scenarios, which were created using NS-3. This type of new 5G service was chosen mainly because it has a rigorous and well-defined standard.

A. Simulation parameters

In this research, cases of different numbers of IoT end devices received by data packets were simulated and analysed. The proposed scenarios were simulated in a simulation area without obstacles of 600 m x 600 m with a User Datagram Protocol (UDP) transport protocol and with a packet size of 512 bytes. Each simulation scenario was run 200 times. The IoT nodes in the network moved with a random model of mobility in the simulated area.

Table I below lists the parameters and values that were used in the simulations.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Frequency	2,160 GHz (LTE), 6 GHz (eMBB), 30 GHz (mmWave)
Bandwidth	20 MHz
Number of IoT nodes	20, 40, 60, 80, 100
End-user's mobility	Random
End-user's speed	1-5 km/h
Size of simulating area	600 x 600 m
Simulation time	100 s
Number of the simulation run	200
Transport protocol	UDP
Packet size	512 bytes

B. Achieved results

This section describes the achieved results of simulations based on energy efficiency and energy consumption in the NS-3 simulator environment. The results were compared for LTE, eMBB and eMBB with mmWave.

Fig. 3 below shows the average values of energy consumption for all types of simulated scenarios. The graph of energy consumption as a function of the number of end-users shows that as the number of end-users increases, the energy consumption per bit increases. Thus, from the point of view of energy consumption, the services of 5G eMBB and mmWave networks are more economical than the older LTE service in all types of simulated scenarios.

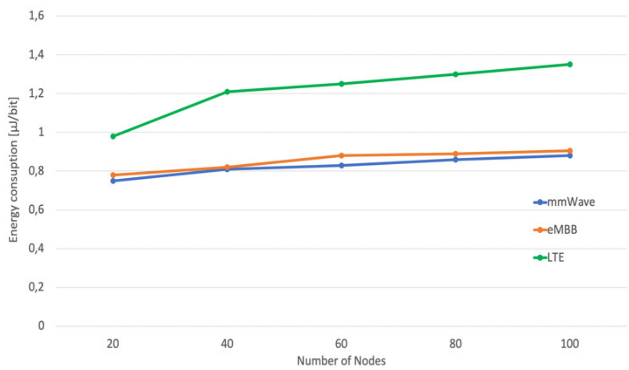

Fig. 3 Average values of energy consumption

We can see that the average values of consumed energy of LTE service range from 0.98 µJ / bit to 1.38 µJ / bit, depending on the number of end-users. Compared to eMBB and eMBB services with mmWave, this is significantly more. The eMBB service ranged from 0.76 µJ / bit to 0.905 µJ / bit. The mmWave service reached similar values, from 0.72 µJ / bit to 0.88 µJ / bit. All average values of energy consumed are shown in Table II below.

TABLE II. AVERAGE VALUES OF ENERGY CONSUMPTION IN MJ / BIT

	20 End users	40 End users	60 End users	80 End users	100 End users
LTE	0,98	1,21	1,25	1,3	1,35
eMBB	0,78	0,82	0,88	0,89	0,905
mmWave	0,75	0,81	0,829	0,86	0,88

If we compare the energy consumption of eMBB and mmWave to LTE, we find that eMBB consumed 29.81% and mmWave 32.22% with 0,05 std value (Standard Deviation) less energy than LTE.

In terms of the energy efficiency of the network, the results achieved were very similar. In Fig. 4, the older LTE service has lower energy efficiency than the eMBB and mmWave services. The average values ranged from 17.75 Mbit / J to 11.42 Mbit / J. The eMBB service ranged from 33.45 Mbit / J to 13.53 Mbit / J. The eMBB service with mmWave achieved on average 1 Mbit / J higher than the eMBB service in all simulated scenarios.

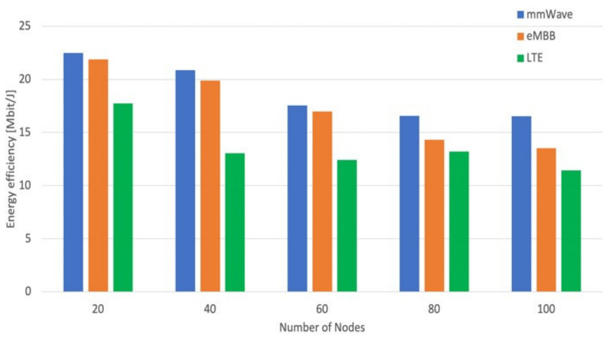

Fig. 4 Average values of energy efficiency

All achieved energy efficiency results are shown in Table III below.

TABLE III. AVERAGE VALUES OF ENERGY EFFICIENCY IN MBIT / J

	20 End users	40 End users	60 End users	80 End users	100 End users
LTE	17,75	13,06	12,43	13,22	11,42
eMBB	21,89	19,88	16,98	14,33	13,53
mmWave	22,49	20,87	17,56	16,58	16,54

IV. CONCLUSIONS AND FUTURE WORK

This work deals with communication using millimeter waves in 5G networks and a comparison of this service with eMBB and LTE services in energy efficiency and energy consumption of IoT nodes.

In this study, we focused on mmWave because, in the future, mmWave will have the most significant impact on transmission networks in terms of bandwidth, transmission speed and energy efficiency compared to eMBB or the older LTE service.

Based on simulations of 4G and 5G networks for the UDP service, the achieved results of energy efficiency and energy consumption of IoT nodes in the network were analyzed. Individual scenarios were simulated using an NS-3 simulator into which mmWave and the energy model were implemented. Based on the achieved results, it can be said that the average values of energy efficiency and energy consumed for 5G networks are many times better than 4G networks. This means that 5G networks are proving to be more efficient in terms of transmission speed, channel capacity, or data transmission efficiency and energy efficiency for IoT.

The achieved results will form a theoretical basis in future work. We will focus on using machine learning algorithms to increase the robustness of the 5G network, which will be experimentally simulated in natural conditions using intelligent devices.

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