An ns3-based Energy Module of 5G NR User Equipments for Millimeter Wave Networks

Argha Sen[1], Abhijit Mondal[1], Basabdatta Palit[3],
Jay Jayatheerthan[2], Krishna Paul[2], Sandip Chakraborty[1]
[1]Indian Institute of Technology Kharagpur, India, [2]Intel Technology Pvt. Ltd. Bengaluru, India,
[3]Indian Institute of Engineering Science and Technology, Shibpur, Howrah India

***Abstract*—This poster presents the design, development and test results of an energy consumption analysis module developed over ns3 Millimeter Wave (mmWave) communication for analyzing power consumption for 5G New Radio (NR) User Equipment (UE) during both continuous and discontinuous packet receptions. This module is important to analyze and explore the energy consumption behavior of the 5G communication protocols under the NR technology. The developed module includes the complete Radio Resource Control (RRC) state machine for 5G NR recommended by 3GPP Specification 38.840. To the best of our knowledge, the designed module is the first of its kind that provides a comprehensive energy analysis for the 5G NR UEs over mmWave communication.**

***Index Terms*—mmwave, ns3, 5G, UE, Energy Consumption**

I. Introduction

5G NR proposes mmWave transmission to facilitate seamless connectivity and very high data rates. However, mmWave communication entails higher device energy consumption leading to faster battery drainage [1]. Longer battery life is, nevertheless, essential for uninterrupted connectivity. To reduce energy consumption across the end-user devices, 3GPP has incorporated several energy-efficient features in 5G. At the same time, efficient algorithms for multiple applications are needed to improve energy consumption further. To design and test such algorithms' efficacy, 5G network simulators, such as ns3, OMNET++, etc., are used. Of these, ns3, based on C++, is one of the most popular simulators. Both the 5G-LENA [2], and the mmWave modules [3] of ns3 have an end-to-end protocol stack, but they lack a sophisticated well-defined UE energy module for implementation and testing of the energy-efficient algorithms for 5G NR UEs. Hence, in this poster, we discuss the design and development of an energy consumption module for simulating 5G NR UEs over mmWave networks. We have tested the energy module considering the mobility of 5G NR UEs. Hence, we adopt mmWave communication systems' dual connectivity in which UEs connects to LTE eNBs for control information exchange and 5G gNBs for data transmission [4]. The source code of the implementation is publicly available in the Github public repository[1].

II. Implementation of the Energy Module in ns3

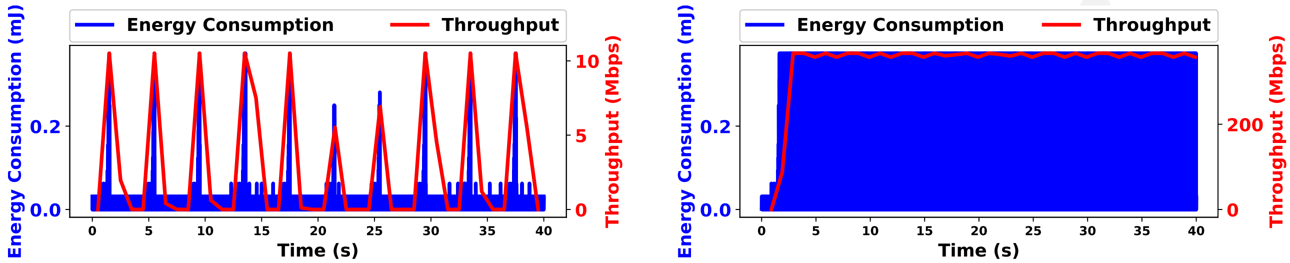
Energy management in 5G NR is governed by an RRC state machine with 3 states - RRC_CONNECTED in which there is active data transmission, the RRC_IDLE state with no active data transmission, and the RRC_INACTIVE state between two successive active transfers. In the RRC_INACTIVE, the UE context is maintained by both the UE and the network. The connection between the access network, and the core network is also kept active to minimize the control plane latency and the energy consumption for the transition from RRC_IDLE to RRC_CONNECTED state.

A. Energy Model Design

The RRC state machine implemented in the ns3 mmWave module [3] includes the RRC_CONNECTED state and the RRC_IDLE state. However, it does not have the newly proposed RRC_INACTIVE state. To this end, we have used the PHY states of the mmWave module, which are used to manage the signaling between the UEs and the Long Term Evolution (LTE) evolved NodeBs (eNBs) and/or next generation NodeBs (gNBs), to derive the UE energy consumption. The four PHY states ($\mathbb{S}$) are - a) IDLE, b) RX_CTRL, c) RX_DATA, and d) TX. In the IDLE state, the UE has no active control information or data transmission. In the RX_CTRL and the RX_DATA state, it respectively receives control and data from the network. In the TX state, it sends data to the gNB. Based on the PHY states, total energy consumption of the UE is $\sum_{\mathcal{S}\in\mathbb{S}}(P_{\mathcal{S}\times t_{\mathcal{S}}})$, where $P_{\mathcal{S}}$ and $t_{\mathcal{S}}$ are the power consumption and the dwell time of the PHY state $\mathcal{S}$, respectively [5, Table 18, 20].

An important point to note here is that to support mobility of UEs, we have used the dual-connectivity mode [4] of mmWave transmission. So, the communication takes place over two frequency ranges - Frequency Range-1 (FR1) from 1GHz to 7GHz for connection to LTE eNB, and b) Frequency Range-2 (FR2) from 7GHz to 50GHz for connection to gNB. The power consumption in both frequency ranges is outlined in [5, Table 18, 20] in terms of a relative power unit with respect to the deep sleep state. In this work, deep sleep state power consumption is 1mw and that for the other states are scaled accordingly. The control channel information is exchanged by the UE with both LTE eNB as well as gNB. The control channel monitoring power or P_{RX_CTRL} is 100 mW and 175 mW for FR1 and FR2 respectively. PDCCH+PDSCH reception happens when a UE receives the downlink data from the gNB, so P_{RX_DATA} is 350 mW. Uplink transmission

[1]https://github.com/arghasen10/ns3-mmwave-1



(a) Discontinuous Packet Transfer

(b) Continuous Packet Transfer

Fig. 1. Throughput & Energy Consumption vs time

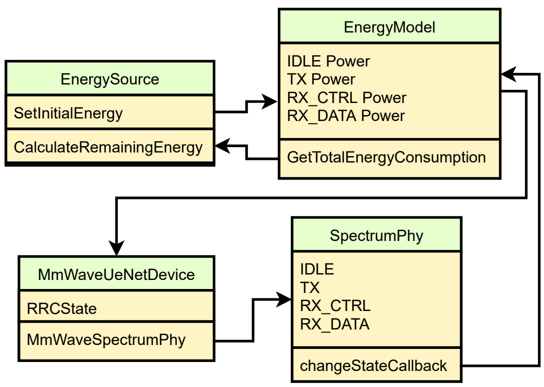


Fig. 2. Energy Model Flow Diagram

TABLE I
SIMULATION PARAMETERS

Parameter Description	Value
Bandwidth of mmwave gNBs/LTE eNB	1 GHz/20 MHZ
Carrier frequency mmwave/LTE	28 GHz/2.1GHz
Bandwidth of the LTE eNB	20 MHz
MIMO array size gNB/UE	$8 \times 8/4 \times 4$
Number of gNB/eNB	2 /1
Number of UEs	4
UE speed	5 m/s
UE Application	Discontinuous and Continuous Packet Transfer

happens when UE stays in the TX state, so P_{TX} is 350 mW. We have considered the micro-sleep state mode [5] and mapped it to the PHY IDLE state with P_{IDLE} as 45mW.

We next draw a correspondence between the RRC states and the PHY states. In the RRC_IDLE state, there is no active data transmission, but the UE remains connected to the network. So, the UE toggles between the PHY IDLE state and TX state. Using the latter, it acquires the Uplink Synchronization. During data transmission in the RRC_CONNECTED state, the UE can be in all the four PHY states. In the RRC_CONNECTED state, the UE enters the PHY IDLE state between two active data transfers. At this point, if the dwell time in the PHY IDLE state is small, we label it as the RRC_INACTIVE state.

B. Implementation in ns3

The energy framework in ns3 consists of the Energy Source and the Device Energy Model (Fig. 2). The former exists on a node, representing the total energy reserved at the node. Multiple device energy models can exist on a single node, representing different network devices. mmWave UE netdevice has an object named `mmWaveSpectrumPhy` which provides a trace source for the PHY state change. Our device energy model uses the corresponding trace sink that triggers `stateChange` function and accordingly updates the total energy consumption based on the PHY state power consumption. It then notifies the energy source about the consumed energy. The energy source checks the remaining energy, and when energy is completely drained, it notifies all the connected device energy models.

III. TEST RESULTS AND CONCLUSION

Two ns3 helper objects – one Energy Source helper and one Energy Model helper, are needed to implement the energy model in the simulation. We set the initial energy of the UE as 90000J, corresponding to the 6000 mAH battery specification of commercial smartphones. The simulation parameters are tabulated in TableI. We have used two different Downlink applications for simulation - UDP-based continuous and discontinuous packet transfer. In the discontinuous app, since packets are transferred at regular intervals, the device mostly stays in the IDLE state. Once the packet transfer is scheduled, the device enters the RX_DATA state, and its energy consumption increases, as shown in Fig. 1(a). The red dots in Fig.1(a) correspond to the timestamps of handovers between gNBs. As the device enters the RX_CTRL state during handovers, energy consumption at that instant is found to be higher than the IDLE state energy. For continuous packet transfer application, since the device stays mostly in the RX_DATA state, throughput, and energy consumption always remain high, as shown in Fig.1(b) The test results indicate that the developed module can nicely characterize the energy consumption behavior of 5G UEs under various scenarios.

REFERENCES

[1] Panagiotis Skrimponis *et. al.*, “Power consumption analysis for mobile mmwave and sub-thz receivers,” in *6G SUMMIT 2020*.
[2] Natale Patriciello *et. al.*, “An E2E simulator for 5G NR networks,” *Simulation Modelling Practice and Theory*, vol. 96, 2019.
[3] Marco Mezzavilla *et. al.*, “End-to-end simulation of 5g mmwave networks,” *IEEE Comm. Surveys Tutorials*, vol. 20, no. 3, 2018.
[4] Michele Polese *et. al.*, “Improved handover through dual connectivity in 5g mmwave mobile networks,” *IEEE JSAC*, vol. 35, no. 9, 2017.
[5] Study on user equipment (ue) power saving in nr. [Online]. Available: https://www.3gpp.org/DynaReport/38840.htm