An End-to-End Simulation Set-Up for Evaluating Device Energy Consumption in 5G mm-wave Networks

Argha Sen[1], Abhijit Mondal[1], Basabdatta[2] Palit, Sandip Chakraborty[1]
[1]Indian Institute of Technology Kharagpur, India, [2]Indian Institute of Engineering Science and Technology, Shibpur, Howrah India

***Index Terms*—mmwave, ns3, Energy Consumption**

I. Introduction

The 5G New Radio (NR) proposes the use of mmwave transmission to facilitate seamless connectivity and very high data rates. However, mmwave communication often results in higher energy consumption at end user devices which may lead to faster battery drainage [1]. However, longer battery life is essential for the success of 5G and to satisfy the need for uninterrupted connectivity. To mitigate the issue of higher energy consumption, 3rd Generation Partnership Projects (3GPPs) has incorporated several energy efficient features in 5G. Nevertheless, 5G includes a wide array of end user devices the total energy content of which is constant. Hence, energy efficient algorithms for various applications are needed to further improve the energy consumption. To design and test the efficacy of such algorithms 5G network simulators, such as NS3, OMNET++, Vienna simulator, are used. Of these, NS3, based on C++, is one of the most popular simulators. Both the 5G-LENA [] and the Mmwave module [] of NS3 have an end-to-end protocol stack. However, both of these modules 5G-LENA lacks a sophisticated UE energy module for implementation and testing of energy efficient algorithms for 5G NR User Equipments (UEs). Hence, in this work, we focus on developing the energy consumption module for 5G NR UEs.

MMwave communication in 5G uses a dual connectivity principle by which end user devices connect to LTE eNBs for control information exchange and to 5G gNBs for data transmission. Such dual connectivity leads to increased battery drainage. In this work, we use the mobility of 5G NR UEs to test our energy module. So, we have also adopted the dual connectivity of mmwave communication systems []. The module is designed in such a manner that it can be extended to sub-THz communication as well.

II. Implementation of the Energy Module in NS3

The energy management in 5G NR is governed by a 3-state Radio Resource Control (RRC) state machine where in addition to the conventional RRC CONNECTED and RRC IDLE state of 4G LTE, there is a third state called RRC INACTIVE. In the RRC INACTIVE the UE context is maintained by both the UE as well as the network. The connection between the Access Network and the Core Network is also kept active in this state so as to minimize the control plane latency as well as the energy consumption for transition from the IDLE to the CONNECTED state. The INACTIVE state can be configured according to the requirements of different use cases of 5G.

A. Energy Model Design

The mmwave module [2] uses a set of PHY states to manage the signaling between the To implement the 5G NR RRC state machine in 5G, we have made use of the PHY states, which are used by the mmwave-module to manage the signalling between the UEs and the LTE evolved NodeBs (eNBs) and/or next generation NodeBs (gNBs). These four PHY states are - a) IDLE, b) RX_CTRL, c) RX_DATA, d) TX. In the IDLE state, the UE has no active transmission of either control information or data. In the RX_{CTRL} and RX_{DATA}state, it receives control and data information from the gNB, respectively. In the TX state it receives signaling information. As mentioned earlier, energy management in 5G NR UEs is monitored by the three RRC states - RRC_{IDLE} Here, we first draw a correspondence between the states of the RRC state machine and the PHY states. In the ns3-mmwave module we have 4 spectrum PHY states namely, IDLE, RX_CTRL, RX_DATA, TX and two major RRC states namely, RRC_IDLE and RRC_CONNECTED. During the RRC_IDLE, UE remains in PHY IDLE state and also in TX state for aquiring Uplink Synchronization (Initial Access/RACH). When UE enters the RRC_CONNECTED state it can have all the four PHY states. So, when the UE is not sending or receiving any data in RRC_CONNECTED state it enters the PHY IDLE state. Thus PHY IDLE can be considered as the RRC_CONNECTED_INACTIVE state.

Based on the four different PHY states, total energy consumption of the UE is the sum of energy consumed in these four states.

$$\begin{aligned} E_{total} = P_{IDLE} * t_{IDLE} + P_{RX\_CTRL} * t_{RX\_CTRL} \\ + P_{RX\_DATA} * t_{RX\_DATA} + P_{TX} * t_{TX} \end{aligned} \tag{1}$$

where E_{total} is the total energy consumption, P_{IDLE}, P_{RX_CTRL}, P_{RX_DATA}, P_{TX} is power consumption in these four states and t_{IDLE}, t_{RX_CTRL}, t_{RX_DATA}, t_{TX} is the total time for which UE stays in these four states. In the study on User Equipment (UE) power saving in the 3GPPs specification 38.840 [3, Table 18, 20], power consumption in different states are mentioned. Based on the study Control channel monitoring power or P_{RX_CTRL} is 175 mW for FR2 (band above 7GHz). PDCCH+PDSCH reception happens when UE receives downlink data from gNB, so P_{RX_DATA} is 350 mW. Uplink transmission happens when UE stays in TX state so P_{TX} is 350 mW. Since ns3 mmwave [2] module, connected Mode Discontinuous Reception (cDRX) is not yet implemented, thus Maximum energy consumption in sleep state is in micro-sleep which is 45 mW. Thus we have considered P_{IDLE} is 45 mW.

B. Implementation in NS3

The energy framework in ns3 consists of two major components, namely, Energy Source and Device Energy Model. Only a single energy source will exist on a node, representing the total energy reserve at the node. Multiple device energy models can exist on a single node, representing different net devices. MmWave UE net device has an object named `MmWaveSpectrumPhy` which provides a trace source for PHY state change. Device Energy model uses corresponding trace sink that triggers `stateChange` function and accordingly updates the total Energy Consumption based on the PHY state power and notifies the energy source about the consumed energy. Energy source checks the remaining energy and when energy is completely drained, it notifies all device energy models connected to it.

III. Simulation Set-up and Evaluation

To implement the energy model in the simulation one Energy Source helper and one energy model helper is needed. We set the initial energy of the UE as 1000J. Simulation Parameters for various simulation scenarios is shown in Table I. We have used two different Downlink applications for simulation. For discontinuous packet transfer application since packets are transfered at regular intervals device mostly stays in the IDLE state. When packet transfer is scheduled device enters the RX_DATA state and thus energy consumption increases as shown in figure 1. Also in figure 1 red dots represent timestamp when handover happened. Since during handovers device enters RX_CTRL state energy consumption at that particular timestamp is slightly higher compared to IDLE state energy. For continuous packet transfer application since the device stays mostly in the RX_DATA state throughput and energy consumption is always high as shown in figure 2.

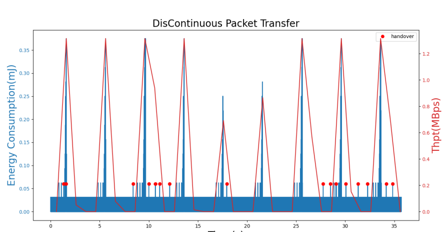

Fig. 1. Throughput & Energy Consumption vs time for discontinuous packet Transfer Application

TABLE I
Simulation Parameters

Parameter	Value	Description
mmWave W_{tot}	1 GHz	Bandwidth of mmWave gNBs
mmWave f_c	28 GHz	mmWave carrier frequency
mmWave P_{TX}	30 dBm	mmWave transmission power
LTE W_{tot}	20 MHz	Bandwidth of the LTE eNB
LTE f_c	2.1 GHz	LTE carrier frequency
gNB antenna	8×8	gNB UPA MIMO array size
UE antenna	4×4	UE UPA MIMO array size
N_{gNB}	3	2 mmwave gNB and 1 LTE eNB
N_{UE}	4	Number of UE
v	5 m/s	UE speed
App	Discontinuous and Continuous Packet Transfer	Applications installed over the UE

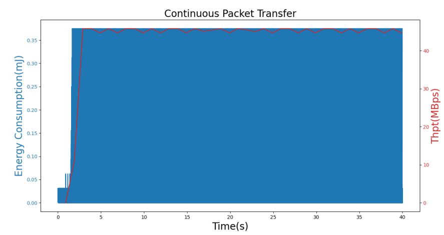

Fig. 2. Throughput & Energy Consumption vs time for continuous packet Transfer Application

IV. Conclusion

In this work, we have developed MmWave energy module for the existing NS-3 mmwave module which enables the researchers community to utilize this for evaluation of energy consumption in mmwave devices. We have made the source code open and deployed it in git hub for public access, for the benefit of the community.

References

[1] P. Skrimponis, S. Dutta, M. Mezzavilla, S. Rangan, S. H. Mirfarshbafan, C. Studer, J. Buckwalter, and M. Rodwell, "Power consumption analysis for mobile mmwave and sub-thz receivers," in *2020 2nd 6G Wireless Summit (6G SUMMIT)*, 2020, pp. 1–5.

[2] M. Mezzavilla, M. Zhang, M. Polese, R. Ford, S. Dutta, S. Rangan, and M. Zorzi, "End-to-end simulation of 5g mmwave networks," *IEEE Communications Surveys Tutorials*, vol. 20, no. 3, pp. 2237–2263, 2018.

[3] Study on user equipment (ue) power saving in nr. [Online]. Available: https://www.3gpp.org/DynaReport/38840.htm