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An ns3-based Energy Module for 5G mmWave Base Stations

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***Abstract*—This poster presents the design, development, and test results of an energy consumption analysis module developed over ns3 Millimeter Wave (mmWave) communication, which can analyze the power consumption characteristics of 5G eNodeB/gNodeB Base Stations. This module is essential for research and exploration of the energy consumption behavior of the 5G communication protocols under the New Radio (NR) technology. To the best of our knowledge, the designed module is the first of its kind that provides a comprehensive energy analysis for the 5G mmWave base stations.**

***Index Terms*—mmWave, ns3, 5G, eNB/gNB, LTE, Energy Consumption**

I. Introduction

With the rapid growth in network traffic demand, next-generation cellular networks like 5G mmWave networks will deploy a massive number of base stations or access points to support high data rates and continuous coverage. The combined energy consumption will significantly impact environmental and resource concerns. Consequently, many recent pieces of research are being focused on the design of energy-efficient cellular network architecture to reduce energy consumption across the base stations. Popular simulation platforms like ns3-mmWave [1], 5G-LENA [2] module is used to design and test such algorithms. However, these simulators don't have any energy consumption model that can be used for measuring and analyzing the energy consumption behavior for the 5G mmWave networks, particularly the energy consumption at the eNBs/gNBs. Previous works such as [3]–[6] have designed User Equipment (UE) energy models for mmWave, LTE, or WiFi networks simulation in ns3. However, these models lack a sophisticated, well-defined Base Station energy module for implementing and testing the energy-efficient algorithms for 5G next-generation eNBs/gNBs. Hence, in this poster, we discuss the design and development of an energy consumption module for simulating 5G New Radio (NR) next-generation NodeBs (gNBs) over mmWave networks. The source code of the implementation is publicly available in the GitHub repository [1].

II. Energy Consumption Modelling

In [7], the authors have used a base station power consumption model under different sleep modes and load conditions. However, in 5G NR base stations as per 3GPP Release 16, the sleep modes are governed by the Radio Resource Control (RRC) state machine with three RRC states viz, (1) `RRC_CONNECTED`, (2) `RRC_IDLE`, and (3) `RRC_INACTIVE`. The newly proposed `RRC_INACTIVE` state occurs between two successive active transfers representing the sleep state. However, the RRC state machine implemented in the ns3 mmWave module [1] doesn't have the `RRC_INACTIVE` state. Thus, this work has used the physical (PHY) states as the deciding factor for base station energy consumption. It can be noted that the PHY states govern the RRC states of an eNB/gNB; therefore, the power consumption behavior can directly be emulated over the PHY states. These PHY states, namely (1) `IDLE`, (2) `RX_CTRL`, (3) `RX_DATA`, and (4) `TX`, are used to manage the signaling between the UEs and the Long Term Evolution (LTE) or mmWave eNBs/gNBs. The `IDLE` state represents the time gap between two consecutive active data transfers. The `RX_CTRL` and `RX_DATA` states represent the reception of control channel or data channel information. The PHY `TX` state represents the transmission of the data from the device. Based on these four PHY states, we have profiled the power consumption values as given in [7]. Accordingly, the net energy consumption of the base station can be given as $\sum_{\mathcal{S}}(P_{\mathcal{S}} \times t_{\mathcal{S}})$, where $P_{\mathcal{S}}$ and $t_{\mathcal{S}}$ are the power consumption and the time taken in the PHY state $\mathcal{S} \in \{IDLE, RX\_CTRL, RX\_DATA, TX\}$. The power consumption values in the four PHY states of a 4×4 macro base station are shown in Table I, as given in [7]; these values can be configured through the corresponding hyper-parameters during the simulation setup.

TABLE I
Power Consumption in different PHY States for a 4x4 Macro Base Station [7]

STATE	P_{RX_CTRL}	P_{RX_DATA}	P_{TX}	P_{IDLE}
Power (W)	138.9	138.9	742.2	12.4

III. Implementation in ns3

The primary basis of the mmWave simulation in ns3 is the ns3-mmWave module [1]. In addition to LTE EPC protocols, it also implements MAC, PHY, and RLC layers as described in the 3GPP specifications. We used this module as the base of our mmWave simulation. The energy framework in ns3 consists of an *Energy Source Model* and the *Device Energy Model* (Fig. 1). The Energy Source Model represents the total energy reserved at the base station node. `mmWaveEnbNetDevice` has an object named `mmWaveSpectrumPhy` that provides

[1]https://github.com/arghasen10/mmwave-energy (Last access: February 22, 2022)

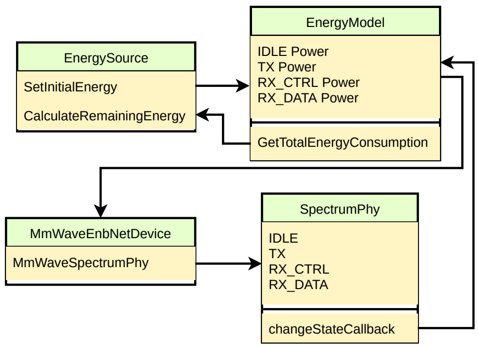


Fig. 1. Energy Model Flow Diagram

TABLE II
SIMULATION PARAMETERS

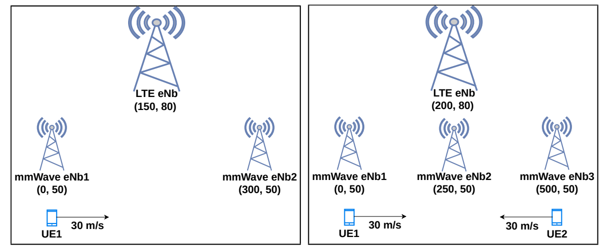
Parameter Description	Value	
	Scenario1	Scenario2
Bandwidth of mmWave gNBs/LTE eNB	1 GHz/20 MHz	
Carrier frequency mmWave/LTE	28 GHz/2.1GHz	
Simulation Time	10 s	
Number of gNB/eNB	2	3
Number of UEs	1	2
UE start Position	(0,-5)	(0,-5) and (500,-5)
UE end position	(300,-5)	(500,-5)
UE speed	30 m/s	
UE Application	UDP Socket	

a trace source for the PHY state change. Our device energy model uses the corresponding trace sink that triggers the `stateChange` function and accordingly updates the total energy consumption based on the PHY state power values (see Table I). It then notifies the energy source about the consumed energy. The energy source checks the remaining energy, and when the energy is completely drained, it notifies the connected device energy model.

IV. TEST RESULTS AND CONCLUSION

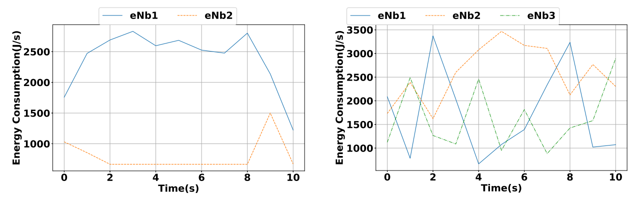
The simulation parameters are tabulated in Table II. We set the initial energy of the base stations to 1 megaJoule (MJ). As shown in Table II, we have used two different simulation scenarios with different sets of UEs and base stations. For Scenario-1 we have kept 1 UE moving from eNB1 (0,50) to eNB2 (300, 50) as shown in Fig. 2(a). Initially, the UE gets connected to its closest eNB1. Most of the time, it stays connected to eNB1, and finally, at around 8s, it makes a handover and gets connected to eNB2. Fig. 3 shows the energy consumption per second for both scenarios. As can be seen in Fig. 3(a), we see a higher energy consumption for the eNB1 in comparison to eNB2, because for most of the time in the simulation, UE stays connected to eNB1 (see Fig. 4(a)[2]). In Scenario-2 there are 3 eNBs at position (0,50), (250,50), and (500,50) as shown in Fig. 2(b). Two UEs at positions (0,-5), (500,-5) initially get connected to the closest base stations, eNB1, and eNB3, respectively. So initially, the energy consumption of eNB1 and eNB3 is higher than that of eNB2, as seen in Fig. 3(b). Gradually, both the UEs get connected to eNB2 and finally to eNB3 and eNB1. The results in Fig. 3(b) show how all the eNBs' energy consumption changes over the simulation time. Since the load of eNB2 becomes two in the middle of the simulation, the net energy consumption of eNB2 is higher than that of eNB1 or eNB3 (also observed in the total TX time for eNB2 in Fig. 4(b)). The test results indicate that the developed module can nicely characterize the energy consumption behavior of 5G base stations under various scenarios. Thus the module can be used for energy consumption study of mmWave base stations.

[2]RX_DATA is negligible as the application is not uplink.



(a) Scenario 1 (b) Scenario 2

Fig. 2. Topology in two Scenarios



(a) Scenario 1 (b) Scenario 2

Fig. 3. Energy Consumption in base stations over time in different scenarios

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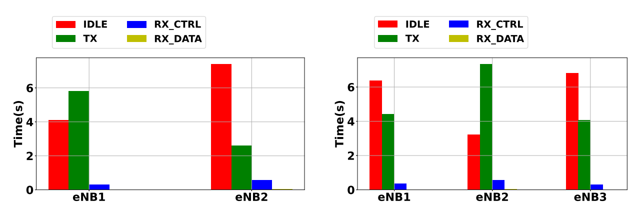

(a) Scenario 1 (b) Scenario 2

Fig. 4. Time spent in each energy state in different scenarios