# A NS-3 Module for LTE UE Energy Consumption

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***Abstract*—NS-3 has evolved into a very popular simulator platform for networking research studies. As energy consumed by LTE user equipment (UE) is of keen interest to researchers working in wireless networks, they often analyze the energy consumed by a UE when running network simulations. Thus, there is a stringent need for the underlying simulator to have an energy consumption model, but NS-3 currently does not have a LTE UE energy expenditure module. In literature, the LTE UE energy expenditure is profiled and modeled for a commercial UE. A corresponding implementation of the same is needed in NS-3. In this paper, we present the design and implementation details of LTE UE energy model in NS-3 and then validate it by running various experiments. Our implementation of LTE UE energy consumption model yields the expected power profile in our experiments with varying scheduling of resources to UEs. We made the LTE UE energy module code open [2] for the research community to get benefited.**

***Index Terms*—NS-3, Power Model, Energy Consumption, LTE.**

## I. Introduction

Network simulators like NS-3, OPNET and OMNET++ are quite popular and commonly used by people in diverse communities to simulate, verify how different networking protocols behave and study their performance. Simulations are advantageous in circumstances where it is extremely costly or time-consuming to setup a testbed. In this paper, we concentrate on NS-3 which is written in C++ and its highly flexible architecture encourages realistic simulation models to be developed. The NS-3 simulation core has support for Wi-Fi, WiMAX, and LTE. The availability of high number of validated and well-maintained models make NS-3 the most preferred open source network simulator for researchers.

While Wi-Fi Radio Energy Module [3] is already implemented in NS-3, it lacks LTE User Equipment (UE) energy module. Though NS-3 supports power control for adjusting the transmit power [4] which is widely used in spectrum model for computing received power at the receiver, it does not have sophistication for measuring energy expenditure in LTE interface of a UE. As LTE UEs are often powered by batteries, the total amount of energy available at each UE and subsequently in the entire network is restricted. Hence, the amount of energy utilized is a key metric while studying performance in mobile wireless networks.

In this work, we develop a LTE UE energy consumption module for NS-3 which permits simulation of energy consumption in LTE UEs. The LTE UE energy module uses commercial UE power profile, experimented and validated by authors in [1]. The hierarchy and dependency of LTE UE energy module are as shown in Figure 1. We also made LTE UE energy module code open, and researchers can be benefited from it [2].

The rest of the paper is organized as follows: Section 2 discusses LTE energy consumption framework in NS-3. We then present in detail the design and implementation of energy consumption model for LTE UE in Section 3. In Section 4, we discuss the validation and results of the proposed model. Finally, in section 5 we present concluding remarks.

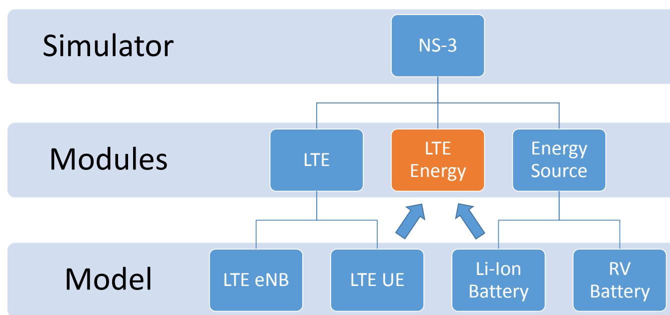


**Fig. 1:** LTE Energy Module Hierarchy and Dependencies in NS-3

## II. Energy Consumption Framework in NS-3

The energy framework in NS-3 provides the basis for energy consumption and energy source modeling. It consists of two main components: Energy source model and Device energy model. The total energy reserve at each node is represented by the energy source. The main functionality of the energy source model is to supply energy for all the netDevices (NICs) associated with that node.

The device energy model represents energy consumption of a netDevice. A node can have more than one netDevice associated at a time (viz., LTE, Wi-Fi) and each netDevice is associated with a device energy model. Every device energy model notifies the energy source about the energy consumed by that netDevice, and thus updates the remaining energy of the source. When energy is completely drained from the energy source, it notifies all device energy models connected

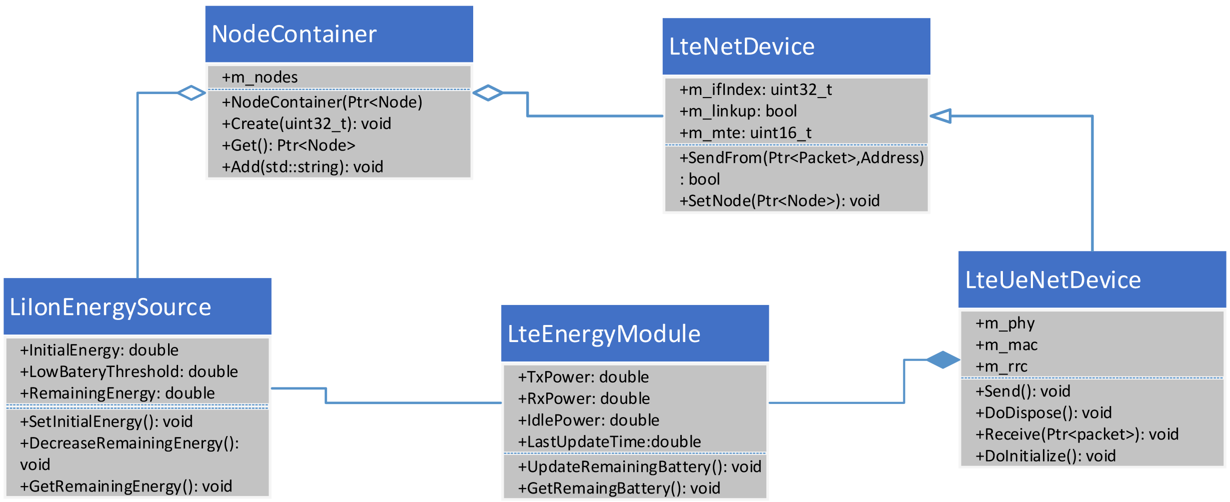


**Fig. 2:** Class Diagram for LTE Energy Module in NS-3

to it. Multiple device energy models can be connected to a single energy source model.

## III. Energy Module Design and Implementation

The energy framework available in NS-3 [3] has a wide scope, modular design and is easy to use. It also has low simulation overhead as the addition of this energy framework has negligible effect on the simulation speeds. The existing energy framework is also easily extensible, as new device or source energy models can be integrated with it, without much hassle.

The framework gives adequate support for the following:

- Energy source models considering linear energy sources which are ideal but do not express key aspects of real-life batteries, such as reliance on battery efficiency on load current. Besides, they also include non-linear energy sources.
- Device energy models which depict energy consumed by netDevices such as the Wi-Fi radio.
- The framework also provides methods that allow information about energy consumption to move to NS-3 objects which are external to the framework.

### A. LTE UE Power Consumption Model

Many works have be done to obtain a perfect UE power consumption model. In [5] authors proposed a trace driven model to analyzing the power expenditure in LTE. They developed Android applications to collect the LTE stats, which they further processed to obtain the power profile. Authors in [1] used commercial UE with very close observation of power expenditure in different physical layer components, which gives a clear insight on power dissipation profile. Hence we preferred to develop NS-3 energy module based on [1]. LTE UE power consumption model in [1] unveils the power spent on different physical layer operations. Authors classified power consumed by LTE UE into four components:

1) Transmitter Base Band Module (TxBB)
2) Transmitter RF Module (TxRF)
3) Receiver Base Band Module (RxBB)
4) Receiver RF Module (RxRF)

A commercial UE (LTE dongle) is used for experiments with power supply from Agilent 6705B DC measurement power supply (5 V, 1 A). The commercial UE follows its power dissipation profile as specified in [6]. The power consumed is modeled as follows

$$\begin{aligned} P_{tot} = m_{idle} \cdot P_{idle} + \overline{m_{idle}}\, \{P_{con} \; + m_{Tx} \cdot m_{Rx} \cdot P_{Rx+Tx} \\ + \; m_{Rx} \cdot [P_{Rx} \; + \; P_{RxRF}(S_{Rx}) \; + \; P_{RxBB}(R_{Rx}) \\ + \; m_{2cw} \cdot P_{2cw}] \; + \; m_{Tx} \\ \cdot [P_{Tx} \; + \; P_{TxRF}(S_{Tx}) \; + P_{TxBB}(R_{Tx})]\} \quad [Watt] \end{aligned} \tag{1}$$

Here, $P_{tot}$ is the total power consumed. $P_{idle}$ and $P_{con}$ correspond to power consumed in idle mode and Radio Resource Control (RRC) connected mode respectively. A UE will be in one of these two modes at any given time. $m_{idle}$ and $\overline{m_{idle}}$ represent the fraction of time a UE is in idle and connected states, respectively. $P_{Tx}$ and $P_{Rx}$ denote the power spent in transmit and receive chains, RxRF and RxBB represent the power consumed in two components of the receiver chain. Similarly, TxRF and TxBB represents the power consumed by components if transmit chain. 2CW corresponds to increased consumption when using two codewords (CW) in the downlink. S denotes the Rx and Tx power levels, and R corresponds to Rx and Tx data rates.

### B. Battery Module

A battery is associated with each UE and energy expenditure module controls its discharging, which is done based on power consumption. Here, energy source considered for implementation is Lithium-Ion energy source. We set the initial energy for every UE as 37800 J (2100 mAh - A typical smartphone battery capacity). A battery is associated with each UE and its discharge is done by energy expenditure module based on the activity of the UE. For every state viz., Transmission, Reception, RRC connected and RRC Idle, the power dissipated is reduced from the Battery module. Callbacks from energy expenditure module of a UE to their corresponding batteries notify the value of power spent in each trigger.

### C. LTE Energy Expenditure Module in NS-3

We develop a new module called *LTE Energy Module (LEM)* in NS-3. As LTE operates at the granularity of one millisecond, we confined granularity of updating the battery values to one millisecond. Updating the battery value every millisecond causes simulation overhead, as in scenarios with multiple UEs, the time taken to complete simulation increases. On the other hand, updating the battery value once in a fixed duration can mislead the algorithms built on top of this energy module. Hence, an optimized design in updating the battery value is required and is as follows: If there is a data transmission, we update the battery value every one millisecond. If there is no data to transmit, or in scenarios where transmission gets completed before the predefined simulation period, then we calculate the time spent in IDLE state and update the battery value accordingly. *LEM* estimates the power spent based on transmission, reception and state changes when an update is triggered. Further, a callback is triggered by LEM to UE battery module to reduce the estimated power.

Function $DoTransmitPdu()$ is used to observe transmission and $DoReceivePhyPdu()$ for reception of packet in $LTE\_UE\_MAC$ and initiate the update trigger. $DecreaseRemainingEnergy()$, a function of Lithium-Ion energy source used to decrease the energy value in the battery. The supply voltage is assumed to be 5V. The default values of power in Watt for different states are shown in Table I. A variable $LastUpdateTime$ is maintained which facilitates us to calculate the amount of time spent in IDLE state, in between transmissions as well as after the completion of the transmission. If a UE remains IDLE throughout the experiment, we calculate the IDLE time and finally the update trigger is done at $DoDispose()$ function of LTE-UE-MAC.

Figure 2 shows the class diagram for LTE Energy Module in NS-3. A node container incorporates $LteNetDevice$ and $LiIonEnergySource$. A helper class is used to associate $LTEUeNetDevice$ object to energy source through $LteEnergyModule$. The developed $LteEnergyModule$ has interface for querying LTE power expenditure rate and remaining energy of the battery. $LteEnergyModule$ reduces the energy from energy source based on the state in which UE is currently in and the power spent on each state, regulated by Equation 1.

## IV. VALIDATION OF LTE ENERGY MODULE

Numerous experiments are conducted on LTE energy module to verify and validate its correctness. Power spent by UE on downloading, uploading and simultaneous usage are profiled. Also, the performance is validated when a large number of users are active in the network. Power profile of all users based on various eNB scheduling algorithms and power expenditure on different handover algorithms are evaluated.

**TABLE I:** Power spent in different states by LTE UE

| State | Notation | Power (Watt) |
|---|---|---|
| IDLE ($m_{idle}$) | $P_{idle}$ | 0.5 |
| CONNECTED ($m_{con}$) | $P_{con}$ | 1.53 |
| ONLY RECEPTION ($m_{Rx}$) | $P_{Rx}$ | 0.42 |
| ONLY TRANSMISSION ($m_{Tx}$) | $P_{Tx}$ | 0.55 |
| TRANSMISSION AND RECEPTION ($m_{Rx+Tx}$) | $P_{Rx+Tx}$ | 0.16 |
| TWO CODE WORD ($m_{2cw}$) | $P_{2cw}$ | 0.07 |

### A. Scenario I: Single eNB and Single UE

**Experiment 1:** A scenario with single UE and single eNB is considered. The UE is receiving UDP packets at regular interval from the remote host. The inter-packet interval is varied from 1 msec to 5 msec. The simulation parameters of various simulation scenarios are given in Table II. Figure 3 plots remaining energy at UE (in J) for different simulation duration. It can be observed from Figure 3 that power spent on lower packet transmission interval is very high, and the power expenditure decreases with increase in packet transmission interval. As the packet transmission interval increases, the number of sub-frames a UE has to be in reception mode typically increases (based on LTE MAC scheduler) which reflects the energy spent. Since LTE MAC scheduler is a controlling entity in energy expenditure of a UE, we have evaluated different MAC schedulers and observed their energy expenditure patterns in other experiments below.

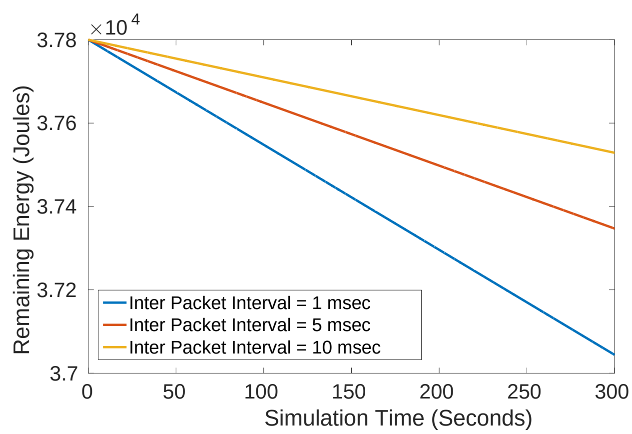


**Fig. 3:** Energy decay for LTE UE in Downlink

**Experiment 2:** Figure 4 shows the energy decay in a UE during uplink with different inter-packet intervals. The power expenditure in uplink is low compared to downlink when the inter-packet interval is 1 msec (downlink energy dissipates 35% faster compared to uplink only with inter-packet interval as 1 msec). This is well explained by Figure 5, because the fraction of packets which are actually transmitted in uplink for a given duration of time is very less compared to packets received in downlink. This is because packet arrived in each

**TABLE II:** LTE Simulation parameters

| Parameter | Scenario I | Scenario II | Scenario III |
|---|---|---|---|
| Simulation Time | 300s | 200s | 200s |
| LTE Mode | FDD | FDD | FDD |
| Bandwidth | 10 MHz | 10 MHz | 10 MHz |
| UE mobility model | Constant position mobility model | Constant position mobility model | Random Walk 2d Mobility model |
| LTE MAC Scheduler | Max Throughput | Proportional Fair, Round Robin, Max Throughput | Proportional Fair |
| Inter packet interval | 1 msec, 2 msec, 5 msec | 10 msec | 10 msec |
| Number of eNB, UE | 1, 1 | 8, 80 | 8, 80 |
| Transmission power (eNB) | 30 dBm | 30 dBm | 30 dBm |
| UE speed | - | - | 3 m/s, 14 m/s and 27 m/s |
| Handover algorithms | - | - | A2-A4 RSRQ, A3-RSRP |
| Application type | UDP | UDP | UDP |
| Packet size | 1500 Bytes | 1500 Bytes | 1500 Bytes |

millisecond has to do uplink scheduling request procedure which incurs a longer time to deliver a packet. Hence, the throughput is less in uplink compared to downlink in the case of 1 msec. For the inter-packet interval of 5 msec and 10 msec, the observed throughput of uplink and downlink are nearly equal, and the rate of power dissipation in uplink is 5.7% faster compared to downlink. This is due to high power expenditure by transmitter components of LTE UE compared to receiver components.

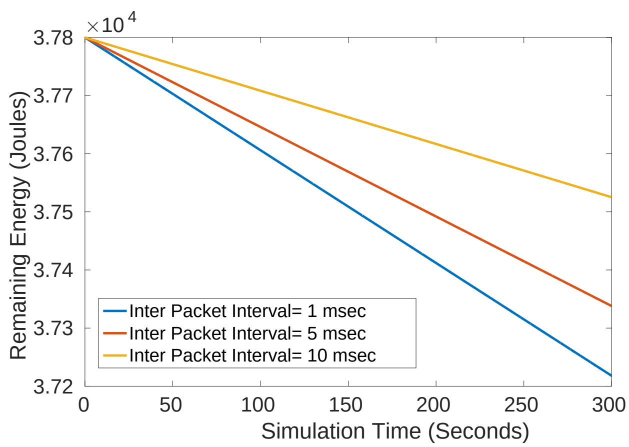


**Fig. 4:** Energy decay for LTE UE in Uplink

### B. *Scenario II: Multiple eNBs and Multiple UEs - LTE MAC Scheduler*

In this scenario, multiple UEs are associated to multiple eNBs in the simulation experiment. UEs are static and have UDP downlink flows. The positions of UEs are randomly allocated to ensure that a fraction of UEs are closer to eNB, and some are at the cell edge as shown in Figure 6. The experiment is to observe the power consumed by UE when different LTE MAC scheduling algorithms are employed at eNBs. Table II shows the other parameters. Figure 7 shows the throughput CDF of all 80 users, where different eNB scheduling algorithms such as Maximum Throughput (MT), Proportional Fair (PF) [7] and Round Robin (RR) are being used. In Figure 8, CDF of UE power expenditure is shown.

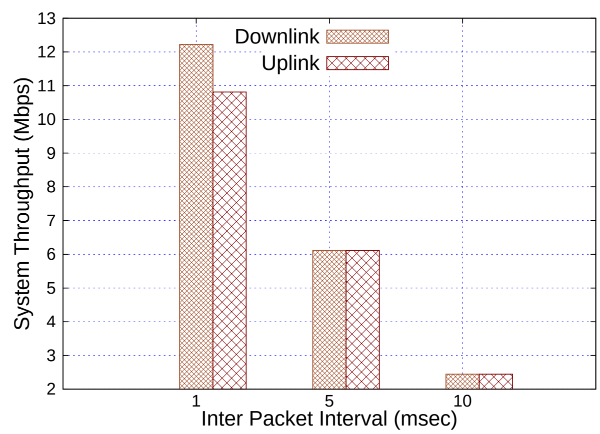


**Fig. 5:** Throughput for LTE UE in Uplink and Downlink

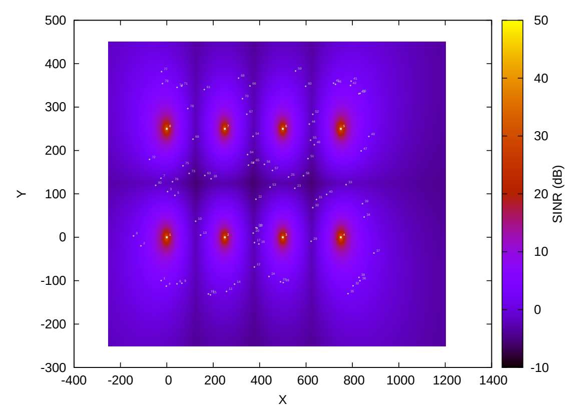


**Fig. 6:** Radio Environment Map for Experiment Scenario II and III

In the case of PF scheduler, we can observe that the energy consumption is almost same for all the UEs. This is due to the fact that, when the PF scheduler tries to ensure fairness in throughput for all UEs, the closest UE gets fewer resource blocks (RBs) compared to farthest UE, thereby the number of TTI (Transmission Time Interval) a UE has to be awake is made equal comparatively. For example, in a TTI the amount of data to be delivered to two different UEs are equal, one UE is closer and another is farther from the eNB. Based on their past observed throughput, closer UE will get less number of RBs and farther UE will get more number of RBs to transmit, but the number of TTIs that will elapse for both UEs to get their data to be delivered are almost same. This phenomenon explains the fair power profile in case of the PF scheduler.

In the case of RR scheduler, we can observe more energy being consumed by the UEs on the cell-edge and less energy by the UEs nearer to the eNB. This is due to RB allocation strategy of RR which gives equal number of RBs to all UEs in each TTI. The farthest UE is expected to receive and transmit in almost all TTIs to get a packet to be delivered even if the packet arrival rate is reasonably small (1 in every 10 msec). This explains the high fluctuation in power consumption profiles.

In the case of MT scheduler,from Figure 7 we can observe that very few UEs consume more energy while the rest consume very less energy. According to MT scheduler, the UE with high CQI will be given all RBs to transmit and hence a very small fraction of UEs is given the opportunity to transmit. This explains why a very small fraction of UEs consume more energy.

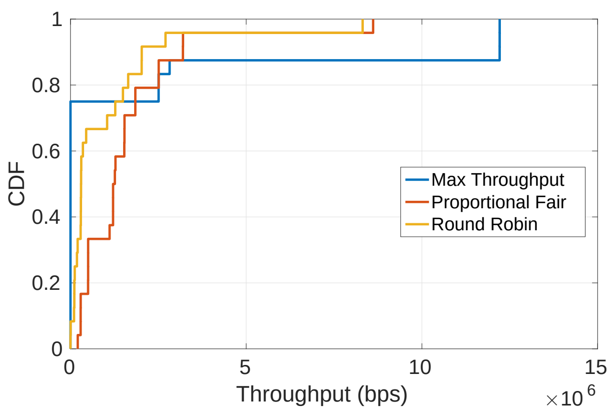


**Fig. 7:** Throughput CDF of various LTE schedulers

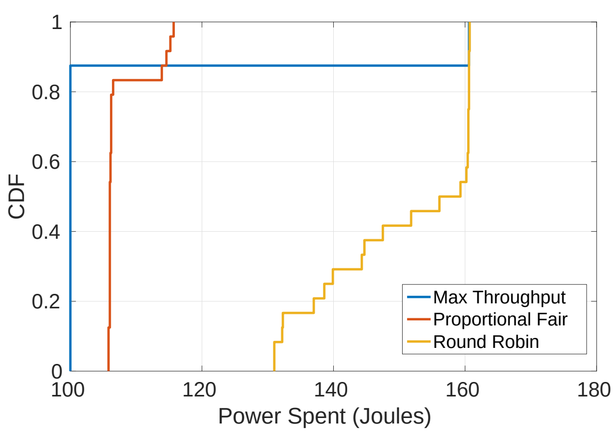


**Fig. 8:** Energy expenditure CDF of various LTE schedulers

### *C. Scenario III: Multiple eNBs and Multiple UEs - LTE Handover*

Figure 6 shows the REM plot of the scenario considered. eNB runs PF MAC scheduler. UEs are configured with Random Walk 2D Model [8], with varying speeds 3m/sec, 14m/sec, 27 m/sec, which correspond to walking, average mobility and high mobility scenarios, respectively. Effect of speed on power expenditure is evaluated in this experiment. Other simulation parameters are given in Table II. The observation corresponds to their throughput profiles.

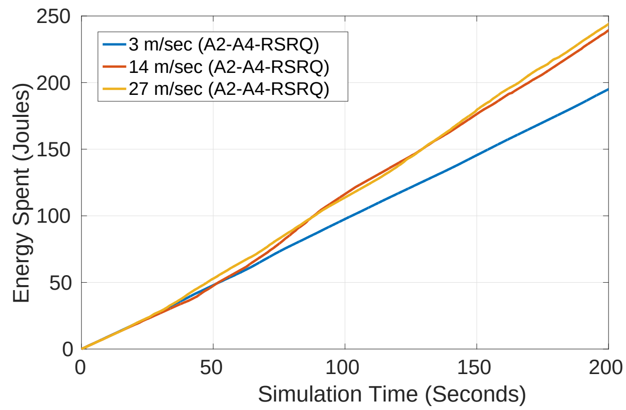


**Fig. 9:** Energy Expenditure at different speeds

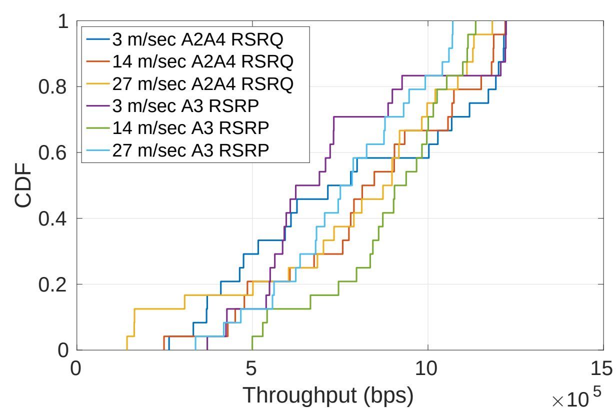


**Fig. 10:** UE Throughput at different speeds

Figure 9 shows power decay at a UE for different speeds. Energy consumed by a radio decreases rapidly in case of high mobility scenario compared to low mobility scenarios, for the same amount of data to be delivered. As the UE moves with high speed the CQI can be either improved or degraded with doppler. In case of degrading the time taken to deliver the packets to destination will be more, which in turn increases the energy consumed. Also in Figure 9 there are some instances at which power spent in 14 m/sec and 27 m/sec case cross over each other. This is due to the effect of handover. At handover the data transmission is paused and only control signaling is involved. Although Random Access Channel (RACH) procedure for attachment with new cell

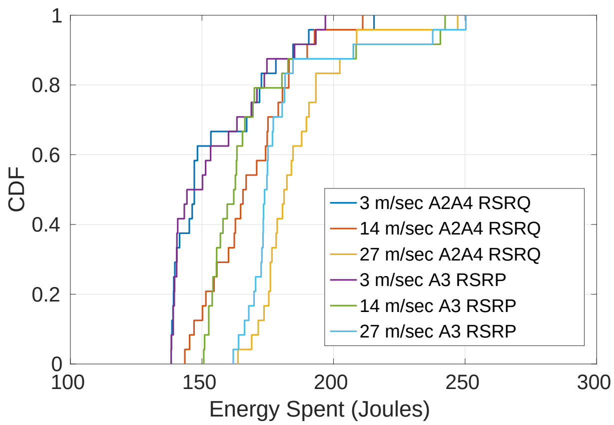


**Fig. 11:** Effect of speed on remaining energy

and association signaling involves high power, the fraction of time a UE spends in this phase is very short hence we have neglected this effect.

Figure 10 shows cdf of handover throughputs when A2A4-RSRQ (RSRQ-Reference Symbol Received Quality) and A3-RSRP (RSRP - Reference Symbol Received Power) handover algorithms are used for different UEs. It reveals that the throughputs are comparable within the same speed category. Across different speeds, the highest speed has the lowest throughput. This effect gets replicated in energy expenditure. Figure 11 shows the energy spent in each category. The UE with lower speed consumes lesser energy compared to high UE speed. A3-RSRP achieves better power optimization compared to A2A4-RSRQ because of its trigger nature. Since A3-RSRP is operating based on hysteresis, the decision making is quite robust and hence better optimized energy expenditure is observed.

It is clear from the above results that LEM in NS-3 performs as expected and it could be used for studying performance of power control and energy saving mechanisms. Also the source code of the developed LTE energy module is made publicly available for the benefit of the community [2].

## V. Conclusions

In this work, we designed and developed LTE energy module for NS-3 which enables the researchers community to utilize this open module. The simulation on various scenarios of static and mobile cases confirm the understanding of energy expenditure is replicated by the proposed model as expected. Also we have profiled the variation observed in power profile for various LTE MAC schedulers. We have made the source code open and deployed it in git hub [2] for public access, for the benefit of the community.

## VI. Acknowledgment

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