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Research Article

NS-3 Module for Machine Type Communication Device Energy Consumption

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Abstract—In networking research studies, NS-3 tools have emerged as a favored simulation platform among researchers. Understanding the energy usage of LTE Machine Type Communication Devices (MTCD), an LTE-M device, is essential for research in machine-type communication networks. However, NS-3 lacks a dedicated module to analyze the energy expenditure of communication between LTE and MTCDs. Scholars have previously profiled and constructed models of LTE UE energy expenditure for commercial equipment, necessitating an equivalent module within the NS-3 simulator for consistent and comparative research outcomes. In this scholarly contribution, we elucidate the conceptualization and execution of an LTE MTCD energy consumption model within the NS-3 framework. The experimental results reveal that the designed energy consumption model for LTE MTCD successfully mirrors anticipated power profiles under varied scenarios for MTCDs.

Index Terms—NS-3, Energy Consumption, LTE, MTCD.

I. INTRODUCTION

Wireless communication experts across diverse sectors frequently employ simulation platforms such as NS-3, OPNET, and OMNET++ to emulate, assess, and understand the nuances of various networking protocols. Deploying simulation test beds becomes an invaluable strategy, especially when establishing a physical testbed is prohibitively expensive or demands significant time. In this work, the focal point remains the NS-3 simulator. Written in C++, the inherent adaptability of NS-3's architecture paves the way for creating real-time simulation models. Its core supports a broad spectrum of wireless standards, including Wi-Fi, WiMAX, and LTE. With its repository of extensively verified and consistently updated models, the NS-3 network simulator is the best open source for the global research community.

NS-3 incorporates a Wi-Fi Radio Energy Module, as outlined in [3]. No module is designed for energy consumption relevant to MTCDs. The power control functionality — a crucial feature facilitating the adjustment of transmit power as delineated in [4] utilized within the spectrum model to calculate the received power at the receiving end. However, the simulator does not include a model for measuring energy expended by the LTE interface within an MTCD, with more reliance on battery power for MTCDs constrained by limited energy reserves. Consequently, with energy resources being finite at the device level and, by extension, across the network, the criticality of energy consumption as a pivotal metric cannot be overstated when conducting performance evaluations in machine-type communication.

The present study introduces an LTE-MTCD energy consumption module meticulously designed for the NS-3 simulator. This module enables energy consumption simulation, specifically in LTE to MTCD communication, providing crucial insights into their energy dynamics. The newly developed LTE-MTCD energy module is informed by and grounded in the power profiles of commercial MTCDs. The authors have thoroughly experimented with and validated these profiles, as documented in [1]. Figure 1 visually delineates the hierarchical structure and the dependencies intrinsic to the LTE-MTCD energy module, offering a graphical representation of its design and functionality.

Section 2 discusses the NS-3 framework of LTE energy consumption. Section 3 explains the design and implementation of the LTE-MTCD energy consumption model. The validation and results of our proposed model are elucidated in Section 4. Section 5 includes concluding remarks and insights derived from our study.

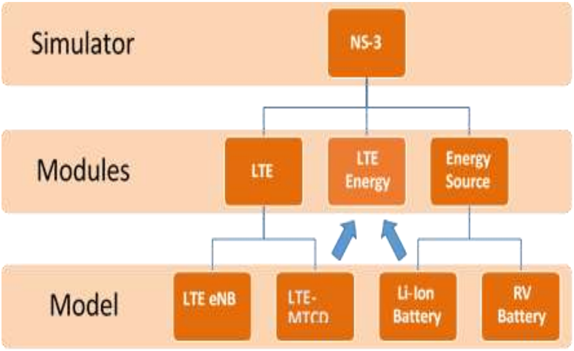

Fig. 1: LTE Energy Module in NS-3

II. RELATED WORKS

Within the scope of 3GPP, Nokia introduced a power model, as documented in [9]. However, this model's parameters are strictly tied to the Radio Resource Configuration (RRC) mode, overlooking factors like data rate and power levels. A different model detailed in [10] elucidates the Power Amplifier (PA) aspects but relies on a consistent power metric for the receiver and is rooted in WCDMA UEs. Carroll and colleagues conducted an analysis of smartphone power usage in 11], yet the depth of their study may need to be more conducive to system-level refinements. Li et al., as cited in [12], offer a comprehensive model predominantly emphasizing Radio Frequency (RF) components. Yet, certain facets, such as the PA model, appear to be obsolete. While chip producers maintain advanced models stemming from developmental platforms, as referenced in [8], these models remain under wraps. The recent debut of LTE networks has ushered in the first generation of LTE UEs in the public domain, paving the way for formulating an empirical model. In these models discussed and analyzed, only the UE model was not for Machine Type Communication Devices (MTCD).

III. ENERGY FRAMEWORK IN NS-3

NS-3's energy framework forms the foundation for modeling energy consumption and its sources. It comprises two pivotal elements: The Energy Source Model and the Device Energy Model. The former symbolizes the cumulative energy reserve for individual nodes. Its chief role is to provision energy to all the network devices (or NICs) affiliated with a given node.

The device energy model characterizes the energy utilization of a netDevice. A singular node might be associated with multiple netDevices concurrently (e.g., LTE, Wi-Fi), and each of these netDevices aligns with its distinct device energy model. Each model communicates the energy consumption specifics of its corresponding net device to the energy source, subsequently updating the source's residual energy. When the energy source is fully depleted, it sends notifications to all linked device energy models. To it. Multiple device energy models can be connected to a single energy source model.

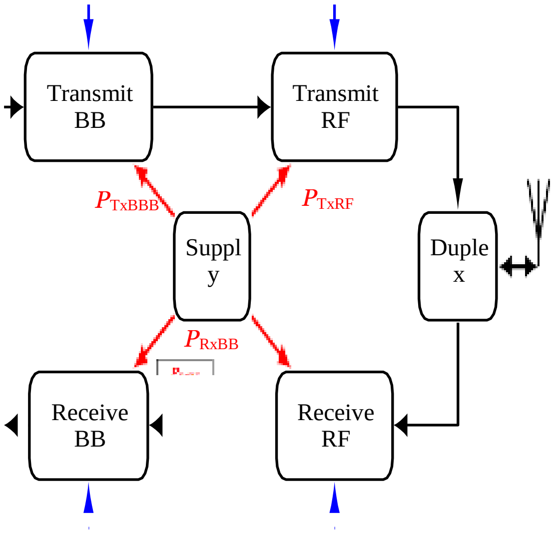

Fig. 1. LTE UE physical layer

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

IV. DESIGN AND IMPLEMENTATION OF NS3 ENERGY MODULE.

In [3], NS-3 energy architecture is discussed. It boasts a comprehensive scope combined with a modular layout, making it user-friendly. Its inclusion imparts minimal simulation overhead, ensuring that simulation velocities remain largely unaffected. Its adaptability further shines through, allowing seamless integration of new devices or energy source models. This framework proficiently caters to the following requirements: • The framework incorporates energy source models that account for linear energy sources. While these are theoretically ideal, they do not fully capture some nuances of actual batteries, like the dependency of battery efficiency on load current. Additionally, the framework encompasses models for non-linear energy sources, enriching its range of representation.

- It encompasses device energy models that illustrate the energy usage patterns of netDevices, notably including entities like the Wi-Fi radio.

- Additionally, the framework offers methodologies to relay energy consumption data to NS-3 entities outside the core energy architecture.

A. *LTE MTCD Power Consumption Model:*

Numerous studies have aimed at devising an optimal MTCD power consumption model. In reference [5], a trace-driven model was introduced to scrutinize power usage in LTE; this involved creating Android applications for LTE statistics collection and subsequent power profile derivation. The researchers in [1] closely monitored power consumption in various physical layer components of commercial MTCDs, providing valuable insights into power dissipation profiles. Due to its comprehensive understanding of power usage, the model presented in [1] was selected as the basis for our NS-3 energy module development. The power consumption model outlined in [1] meticulously breaks down power usage during different physical layer operations, categorizing the power consumption of LTE MTCDs into four distinct components:

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

The power consumed is modeled as follows.

$$P_{tot} = m_{idle} \cdot P_{idle} + m_{idle} \{ P_{con} + m_{Tx} \cdot m_{Rx} \cdot P_{Rx+Tx} + m_{Rx} \cdot [P_{Rx} + P_{RxRF}(S_{Rx}) + P_{RxBB}(R_{Rx}) + m_{2cw} \cdot P_{2cw}] + m_{Tx} \cdot [PT\,x + PT\,xRF\,(ST\,x) + PTxBB(RTx)]\} \; [Watt]$$

Here, the total power consumption is $Ptot$. An MTCD in an idle or connected state. Power consumption in idle and RRC-connected modes are $Pidle$ and $Pcon$, respectively. The $middle$ is the fraction of time an MTCD is in idle and connected states, respectively. PTx and PRx denote the power spent in transmit and receive chains, and $RxRF$ and $RxBB$ represent the power consumed in two components of the receiver chain.Similarly, $TxRF$ and $TxBB$ represent the power consumed by components of the transmit chain. $2CW$ corresponds to increased consumption when using two code words (CW) in the downlink.S denotes the Rx and Tx power levels, and R corresponds to Rx and Tx data rates.

B. Battery Module

Each MTCD is equipped with a battery, with its discharge governed by the energy expenditure module, contingent on the MTCD's power consumption. The chosen energy source for our implementation is the Lithium-Ion type. We initialize every MTCD's energy at 37800 J, corresponding to 2100 mAh, akin to the typical battery capacity of modern smartphones. Depending on the MTCD's operational state - Transmission, Reception, RRC connected, or RRC Idle - the consumed power is deducted from its battery reserve. Whenever an activity is triggered, the MTCD's energy expenditure module communicates with its linked battery through callbacks, updating the exact power expenditure.

C. LTE Energy Expenditure Module in NS-3

In NS-3, we introduced an innovative module named the LTE Energy Module (LEM). We recognized that LTE functions at a millisecond granularity, so we tailored our battery update intervals to this same precision. However, updating the battery every millisecond can impose a simulation overhead. Particularly in multi-MTCD setups, this can protract the simulation's completion time. Conversely, updating battery values at infrequent, fixed intervals might skew the results and potentially misguide any algorithms leveraging this energy module. To strike a balance, our design for battery value updates is bifurcated: During active data transmissions, updates occur every millisecond. In cases where there are no transmissions, or they conclude early, the IDLE mode duration is assessed, leading to battery metric adjustments. The LTE Energy Model (LEM) systematically gauges power consumption, emphasizing transmission, reception, and state transitions during updates. It then interfaces with the MTCD battery module to reduce power consumption.

`DoTransmitPdu()` is employed to track packet transmissions, whereas `DoReceivePhyPdu()` supervises packet reception in LTE MTCD MAC, triggering updates. The `DecreaseRemainingEnergy()` function, part of the Lithium-Ion energy source, modifies the battery's energy metrics. We assume a consistent 5V supply voltage. Table I presents default power values for distinct states. The `LastUpdateTime` variable aids in determining IDLE duration between and after transmissions. If an MTCD remains IDLE throughout, this duration is computed. The concluding update is implemented via the `DoDispose()` function in the LTE-MTCD-MAC.

Figure 2 presents the class structure of the LTE Energy Module within NS-3. Within this framework, a node container amalgamates the LteNetDevice with the LiIonEnergySource. A helper class associates the LTEMTCDNetDevice object with the energy source via the LteEnergyModule to facilitate this integration. The newly devised LteEnergyModule offers an interface to ascertain the LTE power consumption rate and gauge the residual energy in the battery. Based on the MTCD's prevailing operational state and its respective power consumption, as outlined by Equation 1, the LteEnergyModule deducts energy from the source.

V. VALIDATION OF LTE ENERGY MODULE

An experiment has been conducted on the LTE energy module to confirm its accuracy and validity. The energy consumption of Machine Type Communication Devices (MTCDs) during activities such as downloading, uploading, and concurrent usage has been meticulously profiled. Performance validation was also conducted under network conditions involving high user activity. This incorporated an evaluation of the power profiles of users in relation to various eNB scheduling algorithms, as well as an analysis of the energy consumption associated with different handover procedures.

TABLE I: Power spent in different states by LTE MTCD

State	Notation	Power (mWatt)
IDLE $(midle)$	$Pidle$	50
CONNECTED $(mcon)$	$Pcon$	1.52
ONLY RECEPTION (mRx)	PRx	0.47
ONLY TRANSMISSION (mTx)	PTx	0.57
TRANSMISSION & RECEPTION $(mRx + Tx)$	$PRx + Tx$	0.17
TWO CODEWORD $(m2cw)$	$P2cw$	0.06

In a given scenario, a singular UE interacts with a single eNB. The MTCD consistently receives UDP packets from a remote host at predefined intervals. This inter-packet interval fluctuates between 1 msec and 5 msec. Table II delineates the parameters used for the various simulation scenarios. Figure 3 illustrates the remaining energy at MTCD (measured in J) over varying simulation lengths. A clear observation from Figure 3 reveals that shorter packet transmission intervals consume significantly more power. Conversely, as the packet transmission interval elongates, the number of sub-frames in which a UE remains in reception mode tends to rise, contingent upon the LTE MAC scheduler. This is indicative of the energy usage. The pivotal role of the LTE MAC scheduler in determining the energy consumption of an MTCD prompted an evaluation of multiple MAC schedulers to discern their respective energy usage patterns, as detailed in subsequent experiments.

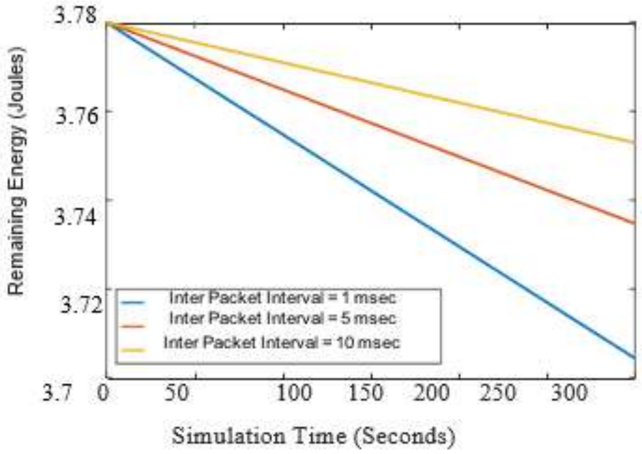

Fig. 3: Energy decay in downlink for MTCD.

VI. CONCLUSION

Comprehensive studies on the LTE energy module were undertaken to ascertain its accuracy and reliability. Meticulous profiling of the energy expenditure of Machine Type Communication Device(MTCD) during download upload. The system's performance was tested when many users were active in the network. Detailed analyses of the energy consumption patterns of all users considered different eNB scheduling methodologies. Moreover, the energy implications of various handover algorithms were thoroughly assessed.

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