Workshop on ns-3

Implementation of mmWave-energy Module and Power Saving Schemes in ns-3

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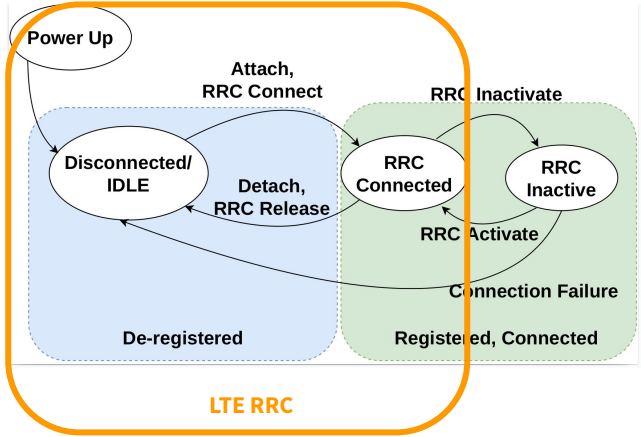
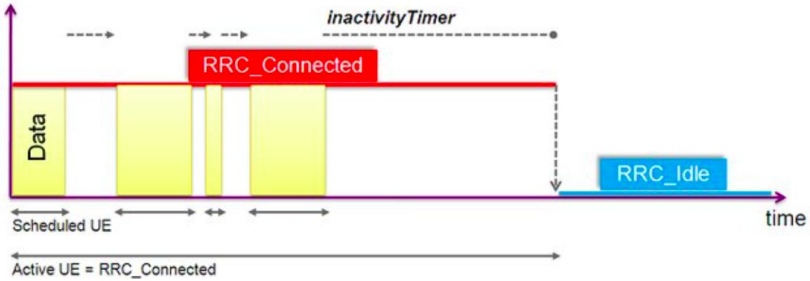
Introduction

- 5G New Radio (NR) cellular networks operating at mmWave frequencies are targeted to support diverse use cases,
  - eMBB,
  - mMTC,
  - URLLC.
- Energy-Efficiency is one of the key performance indicators for NR technology.
- 3GPP, in its 5G release-16, proposed various power-saving schemes
  - RRC INACTIVE state,
  - cDRX
- We implemented and analysed UE RRC state-based energy consumption module, including different power saving schemes in ns3.
- Our module acts as a wrapper over ns3-mmWave * module.
- We have thoroughly evaluated the module and validated the implementation with the 3GPP standards.

* ns3-mmWave https://github.com/nyuwireless-unipd/ns3-mmwave

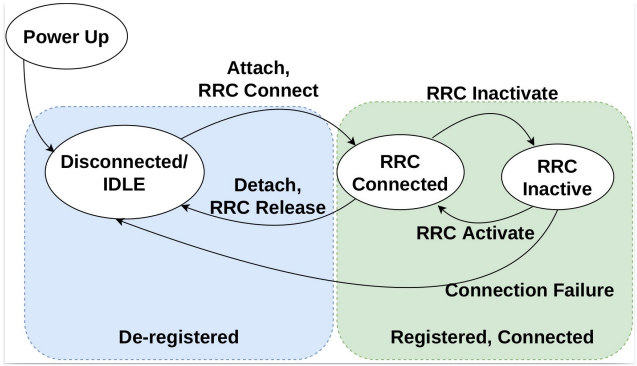
Newly Proposed RRC INACTIVE State





- In 4G LTE, we have 2 RRC States:
  - RRC IDLE
  - RRC CONNECTED
- RRC Inactivity Timer triggers this state change.
- This timer leads to a trade-off b/w power consumption and communication efficiency.
- Longer Timer → Better Battery Life → More Latency !

Newly Proposed RRC INACTIVE State



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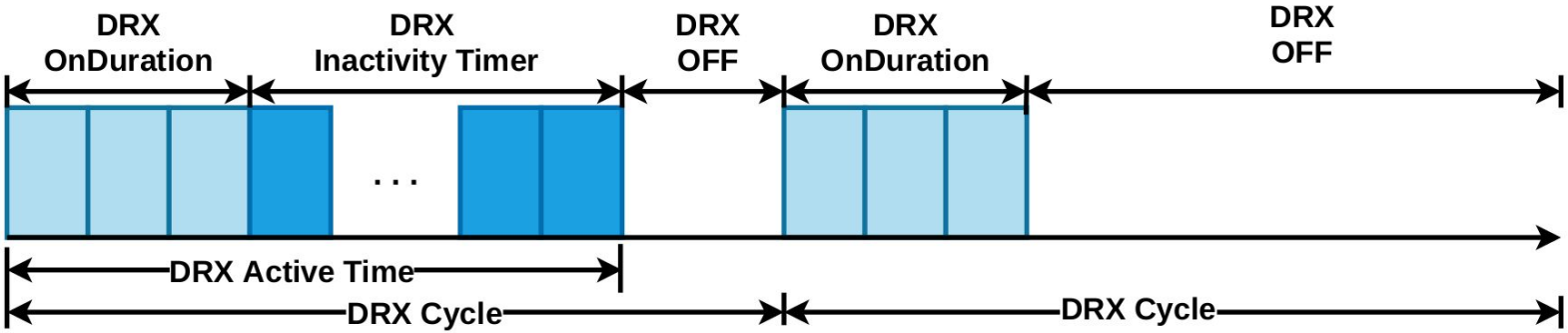
- 5G NR incorporates a new state **RRC INACTIVE**
  - control plane latency
  - signaling overhead
  - energy requirement
- UE identity, context, mobility info is maintained by the n/w

cDRX Mechanism

- RRC signaling sets a cycle where the receiver of the UE is operational for a certain period
- UE needs to detect paging occasion and system information updates coming from the n/w.
- If it receives any PDCCH message, it switches to RRC CONNECTED state and keeps the Inactivity timer turned on.
- On the expiry of the inactivity timer, it then switches back to lower power IDLE state.
- cDRX mechanism allows the UE to enter RRC INACTIVE state periodically.
- Finally helps in lowering the net energy consumption of the UE.



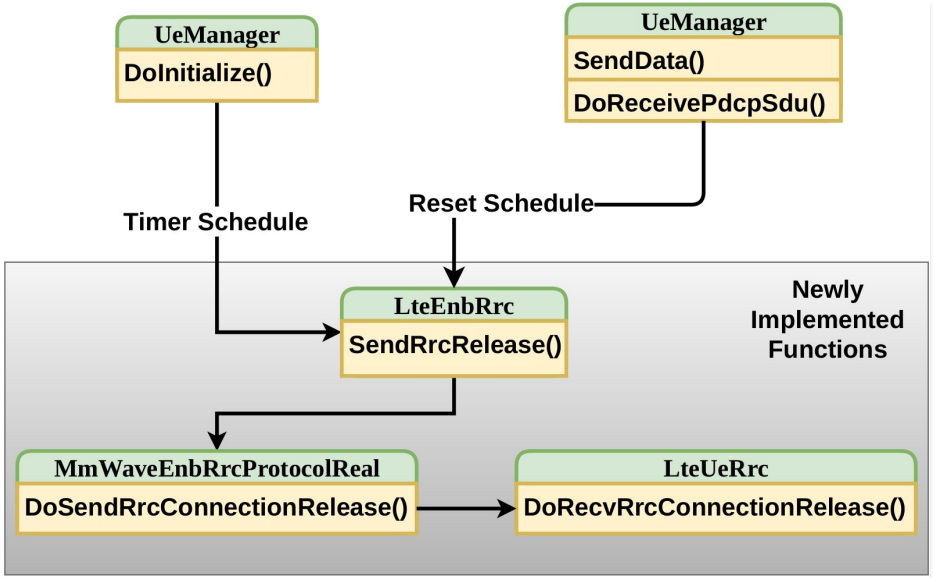
Contributions

Our contributions to the current ns3-mmWave module include

- Development of the RRC Connection Release method
- Paging notifications
- Addition of the newly proposed RRC INACTIVE state
- Implementation of cDRX mechanism
- UE RRC energy module to evaluate UE's energy consumption across different RRC states.

RRC Connection Release Method

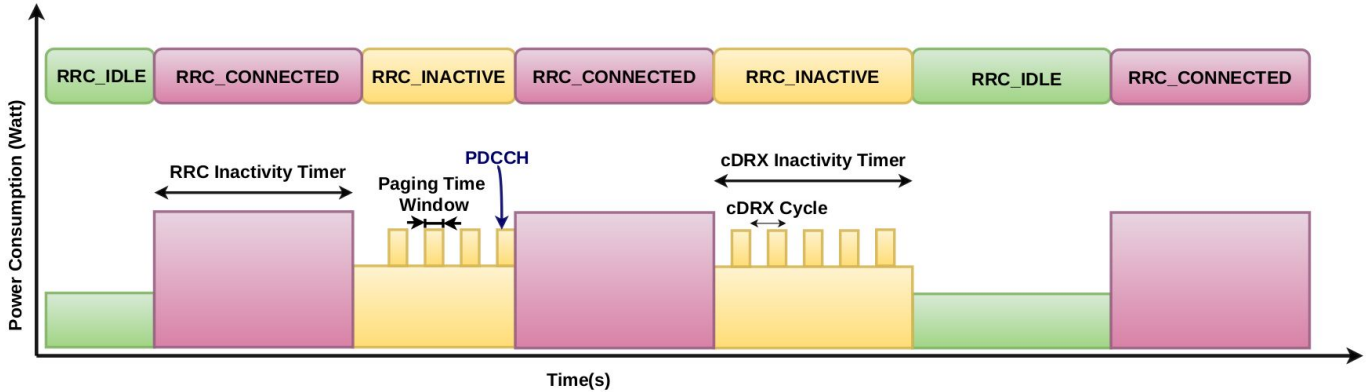
- Current implementation of the ns3-mmWave RRC state machine lacks RrcConnectionRelease method!



- Modified the LTE_ENB_RRC and LTE_UE_RRC files.
- The LTE_ENB_RRC method sends RRC Release message using SendRrcRelease.
- UE switches to low power state RRC INACTIVE.

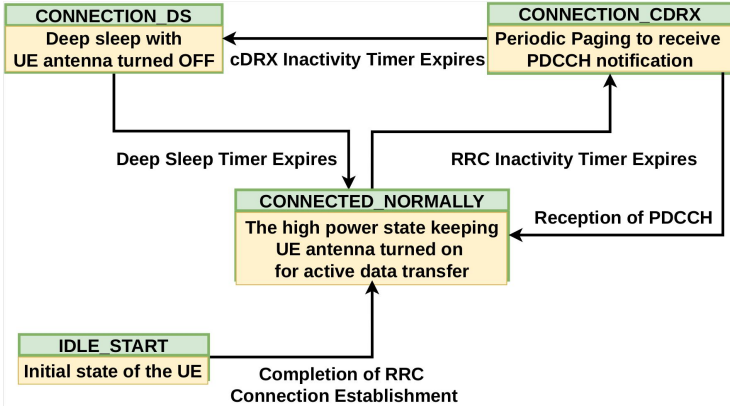
Implementation of Power Saving Schemes

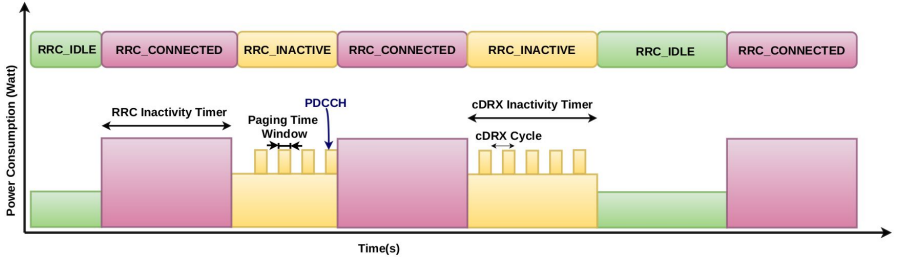
- **Implementation of RRC INACTIVE State:**
  - In RRC INACTIVE state UE enters paging mode periodically, to receive PDCCH DL data notification or the UL data grant from the eNB.
  - The paging direct message is sent to the UE from the eNB using LTE_ENB_RRC.
  - The LTE_RRC_SAP receives the paging information to check for PDCCH reception at the UE.



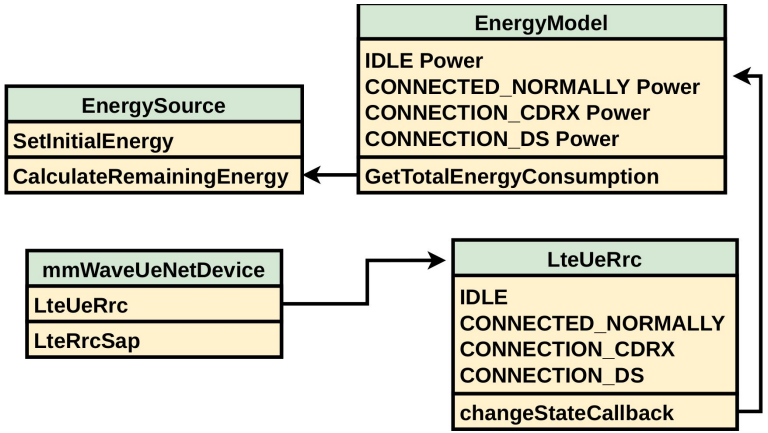
Implementation of Power Saving Schemes

- **cDRX Implementation:**
  - RrcConnectionRelease() function is called using the preset cDRX timers.
  - cDRX timers consists of
    - RRC Inactivity Timer (rrc_release_timer)
    - cDRX Inactivity Timer (inactivity_timer)
  - All the changes implemented in the LTE_UE_RRC and LTE_ENB_RRC





Implementation of RRC Energy Module



- Energy source is installed on the UE node.
- LteUeRrc provides trace source for the RRC state change.
- Energy model uses the corresponding trace sink to update the total energy consumption based on the RRC state power consumption.

Power Consumption Model *

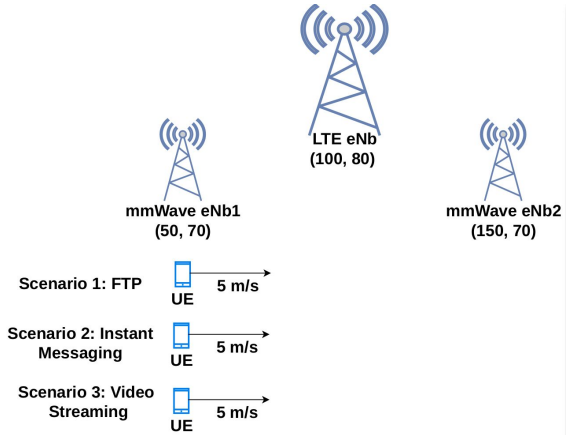
Power State	Relative Power (mW)
Deep Sleep	1
Light Sleep	20
Micro Sleep	40
PDCCH-only	100
PDCCH+PDSCH	300

* 3gpp TR 38.840 – study on user equipment (ue) power saving in nr.

Evaluation Setup

Evaluation Setup

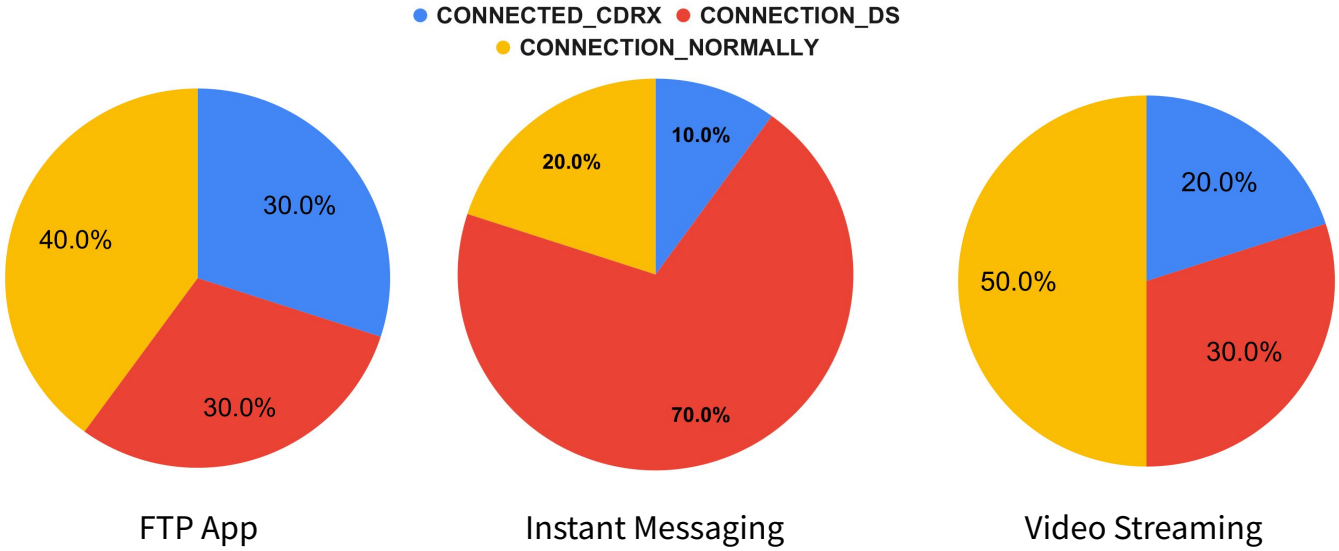
Parameters	Applications		
	FTP Traffic	Instant messaging	Video Streaming
Packet Size	0.5 Mbytes	0.1Mbytes	-
Inter Arrival Time	200ms	2sec	-
{cDRX cycle, cDRX Inactivity Timer, OnDuration}	{320,200,5}, {320, 80, 5}, {160, 100, 4}, {160, 40, 4}, {40, 25, 2}, {40, 10, 2}		



- 3 different user applications
  - File Transfer Protocol (FTP) application
  - Instant Messaging application
  - Video streaming application
- Baseline Energy consumption model:
  - Default ns3-mmWave
  - PHY-state based energy model*

* An ns3-based Energy Module of 5G NR User Equipments for Millimeter Wave Networks (INFOCOM '21)

Evaluation

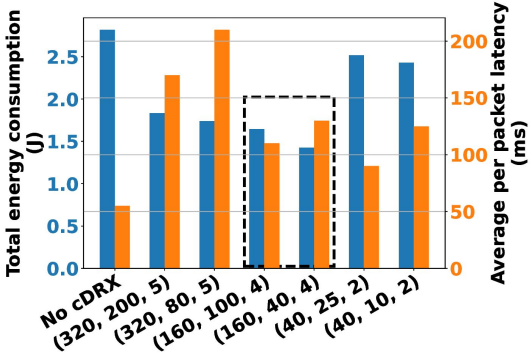


FTP App | Instant Messaging | Video Streaming

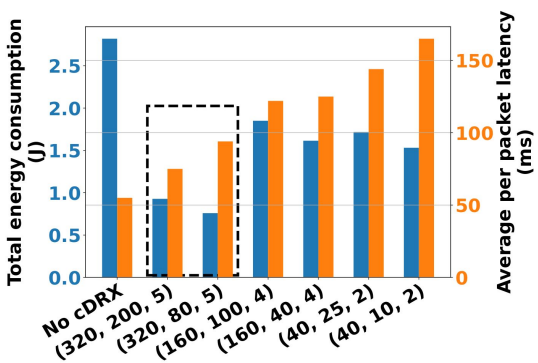
Distribution of time taken in each state for the three different applications

IDLE time for Instant Messaging is max while for Video Streaming application CONNECTED time is max

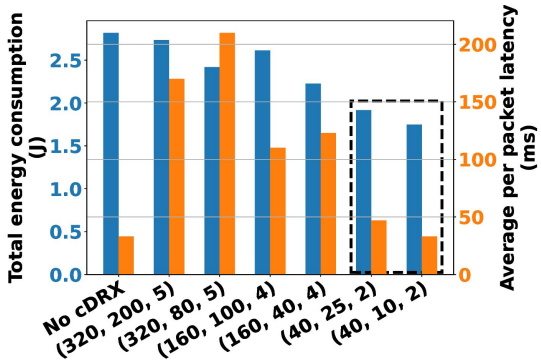
Evaluation



Energy consumption and latency of **FTP application**



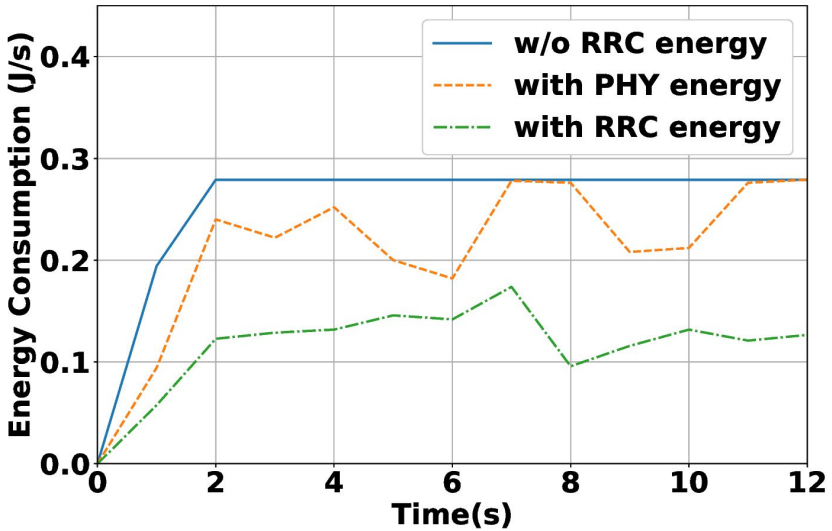
Energy consumption and latency of **Instant Messaging application**



Energy consumption and latency of **Video Streaming application**

- In the instant messaging application the IAT is 2s, so UE stays mostly in IDLE
- A longer cDRX cycle (320ms) in this case gives the minimum energy consumption and minimum latency
- In the video streaming application the UE stays in the CONNECTED mode mostly, thus shorter cDRX cycles (40ms) perform the best

Evaluation



Under FTP application, Change in UE's energy consumption over time with different energy models

- Energy consumption is maximum for the default ns3-mmwave repo
- Our implementation performs better in comparison to the baseline PHY-state based energy consumption model.

Conclusion

- This paper detailed the implementation of the UE RRC energy model and power saving scheme as defined in 3GPP Release-16 38.840, as an extension tool for the ns-3 open-source simulator
- We have thoroughly evaluated the module and validated the implementation with the 3GPP standards.
- Our results were compared with the baseline PHY-state based UE energy consumption model
- This module can help in designing energy-aware user applications as well as networks that can provide better User QoE and longer battery life.
- In our future work, we want to extend this module to support the base station energy modelling, so that an end-to-end energy consumption of the network can be captured.
- Source Code: https://github.com/arghasen10/ns3-mmwave/tree/rrcenergy

Contact me

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Thank you for your attention!