DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

1222·2022 800 ANNI

UNIVERSITÀ DEGLI STUDI DI PADOVA

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An ns-3 Implementation of a Battery-less Node for Energy-harvesting Internet of Things

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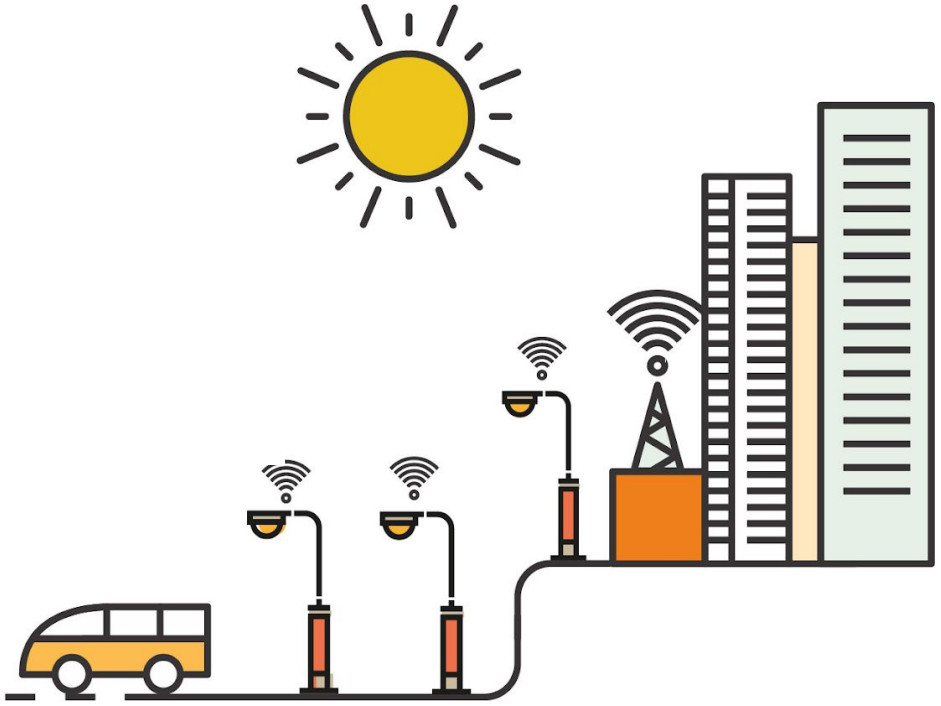
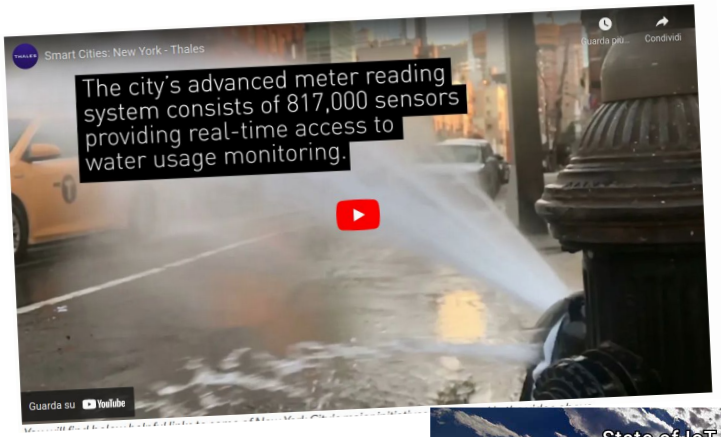
Outline

1. Context and motivation
2. Model of a battery-less device
3. LoRaWAN
4. Validation results
5. Conclusions



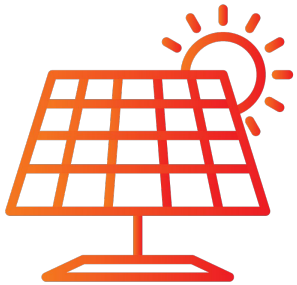
Introduction

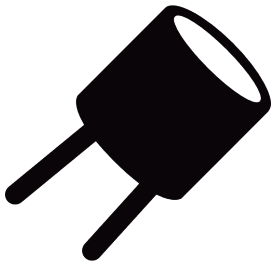
- Internet of Things (IoT)



Battery-less devices

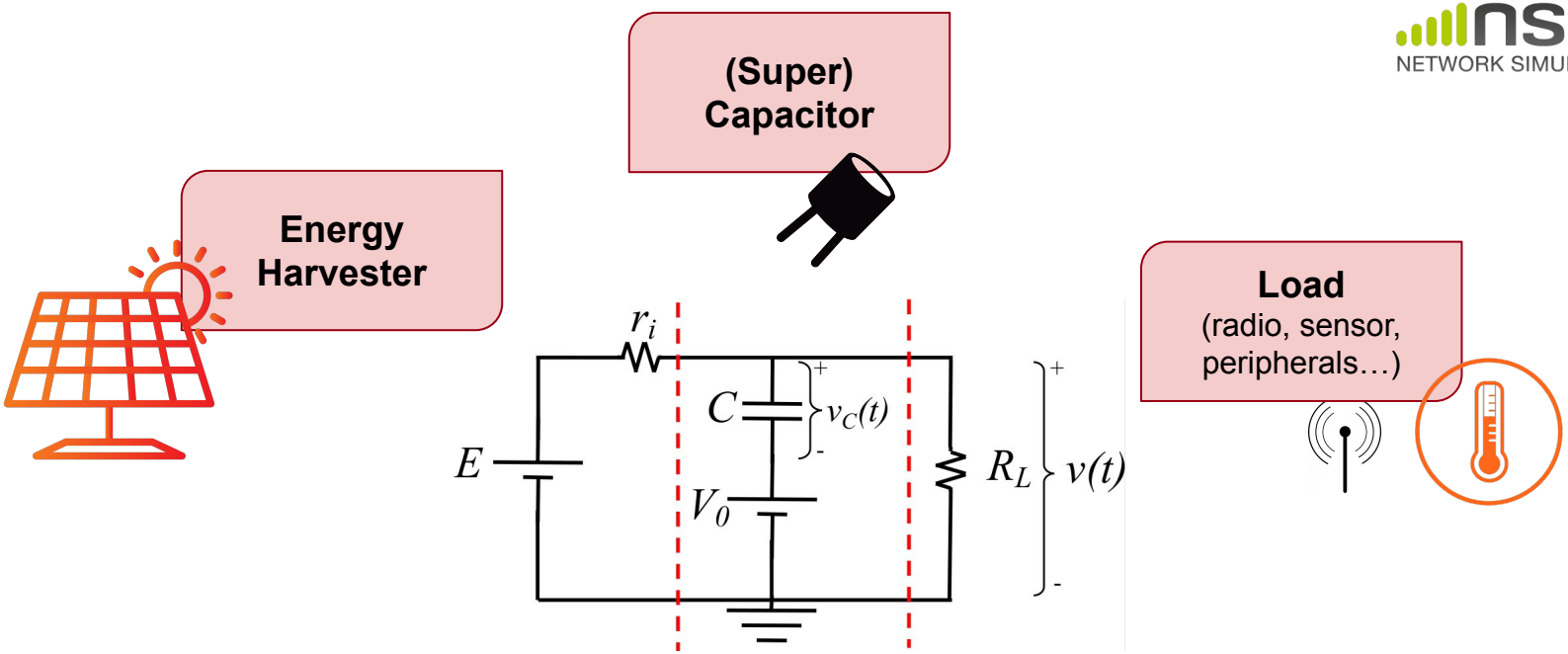
Energy harvesting techniques + (Super) capacitors → **Battery-less Capacitor-based IoT sensor nodes**





(solar, wind, thermal, RF, vibrations, … energy sources)

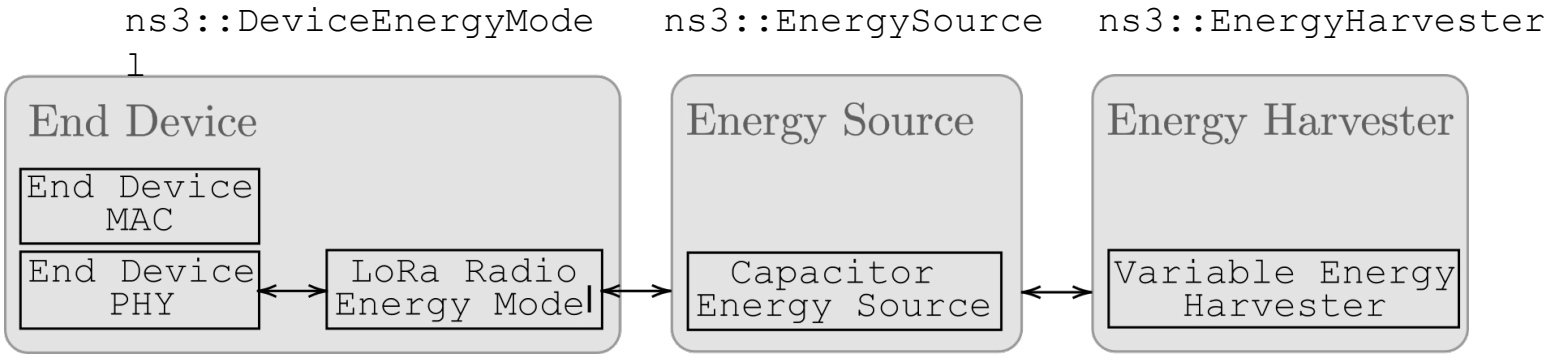
Model of a battery-less device



- Device will switch off if voltage below V_{th_low}
- It can turn on again if the capacitor recharges enough (above V_{th_high})

ns-3 implementation

Relation between classes



Relavant attributes of the `CapacitorEnergySource` class

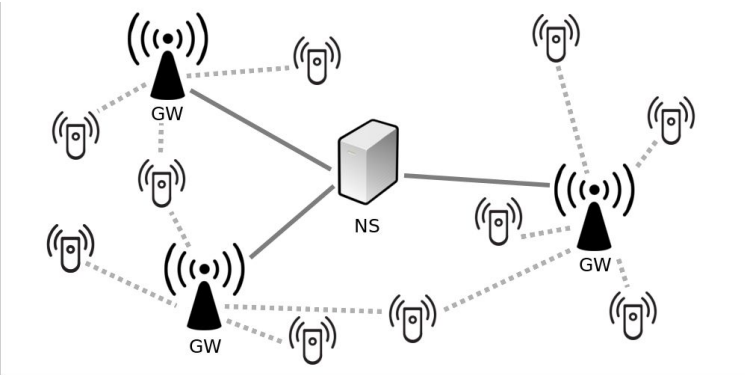
Attribute	Description
Capacitance	Capacitance [F]
CapacitorEnergySourceInitialVoltage	Initial voltage of the capacitor [V]
CapacitorMaxSupplyVoltage	Maximum supply voltage for the capacitor energy source [V]
CapacitorLowVoltageThreshold	V_{th_low}, as fraction of the maximum supply voltage
CapacitorHighVoltageThreshold	V_{th_high}, as fraction of the maximum supply voltage
PeriodicVoltageUpdateInterval	Time interval between periodic voltage updates

Application to a **LoRaWAN** node

- Low Power Wide Area Network technology
- Leverages the LoRa modulation
  - Spreading Factor (SF) $\in \{7, 12\} \rightarrow$ Data Rate $\in \{5, 0\}$

Application to a **LoRaWAN** node

- Low Power Wide Area Network technology
- Leverages the LoRa modulation
  - Spreading Factor (SF) $\in \{7, 12\} \rightarrow$ Data Rate $\in \{0, 5\}$
- Star topology
  - Network Server
  - Gateways
  - End Devices
- Two types of traffic
  - Unconfirmed/confirmed



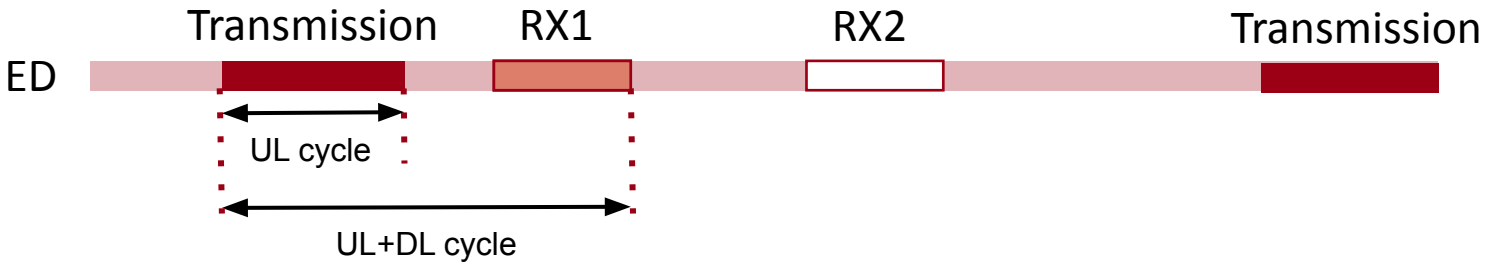
LoRaWAN®

Application to a **LoRaWAN** node

Classes of devices

[BATTERY-POWERED SENSORS]

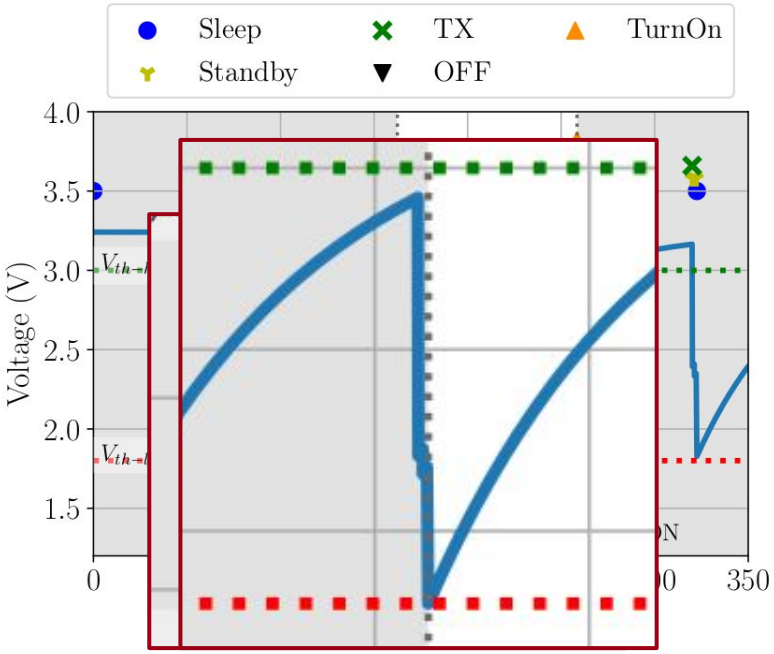
- Class A (all)
  - Mandatory supported by all LoRa devices
  - RX2 uses the lowest DR by default



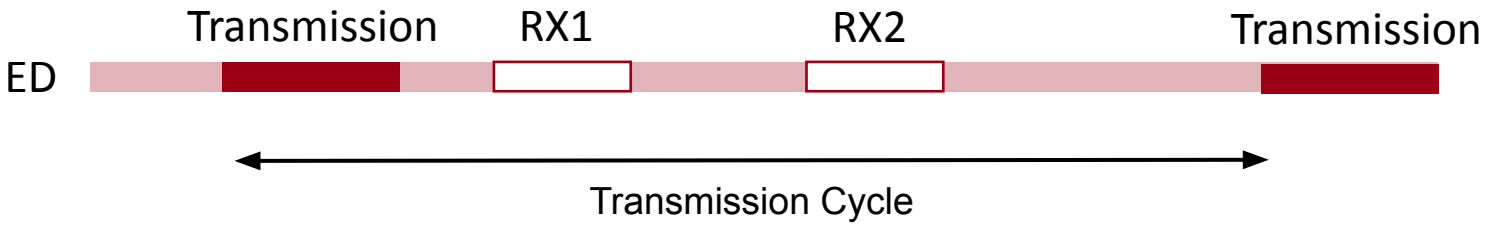
State	MCU	Radio current	Total current
Off	Standby	0	5.5 μA
Turn On	Active	-	15 mA
Sleep	Active	1 μA	5.6 μA
Tx	Active	28 mA	28.011 mA
Idle	Standby	1.5 μA	7 μA
Standby	Standby	10.5 mA	10.5055 mA
Rx	Active	11 mA	11.011 mA

Preliminary considerations

Voltage depletion during different phases

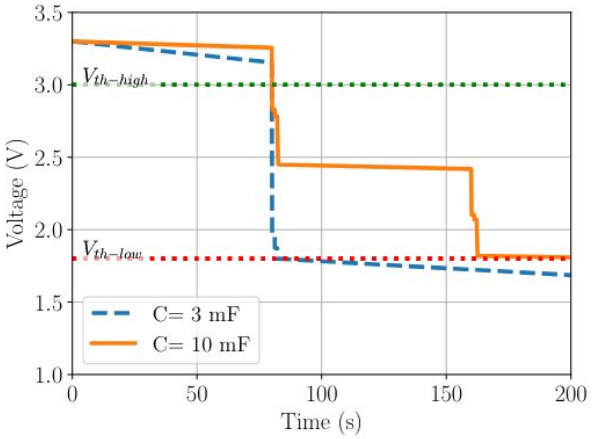


Simulation settings (if not specified)
- 1 ED, 1 GW
- V(0) = 3.3 V
- Vth_low = 1.8 V
- Vth_high = 3 V
- PL = 10 B

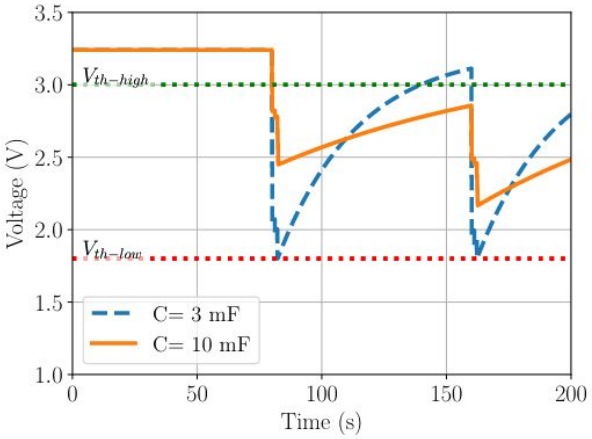


Preliminary considerations

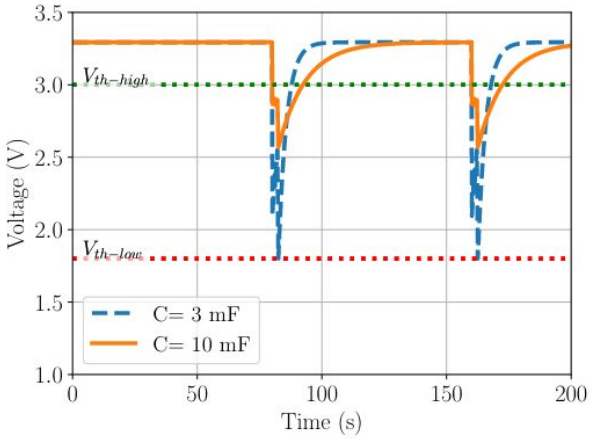
Voltage for different values of $P_{harvester}$ and capacitance



(a) $P_{harvester}$ = 0 W.



(b) $P_{harvester}$ = 0.001 W.

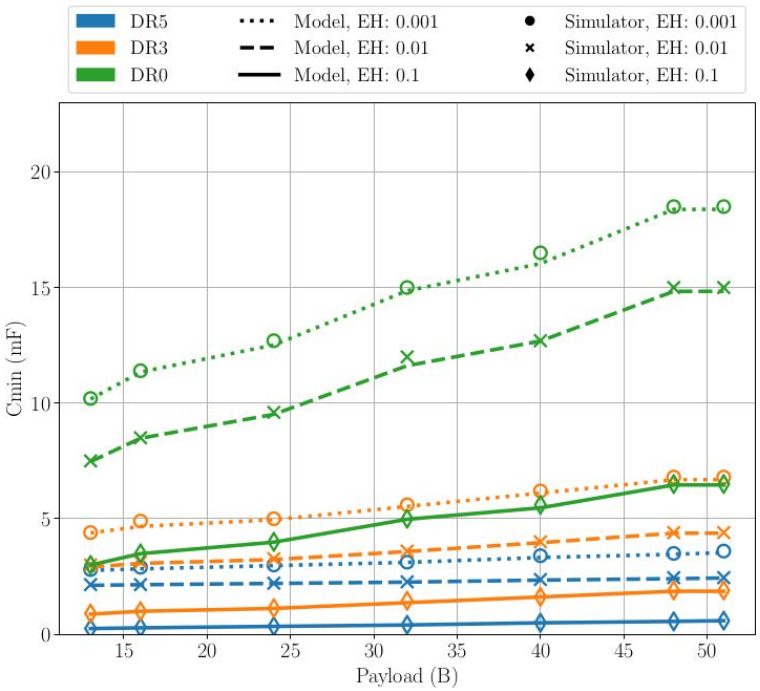


(c) $P_{harvester}$ = 0.01 W.

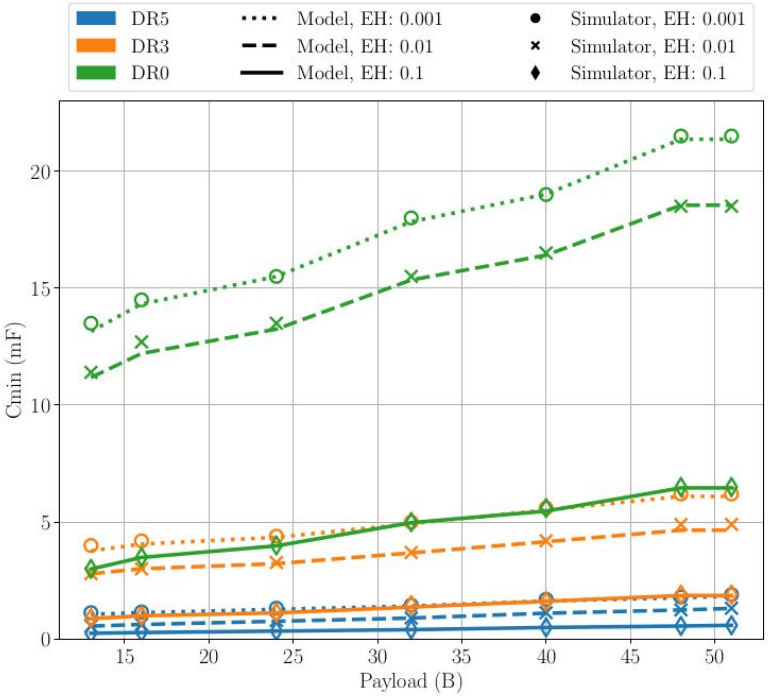
Validation

Minimum capacity (Cmin) to complete a cycle compared to mathematical results, computed as in [4]

UL cycle



UL and DL cycle

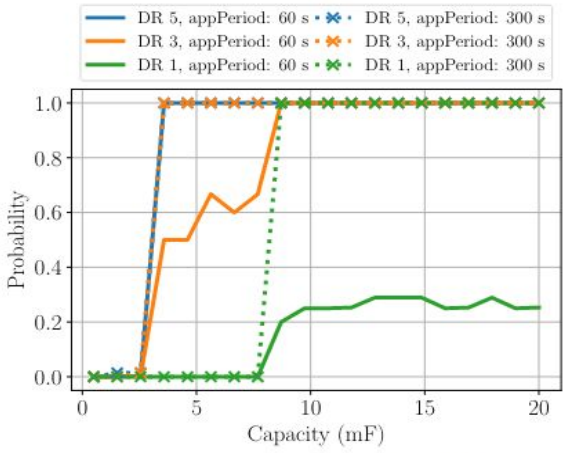


[4] Carmen Delgado, José María Sanz, Chris Blondia Chris, and Jeroen Famaey. 2020. Battery-Less LoRaWAN Communications using Energy Harvesting: Modeling and Characterization. *IEEE Internet of Things Journal* (Aug 2020).

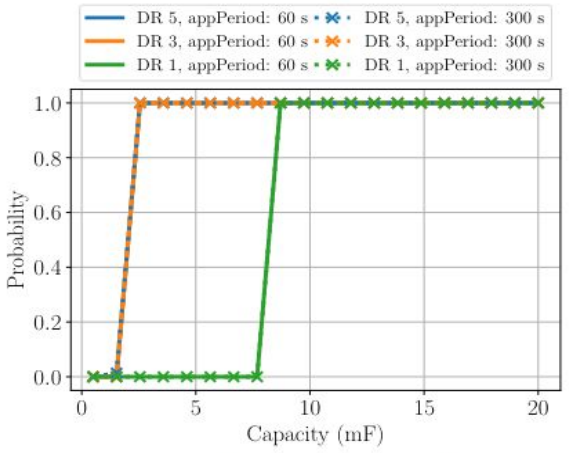
Performance

Success probability for different communication settings

Unconfirmed traffic

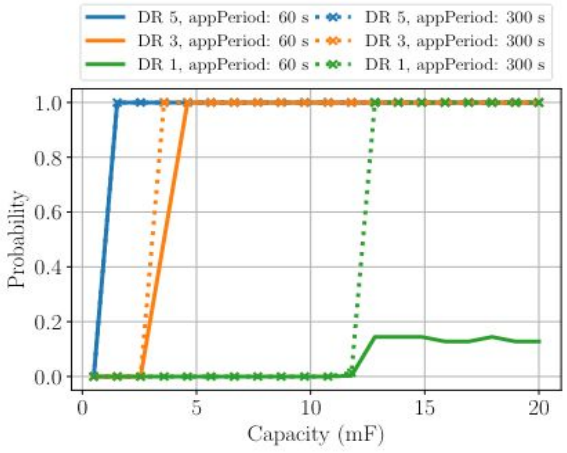


(a) $P_{harvester}$ = 0.001 W

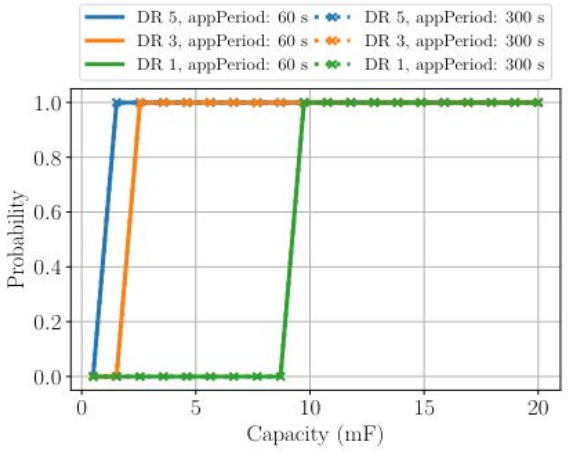


(b) $P_{harvester}$ = 0.01 W

Confirmed traffic



(a) $P_{harvester}$ = 0.001 W



(b) $P_{harvester}$ = 0.01 W

Conclusions

- Implementation of Capacitor Energy Source
- Comparison with mathematical model from the literature
- Application to LoRaWAN node…
  - … but it can be modified/extended to work also with other communication technologies
- Tool to help research on Green IoT networks

[1] Martina Capuzzo. 2021. capacitor-ns3. https://github.com/signetlabdei/capacitor-ns3.

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