Simulation of a Novel MAC Protocol on the NS-3 Platform

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Outline

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Smart Home

- Home appliances controlled remotely
- Fuelled by IoT technologies
- Battery usage increased in IoT era
- Cons of excessive battery usage
  - environmental degradation
  - stress in changing dead batteries

Figure: 1. Smart Home Visual (source: www.bemi.fi).

Introduction (contd...)

Battery-free Smart Home

- Home electronics still dependent on batteries ?

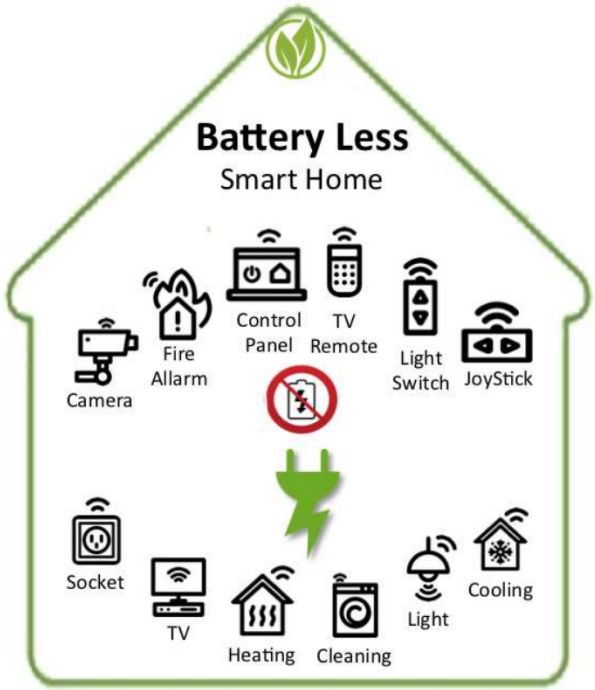

Figure: 2. Battery-free Smart Home

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Objectives

- Introduce the NS-3 library.
- Understanding the Novel MAC protocol.
- Simulate the various battery-free home electronic devices.
- Simulate the Novel MAC protocol on the reader.
- Performance analysis of the MAC protocol.

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NS-3 - An Introduction[1]

The NS-3 Library

- A discrete event network simulator
- C++ and Python
- *Waf* build system
- Abstractions :
  - Node
  - Application
  - Channel
  - Transport
  - Network
  - Data Link
- Helpers

[1] NS-3 Project. *NS-3: Conceptual Overview*. URL: https://www.nsnam.org/docs/release/3.30/tutorial/html/conceptual-overview.html.

Governing Algorithm

Multi-Arm Bandit Problem[2]

- Multiple actions with unknown reward to choose from
- Goal is to maximize reward margin through series of actions
- Example: Website advertisement to visitors
- Exploitation and Exploration
- Action-Reward function:

$$\theta^* = Q(a^*) = \max_{a \in A} Q(a) \tag{1}$$

Where:

$Q(a_t) = \mathbb{E}[\, R|A = a] \, = \theta$

θ^* optimal probability

[2] Richard S. Sutton and Andrew G. Barto. *Reinforcement Learning, An Introduction*. Second. Cambridge, Massachusetts London, England: The MIT Press, 2018.

Governing Algorithm (contd...)

APT-MAC Protocol[3]

- Translates into Multi-Arm Bandit as:
  - Reader: agent performing actions
  - Set of Actions: query tag_i , query tag_j ...
  - State set: ready to perform new query
  - Computing expected reward of each action
  - Keep record of the reward of each action

[3] Gaia Maselli, Mauro Piva, and John A. Stankovic. "Adaptive Communication for Battery-Free Devices in Smart Homes". In: *IEEE Internet of Things* (2019).

Governing Algorithm (contd...) I

Algorithm 1: APT-MAC pseudocode

```
1:  Master M                                          ▷ Reader
2:  Set D                                             ▷ Devices
3:  Map R:( d∈D) →float                               ▷ Reward Devices Map
4:  Set MinQD                                         ▷ Minimum Query Delay
5:  Maximum Query Delay MaxQD
6:  Set DLTH                                          ▷ Data Loss Threshold
7:  for d ∈ D do
8:      R[ d] = 1.0
9:      Set MaxQD
10: end for
11: R = softmax( R)
12: while true do
```

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Governing Algorithm (contd...) II

```
13:     Device next = chooseNext( R)
14:     Bool goodQuery = M.query( next)
15:     if goodQuery then
16:         R[ next] =updateReward( next,bonus)
17:         if getDataLoss < DLTH then
18:             updateMaxQD
19:         end if
20:     else
21:         R[ next] =updateReward( next,malus)
22:     end if
23:     R = softmax( R)
24: end while
```

Governing Algorithm (contd...)

APT-MAC Protocol

- Reward is updated with function:

$$Q(a_i)(n+1) = Q(a_i)(n) + \alpha(Reward - Q(a_i)(n)) \quad (2)$$

Where:

α = learning rate

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Tag-Augmented Nodes

Markov Representation

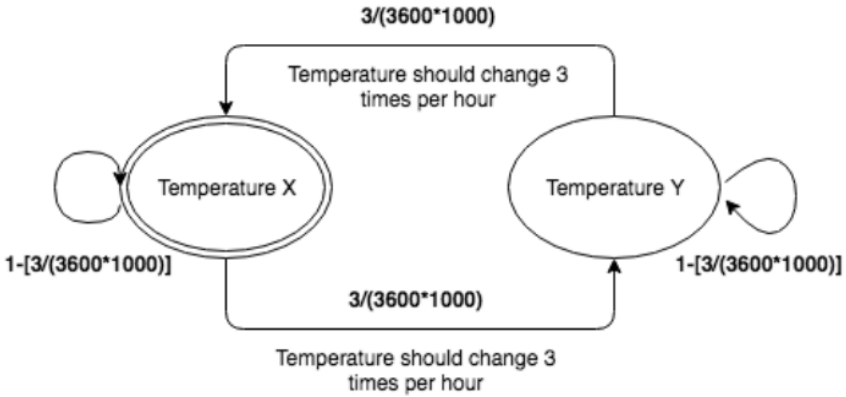

Figure: Temperature Sensor model

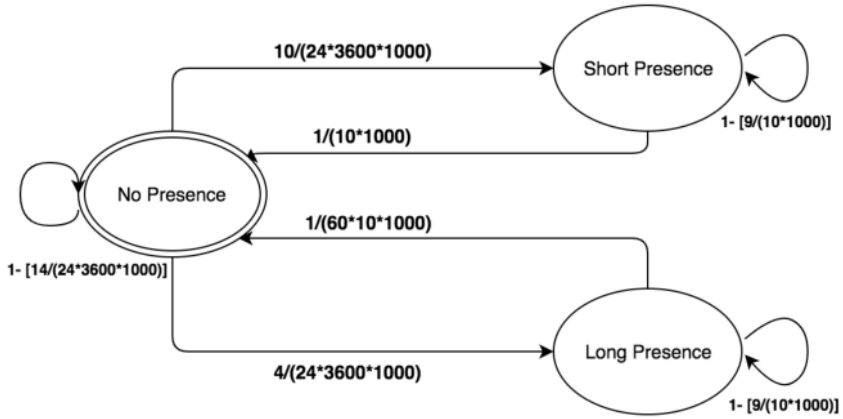

Figure: Presence Sensor model

Tag-Augmented Nodes (contd...)

Markov Representation

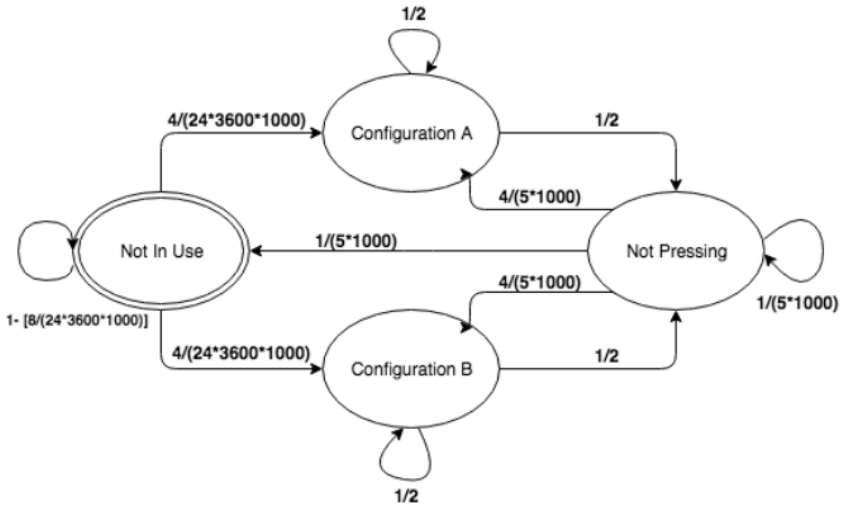

Figure: TV Remote model

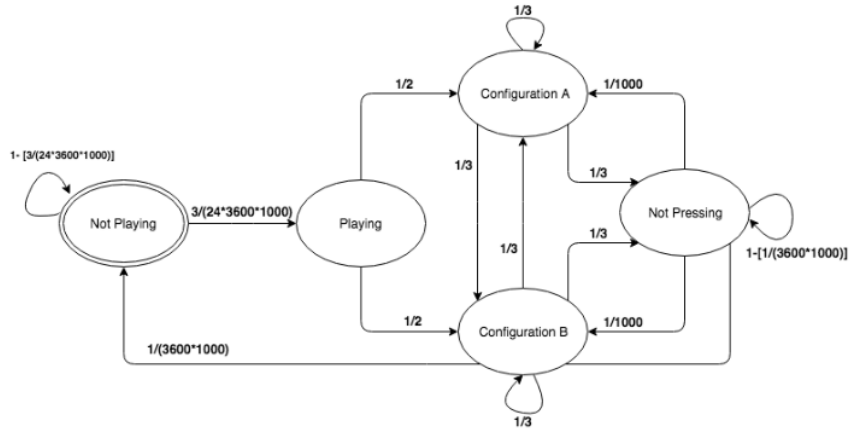

Figure: Joystick model

Tag-Augmented Nodes (contd...)

Packet Header

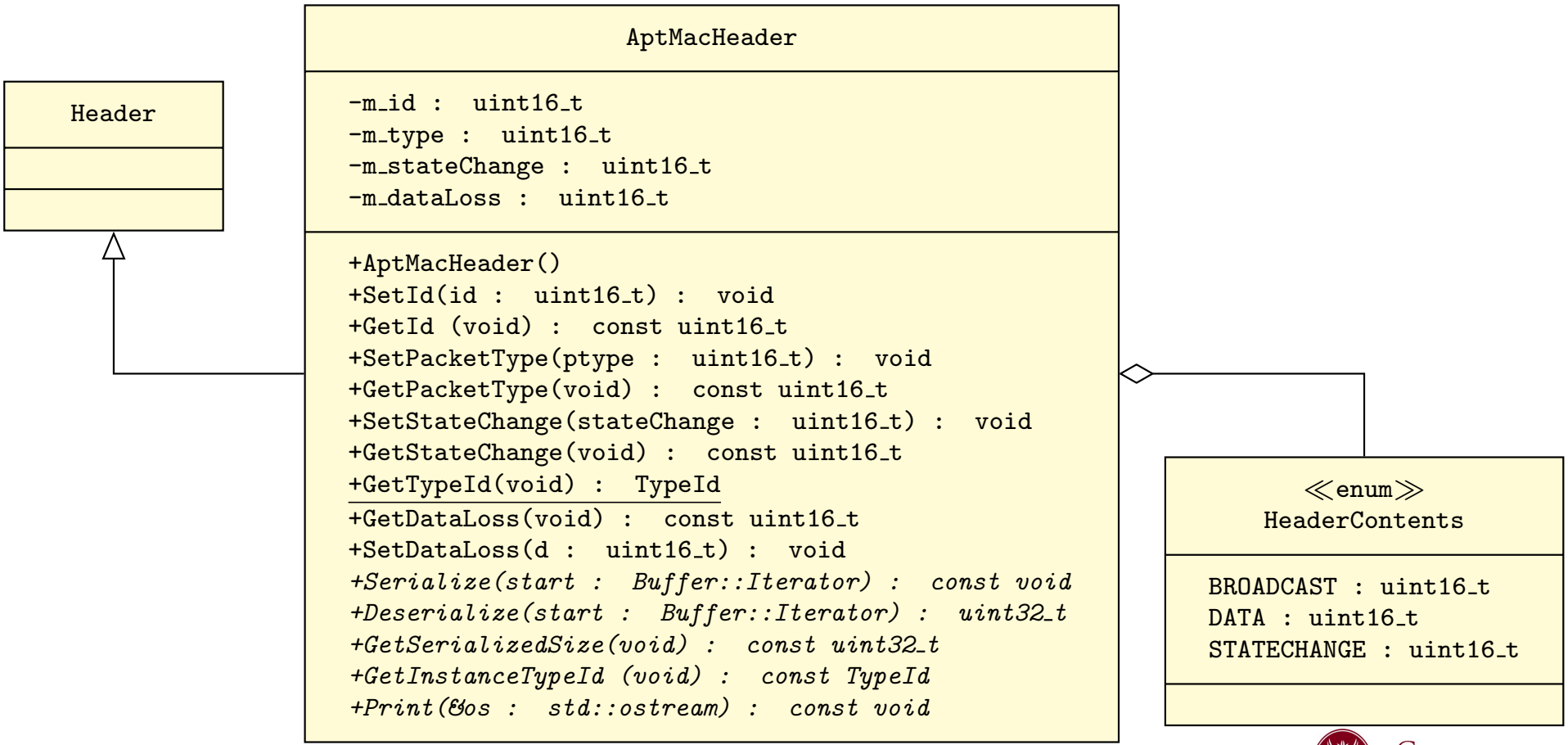

Figure: Class Diagram - APT-MAC Header

Tag-Augmented Nodes (contd...)

Devices Simulation

Figure: Class Diagram - Sensory Nodes

Tag-Augmented Nodes (contd...)

Devices Simulation

- Enumeration of some functions :
  - StartApplication
  - StopApplication
  - HandleBroadcast
  - HandleDataQuery
  - GeneratePacket
  - SchedulePacketGenerate
  - NextState
  - Send
  - UpdateNewDataSent
  - UpdateNewDataProduced
  - GetQueryCounter

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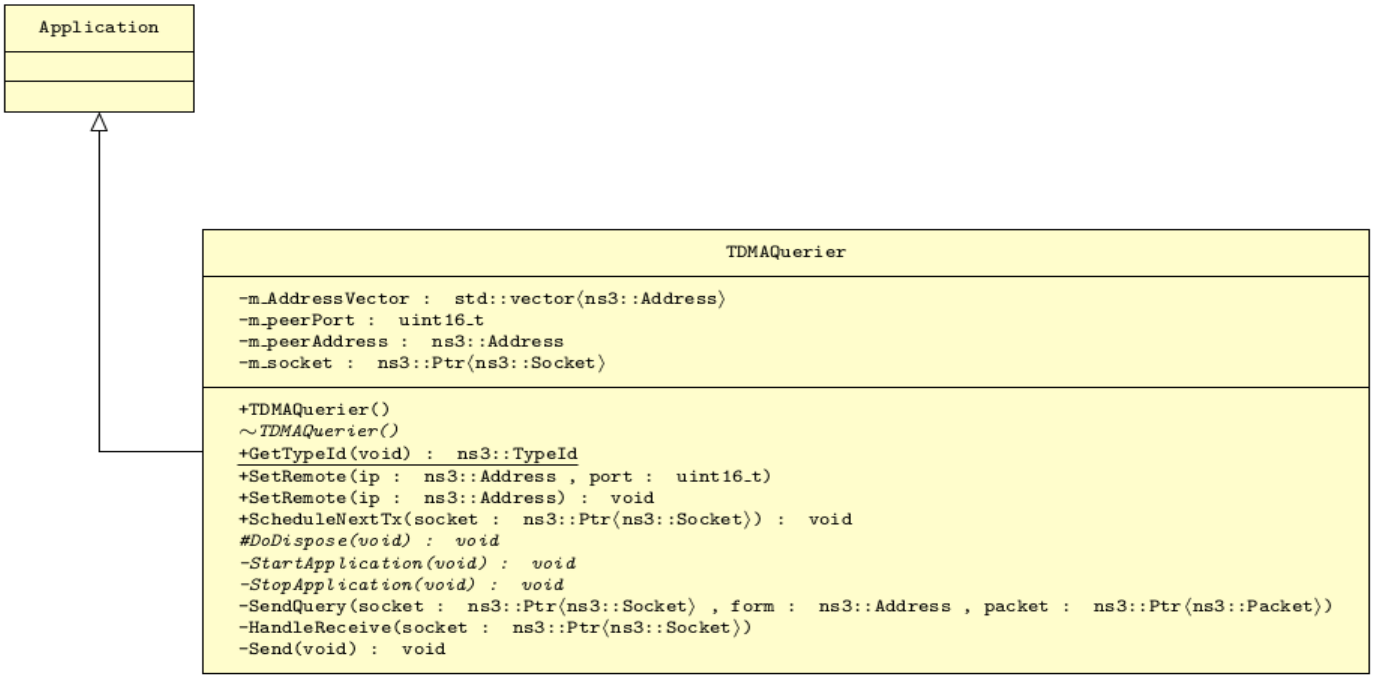
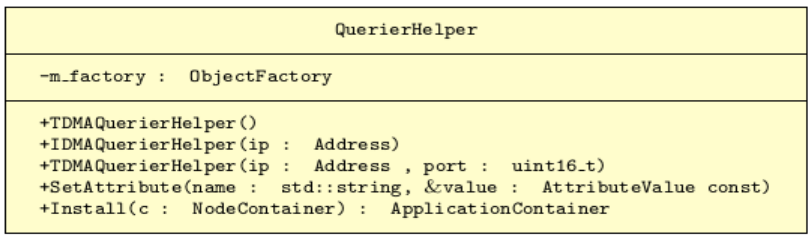
Simulation of Readers

APT-MAC Reader

Simulation of Readers (contd. . .)

TDMA Reader





Simulation of Readers (contd. . .)

Run Configuration.

- Data rate of the net-device and channel set to 640*kbps*.
- Tag memory 256 bits

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Results

Performance Metrics

- Packet Delay :

  the difference in time between generating a packet data and sending to the reader.

- Data Loss :

  this is the percentage of generated data that is not delivered to the reader.

Results (contd. . .)

Table: WORKLOAD SCENARIOS DESCRIPTION

No. of Sensors	Scenario	Joystick	Remote	Env. Sensors
20	Case 1	1	2	17
	Case 2	2	3	15
	Case 3	3	3	14
	Case 4	4	4	12
30	Case 1	1	2	27
	Case 2	2	3	25
	Case 3	3	3	24
	Case 4	4	4	22
40	Case 1	1	2	37
	Case 2	2	3	35
	Case 3	3	3	34
	Case 4	4	4	32

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Results (contd. . .)

Transient time :

duration for APT-MAC device to get into optimum performance of reduced data loss.

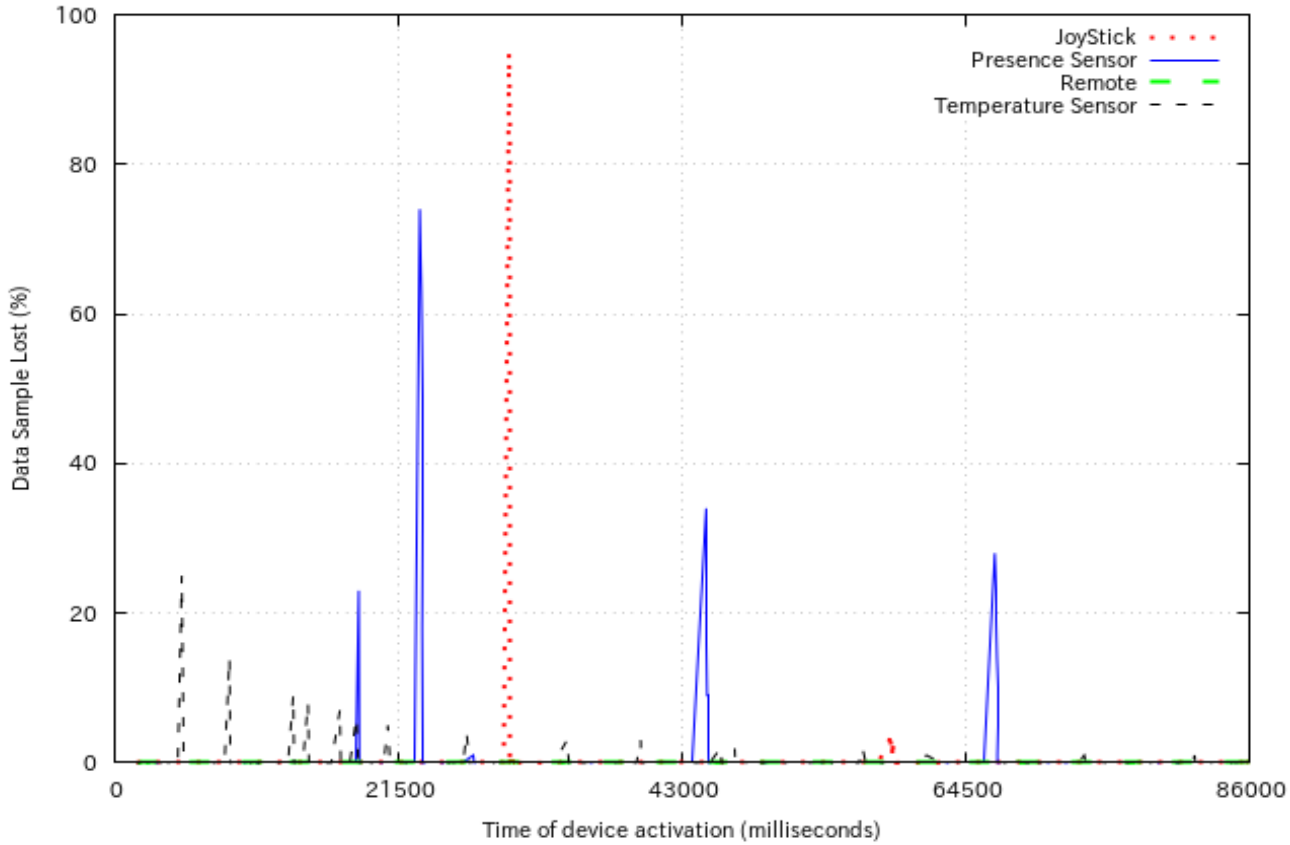

Figure: Transient Time

Results (contd. . .)

Transient time

- approximately $50ms$ to get the data loss of a joystick to less than 15%
- $0.283s$ for presence sensor
- temperature sensor took approximately a milli of a second.

Results (contd. . .)

Performance based on uptime - 20 Devices

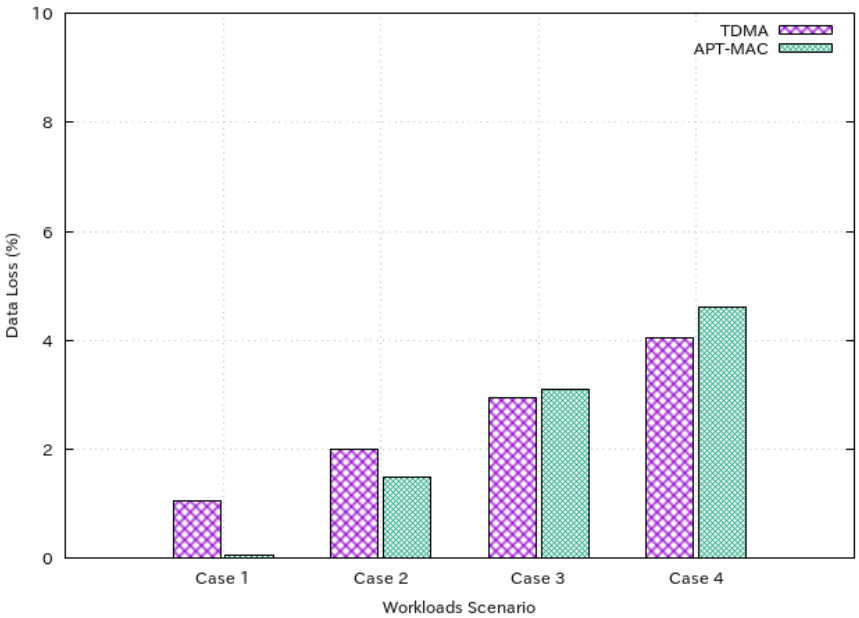

Figure: Data Loss Short Run

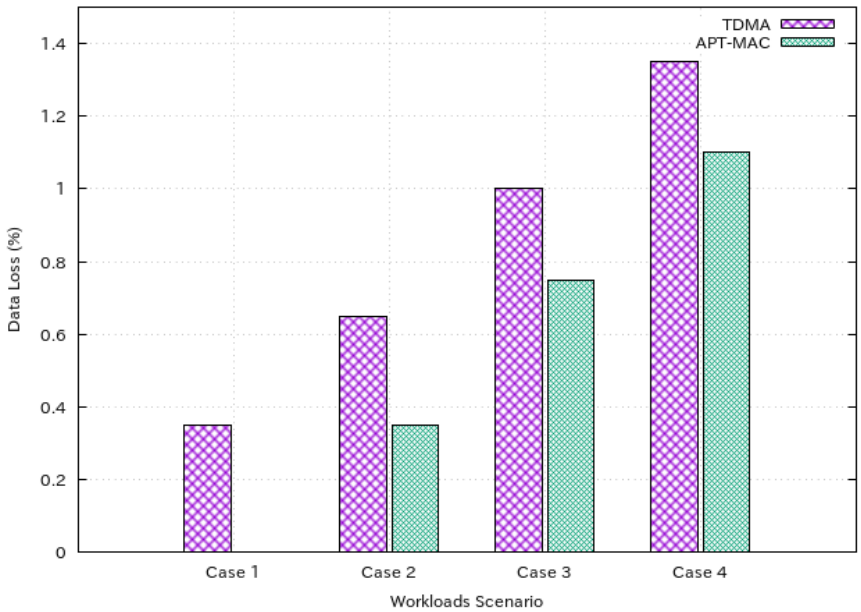

Figure: Data Loss

Results (contd. . .)

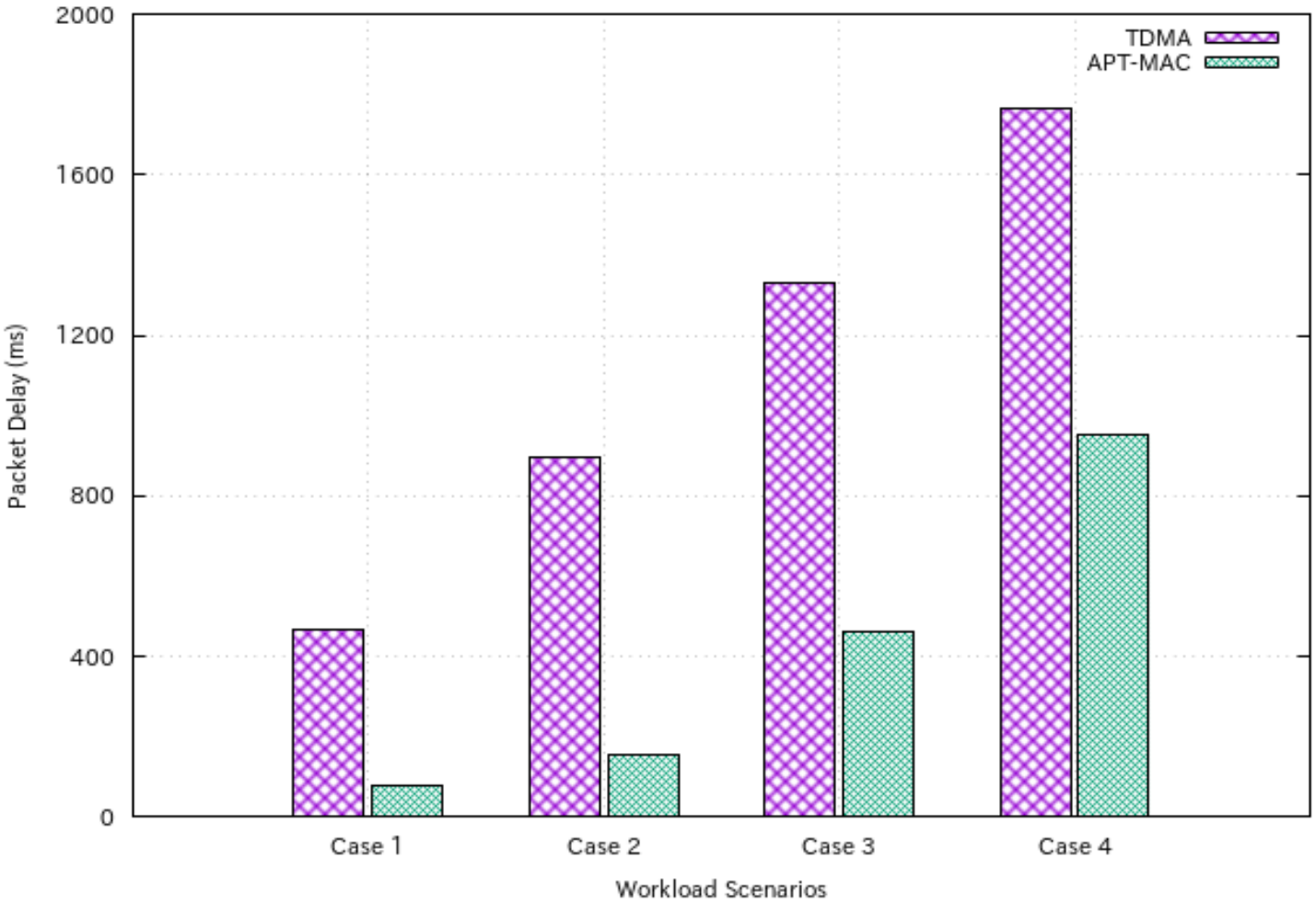

Figure: 20 Devices : Packet Delay

Results (contd. . .)

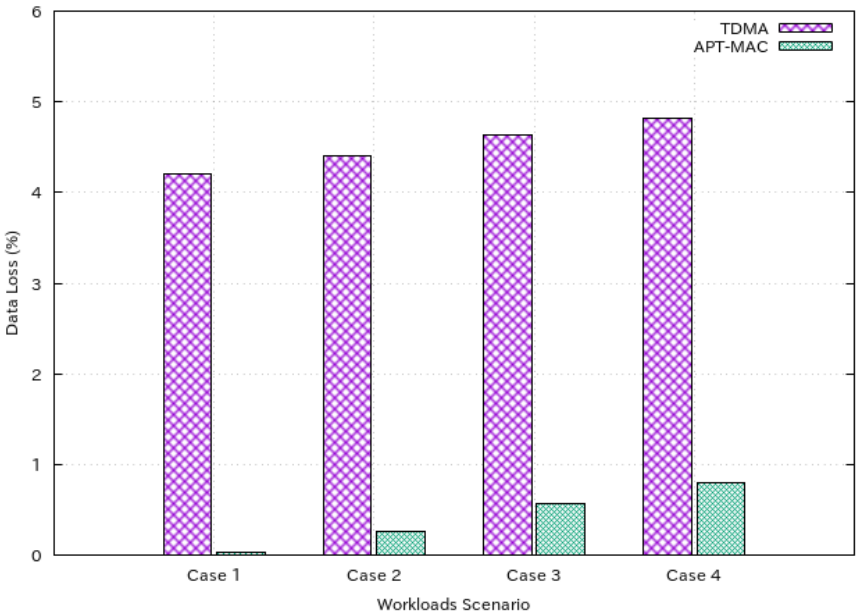

Figure: 30 Devices : Data Loss

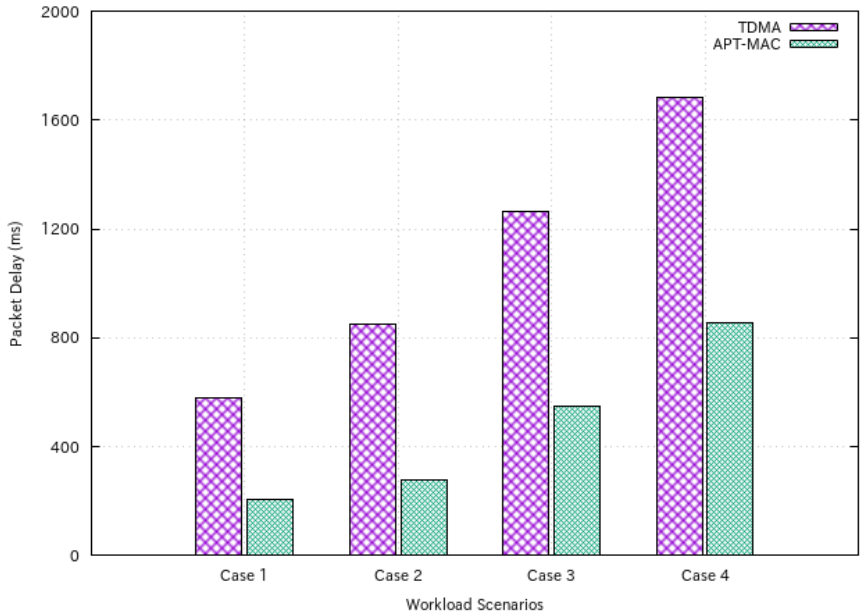

Figure: 30 Devices : Packet Delay

Results (contd. . .)

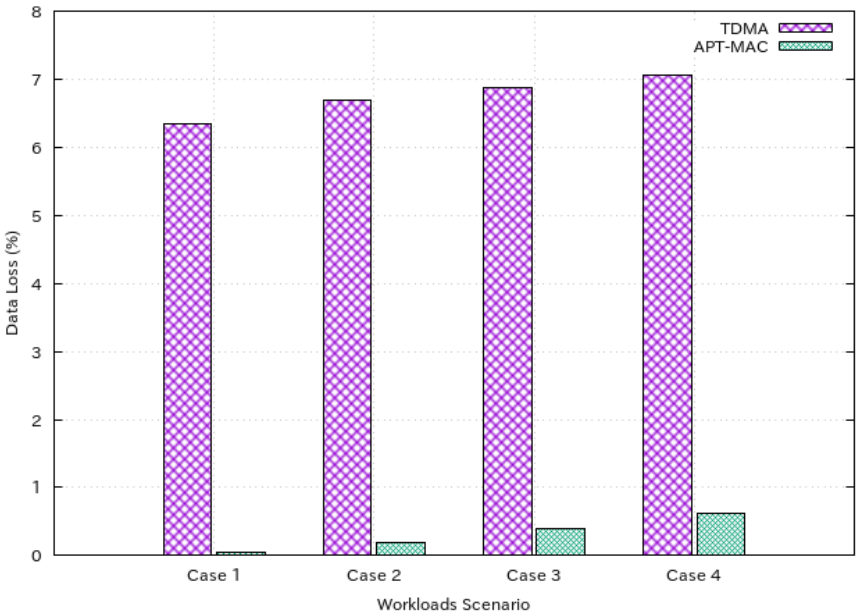

Figure: 40 Devices : Data Loss

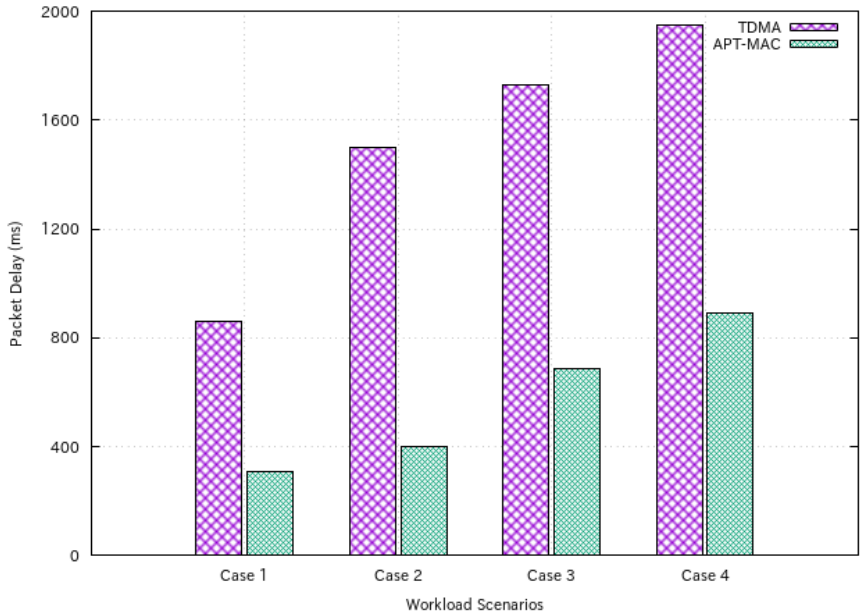

Figure: 40 Devices : Packet Delay

Conclusions and Future Work

Conclusion

- Objectives met
- APT-MAC outperforms TDMA

Future Work

- Mobility of the devices with respect to APT-MAC
- other variants of reinforcement algorithms

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References

- Maselli, Gaia, Mauro Piva, and John A. Stankovic. "Adaptive Communication for Battery-Free Devices in Smart Homes". In: *IEEE Internet of Things* (2019).
- Project, NS-3. *NS-3: Conceptual Overview*. URL: https://www.nsnam.org/docs/release/3.30/tutorial/html/conceptual-overview.html.
- Sutton, Richard S. and Andrew G. Barto. *Reinforcement Learning, An Introduction*. Second. Cambridge, Massachusetts London, England: The MIT Press, 2018.

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