

UNIVERSITY NAME (IN BLOCK CAPITALS)

Thesis Title

by

Author Name

A thesis submitted in partial fulfillment for the
degree of Doctor of Philosophy

in the

Faculty Name

Department or School Name

January 2020

Declaration of Authorship

I, AUTHOR NAME, declare that this thesis titled, 'THESIS TITLE' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date:

“Write a funny quote here.”

If the quote is taken from someone, their name goes here

UNIVERSITY NAME (IN BLOCK CAPITALS)

Abstract

Faculty Name

Department or School Name

Doctor of Philosophy

by Author Name

The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too...

Acknowledgements

The acknowledgements and the people to thank go here, don't forget to include your project advisor...

Contents

Declaration of Authorship	i
Abstract	iii
Acknowledgements	iv
List of Figures	vi
List of Tables	vii
Abbreviations	viii
Physical Constants	ix
Symbols	x
1 Introduction	1
1.1 The Protocols	2
1.1.1 TDMA	2
1.1.2 APT-MAC	3
1.1.2.1 Multi-Arm Bandit	3
1.1.2.2 APT-MAC protocol overview	4
2 Simulation	6
2.1 NS-3	6
A An Appendix	7
Bibliography	9

List of Figures

1.1	Frame Structure	3
-----	-----------------	---

List of Tables

Abbreviations

LAH List Abbreviations **Here**

Physical Constants

Speed of Light $c = 2.997\,924\,58 \times 10^8 \text{ ms}^{-\text{s}}$ (exact)

Symbols

a	distance	m
P	power	W (Js^{-1})
ω	angular frequency	rads^{-1}

For/Dedicated to/To my...

Chapter 1

Introduction

The later part of the past decade has seen a tremendous increase in the research of Internet of Things (IoT) devices mostly geared towards energy efficiency. This is in part, due to the fact that IoT devices have an underlining positive factor of having to save energy usage and hence must be design as not excessively use energy in itself. Not only do these interconnected devices provide comfort but have also become critical parts of our daily lives: saving lives, expediting interactions and transactions. Another factor that fueled the advancement in the research of energy efficient IoT devices is the enormous progress made in the field of Machine learning specifically Reinforcement learning.

Maximizing a numerical reward signal by learning which actions to take in a given situation is what Reinforcement learning is about. The actions to take by the learning agent pertaining to various situations are not preprogrammed into the learner, but instead this is discovered by taking the actions that maximize the reward margin[1]. This works in the cycle of sense-action-goals and learning is from immediate interactions with the environment.

The APT-MAC protocol, which is the focus of this paper, seeks to solve the problem of the reliance on battery. The protocol utilizes the Multi-Arm Bandit algorithm, a reinforcement learning algorithm, in tandem with Radio-frequency identification (RFID) signals to enable battery-free communication of wireless devices[2].

The aim of this work is to simulate the APT-MAC protocol in NS3 and in comparison to the static TDMA protocol.

1.1 The Protocols

Even though the quality of a network service is a cooperative effort of all the stack of communication protocols, the MAC layer is of a peculiar importance as it handles the sharing of the medium on which all other upper-layered protocols depend. MAC protocols do not only solve the problem of medium sharing, hence, support for reliable communication but also, in Wireless Sensor Networks, control of energy utilization, achieve through duty cycling and retransmissions or transmission power control[3].

In wireless sensor network, the MAC protocols are broadly classified into contention-based MAC protocols and scheduled-based MAC protocols depending on how the medium is accessed[4].

The medium in a contention-base MAC protocol is accessed by all the nodes and, as the name suggests, the nodes contend for access to the medium this may result in collision hence, to prevent collision access to the medium is negotiated through probabilistic coordination. A sending node listens to shared medium before sending, if the medium is busy, sending is halted for a specified period of time before retrying. Examples of contention-based MAC protocols used in wireless sensor network are ALOHA (Additive Link On-line Hawaii System) and CSMA (Carrier Sense Multiple Access)[5].

Nodes' medium access in a schedule-based MAC protocol is split into either frequency, Frequency Division Multiple Access, or time, that is, Time Division Multiple Access, or orthogonal pseudo - noise codes (Code Division Multiple Access). Collision is prevented in the medium by making different nodes access the medium in their designated time or frequency and hence not interfering with each other.

This section deals with the description of the protocol: APT-MAC and Time Division Multiple Access (TDMA).

1.1.1 TDMA

In TDMA, the total duration of communication is divided into fixed number of time slots. Time slots are configured into time-frames that are repeated periodically. Each node is allocated a time slot in a time-frame and is allowed to only transmit in that time slot. The TDMA frame structure has extra overhead; preamble and trail bits, added to the information message or bits. Time slots are what make up the information bits/message. Figure 1.1 shows the details of the frame structure.

Preamble: contains the address and synchronization information of the base (sink) node and the identification information of the other nodes.

Guard time: necessary to prevent time-drifting over time.

Trail bit: for error detection in the form of checksum or cyclic redundancy check.

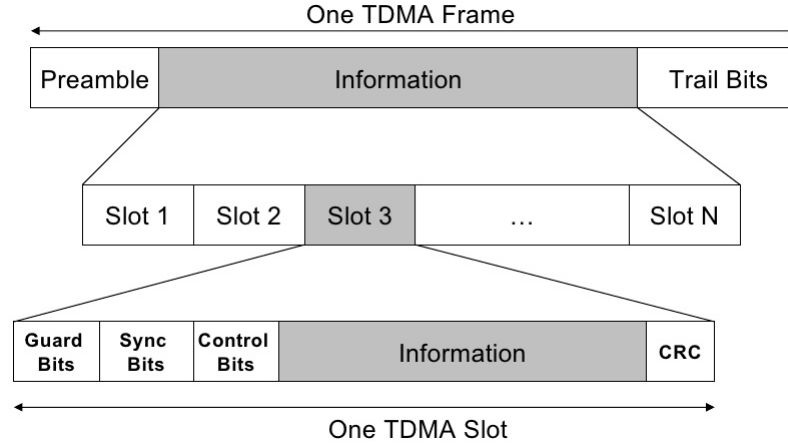


FIGURE 1.1: Frame Structure

The inadequacies of TDMA, chief among them with respect to the aim of the referenced paper [2], is static slot assignment. The slots are assigned before transmission and does not change whatsoever during the transmission process, this does not serve the purpose of a protocol that is needed to scale according to the transmission requirements of the nodes.

1.1.2 APT-MAC

APT-MAC protocol is a zero configuration - manual configuration not needed - mac protocol. Reinforcement learning is utilized to learn the required rate of transmission of each active node and continually update the transmission requirements of nodes. An overview of the reinforcement learning algorithm is given, followed by how it is used the APT-MAC protocol.

1.1.2.1 Multi-Arm Bandit

When one is made to choose between multiple actions with an unknown reward for each action taken and the goal being to maximize the profit margin through a series of actions, the problem is classified as the multi-arm bandit problem. For example, a website deciding on which adverts to show to its visitors. The proprietor must maximize advertisement revenue but does not have enough information about the visitor to pursue

a specific strategy, however, there are a large pool of adverts to choose from. This begs the question of which adverts will drive the maximum revenue. The websites, hence, needs to make a series of decisions, each with unknown results and rewards.

When a set of action(s) is found to maximize reward and those are actions are selected over and over again it is termed *Exploitation*, thus the knowledge of the actions is being exploited whereas when an action is selected for which the reward is not known is *Exploration*. An optimum balance between the exploitation and exploration is needed in most cases to achieve maximum reward.

From a more scientific standpoint, Bernoulli multi-armed bandit can be described as an *action reward-function* tuple $\langle A, R \rangle$. At each time step t an action $A = a$ is taken and a reward $R = r$ is received with reward probability $\{\theta_1 \dots \theta_K\}$. The expected reward which is the value of the action taken is given by $Q(a_t) = \mathbb{E}[R|A = a] = \theta$. The goal is to maximize $\sum_{t=1}^T r_t$, the cummulutative reward, hence an optimal action a^* with and optimal probability θ^* thus:

$$\theta^* = Q(a^*) = \max_{a \in A} Q(a) \quad (1.1)$$

Broadly, the various algorithmic solutions to multi-arm bandit problem can be categorized as; no exploration - greedy, random exploration and exploration intelligently with reference to probability [1].

1.1.2.2 APT-MAC protocol overview

The "battery-freeness" of the protocol is as a result of the use of sensor-augmented RFID tags.

During initialization, the reader sends discovery queries to all nodes and each is assigned a unique identification. In querying tags in such a way as to minimize the difference between the sensor's data generation time and the time of delivery of data to the reader, the Multi-Arm Bandit, describe above, is used. The reader, agent in this case, queries each node - set of actions - and can be in one of two states: querying or ready to query. Expected reward is calculated with the formula 1.2 with the expected reward of each action stored in vector Q .

$$Q(a_i)(n+1) = Q(a_i)(n) + \alpha(Reward - Q(a_i)(n)) \quad (1.2)$$

n is the time slot of the query, a_i is the action of querying tag i and α is the learning rate.

A more detailed explanation of the protocol, such as the learning rate parameter and the evaluation of the *Reward* can be found in [\[2\]](#).

Chapter 2

Simulation

The activities of the simulation is described in this chapter. An overview of NS-3 is given, which is then followed by the actions taken, setup used, assumptions made and overall explanation of the simulation.

2.1 NS-3

Appendix A

An Appendix

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Vivamus at pulvinar nisi. Phasellus hendrerit, diam placerat interdum iaculis, mauris justo cursus risus, in viverra purus eros at ligula. Ut metus justo, consequat a tristique posuere, laoreet nec nibh. Etiam et scelerisque mauris. Phasellus vel massa magna. Ut non neque id tortor pharetra bibendum vitae sit amet nisi. Duis nec quam quam, sed euismod justo. Pellentesque eu tellus vitae ante tempus malesuada. Nunc accumsan, quam in congue consequat, lectus lectus dapibus erat, id aliquet urna neque at massa. Nulla facilisi. Morbi ullamcorper eleifend posuere. Donec libero leo, faucibus nec bibendum at, mattis et urna. Proin consectetur, nunc ut imperdiet lobortis, magna neque tincidunt lectus, id iaculis nisi justo id nibh. Pellentesque vel sem in erat vulputate faucibus molestie ut lorem.

Quisque tristique urna in lorem laoreet at laoreet quam congue. Donec dolor turpis, blandit non imperdiet aliquet, blandit et felis. In lorem nisi, pretium sit amet vestibulum sed, tempus et sem. Proin non ante turpis. Nulla imperdiet fringilla convallis. Vivamus vel bibendum nisl. Pellentesque justo lectus, molestie vel luctus sed, lobortis in libero. Nulla facilisi. Aliquam erat volutpat. Suspendisse vitae nunc nunc. Sed aliquet est suscipit sapien rhoncus non adipiscing nibh consequat. Aliquam metus urna, faucibus eu vulputate non, luctus eu justo.

Donec urna leo, vulputate vitae porta eu, vehicula blandit libero. Phasellus eget massa et leo condimentum mollis. Nullam molestie, justo at pellentesque vulputate, sapien velit ornare diam, nec gravida lacus augue non diam. Integer mattis lacus id libero ultrices sit amet mollis neque molestie. Integer ut leo eget mi volutpat congue. Vivamus sodales, turpis id venenatis placerat, tellus purus adipiscing magna, eu aliquam nibh dolor id nibh. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Sed cursus convallis quam nec vehicula. Sed vulputate neque eget odio fringilla ac sodales urna feugiat.

Phasellus nisi quam, volutpat non ullamcorper eget, congue fringilla leo. Cras et erat et nibh placerat commodo id ornare est. Nulla facilisi. Aenean pulvinar scelerisque eros eget interdum. Nunc pulvinar magna ut felis varius in hendrerit dolor accumsan. Nunc pellentesque magna quis magna bibendum non laoreet erat tincidunt. Nulla facilisi.

Duis eget massa sem, gravida interdum ipsum. Nulla nunc nisl, hendrerit sit amet commodo vel, varius id tellus. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nunc ac dolor est. Suspendisse ultrices tincidunt metus eget accumsan. Nullam facilisis, justo vitae convallis sollicitudin, eros augue malesuada metus, nec sagittis diam nibh ut sapien. Duis blandit lectus vitae lorem aliquam nec euismod nisi volutpat. Vestibulum ornare dictum tortor, at faucibus justo tempor non. Nulla facilisi. Cras non massa nunc, eget euismod purus. Nunc metus ipsum, euismod a consectetur vel, hendrerit nec nunc.

Bibliography

- [1] Richard S. Sutton and Andrew G. Barto. *Reinforcement Learning, An Introduction*. The MIT Press, Cambridge, Massachusetts London, England, second edition, 2018.
- [2] Gaia Maselli, Mauro Piva, and John A. Stankovic. Adaptive communication for battery-free devices in smart homes. *IEEE Internet of Things*, 2019.
- [3] M. Aykut Yigitel, Ozlem Durmaz, and Cem Ersoy. Qos-aware mac protocols for wireless sensor networks: A survey. *Computer Networks - Elsevier*, February 2011.
- [4] Pijus Kumar Pal and Punyasha Chatterjee. International journal of emerging technology and advanced engineering. *International Journal of Emerging Technology and Advanced Engineering*, 4, June 2014. URL <http://www.ijetae.com>.
- [5] Andrew S. Tanenbaum and David J. Wetherall. *Computer Networks*. Prentice Hall, Boston Columbus Indianapolis New York San Francisco Upper Saddle River, fifth edition, 2011.