

2112087 - Proposal

by Jacob Brown

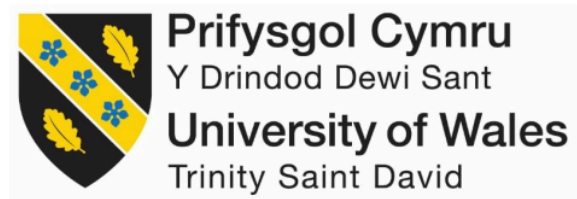
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**Analysis and research into the application of
deep learning and artificial intelligence in a
congested signals environment**

by
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Supervisor: Yet to be Assigned

Project proposal submitted as part of the requirements
for the award of
BEng (Hons) Embedded Electronics Engineering

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Initial Overview

The issue under investigation in this report is one defined by a clear objective and necessitated by the evolving communications space in both a contested and congested environment. Through this rapidly advancing domain defined by a plethora of generations and frequencies, it is increasingly drifting out of the control of a human observer to exert control over and monitor with an effective degree of response time and accuracy.

Herein, this proposal seeks to outline the application and design of a system capable of diagnosing the radiofrequency environment with a high degree of accuracy and to automatically monitor to such a degree that power mitigation and optimal routing may be achieved, subject to further research and implementation.

Current iterative research suggests that the best method of implementation that would yield the most useful results would be that of investigating deep learning algorithms and their potential in such environments as outlined.

Primary Objectives

The primary goal of this project is to investigate potential behind this recently developed deep learning methodologies, additional research goals will likely be defined as more facets are developed and discovered. Presently, this comprises of only the following.

- Identify specific areas of operation
- Performing basic synthetic tests for proof of concepts
- Developing algorithms for processing of static, discrete synthetic data
- Conducting initial controlled data collections
- Developing algorithms for static and discrete real-world data
- Conducting testing comparing both systems
- Reevaluating feasibility for continuous data and exploring alternative design methods
- Producing a response system for either continuous or discrete
- Publishing a report or summary of the function and findings

Secondary Objectives

Secondary objectives here largely include the extended goals that are either not critical to project or might be infeasible for the timescale provided for. These include the following.

- Oversee the development of a physical system for the proof of the operational practicality
- Develop a specific algorithm specifically optimised for continuous data streams
- Perform real world data collects
- Test on infield data and implemented equipment
- Research of tangential data management solutions for a smaller scale or exclusively local-based system

It is critical to note that these objectives, while important for the allocation of additional resources, are not vital for the proceeding of the project as a whole and are likely to not be pursued without those additional resources.

Objectives Summary

In order to establish a high degree of knowledge and proof of function it is necessary to follow most of the primary objectives diligently. The final deliverables are notably the report and the response system. The response system has the potential to be implemented within the software space for the demonstration of effectiveness should holdups be met in physical implementation.

Throughout the project, due to the nature of the research conducted, smaller scale reports will be repeatedly produced as to affirm the tests and collects, as such this will provide constant and measurable results with which momentum and progress will be continuously measurable thus allowing for constant orientation when required.

Literature

Due to the emerging nature of a lot of these concepts and algorithms, the actual documentation of exact replicas is almost completely non-existent. Of the available reports on similar topics, there are broadly two types that can be classed as either algorithmic or technical, with the features of these explained herein.

These lists are non-exhaustive and instead represent a small selection of useful sources. No comparison table is given due to the difference between the papers, the author of this proposal instead opted for a brief summary of a select few useful sources.

Algorithmic

Algorithmic forms of literature are all exceedingly modern, with some of the most fundamental concepts being defined in reports from the early end of the current decade. These all largely pertain to the design, operating principles and functions of the current forerunners in this early stage of research.

- A machine learning framework for predicting downlink throughput in 4G-LTE/5G cellular networks. Useful for its Deep Learning (DL) implementation and machine learning techniques. [1]
- Deep Reinforcement Learning for Downlink Power Control in Dense 5G Networks. Useful due to the application given to a Deep Q-Network (DQN) and Rainbow DQN, reward metrics and requirements similarity. [2]
- A Deep Q-Learning Method for Downlink Power Allocation in Multi-Cell Networks. Useful because of the benchmarking system used and hidden layer architecture which closely resembles earlier research conducted in house. [3]

Technical

Technical documentation and literature largely pertain to the signal side of the design process. This includes systems wherein AI in some respect has been employed to a similar field or defining protocols necessary for implementation and where definition of operating parameters are characterised or demonstrated.

- Distributed spectrum management based on reinforcement learning. Defines operating spectrum details and demonstrates reinforcement learning regarding spectrum management. Outputs a binary mask as required in this work package. [4]
- Deep Learning Approach to Spectrum Allocation in Shared Spectrum Systems. Utilises a CNN regarding a primary and secondary user. Defines and provides example for small hardware testbed, provides signal allocation for multiple users. [5]
- Intelligent spectrum management based on reinforcement learning schemes in cooperative cognitive radio networks. Demonstrates two novel ideas for spectrum allocation using a decentralised approach, using several novel applications for reinforcement learning in a radio based context. [6]

Design

Due to the current stage of research, it is difficult to diagnose the hardware requirement as the exact level of computational power required and the level of hardware complexity are as yet unknown. At this point, structural diagrams for an algorithm are possible based off currently researched designs however, even this is subject to further research and alteration.

Models

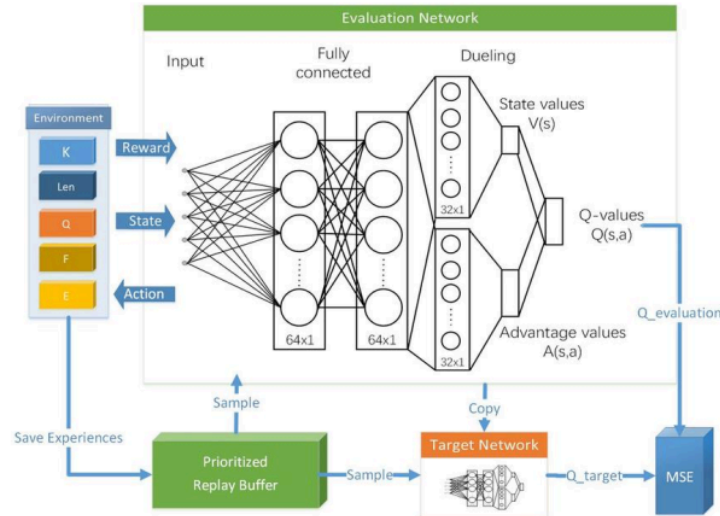


Figure 1, Above, Diagram of a DQN structural Network[7]

In figure 1, it is possible to observe a rudimentary rainbow DQN, while adaptations would be required for fully effective usage in a radio frequency (RF) domain, the principal design demonstrated above holds true for most DQN models. This design, while well utilised and effectively implemented in the present stage of research, is likely not to be used in perpetuity due to its limitations in continuous data spaces. The subsequent algorithm is likely to be that of a Proximal Policy Optimisation kith, with the primary difference in design featured in the processing of live data along with an accompanying critic adjustment as demonstrated in the data flow diagram in figure 2.

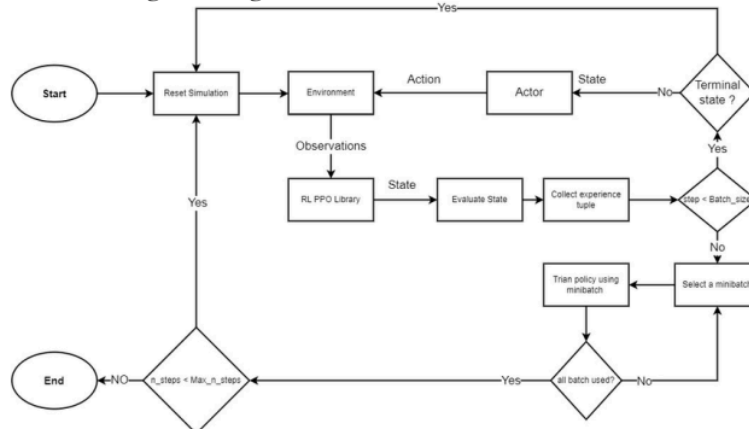


Figure 2, Above, Data flow network of a Proximal Policy Optimisation Algorithm[8]

At present there are several methods currently implemented onto physical systems, following architectures compliant with You Only Look Once (YOLO) in its early iterations and other alternatives with similar single processing step models. This also holds a similar problem to the DQN except it features older methodologies, limiting its configurability.

Data Management and Utilisation

Data utilisation will largely comprise the training data for the model and testing data. Contrary to traditional machine learning techniques, the present deep learning investigation has the potential to create an almost entirely supervisor-removed training method, as such data usage will be limited largely to processing it into acceptable formats for interpretation. This data will all be environment captures in controlled spaces for the near future and potentially urban captures in the further future. This data is not subject to GDPR regulation and will instead be managed in accordance with its classification as laid out by the official secrets act. This will be fed into the algorithm, while ensuring that all data is collected or produced internally to the organisation to avoid ethical implications of public training.

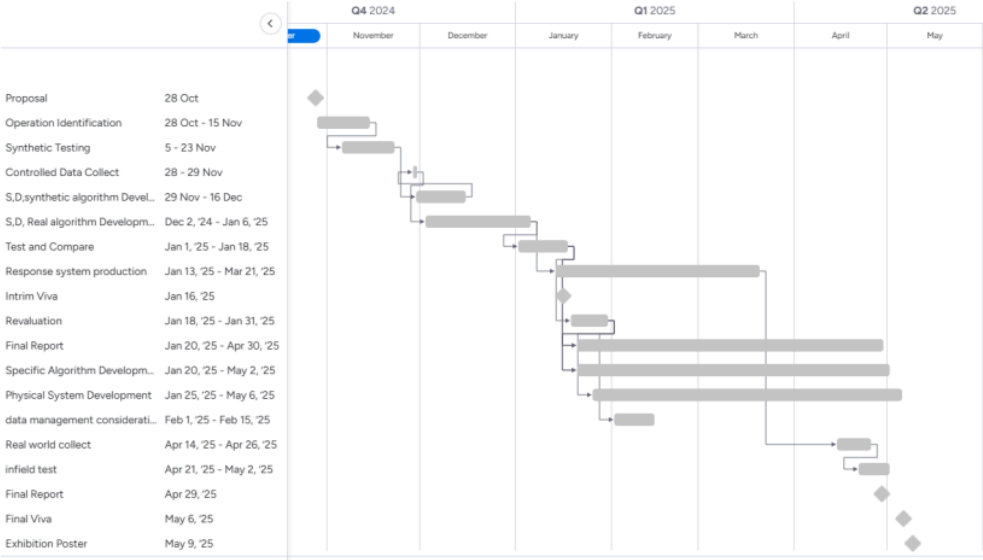
Implementation Mechanisms

Implementation is largely synthetic at present, while hardware is in the pipeline it is pending specifications from research. If an architecture is sufficiently outlined within a decent timeframe, it might be that implementation onto a bespoke system will be conducted. In leu of this, it is more likely that existing hardware will be modified or simulated according to said hardware. The software to be used as a tool for the foreseeable future is likely to be Python Anaconda environments with some smaller elements demonstrated on Simulink. Largely due to the PyTorch libraries and the ease of experimentation that this accompanies. Some form of SDR or similar bespoke software, such as Deepwave systems are likely to also be used for the hardware end due to their existing use in the project and thus comparability of efficiency without accounting for hardware differences

Timeframes

The timeframes for the project are to be quite loosely followed with regards to the majority due to the nature of research, it is necessary to allow a wide critical path with plenty of overlap to account for this.

GANTT



The Gantt chart presented above is a rough outline of events when they are undertaken, this is subject to change and almost certainly will change as difficulties arise. With the response production being the most vulnerable to changing timeframes, however, enough leigh way is granted where deemed necessary as represented by the overlaps. While some tasks are dependant on a prior to complete, the current structure does allow for flexibility if required.

Deliverable summary

The deliverables, as defined in the [objectives](#) section of the report, comprise of two foremost components, that of the report and responsive system, this system may take multiple different forms to be acceptable to the interest groups. However most ideally this would be a functional simulated python program that would then be interoperable with physical hardware in leu of direct hardware demonstration.

- [1] A. Al-Thaedan *et al.*, “A machine learning framework for predicting downlink throughput in 4G-LTE/5G cellular networks,” *International Journal of Information Technology*, vol. 16, no. 2, pp. 651–657, Feb. 2024, doi: 10.1007/s41870-023-01678-w.
- [2] S. Saeidian, “Deep Reinforcement Learning for Downlink Power Control in Dense 5G Networks,” Stockholm, 2019.
- [3] K. I. Ahmed and E. Hossain, “A Deep Q-Learning Method for Downlink Power Allocation in Multi-Cell Networks,” Apr. 2019.
- [4] F. Bernardo, R. Agusti, J. Perez-Romero, and O. Sallent, “Distributed spectrum management based on reinforcement learning,” in *2009 4th International Conference on Cognitive Radio Oriented Wireless Networks and Communications*, IEEE, Jun. 2009, pp. 1–6. doi: 10.1109/CROWNCOM.2009.5189161.
- [5] M. Ghaderibaneh, C. Zhan, and H. Gupta, “DeepAlloc: CNN-Based Approach to Efficient Spectrum Allocation in Shared Spectrum Systems,” Jan. 2022, doi: 10.1109/ACCESS.2024.3352034.
- [6] A. Kaur and K. Kumar, “Intelligent spectrum management based on reinforcement learning schemes in cooperative cognitive radio networks,” *Physical Communication*, vol. 43, p. 101226, Dec. 2020, doi: 10.1016/j.phycom.2020.101226.
- [7] J. Li, H. Zhang, and H. Ma, “DRL-based transmission control for QoE guaranteed transmission efficiency optimization in tile-based panoramic video streaming,” *Multimed Syst*, vol. 29, no. 5, pp. 2761–2777, Oct. 2023, doi: 10.1007/s00530-023-01129-3.
- [8] A. Irshayyid and J. Chen, “Comparative Study of Cooperative Platoon Merging Control Based on Reinforcement Learning,” *Sensors*, vol. 23, no. 2, p. 990, Jan. 2023, doi: 10.3390/s23020990.

FINAL GRADE

GENERAL COMMENTS

73/100

Intro / Aims & Objectives		
The introduction discusses diagnosing the radiofrequency environment with high accuracy and automatically monitoring it to enable power mitigation and optimal routing. Explaining why this research is necessary and what makes it important could strengthen this section. Additionally, while the objectives are outlined, they remain general, and the inclusion of technical ideas and detailed insights into how these objectives will be achieved is missing here. Highlights key areas of operation effectively	20	12
Background to the Project / Literature Review		
The literature review includes references to many journal papers, which is commendable. Algorithmic forms and technical points are well explained. However, this section could be enhanced by incorporating visualizations to illustrate the concepts and methods discussed. The block diagram included, requires a more detailed explanation of the flow of each block to improve clarity.	20	15

Good technical details with room for visualizations.		
Project Design		
The block diagram could be appropriately placed in this section to better align with the project design structure. The explanation of "Data Management and Utilization" is good but could be improved by providing more details on its implementation. Good alignment of project design with key elements	30	24
Resources / Planning		
The project planning section is well-structured with clearly defined time scales. The submission of the ethics form is noted. Adding a clear breakdown of how the project is divided into phases or tasks would improve the presentation and allow for a better understanding of the workflow. Good focus on time management and planning !	15	13
Document Presentation		
The document is neatly presented with minimal errors. However, the writing could be improved by organizing content more effectively under distinct topics, such as Introduction, Literature Review, Project Design, and Planning, for better structure and readability.	15	9

Neat presentation; improved topic organization recommended.		
TOTAL	100	73

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