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# Design of a Reinforcement Learning Based Clustering in MANETs

CENG797 Ad Hoc Networks
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Term Project Report

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## Abstract

Write your abstract here.

An abstract summarizes, in one paragraph (usually), the major aspects of the entire paper in the following prescribed sequence [**?**]:

- the question(s) you investigated (or purpose), (from Introduction) state the purpose very clearly in the first or second sentence.
- the experimental design and methods used; clearly express the basic design of the study; name or briefly describe the basic methodology used without going into excessive detail-be sure to indicate the key techniques used.
- the major findings including key quantitative results, or trends; report those results which answer the questions you were asking; identify trends, relative change or differences, etc.
- a brief summary of your interpretations and conclusions; clearly state the implications of the answers your results gave you.

The length of your Abstract should be kept to about 200-300 words maximum. Limit your statements concerning each segment of the paper (i.e. purpose, methods, results, etc.) to two or three sentences. The Abstract helps readers decide whether they want to read the rest of the paper, or it may be the only part they can obtain via electronic literature searches or in published abstracts. Therefore, enough key information (e.g., summary results, observations, trends, etc.) must be included to make the Abstract useful to someone who may to reference your work [**?**].

How do you know when you have enough information in your Abstract? A simple rule-of-thumb is to imagine that you are another researcher doing an study similar to the one you are reporting. If your Abstract was the only part of the paper you could access, would you be happy with the information presented there?

The Abstract is ONLY text. Use the active voice when possible, but much of it may require passive constructions. Write your Abstract using concise, but complete, sentences, and get to the point quickly. The Abstract SHOULD NOT contain [**?**]:

- lengthy background information,
- references to other literature,
- elliptical (i.e., ending with ...) or incomplete sentences,
- abbreviations or terms that may be confusing to readers,
- any sort of illustration, figure, or table, or references to them.

# Table of Contents

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# 1 Introduction: Can we use RL based clustering algorithm in a dynamic environment? What is the efficiency?

Mobile ad hoc networks (MANETs) consist of wireless nodes that are capable of self-organizing without fixed infrastructure. However, in MANETs, as node density and mobility increase, flat schemes incur much more overhead and instability. To solve this scalability issue, clustering, partitioning nodes into groups with one or more cluster heads (CHs) that coordinate intra/inter-cluster operations, has been used to reduce control traffic, localize topology changes, and improve scalability. The central problem studied in this project is: *how to design a reinforcement-learning (RL) based clustering algorithm that determines clusters and CHs, and maintains clusters adaptively to the environment under high mobility and dynamic energy constraints, while minimizing control cost and maintaining packet delivery performance.*

Clustering directly affects the control overhead, path stability, energy balance, and ultimately end-to-end latency and packet delivery ratio (PDR). While well-formed clusters improve the network performance dramatically, bad CH selection or frequent and redundant re-clustering leads to energy wasting and route flapping. Since there are many parameters and there is no direct solution, a learning-driven design promises sensing many parameters in the network, including network performance, updating decisions adaptively, and balancing between stability and responsiveness as conditions change.

There are three aspects that make the problem challenging. First, the environment is non-stationary. It changes as the nodes move and simultaneously adapt, which results in a violation of the assumptions and destabilisation of the network. Second, the environment is observed partially, and it is noisy. Local views of residual energy, degree, RSSI/SINR, and link duration are noisy and time-correlated, causing wrong assumptions and decisions. Third, there is no strict ideal purpose. Maximizing PDR and stability often conflicts with minimizing control overhead and balancing energy across CHs. Traditional threshold heuristics generalize poorly across mobility regimes, while deep models can be heavy for on-node execution. A balance has to be found to be more practical in real environments.

Classical algorithms such as LID, HCC, WCA [1], HEED [2], and MOBIC work with fixed weights or periodic re-clustering, which may perform well under certain scenarios but sub-optimal under dynamic conditions and heterogeneous nodes. Surveys by Yu and Chong [3], Cooper et al. [4], and Katiyar et al. [5] highlight the persistent trade-offs between stability and control overhead, and call for adaptive, learning-based designs. There is a need for a light-weight, sample-efficient design that couples robust state shaping with simple RL updates and explicit switching-cost control. Reinforcement learning (RL) provides a framework to optimize long-term performance but has rarely been applied to general MANET clustering.

The proposed design employs **Q-learning**, where each node acts as an agent that observes local state features—residual energy, degree, mobility variance, and link quality—and learns CH candidacy and re-clustering policies to maximize long-term reward combining PDR, delay, overhead, and fairness. The algorithm will be implemented in OMNeT++/INET and evaluated under multiple topology, mobility, and protocol settings, with 95% confidence intervals computed over repeated runs.

### Summary of Contributions

- Formulation of clustering as a sequential decision process and design of an RL-based CH election and maintenance algorithm.
- Integration and simulation in OMNeT++ 6.2.0 / INET 4.5.4 across various topologies, mobility, obstacle, energy, and traffic models.
- Evaluation of cluster quality, overhead, communication efficiency, energy balance, scalability, robustness, and fairness metrics.
- Comparison with baseline clustering protocols (LID, HCC, WCA, HEED) using multiple routing (AODV, DSDV, GPSR) and MAC (BMAC, CSMA/CA, etc.) layers.

# 2 Background and Related Work

## 2.1 Background

A MANET is a distributed network where mobile nodes act as both routers and hosts. Frequent topology changes, limited energy, and the absence of centralized control make routing and coordination difficult. Clustering introduces hierarchy by electing cluster heads (CHs) to coordinate intra-cluster communication and act as local routing hubs. Design dimensions include: (i) *priority metrics* (ID, degree, mobility, energy, or weighted combinations); (ii) *maintenance policy* (periodic or event-driven re-clustering); (iii) *scope* (one-hop or multi-hop clusters); and (iv) *objectives* (stability, overhead, lifetime, fairness).

Reinforcement learning (RL) provides an adaptive framework in which each node learns actions that maximize long-term reward. Q-learning [6, 7] updates an estimated value function

$$Q(s,a) \leftarrow Q(s,a) + \alpha[r + \gamma \max_{a'} Q(s',a') - Q(s,a)]$$

to discover the optimal policy. In clustering, actions may represent "become CH," "join CH $i$," or "trigger re-clustering," and the reward can combine throughput, overhead, stability, and energy metrics. Optionally, fuzzy inference [8] can preprocess noisy features (energy, mobility, degree) into smooth suitability scores that stabilize learning.

## 2.2 Related Work

**Classical MANET clustering.** Yu and Chong [3] systematically reviewed early MANET clustering algorithms and classified them as ID-based, connectivity-based, mobility-based, energy-based, or hybrid. Representative methods such as LID, HCC, WCA [1], HEED [2], and MOBIC achieve specific trade-offs but rely on static weights and periodic re-clustering, which degrade under fast mobility.

**Design dimensions and VANET lessons.** Cooper et al. [4] extended this taxonomy to vehicular ad hoc networks (VANETs), identifying dimensions such as CH election criteria, cluster maintenance strategy, and re-affiliation rules. Their analysis demonstrated that frequent re-clustering dominates channel usage, motivating adaptive timing and learning-based control.

**AI-driven clustering.** Katiyar et al. [5] surveyed state-of-the-art VANET clustering and reported emerging applications of AI, fuzzy logic, and reinforcement learning for CH selection and cluster stability. They noted that most learning-based approaches remain centralized or domain-specific, leaving a gap for lightweight, distributed RL methods applicable to general MANETs.

**Fuzzy/RL hybrids.** Hybrid fuzzy–Q-learning models [8, 6, 7] improve robustness by converting instantaneous node metrics into smooth suitability scores before RL updates. These approaches inspire the state representation adopted in this project.

**Positioning of this work.** Prior surveys [3, 4, 5] identify open issues of high overhead, instability, and lack of adaptive weighting. The present project contributes by implementing a distributed RL-based clustering algorithm in OMNeT++ / INET, designed for real-time adaptability under heterogeneous mobility, energy, and communication conditions.

# 3 Main Contributions

You can introduce multiple sections for presenting your contribution. Provide content specific titles.

## 3.1 Your Contribution 1

Present your proposals, algorithms, techniques etc. here.

## 3.2 Your Contribution 2

Present your proposals, algorithms, techniques etc. here.

# 4 Results and Discussion

## 4.1 Methodology

Writing the methodology lies at the core of the paper, and fulfills one of the basic principles underlying the scientific method. Any scientific paper needs to be verifiable by other researchers, so that they can review the results by replicating the experiment and guaranteeing the validity. To assist this, you need to give a completely accurate description of the equipment and the techniques used for gathering the data [**?**].

Other scientists are not going to take your word for it, and they want to be able to evaluate whether your methodology is sound. In addition, it is useful for the reader to understand how you obtained your data, because it allows them to evaluate the quality of the results. For example, if you were trying to obtain data about shopping preferences, you will obtain different results from a multiple-choice questionnaire than from a series of open interviews. Writing methodology allows the reader to make their own decision about the validity of the data. If the research about shopping preferences were built upon a single case study, it would have little external validity, and the reader would treat the results with the contempt that they deserve [**?**].

Describe the materials and equipment used in the research. Explain how the samples were gathered, any randomization techniques and how the samples were prepared. Explain how the measurements were made and what calculations were performed upon the raw data. Describe the statistical techniques used upon the data [**?**].

## 4.2 Results

This is probably the most variable part of any research paper, and depends upon the results and aims of the experiment. For quantitative research, it is a presentation of the numerical results and data, whereas for qualitative research it should be a broader discussion of trends, without going into too much detail. For research generating a lot of results, then it is better to include tables or graphs of the analyzed data and leave the raw data in the appendix, so that a researcher can follow up and check your calculations. A commentary is essential to linking the results together, rather than displaying isolated and unconnected charts, figures and findings. It can be quite difficulty to find a good balance between the results and the discussion section, because some findings, especially in a quantitative or descriptive experiment, will fall into a grey area. As long as you not repeat yourself to often, then there should be no major problem. It is best to try to find a middle course, where you give a general overview of the data and then expand upon it in the discussion - you should try to keep your own opinions and interpretations out of the results section, saving that for the discussion [**?**].

### 4.3 Discussion

This is where you elaborate upon your findings, and explain what you found, adding your own personal interpretations. Ideally, you should link the discussion back to the introduction, addressing each initial point individually. It is important to try to make sure that every piece of information in your discussion is directly related to the thesis statement, or you risk clouding your findings. You can expand upon the topic in the conclusion - remembering the hourglass principle [**?**].

## 5 Conclusion

In general a short summarizing paragraph will do, and under no circumstances should the paragraph simply repeat material from the Abstract or Introduction. In some cases it's possible to now make the original claims more concrete, e.g., by referring to quantitative performance results [**?**].

The conclusion is where you build upon your discussion and try to refer your findings to other research and to the world at large. In a short research paper, it may be a paragraph or two, or practically non-existent. In a dissertation, it may well be the most important part of the entire paper - not only does it describe the results and discussion in detail, it emphasizes the importance of the results in the field, and ties it in with the previous research. Some research papers require a recommendations section, postulating that further directions of the research, as well as highlighting how any flaws affected the results. In this case, you should suggest any improvements that could be made to the research design [**?**].

# References


[1] M. Chatterjee, S. K. Das, and D. Turgut, ‘‘Wca: A weighted clustering algorithm for mobile ad hoc networks,’’ in *Cluster Computing*, 2002.

[2] O. Younis and S. Fahmy, ‘‘Heed: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks,’’ *IEEE Transactions on Mobile Computing*, vol. 3, no. 4, pp. 366--379, 2004.

[3] J. Y. Yu and P. H. J. Chong, ‘‘A survey of clustering schemes for mobile ad hoc networks,’’ *IEEE Communications Surveys & Tutorials*, vol. 7, no. 1, pp. 32--48, 2005.

[4] C. Cooper, D. Franklin, M. Ros, F. Safaei, and M. Abolhasan, ‘‘A comparative survey of vanet clustering techniques,’’ *IEEE Communications Surveys & Tutorials*, vol. 19, no. 1, pp. 657--681, 2017.

[5] A. Katiyar, D. Singh, and R. S. Yadav, ‘‘State-of-the-art approach to clustering protocols in vanet: a survey,’’ *Wireless Networks*, vol. 27, no. 7, pp. 4597--4622, 2021.

[6] C. J. C. H. Watkins and P. Dayan, ‘‘Q-learning,’’ *Machine Learning*, vol. 8, pp. 279--292, 1992.

[7] R. S. Sutton and A. G. Barto, *Reinforcement Learning: An Introduction*, 2nd ed. MIT Press, 2018.

[8] L. A. Zadeh, ‘‘Fuzzy sets,’’ *Information and Control*, vol. 8, no. 3, pp. 338--353, 1965.

# Appendix A About Appendices

Appendices should contain detailed proofs and algorithms only. Appendices can be crucial for overlength papers, but are still useful otherwise. Think of appendices as random-access substantiation of underlying gory details. As a rule of thumb: (1) Appendices should not contain any material necessary for understanding the contributions of the paper. (2) Appendices should contain all material that most readers would not be interested in [**?**].

# Appendix B Assessment

Your report will be assessed based on the following list of criteria.

## Appendix B.1 Style

[15 points] The report states title, author names, affiliations and date. The format follows this style?

1. Structure and Organization: Does the organization of the paper enhance understanding of the material? Is the flow logical with appropriate transitions between sections?
2. Technical Exposition: Is the technical material presented clearly and logically? Is the material presented at the appropriate level of detail?
3. Clarity: Is the writing clear, unambiguous and direct? Is there excessive use of jargon, acronyms or undefined terms?
4. Style: Does the writing adhere to conventional rules of grammar and style? Are the references sufficient and appropriate?
5. Length: Is the length of the paper appropriate to the technical content?
6. Illustrations: Do the figures and tables enhance understanding of the text? Are they well explained? Are they of appropriate number, format and size?

## Appendix B.2 Abstract

[10 points] Does the abstract summarize the report? These are the basic components of an abstract in any discipline:

1. Motivation/problem statement: Why do we care about the problem? What practical, scientific, theoretical or artistic gap is your research filling?
2. Methods/procedure/approach: What did you actually do to get your results? (e.g. analyzed 3 novels, completed a series of 5 oil paintings, interviewed 17 students)
3. Results/findings/product: As a result of completing the above procedure, what did you learn/invent/create?
4. Conclusion/implications: What are the larger implications of your findings, especially for the problem/gap identified?

## Appendix B.3 The Problem

[15 points] The problem section must be specific. The title of the section must indicate your problem. Do not use generic titles.

1. Is the problem clearly stated?
2. Is the problem practically important?
3. What is the purpose of the study?
4. What is the hypothesis?
5. Are the key terms defined?

## Appendix B.4 Background and Related Work

[15 points] Does the report present the background and related work in separate sections.

1. Are the cited sources pertinent to the study?

2. Is the review too broad or too narrow?
3. Are the references recent?
4. Is there any evidence of bias?

### Appendix B.5 Design

[15 points] Does the report present the design of the study.

1. What research methodology was used?
2. Was it a replica study or an original study?
3. What measurement tools were used?
4. How were the procedures structured?
5. Was a pilot study conducted?
6. What are the variables?
7. How was sampling performed?

### Appendix B.6 Analysis

[15 points] Does the report present the analysis?

1. How was data analyzed?
2. Was data qualitative or quantitative?
3. Did findings support the hypothesis and purpose?
4. Were weaknesses and problems discussed?

### Appendix B.7 Conclusion and Future Work

[15 points] Does the report state the conclusion and future work clearly?

1. Are the conclusions of the study related to the original purpose?
2. Were the implications discussed?
3. Whom the results and conclusions will effect?
4. What recommendations were made at the conclusion?