THESIS REVIEWER'S REPORT

I. IDENTIFICATION DATA

Thesis title:	**Communication Infrastructure Building in Mobile Robot Exploration**
Author's name:	**Bc. Martin Zoula**
Type of thesis :	master
Faculty/Institute:	Faculty of Electrical Engineering (FEE)
Department:	Department of Computer Science
Thesis reviewer:	Mgr. Martin Pecka, Ph.D.
Reviewer's department:	Department of Cybernetics

II. EVALUATION OF INDIVIDUAL CRITERIA

Assignment — extraordinarily challenging

How demanding was the assigned project?

The assignment requires not only to understand the state of the art in ad-hoc communication infrastructure building and developing of a novel deployment algorithm, but also experimental verification of the proposed model against the state-of-the-art methods. Given the complexity of real-world deployment in this context, the assignment is very challenging.

Fulfillment of assignment — fulfilled with minor objections

How well does the thesis fulfill the assigned task? Have the primary goals been achieved? Which assigned tasks have been incompletely covered, and which parts of the thesis are overextended? Justify your answer.

The thesis presents a broad overview of wireless signal propagation models. It presents and evaluates implementations of six relevant models, one of which is a novel model proposed by the author of the work. An integrated exploration method is presented which utilizes the propagation models to propose best places for dropping a comms relay module. A large and high-quality dataset has been collected for this thesis and is used for training and extensive evaluation of the propagation models. Unfortunately, the dataset has not been published. I understand that the city utility tunnels are critical infrastructure so publication of that data is not possible, but the student mentions also other places where measurements were conducted which are probably not critical infrastructure. It would be very good for the scientific community if some of these datasets would be published. Experimental verification of the whole pipeline has been conducted in a gold mine, although the tested scenario was trivial and did verify neither the behavior in any of the more complex tunnel geometries, nor any of the non-baseline methods.

Methodology — correct

Comment on the correctness of the approach and/or the solution methods.

First of all, a large dataset containing both RF propagation data and precise 3D models of the environment was collected (although this claim cannot be verified as the dataset is not publicly available). There are also descriptions of the materials the venue of the dataset consists of, which might affect the RF propagation. Using this dataset, the student has trained several propagation models and performed extensive evaluation of their performance, both in interpolation and extrapolation capabilities. The division to interpolation and extrapolation scenarios is a clever insight into the model capabilities. Some of the methods use Signal Shortest Path as the underlying environment model. This choice is not explained in the thesis and I have doubts about its suitability to represent RF signal propagation, which usually does not "align with the center of the corridor", but goes simply by the shortest unobstructed path, including reflections from obstacles. Moreover, SSP depends on the waypoints from unrelated planner module. In Figure 5a, it also seems that the local tunnel curvature can be computed for any point in the tunnel, whereas the text description talks only about angles between neighboring waypoints. Section 8.7 mentions use of a simulator. However, it also states that no signal propagation data are available in the simulator. It is therefore not clear why is this section even included in the thesis (it was probably only used to debug the dropping mechanism integration, which is of no interest to the reader of the thesis).

Technical level — B - very good.

Is the thesis technically sound? How well did the student employ expertise in the field of his/her field of study? Does the student explain clearly what he/she has done?

The thesis presents sufficient information to support all the theoretical claims and explains the used methods, including illustrations that help understanding the presented topics. The construction of the measurement rig was an important part of the work and it seems it has been done correctly to provide the requested data. The design of the measurement phase with two rigs moving throughout the space and continuously recording data also seems to be a good choice. What is not clear is how mote placement was done in the real-world experiment. All the models assume the antennas of transmitter and receiver are vertically positioned. However, by construction of the mote as presented in Figure 3, there is no mechanism to keep the deployable mote upright after deployment. So I assume that after deployment, the mote just lays horizontally on the ground, positioning also the antenna into a horizontal direction. That would go completely against both the assumptions of the models and the intuition that if a horizontal structure is to be covered, the antennas should be oriented vertically to achieve the best coverage.

Formal and language level, scope of thesis — C - good.

Are formalisms and notations used properly? Is the thesis organized in a logical way? Is the thesis sufficiently extensive? Is the thesis well-presented? Is the language clear and understandable? Is the English satisfactory?

The English language used throughout the thesis is generally good, but there are also tens of typos or grammar errors. None of them prevent smooth understanding of the document, but they distract the reader. Organization of the thesis is excellent and each section is extensive enough. I have objection to the usage of mathematical symbols in Chapter 6, mostly Section 6.1. The number of defined symbols is overwhelming, and the student used some very non-standard symbols like $\check{\mathcal{F}}_f$ or ř to designate variables. I argue that using verbose super-/subscripts such as F^{steady} instead of $\check{\mathcal{F}}_f$ would help. It is very easy to lose track of the meaning of the symbols, which makes understanding of the following equations very difficult.

Selection of sources, citation correctness — D - satisfactory.

Does the thesis make adequate reference to earlier work on the topic? Was the selection of sources adequate? Is the student's original work clearly distinguished from earlier work in the field? Do the bibliographic citations meet the standards?

The state of the art review section and explanation of the used methods are accompanied with a reasonable number of relevant citations, both of works from CTU FEE and other renowned electrical engineering departments. The student mentions his previous work [118] and clearly states that the topic of the work is different from the thesis topic, although some parts may be shared. There are a lot of inconsistencies in the bibliography section – capitals in paper titles are mostly "downgraded" to lower-case letters. Some works have their title in italics, while other works have the journal name in italics. There is also a lot of excess citations that definitely do not need to be present – it makes no sense to cite the USB-IF standard defining USB communication protocol, as well as it does not make sense to cite Intel corporation in general, and so on. Links to sensor datasheets or product pages would be better typeset as footnotes than as citations, as well as references to CRL and CRAS and some places/venues. Citation [137] is invalid (STDR simulator, the URL from the thesis does not resolve and is an invalid WWW URL).

Additional commentary and evaluation (optional)

Comment on the overall quality of the thesis, its novelty and its impact on the field, its strengths and weaknesses, the utility of the solution that is presented, the theoretical/formal level, the student's skillfulness, etc.

The software accompanying this thesis is very extensive. It almost seems the created framework is more sophisticated than would be required just for this thesis, so I hope it will be used in further research. Although it is the author's right to choose the license of the software he creates, I propose that Beerware is not a good choice. It is one of the informal licenses as "recognized" by the Free Software Foundation. FSF suggests "If you want your code to be free, don't invite gratuitous trouble for your users. Please choose and apply an established free software license."

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III. OVERALL EVALUATION, QUESTIONS FOR THE PRESENTATION AND DEFENSE OF THE THESIS, SUGGESTED GRADE

Summarize your opinion on the thesis and explain your final grading. Pose questions that should be answered during the presentation and defense of the student's work.

Work on this this thesis led to conducting of high-quality research accompanied by collecting and processing of a high-quality dataset (unfortunately non-public). Moreover, the thesis was completed with a real-world experiment with a robotic platform integrating all parts together (although the scenario was too trivial to showcase anything interesting). The formal part of the thesis is slightly under par, but nothing that would prevent understanding the presented ideas.

Questions for the defense:

1. The visualization of the cross-validation evaluation in Figure 18 is confusing or inconsistent with following claims about the best performing models. Regarding extrapolation, FSPL-β (a baseline method) seems to be better than ERM in all cases, not speaking about the other methods which seem to be significantly worse. So it is not clear why the author states in chapter Conclusion that "The VWM performed the best among the proposed models, being able to extrapolate the signal with around 11 dB standard deviation and no significant bias." Could you please add a statement that would explain this inconsistency?
2. What was the physical orientation of the deployed motes in the real-world experiment? Did they land in horizontal position, placing the antenna also horizontally? What could be done to place the antenna in a more suitable pose?
3. What is potential further use for the environment properties extracted from WLM model?
4. How would possible mapping drift influence the performance of the presented models?
5. What model would be suitable for the DARPA SubT Systems missions in each of its rounds, and for SubT Virtual missions with their simplified RF propagation model based on path-planning distance and visibility, which include discrete jumps in RSSI when crossing boundaries between simulated world tiles?
6. Could splines be used to represent the environment instead of straight and bent segments? Could that help?
7. Figure 5a shows a color scale of bending radius, which goes from 0 m to 20 m. The straight segments are assigned pink color, corresponding to 20 m. However, straight segments have infinite radius. Could you explain this discrepancy?
8. Do you plan publishing some dataset?
9. What is the relation between Signal Shortest Path and the planner waypoints? What requirements does it impose on the planner? (i.e. distance of waypoints, placement of waypoints, …)

The grade that I award for the thesis is B - very good.

Date: 21.01.23 Signature: