Tampereen yliopisto
Tampere University

Doctoral Programme of Computing and Electrical Engineering

EXTERNAL PRE-EXAMINER'S REPORT ON DOCTORAL THESIS

Kindly complete this report and forward it to the Programme by email to cee.doc.tau@tuni.fi within two (2) months' time.

Candidate's particulars

Name of the candidate: MSc. Asad Ali

Title of the thesis: Performance dynamics of directional extended reality networks.

Assessment of thesis

(1) General evaluation of the thesis

Please evaluate all items 1-10 and mark clearly just one box in each item.

	Excellent	*Very good*	*Good*	*Satisfactory*	*Sufficient*	*Insufficient*
1. Originality	☐	☐	☑	☐	☐	☐
2. Clarity of research questions, objectives and conclusions	☐	☑	☐	☐	☐	☐
3. Significance of research contribution	☐	☐	☑	☐	☐	☐
4. Technological relevance	☐	☑	☐	☐	☐	☐
5. Coherence: does the manuscript comprise a coherent unified entity	☐	☑	☐	☐	☐	☐
6. Soundness of research methodology	☐	☐	☑	☐	☐	☐
7. Adequacy and completeness of references	☐	☑	☐	☐	☐	☐
8. Logical organization, presentation and language	☑	☐	☐	☐	☐	☐
9. Independent contribution considering also the role in co-authored publications	☐	☐	☑	☐	☐	☐
10. Maturity and critical attitude	☐	☐	☑	☐	☐	☐

(2) Report on the thesis *(Please use separate sheets, if necessary.)*

Please write here a free-format report of 1-2 pages for summarizing your opinion about the scientific value of the work (the most important results and merits of the dissertation) and the discovered shortcomings. Justify the grades awarded to the individual components in the table above, especially if exceptionally high or low grades are suggested. Minor mistakes and stylistic corrections may be communicated directly to the doctoral candidate, but such suggestions should be noted in the statement.

(3)Recommendation on thesis pre-examination result

As your overall assessment, place the thesis in one of the following categories by a tick (x) mark.

1. I recommend the permission to publish the thesis. ☑
   (Pre-examiner is allowed to suggest minor amendments and minor technical revisions.)
2. I don't recommend the permission to publish the thesis for the reasons set out in my detailed report. ☐

(4) Recommendation for the grade

The faculty council approves and evaluates the dissertation based on the written statements of the opponents, the proposed grade of the possible evaluation board, the pre-examination statements and other written comments.

Doctoral dissertations are graded on a scale of *approved with distinction*, *approved*, and *failed*.
A dissertation approved *Pass with distinction* is uncommonly meritorious compared to a dissertation at the approved *Pass* level. The aim is that a dissertation approved *Pass with distinction* belongs among the internationally best dissertations (10-15 % of dissertations), achieves the level of an approved dissertation along all sub-areas, and is additionally so strong in some respects that it can be overall seen as exceptional.

My recommendation for the grade:

Approved with distinction	Approved	Failed
☐	☑	☐

Date: 24/07/2024

Name: Nitin Jonathan Myers

Signature: Nitin J. Myers

This thesis analyses the system-level performance of millimeter wave (mmWave) systems under important practical challenges such as interference and beam misalignment. The topic is very relevant, especially in the context of on-body extended reality mmWave devices, due to two reasons. First, directional beams in on-body mmWave systems are susceptible to beam misalignment due to micro-mobility. Second, interference will be a key issue in dense gaming environments. The research questions are well formulated and addressed through a system-level study using tools from stochastic geometry, queuing theory and array processing. The study is coherent with the research questions and provides key takeaways such as:

- The use of narrow beams and high transmit power increases the session rejection probability.
- Considering interference effects in dense on-body networks, there exists an optimal transmit power at which the data rate per square meter is maximized.

To the best of my knowledge, the above conclusions are novel. The results are of practical value as they provide useful insights into the design on-body communication systems. Based on my review of the thesis, I could assess that the candidate has a good mathematical background and was able to apply advanced mathematical tools from stochastic geometry and queuing theory. The candidate also has two first-authored publications in peer-reviewed IEEE Journals and three first-authored conference publications, highlighting the candidate's independent contributions.

In the thesis, the candidate made certain approximations (see technical comments listed below) without discussing the conditions under which they are valid. It is important to state these conditions, to assess whether the developed framework can be applied to future extended reality systems operating in different settings (e.g. large antenna arrays, near-field). While the thesis accounts for key challenges due to micro-mobility and beam misalignment in on-body networks, issues due to polarization mismatch under micro mobility were not discussed.

The candidate is requested to address the following list of comments in the revised version:

Technical comments:

- Pg 20, sentence 3: It is not correct to state that shorter wavelengths at mmWave enable high-speed data transmission. Please rephrase.
- Please include a figure to illustrate \alpha and \theta in Page 34.
- The assumptions under which (2.1) is valid must be listed. It appears that the directivity model in (2.1) breaks down for a large number of antennas. For an N-

element antenna array, \theta scales as 1/N and it can be observed that D_o in (2.1) as N^2. The array gain, however, scales as N and not N^2. Given the interest in employing large antenna arrays at mmWave, I think it is important to discuss the regime in which (2.1) is valid.

- Equation (2.8): There needs to be min{Prx/Pn, SNRmax} within the log.
- Please add a sketch to show x(\alpha), d(\alpha) and \alpha before (3.5).
- Equation (3.32): The numerator and denominator must have exp(+2k\gamma) and not exp(-2k\gamma). Also, it is not clear how the fraction can be approximated as exp(-2k\gamma). Shouldn't there be an extra factor of 2? Also, under what assumptions is this approximation valid?
- Equation (3.36): Need to set the expression to zero to arrive at (3.37).
- The directivity reduction factor \rho (\alpha) is 0 for \alpha> \theta (HPBW). This is not realistic as the directivity reduction factor, which is -3dB at \theta, does not drop off to zero immediately for \alpha> \theta. Please discuss the limitations of the model used for \rho (\alpha). This comment also relates to the assumption that a transmission failure occurs for \alpha>\theta.
- Page 100: Provide numbers of maximum MCS level and corresponding SNR in IEEE 802.11ad/ay standards.
- In future work, the beam misalignment problem for THz systems is discussed. The candidate should discuss the near-field effects that may arise while transitioning to THz carrier frequencies. The discussion should account for the property that beams in such systems focus power in a region unlike far-field beams that focus power along a direction.

Writing-related comments:

Abstract, Pg vi: Add is in "beam misalignment high", delete "ing" in revealing.

Page 20: Prograssive to Progressive.

Page 23: Add "in the" in "devices operating mmWave band".

Page 30: "robust methodology" is vague. Please indicate what is the method robust to.

Page 37: l_{i->k+1} is defined twice.

Page 46: Missing period ('.') in the sentence following (3.1).

Page 61, (3.36): The exponent of (\lambda_s/ \mu) should be k and not n.

Page 94: it is assumed \alpha -> \alpha is assumed ...

Add an illustration to Fig. 4.1 to explain the terms in equation (4.5)

Page 98: he data rate -> the data rate; For required “transformation transformation”

Missing publication venues for references [4] and [5]

Report by:

[redacted]

Dr. Nitin Jonathan Myers,
Assistant Professor,
Delft Center for Systems and Control,
Delft University of Technology,
The Netherlands.