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Review of Thesis

submitted in partial fulfilment of requirements for promotion to associate professorship

Specialization: Water Management and Hydraulic Engineering

Applicant: Dr. Ing. Vojtech Bares

Reviewer: Prof. Dr. Peter Molnar

Thesis title: Quantitative Rainfall Estimation from Commercial Microwave Links and Its Application to Urban Catchment Runoff Predictions

Importance of topic of thesis

Comments: The Thesis topic is the use of commercial microwave links (CML) for high-resolution path-averaged rainfall estimation in urban areas and subsequent flood and drainage system modelling. The importance of this topic is high. Traditional rainfall sensors such as collecting or optical raingauges, rainfall radar and satellites, are widely applied and much is known about the problems and accuracy of the data they produce. However, in urban areas, where ground point gauges may miss heavy rainfall cell centers and weather radar does not provide accurate high-resolution estimation of rainfall intensity, the result often is unexpected local urban flooding and damage. This is where indirect (what the candidate calls opportunistic) measurements, such as those from CMLs are useful, at basically only data-processing and operation costs.

The field is very new. To my knowledge, the first paper on CMLs for rainfall estimation was the work of Messer et al. in 2006. Since that time many local studies have tested this approach and provided numerous examples. However, in my view it is only the work of Dr Bares and colleagues at CTU that has truly described a working real-time system and how it could acquire and process CML data from telecommunications providers in Czechia into a useful rainfall product. While this Thesis is maybe not ground-breaking in basic research in urban rainfall, it is certainly a very important contribution in the application-oriented research side of CML use in urban hydrology.

Superior	Good	Average	Poor	Not applicable
☐	☒	☐	☐	☐

Method of solution

Comments: Methodologically the Thesis covers the complete workflow of CML use for urban hydrology: from data acquisition, quality control, bias correction, to applications in urban rainfall-runoff modelling. The solution is truly comprehensive, consisting of logically connected steps in the whole operation chain. Solutions in the area of data acquisition concentrate on the real-time processing of CML data at country scale. Then, the acquired data are compared with ground observations and a wet-antenna attenuation (WAA) correction approach is developed. Finally, it is shown how the newly acquired high-resolution path-average rainfall estimates can complement and improve urban flood predictions in Prague and Tabor. The latter is the core aim of the Thesis.

The Thesis is organized into two parts. The first part (Chapters 1-4) consists of chapters which identify research gaps on the basis of a synthetic review of the state-of-the-art in CML rainfall retrieval, and present a very interesting CML data-acquisition protocol for Czechia called Tel4Rain. The second part (Chapter 5) then presents the main results of the experiences gained with the applicaiton of such data to urban catchment runoff prediction in two locations, in 5 published scientific papers. Chapter 6 provides a summary and outlook.

Overall, the solution methodology in the Thesis is robust, building up foundation knowledge, identifying the main unknowns, generating new data, and providing very clear examples of their application to urban hydrology. All of this is done in a succint way, the descriptions are

sometimes perhaps too short, but at the same time they are clear, which at the end makes this package a very readable and usable compendium.

Superior	Good	Average	Poor	Not applicable
☐	☒	☐	☐	☐

Quality and correctness of results achieved

Comments: The quality and correctness of the results are good. I see the main strengths of this Thesis in the following areas:

(a) It provides a robust empirical basis. Across all papers, the candidate employs unique, multi-year datasets involving many CMLs and high frequency sampling (1 min or less) which is unusually rich by international standards. It also allows the study of link frequency and CML length effects which in my view are unique because of this richness of empirical data.

(b) It has methodological rigour. Multiple retrieval models are tested, calibration regimes, and validation approaches are tested (Paper 4). The hydrodynamic model evaluations are done with independent data, tested across many rainfall events, and include uncertainty quantification (e.g. Papers 2, 5). Temporal dynamics are repeatedly evaluated using common efficiency metrics, correlation metrics, and timing diagnostics (Papers 2, 3, 5).

(c) There is demonstration of added hydrological value for urban areas. The papers consistently show that CML based rainfall outperforms sparse municipal rain gauge networks in predicting hydrograph timing, rising limb dynamics, peak discharges, and this increase in performance is clearly linked to highly spatially variable convective storms (Papers 3, 5).

(d) Transparency about limitations. I also appreciate that the work is unusually careful in acknowledging weaknesses in CML data processing into rainfall rate, WAA correction, antenna hardware, and other CML network idiosyncrasies (all Papers). This is commendable.

The results also indicate some areas of weakness of this research, for example:

(a) Generalizability concerns. Although applicatively interesting, it is not clear to me how the empirical data collected in a few metropolitan regions in Czechia and hardware from one Telecom provider (Ericsson Mini Link) are transferable to different climates, antenna radome materials, different link geometries and frequencies, and other effects.

(b) Dependence on reference data of limited spatial representativeness. Several calibration procedures (especially in Papers 4 and 5) rely on (few) rain gauges located outside of the urban areas, which can undermine calibration validity for convective storms and lead to undesired path-averaging (smoothing). The authors acknowledge this, but it still remains a weakness.

(c) Residual uncertainty in WAA modelling. I find the WAA correction (Paper 4) the highlight of the Thesis, even though it remains partially underdetermined, the performance is rain type dependent, and calibrated parameters may be partially compensating for other unmodelled processes. More work could have been devoted to testing WAA correction parameter stability across hardware types.

Overall, I consider the quality and correctness of the results good, acknowledging also the complexity of the problem tackled.

Superior	Good	Average	Poor	Not applicable
☐	☒	☐	☐	☐

Originality of results achieved

Comments: The originality and novelty of the Thesis in my view lies in demonstrating that opportunistic sensing via CMLs can produce rainfall estimates suitable for operational hydrology.

Key original contributions:

(a) Demonstrating rainfall retrieval from dense CML networks does provide added value to small-scale rainfall space-time field variations (Papers 1 and 2). A bias is reported compared to ground stations, but overall CMLs are shown to reproduce hydrograph dynamics better than conventional

rain gauges (Papers 2 and 3).

(b) Revealing the effect of CML hardware. This work quite clearly shows the dependence of hydrological performance on link geometry and frequency (Paper 2). In Tel4Rain it also provides a proof-of-concept that real-time acquisition from Telecom providers may be possible, which as far as I can judge is one of the first demonstraitons thereof.

(c) Introducing transferable WAA models calibrated on minimal auxiliary data (Paper 4), this to me is the genuinely original innovation in this Thesis, including the systematic comparison of empirical WAA models.

(d) Demonstrating that CMLs can substitute rain gauges for uncertainty-aware runoff prediction, including calibration on discharge data alone (Paper 5), this is conceptually novel for hydrological practice.

Overall, I judge the novelty to be average to good, simply because it still leaves questions of generalizability open, it has been well tested in Czechia, but not anywhere else.

Superior	Good	Average	Poor	Not applicable
☐	☒	☒	☐	☐

Publication rate of results achieved

Comments: The work behind this Thesis consists of 5 scientific papers, published in scientific journals of good standing: Water Science and Technology, J. of Environmental Management, IEEE Transactions on Geoscience and Remote Sensing, and J. of Hydrology. They have good citation rates: three of the papers (Papers 1, 4, 5) have field-weighted-citation ratios greater than 1 which means they are cited more than average in the field. In particular Paper 1 (FWCI=2.6) is likely to become a standard review paper in the CML field, and Paper 4 (FWCI=1.8) on the WAA correction in my view will also have high impact.

I am also aware that the candidate has also co-authored many other works on CML use in urban hydrology. On this basis I consider the publication rate sufficient.

Superior	Good	Average	Poor	Not applicable
☐	☒	☒	☐	☐

Response to results and citation rate

Comments: See comments above on the FWCI, I believe the citation rate of the papers submitted in this Thesis is not outstanding but appropriate for urban hydrology, and I consider two of the submitted papers to have very high future citation impact potential.

Superior	Good	Average	Poor	Not applicable
☐	☒	☒	☐	☐

Applicability of results to development in the field and for further research

Comments: The Thesis results advance the argument that CML networks can serve as low cost, high resolution rainfall monitoring infrastructure. Few groups internationally (e.g. TU Delft, KNMI, Eawag) have developed similarly comprehensive pipelines for CML data in quantitative precipitation estimation (QPE). However, in my view the Czech approach presented by the candidate is the most comprehensive and in-depth exploration of this potential yet.

Further research outlooks are briefly touched upon by the candidate in Chapter 6. More could have been put forward there related to the hardware developments, and the dynamic nature of the technological developments insofar they will improve the use of CML data for rainfall estimation (or not) in the future.

I do appreciate the proposition raised by tha candidate that developing countries of the Global South may look at CML rainfall estimation in urban areas as an alternative to very costly ground monitoring by raingauges. This is indeed an interesting synergetic alternative to activities like e.g. TAHMO (Trans-African Hydrometeorological Observatory) in Africa. But it would need to be

explored in more detail.

Superior	Good	Average	Poor	Not applicable
☐	☒	☐	☐	☐

Applicability of results to technical practice

Comments: The Thesis has in my view a place in technical practice, in that is can provide an opportunity for telecommunication companies to collaborate with rainfall experts on their weather-related signal losses at antennas, and in the process improve rainfall estimation in real-time. To me it is this real-time aspect of QPE estimation by CMLs that is attractive, if telecommunication data can be accessed and processed in workflows that are close-to real time. In my opinion the potential here is high to capture the very high rainfall intensities in storms in urban areas which could be superior to weather radar and thereby assist hazard asesment and warning systems. This would be a direciton that has future impact in technical practice, even though the Thesis doesn't quantify it very clearly.

Superior	Good	Average	Poor	Not applicable
☒	☒	☐	☐	☐

Compliance with requirements on thesis – quality of thesis

Comments: The Thesis is more on applied than fundamental research.The five core papers in the Thesis form a coherent research trajectory, moving through the stages of establishing feasibility of CMLs as rainfall sensors for urban catchments; solving the critical wet antenna attenuation problem; demonstrating the added value of CMLs for runoff prediction, and ultimately quantifying prediction uncertainty under real operational conditions.

I am not fully familiar with the Thesis requirements of CTU, for my institution's standards this Thesis would have been considered rather short and not exploring all the scientific details in full depth. At the same time, in its conciseness I truly appreciate the clarity that the Thesis brings -- it is certainly a very informative and competent survey of the CML use in urban hydrology. On this basis, I judge the quality of the Thesis to be good.

Superior	Good	Average	Poor	Not applicable
☐	☒	☐	☐	☐

Comments

Overall evaluation of thesis
The candidate presents a technically rigorous, empirically rich, and methodologically coherent research program in his Thesis, that advances the use of commercial microwave links (CMLs) for high resolution rainfall estimation and urban hydrological modeling. The overall contribution is very good in quality and originality, and has the potential to have high impact in the engineering practice of urban hydrology. The candidate convincingly demonstrates that CML rainfall estimates can outperform conventional gauges for urban hydrology, especially in capturing temporal runoff dynamics and spatially variable convective storms. The work on wet antenna attenuation is particularly original and impactful. While the research would benefit from validation in climatically and technologically diverse settings, the overall contribution is in my opinion internationally excellent, and shows a clear leadership of the candidate in the emerging field of opportunistic microwave monitoring of rainfall in urban hydrology. Additional comments on the thesis and the author: In my view the candidate is an authority on CMLs in the European urban hydrology domain. He has the engineering skills to produce advancements in rainfall estimation for urban hydrological predictions that have a practical impact, and he clearly is able to lead his team members in that direction. I recomend that his Thesis is accepted towards promotion to associate professor.

Promotion to associate professorship recommended	***yes*** ☒	***no*** ☐

Date: 28.02.2026

Reviewer's signature: .....[redacted].....