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# Master Thesis

# Implementation and Performance Evaluation of a C-V2X Routing Protocol

Efficient traffic routing in vehicular ad-hoc networks (VANETs) has gained research interest in the past [1]. Recent work has shown that the proactive integration of context information, such as trajectory knowledge [2] and environmental sensing [3], leads to a significantly more robust and lower latency end-to-end performance. Although the concepts are proven, evaluation has been carried out for WiFi mesh networks. However, modern intelligent transportation systems (ITSs) are expected to rely on cellular vehicle-to-everything (C-V2X) communication technology and its following generations. Node relaying will be part of upcoming releases, as possible routing protocol stacks are currently investigated by the 3GPP standardization organization [4]. The benefits from a direct mesh routing with C-V2X are versatile, as it enables coverage enhancements, 5G network relaying, lower latencies, spontaneous deployments, and much more.
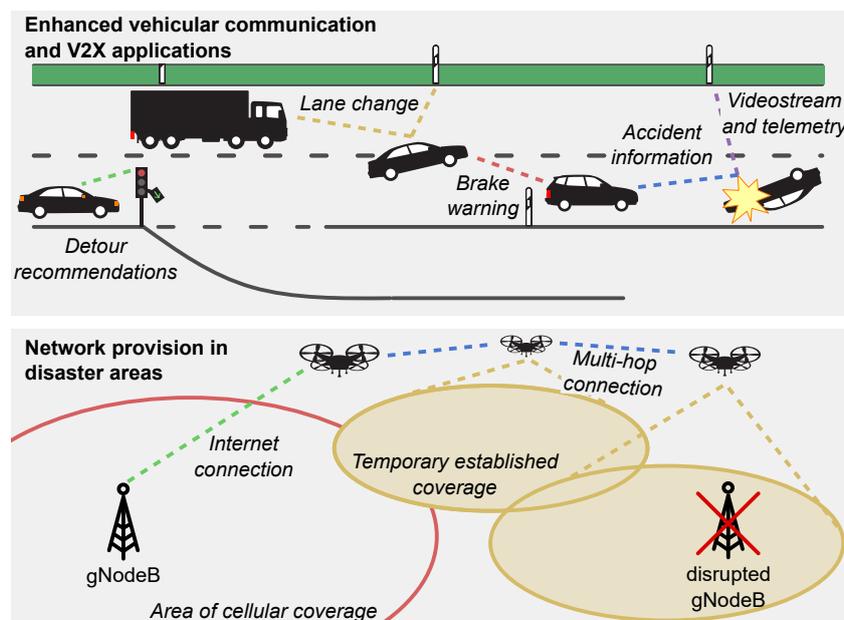


The scope of this thesis is to implement and adapt a routing protocol to the specific needs of C-V2X. Thereby existing C-V2X simulation frameworks [5] are to be analyzed, extended, and a simulation framework for the routing protocol is to be added [6]. A comprehensive performance analysis is carried out based on selected V2X use cases, with focus on primary key performance indicators (KPIs), such as service level reliability, latency, and jitter, but as well as a scalability and robustness analysis.

The development and analysis is done simulative with the network simulator ns-3. An experimental validation is also reasonable, but not mandatory.

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**Requirements:**

- Experience with C++, Python
- Knowledge in results visualization with Python
- Knowledge of multi-hop routing protocols
- Knowledge in C-V2X (device-to-device communication)
- Experience with ns-3, Linux, git (optional)

**References**

[1] E. R. Cavalcanti, J. A. R. de Souza, M. A. Spohn, R. C. d. M. Gomes, and A. F. B. F. d. Costa, "VANETs' research over the past decade: Overview, credibility, and trends," *SIGCOMM Comput. Commun. Rev.*, vol. 48, no. 2, pp. 31–39, May 2018.

[2] B. Sliwa, C. Schüler, M. Patchou, and C. Wietfeld, "PARRoT: Predictive ad-hoc routing fueled by reinforcement learning and trajectory knowledge," in *2021 IEEE 93rd Vehicular Technology Conference (VTC-Spring)*, Helsinki, Finland, Apr. 2021, Best student paper award.

[3] C. Schüler, B. Sliwa, and C. Wietfeld, "Towards machine learning-enabled context adaption for reliable aerial mesh routing," in *2021 IEEE 94rd Vehicular Technology Conference (VTC-Fall)*, Virtual, Sep. 2021.

[4] 3rd Generation Partnership Project, "Study on NR sidelink relay," 3rd Generation Partnership Project, Tech. Rep. 38.836, Mar. 2021, version 17.0.0.

[5] F. Eckermann, M. Kahlert, and C. Wietfeld, "Performance analysis of C-V2X mode 4 communication introducing an open-source C-V2X simulator," in *2019 IEEE 90th Vehicular Technology Conference (VTC-Fall)*, Honolulu, Hawaii, USA, Sep. 2019.

[6] C. Schüler, M. Patchou, B. Sliwa, and C. Wietfeld, "Robust machine learning-enabled routing for highly mobile vehicular networks with PARRoT in ns-3," in *Proceedings of the 2021 Workshop on Ns-3*, Virtual, Jun. 2021.

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