

An Optimization-Driven Energy and Throughput-Aware Stable Multipath Flow Routing Scheme Considering Flow Interactions for Software-Defined Vehicular Networks

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Uncertain link states and the presence of dynamic vehicular topologies pose significant challenges in Software-Defined Vehicular Networks (SDVNs) when considering the reliability of data delivery. Current methods fail to model uncertainty and estimate link lifetime accurately; therefore, the risk of packet loss is greater. In addition, they do not compute optimal flow fractions based on sub-flow throughput, energy consumption, latency, and packet delivery ratio, nor do they consider the effect of flow interactions. In this study, an original link lifetime estimation model is proposed along with an optimization-based multipath flow routing framework. The optimization model is formulated as a nonlinear optimization problem with the aim of optimizing flow delivery with the objectives of maximizing throughput and packet delivery ratio while minimizing latency and packet transmission energy. The proposed framework aims to model the effect of flow interactions in the optimization model to capture the effects of congestion and interference among different flows. Through the introduction of constraints for heterogeneous channel utilization, the proposed framework aims to avoid network congestion, while Quality of Service (QoS) threshold constraints guarantee a QoS-aware routing solution, ensuring data integrity and reliability. Prediction of link lifetime uses probability-based methods incorporating vehicle mobility scenarios, such as approaching/leaving junctions or other nearby vehicles, with corresponding sensor data like relative velocity and acceleration. The link lifetime modeling includes the effects of vehicular density and propagation path loss on link stability and is derived using the Cost-231 path loss model for line-of-sight and non-line-of-sight scenarios with urban building obstructions. Our study evaluates the proposed routing framework against existing approaches in terms of delivery ratio, latency, energy consumption, and throughput for different speeds and flow sizes. The results demonstrate the superiority of the proposed framework with a consistent packet delivery ratio of 98–100% and much lower latency (10–15 ms) compared to benchmark schemes (e.g., QRSDN at 60% delivery and 80 ms latency), while maintaining stable throughput.

Keywords: SDVN, Link lifetime estimation, Multipath flow routing, Nonlinear optimization, Energy efficiency