Study of Network Clustering for Connected VRU

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Agenda

- Introduction
- Connected Active VRU
- Clustering Techniques and VRU Safety
- VRU Awareness Approach
- Future Work

Introduction

- **Increased Interest in Vulnerable Road Users (VRU) Integration and Detection**: Recent years have seen a significant rise in the study of Vulnerable Road Users (VRU) within vehicular traffic contexts, with hundreds of articles published on IEEE Xplore [1].
- **Recognition by Standardization Bodies**: Organizations such as ETSI have acknowledged the critical role of VRU, emphasizing their vulnerability and the necessity for their consideration in autonomous driving technologies [2].
- **Autonomous Systems and VRU Detection**: The detection of VRU in autonomous systems primarily relies on sensor and camera technologies for real-time recognition.

[1] Silva R. et al **"Vulnerable Road User Detection and Safety Enhancement: A Comprehensive Survey,"** arXiv preprint arXiv:2405.19202 (2024).

[2] ETSI. "**Intelligent Transport System (ITS); Vulnerable Road Users (VRU) awareness; Part 1: Use Cases definition; Release 2**,". Standard ETSI TR 103 300-1 V2.1.1. 2019

Introduction

- **Challenges in Visibility:** In situations where VRU may not be detected by sensors, wireless networks offer a cooperative solution [3].
- **Potential of C-V2X Networks:** C-V2X networks show considerable promise by integrating VRU through smartphones, enabling active participation in wireless networks.
- **VRU Connected Devices:** Devices with Internet connectivity can publish positional information and form VRU clusters via direct communication, enhancing safety and environmental awareness without overloading the 5G network core.
- **Alerting Motorized Vehicles:** VRU clusters utilize wireless network capabilities to alert motorized vehicles in traffic contexts

[3] Z. Chaima et. Al. "5G-enabled V2X communications for Vulnerable Road Users Safety Applications: a review," Wireless Networks 29, 3 (2023), 1237–1267.

Connected Active VRU

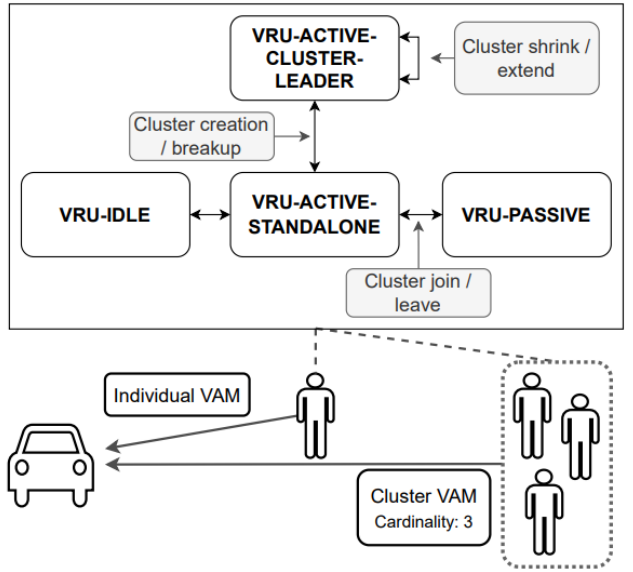
- Active approach for connected VRU
  - Periodically sent VRU Awareness Messages (VAM)
  - Congested Scenarios
    - Many VAMs could be generated
    - Wireless Network degradation

VRU clustering algorithms

Clustering Techniques and VRU Safety

VRU clustering algorithms

- VRU's roles:
  - Cluster Head (CH) or Leader
  - Cluster Member (CM) or Follower
- VRU's states:
  - Active Standalone
  - Active Cluster Leader
  - Passive



Source: [4]

[4] M. Rupp and L. Wischhof. **"Evaluation of the Effectiveness of Vulnerable Road User Clustering in C-V2X Systems,"** 2023 IEEE International Conference on Omni-Layer Intelligent Systems, COINS 2023. https://doi.org/10.1109/COINS57856.2023.10189204

Clustering Techniques and VRU Safety

VRU clustering algorithms

- Benefits:
  - Improve network scalability
  - Reduce user interference
  - Better use of network resources
  - Clusters create an additional layer of privacy and security
  - Traffic management
  - Real-time decisions – Lower Latency
- Disadvantages:
  - Creation procedures – increase latency
  - Switching states – over-signalling
  - Overhead – Congested scenarios

Clustering Techniques and VRU Safety

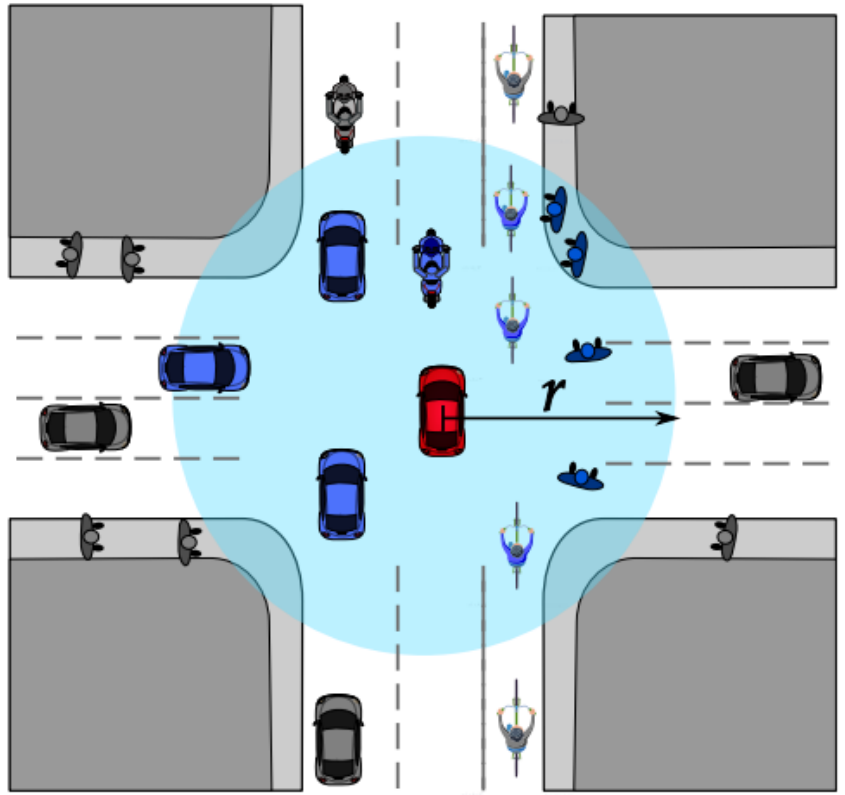
Summary of the comprehensive study:

- **25** articles related to network clustering in vehicular context from 2018 to 2024.
- **10** considering urban scenarios.
- **4** are focused on VRU and the main reference is the ETSI proposal
- Mobility of nodes is a recurrent metric for cluster formation
- **5G** appears as a key technology in terms of VRU inclusion.
- Performance metrics:
  - End-to-end delay EED, Packet Delivery Ratio PDR, Packet Loss Ratio PLR, and network bandwidth usage.
  - CH and CM lifespan, node state changes, and cluster count.

VRU Awareness Approach

- VRU Awareness Probability VAP [5]

$$\mathrm{VAP}_{i,r,t} = \frac{\mathrm{NRV}_{i,r,t}}{\mathrm{NTV}_{i,r,t}}, \quad \Rightarrow \quad \mathrm{VAP}_{i,r,t} = \frac{\mathrm{NKV}_{i,r,t}}{\mathrm{NTV}_{i,r,t}},$$



[5] A. Yáñez, S. Céspedes, and C. Azurdia-Meza. **"Know Your Vulnerable Neighbors: Awareness Model for 5G C-V2X Communications Mode 2."** In Proceedings of the Int'l ACM Symposium on Design and Analysis of Intelligent Vehicular Networks and Applications. 17–21 2023

Future Work

- Simulations Over 5G Side-link
- Implement Clustering Algorithms
  - Network Reliability
  - VRU safety analysis
- Urban scenario - building occlusions
- Different VRU densities and mobilities

Thank you

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