Open-source framework for simulation of services based on Vehicle-to-Pedestrian Communication

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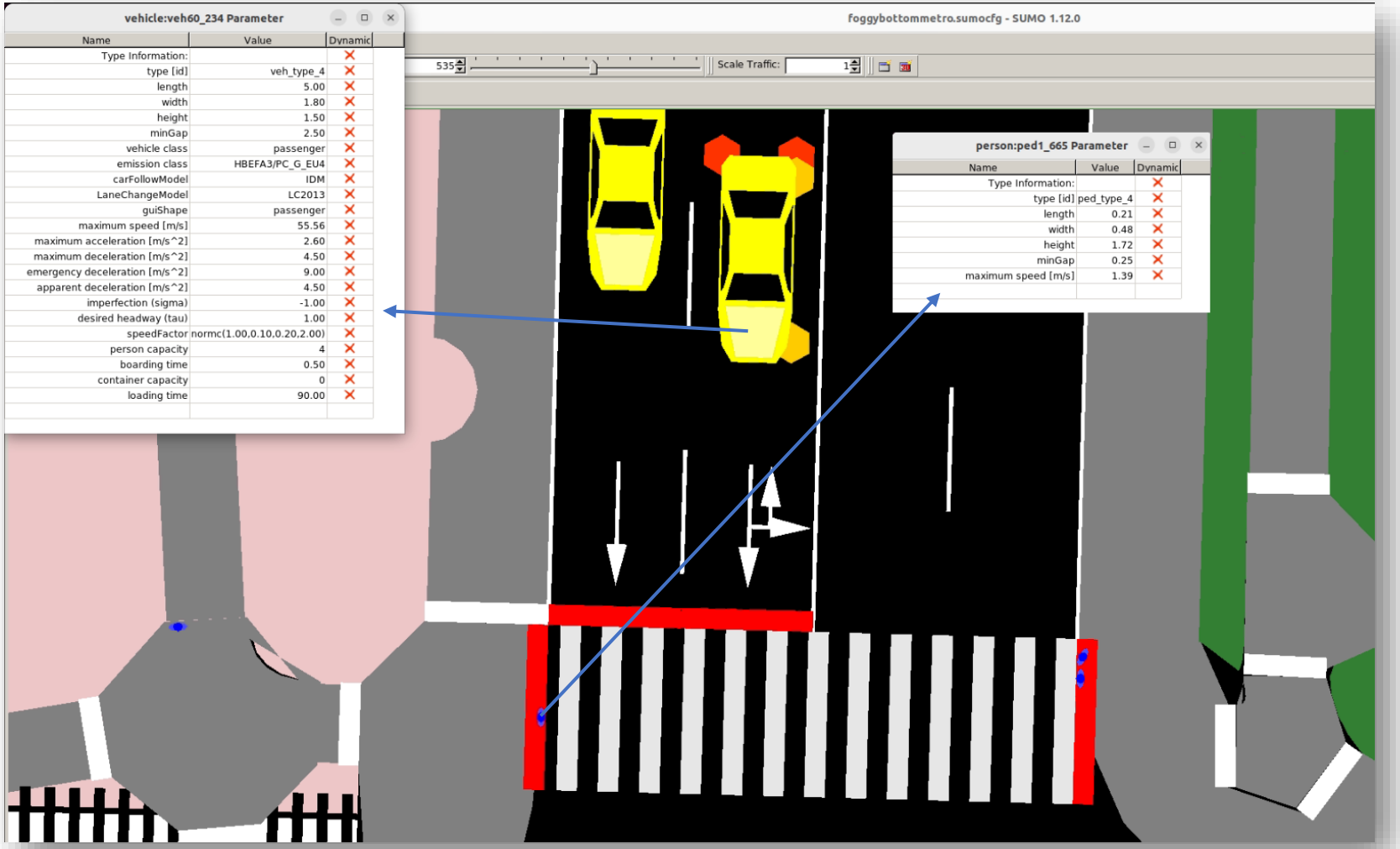
Introduction

- Connected Cooperative and Automated Mobility (CCAM) is transforming transportation by improving safety, efficiency, and decreasing the environmental impact.
- Vehicle-to-Everything (V2X) communication plays a crucial role in enabling CCAM.
- Vehicle-to-Pedestrian (V2P) communication presents unique challenges due to pedestrian mobility and device constraints.
- This study introduces a simulation framework integrating open-source tools to enhance V2P communication modeling.

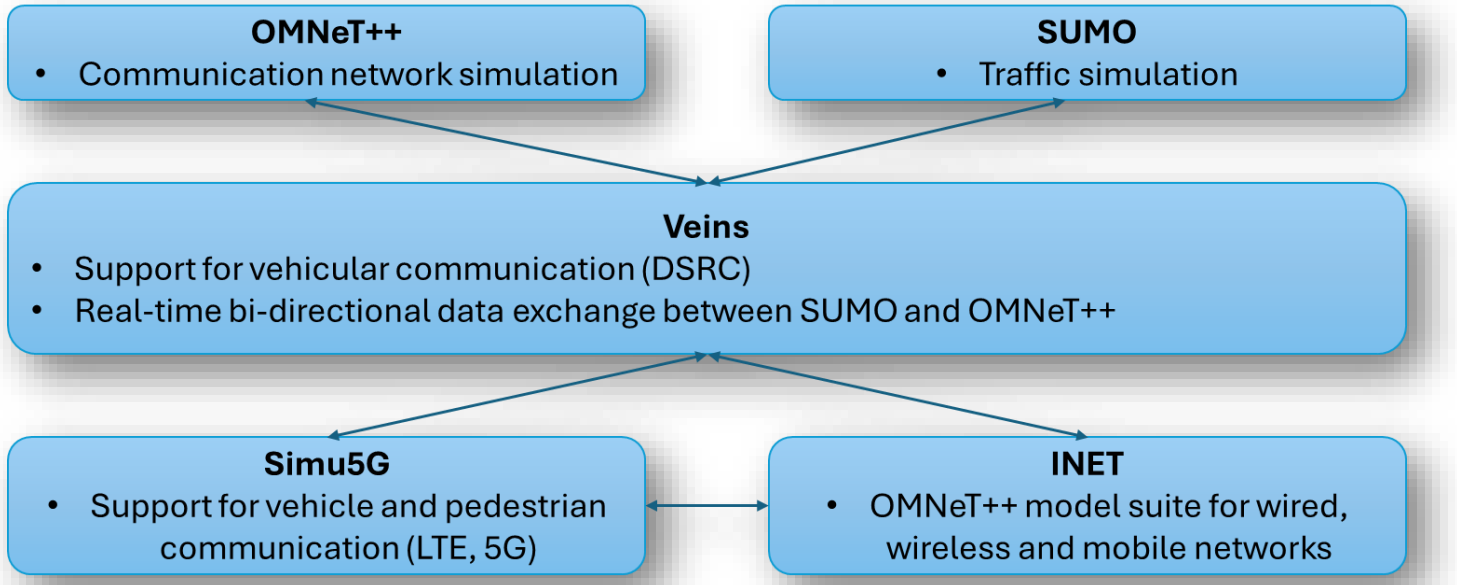
Motivation

- V2X communication is essential for smart mobility but lacks sufficient simulation frameworks for pedestrian interactions.
- Real-world testing in the early stages of V2P systems development is costly and impractical due to regulatory and infrastructure barriers.
- Objective: Extend existing validated and calibrated simulation tools to develop a simulation framework, bridging gaps in pedestrian communication modeling.
- Significance: Supports prototyping of Cooperative Intelligent Transport Systems (C-ITS) and development of services for Vulnerable Road Users (VRUs).



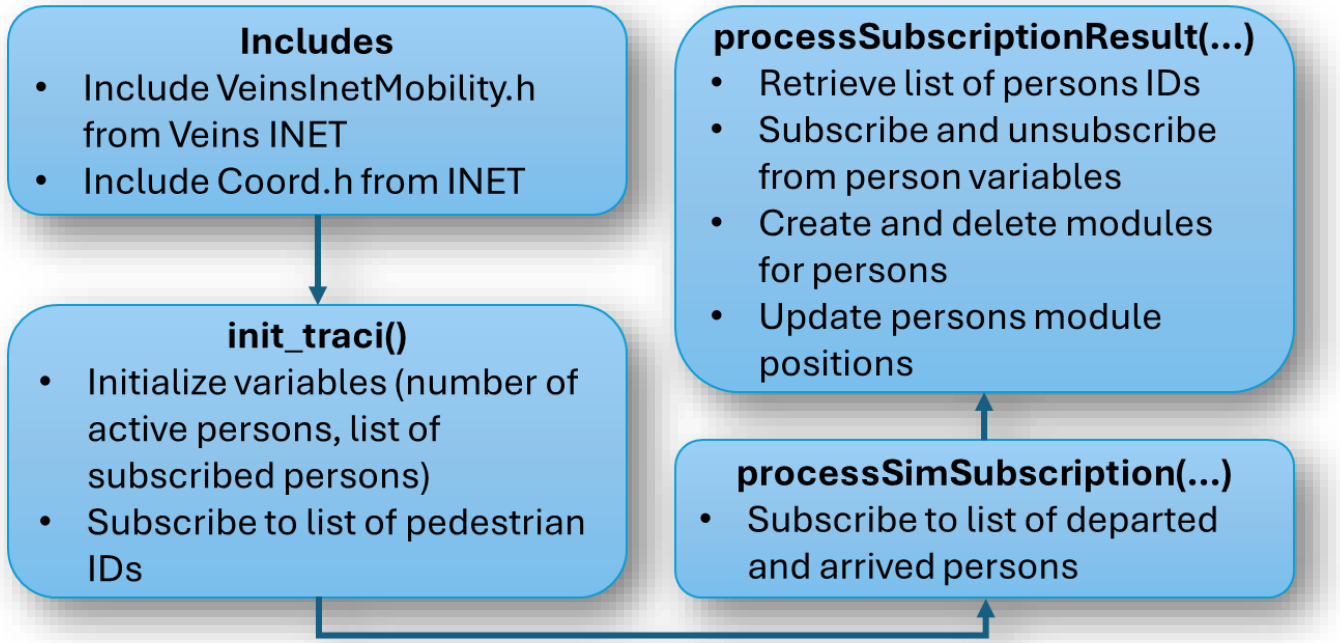
Methods I

- **Simulation tools used:**
  - OMNeT++ (communication network simulator)
  - SUMO (traffic simulator)
  - Veins (vehicular communication framework, integration of OMNeT++ and SUMO)
  - Simu5G & INET (cellular communication and internet stack model libraries)

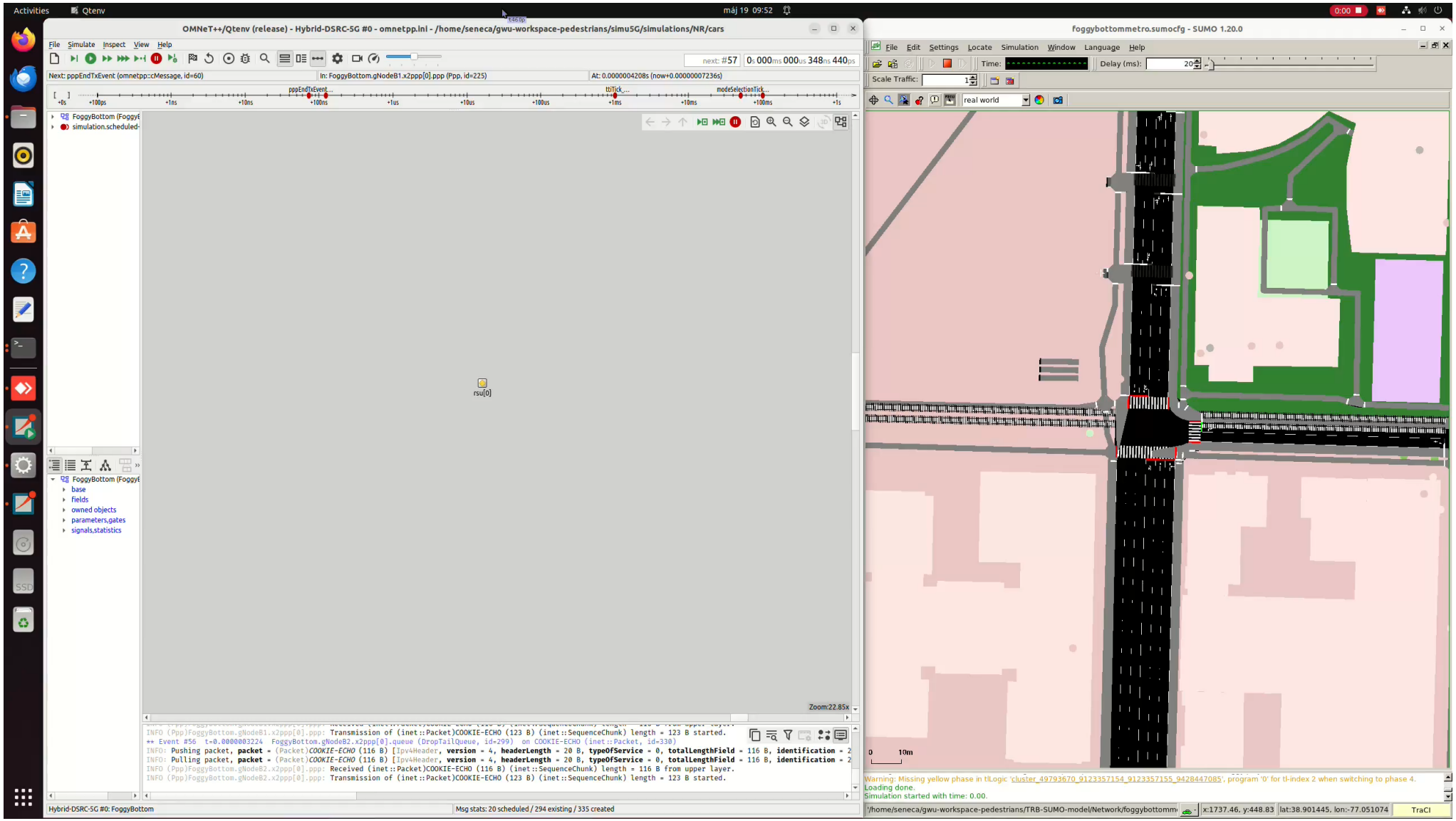


Methods II

- **Enhancements to Veins:**
  - Extended to support runtime exchange of pedestrian communication variables via bi-directional coupling of OMNeT++ and SUMO - TraCI
  - Integration of cellular technologies for realistic V2P interactions



Results I


Activities
Qtenv
máj 19 09:52
OMNeT++/Qtenv (release) - Hybrid-DSRC-5G #0 - omnetpp.ini - /home/seneca/gwu-workspace-pedestrians/simu5G/simulations/NR/cars
File Simulate Inspect View Help
Next: pppEndTxEvent (omnetpp::cMessage, id=60)
In: FoggyBottom.gNodeB1.x2ppp[0].ppp (Ppp, id=225)
At: 0.0000004208s (now+0.000000072365)
FoggyBottom (FoggyE
simulation.scheduled-
rsu[0]
Zoom:22.85x
base
fields
owned objects
parameters,gates
signals,statistics
INFO (Ppp)FoggyBottom.gNodeB1.x2ppp[0].ppp: Transmission of (inet::Packet)COOKIE-ECHO (123 B) (inet::SequenceChunk) length = 123 B started.
** Event #56 t=0.0000003224 FoggyBottom.gNodeB2.x2ppp[0].queue (DropTailQueue, id=299) on COOKIE-ECHO (inet::Packet, id=330)
INFO: Pushing packet, packet = (Packet)COOKIE-ECHO (116 B) [Ipv4Header, version = 4, headerLength = 20 B, typeOfService = 0, totalLengthField = 116 B, identification = 2
INFO: Pulling packet, packet = (Packet)COOKIE-ECHO (116 B) [Ipv4Header, version = 4, headerLength = 20 B, typeOfService = 0, totalLengthField = 116 B, identification = 2
INFO (Ppp)FoggyBottom.gNodeB2.x2ppp[0].ppp: Received (inet::Packet)COOKIE-ECHO (116 B) (inet::SequenceChunk) length = 116 B from upper layer.
INFO (Ppp)FoggyBottom.gNodeB2.x2ppp[0].ppp: Transmission of (inet::Packet)COOKIE-ECHO (123 B) (inet::SequenceChunk) length = 123 B started.
Hybrid-DSRC-5G #0: FoggyBottom
Msg stats: 20 scheduled / 294 existing / 335 created
foggybottommetro.sumocfg - SUMO 1.20.0
File Edit Settings Locate Simulation Window Language Help
Time:
Delay (ms):
Scale Traffic:
real world
0 10m
Warning: Missing yellow phase in tlLogic 'cluster_49793670_9123357154_9123357155_9428447085', program '0' for tl-index 2 when switching to phase 4.
Loading done.
Simulation started with time: 0.00.
'/home/seneca/gwu-workspace-pedestrians/TRB-SUMO-model/Network/foggybottomm
x:1737.46, y:448.83
lat:38.901445, lon:-77.051074
TraCI

Results II

- Framework successfully simulates hybrid V2X networks including VRUs and vehicles, using both cellular networks and DSRC.
- Pedestrian movement is accurately modeled with real-world mobility patterns.
- Extended Veins files are available publicly and can be modified to suit project-specific needs
- Validation by real-world measurements is currently being carried out
- Recommendations:
  - Further refinement of pedestrian mobility models
  - Integration of energy consumption models

Energy Consumption Analysis for P2I Communication

Introduction

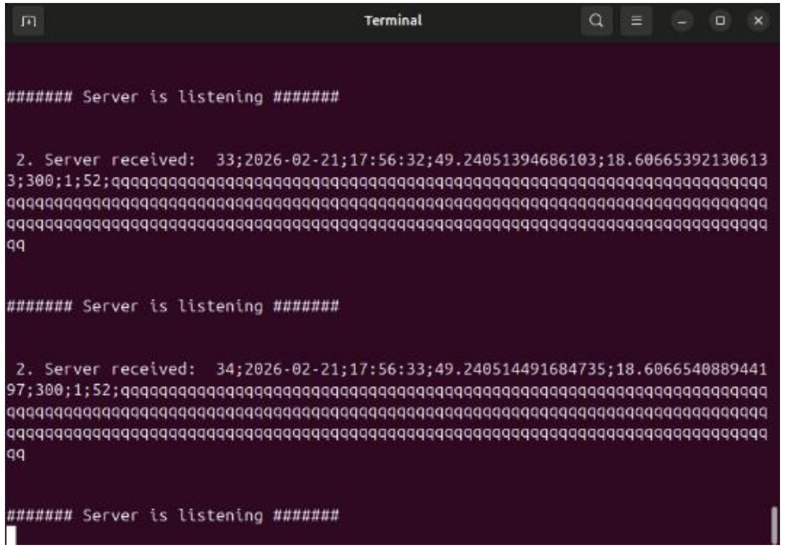
- Focus on Pedestrian-to-Infrastructure (P2I) communication in Cooperative Intelligent Transport Systems (C-ITS)
- Goal: analyze the impact of communication parameters on smartphone energy consumption and propose a model for estimating energy consumption
- Motivation: mobile devices used in P2I systems are battery constrained
- Communication parameters studied: message frequency and packet size

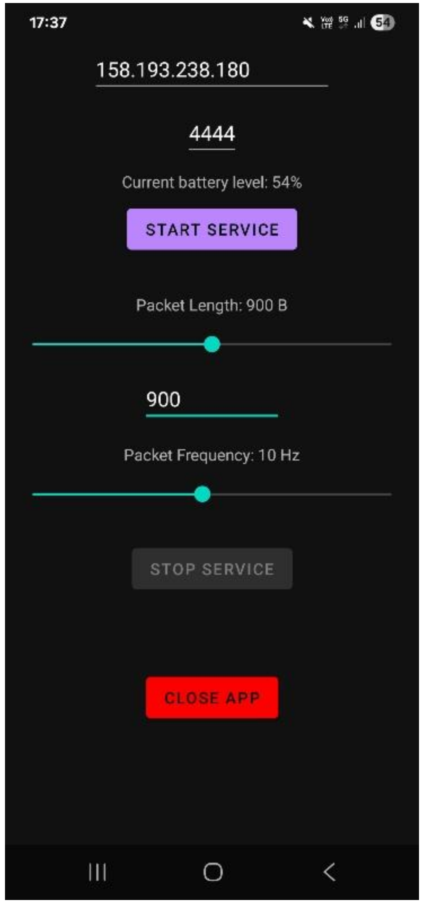
Research Objectives

- Measure energy consumption during P2I communication in real urban environments
- Analyze influence of message generation frequency and packet size
- Develop a mathematical regression model for estimating energy consumption
- Validate the model using additional measurements

Methodology

- Android application used to emulate P2I communication
- Messages transmitted through LTE/5G mobile networks
- UDP server collected communication logs and timestamps
- Battery level monitored during communication experiments



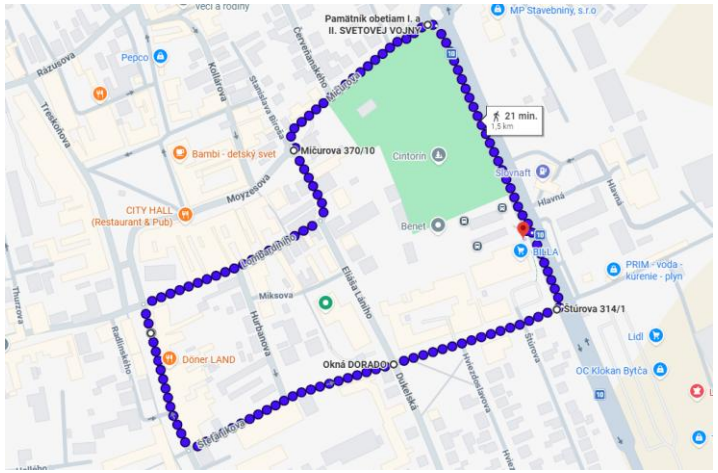


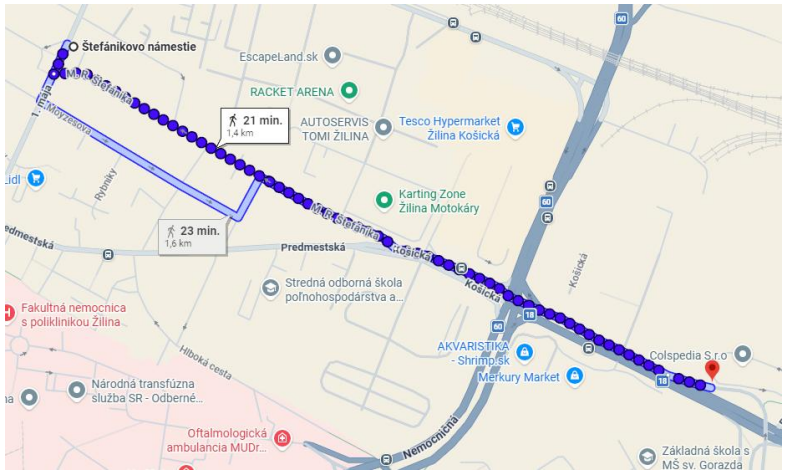
Measurement Setup

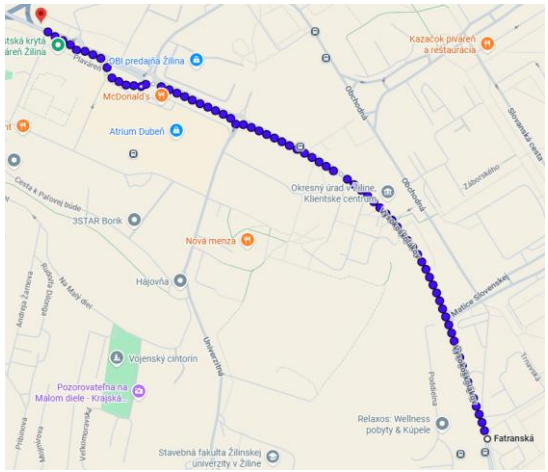
- Device: Samsung Galaxy S22 (Android 15)
- Communication frequencies: 1 Hz, 5 Hz, 10 Hz
- Packet sizes: 300 B, 900 B, 1500 B
- Measurements repeated 5 times for each configuration

Measurement Environments

- Route 1: Bytča city center – low to medium urban density
- Route 2: Žilina Štefánikovo – dense urban environment
- Route 3: Žilina Vysokoškolákov – boulevard environment





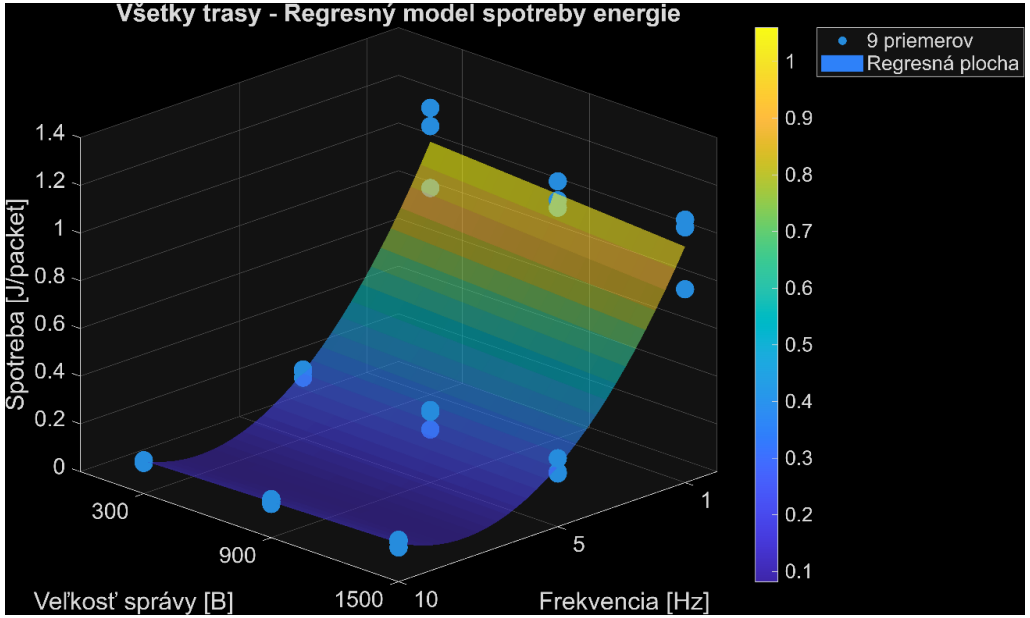


Energy Consumption Model

- Polynomial regression models of first and second order were evaluated
- Inputs: message frequency (F) and packet size (S)
- Output: energy consumed per transmitted packet
- Second-order polynomial regression achieved the best performance

Global Regression Model

- Global model built from all measurement routes
- Equation: $Z = 1.3672 - 0.3088F + 0.0001S + 0.0185F^2 + 0.000009FS$
- $R^2 = 0.9694$ indicating strong fit with measured data
- Frequency of generated messages had the strongest impact on energy usage



Key Results

- Higher message frequencies reduced average energy per packet
- Packet size had smaller influence than frequency
- Global model showed strong generalization ability
- Best verification performance observed on urban routes

Model Verification

- Verification performed with unseen communication configurations
- Validation frequencies: 3 Hz and 8 Hz
- Metrics used: RMSE, R^2, correlation coefficient
- Global model achieved $R^2 = 0.9189$ and RMSE = 0.1319

Limitations

- Measurements performed using only one smartphone model
- Limited number of urban environments and scenarios
- Signal variability and network congestion influenced results
- Model focused only on P2I communication over LTE/5G

Conclusion I

- The activity developed a practical regression model for P2I energy estimation
- Message frequency is the dominant factor affecting energy consumption
- Real-world measurements improve realism compared to simulation-only approaches
- The model unlike other models available in the literature considers the overal consumption of the whole data processing chain at the sender’s terminal
- The model can support design of energy-efficient C-ITS applications

Conclusion II

- This study addresses a critical gap in V2P communication simulations by enhancing existing open-source frameworks.
- The proposed framework provides a cost-effective and flexible platform for testing V2X services.
- Future research directions:
  - Advanced pedestrian behavior modeling
  - VRU-specific communication messages
  - Broader integration with urban mobility simulations

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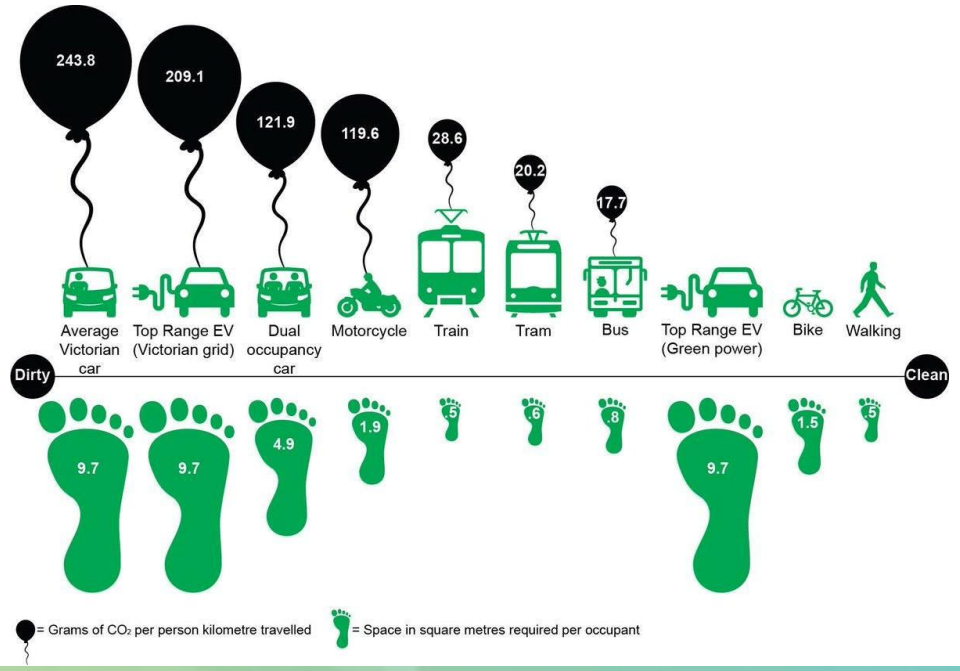
Download on GitHub



Thank you

Questions & feedback:

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