Smart Infrastructure Support for Future Mobility

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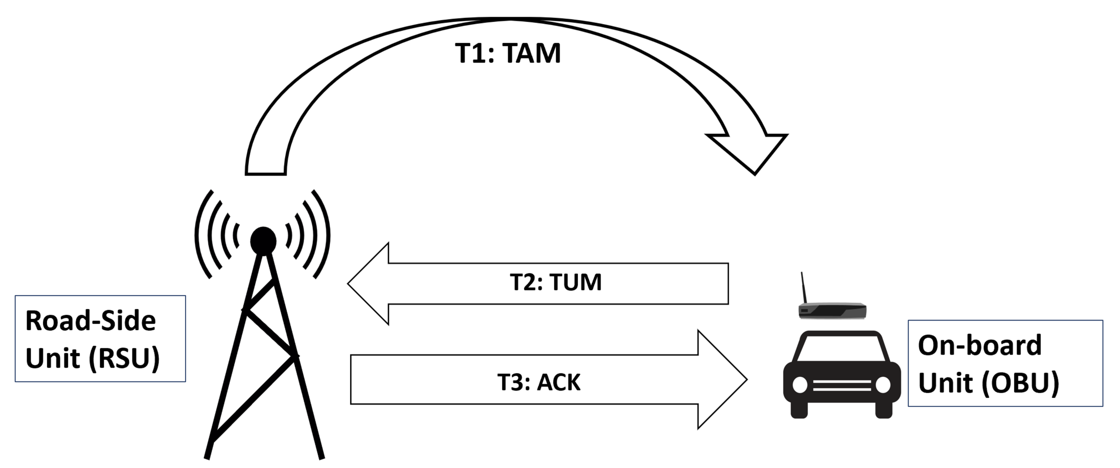
1. Overview

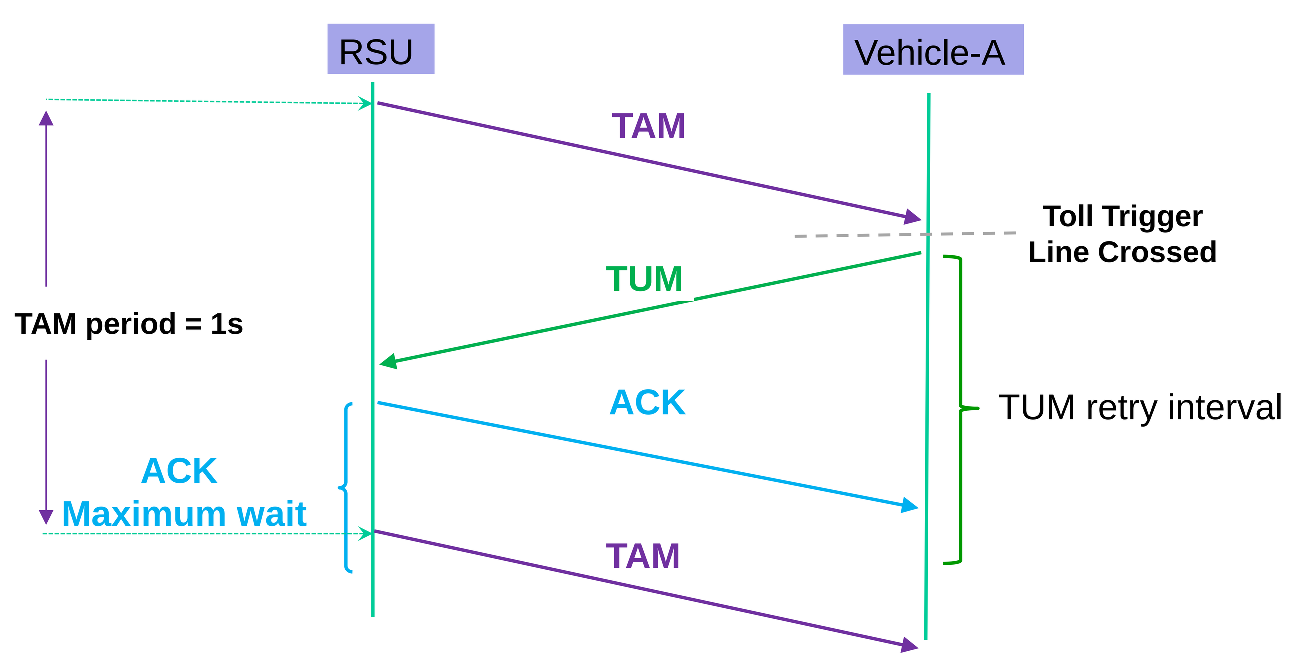
- Our current infrastructures are well-suited for human drivers, not for autonomous vehicles (AV), whereas AV is part of the solution for efficient mobility.
- **Smart Infrastructures can complement by directly 'talking' to road-user entities** (ie by information-sharing over radio network).
- To attain benefits in transportation, use-cases must be defined and efficient **application layer services** must be designed for all sorts of use-cases.
  - The service needs to be efficient (complete usage in least possible time)
  - With no impact on the periodic Basic Safety Messages (BSM).
- We utilize **Cellular-V2X** protocol to build an application that can aid a service provider in transaction mechanisms where handshaking and arbitration between multiple entities are relevant.
- Applications of such services may include **toll collection**, dynamic charging, EV road sharing etc.

2. Service Prototype Design

- **Toll Advertisement Message (TAM)** broadcast from the toll collector unit (modelled as a C-V2X equipped Road-Side Unit), serves as an announcement for the service, includes info about subscription and tariff.
- **Toll Usage Message (TUM):** vehicle intends to use the announced service.
- **TUM-Acknowledgement Message (ACK) :** RSU confirms the subscription and usage completion.

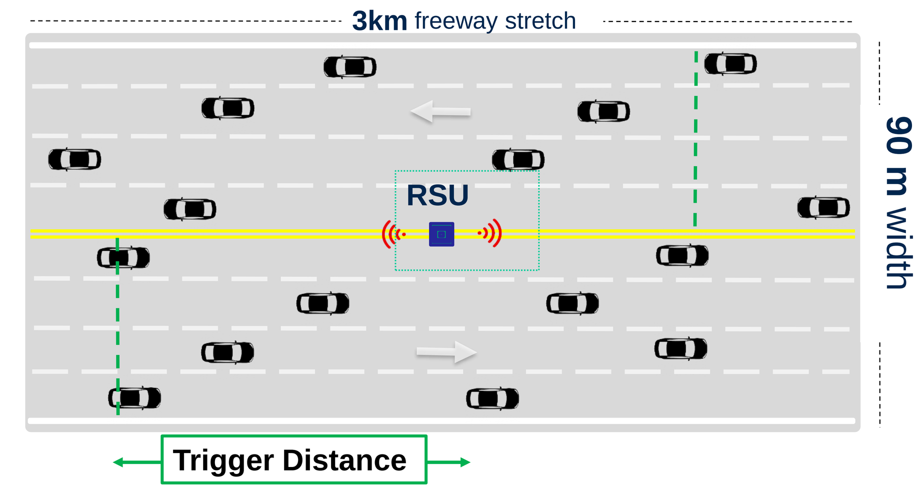


- Vehicle sends TUM only after crossing a virtual Toll Trigger Line.
- Vehicles resend request (TUM) if no ACK is received within an interval.
- RSU can reply to vehicles one-by-one or in batch.
  - In case of batch reply, RSU replies to all TUMs received within a wait period.



3. Scenario & Simulation Setup

- We modelled a 3km freeway with bidirectional traffic, with one RSU in the middle. The RSU and all vehicles are equipped with C-V2X.



- We leveraged a link-level network simulator (ns3) to simulate the radio communication in a realistic environment.
- The air interface is modelled and validated using mobility data collected from I-405 freeway. [1]

3GPP C-V2X protocol stack (V2I enhancements)

Application Layer
- Incorporating V2I Packet classes
- Protocol Implementation: Generate and manage successive interaction between RSU and OBU

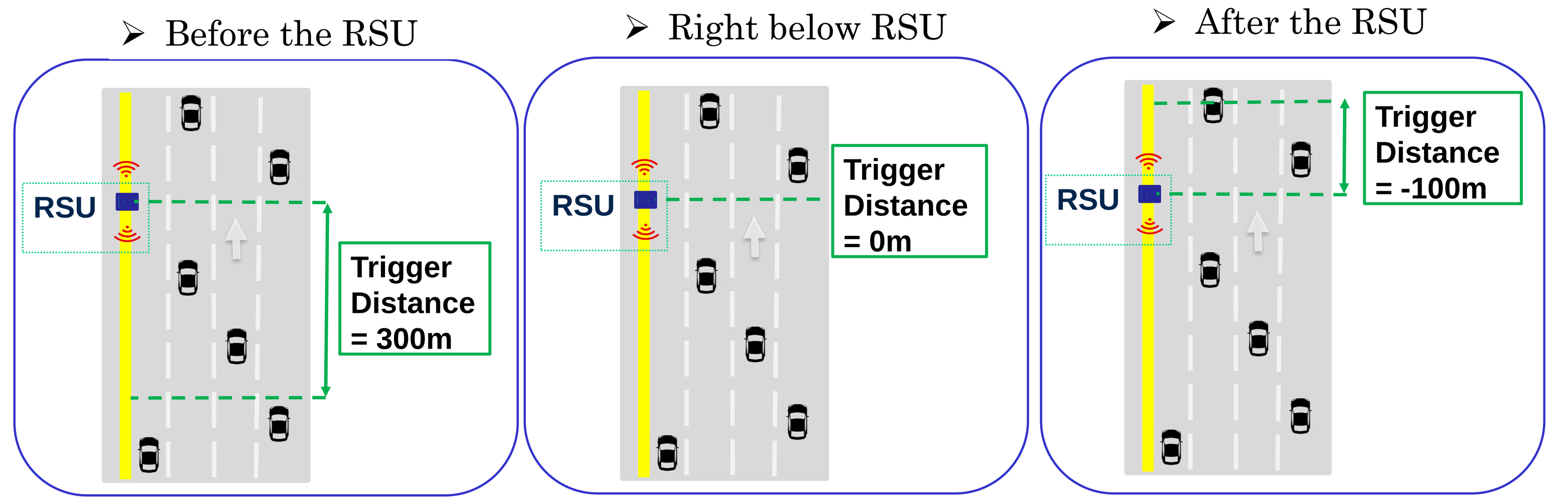
Radio Link Control (RLC) Layer
- Packet Priority Handling

Medium Access Control (MAC) Layer
- Packet Priority Handling
- Queue Management

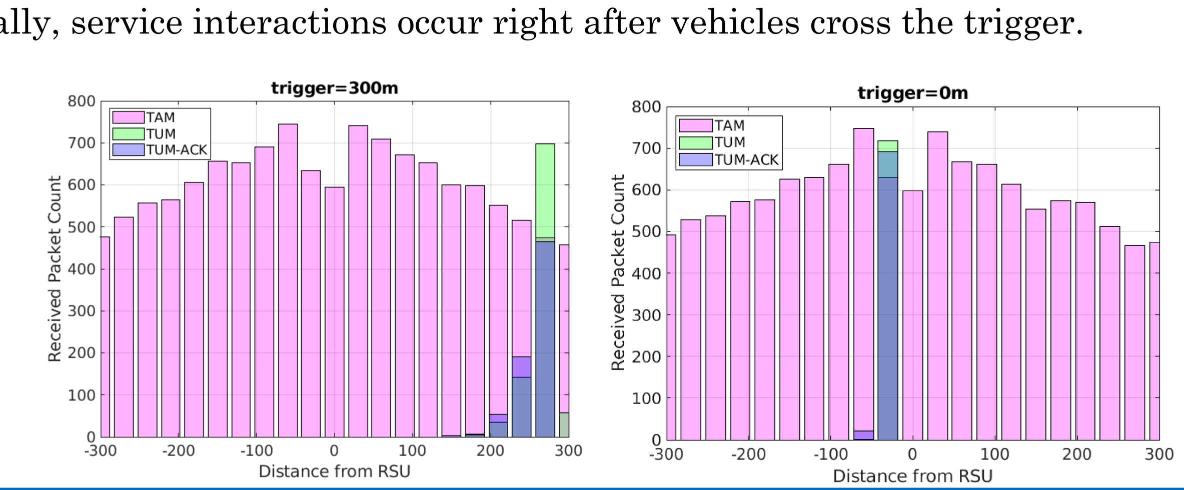
Physical Layer

4. Analysis & Results

- Where should the virtual trigger line be?
  - Before the RSU
  - Right below RSU
  - After the RSU

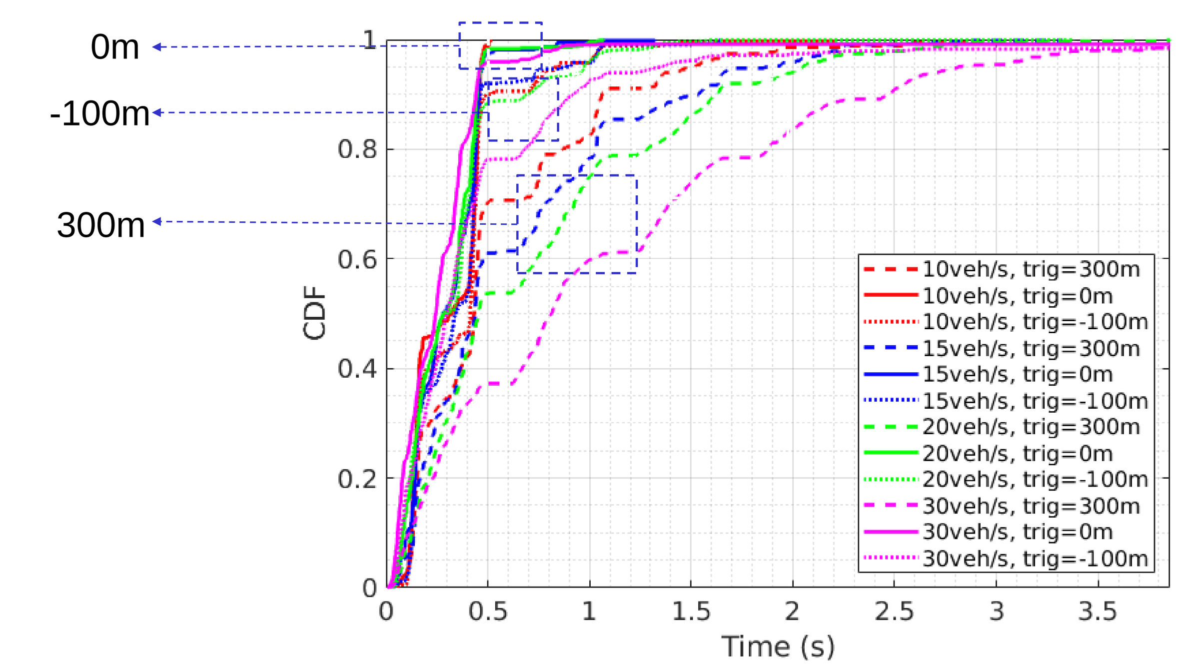


- Spatially, service interactions occur right after vehicles cross the trigger.

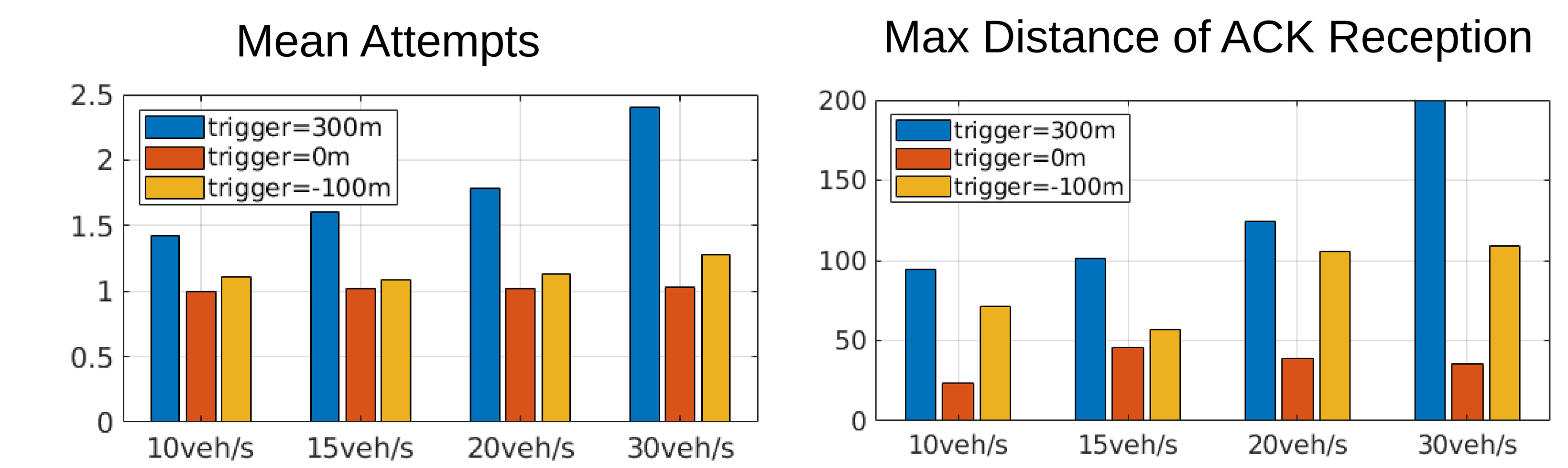


4. Analysis & Results (cont'd)

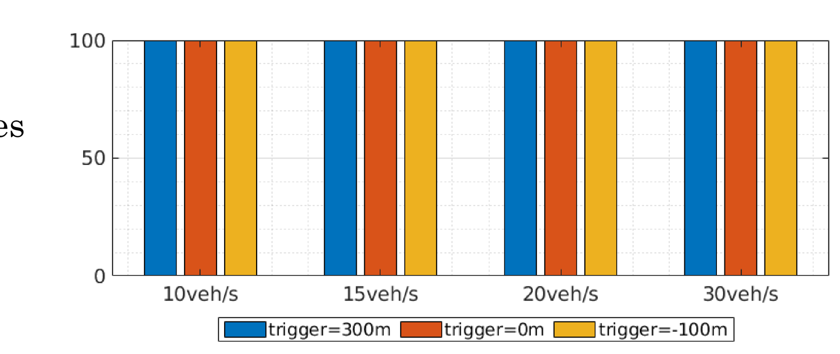
- **Toll Completion Time (time from TUM Transmission to ACK reception)** is lowest when interactions occur close to RSU (ie with 0m trigger distance).



- With 0m trigger, Vehicles accomplish service utility with:
  Left: least number of average attempts (average over total count of first and repeated attempts),
  Right: closest in RSU vicinity (critical for reliable payment activities)



- At higher density (ie higher traffic flow rate), packet loss increases, thus Toll Completion Time increases. However, in all cases, comparatively better service is achieved with 0m trigger.
- Resource allocation in C-V2X favors communication among vehicle pairs in close proximity. [2]
- For all trigger configurations, 100% of vehicles who starts the usage are able to finish. →



5. Take-away

- Using cellular networks, Smart Infrastructures can assist in dynamic transaction services for efficient traffic navigation.
- Our prototype service can be adapted and fine-tuned for toll collection without the need for additional installation overhead.
- In the ongoing study, we are studying other hyperparameters of the service covering the time thresholds, batchsize for ACKs etc. By the end of our study, we aim to propose a complete service prototype for transactions on vehicular networks.

6. References

[1] B. Toghi *et al.*, "Multiple Access in Cellular V2X: Performance Analysis in Highly Congested Vehicular Networks," *2018 IEEE Vehicular Networking Conference (VNC)*, 2018, pp. 1-8, doi: 10.1109/VNC.2018.8628416.

[2] M. Saifuddin et al., "Performance Analysis of Cellular-V2X with Adaptive & Selective Power Control," *2020 IEEE 3rd Connected and Automated Vehicles Symposium (CAVS)*, 2020, pp. 1-7, doi: 10.1109/CAVS51000.2020.9334605.