Cooperative Offloading in Context-Aware Networks

A Game-Theoretic Approach

13th ACM International Conference on Distributed and Event-based Systems
June 26th, 2019

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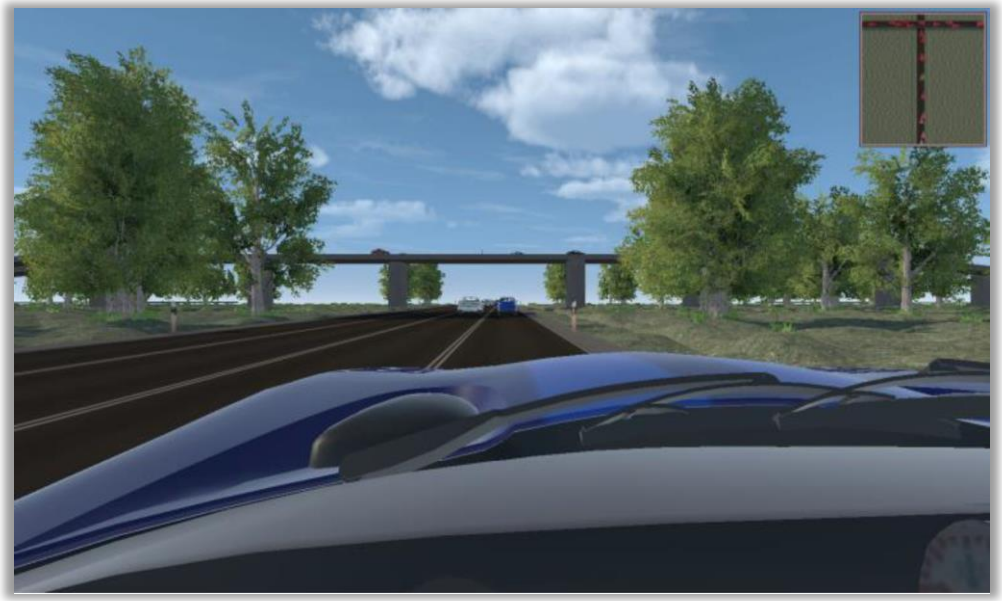

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Prof. Dr.-Ing. Ralf Steinmetz
KOM - Multimedia Communications Lab

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Motivation for Sharing of Road Traffic Data

Offloading in Vehicular Networks

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Vehicles exchange road traffic data

- Achieve awareness beyond their local perception
- Increase traffic safety and driver comfort

Bandwidth for the exchange of road traffic data is limited

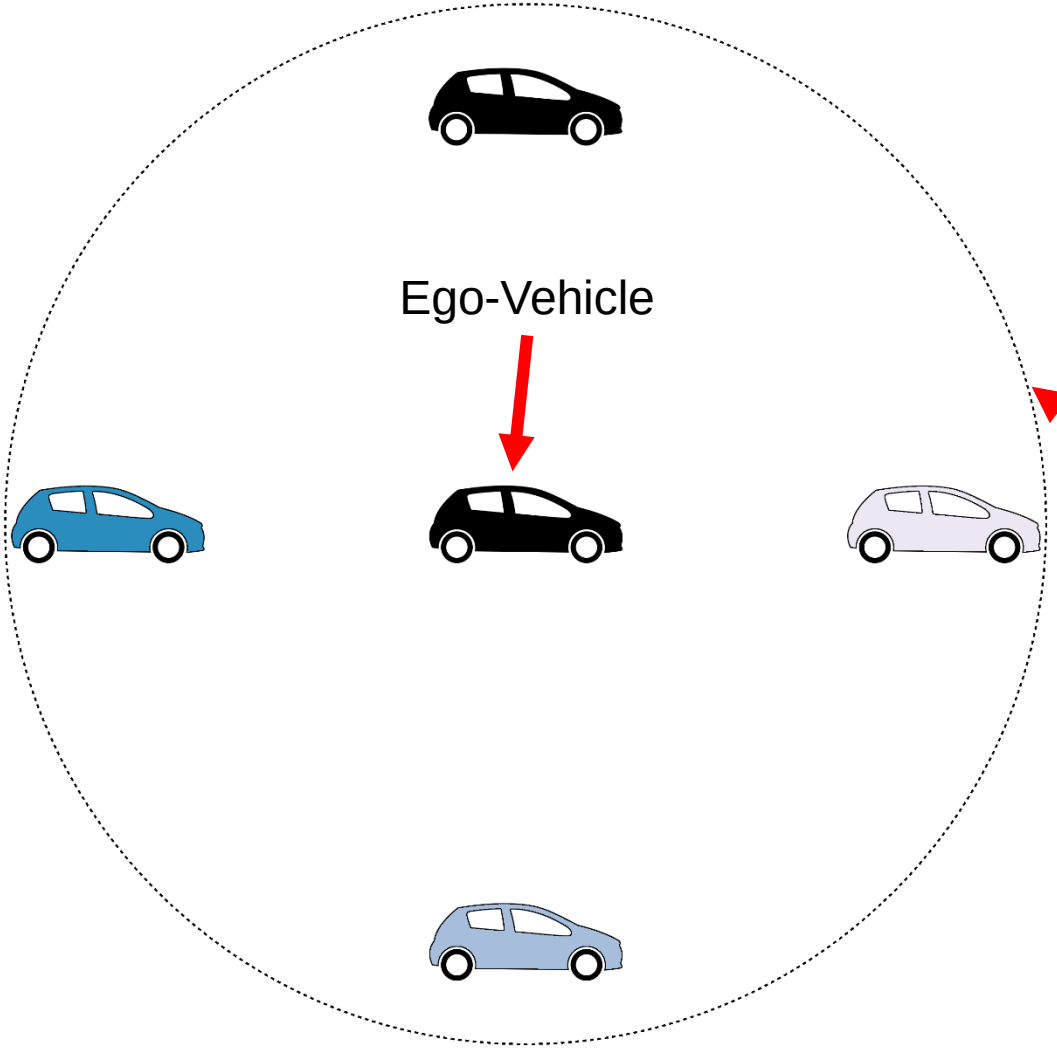
- Vehicles cannot receive every data entry that is available
- Filtering based on context and type of messages is required

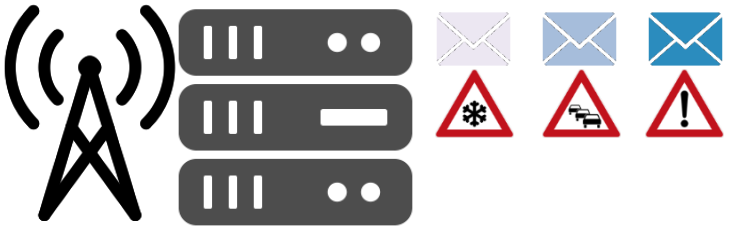
Improve resource efficiency through offloading

- Vehicles share received messages received via the cellular network with vehicles in proximity via Wifi-based communication technology

How to coordinate the offloading process
in a distributed and highly-mobile network?

Scenario Description

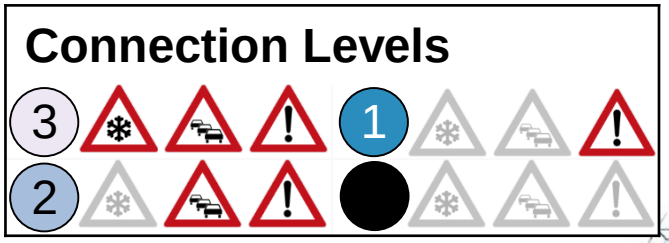




Cell tower

Server

Wifi range



System Assumptions

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Bandwidth

- The average bandwidth is limited
- Physically available bandwidth is much higher, i.e., bandwidth can be temporarily exceeded

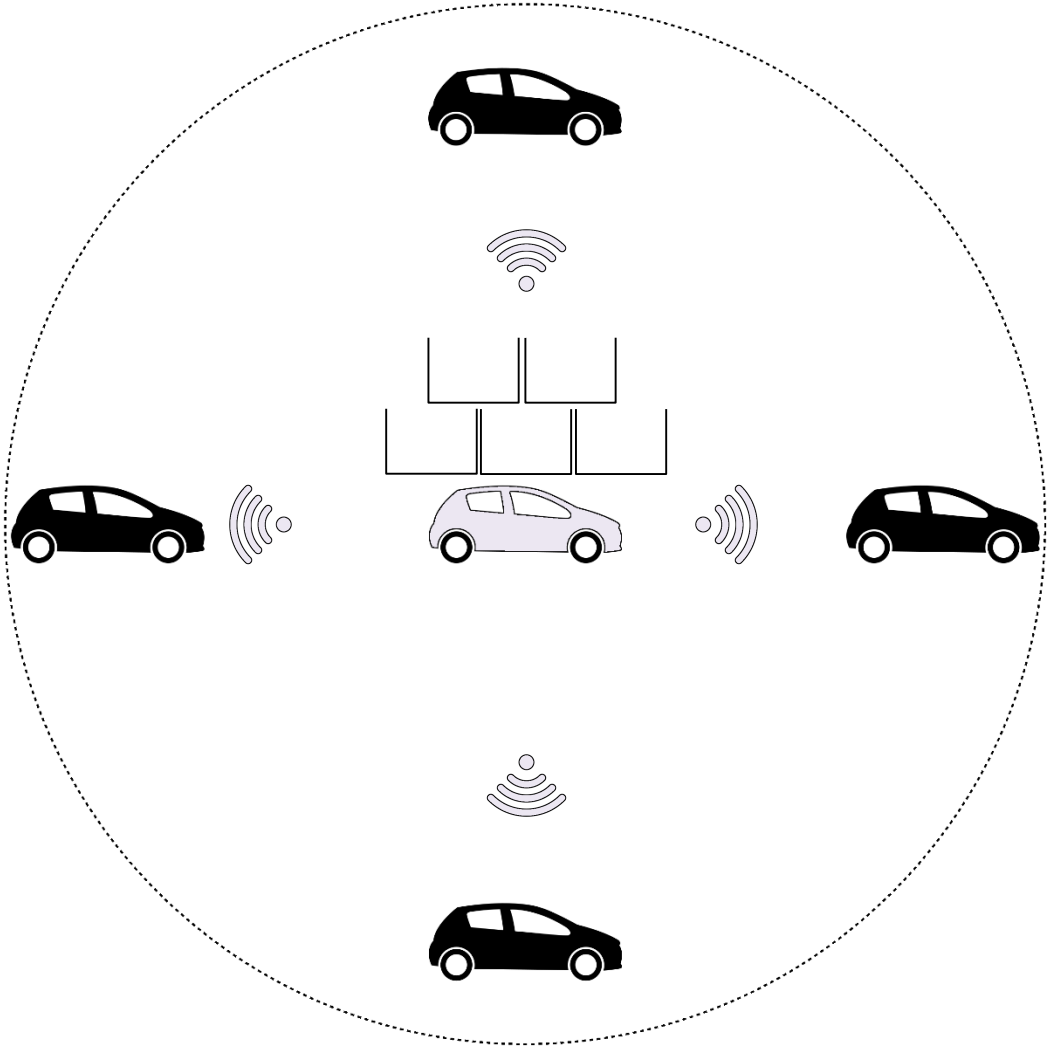
Push-based Communication

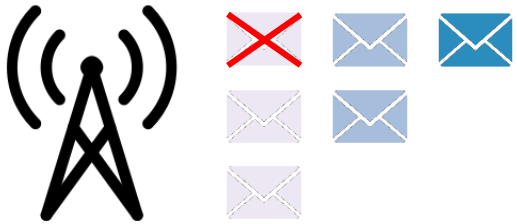
- Vehicles sense their environment and share the data with a central server
- Server pushes collected data back to concerned vehicles
- Vehicles subscribe to interesting content and provide context information

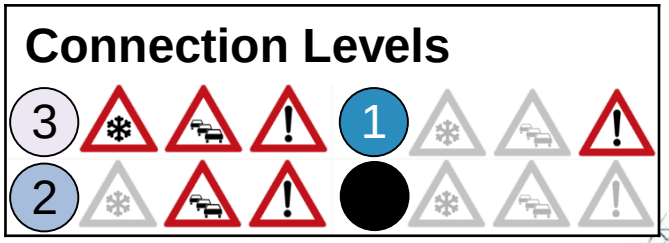
Vehicles aim to receive as many messages as possible

- Every message published by the server is unique
- The impact of each message for every vehicle can be estimated

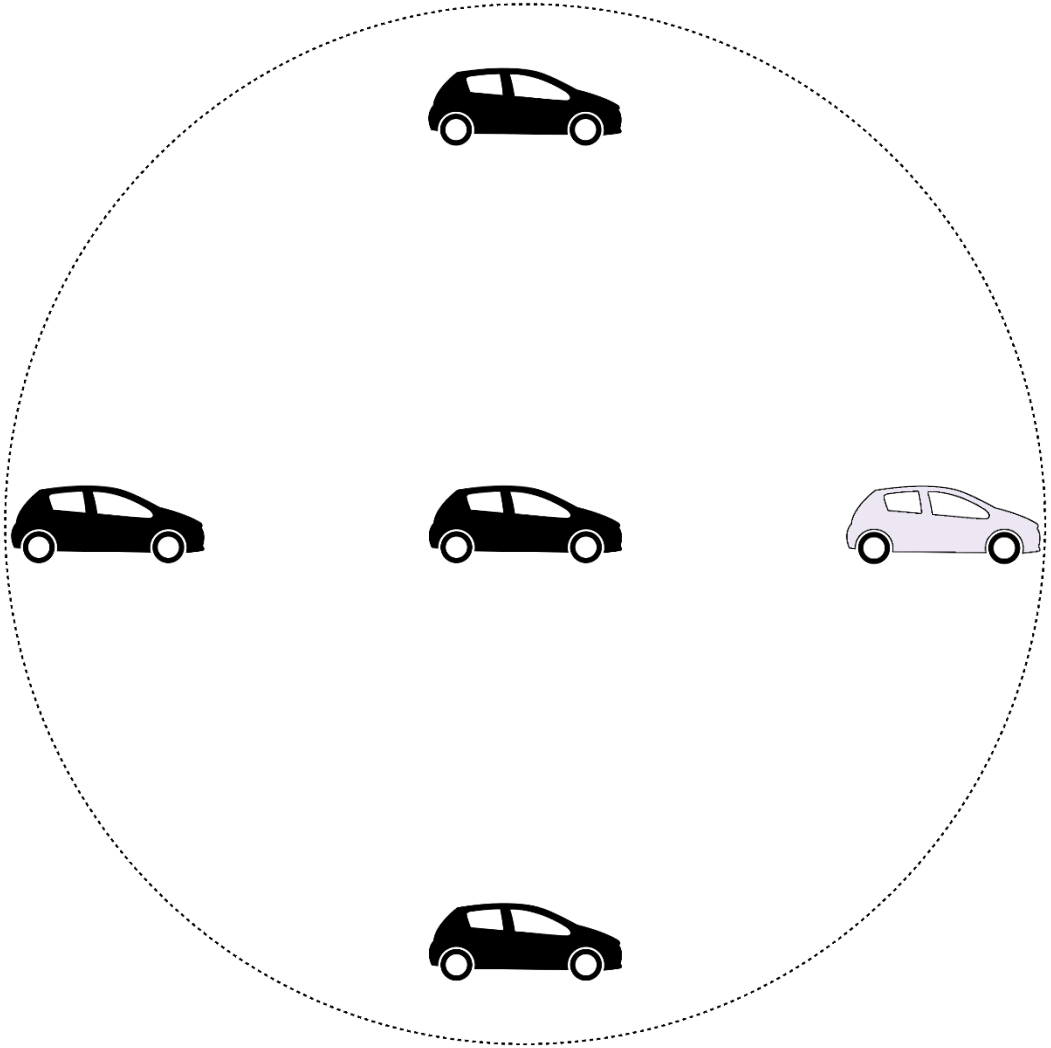
Impact-based Offloading via Clustering

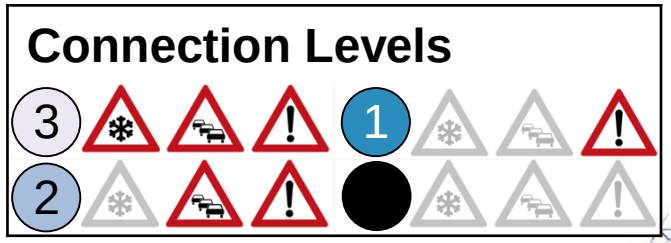






Issues of Clustering under High Mobility





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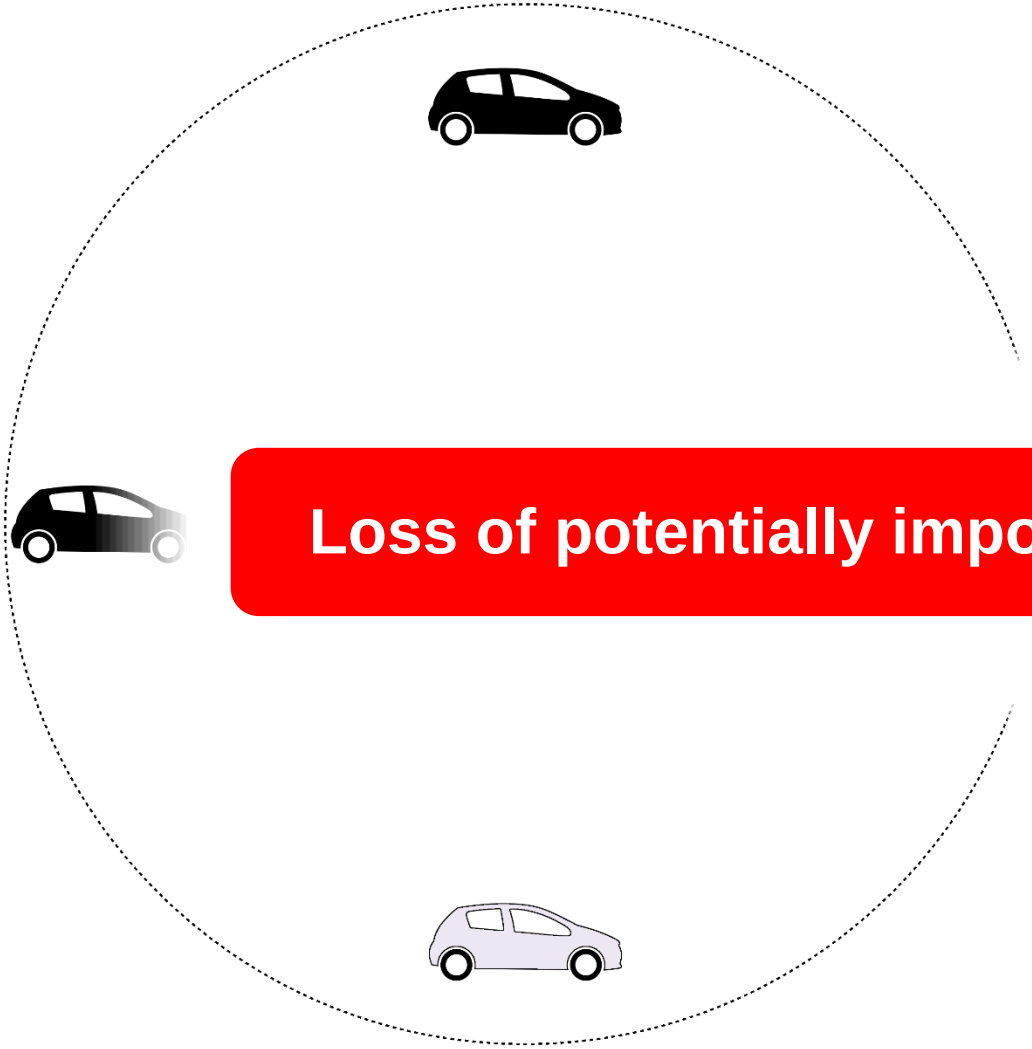

Loss of potentially important messages

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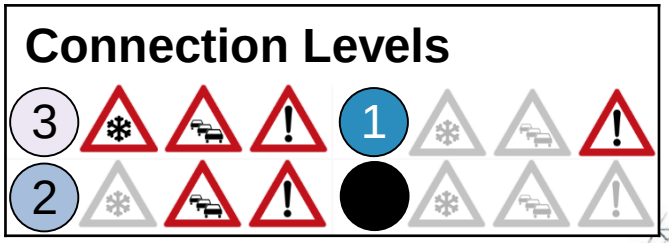
needs to



Robust Communication of Traffic Data

Redundant transmission of important data

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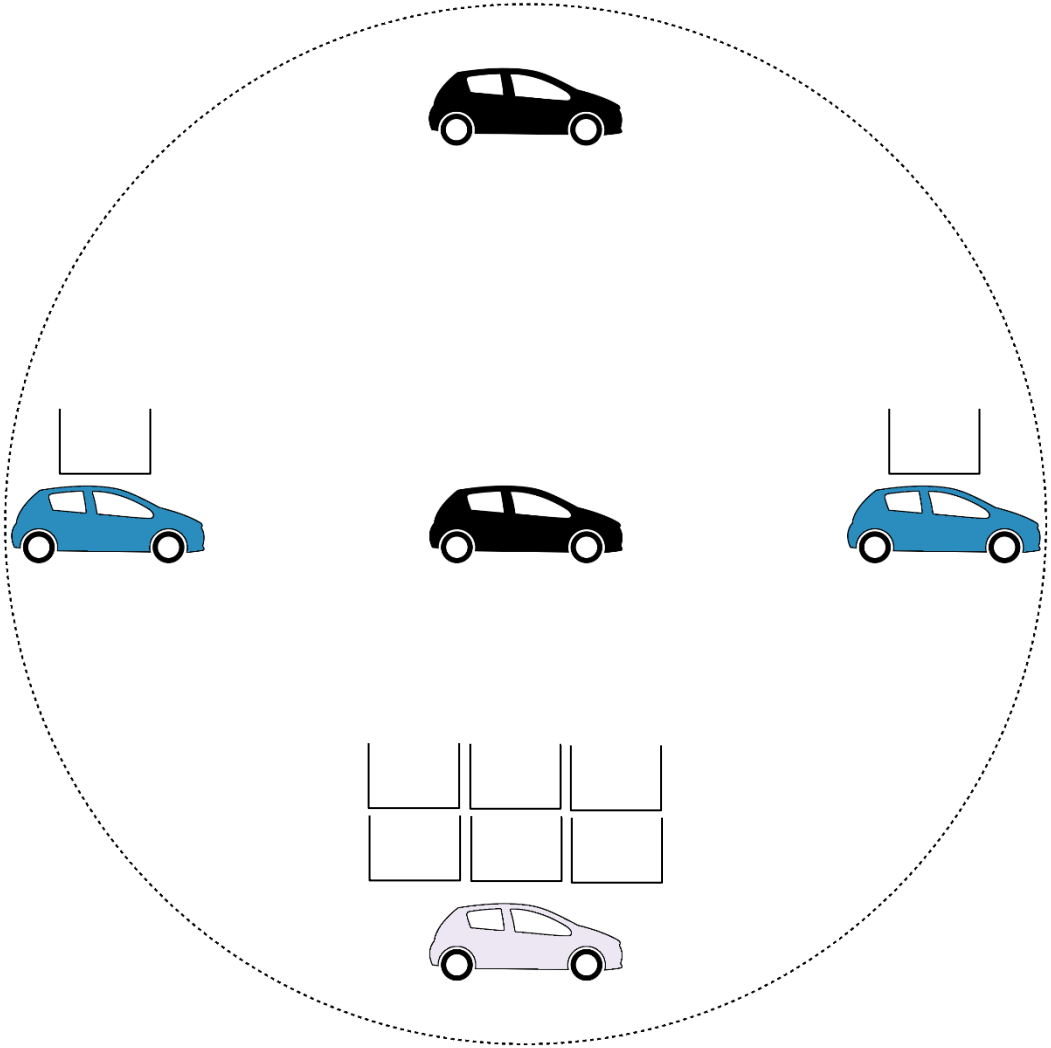

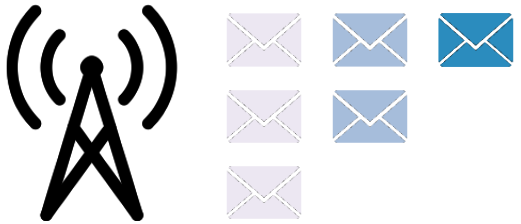

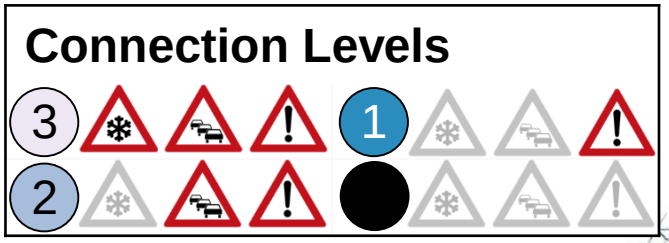

Game-Theoretic Solution

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Actors and Strategies/Actions

- **Vehicles** determine the **minimum impact** of a message that they want to receive via the cellular network **locally**
- The subscription is **dynamically changed** (probabilistically)
- The **server** rates the **impact of a message** for the vehicles and transmits the message to concerned vehicles

Additional assumptions

- The vehicles share all received information with their neighborhood
- The impact of a message to vehicles in proximity is similar
- The neighborhood of vehicles in proximity is similar
- Do not need guarantee the reception of any message with finite impact

Goal

- Maximize the sum of impact values of received messages

Game-Theoretic Solution

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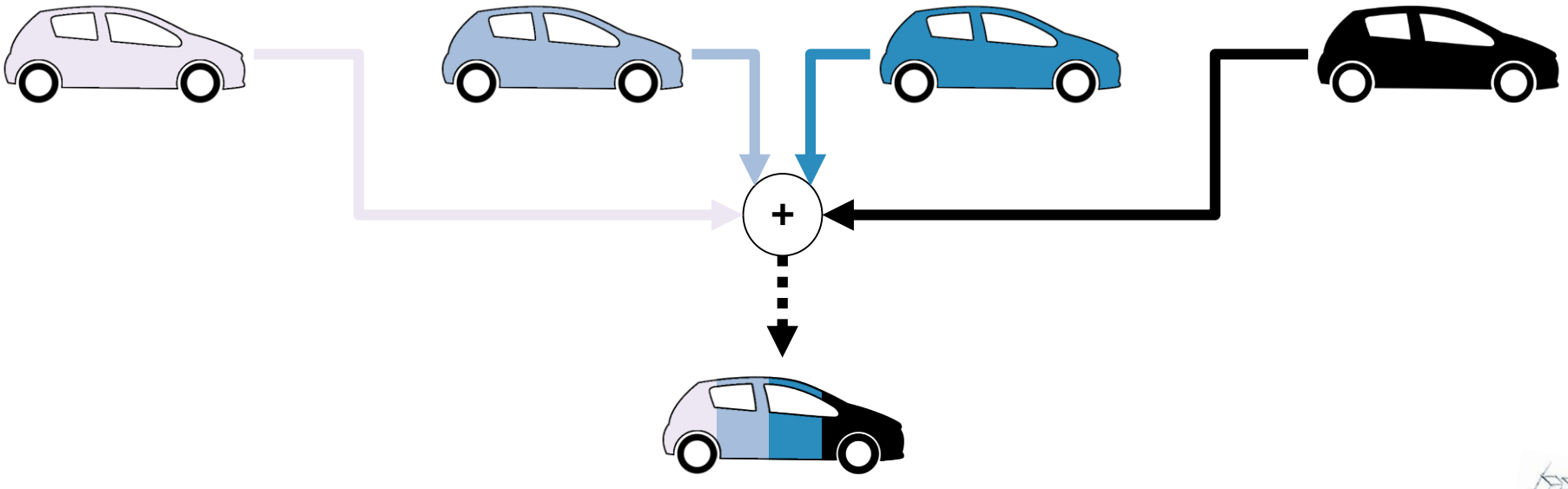
Vehicle follow a mixed strategy to maximize the utility of their received messages

- A vehicle cannot increase its utility while decreasing the utility of others
- All vehicles in proximity follow the same strategy, i.e., the disappearance of a single vehicle is less impactful



Impact-based Communication

Implicit Coordination

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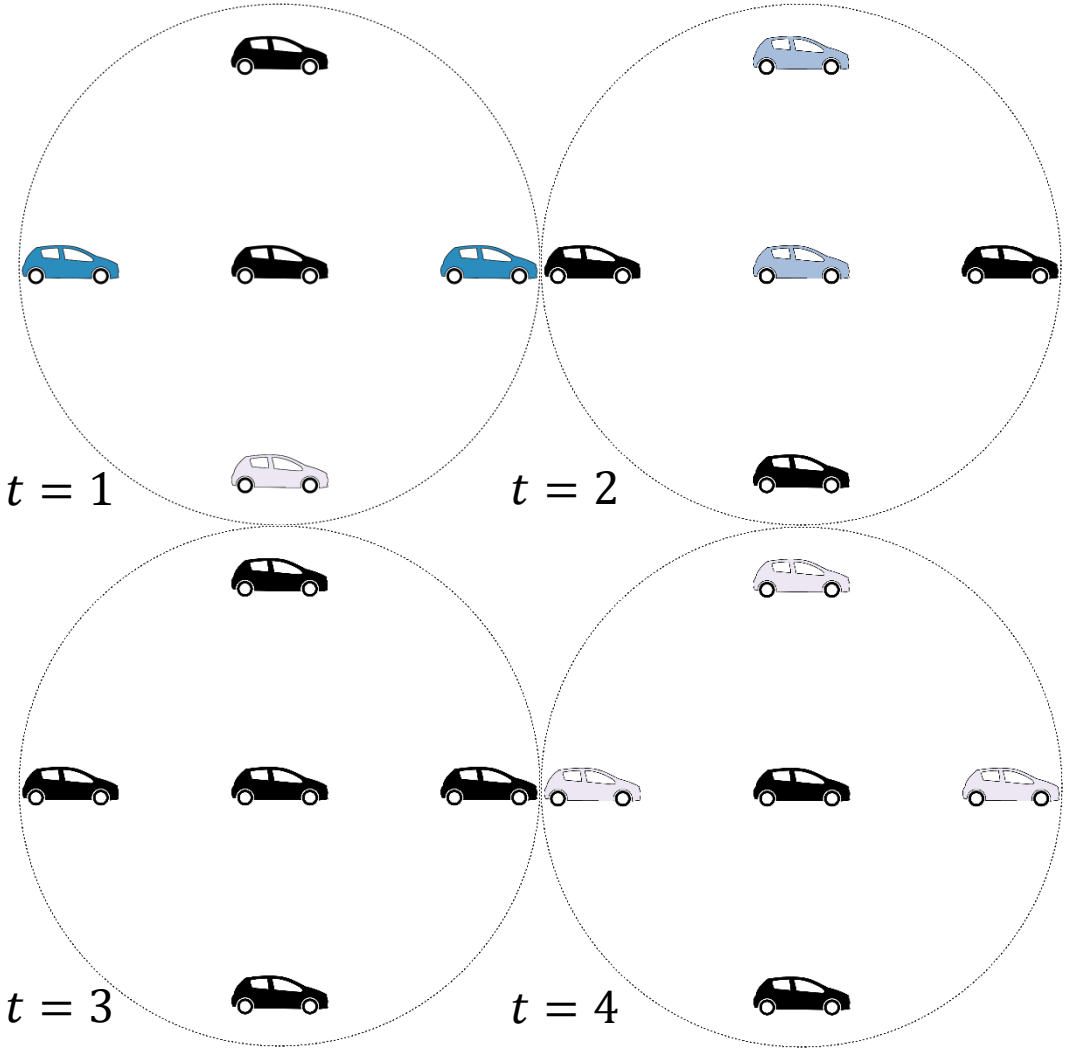

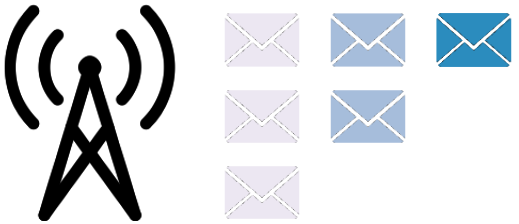

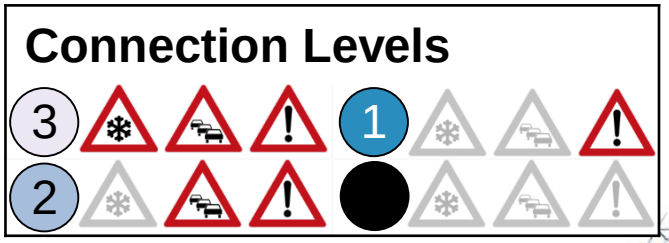

Impact-based Communication

Example of Subscription Strategy of the Vehicles

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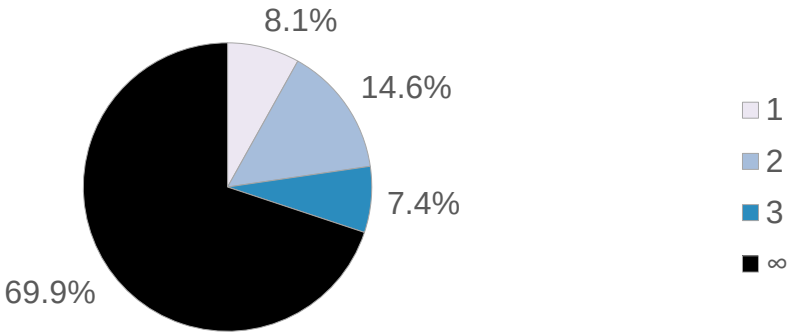
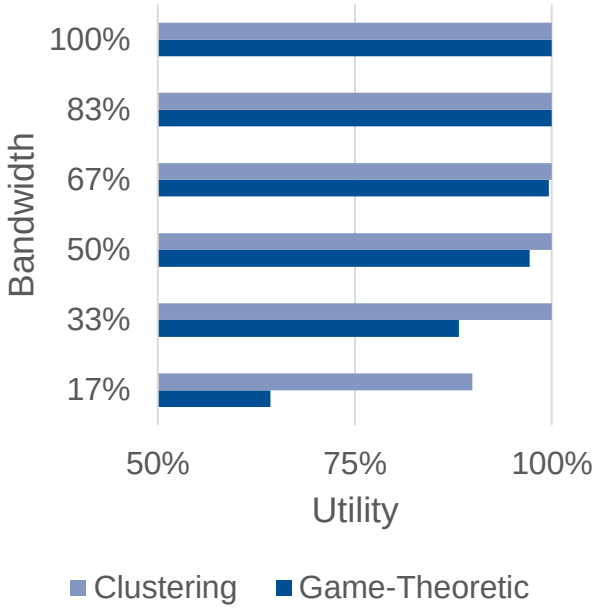
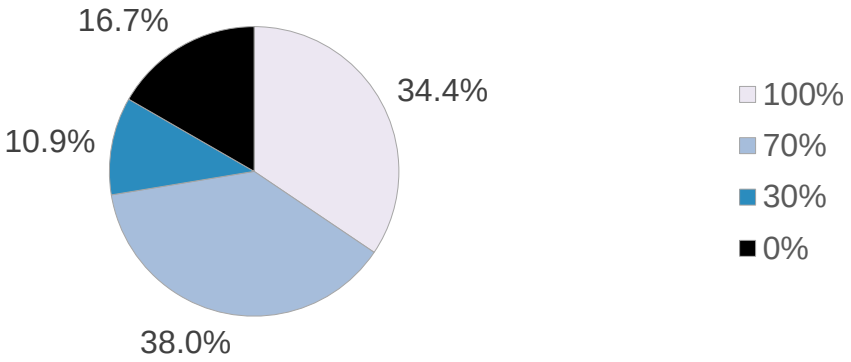
Strategy per Vehicle



Influence of Bandwidth



Probability of Specific Utility



Connection Levels

3	$I \geq 1$	1	$I \geq 3$
2	$I \geq 2$	●	$I \geq \infty$

Impact-based Communication

Example of Subscription Strategy of the Vehicles

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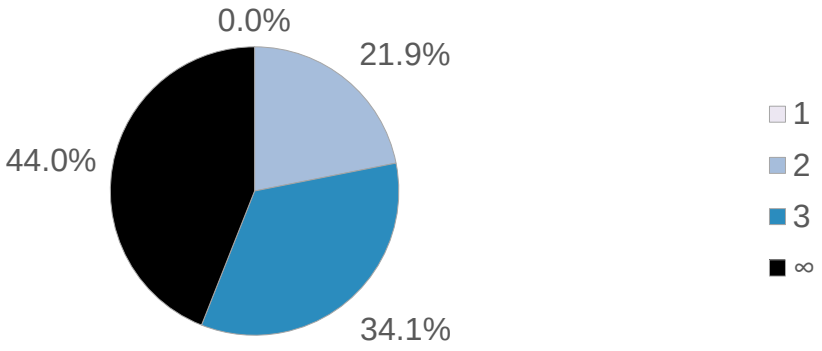
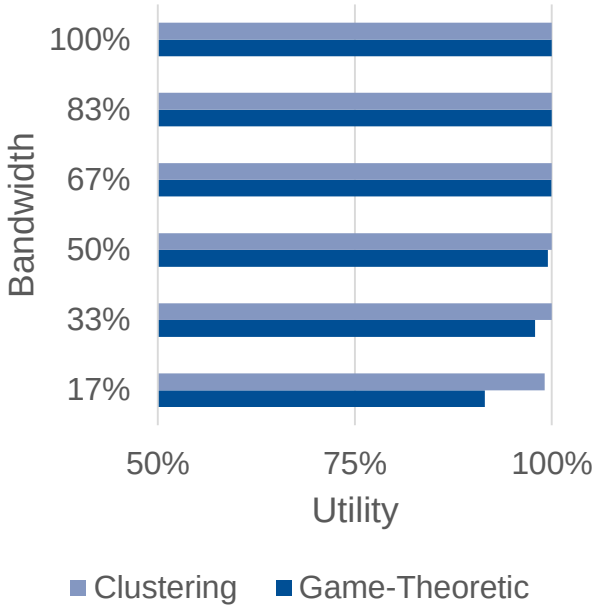
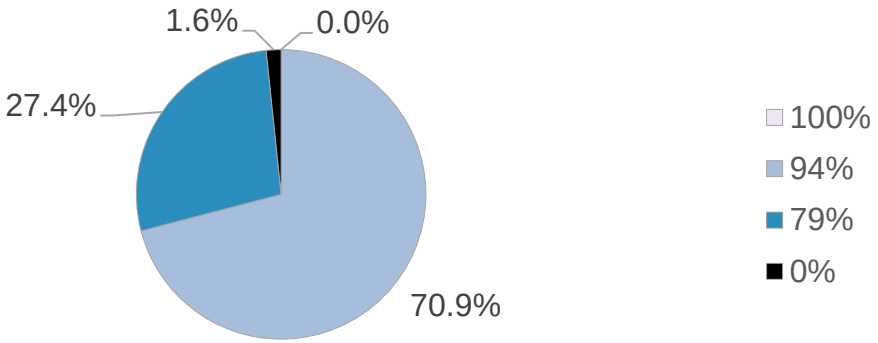
Strategy per Vehicle



Influence of Bandwidth



Probability of Specific Utility



Connection Levels

3	$I \geq 1$	1	$I \geq 100$
2	$I \geq 10$	●	$I \geq \infty$

Impact-based Communication

Example of Subscription Strategy of the Vehicles

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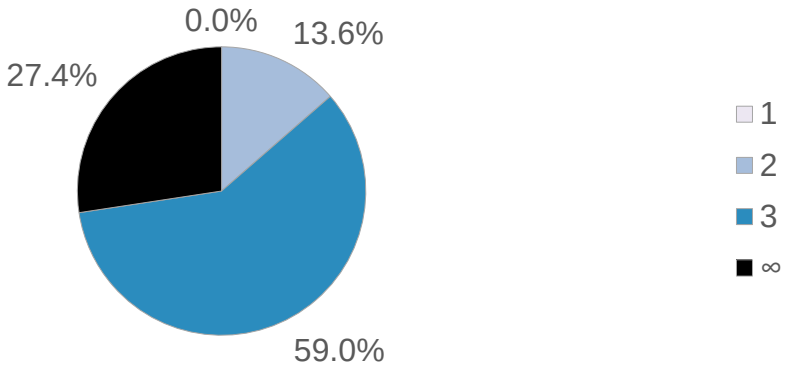
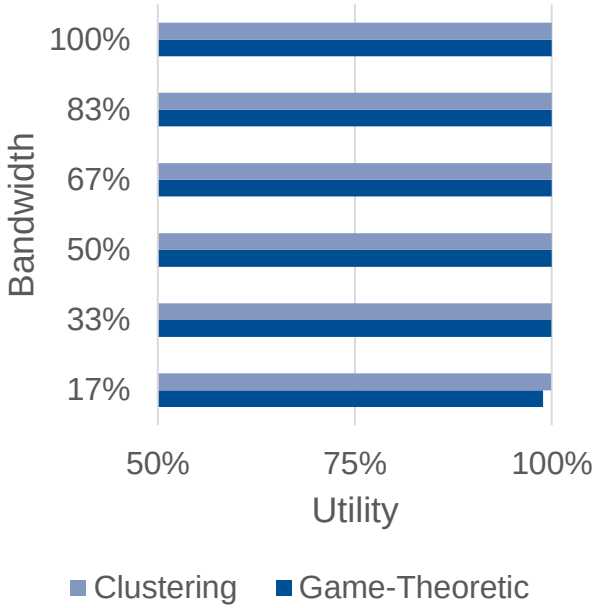
Strategy per Vehicle



Influence of Bandwidth



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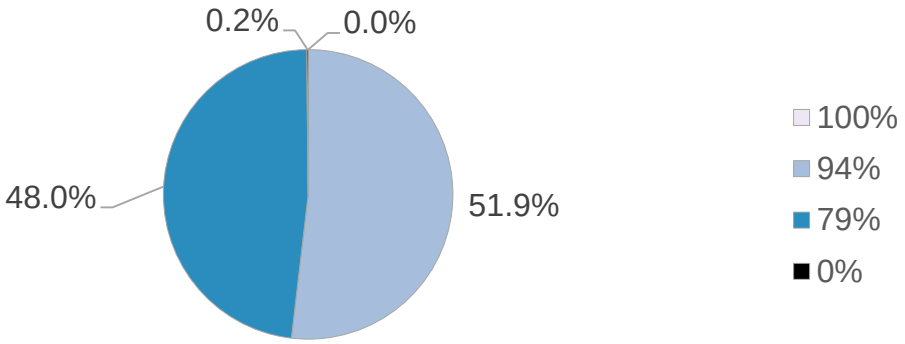
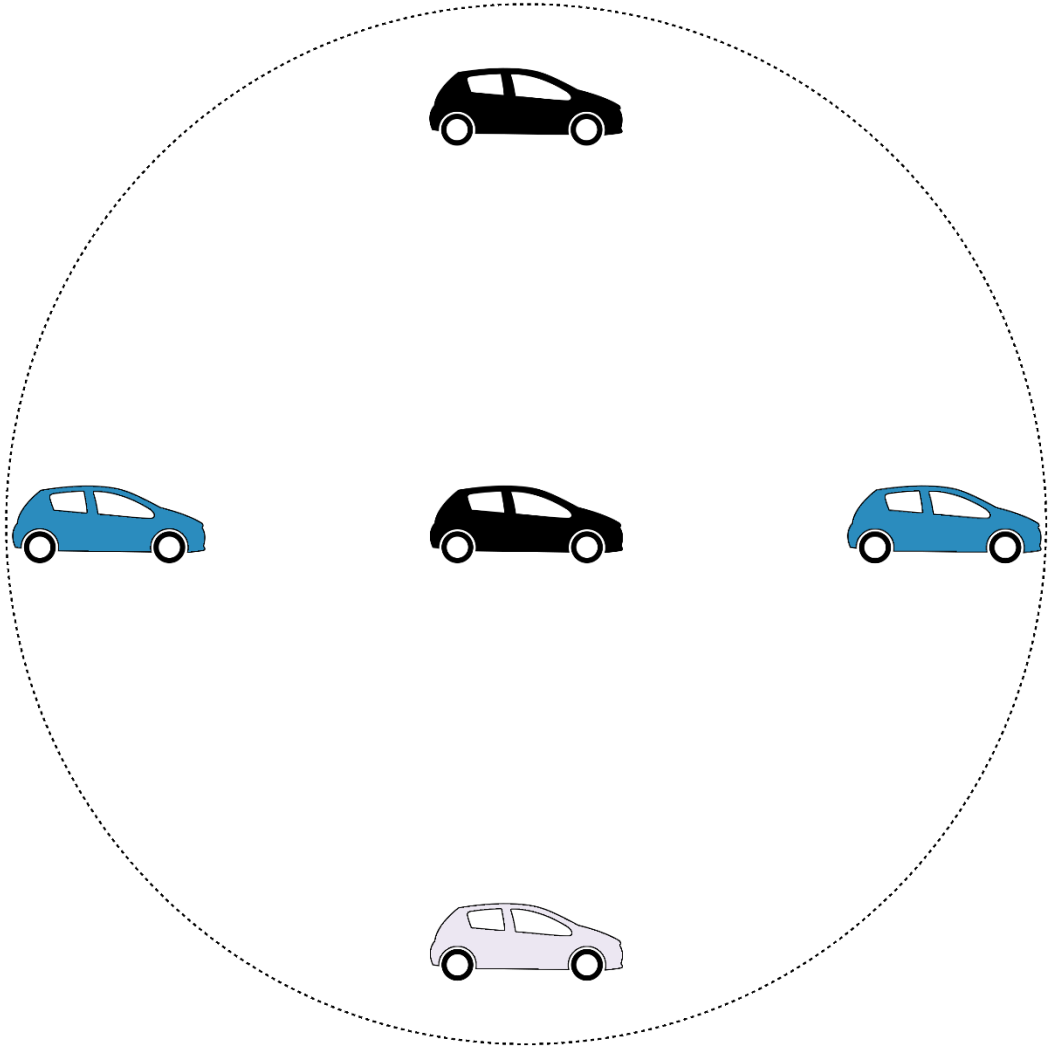


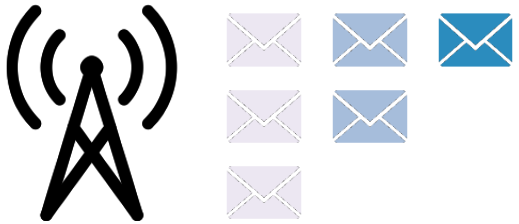
Connection Levels

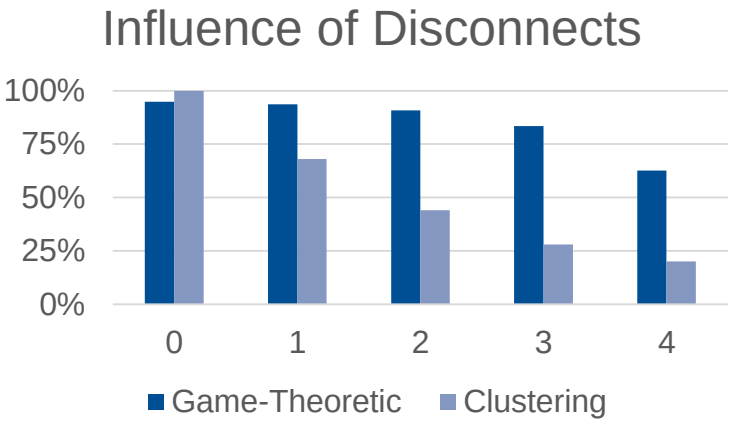
90	$I \geq 1$	1	$I \geq 10^4$
9	$I \geq 10^2$	●	$I \geq \infty$

Impact-based Communication

Implicit Coordination - Disconnects







Connection Levels

3	$I \geq 1$	1	$I \geq 100$
2	$I \geq 10$	●	$I \geq \infty$

Simulation-based Evaluation

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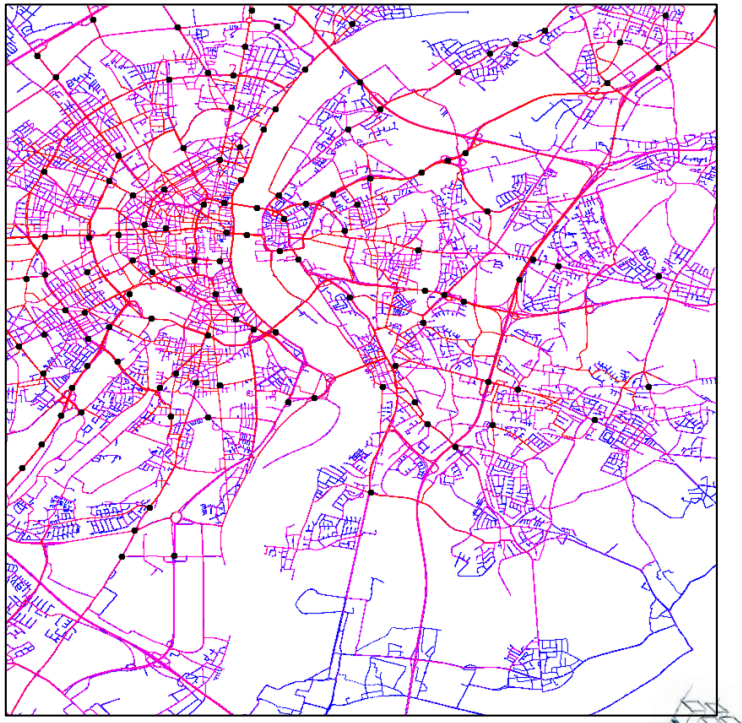
Realistic vehicle movement

- SUMO for movement simulation
- TAPAS Cologne Scenario for the movement traces

Network simulation based on the Simonstrator platform

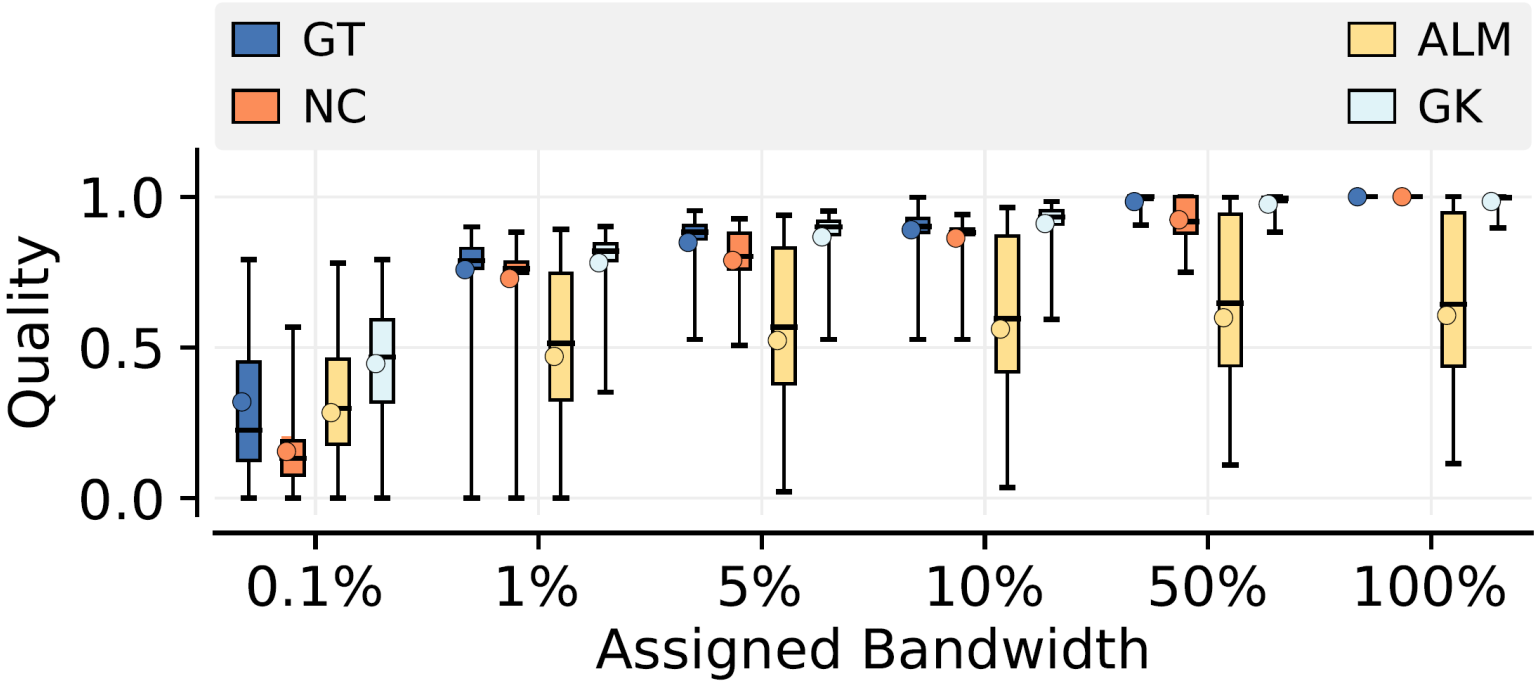
Evaluation Variable	Values
Event Costs (vector)	{(**1, 10, 100, 1000**)}
Event Probability (vector)	{(**90%, 9%, 0.9%, 0.1%**)}
Assigned Bandwidth	{0.1%, 1%, 5%, **10%**, 50%, 100%}
Message Load per Vehicle	{**10**, 50, 100}
Monitoring	{**Inactive**, Active}
Dissemination	{**Broadcast**, Geocast}
Message Size	1000*Bytes*
Wifi bandwidth	12*Mbps*
Wifi range	150*m*
Cellular bandwidth	50*Mbps*

Table 2: Parameters used for the evaluation. If more than one value is given, the bold value is used as default.



Evaluation

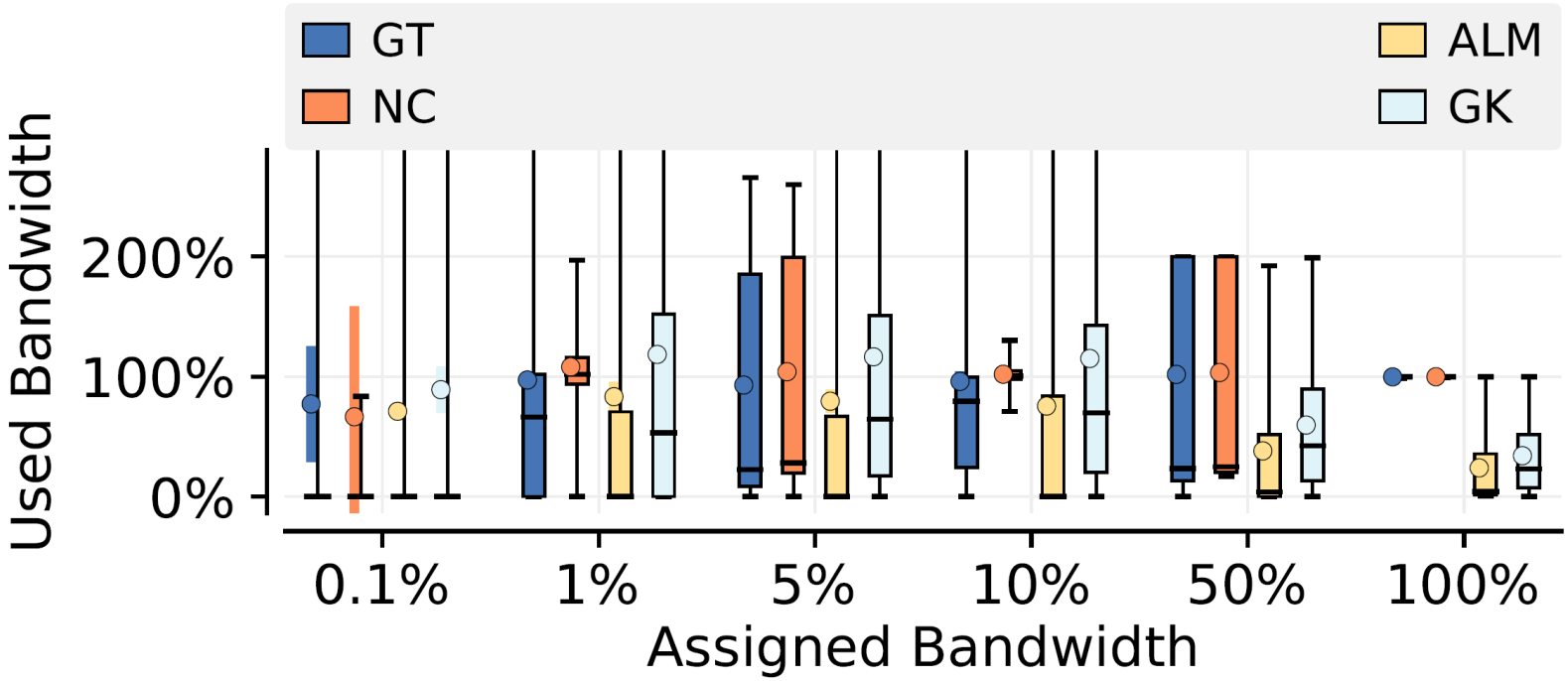
Achieved Relative Utility



Our GT-approach significantly outperforms the approach without cooperation (NC) and the cluster-approach (ALM).

Evaluation

Utilized Bandwidth



Most approaches stick to the predefined average bandwidth requirements.

Conclusion and Outlook

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We modeled the offloading process as a non-cooperative game

- Maximizes the sum of impact values of received messages
- Limits the average bandwidth consumption for each vehicle
- Introduces reliability through redundancy

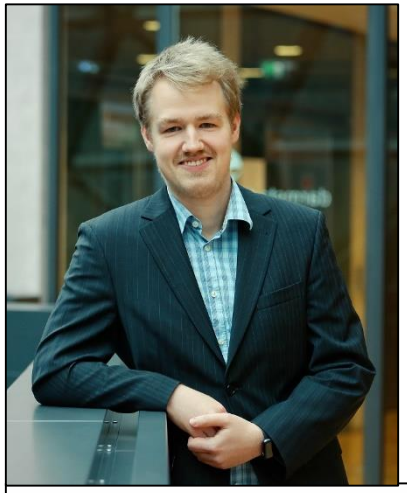
We derived an optimal solution for our game-theoretic model

- Nash-equilibrium
- Optimal under the assumption of similar roles of the vehicles

Future work

- Prevent free-riding
- Enable the subscription to individual impact levels instead of threshold
- Ensure the protection of location-privacy for privacy sensitive vehicles

Questions & Contact



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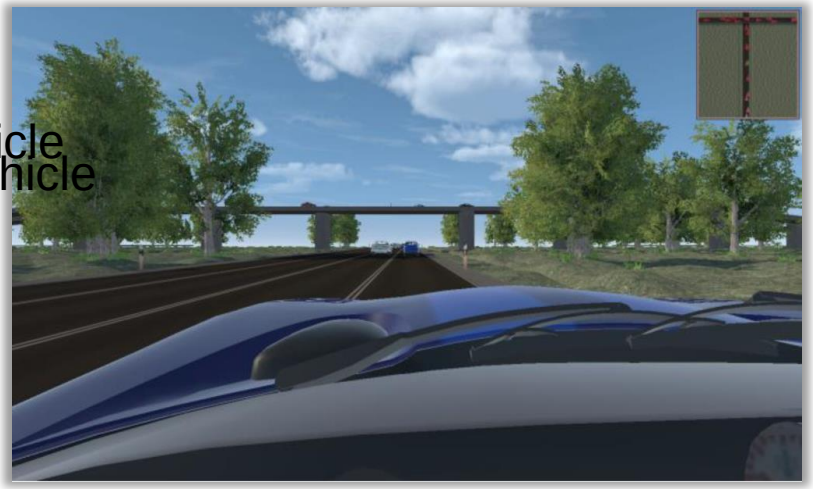
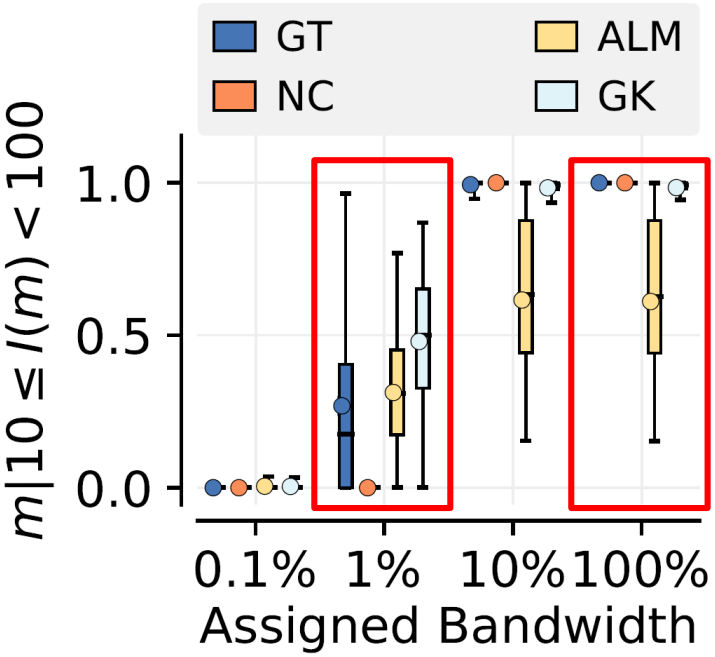
Ego-Vehicle

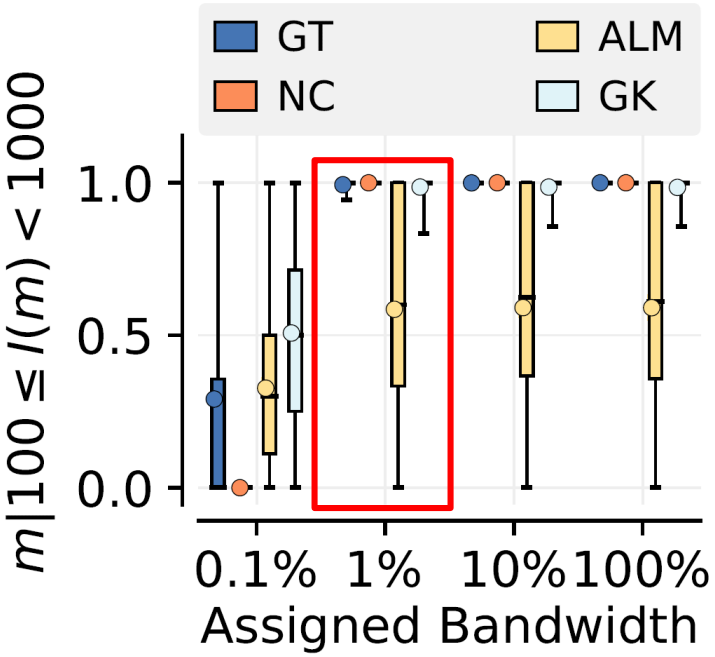
Ego-Vehicle



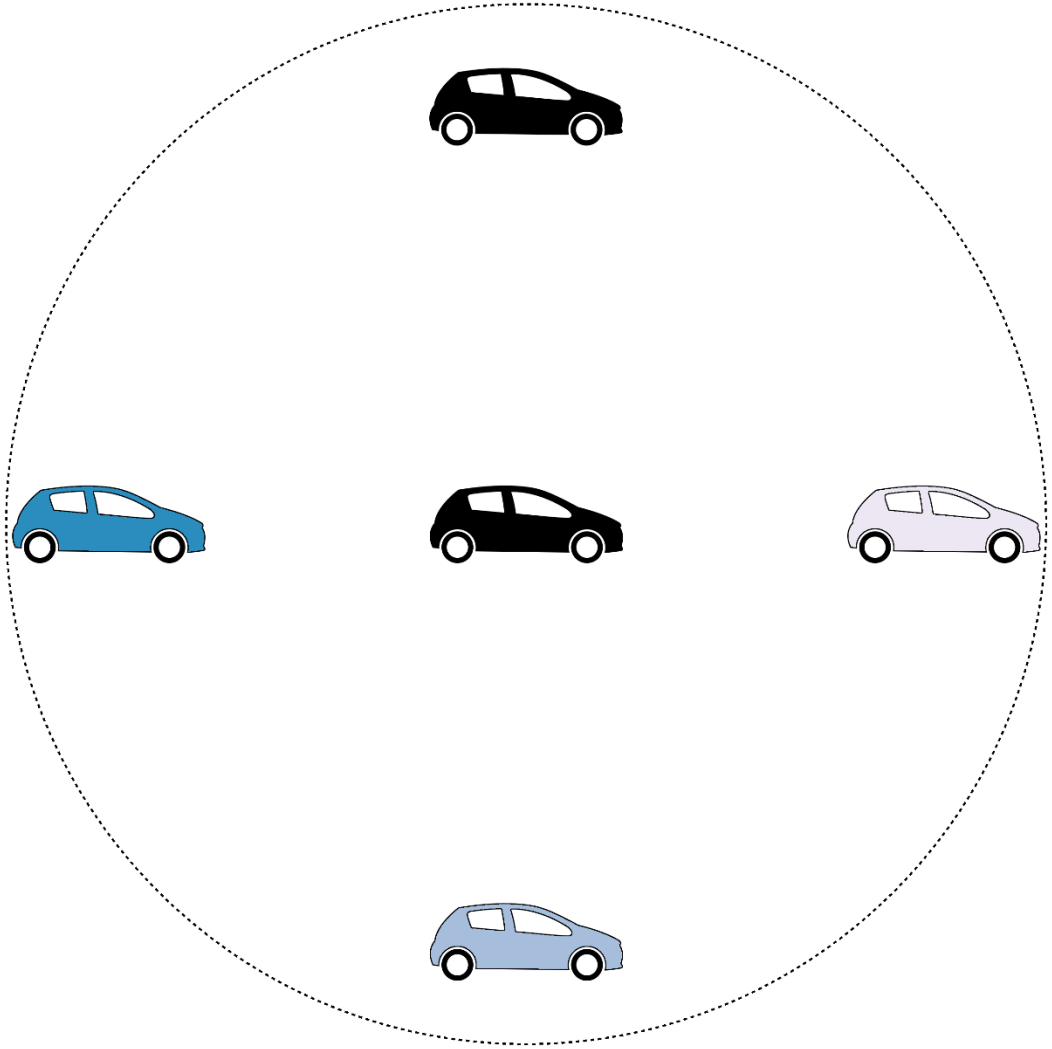
Evaluation

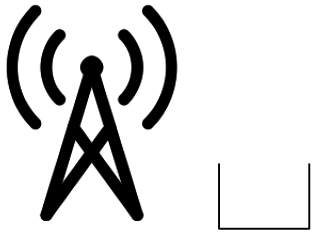
Achieved Relative Utility by Message Impact

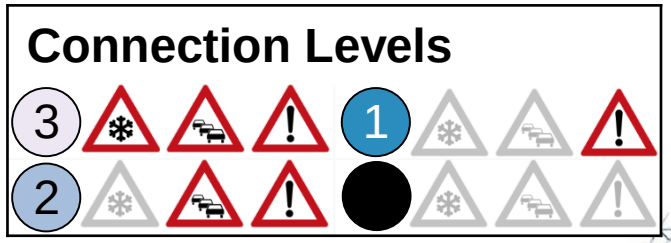




Our GT approach can receive messages that cannot be received without cooperation.






Connection Levels
3
1
2

What is the goal of communication?

How to measure the quality of communication?

Motivation

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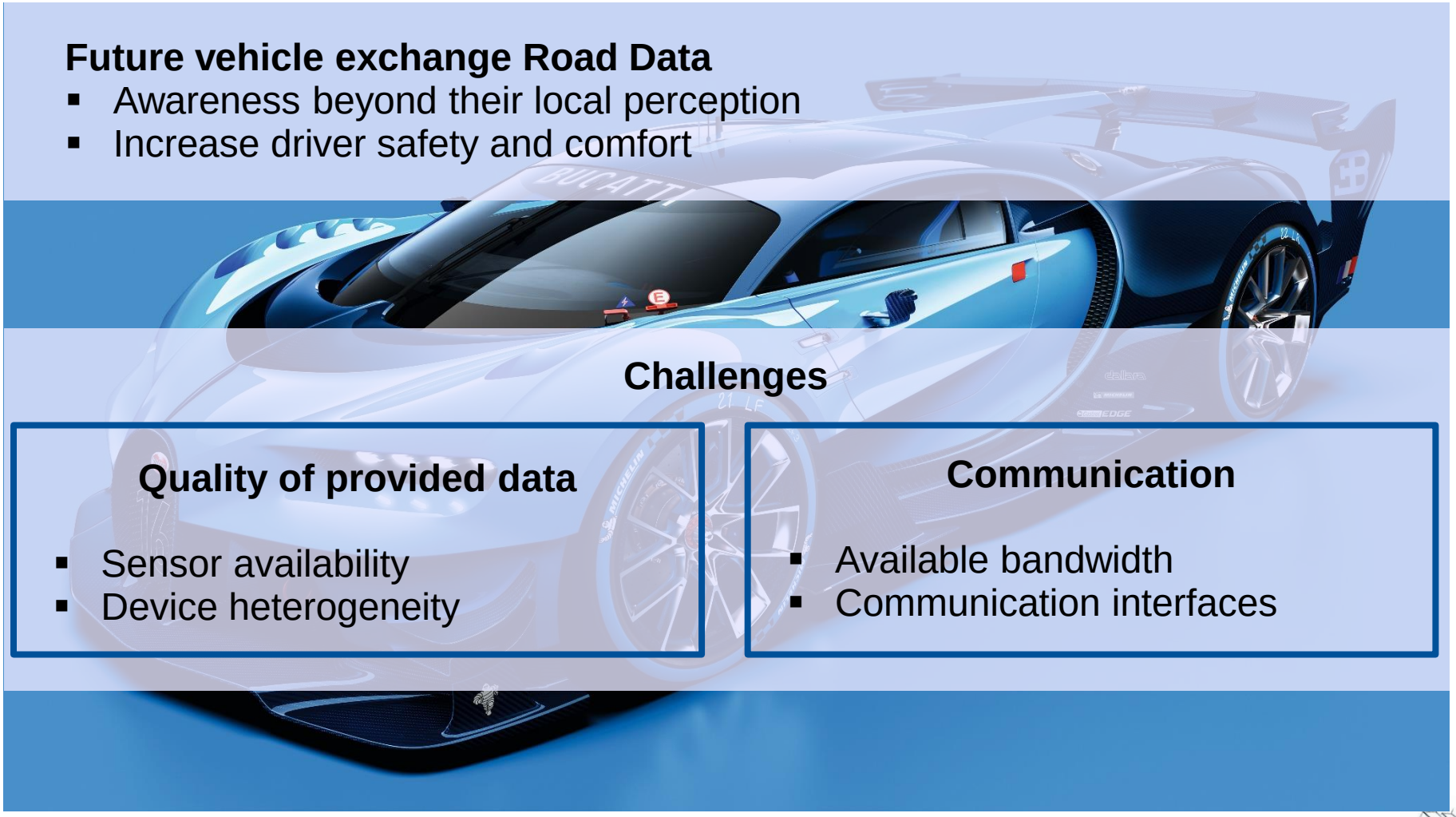
Future vehicle exchange Road Data

- Awareness beyond their local perception
- Increase driver safety and comfort



Challenges

Quality of provided data

- Sensor availability
- Device heterogeneity

Communication

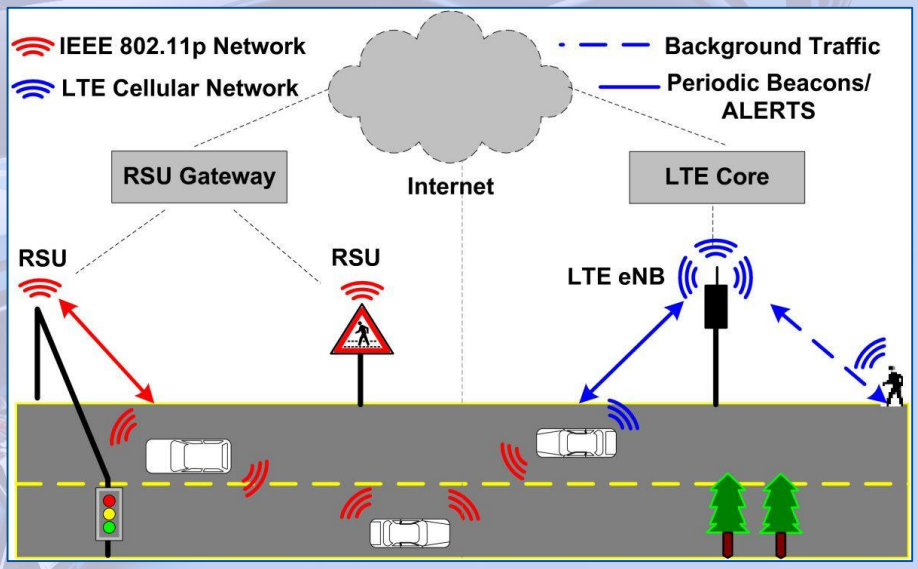
- Available bandwidth
- Communication interfaces

https://www.autopartswarehouse.com/blog/wp-content/uploads/2015/12/gran-turismo-4.jpg

Communication

Communication Interfaces

- Cellular communication interfaces
- Local Vehicle-to-Vehicle (V2V) communication
- ~~Vehicle-to-Infrastructure (V2I) communication (RSU)~~

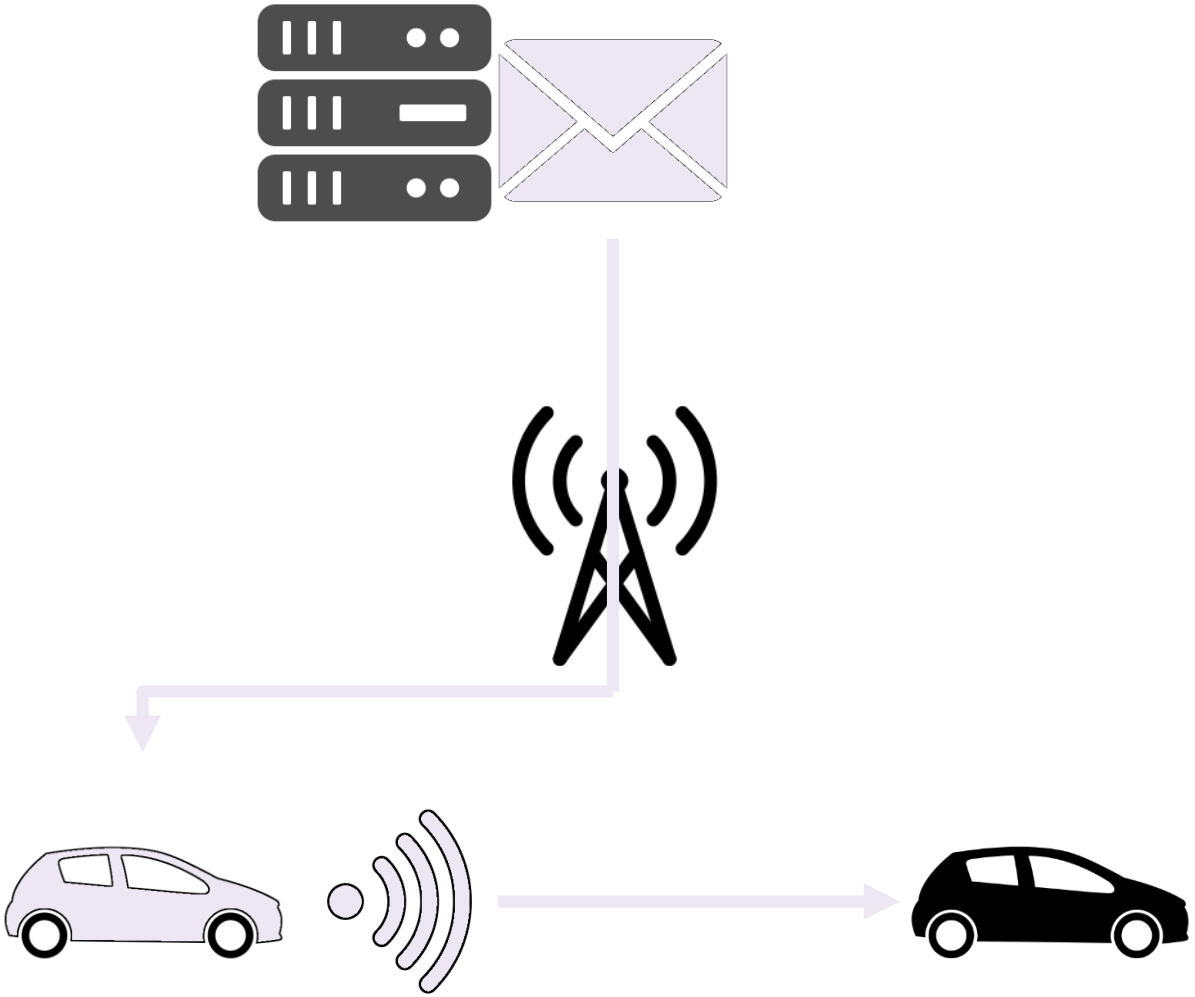


Limitations of cellular communication

- Bandwidth is limited
  - Physically available bandwidth is limited
  - High bandwidth usage over longer durations is not feasible
- Bandwidth is hardly plannable

https://www.autopartswarehouse.com/blog/wp-content/uploads/2015/12/gran-turismo-4.jpg
Mir et al. "LTE and IEEE 802.11 p for vehicular networking: a performance evaluation." *EURASIP* 2014.1

Scenario




M
Multi Mechanismen
A
Adaption für
K
das künftige
I
Internet
DUDEN
Maki
change
change
Lost in
Transition
QUALITY
Internet
Kaiserschmarrn
Zukunft
2015
2016
faster
bigger
better
stronger

Message Propagation

Influence of the Vehicle's State