Conception, Implementation and Evaluation of the Safety-Critical Application „Intersection Movement Assist (IMA)” Based on Simulation and C-V2X Experimental Vehicles

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Overview

Functional description

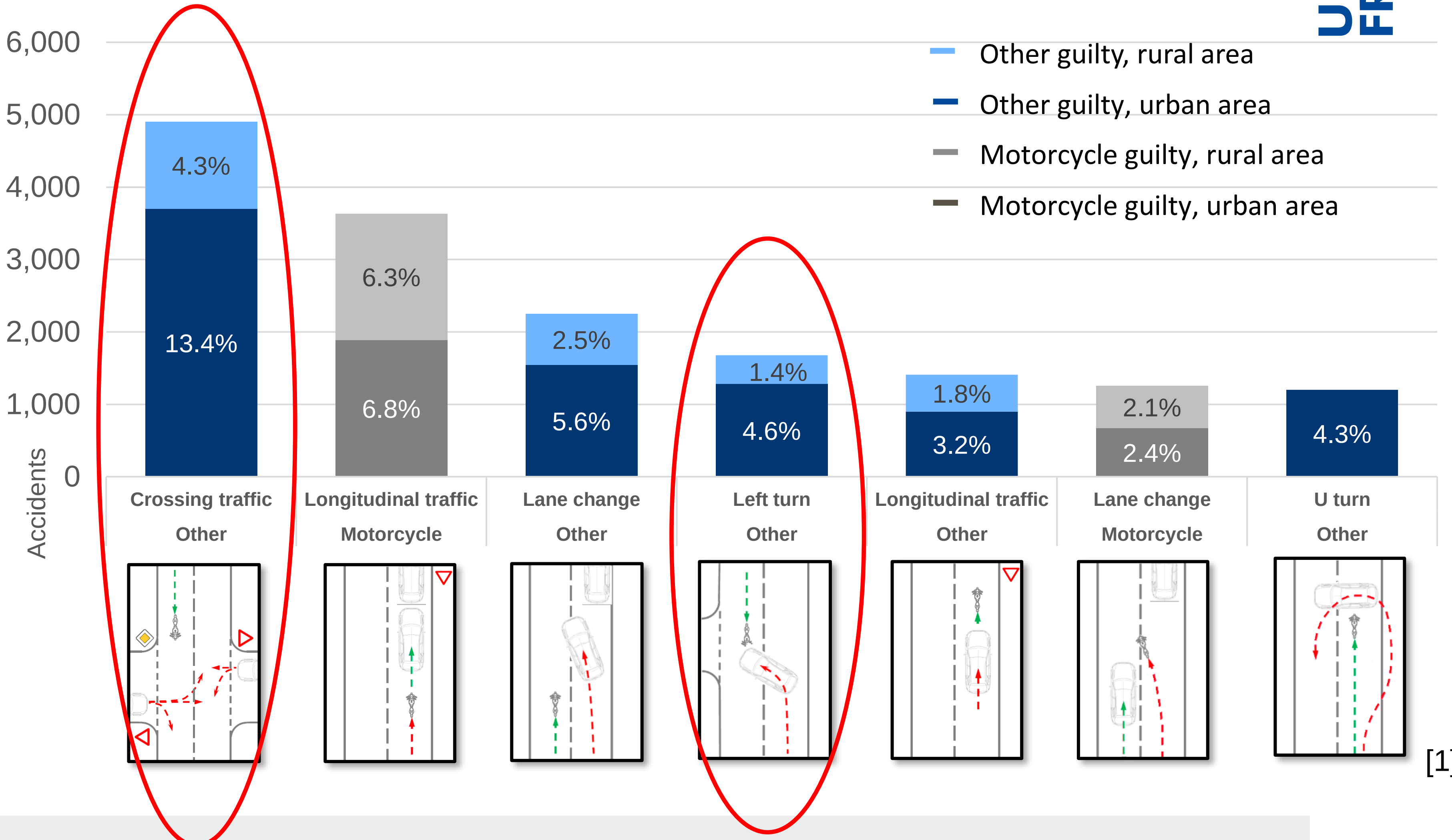
Implementation of 4 different approaches

Evaluation by means of simulation

Implementation of one approach on prototype vehicles

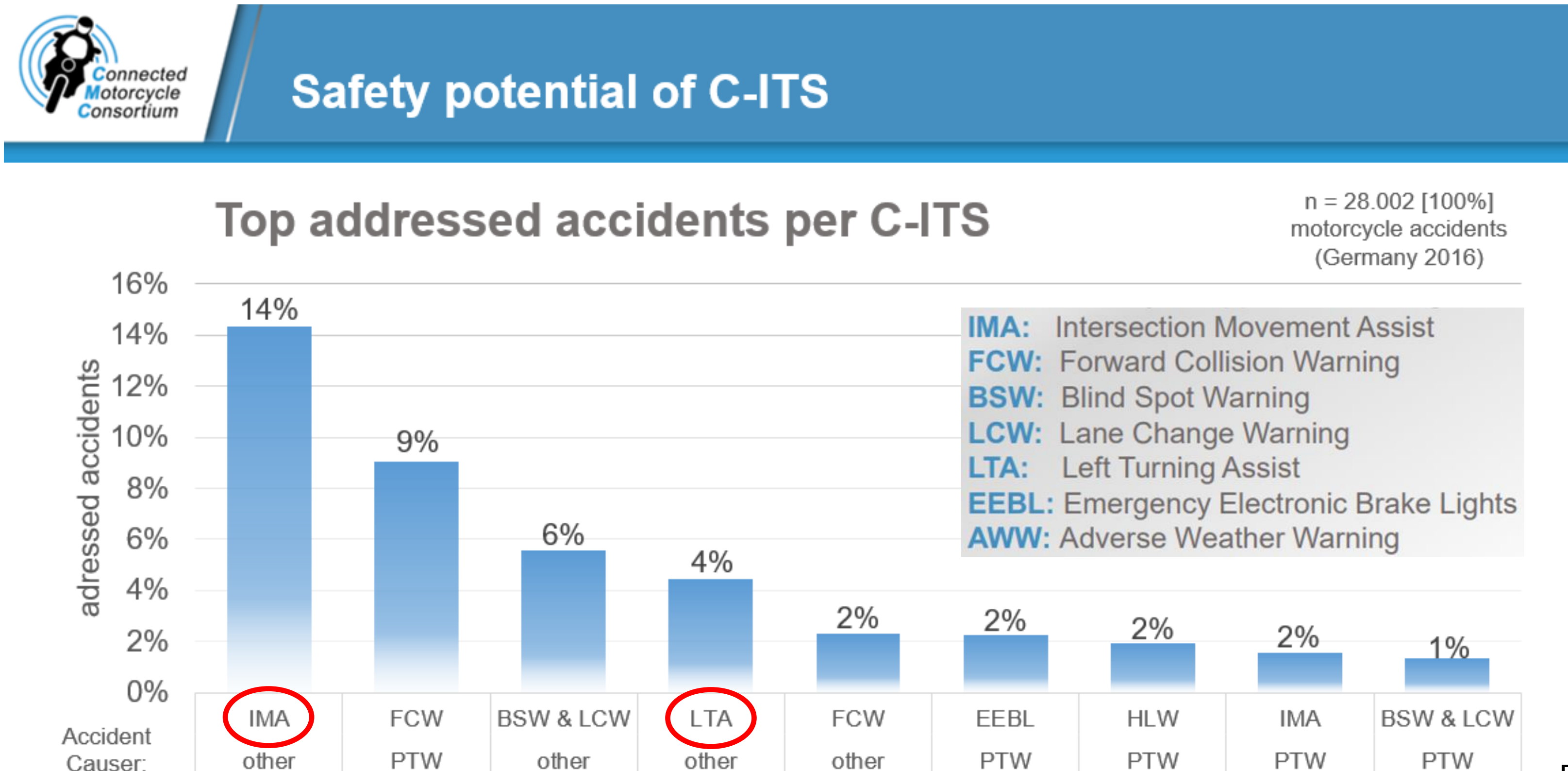
Validation using prototype vehicles

The problem



[1]

The initiative



[2]

The question

How should be the V2X-Application IMA designed in order to ensure maximal reliability and acceptance?

Exchange of information between vehicles.

Low rate of missed warnings and usable information for the driver.

Very low rate of false warnings.

The elements of the application

V2X Communication (C-V2X)

- Exchange of odometry data over direct communication between vehicles.

Localisation

- Position detection.

HMI

- Advertisement of notifications and warnings.

Digital map

- Information about the location and size of intersections and junctions.

Algorithm

- Computation of probability of collision.

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Key requirements

- Criticality estimation based on a single V2X-message.
- Processing of over 1000 V2X-messages per second.
- Adjustable sensitivity for warnings.

Implementation of different approaches

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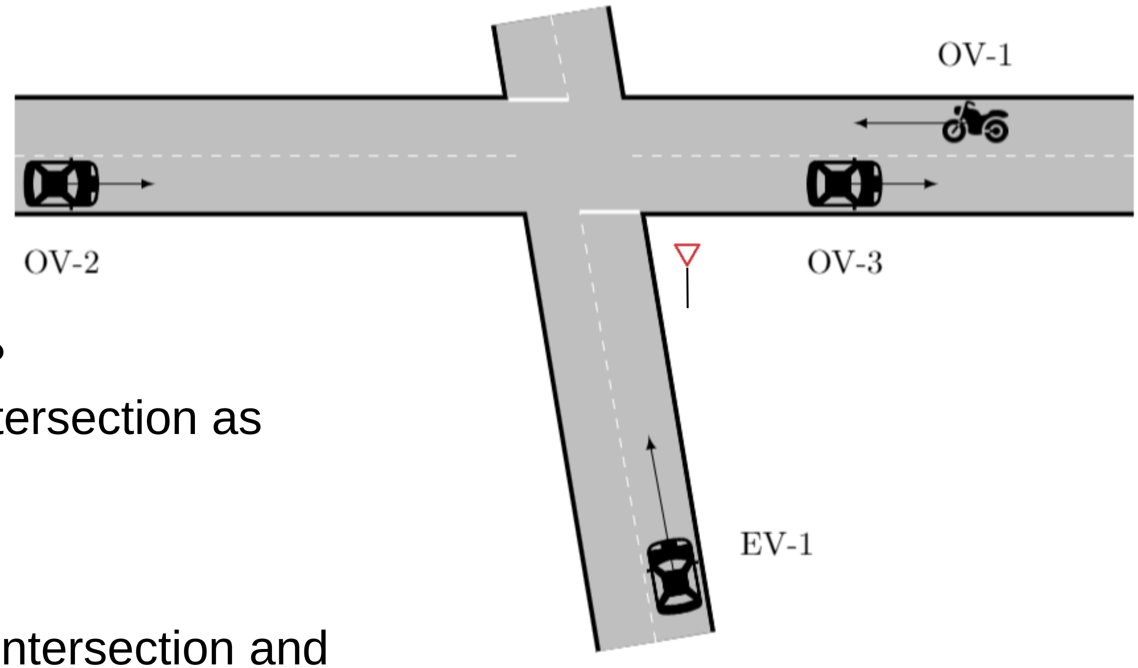
Base scenario for comparing approaches



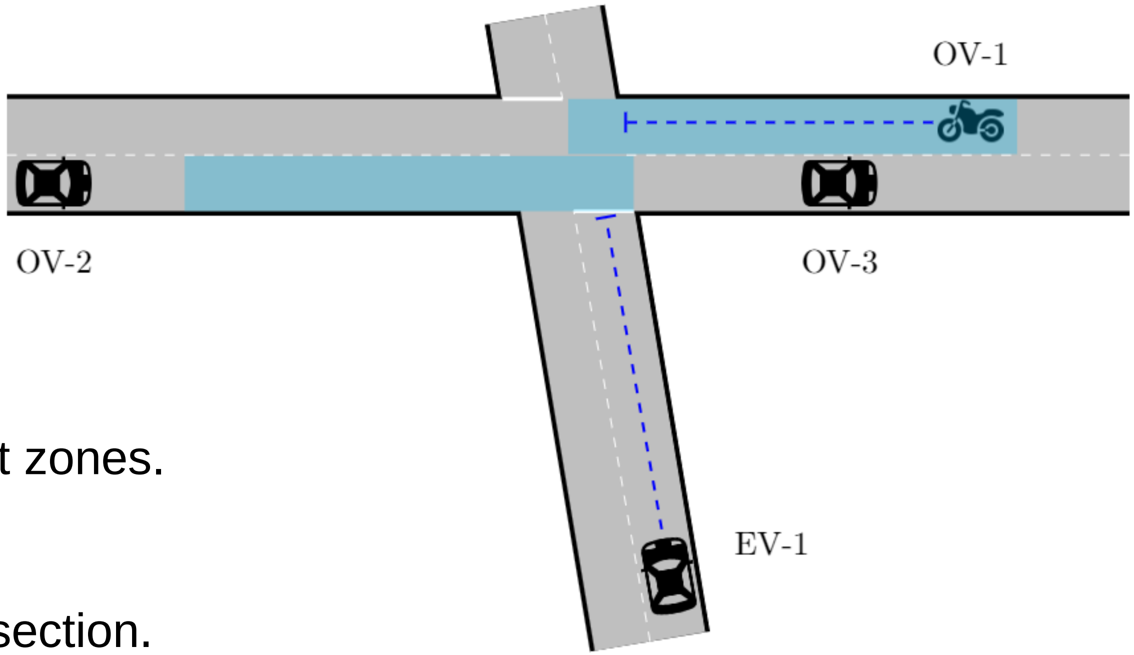
What is happening here?
EV-1 wants to cross the intersection as quickly as possible.

Where is the problem?
OV-2 is far away from the intersection and drives slowly. OV-3 blocks the line-of-sight between OV-1 von EV-1.

What are the possible outcomes?

OV = Other-vehicle
EV = Ego-vehicle (having IMA)

The SAE-based approach

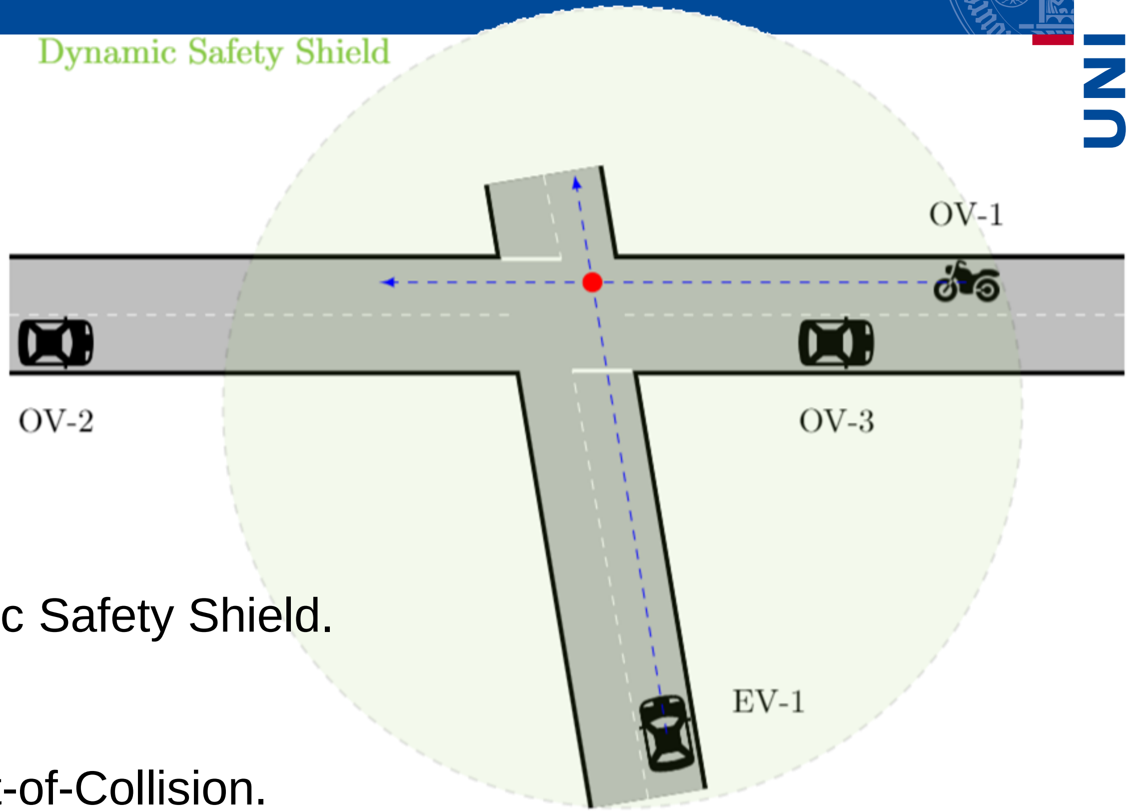


Who is considered?
Vehicles inside the relevant zones.

What is computed?
Time for reaching the intersection.

What triggers the warning?
Time difference between both vehicles for reaching the intersection.

The ETSI-based approach

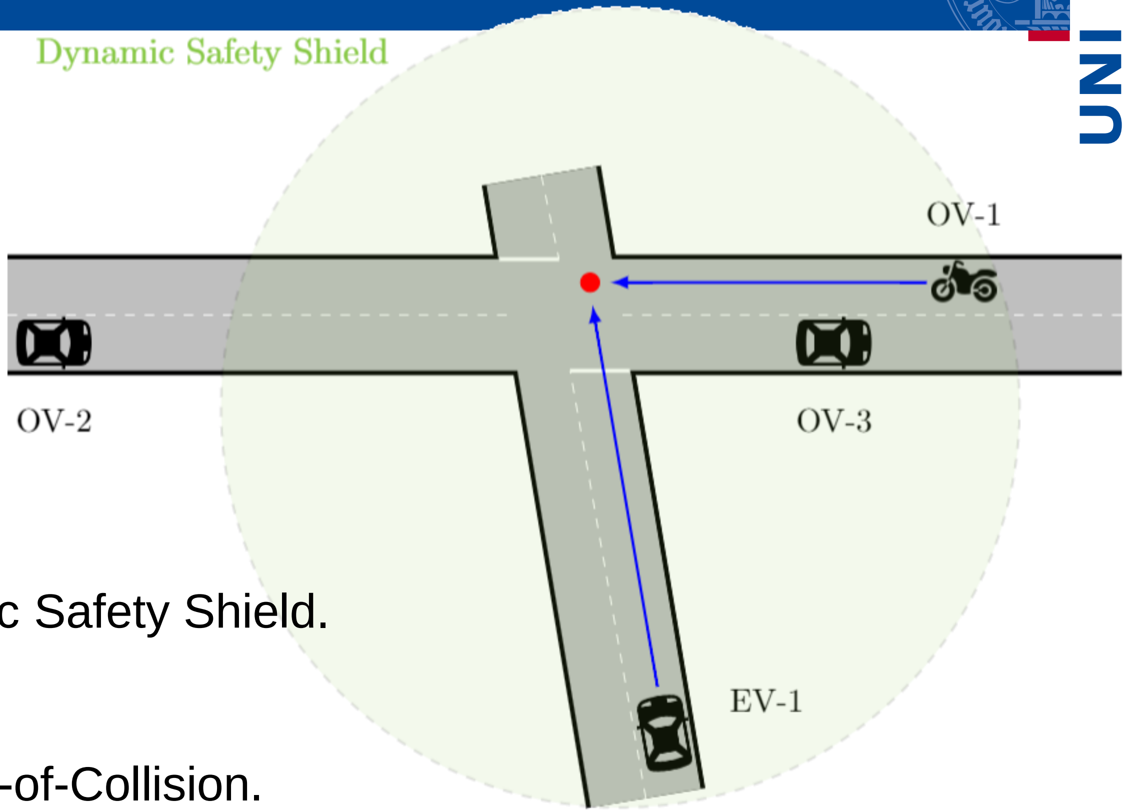


Who is considered?
Vehicles inside the Dynamic Safety Shield.

What is computed?
Time for reaching the Point-of-Collision.

What triggers the warning?
Time difference between both vehicles for reaching the Point-of-Collision.

The ETSI-Map approach

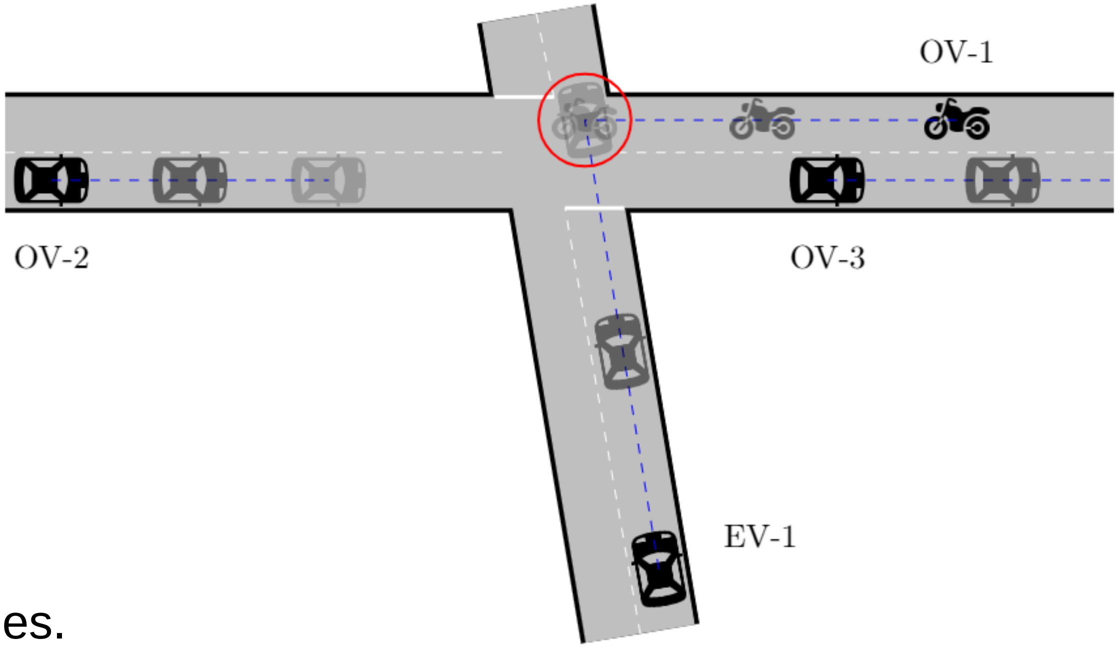


Who is considered?
Vehicles inside the Dynamic Safety Shield.

What is computed?
Time for reaching the Point-of-Collision.

What triggers the warning?
Time difference between both vehicles for reaching the Point-of-Collision.

The ghost vehicles approach



Who is considered?
All vehicles.

What is computed?
Future position of the vehicles.

What triggers the warning?
Distance between the ghost vehicles.

Evaluation and comparison

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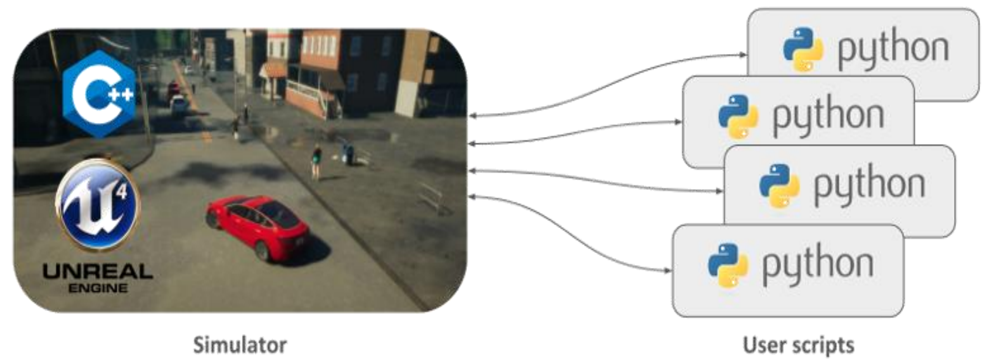
The procedure

Functional description

Simulation environment

Accident scenarios

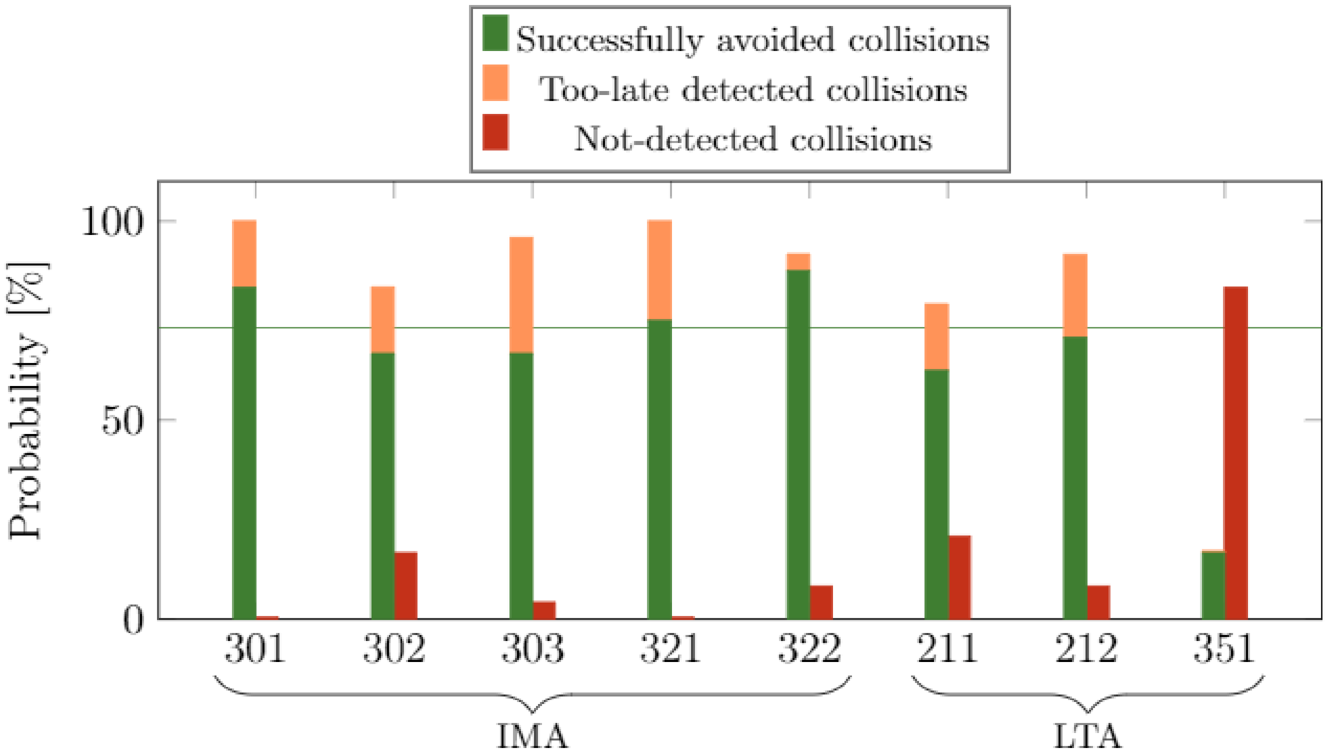
Framework for
the implementation



The performance indicators

	Dangerous situation	Non-dangerous situation
Warning given	**Detected collisions** (Warnings on time) **Detected collisions** (Warnings too late)	**False Positives** (False warnings)
Warning not given	**Not detected collisions** (False Negatives/ Missed warnings)	**True Negatives** (No warning needed, no warning given)

Results for dangerous situations (ETSI-Map)



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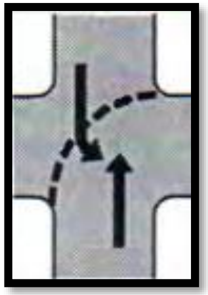
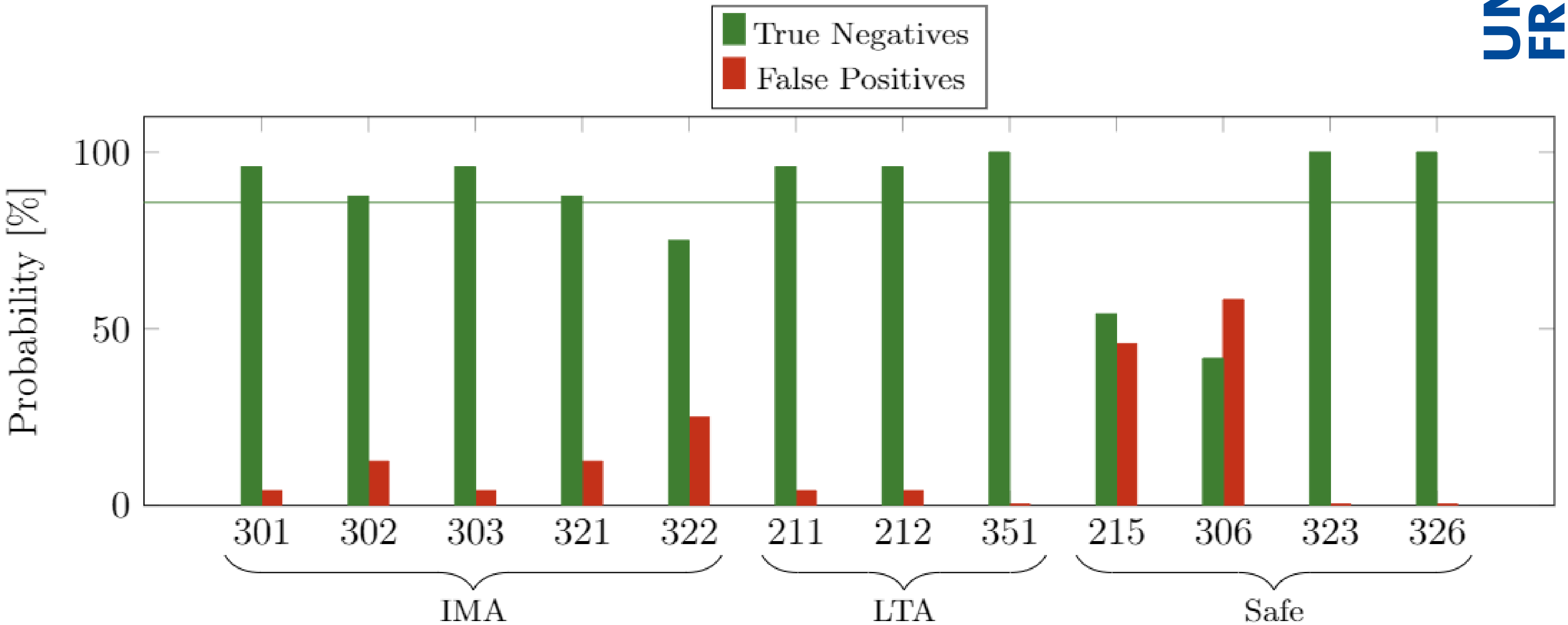
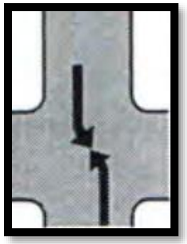


351: OV turns left.
EV drives straight.

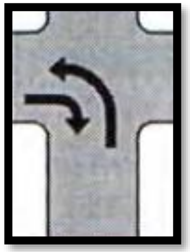
Results for non-dangerous situations (ETSI-Map)





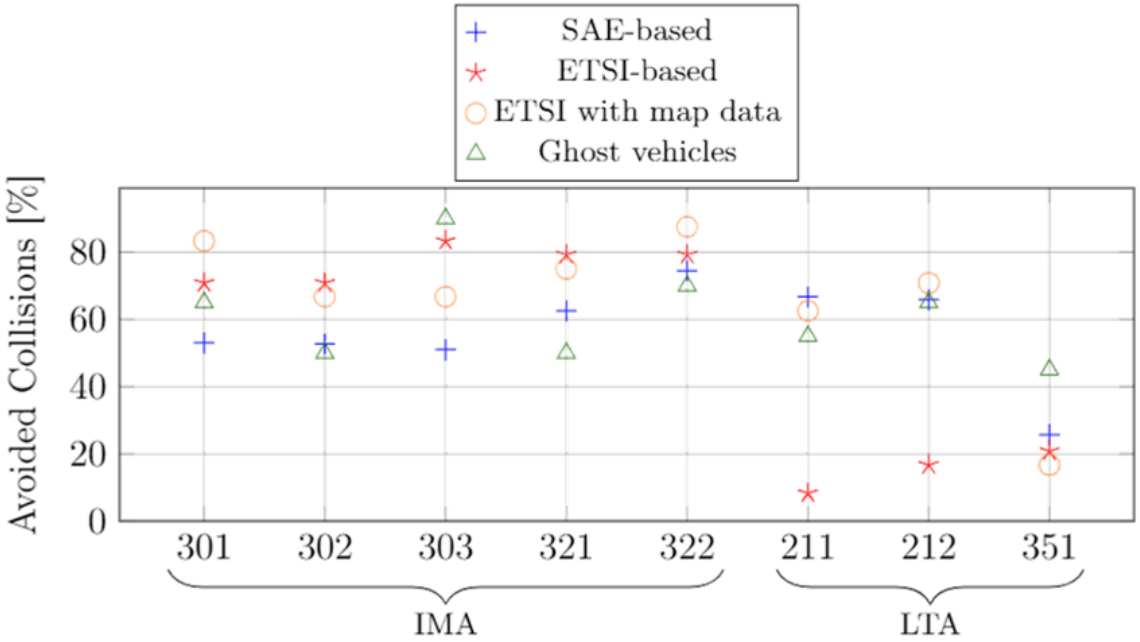
[3]

215: The vehicles turn left in front of each other.



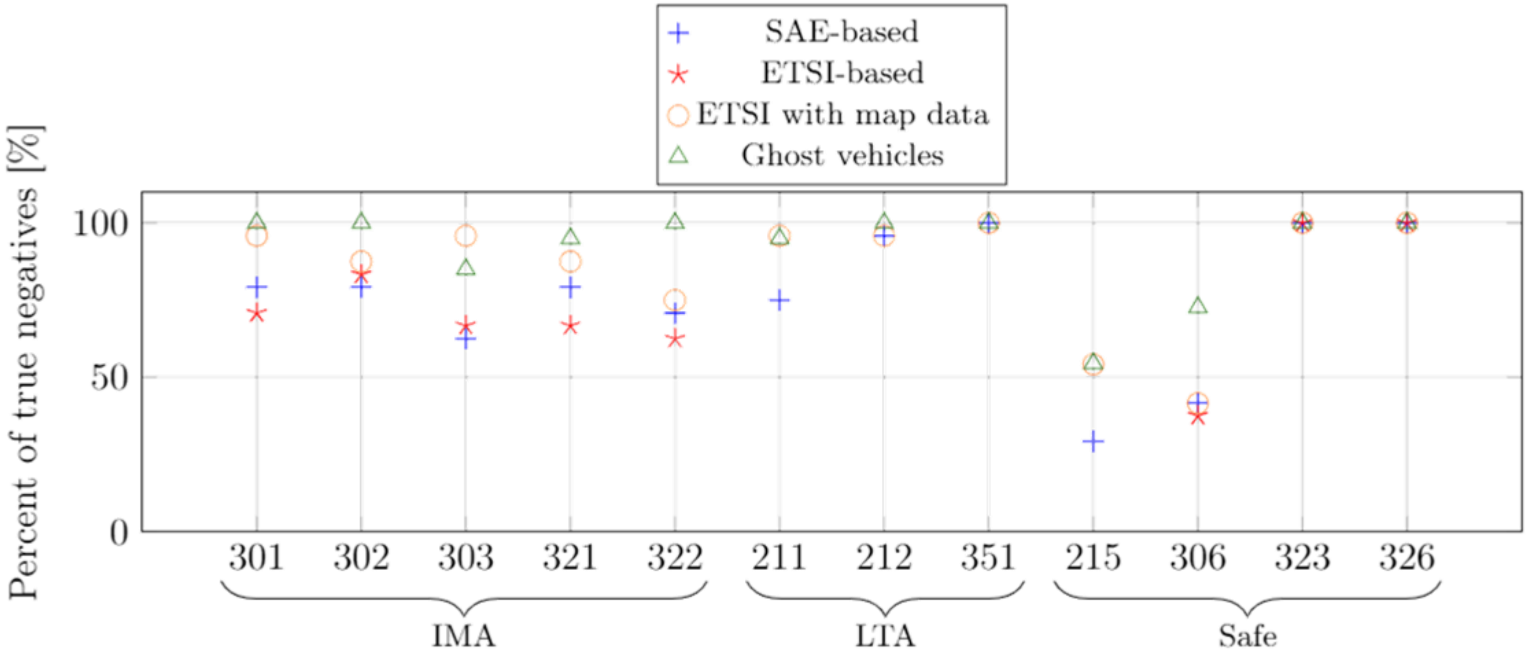
306: OV comes from the left and turns right. EV turns left.

Comparison across all four approaches



Dataset: Dangerous situations

Comparison across all four approaches



Dataset: Non-dangerous situations

Validation (ETSI-based approach)

Use Case	Scenario	Trials	TP	TN
IMA	Straight crossing path	16	✓	✓
IMA	Left turn into crossing	16	✓	✓
IMA	Other-vehicle turning left from right	16	✓	✓
LTA	Left turn with oncoming-traffic	8	✓	✓
LTA	Other-vehicle turning left ahead	8	✓	✓
LTA	Waiting before turning left	4	✓	✓
LTA	Waiting before turning left (after half turn)	4	✓	✓
IMA/LTA	Free-ride (Both vehicles moving)	1	✓	✗
IMA/LTA	Free-ride (Only one vehicle moving)	1	–	✓

Summary and next steps

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Summary

Potential of V2X-Communication for avoiding accidents at intersections was confirmed.

Recommended approach:
ETSI-based with map data.

Digital map:
Mandatory for the implementation of LTA.

Biggest challenge:
Detecting the next maneuver of the Other-vehicle.
Privacy requirements make this detection difficult.

Proposed next steps

Fusion of conventional sensors and V2X-communication:
CARLA Simulator offers a variety of sensors, e.g. RGB Camera, Depth Camera, DVS Camera, LiDAR, Radar, among others.

Optimization of parameters for increasing customer acceptance:
Field study with volunteers for the topics warning time and HMI.

Implementation of AI-methods for detecting collisions:
Focus on comprehensibility of decisions.

Adaptable sensitivity of sensors:
By using V2X-communication, the sensitivity of conventional sensors can be adjusted when there is a motorcycle around.

Thank you!

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References

[1] Evaluation of accidents registered on GIDAS (2005-2017), weighted to DESTATIS 2017. n = 27.714 accidents involving motorcycles (Germany, 2017). Study performed by: VUFO GMBH.

[2] Assessment of C-ITS application potential. Connected Motorcycle Consortium (CMC), 2020.

[3] Catalog for accident types: Guideline for determining types of accidents. GDV, 1998. (Original title: Unfalltypen-Katalog: Leitfaden zur Bestimmung des Unfalltyps).

Backup slides

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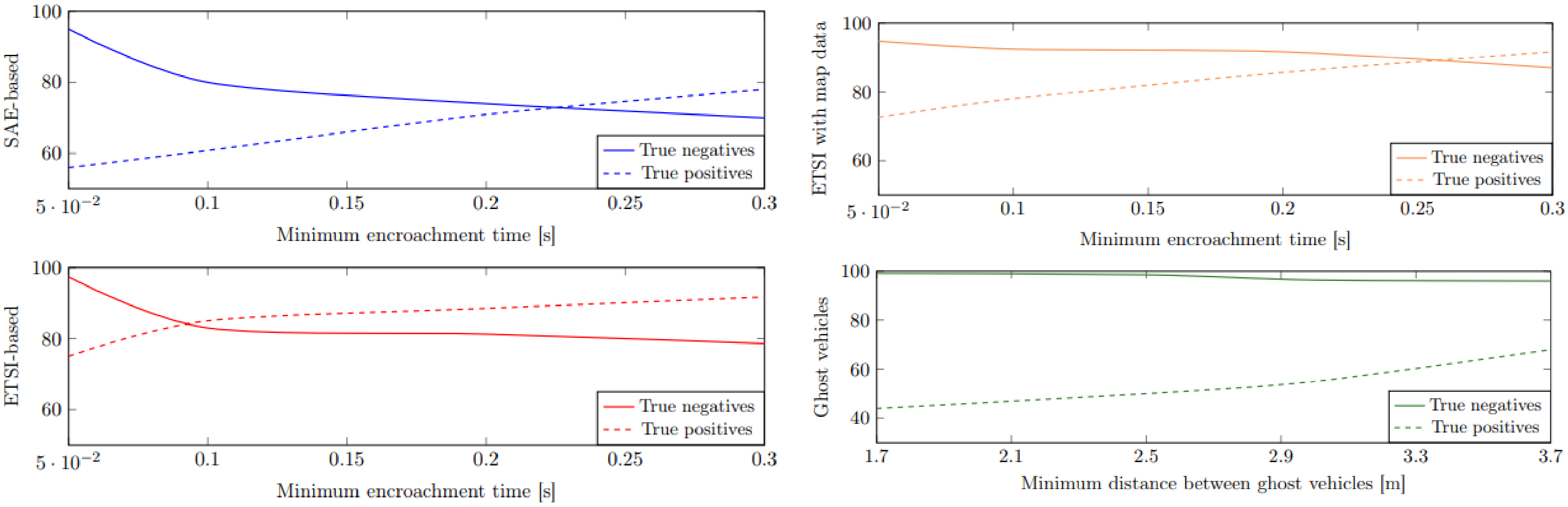
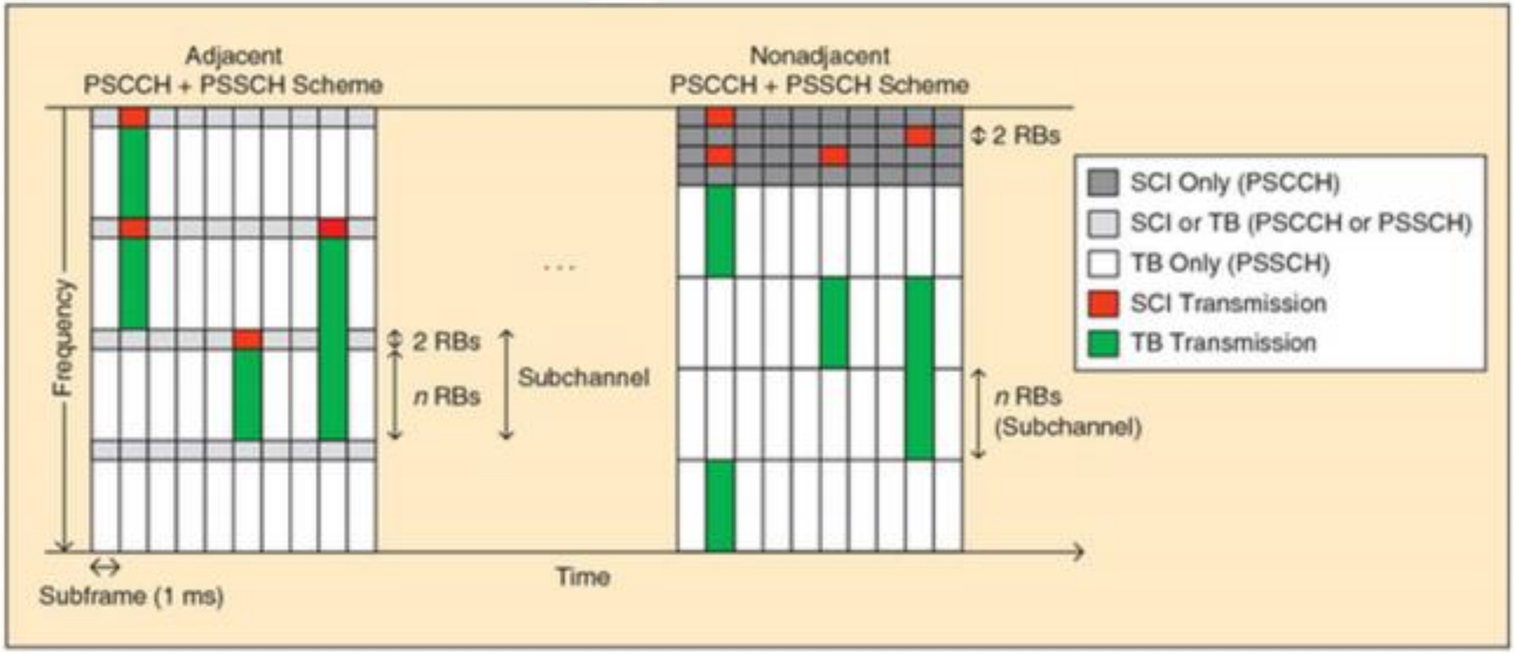
Characteristics of approaches

Characteristics	Approaches			
	SAE	ETSI	ETSI_{Map}	Ghost
Accuracy of true warnings for IMA	$+$	$++$	$++$	$+$
Accuracy of notifications for IMA	$++$	$+$	$+$	$+$
Accuracy of true warnings for LTA	$+$	$--$	$++$	$+$
Accuracy of notifications for LTA	$++$	$--$	$+$	$+$
Robustness against false warnings	$+$	$--$	$+$	$++$
Independence of intersection geometry	$-$	$++$	$+$	$+$
Scalability regarding size of intersection	$+$	$++$	$+$	$-$

Adjustable sensitivity



C-V2X sub-channelization



R. Molina-Masegosa et al.: "LTE-V for Sidelink 5G V2X Vehicular Communications: A new 5G Technology for short-Range V2X Communications", IEEE Vehicular Technology Magazine 2017

ETSI-based approach at closed curves

Other use cases

Conspicuity Enhancement
Increase the perception of motorcycles by other road users.