ROADART

H2020 - 636565

Research On Alternative Diversity Aspects foR Trucks

REQUIREMENTS FOR V2X-ARCHITECTURE AT TRUCKS

Deliverable Identifier:	**D1.1**
Delivery Date:	**31 October 2015**
Classification:	**Public**
Editors:	Sebastian Völl, MAN Frank Meyering, IMST A.Marousis, UPRC Ellen van Nunen, TNO
Document version:	V2.0

Contract Start Date:	1st Mai 2015
Duration:	36 months
Project coordinator:	IMST (Germany)
Partners:	MAN (Germany), TNO (Netherlands), UPRC (Greece)

Horizon 2020
Call: H2020-MG-2014_TwoStages
Topic: MG-3.5a-2014
Type of action: RIA
Proposal number: SEP-210181921
Proposal acronym: ROADART

European Commission

Revision History

Version	**Date**	**Description and comments**	**Edited by**
0.1	17/06/2015	First Draft Version	Frank Meyering
0.2	14/10/2015	Restructured, add truck specific content	Sebastian Völl
0.3	21/10/2015	Adjusted	Sebastian Völl
0.4	27/10/2015	Add pictures, add input, UPRC, IMST	Sebastian Völl, Frank Meyering, A. Marousis
0.5	29/10/2015	Add input TNO	Ellen van Nunen
1.0	31/10/2015	Adjusted	Sebastian Völl
2.0	18/05/2017	Deliverable classification change from *Restricted* to *Public* after unanimous agreement of the partners and the PO	C. Oikonomopoulos

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1 Introduction

1.1 Background

This document is the result of a deliverable for the ROADART project. This project aims to evaluate diversity techniques and antenna concepts in order to develop an in-vehicle platform for cooperative ITS systems for trucks and heavy duty vehicles in the Horizon 2020 call MG-3.5a-2014 "Cooperative ITS for safe, congestion-free and sustainable mobility."

The ROADART project is defined by means of 9 work packages (WPs):
WP1 Requirements and Design
WP2 Channel Measurements, Characterization and Modelling
WP3 T2X Communication Techniques
WP4 Development of the ITS communication platform
WP5 Robust Cooperative Adaptive Cruise Control
WP6 Integration
WP7 Test, Demonstration and Evaluation
WP8 Dissemination and exploitation
WP9 Project Management

This deliverable is part of WP1: Requirements and Design.
The project and the objectives will be further explained in section 1.1.1 and 1.1.2.

1.1.1 **The project**

The main objective of ROADART is to investigate and optimise the integration of ITS communication units into trucks. Due to the size of a truck-trailer combination the architecture approaches investigated for passenger cars are not applicable. New architecture concepts have to be developed and evaluated in order to assure a sufficient Quality of Service (QoS) for trucks and heavy duty vehicles. An example of a specific use case is the platooning of several trucks driving close behind each other through tunnels with walls close to the antennas that support the communication systems. Due to the importance of tunnel safety, significant research effort is needed in order to check the behaviour of the antenna pattern, diversity algorithms and ray tracing models especially for trucks passing through tunnels. V2V and V2I systems specified from the C2C Communication Consortium are focussing on road safety applications. The ROADART project aims to demonstrate especially the road safety applications for T2T and T2I systems under critical conditions in a real environment, like tunnels and platooning of several trucks driving close behind each other. Besides that traffic flow optimization and therefore reducing Greenhouse Gas emissions are positive outcomes of the use cases demonstrated in this project. Demonstration and Evaluation of the use cases will be performed by simulation and by practical experiments on several levels. Besides evaluation on component and system level, the complete system will be evaluated in practice.

1.1.2 **Objectives**

The ROADART project aims to evaluate diversity techniques and antenna concepts in order to develop an in-vehicle platform for cooperative ITS systems for trucks and heavy duty vehicles in the Horizon 2020 call MG-3.5a-2014 "Cooperative ITS for safe, congestion-free and sustainable mobility."

1.2 The objective of this deliverable

This deliverable describes the requiremenst for the T2T/T2I-communicationen regarding antenna design, communication architecture, V2X-Stack for CACC and for the localization.

Chapter 2 describe the typical motorway Use Cases of trucks at the right lane of motorways for testing of the communication system.

Chapter 3 will summarize the status quo regarding antenna patterns, positions and architecture for a tractor – trailer combination. Chapter 4 will define the resulting requirements. Chapter 5 describe the requirements for the localization.

2 Communication Use Cases for ROADART

For the communication Use Cases in ROADART the standard tractor-unit with trailer will be used (Figure 4, a). For the highway Use Cases the relative motion between truck and trailer is around 0 to ± 2 degree

The typical simple driving situation is a single truck on the right line of a motorway, which has to be evaluated (Figure 1).

Figure 1: single truck at right lane

If more than one truck driving in a convoy, there are typical distances between the trucks which have to be considered for communication (e.g. 50 m, 30 m, 20 m, 10 m).

Figure 2: straight following trucks

In addition of straight following vehicles there could be a lateral offset between the different trucks (up to 1.25 m based on vehicle and lane width).

Figure 3: collocation of trucks with offsets

Of course the environment influences the communication between the truck convoy. So ROADART will investigate the communication effects and quality in some special environments like tunnels (or under bridges).

So there are the following communication Use Cases, which will be considered in ROADART[1]:

1. Single Truck driving for evaluating antenna, diversity and Ray Tracing

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[1] These Use Cases will be considered at least for simulation. Integration, implementation and demonstration will be done for a subset of Use Cases resp. for a reduced numbers of trucks. The Use Cases for CACC are mentioned in Deliverable 5.1 with the CACC-relevant description and refers to UC_2a and UC_2b.

2. Truck convoy up to short distances on a private testing area and, if possible, in real traffic on highway, driven manually at large distance or by CACC at smaller distances
    a. Exactly following
    b. Lateral offsets (up to 1.25 m)
3. convoy of trucks in highway tunnels (if possible) at large distance for channel measurement and object tracking without GNSS.
    a. Exactly following
    b. Lateral offsets (up to 1.25 m)

ID	**UC_1**	
Name	Short-distance truck platooning	
Use case description	Truck driving on a highway, on right lane, with a velocity of 80 km/h and in mixed traffic.	
Background attributes	Area type	Highway; e.g. A270 (NL) or A99, A8 or A9 (D), no tunnel, private test area
	Environmental conditions	Mixed traffic, typical highway environment
	Speed range	70-90 km/h
Participant 1 attributes (T1)	Type of participant	Truck which communicates CAM
	Manoeuvre	Manual driving and manual steering.
Participant 2 attributes (T2)	Type of participant	-
	Start of position	-
	Manoeuvre	-
Sketch		

ID	**UC_2a**	
Name	**Truck convoy up to smaller distances**	
Use case description	Truck driving on a highway, on right lane, with a velocity of 80 km/h and in mixed traffic.	
Background attributes	Area type	Highway; e.g. A270 (NL) or A99, A8 or A9 (D), no tunnel private test area
	Environmental conditions	Mixed traffic, typical highway environment,
	Speed range	70-90 km/h
	Number of trucks	2 - 4
	Collocation	Straight following
Participant	Type of participant	Truck which communicates CAM at large

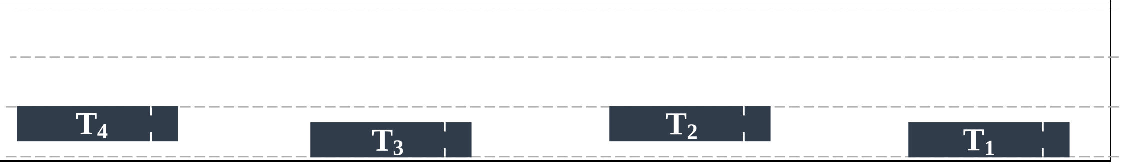
1 attributes (T_1)		distances Truck which communicates CACC-specific messages at smaller distances
	Manoeuvre	Manual driving and manual steering at large distances ACC at smaller distances.
Participant 2-4 attributes (T_2, T_3, T_4,)	Type of participant	Truck which communicates CAM at large distances Truck which communicates CACC-specific messages at smaller distances
	Manoeuvre	Manual driving and manual steering at large distances CACC at smaller distances.
Sketch		

ID	**UC_2b**	
Name	**Truck convoy up to smaller distances**	
Use case description	Truck driving on a highway, on right lane, with a velocity of 80 km/h and in mixed traffic.	
Background attributes	Area type	Highway; e.g. A270 (NL) or A99, A8 or A9 (D), no tunnel private test area
	Environmental conditions	Mixed traffic, typical highway environment,
	Speed range	70-90 km/h
	Number of trucks	2 - 4
	Collocation	lateral offsets up to 1.25 m based on vehicle and lane width
Participant 1 attributes (T_1)	Type of participant	Truck which communicates CAM at large distances Truck which communicates CACC-specific messages at smaller distances
	Manoeuvre	Manual driving and manual steering at large distances ACC at small distances.
Participant 2-4 attributes (T_2, T_3, T_4,)	Type of participant	Truck which communicates CAM at large distances Truck which communicates CACC-specific messages at smaller distances
	Manoeuvre	Manual driving and manual steering at large distances CACC at smaller distances.

Sketch	

ID	**UC_3a**	
Name	**Truck convoy at highway tunnel**	
Use case description	Truck driving on a highway, on right lane, with a velocity of 80 km/h and in mixed traffic.	
Background attributes	Area type	Highway tunnel
	Environmental conditions	Mixed traffic
	Speed range	70-90 km/h
	Number of trucks	2 - 4
	Collocation	Straight following
Participant 1 attributes (T_1)	Type of participant	Truck which communicates CAM at large distances Truck which communicates CACC-specific messages
	Manoeuvre	Manual driving and manual steering
Participant 2-4 attributes (T_2, T_3, T_4,)	Type of participant	Truck which communicates CAM resp. the CACC-specific messages
	Manoeuvre	Manual driving and manual steering
Sketch		

ID	**UC_3b**	
Name	**Truck convoy at higway tunnel**	
Use case description	Truck driving on a highway, on right lane, with a velocity of 80 km/h and in mixed traffic.	
Background attributes	Area type	Highway tunnel
	Environmental conditions	Mixed traffic
	Speed range	70-90 km/h
	Number of trucks	2 - 4
	Collocation	lateral offsets up to 1.25 m based on vehicle and lane width
Participant 1 attributes (T_1)	Type of participant	Truck which communicates CAM at large distances Truck which communicates CACC-specific messages
	Manoeuvre	Manual driving and manual steering

Participant 2-4 attributes (T_2, T_3, T_4,)	Type of participant	Truck which communicates CAM resp. the CACC-specific messages
	Manoeuvre	Manual driving and manual steering
Sketch		

3 Status quo regarding T2T/T2X-communication

3.1 Truck specifics

Within the last years a lot of research work regarding antenna positions and architecture for usage of WLAN 802.11p (ITS G5) are made by suppliers or car manufacturer.

The basic conditions for trucks resp. for heavy duty vehicles in general differs from the cars conditions. Usually a heavy duty vehicle can be divided in a towing and a towed vehicle. New bus concepts arrange a towing vehicle to. Vehicle combinations are tractor-trailer, truck with trailer or solo truck with different vehicle combination length (Figure 4).

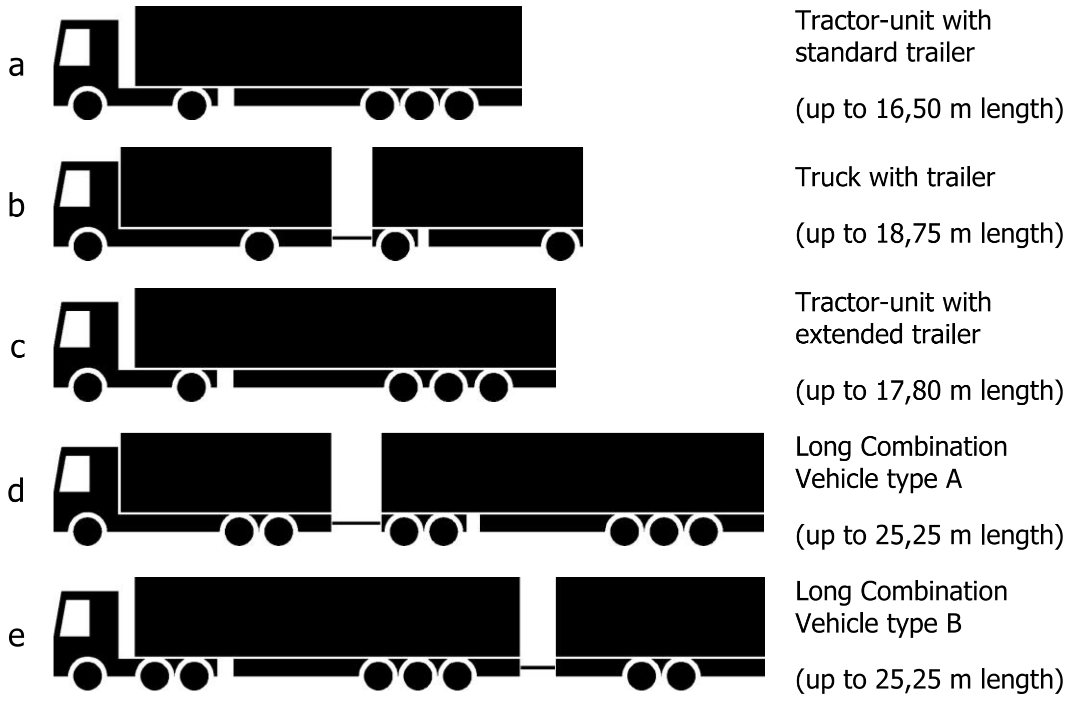


Figure 4: different vehicle combinations

Of course there is a relative motion between a towing and a towed vehicle. The dimension of the angle of articulation between tractor-unit and trailer could reach up to ±40 to ±60 degree for reversing and turning, but at a motorway scenario the number is located around 0 to less than ±2 degree for driving straight resp. to less than ± 10 degrees at motorway entrance or exit.

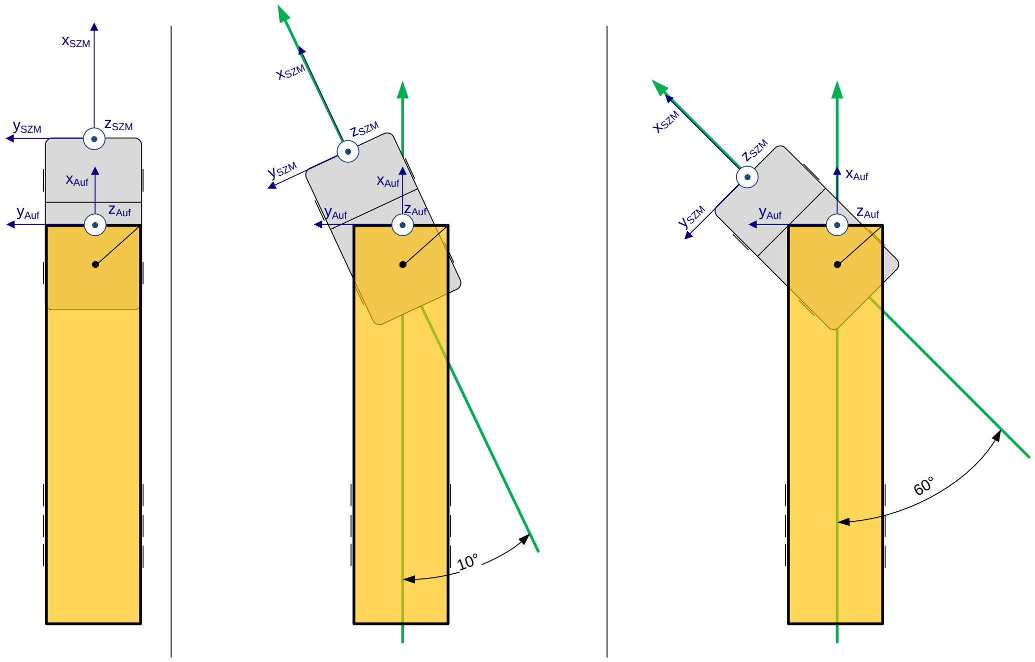


Figure 5: different angles of articulation between tractor unit and trailer

At least there is one vehicle with a huge geometry in relation to cars.

In addition a truck manufacturer produces only a tractor unit or a truck chassis. The tractor unit will be combined with a trailer by the customer, the truck chassis gets a body, which is not even known in detail to the truck manufacturer at production due to a defined interface between chassis and body, which can be used by any body manufacturer.

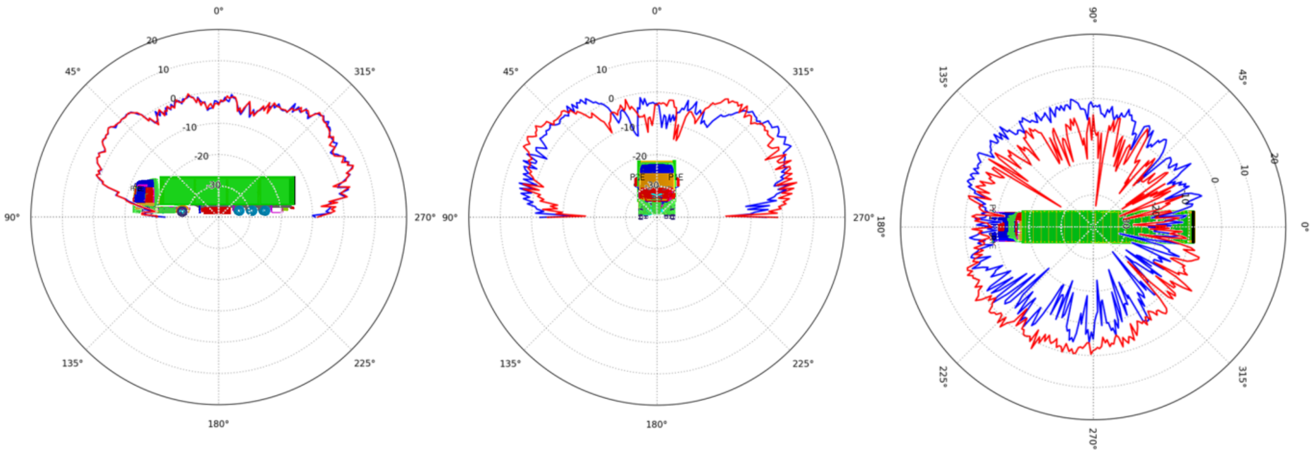
A last speciality of trucks is the huge diversity of variants in a vehicle family which can be chosen by the customer. In a basic vehicle family like long haul, traction or distribution the drivers cab size, wheelbase, chassis length, number of axles and others can vary.

Especially the drivers cab size in combination with the (unknown) body resp. the unknown trailer of a tractor-unit results in special requirements for antenna pattern, antenna positions, the associated architecture and the processing of data to be sent or received.

3.2 Antenna field and mounting position at trucks

Due to the geometry, the mentioned vehicle combinations and the basic conditions the mounting of one or two antennas at the roof of a drivers cab seems to be not suitable for fulfilling the task to communicate with other vehicles in the surrounding. Some first antenna field simulations with two omnidirectional antennas placed at the roof of a typical long haul tractor with a tarpaulin-hoops trailer confirm the assumption of shielding by the trailer. Especially in the rear and front at the bottom of the surroundings the radiated power is greatly reduced (Figure 6).

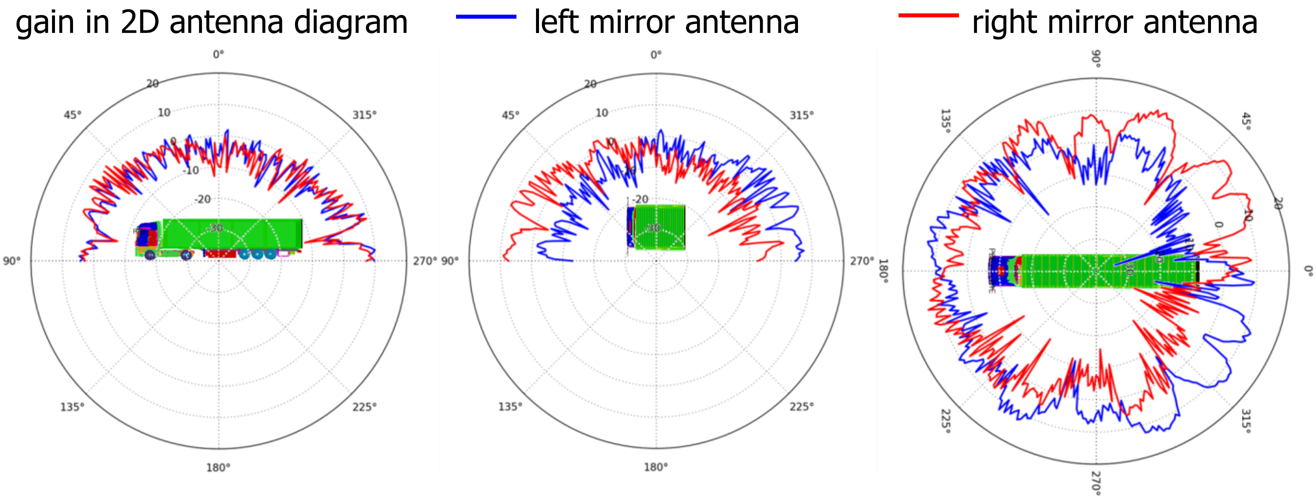
gain in 2D antenna diagram — left antenna — right antenna



Side view Front view Top view

Figure 6 antenna diagrams for 2 roof mounted omnidirectional antennas at long haul vehicle combination

It seems that the roof is not the right place for mounting V2V antennas at trucks. A popular and significant place for mounting and integration of V2V antennas in trucks are the main mirrors. Due to their function the mirrors are attached to the front of the driver's cabin and projects beyond the edge of the vehicle as well towing as towed. Figure 7 shows the antenna diagram for a omnidirectional antenna mounted in the main mirrors, one antenna per mirror.

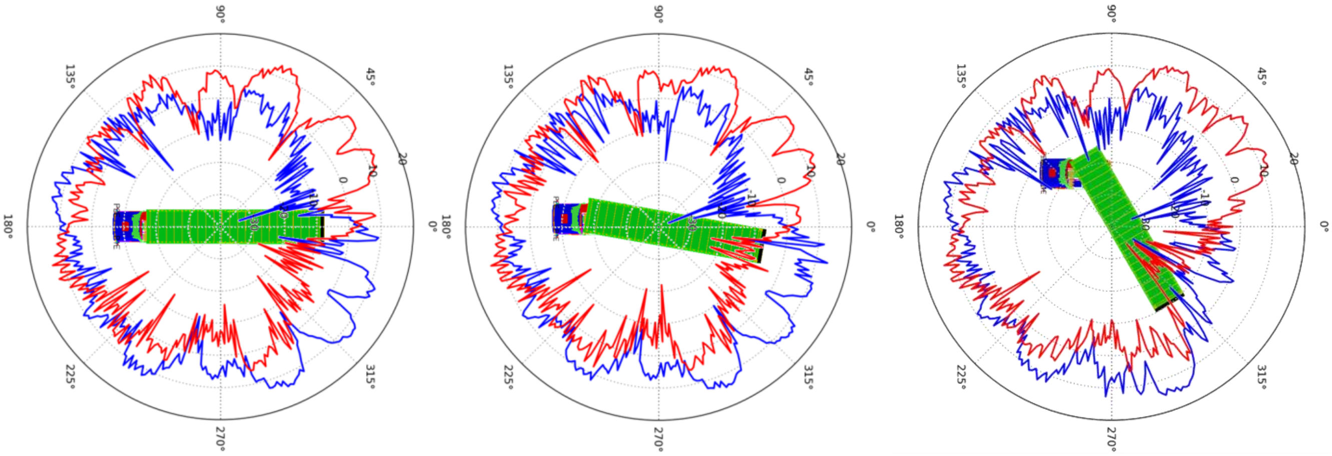


Side view Front view Top view

Figure 7: antenna diagrams for main mirror mounted omnidirectional antennas at long haul vehicle combination

Based on these first simulations with simple antennas (radiators) the mirrors seem to be more suitable places for antennas than the roof.

Regarding the different angle of articulation mentioned in chapter 1 the resulting antenna pattern are shown in Figure 8.



0° 10° 60°

Figure 8: resulting antenna pattern for different angle of articulation

ROADART will extend these first impressions at a single truck by doing more detailed simulations with more complex antennas which consider as well the mirror as the truck itself as mounting environment, support diversity and do research work on complex antenna techniques in typical truck relevant Use Cases.

In chapter 4.2 the requirements are mentioned.

3.3 Antenna and radiator assigned architecture at trucks

The possible placing of antennas in mirrors results in some further issues. For the connections with currently available communication stacks with diversity techniques coax cable is used. Due to the distance and the typical cable routes the length of the coax cable results in 2 to 4 meter. There are some serious reasons to avoid such long coax cable: Due to the high frequency of WLAN 802.11p the shielding of the cable has to be very good

Unfortunately this results in expensive and inflexible cables. Despite the shielding a cable loss of around 1 dB per meter is currently standard.

The inflexibility of a shielded coax-cable results in a time-consuming cable laying. Additionally there are currently two kink areas which have to be overcame (mirror base to door and door to drive’s cab). These kink areas results in additional mechanical stress of the cable and increase the cable loss with passing of time.[2]

Figure 9 shows the current cable route from left main mirror to the inner of the driver’s cab where the two cables from the two antennas could be connected to one communication hardware (radio). The addition results in approx. 4 m cable length with the two kink areas.[3] With this cable length a cable loss of 4 dB has to be counterbalanced.

The resulting architecture is shown in Figure 10, two RF-modules are integrated in a communication unit. The antennas (radiators) are connected via coax-cable.

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[2] Due to the effort to replace the mirrors through camera monitor systems to reduce the air resistance kink areas could be avoid in future.

[3] By replacing the mirrors through camera monitor systems there will be a cable length of at least 1.5 to 2 m without kink areas, if the cameras are driver’s cab mounted.

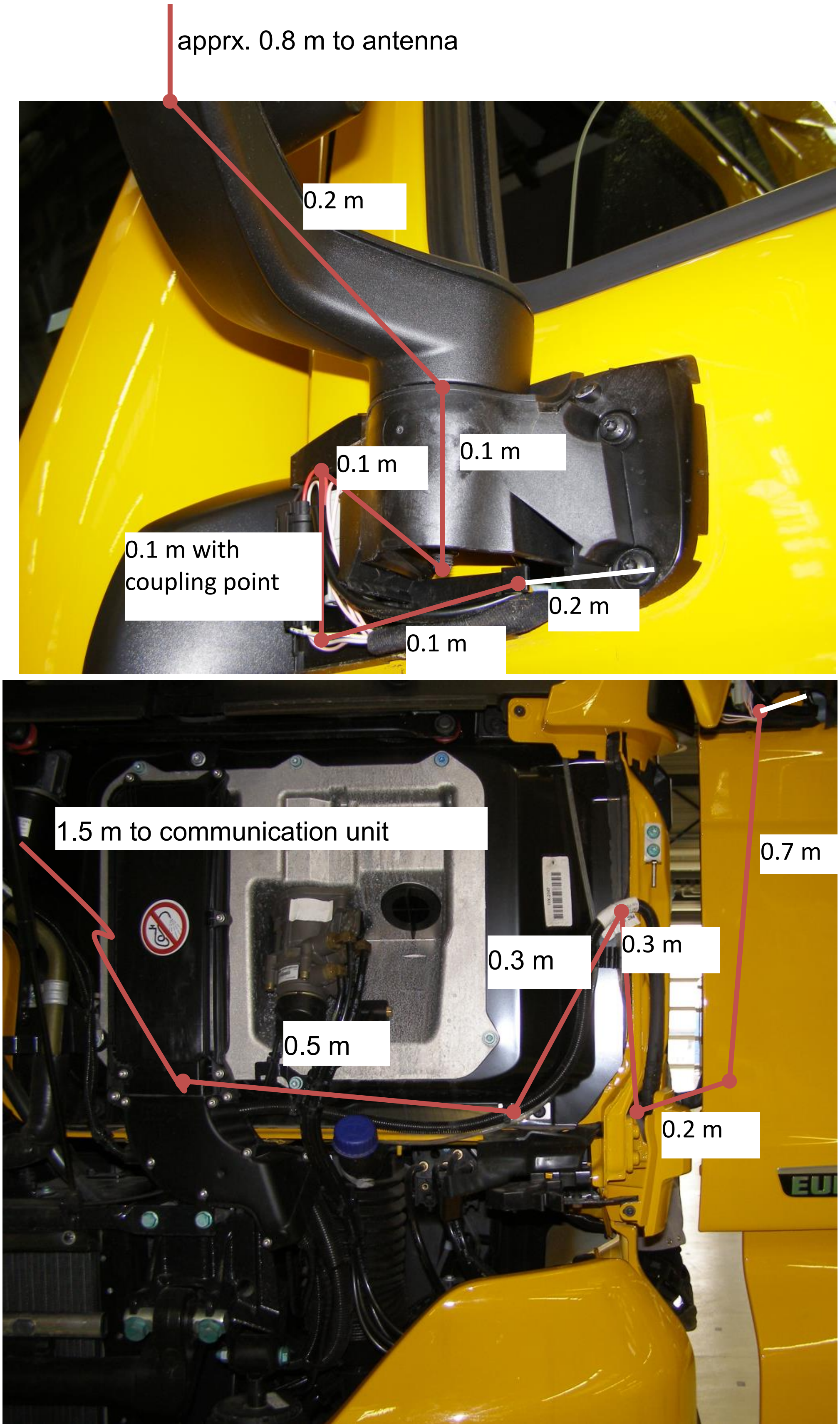

Figure 9: Current cable route from mirror to inner driver's cab at MAN TGX XXL

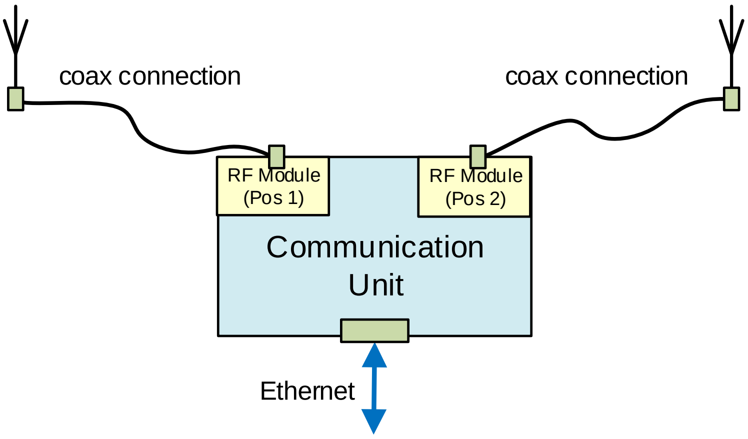

Figure 10: centralized RF modules with coax cable connection of two antennas

In ROADART long coax-cable connections should be avoid through a very early digitalization through the RF-modules. If to each antenna a RF module is connected there must be afterwards an algorithm to merge the digitalized information from each RF-modul of the two mirrors for compliance with regulations regarding V2V-communication.

So the in ROADART to be developed architecture should look like Figure 11. The number of radiators is to be defined within the project. The digital connection should be extendable up to 10 m for the usage in city buses or coaches.

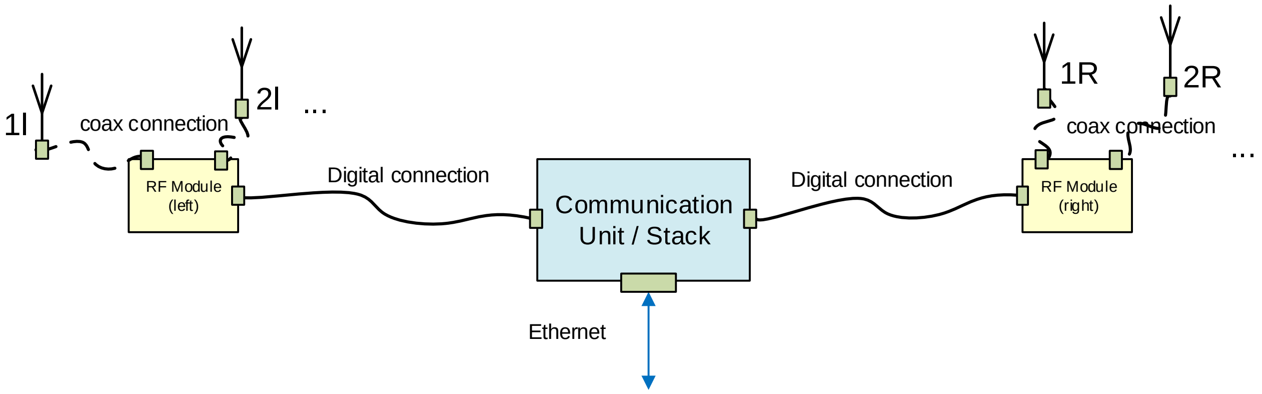

Figure 11: decentralized RF modules with radiators and coax connection to central Communication Unit / Stack

As mentioned in the precedent section, various significant effect on performance of the multi-antenna T2T/T2I communication system and should be investigated. Such issues are:

i. The antenna positioning on the truck
ii. The inter-element distance in multi-antenna modules
iii. The existence of conductive parts and materials in the near field region of the antenna

Therefore, the main goal is to collect results from the investigated transmission techniques and determine an optimal but realistic antenna positioning subjected to specific constraints imposed by the vehicle. Furthermore, optimized diversity techniques and cooperative architectures based on the selected antenna configurations will be developed for efficient and reliable T2T and T2I communications. A main objective of WP3 is to deal with the aforementioned issues taking into account the constraints and requirements described in this document.

Concerning the antenna modules, alternative configurations of switched parasitic arrays (SPAs) and electronically steerable passive array radiators (ESPARs) will be designed taking into account the effects imposed by the truck-trailer bundle. Specific performance measures will be investigated and evaluated. The design parameters include the number of active and parasitic elements, alternative element arrangement and element shapes, implementations with patches or dipoles, alternative control circuit elements, etc. Hardware technologies that will be investigated for the control circuit of the developed antenna configurations are p-i-n diodes or varactors. Implementation using Micro-Electro-Mechanical System (MEMS) may be investigated, since they provide fast switching times, and are widely available as surface-mount components. The investigated solutions will aim at faster switching time, preserve low RF loss, low power consumption and good linearity.

In chapter 4.3 the requirements are mentioned.

4 Requirements for T2T/T2I-communication at heavy duty vehicles

4.1 In general

- For the project the standards according to ETSI ITS G5 plugtest 4 should be used. If there are any requirements (e.g. regarding CACC) which result in deviation of these standards, it will be mentioned during the specification phase. These deviations could be used for future standardization regarding ITS G5 or special applications
- Security features will be not implemented.
- The coexistence between ETSI ITS G5[4] and HDR DSRC 5.8 GHz[5] is explicitly not part of ROADART.
- A very important aspect when mounting antennas near the driver is the induced electrical field strength inside the drivers cabin. Therefore these levels especially in the transmit case should be at least investigated using appropriate manlike phantoms for EM-Simulations. The yielded results can be afterwards analyzed to show weather these fields could be hazardous for the driver.
- The system shall comply to the ETSI ITS G5 specification and the Basic System Profile of the C2C Communication Consortium, except for the requirements caused by the demonstration subject of the project (C-ACC). This may lead to increased packet rates or other modifications of the Basic System Profile requirements. The documents to be considered are in detail:
    - Mandatory:
        - Facility layer (TS 103 301, TS 102 894-1, TS 102 890-3)
        - CAM (EN 302 637-2)
        - DENM (EN 302 637-3)
        - LDM (EN 302 895)
        - Common Data Directory (TS 102 894-2)
        - BTP (EN 302 636-5-1)
        - Geo networking (EN 302 636-4-1)
        - DCC (DCC Whitepaper Day 1, TS 102 687, TS 102 724, TS 103 175)
        - Access Layer (EN 302 663)
        - Channel Usage (TS 102 724)
        - 802.2 LLC / 802.11p MAC

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[4] According to EN 302571

[5] According to EN 12253

    - 802.11p PHY
    - R&TTE Directive (EN 302 571 > 1.2.x). This specification is reworked at the moment, the upcoming release will be taken into account
  - Optional:
    - IPV6 over Geonetworking (EN 302 636-6-1)
    - C-ACC (TR 103 299)
    - Platooning (TR 103 298)
- The ROADART Demonstration System shall use the 5.9 GHz Frequency band. 63 GHz may be considered during WP2 and WP3 for the channel models and the simulation environment
- The communication will take place using the "Control Channel" of the ITS G5 band (TS 102 724).

4.2 Antenna Subsystem

Single truck:

- Number of radiators as small as possible
- Positive antenna gain
- Diversity techniques for each mirror side
- No effacements due to using of more than one radiator
- For mounting of antennas in mirrors protection from splash water
- Positive antenna gain
- Suitable design for truck integration
- Antenna pattern
  - According to current standardization
  - By using beamforming there should be a possibility to influence the resulting antenna pattern from extern, like function, application etc.

In addition for multiple truck convoy:

- Communication between trucks has to operate in the different Use Cases mentioned above
- Communication has to operate in the different environments mentioned above

4.3 Architecture / Truck Integration

- Connection with coax cable as short as possible
- For all components not located in driver’s cab protection from splash water
- Length of digital connection of RF-modules with communication unit should be extendable up to 10 m (for use in city buses and coaches)

- Antenna subsystem and architecture should work according the current standardization of V2X via WLAN 802.11p

4.4 V2X-stack for CACC

The V2V-Cooperative Awareness Message (CAM) content is based on ETSI standards and has been slightly modified to enable CACC functionality for research development purposes. The CAM message content is shown in the following Table 1.

	RX table	**Signal**	**Accuracy**	**Resolution**	**Range**	**Remarks**
3. V2V (CAM)	(n-1)*37+15	Message ID	1	1	0: CAM1: DENM2: Service enhancements3: Geo networking	
	(n-1)*37+16	Generation time of the message, seconds	0.5 s	1 s	[0,2^32-1] s	Based on GPS time stamp, if not equal. Only whole seconds, floored.
	(n-1)*37+17	Generation time of the message, milliseconds	0.5 ms	1 ms	[0,999] ms	Milliseconds since last seconds update
	(n-1)*37+18	Station ID	–	1	[0,2^32-1]	Station = object vehicle
	(n-1)*37+19	Station characteristics: mobile	–	–	0: RSU 1: vehicle	
	(n-1)*37+20	Station characteristics: private	–	–	Private {0,1}	Private = not public
	(n-1)*37+21	Station characteristics: physical	–	–	Physically relevant {0,1}	
	(n-1)*37+22	Vehicle type	–	1	0: invisible [1,255]: visible	
	(n-1)*37+23	Vehicle length	≤ 0.1 m	0.01 m	[0,40.95] m	
	(n-1)*37+24	Vehicle rear axle location w.r.t. geometrical center	≤ 0.1 m	0.01 m	[0,40.95] m	Location w.r.t. geometrical center; non-CAM
	(n-1)*37+25	Vehicle width	≤ 0.1 m	0.01 m	[0,10.23] m	
	(n-1)*37+26	Controller type	–	1	0: Manual 1: CC 2: ACC 3: CACC	
	(n-1)*37+27	Vehicle response time constant	≤ 0.01 s	0.01 s	[0,10] s	Non-CAM
	(n-1)*37+28	Vehicle response time delay	≤ 0.01 s	0.01 s	[0,10] s	Non-CAM
	(n-1)*37+29	Vehicle rear-axle position, easting	≤ 1 m	≤ 0.1 m	[0,1e6] m	UTM or ENU, rear axle center 0: never had a fix
	(n-1)*37+30	Vehicle rear-axle position, northing	≤ 1 m	≤ 0.1 m	[0,20e6] m	UTM or ENU, rear axle center 0: never had a fix
	(n-1)*37+31	Position conf. interval 95%	–	≤ 0.1 m	[0,20e6] m	
	(n-1)*37+32	Vehicle heading	≤ 0.02 rad	≤ 0.002 rad	$[-\pi,\pi]$ rad	UTM or ENU (clockwise positive w.r.t. northing), rear axle center 0: never had a fix
	(n-1)*37+33	Heading conf. interval 95%	–	≤ 0.002 rad	$[-\pi,\pi]$ rad	
	(n-1)*37+34	Longitudinal vehicle velocity	≤ 0.1 m/s	0.01 m/s	[0,327.65] m/s	Rear axle center
	(n-1)*37+35	Velocity conf. interval 95%	–	0.01 m/s	[0,327.65] m/s	
	(n-1)*37+36	Vehicle yaw rate	≤ 0.02 rad/s	0.0002 rad/s	[-5.7,5.7] rad/s	
	(n-1)*37+37	Yaw rate conf. interval 95%	–	0.0002 rad/s	[0,5.7] rad/s	
	(n-1)*37+38	Longitudinal vehicle acceleration	≤ 0.2 m/s2	0.01 m/s^2	[-10,10] m/s^2	Rear axle center; non-slip condition
	(n-1)*37+39	Longitudinal acceleration conf. interval 95%	–	0.01 m/s^2	[0,10] m/s^2	
	(n-1)*37+40	Desired longitudinal vehicle acceleration	–	0.01 m/s^2	[-10,10] m/s^2	Non-CAM
	(n-1)*37+41	MIO ID (as measured by object vehicle)	–	1	[0,2^32-1]	Non-CAM. 0: no ID
	(n-1)*37+42	MIO range (as measured by object vehicle)	≤ 0.1 m	0.01 m	[0,655.35] m	Non-CAM

	(n-1)*37+43	MIO bearing (as measured by object vehicle)	≤ 0.02 rad	≤ 0.002 rad	[-π,π] rad	Non-CAM
	(n-1)*37+44	MIO range rate (as measured by object vehicle)	≤ 0.1 m/s	0.01 m/s	[-327.65,327.65] m/s	Non-CAM
	(n-1)*37+45	Time headway	–	0.1 s	[0,3.6] s	Non-CAM
	(n-1)*37+46	Cruise speed	–	0.01 m/s	[0,50] m/s	Non-CAM
	(n-1)*37+47	RSU emulation	–	1	0: V2X 1: I2X	Non-CAM
	(n-1)*37+48	Minimum safety time headway	–	0.1 s	[0,10]	
	(n-1)*37+49	Desired time headway	–	0.1 s	[0,10]	
	(n-1)*37+50	Merge request flag	–	1	0: default 1: merge requested	Non-CAM
	(n-1)*37+51	Object-updated flag	–	1	0: not updated 1: updated	
	The data of max. n=10 objects is received. The data of each object is a structure containing the above 37 specified signals. The maximum number of objects is received on each sample (even if one or more buffers are empty). Consequently, there are 10*37 = 370 signals in total.					

Table 1: Information to be transferred for CACC

4.5 Measurement campaign

The measurement campaign strongly depends on the choosen antenna concept and following architecture. So the definition and requirements for the measurement campaign will be done at Deliverable 7.1.

5 Requirements for localization with advice of T2I and T2T-communication

5.1 Localization Requirements

T2T-enabled platooning in tunnels includes the additional challenge that GNSS is not available and localization has to be realized using alternative techniques preserving the accuracy to an acceptable predefined level. In addition to the available GNSS signals, a set of available vehicle data (e.g. motion, acceleration, gyroscope, proximity) will be used. Information from the specific sensors can be also combined with last known/reliable and accurate GNSS positioning information. Based on these information data, localization algorithms will be investigated and evaluated in Work Package 5 taking into account the accuracy requirements of the project. Furthermore, wireless-communication-based localization algorithms will also be investigated and evaluated offering not only an alternative to the above algorithms, but also an added value to the localization reliability and accuracy during the motion in the tunnels.

The required localization accuracy is determined by the safety distances and the time needed for the system-vehicle to respond in various emergency situations. We can discriminate the possible cases in two main categories. The first case is characterized as the classical one where no platooning architectures or functions are active. In this case, the safety distances are determined by the rule that the cars have to keep a safety distance of at least 2 seconds. This requirement corresponds to a distance of ~44m for a speed of 80Km/h. For the case of trucks, the safety distances, as long as the vehicles are on the same line, have to be taken well above these values.

In the second case, platooning operation/functions are active. In this situation and for the efficient operation of the whole concept, in terms of energy consumption minimization, the trucks will drive with a gap of merely 0.5 seconds or ~11 meters. It has to be noted that there is a limit on how close it as actually worth to cruise which is experimentally determined about ~6 meters. Hence, for advantageous platooning a distance of about 6-10 meters should be considered as a target.

In addition, platooning will allow optimized use of the available road capacity. Considering a normal situation with 2 trucks driving 80 km/h with a 2 seconds gap. With a truck length of 18.75m this results in a claim of 82m road, excluding the gaps in front of the first truck and behind the following truck. Using platooning, a 0.3 second gap (6.67m) would decrease the length of those two trucks with 46% to 44m.

Typical performance of standalone GNSS localization systems offer an accuracy of ~20m (±10m) which is sufficient for the cases where digital map data are used for enhancing the related positioning accuracy (~5-10m). Required localization accuracies depend on the exact application. Specific values are given in Table 1. This level of accuracy is not acceptable for direct use in the framework of platooning. One possible solution to mitigate the weaknesses of standalone-GPS localization (except Differential GPS – DGPS option) is the combination with other independent sensor information. Especially, in the automotive domain, additional sensor measurements from the in-vehicle ESP and ABS sensors (e.g. velocity and acceleration) are available through the CAN bus (e.g. autobox). It is noted that the combination of GPS observations and odometry measurements represents the GPS/INS integration. Although the GPS/INS integration is useful to stabilize the positioning solution, it cannot be used to further improve the absolute accuracy to lane-level. Hence, additive techniques and algorithms that utilize also the use of RF signals and the data availability from on board sensors have to be implemented in order to achieve the required accuracy for the platooning operation.

Table 2. Required localization accuracy for various applications

Application	Required Localization Accuracy		
	Low (10-20m)	Medium (1-5m)	High (< 1m)
Data Dissemination	√		
Map Localization	√		
Cooperative Adaptive Cruise Control (CACC)		√	
Cooperative Intersection Safety (CIS)		√	
Blind Spots (BS)		√	
Platooning		√	
Vehicle Collision Warning System (CWS)			√
Vision Enhancement			√
Automatic Parking			√

In order to put the localization technologies and algorithms in practical/comparative context the following performance criteria can be used.

- Accuracy: Accuracy of a vehicle location estimate is defined as the degree of closeness of a vehicle’s location estimate to its actual (true) location.
- Availability: Availability of a vehicle location estimate is defined as the ratio of the number of estimates produced to the number of estimates expected per one unit of time.
- Response Time: Response time is the time required by a localization technique to produce a location estimate.
- Integrity: Integrity is defined as the level of confidence that can be placed in the correctness of the location estimate.

5.2 Required Sensors Reading from Trucks for Localization

The sensors on a vehicle can be divided into 2 groups. In the 1st group, the sensors detect the distance between trucks and other vehicles. In the 2nd one the sensors communicate with the brakes and engine, monitoring and controlling velocity, acceleration and brakes.

In the framework of ROADART project and especially in platooning operation, the localization techniques is expected to be assisted by the additive information coming from on board sensors that are able to calculate/estimate:

- Direction
- Speed
- Acceleration (in X axis and Y axis)
- Proximity sensors (front and rear)

System/Sensor readings that can be taken into account in localization techniques/algorithms, in the framework of platooning, are coming from:

- ESP [direction, speed, acceleration]
- ABS [speed]

- Odometer / Tachometer (wheel speed encoder) [speed]
- Digital compass [direction of motion]
- Gyroscope [Steering angle]
- radar (RF, Laser, ultrasonic) [proximity sensor][distance from other vehicles]
- Electronic braking system in trucks
  - Velocity, acceleration, brakes (as measured at the pedals)
  - Radar-based active braking system

5.3 Requirements for Efficient Localization in Harsh Environments

In ROADART, the objective is to develop a hybrid, novel positioning algorithm that will be able to benefit from multiple sources of information in order to estimate the position with proper data fusion. Furthermore, cooperative strategies (cooperative estimation) will be developed in order to improve the positioning results for a set of vehicles (e.g. a truck platoon). In this framework, T2T communication platform will be potentially used for exchange of sensor data enhancing accuracy, reliability and robustness of the localization functions in a cooperative fashion.

In order to achieve the ROADART objectives regarding the positioning algorithm, the following approaches will be used:

- **Radio localization**: The algorithm will use estimates of properties of radio signals in order to extract the position of the vehicle. These signal properties are:
  - Received Signal Strength
  - ToA / TDoA
  - If possible, the algorithm will benefit from the use of an estimate of AoA.

It is noted that in order to take advantage of ToA information, the radio signal bandwidth should definitively exceed 50 MHz (i.e. maximum 6 meters of accuracy with the use of a ToA method solely).

- **Radio Mapping**: The use of radio signals for localization can be drastically improved with the knowledge of the statistical behaviour of radio signals in specific reference points placed properly in the location of interest. Moreover, known signals can be used, transmitted from known locations as beacons to facilitate the estimation procedure.
- **Odometry quantities**: The algorithm will use adaptively odometry information that can be measured by on-vehicle sensors. These quantities are: Speed, Acceleration, and Orientation.
- **Cooperative techniques**: Estimation accuracy in a given set of vehicles can be furtherly improved with:
  - The use of GPS measurements from the subset of vehicles that is under GPS coverage at a given instance.
  - The use of distance measurements between adjacent vehicles of a given set. The distance measurements can be extracted from on-vehicle radar sensors and/or proper image processing (from an on-board camera).
  - The exchange of the aforementioned information via proper radio channels between the vehicles of the set.

The ROADART hybrid solution under investigation aims in the development of a novel non-linear, dynamic system (a Kalman-type filter similar to Extended and/or Fingerprint Kalman filters) that uses simultaneously:

  - RSSI, ToA radio measurements from available radio signals and radio beacons with bandwidth > 50 MHz.
  - Odometry measurements from on-board sensors.
  - Distance measurements from on-board radars/cameras.

  - GPS measurements from vehicles and/or reference points that remain under GPS coverage cooperatively.

Thus, the ROADART positioning platform requires:

- Radio signal measurement unit (e.g. measurement of an interpolated ITS radio signal from the on-board radio transceiver).
- Access to on-board sensors for odometry information.
- Use of GPS information where/when available.
- Access to measurements from on-board radar units or relevant systems.