Rijkswaterstaat
Ministerie van Infrastructuur en Milieu

RSU Placement Guidelines

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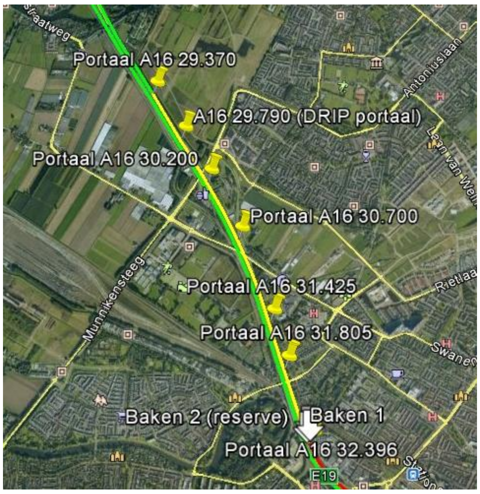

Cooperative ITS Corridor
Joint deployment

Colofon

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Inhoud

1 Introduction

1.1 Purpose of this Document

The purpose of this document is to provide guidelines to determine the position of cooperative roadside ITS stations (Roadside Unit, RSU). These are stations equipped with ITS-G5 technology to enable wireless exchange of information with ITS-G5 enabled vehicles.
Based on a functional use case perspective and specifications of RSUs, this document provides insights and guidelines on where an RSU should be placed. As a result, with the help of this document, it can be determined where to deploy C-ITS roadside stations.

1.2 Approach

The content of this document is based on literature review (see sections 6.1 and 6.2) and interviews (see section 6.3 for a list of the respondents). Interviews were held with experts from roadside unit manufacturers and suppliers, knowledge centres and Rijkswaterstaat.

To a large extent, the guideline and requirements formulated in this document are of a functional nature. They do not prescribe the exact position and specifications of the RSU, but remain on the level of dissemination areas, i.e. areas of the road network where messages can be received by the potentially targeted vehicles. The main reasons for not being more precise, are the situation and equipment variables at play as described in chapter 3. Within the boundaries defined by this guideline, it is up to, for example, the contractor to choose the most suitable solution, related equipment type (e.g. antenna type(s)) and exact positions.
The aim of this first version of a placement guideline for RSU is to initiate a discussion on the subject with a larger community. For that reason, it will be submitted to the Dutch round table on Architecture and Interoperability. Based on the outcome of such discussions the document will be adapted and completed iteratively. Similarly, the lessons learned from on-going and upcoming pilot projects will be incorporated.

1.3 Assumptions

This document was prepared with the following assumptions and limitations in mind:

- While this document provides guidelines on RSU placement, it can never be guaranteed a message is received by either the OBU or RSU. This is because of the different types of RSUs and OBUs (i.e. the hardware used and the placement of antennas) and many external factors that have an impact on communication (see par. 3.2).
- For now, the purpose of this document is to provide placement guidelines for day 1 applications. Thus, it focusses on an optimal service level given a limited number of RSUs (and OBUs). Also, it is therefore accepted C-ITS equipped vehicles might miss messages due to limited coverage (temporal and spatial).
- For day 1 deployment, without 100% coverage, it is unavoidable that events may be missed by some vehicles and/or that some vehicles will arrive at an event position without or with outdated information. This also means that the information provided by roadside signals may differ from information available in the vehicle.

- The guideline is intended for the road network of Rijkswaterstaat: the highway network. The guideline is currently not harmonized with other parties (other road authorities, OEMs, suppliers, etc.).
- Rules, statements, and advice should be interpreted as guidelines and not requirements, unless it is explicitly stated that they are requirements. Specific situations are always possible in which recommendations do not hold and a different approach is advisable.
- Message forwarding is not taken into account. Message forwarding means that ITS stations can repeat and thus forward a message down- or upstream, also known as multi-hop. Within the C-ITS community there is a lively debate whether multi-hop offers an advantage or is a burden to the channel capacity.
- Vehicle ITS stations (Onboard Units, OBUs) can temporarily store incoming messages and data. Messages may be received some distance upstream of an event position, while the information can be shown to the driver at a later point. It is not assumed that, for the extended PVD use case, probe vehicle data can be stored until the vehicle comes in range of an RSU and then transmits the PVD packet.
- All vehicles must be able to pass a relevant dissemination area to receive event data (see paragraph "Service quality" in chapter 2).
- For day 1, the likelihood of false negatives must be favoured over false positives (see paragraph "Service quality" in chapter 2).

1.4 'Connected'

As of writing, there is much discussion regarding a second medium of communication via cellular technology (i.e. 3G/4G and 5G). While a 'hybrid' solution using both ITS-G5 and cellular technology is currently being explored, it is not considered in this document. It is clear however, that such a solution would potentially have a significant impact on the placement guidelines.

1.5 Document Structure

The next chapter derives requirements on RSU placement from the functional perspective of use cases. Thereafter, chapter 2.4 provides information on specifications of RSUs and external factors which affect the performance of RSUs. Chapter 4 provides recommendations. Finally, chapter 5 provides an overview of references, sources, respondents, definitions and abbreviations.

2 Functional perspective

The RSU placement guideline must facilitate day 1 deployment of Road Works Warning (RWW), Probe Vehicle Data (PVD), In-Vehicle Signage (IVS) and Collision Risk Warning (CRW). A description of these use cases is given in [1]. While RWW, IVS and CRW[1] are all I2V based use cases, PVD is V2I centred, but all services are based on message broadcast which means unidirectional communication. Although I2V and V2I use cases may pose different requirements on RSU placement, it is for the time being assumed, and until the requirements of PVD are better understood, that the RSU placement resulting from the first three use cases will also serve the purpose of PVD.
RWW, IVS and CRW are all targeted to event positions, being a road work, a road sign or a hazardous location. In the dictionary of in-vehicle information (IVI) data structure [2] these are referred to as 'relevance zone' which is preceded by a driver awareness zone and a detection zone. The former describes parts of road network on which a message is presented to inform drivers about upcoming situations, whereas the latter describes a part of the road network that is passed by a vehicle in approach of the relevance zone. Together these zones must ensure a timely detection of the event and timely informing of the driver. As a general rule, the more safety-centred a use case is, the higher the requirements on timeliness and reliability are. Current road signalling guidelines [3] indicate that drivers must first be informed about events such as road works 1000-500 meters upstream of the event position.

- ➔ **Req.1a: The position of the RSU shall be such that reception of messages is most likely at least 500 meters upstream of the event position.**

In addition to the road signalling guidelines, human machine interface guidelines [4] indicate that in-vehicle signalling should start at 2000-1400 meters before the event position.

- ➔ **Req.1b: Given requirement 1a, a distance of 2000-1400 meters is preferred over the minimum of 500 meters.**

It is important to note that these distances are general recommendations for minimum radio coverage in relation to an event position. From the perspective of the profile of certain use cases (e.g. RWW) a more elaborate coverage could be desired. For example, for the RWW use case traces of up to 1.5 km are recommended. The minimum distance of 500 meters is insufficient to fully utilize those traces. Similarly, to be able to send updates about the road works, a more elaborate coverage of the road works area is needed.
Thus, the profiles give the full desired specification, but practical implementation is dictated by the physical C-ITS infrastructure. The distances mentioned in Req. 1 are therefore the distances that enable most use cases, be it with a minimum service level.

[1] Note that CRW as described in the Dutch C-ITS Corridor project [1] means that a vehicle from the road authority sends a message to the C-ITS-S which then disseminates the message (warning) via R-ITS-Ss. This is different from the more common alternative interpretation of the CRW use case as a V2V service.

2.1 Long-term scenario

On the long-term it is expected that vehicles will continuously interact with other vehicles and infrastructure. In this scenario, the density of RSUs along highways is sufficient to support continuous coverage of the radio signal, i.e. continuous connectivity, with sufficient signal strength and packet delivery ratio (see chapter 4). RSUs can interact with all vehicles and send information updates whenever required. For day 1 deployment full coverage is not realistic and the number of RSUs will be limited to a subset of these. This subset is a set of locations which ensures the highest attainable service quality at the least investment cost.

2.2 Service quality

A smaller number of RSUs along highways inevitably affects the service quality in term of availability and reliability of in-car information. RWW, IVS and CRW all aim to inform drivers about event positions, being a road work location, a road sign location or a hazardous location. For safety, liability and regulatory reasons, all C-ITS equipped vehicles that will pass an event position must be able to obtain associated message(s) timely. In the dictionary of in-vehicle information (IVI) data structure [2], a *dissemination area* is defined as part of the road network where messages can be received by the potentially targeted vehicles. To ensure such minimum *availability* of information about event positions and since it is not known where, over time, event positions will be located, such a dissemination area must at least be located at each entrance of the highway, i.e. at all on-ramps and junctions.

- ➔ **Req.2: a dissemination area must be located at least at each highway on-ramp and junction.**

It is important to note that passing a dissemination area does not guarantee that all vehicles will receive the necessary messages. Communication failure for reasons like malfunction, packet loss or occlusion may prevent message reception.
In addition, having dissemination areas only at on-ramps and junctions for day 1 implies that two consecutive dissemination areas may be multiple kilometres apart. As a consequence, and due to the nature of some use cases, the validity of the information that is available in the vehicle may expire and therefore not reflect reality. This may lead to one of three situations: false positives, false negatives or incorrect information. In case of a <u>*false positive*</u> the driver is warned about an event which is not there, whereas in case of a <u>*false negative*</u> the driver is not warned about an event which in fact is present. Incorrect information may concern, for example, the wrong (dynamic) legal speed limit.
For day 1, there are only a few situations in which C-ITS messages are broadcasted. Most of the time, no messages are received / displayed by C-ITS equipped vehicles (i.e. not getting a message could be seen as the default situation). Therefore, for day 1, false negatives are favoured over false positives. In the long term when C-ITS messages are more common, when making a trade-off, false positives arguably are less harmful and therefore to be favoured over false negatives, especially when considering the risk of accidents.

2.3 Dissemination areas

As stated earlier, all vehicles must pass a relevant dissemination area to receive event data. Consequently, a dissemination area must, *at least*, be located at each highway on-ramp and junction. In addition, when on-ramps are far apart, the service quality can be improved by placing additional RSUs. A suitable interval can be derived from common practice in roadside signalling or human machine interface guidelines [3, 4]. As mentioned earlier, events requiring action from the driver should preferably be announced 2000-1400 meters upstream of the event position.

Considering that OBUs can store relevant information for a short period, three times this distance seems acceptable for C-ITS equipped vehicles. The factor *three* is currently a best guess and should be tested and evaluated in upcoming projects. One approach to determine the factor is to look at the *validityDuration* of certain C-ITS messages (i.e. the duration the message is valid). For example, the maximum distance should be such that the duration a message is valid is equal to or longer than the time a vehicle needs to cover that distance during congestion.
Currently, the *validityDuration* for RWW (DENM) messages is profiled at 720 seconds (i.e. 12 minutes). That duration, when combined with a congested speed of 30 km/h, results in a distance of 6 kilometres. Given the announcement distance of 2000-1400 meters, that results in the previously mentioned factor of *three* (6 km / 2000 meters). In free flow conditions (120 km/h) this would imply that a vehicle passes a dissemination area at least every 3 minutes.

➔ **Req.3: a dissemination area must be present at least every 6 kilometres.**

2.4 Planned and unplanned events

From this perspective, it is useful to distinguish between planned and unplanned events. Planned events are associated with information and awareness use cases like road works, whereas unplanned events are associated with warning and active-safety use cases like temporary hazardous locations. Consequently, unplanned events have a much shorter time-to-collision (i.e. the time between signalling and the arrival at the event position) than planned events.

In case of planned events, a portable RSU could be placed near the event position (i.e. the start of work zone) to ensure that vehicles also receive the latest information in case the information changed since passing the previous RSU.

However, in case of unplanned events, when the presence of a third party (e.g. road authority, emergency services, contractors, etc.) is not required, a temporary portable RSU is impractical and probably uneconomical. C-ITS use cases based on such events (e.g. slow vehicle indication, black ice, etc.) are foreseen only after day 1 and will probably rely on V2V services.

For day 1, portable RSUs should always be considered, whereas in the long term, portable RSUs shall only be considered for unplanned events in case the presence of the road authority, contractor, emergency vehicles or other special vehicles is required (i.e. unplanned road works (repair), major accidents, certain diversions, etc.).

➔ **Req.4: the use of portable RSUs shall be considered in the case of planned events and for unplanned events as well, when the presence of the road authority, contractor, emergency vehicles or other special vehicles is required.**

3 RSU perspective

This chapter describes specifications of RSUs and factors affecting the performance of RSUs. Both can be used to evaluate the appropriateness of the exact location of an RSU.

3.1 Transmission range

There are different perspectives to the transmission range of RSUs. These are discussed in this section.

3.1.1 Sending range

Many surrounding factors affect the transmission range of an RSU. Consequently, none of the suppliers guarantees a default transmission range. In addition, the transmission range depends on the type and number of antennas that are used. The two types of antennas that are most common are directional antennas and omnidirectional antennas. The former has a larger transmission range (along a single axis) but a weaker signal near the antenna, whereas the latter has a uniform signal strength in all directions (along two axes) but a smaller – though generally sufficient – transmission range.
One option is to use three antennas for a single channel: one set of directional antennas for each direction of travel (two in total) and one omnidirectional antenna to compensate for the weaker signal near the RSU. Note however, that while an omnidirectional antenna has a better signal close to the antenna in comparison to a directional antenna, it can still be problematic. Slightly tilting the antenna towards the road can improve the signal close to the antenna.
Indications of the average transmission range vary from 500 meters for omnidirectional antennas, up to 2 kilometres for directional antennas. Factors affecting the transmission range are listed in section 3.2.

3.1.2 Reception range

Tests revealed that the V2I and I2V transmission range is asymmetric, i.e. the transmission range of RSUs was on average larger than the transmission range of OBUs. This implies that the transmission range is a product of both the OBU as sender and the RSU as receiver, and different for the reversed case. As a result, requirements for RSU placement might be different for I2V and V2I based use cases. Figures 1 and 2 schematically shows the difference in transmission ranges for an OBU and an RSU. The outer circles represent the default transmission ranges, i.e. under normal surrounding conditions. The inner striped circles represent the minimum transmission range resulting from surrounding factors like weather and obstruction and possible Decentralized Congestion Control (Transmit Power Control specifically) [5]. Depending on the needs of the deployed services, this knowledge can be used to decide to place RSUs closer or farther apart.

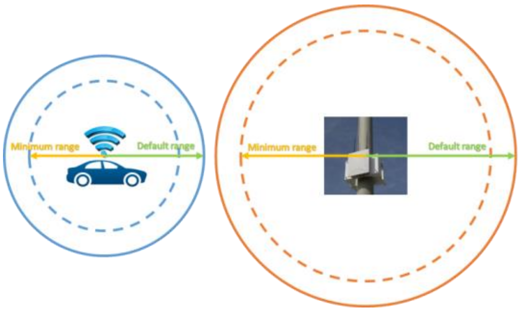

Figure 1: asymmetric transmission range OBU and RSU

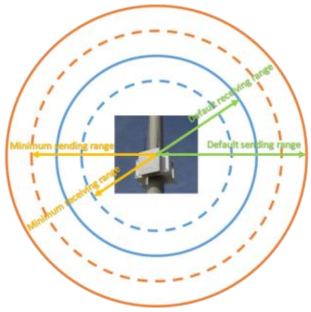

Figure 2: sender and receiver ranges for RSU

3.1.3 *Unidirectional reception*

Another finding from field tests is that some vehicles are unable to receive messages which are transmitted to them in the downstream direction. Due to placement of the antenna behind the windscreen of the vehicle the sight of the antenna is limited to the front of the vehicle, which prevents receiving messages coming from the rear (i.e. upstream). Moreover, during day 1 deployment and especially in the case of after-market OBUs it is likely that antennas will be placed behind the windscreen. Therefore, to increase the likelihood that vehicles are physically able to receive messages, the RSU placement should be such that the antenna beam is directed into the upstream direction, i.e. that messages are transmitted to the front of the vehicles.

- ➔ **Req.5: placement of RSUs must ensure that (part of) the signal can be received from the front of the vehicles[2].**

3.2 External factors

Within the spatial boundaries defined by dissemination areas and functional requirements of use cases (see chapter 2), it is up to contractors to determine the exact positions of RSUs in combination with the choice of antennas. Nevertheless, based on field tests there are several known external factors that may steer the decision which are listed below. These factors were obtained through literature review and interview with experts and suppliers.

3.2.1 *Surrounding factors*

- Viaducts: usually requires an RSU on both sides to ensure line of sight.
- Road incline: antennas should be directed parallel to the road surface and,
- Antennas should be slightly tilted towards the road to improve communication near/under the antenna.
- Weather conditions:
  - Humidity (e.g. rain, snow, fog) reduces performance. Due to the surface structure snow reduces performance more than rain and fog.
  - To a lesser extent, high temperature reduces performance, but low temperature can have a positive effect.

[2] This is an explicit choice that the road authority should make. Car manufacturers probably assume that they can communicate towards the rear of the car, while simple aftermarket solutions do not. Also R-ITS-Ss that send in one direction cannot see each other (A -> B, but not B -> A). That might disrupt some protocols: a unit listens if the channel is busy or not, if it is not, it waits a random amount of time and listens again. If it is not busy it sends. However, if one beacon cannot hear the other, it might overshadow it (i.e. not give an opportunity for the other to send).

- Traffic conditions: dense traffic or a single truck can weaken, divert or block the signal.
- Foliage: leaves and vegetation have a strong absorbing effect on the radio signal.
- Constructions: buildings and especially metal have an obstructing/disrupting effect.
- Surface: reflection or absorption is based on type of surface.

3.2.2 *Installation factors*

- Line of sight with vehicles is necessary to ensure connectivity.
- Installation on the inside of the road (usually left) is preferable because of extreme shadowing effects by trucks.
- A minimum height of the antenna should be respected to exceed the height of trucks. Also, a minimum height is recommended because of a physics point of view of the signal. At present there is not consensus what these heights should be.
-
- A fixed network connection is recommended, preferably with fibreglass. However, a wireless connection is also possible, but less preferable, since it results in a lower service level.
- All RSU's need some form of energy source. In practice nearby energy sources frequently determine the definitive position of road side equipment. The presence of existing power sources is therefore an important factor when considering RSU locations.
- Different setups and configurations for the control and service channel can exist in parallel (i.e. because of the different channel frequencies they do not interfere with each other).
- Distance between router and antenna should be considered as antenna cables cause 0.5 dBi loss per meter cable. When a strong signal is required, a distance less than 1 meter is recommended. One should, however, also consider maintenance cost (accessibility of the router). It could be more economical to invest in a more expensive high quality cable than a poorly accessible router.

3.2.3 *Technical factors*

- Type of antenna(s), e.g. omnidirectional or directional.
- If there are many antennas in the same area, they can disrupt each other's signal. Given that there are two solutions with a similar level of radio coverage, it is therefore preferable to opt for the one with the least number of antennas.
- Generally, a strong signal reaches further, but is also noisier. A weaker signal is clearer, but has a lesser reach. The control channel has a limit of 33 dBm [11]. The best signal strength depends on the hardware used and required signal quality (see par. 4.2).
- Packet delivery ratio (PDR) (i.e. % of arrived packets, 90% recommended). This is the net number of packages that are successfully received. At certain distances it is possible that not all bits are received (correctly) and a package is corrupt. In practice a PDR of 90% within the prescribed area, distance, etc. results in a reliable performance. Therefore, a PDR of 90% is recommended at the desired (maximum) distance.
- RSUs should not interfere and/or disrupt each other.
- Network channel capacity (see section 3.3.1).

- Public Key Infrastructure.

Note: the transmission range of an RSU is subject to many internal and external factors. To quantify the performance of an RSU one should examine the packet delivery ratio at different distances from the RSU. The packet delivery ratio is the product of interdependent factors like sender, receiver, signal strength, packet size, traffic density and surrounding factors.

3.3 RSU capacity

3.3.1 Channel Load

There is a maximum amount of information that can be transmitted via radio communication from a physics perspective. In other words, based on the used frequency and protocols, there is a limited capacity for ITS-G5. As a figure to determine how much of the capacity is used, one can look at the *channel load.* This channel load is dependent on a number of factors:

- The number of generated packets by both OBUs and RSUs (which is dependent on the number of vehicles within transmission range).
- The size of the packets.

Currently, there are two main mechanisms for counteracting high network channel loads.

- Decentralised Congestion Control (DCC) [5] acts based on an estimation of the number of neighbours using the Channel Busy Ratio (CBR). It has three strategies to counteract a busy channel:
  - Transmit Rate Control: restricts the number of generated packets in each and every vehicle as the CBR increases (output power and transfer rate are kept constant). For example, at a channel load <30% the transmit rate is 10 Hz, while at a channel load >60% the transmit rate is 2 Hz.
  - Transmit Power Control: reduces the output power as the CBR increases. This shortens the effective transmission range and thus fewer vehicles will receive the message.
  - Transmit Data Rate Control: uses a higher transfer rate for increasing CBR, keeping the channel less busy because the packets will be in the air shorter.

  For day 1 applications only Transmit Rate Control has been selected. In addition, a priority mechanism is adopted that does not restrict DENMs and applies DCC primarily to CAM. It is planned to revisit DCC for day 2 applications.
- The CAM generation frequency is managed by the CA basic service; it defines the time interval between two consecutive CAM generations [9]. The upper limit of the transmission interval is 10 Hz and the lower limit of the transmission interval is 1 Hz. CAM generation – and transmission – is subject to the changes in vehicle heading, position or speed, and channel usage requirement of DCC. The definition of the CAM rate is such that it allows each OBU to broadcast a reasonable minimum number of CAMs for Day 1 applications, more or less equal to other OBUs in the same area, and also in congested situations.

In the C-ITS platform report [7] it is stated that predictability of DCC must be further developed, especially because the CBR does not consider the number of vehicles within radio range. It suggests a kind of differentiation of V2I application

from I2V applications, the latter being based on infrastructural messages that are critical for safe operation of the vehicles. Consequently, different DCC mechanisms could apply for RSUs and for OBUs, but this is to be further explored with relevant stakeholders as discussions on this subject are ongoing.
While the DCC algorithm still must be further developed, it is clear that the transmit power might be reduced in the future. Thus, the radio coverage in effect becomes smaller. If that is a possibility it might be desirable to place multiple weaker RSU's in contrast to a few strong ones. An additional benefit of multiple RSU's is that the workload (e.g. security key validation) of the message handling is distributed among them.

4 Recommendations

4.1 Testing for compatibility

There are many standards from ETSI, ISO and CEN that provide requirements and/or restrictions to ensure interoperability on the level of ITS-G5 over-the-air communication. For the Dutch context, the "Dutch ITS Profile" [10] provides additional requirements and/or restrictions with respect to the standards.

To verify equipment, it must be subjected to interoperability and conformance tests. Interoperability ensures that a sender and receiver work well together, but it does not necessarily mean that both use the correct implementation of the standards and additional requirements.
Conformance testing on the other hand, does not guarantee two devices will work well together, but does confirm the equipment correctly implemented the standards and additional requirements.

Interoperability testing is partly arranged by ETSI through plug-tests. In plug-tests, engineers get together to test the interoperability of their implementations. However, not all aspects of interoperability are covered by those test (e.g. packet delivery ratio). Therefore, it is recommended to set up additional tests.

When a profile (for a use case) is complete, i.e. it is detailed and mature enough to guarantee interoperability, a test suite for conformance needs to be defined. The test systems that implement the test suite need to be build and verified. That test suite can then be used to test new equipment for conformance.

Although this sounds complex, about 90% is already available. This is also currently discussed and adopted by the C-ITS platform, and is almost finished for vehicles by the C2C CC.

4.2 Signal quality

The previous paragraph ensures that RSU and OBU understand each other when messages are received. In addition, a set of parameters for signal quality in combination with a tool to measure them need to be defined (and verified). Examples or such parameters are:

- Transmission range.
- Signal strength (dBm).
- Packet delivery ratio (i.e. % of arrived packets) given a certain packet size.

This tool can then be used to test RSUs so that they meet a, to be determined, minimum quality level. That way, chances are improved that the OBU not only understands the RSU, but it can also 'hear' it.

It is unfortunately impossible to guarantee reception from the RSU, because of the (dynamic) factors mentioned in 3.2 (e.g. downfall, changing foliage, temperature, and traffic conditions) and differences in OBUs (i.e. the hardware used and the placement of antennas). Vice versa, it is therefore also impossible to guarantee reception from the OBU by the RSU.

A possible solution could be to specify in detail the requirements on the OBU. However, requiring OBUs that meet such specifications (by law), would impose such a large barrier that would make C-ITS deployment almost impossible.

4.3 Probe vehicle data

The PVD use cases may benefit from specific placement of RSU's other than described in the requirements above. What locations are optimal for PVD was not examined in this report mainly because, although the general idea of PVD is agree upon, the details are still unclear. For example, if PVD is used for automatic incident detection (AID), a much denser network is required than the mentioned guidelines suggest. It is recommended to explore in more detail what is most effective when the PVD use case is more mature.

4.4 Learn from other domains

When planning for placement of RSUs in longer term scenarios, i.e. full coverage, it is recommended to study common practice and lessons learned from wireless networks based on 5 GHz Wi-Fi and, although quite different, cellular (3G/4G) networks. For example, in both domains there are experts in determining optimal antenna positions to cover the surrounding area best.

4.5 Integrate experience from pilot projects and demonstrations

Given the novelty of C-ITS, learning by doing is another strategy. Nationally and internationally more and more experience is gained with respect to ITS-G5 radio signals through pilot projects, demonstrations and tests. It is very important to collect the lessons learned during those projects. Moreover, relevant stakeholders like equipment manufacturers and system integrators were interviewed to prepare this document, but they continue to gain new insights. Also, once the structure and approach proposed in this document is adopted by a larger part of the industry, new questions might arise based on what is already written and is still required.

4.6 Additional tests

It is strongly recommended to perform some "on street" tests, as follow-up on the first experiences of the corridor pilots. In these tests, some specific configurations and conditions can be tested including the usage of different on-board units. There are several equipped test facilities in the EU, like the test site in Helmond.

4.7 Advance start of broadcasting

Given the limited signal coverage in day 1, for planned situations, one might choose to advance the broadcasting of messages about an event so that it is certain that all vehicles passing the event location have received information upstream about the event. For example, an RSU upstream of the event location could inform about a lane closure some time before the lane is actually closed. That amount of time should be shorter than the optimum (or shortest possible) travel time to prevent false positives. It should be noted, however, that he timing of messages is a profiling issue and not a RSU placement issue. It is obvious, nonetheless, that the two are closely related.

5 References, Definitions and Abbreviations

5.1 References

#	Reference
1	Cooperative ITS Corridor. Description of the System Concept. Version 1.0 – 4 July 2016. Rijkswaterstaat.
2	ISO TS 19321:2015 (2015-04-15). Dictionary of in-vehicle information (IVI) data structures.
3	Handboek wegafzettingen Autosnelwegen (CROW 96a)
4	Human factor guidelines for the design of safe in-car traffic information services (2014). Rijkswaterstaat.
5	ETSI TS 102 687 (2011-07). Decentralized Congestion Control Mechanisms for ITS-G5 (DCC)
6	https://en.wikipedia.org/wiki/Fresnel_zone
7	C-ITS platform final report
8	TS 102 687 V1.1.1. Intelligent Transport Systems (ITS); Decentralized Congestion Control Mechanisms for Intelligent Transport Systems operating in the 5 GHz range; Access layer part
9	ETSI EN 302 637-2 V1.3.2. Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service
10	Dutch ITS Profile: http://ditcm.eu/its-round-tables/architecture-interoperability
11	ETSI EN 302 663 V.1.2.1. Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band.

5.2 Sources

#	Source
1	Wi-Fi Location-Based Services 4.1 Design Guide
2	Verkeerskundige richtlijnen autosnelweginstrumentatie
3	Stichting Wireless Leiden. URL: https://www.wirelessleiden.nl/over-wireless-leiden
4	Draadloos Groningen. URL: http://draadloosgroningen.nl/wordpress/
5	https://en.wikipedia.org/wiki/Municipal_wireless_network
6	simTD project. URL: http://www.simtd.de/index.dhtml/deDE/index.html
7	FOTsis project. URL: http://www.fotsis.com/

5.3 Respondents to interviews

#	Respondent
1	Cohda, Peter Hierholzer
2	Commsignia, András Váradi
3	Dynniq, Nuno Rodrigues
4	RWS, Henk Stoelhorst
5	RWS, Michel Kusters
6	Siemens, Eddy Verhoeven
7	Swarco, Peter Smit
8	TASS International, Igor Passchier

5.4 Abbreviations

CACC	Cooperative Adaptive Cruise Control
C2C	Car to Car
CAM	Cooperative Awareness Messages
C-ITS	Cooperative ITS
C-ITS-S	Central ITS Station
CBR	Channel Busy Ratio
CEN	European Committee for Standardization
CRW	Collision Risk Warning
CZ	Communication Zone
DCC	Decentralized Congestion Control
DENM	Decentralized environmental Notification Message
ETSI	European Telecommunications Standards Institute
I2V	Infrastructure to vehicle
ISO	International Organization for Standardization
IVI	In-Vehicle Information
IVS	In-Vehicle Signage
ITS	Intelligent Transport Systems
ITS-S	ITS Station (e.g. V-ITS-S, R-ITS-S, C-ITS-S)
MTM	Motorway Traffic Management
OBU	On-Board Unit
PDR	Packet Delivery Ratio
PKI	Public Key Infrastructure
PVD	Probe Vehicle Data
RIS	Roadside ITS Station
R-ITS-S	Roadside ITS Station
RSU	Roadside Unit
RWS	Rijkswaterstaat
RWW	Road Works Warning
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V-ITS-S	Vehicle ITS Station