Paper TP0845

Guideline Placement C-ITS Roadside Units

Yvonne Dierikx-Platschorre[1], Jaap Vreeswijk[2*], Anton Wijbenga[3], Patrick Hofman[4], Ruben van Ardenne[5]

1. Information Analyst Traffic Management, Rijkswaterstaat, The Netherlands (yvonne.dierikx@rws.nl)
2. Traffic Architect C-ITS, MAP Traffic Management, The Netherlands (jaap.vreeswijk@maptm.nl)
3. Traffic Engineer, MAP Traffic Management, The Netherlands (anton.wijbenga@maptm.nl)
4. Traffic Engineer, MAP Traffic Management, The Netherlands (patrick.hofman@maptm.nl)
5. Manager Strategie, Compass, The Netherlands (ruben.vanardenne@compass.nl)

Abstract

Based on a functional use case perspective and specifications of RSUs (Road Side Unit), Rijkswaterstaat published a document 'RSU Placement Guidelines' (2017) what provides insights and guidelines on where an RSU should be placed. The purpose of the guidelines is not to prescribe the exact position and specifications of the RSU, but dissemination areas, i.e. areas of the road network where messages can be received by the potentially targeted vehicles. These dissemination areas can be determined concerning five requirements on functional perspective and RSU perspective. The transmission range of an RSU is subject to many internal factors, such as RSU capacity (channel load), and external factors, such as surrounding factors, installation factors and technical factors. As a result, with the help of this guideline, it can be determined where to deploy C-ITS roadside stations, which is demonstrated by an example provided in this paper.

Keywords:

Roadside Unit (RSU), ITS-G5, RSU placement guidelines

Introduction

Based on a functional use case perspective and specifications of RSUs (Road Side Unit), Rijkswaterstaat published a document 'RSU Placement Guidelines' (2017) [1] which provides insights and guidelines on where an RSU should be placed. The purpose of the guidelines is not to prescribe the exact position and specifications of the RSU, but dissemination areas, i.e. areas of the road network where messages can be received by the potentially targeted vehicles. The content of this document is based on literature review and interviews. Interviews were held with experts from roadside unit manufacturers and suppliers, knowledge centres and a road authority (Cohda, Commsignia, Dynniq, Rijkswaterstaat, Siemens, Swarco & TASS International). This paper contains the highlight of the guideline. Full details, motivation and arguments can be found in the guidelines itself [1].

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.
- 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.
- For day 1, the likelihood of false negatives must be favoured over false positives.

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 [2]. While RWW, IVS and CRW 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 [3] 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.

- ➔ 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.

Service quality

A smaller number of RSUs along highways inevitably affects the service quality in term of availability and reliability of in-car information. 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 [3], 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.

Dissemination areas

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 [4,5]. 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.

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.

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.

Transmission 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. 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) [6]. Depending on the needs of the deployed services, this knowledge can be used to decide to place RSUs closer or farther apart.

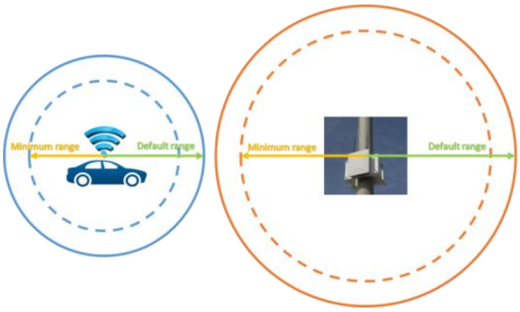

Figure 1: asymmetric transmission range OBU and RSU

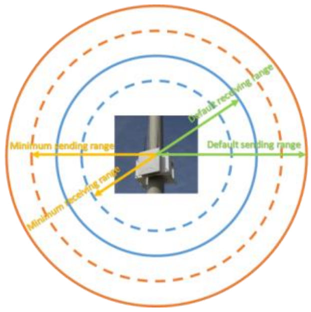

Figure 2: sender and receiver ranges for RSU

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.

External factors

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 successful transmission ratio at different distances from the RSU. The successful transmission ratio is the product of interdependent factors like signal strength, packet size, traffic density and surrounding factors. Based on field tests there are several known external factors, that may steer the decision to determine the exact position of RSUs, which are listed below.

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.
- 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.

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.

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 [10]. The best signal strength depends on the hardware used and required signal quality.

- 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 RSU capacity).
- Public Key Infrastructure.

RSU capacity

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) [6] 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.
- The CAM generation frequency is managed by the CA basic service; it defines the time interval between two consecutive CAM generations [8]. 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. 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.

Case study

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 guideline was applied to the case of the A16 motorway, to demonstrate where roadside ITS stations would be placed if the guideline was implemented.

It was assumed that the RSUs would be placed during replacement of existing signage gantries, i.e. the installation would be combined with regular maintenance. RSUs would be placed along a road section of 20 kilometres and antennas would be attached to the lower side of the signage gantries. The transmission range of the antennas was assumed to be 1600 meters.

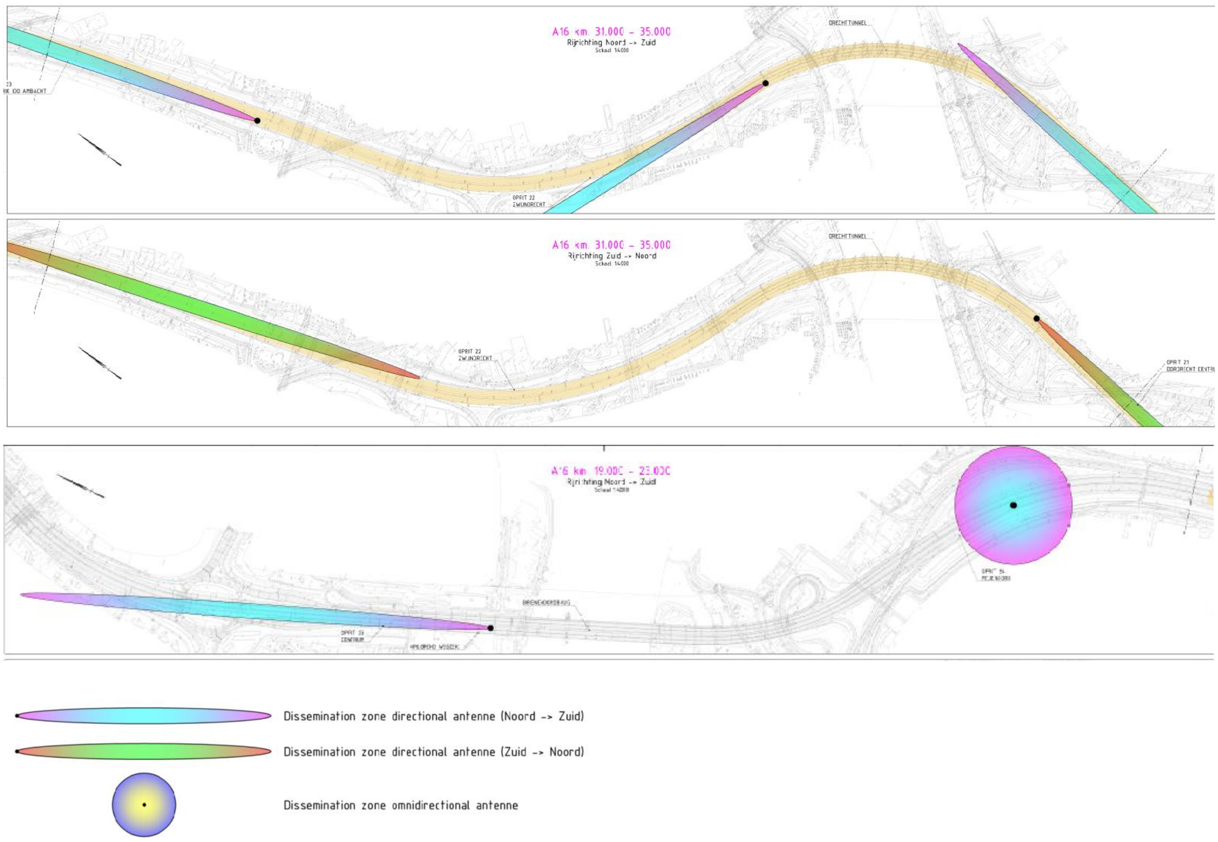

Figure 3 - Antennas and their dissemination zones on a road section of the use case A16

Applying the guidelines, the contractor projected 13 antennas on this road section of 20 kilometres. A bridge in this road section was found to be an obstruction that required an extra antenna, whereas an acoustic barrier was expected to serve as a reflector and therefor increase the transmission range. In the figures above a part of this road section is displayed. The figure shows the antennas and the dissemination zones in this road section.

Conclusions / Recommendations

Based on a functional use case perspective and specifications of RSUs, Rijkswaterstaat published a document 'RSU Placement Guidelines' (2017) [1] which provides insights and guidelines on where RSUs should be placed. This guideline was applied to a motorway section near Rotterdam. The aim of this first version of a placement guideline is to initiate a discussion on the subject with a larger (international) community. Based on first discussion the following recommendations were made:

Conformance testing

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" [9] provides additional requirements and restrictions compared 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.

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 agreed 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.

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.

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.

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.

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 negatives. It should be noted, however, that the timing of messages is a profiling issue and not a RSU placement issue. It is obvious, nonetheless, that the two are closely related.

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