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Relevance Estimation of Cooperative Awareness Messages in VANETs

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***Abstract*—In Vehicular Ad-Hoc Networks (VANETs) a vehicle receives multiple Cooperative Awareness Messages (CAMs) from neighboring nodes which inform it about their status. As the rate of received CAMs may be high, their processing may be a challenge especially in series vehicles because their resources are constrained for economic reasons. In this work, we assume that only a fraction of the received CAMs can be handled. We suggest that most relevant messages should be preferably processed. This requires a simple function that calculates with little effort an estimate of the relevance of CAMs based on information such as location and speed of the sender that is contained in any CAM. We propose a function that – roughly speaking – calculates the relevance of a CAM for its receiver. That value increases with the potential of collision with the sender of the CAM. The function has only a few parameters. Another contribution of the paper is the receiver-centric analysis of the chosen relevance function. It illustrates the effect of the function's parameters on the relevance of CAMs originating from vehicles in different positions and movements relative to the receiver.**

***Index Terms*—Vehicular Ad-Hoc Networks, Relevance Estimation, Scalability**

I. INTRODUCTION

In the last years communication between vehicles and road side infrastructure received a lot of attention by the car industry and research institutes. Under terms like *Car-to-X-Communication* (Car2X, C2X) or *Vehicular Ad-Hoc Networks* (VANETs) the corresponding activities are summarized. This technology enables a vast number of new functions to increase safety, improve driving comfort, and raise economic and ecological efficiency in daily traffic [1].

Worldwide standardization and harmonization between the vehicle manufacturers, suppliers and the public sector is taking place [2]. The European standardization process produced the *Cooperative Awareness Message (CAM)* format to continuously disseminate status information about a vehicle [3]. A CAM is broadcasted to all nearby vehicles when a set of rules is met, and the message broadcast frequency lies between 1 and 10 Hz [3, Appendix B]. CAMs have to be processed by each receiving vehicle and allow to track the movement and state of the senders of these CAMs. Many applications rely on creating vehicle trajectories from successive CAMs and on recognizing traffic patterns out of these trajectories.

In today's testbeds, vehicles are well capable to process the rate of received CAMs for two reasons. First, the current penetration rate of VANET technology is low so that test vehicles receive only low rates of CAMs. Second, test vehicles are equipped with powerful hardware that is able to process much more messages than resource-constrained hardware of future series vehicles. In case of high traffic density and high percentage of vehicles being able to send CAMs, a vehicle can receive a large rate of CAM messages, requiring lots of processing power. Initial simulation results indicate high message rates in various realistic scenarios for receivers. We omit the presentation of these results due to lack of space.

We propose to deal with this challenging situation by processing only the most relevant messages. If the rate of received CAMs is larger than the processing rate, the least relevant messages are possibly discarded. This concept requires a function that assigns a relevance value to each received CAM; based these values the most relevant CAM is selected for processing. The relevance function must reflect the view of typical use cases and has to be computable with an effort that is significantly lower than the processing of the CAM itself.

The remainder of this paper is organized as follows. Section II briefly reviews related work and mentions the use case cluster we focus on. In Section III we discuss how CAMs may be filtered based on relevance estimates to cope with overload situations. Section IV presents the derivation of the proposed relevance function. We illustrate the impact of tunable parameters of this function on the relevance of CAMs sent by vehicles with different location and speed relative to the receiving vehicle in Section V. Finally, Section VI summarizes this work and provides an outlook on further research.

II. RELATED WORK

Delot et al. proposed a relevance estimation mechanism to classify events and other information by their relevance to the driver [4]. They use mobility and direction vectors to compute a so-called *encounter probability* as a base for the relevance calculation. Also they develop a message dissemination protocol for such values. Their work gave us some valuable input, but has a different focus. This proposal also incorporates parameters we find difficult to determine and there are problems with moving entities of (almost) the same heading.

Zhou et al. propose a *Layer of Interest (LoI)* for publish-subscribe systems to avoid congestion. They suggest to use different classes for messages of no interest, high interest, medium interest, and regular interest. Their approach gives some input for VANETs as the different application classes have also a different range of interest [5].

Boll et al. developed an adaptive prefetching algorithm for the streaming of MPEG movies [6]. Their algorithm pulls frames over a network according to their relevance values. These values respect the importance of the frames for decoding of groups of pictures that are likely to be viewed in the near future. A global relevance function is proposed which combines static and dynamic relevance functions to provide a single overall relevance value.

There is a vast number of applications for VANETs which cannot be covered in this work. We concentrate on safety applications which try to avoid collisions with other objects, mostly other vehicles. Therefore, they need the same CAMs as their information base. Examples are: Overtaking Vehicle Warning, Intersection Collision Warning, Lane Change Assistant, Co-Operative Forward Collision Warning, Pre-Crash Sensing Warning, Co-Operative Merging Assistance [7].

III. ARCHITECTURE FOR MESSAGE PROCESSING

The European Telecommunications Standards Institute (ETSI) passed an architectural layer model to describe the modules necessary for VANET technology deployment [8]. The *facilities* layer is located between the *networking & transport* layer and the *applications* layer. It contains elements of the ISO/OSI layers application, presentation, and session, and serves as an information aggregation block. Information from different sources is collected here and accessible by the applications. A central part in the facilities layer is the *Local Dynamic Map* (LDM) which is a representation of the vehicle's surrounding based on received information such as CAMs. Therefore, the facilities layer has to provide central functions for CAM aggregation. With high incoming message rates the load can increase significantly in the aggregation mechanism and in the data exchange between the facilities and applications layers. It is an open challenge to design the information flow and storage inside and between these layers to avoid redundant tasks.

We propose that CAMs received by a vehicle are first processed by a module which assigns a relevance value to them and based on that value it inserts them into a sorted queue with limited space. This is illustrated in Figure 1. Then, the LDM or applications can pull these CAMs according to their relevance for processing. If the queue is full and a new CAM is received, that CAM displaces the least important CAM from the queue if it is more important. As a consequence, most relevant messages are preferably processed and least relevant messages are likely to be dropped.

This basic concept may be augmented by feedback from applications. When an application, e.g., a forward collision avoidance application, is tracking a specific vehicle because of its possibly dangerous movement, new CAMs from this vehicle have to get processed with high priority. Thus, rules are needed to override relevance estimates by feedback of greedy applications. This, however, is not in the focus of this work and subject to further research.

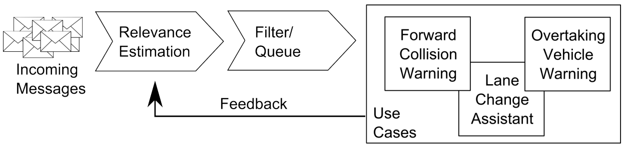


Fig. 1. Preferred processing of most relevant CAMs by a vehicle.

IV. DERIVATION OF THE RELEVANCE FUNCTION

In this section, we first sketch how the relevance of other vehicles for potential collision could be estimated in a relatively accurate way, but also conclude that this approach is computationally demanding so that it is infeasible under resource constraints. Then, we derive a relevance function in three steps and show that it is easy to calculate.

A. Complex Relevance Calculation of CAM Messages

A CAM message contains information about the position $\mathbf{p_s} = \begin{pmatrix} \mathbf{p_s}.x \\ \mathbf{p_s}.y \end{pmatrix}$, the speed $|\mathbf{v_s}|$, and the heading ψ_s of its sender. The speed may be negative if the vehicle is moving backward. The relevance estimation module uses these values and has access to the corresponding values $\mathbf{p_r}$, $|\mathbf{v_r}|$ and ψ_r of the receiver.

By choosing collision-related applications the encounter probability suggests itself as a relevance measure. A calculation of this probability is possible in various ways. With the help of a street map and by using the most probable path one could determine whether sender and receiver can meet in the near future. Although this approach may yield quite good estimates, there are several reasons why it is not suitable for our proposed concept:

- A street map has to be available for the current area. However, often vehicles are only equipped with maps for one country or a certain region.
- Map data require huge available storage space.
- Street maps are static while the real road system is changing steadily. Changes exist temporarily or on a long-term basis.
- Map access, most probable path calculation, and map matching, i.e., determining the exact own location in a map by a match of the driven trajectory with map data, are CPU-intensive.

B. A Simple Relevance Function for CAM Messages

We derive a simple relevance function for CAM messages. It decreases with increasing distance between communicating vehicles, extrapolates their movements, and adds a penalty factor when the vehicles meet only in the future. The function excels by its simple calculation.

1) Distance-Based Relevance Estimation: As the probability for a collision of two vehicles decreases with their distance, we propose the base relevance function

$$R(s,r) = \left(\frac{d(s,r)}{\mathrm{m}}\right)^{-\alpha}. \tag{1}$$

As we consider safety applications, we propose that the relevance of a CAM decreases with increasing straight-line distance $d(s,r)$ between the sender s and the receiver r of a CAM. We use $\left(\frac{d(s,r)}{\mathrm{m}}\right)^{-\alpha}$ as a base where the distance is normalized by the unit meter m and the parameter α allows to control the decrease of the relevance with increasing distance. We argue that all vehicles within a radius of d_{min} are equally important for various reasons. It is hard to exactly determine positions of vehicles and their distance using GPS, the CAM information may not be accurate anymore since time has passed between the measurement of the data and the reception of the CAM message, and vehicles can quickly change their movements, e.g., through acceleration, braking, or steering. As a result, all vehicles within a radius of d_{min} around the receiver can suddenly become very relevant or are already highly relevant. Therefore, we suggest

$$R(s,r) = \left(\frac{\max(d(s,r), d_{min})}{\mathrm{m}}\right)^{-\alpha} \tag{2}$$

as a simple relevance function. The maximum relevance is limited to $R_{max} = \left(\frac{d_{min}}{\mathrm{m}}\right)^{-\alpha}$.

2) Mobility-Based Relevance Estimation: Equation (2) describes the relevance of a CAM for the time it is received. However, CAMs of vehicles departing from the receiver tend to become less relevant over time while CAMs of vehicles approaching the receiver tend to become more relevant. To predict the positions of the sender and the receiver of a CAM in the near future, we assume that they do not change their movements. We first derive the mobility vector from the velocity $|\mathbf{v_s}|$ and heading ψ_s of the sender by

$$\mathbf{v_s} = \begin{pmatrix} \mathbf{v_s}.x \\ \mathbf{v_s}.y \end{pmatrix} = \begin{pmatrix} |\mathbf{v_s}| \cdot cos(\psi_s) \\ |\mathbf{v_s}| \cdot sin(\psi_s) \end{pmatrix}. \tag{3}$$

Then, we calculate the time-dependent distance $d(s,r,t)$ between sender and receiver by

$$d(s,r,t) = |\mathbf{p_r} + (t - t_{now}) \cdot \mathbf{v_r} - (\mathbf{p_s} + (t - t_{now}) \cdot \mathbf{v_s})|$$

where variable t_{now} represents the current time. On this basis we propose the time-dependent relevance function

$$R(s,r,t) = \left(\frac{\max(d(s,r,t), d_{min})}{\mathrm{m}}\right)^{-\alpha}. \tag{4}$$

This equation does not yet respect the fact that vehicles meeting in the far future should yield a lower relevance value than vehicles meeting very soon. We achieve that by adding a penalty term to the formula:

$$R(s,r,t) = \left(\frac{\max(d(s,r,t), d_{min})}{\mathrm{m}}\right)^{-\alpha} \cdot \left(1 + \frac{t - t_{now}}{\mathrm{s}}\right)^{-\beta}. \tag{5}$$

Parameter β allows to control the penalty factor over time and the time is normalized by the unit second.

Finally, we define the maximum time-dependent relevance as the new relevance value:

$$R(s,r) = \max_{t_{now} \le t \le t_{now} + D_{max}} \left(R(r,s,t)\right). \tag{6}$$

We perform this maximization only over an interval of duration D_{max} since the assumption of a constant mobility vector may be valid only for limited time.

3) Elimination of the α-Parameter: Equation (5) uses the two parameters α and β which both need to be tuned. However, we can transform the equation by exponentiating both sides by $\frac{1}{\alpha}$. As the relative order induced by the values proposed in Equation (5) does not change by this transformation, we adopt the result as a simplified relevance function with $\gamma = \frac{\beta}{\alpha}$:

$$R(s,r,t) = \left(\frac{\max(d(s,r,t), d_{min})}{\mathrm{m}}\right)^{-1} \cdot \left(1 + \frac{t - t_{now}}{\mathrm{s}}\right)^{-\gamma}. \tag{7}$$

4) Efficient Calculation of the Relevance Function: We calculate the relevance value using Equations (6) and (7) in an efficient way. If the distance between sender and receiver is at most d_{min} when the CAM is received, then the relevance is set to the maximum value R_{max}. Otherwise, the maximum of the time-dependent relevance values in $[t_{now}; t_{now} + D_{max}]$ needs to be determined. There is a set $\mathcal{T}$ of at most four potential instances for that maximum:

1) the beginning of the considered interval, namely t_{now},
2) the time t_{max} which is either the instance t_{min} when the time-dependent distance becomes d_{min} for the first time or the end of the interval $t_{now} + D_{max}$ when no point t_{min} does exist within that interval,
3) potential extreme values of $R(s,r,t)$ within $[t_{now}; t_{max}]$ – at most two such values $t^{1,2}_{\text{inside}}$ can exist.

Thus, the relevance value can be calculated by $R(s,r) = \max_{t \in \mathcal{T}} \left(R(s,r,t)\right)$. Two challenges remain: the calculation of t_{min} and the calculation of $t^{1,2}_{\text{inside}}$.

a) Calculation of t_{min}: We determine t_{min} by calculating

$$t^{1,2}_{min} = t_{now} \pm \frac{\sqrt{-4z(x + d^2_{min}) + y^2} - y}{2z} \tag{8}$$

with

$$\begin{aligned} x =& (\mathbf{p}_r.x - \mathbf{p}_s.x)^2 + (\mathbf{p}_r.y - \mathbf{p}_s.y)^2 && (9) \\ y =& 2(\mathbf{p}_r.x - \mathbf{p}_s.x)(\mathbf{v}_r.x - \mathbf{v}_s.x) \\ & + 2(\mathbf{p}_r.y - \mathbf{p}_s.y)(\mathbf{v}_r.y - \mathbf{v}_s.y) && (10) \\ z =& (\mathbf{v}_r.x - \mathbf{v}_s.x)^2 + (\mathbf{v}_r.y - \mathbf{v}_s.y)^2 && (11) \end{aligned}$$

and set t_{min} to the smallest one of these values $t^{1,2}_{min}$ in the range $[t_{now}; t_{now} + D_{max}]$ if such values exist. Otherwise, t_{min} is set to $t_{now} + D_{max}$.

b) Calculation of $t^{1,2}_{inside}$: As $d(s, r, t_{now}) > d_{min}$ holds, the distance cannot become zero before t_{min}. Therefore, extreme values of $R(s, r, t)$ within $[t_{now}; t_{max}]$ are also extreme values of its inverse $f(t) = \frac{\max(d(s,r,t),d_{min})}{\mathrm{m}} \cdot \left(1 + \frac{t-t_{now}}{\mathrm{s}}\right)^{\gamma}$. Zeros of the derivative of f are

$$\begin{aligned} t^{1,2}_{\text{inside}} =& t_{now} - \frac{y + 2\gamma y + 2z}{4z(1+\gamma)} \\ & \pm \frac{\sqrt{(2\gamma y + y + 2z)^2 - 8z(\gamma+1)(2\gamma x + y)}}{4z(1+\gamma)}. \end{aligned} \tag{12}$$

They exist only if the discriminant under the square root in Equation (12) is not negative.

V. EVALUATION

In this section we illustrate the impact of the position and speed of the CAM sender relative to the CAM receiver on the relevance value. Moreover, we show how the parameters of the relevance function d_{min}, D_{max}, and γ influence the results.

A. Receiver-Centric Analysis

For evaluation purposes we use a receiver-centric analysis. The receiver is still and located at the origin of a coordinate system. Potential senders move from the right to the left with a certain speed. Any other point in the coordinate system represents the position of a potential sender. From any such sender we evaluate the relevance of CAMs for our considered receiver.

Any pair of real sender and receiver can be mapped into the coordinate system of the receiver-centric analysis such that the position and speed of the sender relative to the receiver do not change. The receiver is moved to the origin and the sender takes an intermediate position $\mathbf{p_s} - \mathbf{p_r}$ and mobility vector $\mathbf{v_s} - \mathbf{v_r}$. The sender finds its final position by a rotation around the origin such that its mobility vector points from right to the left. Since the relevance function depends only on the relative position and speed of a sender and receiver, the translation of sender and receiver into the receiver-centric coordinate system does not change the relevance value of CAMs.

B. Impact of Relative Speed Δv

In the upper part of Figures 2(a)–2(f), we use the receiver-centric analysis and color points in a coordinate system according to the relevance value of CAMs originating from them under the assumption that the sender has a certain (relative) speed Δv. Darker points represent higher relevance values as indicated in the legend. This presentation easily allows us to see which relative positions and mobility vectors are considered important by the relevance function. The lower parts of the figures indicate the absolute relevance values in a cross section for $Y = 0$.

If not mentioned differently, we set $\Delta v = 5\ \frac{\mathrm{m}}{\mathrm{s}}$, $d_{min} = 10$ m, and $D_{max} = 120$ s. To avoid an abrupt transition of the relevance for distant moving senders, we set γ such that we get $(1 + \frac{D_{max}}{\mathrm{s}})^{-\gamma} = 0.1$, i.e., $\gamma = -\frac{\ln(0.1)}{\ln(1+\frac{D_{max}}{\mathrm{s}})}$.

Figure 2(a) shows the relevance function for a relative speed of $\Delta v = 0\ \frac{\mathrm{m}}{\mathrm{s}}$, i.e., sender and receiver are not necessarily still, but they have the same mobility vector. According to the construction of the function, the relevance is highest within a radius of d_{min} and decreases with distance from the origin in all directions. Figure 2(b) changes the relative speed to $\Delta v = 5\ \frac{\mathrm{m}}{\mathrm{s}}$. We can interpret the horizontal line at $Y = 0$ as a situation where the sender and the receiver are approaching to each other. The positive mobility vector of the sender effects that the area of same relevance values are stretched to the right when comparing it to the figure with $\Delta v = 0\ \frac{\mathrm{m}}{\mathrm{s}}$. We observe that for $\Delta v = 5\ \frac{\mathrm{m}}{\mathrm{s}}$ the sender positions from which senders can eventually collide with the receiver also yield large relevance values. These large values slowly fade out with distance from the origin.

Increasing the relative speed to $\Delta v = 10\frac{\mathrm{m}}{\mathrm{s}}$ leads to Figure 2(c). The area of high relevance for approaching vehicles now gets higher values than with $\Delta v = 5\ \frac{\mathrm{m}}{\mathrm{s}}$. We see that by the darker colors in the tail to the right. The faster a vehicle moves towards the receiver, the earlier it reaches the receiver's close vicinity so that a lower penalty factor is applied. This essentially causes the difference between Figures 2(c) and 2(b).

C. Impact of the Minimum Distance d_{min}

We now set the minimum distance to $d_{min} = 20$ m for which the results are given in Figure 2(d). Compared to Figure 2(b), the maximum relevance $R_{max} = \frac{1}{d_{min}}$ is lower and so the values in the vicinity of the receiver are lower. The relevance values of positions from where vehicles can collide with the receiver are also affected by this change. We chose these values for d_{min} based on our experience with vehicle dynamics; higher values of d_{min} are possible but lead to less differentiation in relevance values among messages.

D. Impact of the Maximum Time D_{max}

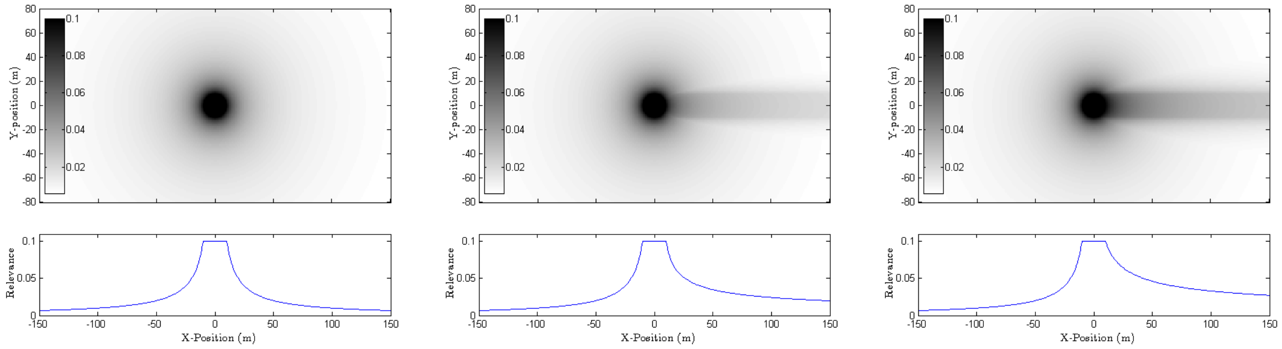
We set the maximum time $D_{max} = 15$ s but leave γ the same value as for $D_{max} = 120$ s and present the corresponding relevance values in Figure 2(e). Compared to Figure 2(b), we see in the lower plot that there is now a clear discontinuity at the edge between vehicles getting into the close vicinity of the receiver and other vehicles. Therefore, we suggest to use a higher value of $D_{max} = 120$ s in order to damp the discontinuity and shift it to the far right.

E. Impact of the Control Factor γ

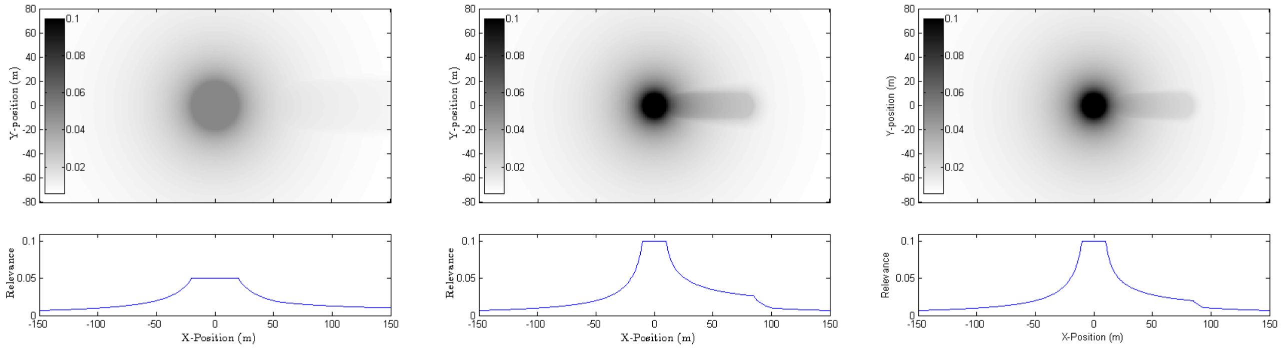
We initially decided to set $\gamma = -\frac{\ln(0.1)}{\ln(1+\frac{D_{max}}{\mathrm{s}})}$. In Figure 2(f) we set $D_{max} = 15$ s and γ such that $(1 + \frac{D_{max}}{\mathrm{s}})^{-\gamma} = 0.2$. In comparison to Figure 2(e) we see that a lower γ value leads to a less harsh discontinuity. On the other hand the tail to the right is almost invisible, which depicts a neutralization of our approach of considering the vehicles' mobility. Therefore, we suggest to use $(1 + \frac{D_{max}}{\mathrm{s}})^{-\gamma} = 0.1$ in combination with a large value of $D_{max} = 120$ s.

VI. CONCLUSION AND FUTURE WORK

In a widely deployed VANET, vehicles have to process a large amount of Cooperative Awareness Messages (CAMs). As



(a) $\Delta v = 0\ \frac{\text{m}}{\text{s}}$, $d_{min} = 10$ m, $D_{max} = 120$ s (b) $\Delta v = 5\ \frac{\text{m}}{\text{s}}$, $d_{min} = 10$ m, $D_{max} = 120$ s (c) $\Delta v = 10\ \frac{\text{m}}{\text{s}}$, $d_{min} = 10$ m, $D_{max} = 120$ s



(d) $\Delta v = 0\ \frac{\text{m}}{\text{s}}$, $d_{min} = 20$ m, $D_{max} = 120$ s (e) $\Delta v = 5\ \frac{\text{m}}{\text{s}}$, $d_{min} = 10$ m, $D_{max} = 15$ s (f) $\Delta v = 5\ \frac{\text{m}}{\text{s}}$, $d_{min} = 10$ m, $D_{max} = 15$ s, modified γ

Fig. 2. Relevance values for senders moving from right to left depending on position and speed relative to a sender at the origin.

hardware in series vehicles will be limited, only most relevant CAMs can be handled. To that aim, we proposed a function to estimate the relevance of CAMs for a receiver. It uses only the position, velocity, and heading of the sender which are contained in the CAM, and it can be easily calculated. The function uses the parameters d_{min}, D_{max}, and γ. Parameter d_{min} is rather intuitive and we provided recommendation on how to set D_{max} and γ. We developed a receiver-centric analysis and used it to illustrate the effect of the sender's position, velocity, and heading relative to the receiver in a comprehensive way. Moreover, we depicted the impact of the tunable parameters of the function.

Our proposal for relevance estimation and CAM selection is only a first step in bringing VANETs into series vehicles. In future work we will provide a more elaborate relevance function that allows changing the mobility vector of sender and receiver over time. This will widen the area of senders with high relevance values and is needed to capture vehicles driving curves. The quality of the pre-selected CAMs needs to be assessed with regard to the requirements of various applications. Experience from currently conducted field operational tests may be helpful. The integration of applications overriding relevance values by giving direct feedback to the facilities layer is an open research issue.

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