An Improved Relevance Estimation Function for Cooperative Awareness Messages in VANETs

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Abstract. According to the current status of European Vehicular Ad-Hoc Network (VANET) standardization, vehicles gather and process Cooperative Awareness Messages (CAMs) sent from their environment. The rate of CAMs received by each vehicle can be high, and due to limited resources in series vehicles their processing is an open challenge. Following previous work, we present an improved relevance estimation function which calculates a relevance value for each received message based on basic information like position, speed, and heading without map data. Other than before, the new function incorporates non-static movement extrapolation of vehicles. We evaluate the newly proposed function using a receiver-centric approach.

1 Introduction

Wireless communication between vehicles and road side infrastructure is one of the key technologies to increase road traffic safety, to enable more comfortable driving, and to improve ecological and economic efficiency of road traffic [1]. The industry, research institutes, and the public sector made great efforts to develop technologies and standards for such systems. The most common terms for these efforts are *Vehicular Ad-Hoc Networks* (VANETs), *Vehicle-to-Vehicle Communication* (V2V), or *Car-to-Car-Communication* (Car2Car, C2C).

After years of research and standardization, VANET technology is on the leap to market introduction [2]. National and international field tests demonstrate the feasibility of the elaborated standards [3]. In Europe VANETs are mainly based on two message types: status information messages and event-based messages [4][5]. While the latter are sent rarely on detection of specific events, status information messages are frequently sent to give their receivers the possibility to maintain a local dynamic map of their surrounding vehicles. Based on this information various applications can be implemented which need access to the knowledge of the current traffic situation.

The standards for VANETs focus on the interoperability between vehicles from all car manufacturers and hardware from different suppliers. Hence, the message transmission on the wireless channel is well studied. In contrast, the processing of status messages inside the receiving cars requires more investigation. The implementations in field tests either utilized powerful hardware or had to handle only few communicating vehicles. In series vehicle systems, the hardware is embedded and less powerful than in research systems. Also, the number of participating vehicles will increase steadily in the coming years [6]. Therefore, each equipped series vehicle must be able to cope with a rising penetration rate of VANET technology in vehicular traffic. However, this goal must be reached with a small-sized embedded VANET implementation for the entire lifetime of the vehicle [7]. Assuming the wireless channel and the network stack to be sized appropriately, the handling and processing of received messages remains a challenge.

Our approach to this problem is to estimate the relevance of messages on arrival and to process most relevant messages first. In case of overload in the receiving vehicle, least relevant messages are dropped or processed late. A particular difficulty of that approach is the relevance estimation. It should not rely on map information because map matching is considered an expensive operation.

A general assumption is that the relevance of messages from nearby senders is higher than from distant senders. However, vehicles are moving so that they could come closer within short time, which would also result in relatively high relevance values. In previous work [8] we have proposed a simple relevance estimation function that maximizes the relevance value of a message by extrapolating the position of the sender based on static movement, without changes in speed and heading. This work extends that approach by considering the sending vehicle may brake, accelerate, or drive curves to maximize the relevance value.

The remainder of this paper is organized as follows. Section 2 briefly reviews related work, introduces the Cooperative Awareness Message type, and summarizes our earlier work about a simple relevance estimation function. In Section 3 we derive an improved relevance function in several steps. We illustrate the effects of that function under various conditions in Section 4. Finally, Section 5 concludes this work and gives an outlook on further research.

2 Related Work

We first give a brief overview of field operational tests of VANETs. Then, we introduce Cooperative Awareness Messages (CAMs) and summarize our study of future CAM rates that series vehicles are likely to be faced with. Moreover, we give an introduction to the simple relevance estimation function we proposed in previous work. Furthermore, we delimit our work from research in the field of automotive situation assessment.

2.1 Field Operational Tests

Standards for VANET technologies are currently finalized, and field operational tests are conducted to investigate their interoperability and feasibility. In this context there are three big field operational tests in Europe: sim$^{\mathrm{TD}}$ (Germany), score@F (France) and DRIVE C2X (international) [9][10][11]. All of these tests utilize powerful hardware which cannot be used for series vehicles because of special automotive requirements regarding robustness, size, and cost.

2.2 Cooperative Awareness Messages

All vehicles in a VANET should be able to track their surrounding traffic situation. To facilitate this, vehicles and certain road side stations sends status messages on a regular basis. They are called Cooperative Awareness Messages (CAMs) and contain information like message identifier, station type, position, heading, speed, acceleration, and more. Upon reception and interpretation of CAMs the receiver can create a local dynamic map (LDM). CAMs are triggered when the heading, position or speed of a vehicle changes by more than given thresholds. The CAM send frequency lies between 1 and 10 Hz [5].

2.3 Analysis of CAM Rates

In an earlier work we analyzed the rates of CAMs in typical highway scenarios [12]. We used a new statistical channel model based on the Nakagami m-distribution for signal attenuation. Our simulations resulted in rates of 500 $\frac{\text{CAMs}}{\text{s}}$ which are received by vehicles in the presence of a VANET penetration rate of 40% and an uncongested channel. This gives an order of magnitude for the processing requirements in series vehicles.

2.4 Simple Relevance Estimation Function

In previous work [8] we presented a simple relevance estimation function for collision related VANET applications. Given basic information (positions, headings, speeds) about the sender α and receiver β of the message, the function calculates a relevance value $R(\alpha, \beta)$ by

$$R(\alpha,\beta) = \max_{t_{\text{now}} \leq t \leq t_{\text{now}} + T_{\max}} \left[\frac{\text{m}}{\max(d(\alpha,\beta,t), d_{\min})} \cdot \left(1 + \frac{t - t_{\text{now}}}{\text{s}}\right)^{-\gamma} \right] \quad (1)$$

with starting time t_{now}, extrapolation duration $T_{\max}$ ($D_{\max}$ in [8]), minimum distance $d_{\min}$ and time penalty exponent γ [8]. Distances are given in meters and time is given in seconds. The term $d(\alpha, \beta, t)$ denotes the straight-line distance between sender and receiver at time t and can be computed by

$$d(\alpha,\beta,t) = |\mathbf{p}_\beta + (t - t_{\text{now}}) \cdot \mathbf{v}_\beta - (\mathbf{p}_\alpha + (t - t_{\text{now}}) \cdot \mathbf{v}_\alpha)| \quad (2)$$

with position vectors $\mathbf{p}_\alpha$, $\mathbf{p}_\beta$ and constant velocity vectors $\mathbf{v}_\alpha$, $\mathbf{v}_\beta$ for sender and receiver, respectively. The maximization of the expression in brackets essentially means that the relevance of a message can be also high if its sender approaches the receiver only over time. The relevance function $R(\alpha, \beta)$ can be calculated efficiently for each received CAM [8].

However, it has some limitations that result from the assumption of static movement along the initial direction with constant speed. As a consequence, the relevance of distant senders is too much dominated by their headings. If they point towards the receiver, their static movement will bring them eventually very close to the receiver leading to a high relevance. If their heading is only slightly different, static movement will cause them to never reach the vicinity of the receiver, leading to a low relevance. The large difference in relevance is not plausible since vehicles can easily change their headings, especially if they are not too fast and still far away. This will be accounted by the relevance function that will be presented in this paper.

2.5 Situation Assessment

In the last years vehicular systems for environment perception made a huge step in microscopic situation assessment. Based on radar and cameras, sophisticated algorithms assess the situation and evaluate different movement paths [13][14]. Work from this area has two drawbacks which prohibit their usage in our context: Its microscopic perspective is related to the direct vicinity of vehicles, while we want to cover an area of about 1000 m radius. Also situation assessment algorithms require powerful processing units and base on complex physical and mathematic models for only few vehicles in parallel.

3 Derivation of an Improved Relevance Estimation Function

In this section we derive an improved relevance estimation function by extending the simple relevance estimation function from Equation (1). We use a receiver-centric notation to keep the equations simple. The circular path movement approach allows for changes in the heading of vehicles over time. Accelerations allow for speed changes over time. Additional improvements aim at a more sophisticated distance determination formula replacing $d(\alpha, \beta, t)$ while keeping the rest of the relevance estimation formula $R(\alpha, \beta)$ the same as described in Equation (1). In the last section we discuss shortcomings of our proposals.

3.1 Receiver-Centric Notation

In the following we use a receiver-centric translation of original positions and movement vectors of both sender and receiver [8]. This allows us to use some simplifications in the following sections which do not change basic ideas and results but facilitate an easier notation. The receiver is still and located in the origin of a two-dimensional coordinate system. The sender is located relatively to the receiver such that its relative movement vector is pointing horizontally from right to left.

We denote the translated position of a sender by $\mathbf{p}_\alpha^{\text{rel}} = \begin{pmatrix} x_\alpha^{\text{rel}} \\ y_\alpha^{\text{rel}} \end{pmatrix}$ and the movement vector by $\mathbf{v}_\alpha^{\text{rel}} = \begin{pmatrix} v_\alpha^{\text{rel}} \\ 0 \end{pmatrix}$. The receivers position and movement vectors correspond to the null vector in receiver-centric notation.

3.2 Circular Path Movement

This section describes how sender movement on a circular path can be added to the simple relevance estimation function. First, we explain the basic idea, then we show how physical effects leading to a minimum curve radius can be respected.

Basic Idea. The basic idea behind a circular path movement extrapolation is the pessimistic assumption that the sender will head towards the receiver's position and eventually collide.

To collide with the receiver, we allow a continuous change of direction that results in a circular movement of the sender. The receiver "attracts" the sender like a magnet, i.e., the sender changes its heading continuously over time. Figure 1 depicts this approach. Sender α_{right} is located to the right of the receiver and sender α_{left} is located to the left of the receiver. Both are initially driving horizontally from right to left. According to the circular movement model they change their heading in a way that they eventually reach the receiver's position. If vehicles keep their speed and change only their headings, they will follow the arcs $b_{\text{forward}}^{\text{left}}$ or $b_{\text{forward}}^{\text{right}}$, respectively. However, they may easily change their relative movement by braking or accelerating backwards so that they also could approach the receiver on the arcs $b_{\text{backward}}^{\text{left}}$ or $b_{\text{backward}}^{\text{right}}$, respectively. In the following, we derive formulae for senders to the right of the receiver ($x_\alpha > 0$ m). Similar formulae exist for senders to the left of the receiver.

The positions of both sender and receiver and the initial heading of the sender define a circle. Its center has the coordinates

$$\mathbf{p}_c = \begin{pmatrix} x_\alpha^{\text{rel}} \\ -\frac{1}{2} \cdot \frac{(x_\alpha^{\text{rel}})^2 - (y_\alpha^{\text{rel}})^2}{y_\alpha^{\text{rel}}} \end{pmatrix}. \tag{3}$$

The radius r of the circle is given by

$$r = \frac{1}{2} \cdot \frac{(x_\alpha^{\text{rel}})^2 - (y_\alpha^{\text{rel}})^2}{y_\alpha^{\text{rel}}}. \tag{4}$$

The length of the arc $b_{\text{forward}}^{\text{right}}$ can by calculated by

$$b_{\text{forward}}^{\text{right}} = 2 \cdot r \cdot \arcsin\left(\frac{|\mathbf{p}_\alpha^{\text{rel}}|}{2 \cdot r}\right). \tag{5}$$

The length of arc $b_{\text{backward}}^{\text{right}}$ can be derived accordingly. If we allow sender vehicles to change heading, we implicitly assume that they move on a circular arc. As

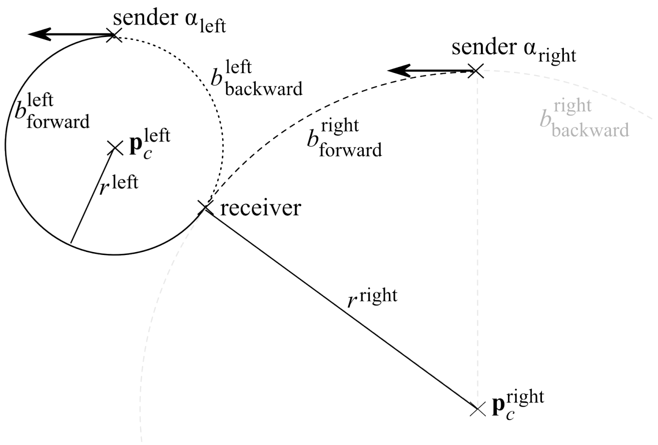

Fig. 1. Circular movement of sending vehicles towards the receiving vehicle; the illustrated movement is relative to the receiver's position.

a consequence, we need to respect that in the distance calculation required for Equation (1). The adapted distance function is

$$d^{\text{circular}}_{\text{arc}}(\alpha, \beta, t) = b^{\text{right}}_{\text{forward}} - |\mathbf{v}^{\text{rel}}_{\alpha}| \cdot t, \tag{6}$$

which replaces $d(\alpha, \beta, t)$ in Equation (1).

In [8] we derived an analytical expression for the maximum value of Equation (1) so that it could be easily calculated. This expression can be adapted to the modified distance function $d^{\text{circular}}_{\text{arc}}(\alpha, \beta, t)$.

Minimum Curve Radius. In the preceding section we described how a circular path movement can be realized. This model gives reasonable results, but is inaccurate by allowing very small curve radii. Considering the centrifugal force, the curve radius at a specific speed v cannot be lower than

$$r_{\min}(v) = \frac{v^2}{g \cdot \mu}, \tag{7}$$

where g corresponds to the force of gravity and μ is the friction value [15].

If the speed for a given sending vehicle is too high, it might be physically impossible for it to collide with the receiver because that would require a too small curve radius. As a consequence, the circular path derived in Section 3.2 is not valid. Therefore, we assume that the vehicle follows a circular path with the minimum radius $r_{\min}$ as computed in Equation (7). Since the proposed arc does not link sender and receiver, we use the straight-line distance as distance measure under these conditions:

$$d^{\text{circular}}_{\text{straight}}(\alpha, \beta, r, t, \mathbf{v}^{\text{rel}}_{\alpha}) = \left| \begin{pmatrix} x_\alpha - \sin\left(\frac{|\mathbf{v}^{\text{rel}}_{\alpha}|}{\max(r, r_{\min}(|\mathbf{v}_\alpha|))} t\right) \cdot \max(r, r_{\min}(|\mathbf{v}_\alpha|)) \\ y_\alpha - \cos\left(\frac{|\mathbf{v}^{\text{rel}}_{\alpha}|}{\max(r, r_{\min}(|\mathbf{v}_\alpha|))} t\right) \cdot \max(r, r_{\min}(|\mathbf{v}_\alpha|)) \end{pmatrix} \right| \tag{8}$$

To keep things simple and avoid discontinuities we also use the straight-line distance for senders and receivers that may collide.

3.3 Accelerations

One drawback of the simple relevance estimation function is the assumption of constant speed, because each vehicle might slow down or speed up after the message is sent.

Changes in speed may have the effect that a short distance on the arc in Equation (6) or a short straight-line distance in Equation (8) may be reached earlier than without acceleration which increases the maximum relevance value of a message.

In this section we consider positive and negative accelerations of the sender in the relevance function. First, we introduce a function which utilizes constant accelerations, then we allow for speed-dependent acceleration.

Constant Acceleration. We first propose to integrate a "worst-case" acceleration $a_{\max}$ in the distance function. The value for $a_{\max}$ can be taken from empirical studies [16].

Constant accelerations can be integrated into Equation (8) by replacing $|\mathbf{v}_\alpha^{\text{rel}}|$ with the term $|\mathbf{v}_\alpha^{\text{rel}}| \cdot t + \frac{1}{2} \cdot a_{\max} \cdot t^2$. As $r_{\min}(v)$ depends on the speed, we take the maximum sender speed $v_{\max}$ between t_{now} and $t_{\text{now}} + T_{\max}$ as input. These changes yield

$$d_{\text{straight}}^{\text{const. acc.}}(\alpha, \beta, r, t, \mathbf{v}_\alpha^{\text{rel}}) = \left| \begin{pmatrix} x_\alpha - \sin\left(\frac{|\mathbf{v}_\alpha^{\text{rel}}| \cdot t + \frac{1}{2} \cdot a_{\max} \cdot t^2}{\max(r, r_{\min}(v_{\max}))} t\right) \cdot \max(r, r_{\min}(v_{\max})) \\ y_\alpha - \cos\left(\frac{|\mathbf{v}_\alpha^{\text{rel}}| \cdot t + \frac{1}{2} \cdot a_{\max} \cdot t^2}{\max(r, r_{\min}(v_{\max}))} t\right) \cdot \max(r, r_{\min}(v_{\max})) \end{pmatrix} \right| \tag{9}$$

Speed-Dependent Acceleration. The assumption of constant acceleration is not considering the vehicles' current speeds and leads to unrealistic speed changes. In reality, the maximum achievable acceleration depends on the current speed.

We now introduce an algorithm for relevance estimation based on speed-dependent acceleration. The algorithm has three steps. First, we determine the maximum speed of the sending vehicle. Second, we check if this maximum speed is too high for the curve radius needed to collide with the receiver. Third, we iterate over all time steps in the respective time interval to extrapolate the movement and calculate the relevance value for each time step. The maximum relevance value of this iteration yields the overall relevance value. The following sections refer to Algorithm 1.

Step 1: Determination of the Maximum Speed of the Sender (Lines 1–8). We first determine the maximum sender speed $v_{\max}$ in the interval from t_{now} to $t_{\text{now}} + T_{\max}$ in steps with duration Δt.

Algorithm 1: Calculation of the relevance value R.

```
   Input : Curve radius $r$, absolute sender speed $|\mathbf{v}_\alpha|$, starting time $t_{\mathrm{now}}$,
           extrapolation time $T_{\max}$, time step duration $\Delta t$, minimum distance $d_{\min}$,
           time penalty exponent $\gamma$, sender $\alpha$, and receiver $\beta$
   // Step 1: Determine the maximum speed $v_{\max}$
 1 $v \leftarrow |\mathbf{v}_\alpha|$;                                   // Initial speed
 2 $t \leftarrow t_{\mathrm{now}}$;
 3 repeat
 4     $a \leftarrow a(v)$;                  // Target accelerations from Table 1
 5     $v \leftarrow v + \Delta t \cdot a$;                       // Calculate new speed
 6     $t \leftarrow t + \Delta t$;
 7 until $t > t_{\mathrm{now}} + T_{\max}$;
 8 $v_{\max} \leftarrow v$;
   // Step 2: Check if curve radius $r$ is less than $r_{\min}(v_{\max})$
 9 if $r < r_{\min}(v_{\max})$ then
10     $r \leftarrow r_{\min}(v_{\max})$;                  // Use minimum curve radius
11 end
   // Step 3: Calculate the relevance value $R$ iteratively
12 $R \leftarrow -\infty$;
13 $t \leftarrow t_{\mathrm{now}}$;
14 repeat
15     $d \leftarrow d^{\mathrm{circular}}_{\mathrm{straight}}(\alpha, \beta, r, t, v)$;   // Calculate sender and receiver distance
16     $R \leftarrow \max\left(R, \frac{\mathrm{m}}{\max(d, d_{\min})} \cdot \frac{1}{(1+\frac{t}{\mathrm{s}})^{\gamma}}\right)$;   // Maximum relevance until $t$
17     $t \leftarrow t + \Delta t$;
18 until $t > t_{\mathrm{now}} + T_{\max}$;
   Output: Relevance value $R$
```

Initially, speed variable v is set to the sender's absolute speed $|\mathbf{v}_\alpha|$. For each time step we extract the current acceleration a with function $a(v)$ from a lookup table for the current speed v. Eventually, this yields the maximum speed $v_{\max}$ in the considered time interval. The minimum (negative) speed can be derived accordingly.

We use lookup tables to assign accelerations to speeds. Table 1 and Table 2 provide the values we used for positive and negative accelerations, respectively. The values can be extracted from empirical studies [16]. The accelerations decrease with higher speeds. Decelerations are high for positive speeds to allow for full braking, while driving backwards enables only low decelerations.

Step 2: Minimum Curve Radius Check (Lines 9–11). We use the maximum speed $v_{\max}$ in Equation (7) to determine whether the calculated curve radius r from Equation (4) for a collision of sender and receiver is too small. If that is the case, $r_{\min}$ replaces r as curve radius in the following calculations.

In our proposal we do not consider changing minimal curve radii due to changing speeds over time. Such an approach would lead to multiple possible paths the vehicles could take in order to collide. This is an optimization problem which would be too inefficient to solve for our operational scenario.

Speed	Acceleration
$0 < v \leq 60\ \frac{\mathrm{km}}{\mathrm{h}}$	$3.79\ \frac{\mathrm{m}}{\mathrm{s}^2}$*
$60\ \frac{\mathrm{km}}{\mathrm{h}} < v \leq 80\ \frac{\mathrm{km}}{\mathrm{h}}$	$3.42\ \frac{\mathrm{m}}{\mathrm{s}^2}$*
$80\ \frac{\mathrm{km}}{\mathrm{h}} < v \leq 100\ \frac{\mathrm{km}}{\mathrm{h}}$	$2.83\ \frac{\mathrm{m}}{\mathrm{s}^2}$*
$100\ \frac{\mathrm{km}}{\mathrm{h}} < v \leq 120\ \frac{\mathrm{km}}{\mathrm{h}}$	$2.43\ \frac{\mathrm{m}}{\mathrm{s}^2}$*
$120\ \frac{\mathrm{km}}{\mathrm{h}} < v$	$1.5\ \frac{\mathrm{m}}{\mathrm{s}^2}$

Table 1. Used acceleration values (* taken from [16]).

Speed	Deceleration
$0 < v$	$10.5\ \frac{\mathrm{m}}{\mathrm{s}^2}$*
$-10\ \frac{\mathrm{km}}{\mathrm{h}} < v \leq 0\ \frac{\mathrm{km}}{\mathrm{h}}$	$1\ \frac{\mathrm{m}}{\mathrm{s}^2}$
$v \leq -10\ \frac{\mathrm{km}}{\mathrm{h}}$	$0\ \frac{\mathrm{km}}{\mathrm{h}}$

Table 2. Used deceleration values (* taken from [16]).

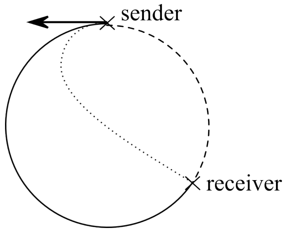

Fig. 2. The circular path might not be the fastest way for the sender to reach the receiver.

Step 3: Maximizing the Relevance Value (Lines 12–18). We calculate the relevance value in an iterative way. For each time step we first calculate the distance between sender and receiver d. We use this distance to calculate the relevance value for each time step. The resulting maximum relevance value R is an approximation for the result of Equation (1) with distance function $d^{\text{circular}}_{\text{straight}}(\alpha, \beta, r, t, v)$.

3.4 Criticism

The presented approach may not find the fastest path for the sender to reach the receiver and, therefore, yield too low relevance values. Figure 2 illustrates an example: our approach supports movement on the solid and dashed line paths. Instead, the sender may drive on the dotted path by first taking a turn with low speed and accelerate afterwards. Depending on the initial conditions, this path may lead to higher relevance values.

When a vehicle accelerates, it may first drive a narrow curve at low speed and a wider curve only at high speed. In sum, the vehicle may have changed its direction more than under the assumption that the minimum radius of the curve was governed by the maximum speed. Thereby, the relevance of senders in some positions may be underestimated.

A shortcoming of the proposed functions is that they do not yet account for potential movement changes of the receiver. That is also relevant: a sender may follow a receiver both driving at 200 $\frac{\mathrm{km}}{\mathrm{h}}$. While the sender can hardly accelerate at that speed, the receiver can brake which quickly reduces the distance between the two vehicles.

4 Evaluation

In this section we evaluate the improved relevance estimation function. First, we describe the evaluation methodology. Then, we demonstrate the impact of different parameter sets on the relevance values.

4.1 Methodology

The evaluation in the following section is based on the receiver-centric notation as described in Section 3.1. The senders' and receivers' position and movement vectors are translated such that the receiver is still and located in the origin of a two-dimensional coordinate system. The sender is located relatively to the receiver such that its movement vector is pointing horizontally from right to left.

If not stated differently, we set $d_{\min} = 10$ m and $T_{\max} = 8\ s$. We set the time penalty exponent such that $(1 + \frac{T_{\max}}{\mathrm{s}})^{-\gamma} = 0.3$, i.e., $\gamma = -\frac{\ln(0.3)}{\ln(1+\frac{T_{\max}}{\mathrm{s}})} = 0.548$ to prevent steep transitions for distant senders.

We evaluate the relevance estimation function by calculating the relevance values for all sender positions in a 160 m × 300 m rectangle around a potential receiver. The selectable parameters for the experiment are $d_{\min}$, $T_{\max}$, γ, $|\mathbf{v}_\alpha^{\mathrm{rel}}|$, and $|\mathbf{v}_\alpha|$. Figures 3(a)–3(f) show the results of our experiments. The x- and y-axis indicate the position of a sender relative to the receiver. The color in the figures indicates the relevance of the sender due to its position and other parameters. The diagrams below the figures show the relevance of senders with $y = 0$ m depending on their x-positions. In the following, we discuss these diagrams for different sets of selectable parameters.

4.2 Impact of Relative Speed $|\mathbf{v}_{\boldsymbol{\alpha}}^{\mathbf{rel}}|$ and Sender Speed $|\mathbf{v}_{\boldsymbol{\alpha}}|$

In Figure 3(a) the initial relative speed of sender and receiver is $0\ \frac{\mathrm{m}}{\mathrm{s}}$ and the absolute speed of the sender $|\mathbf{v}_\alpha|$ is also $0\ \frac{\mathrm{m}}{\mathrm{s}}$, i.e., both vehicles are standing still. We identify two effects. First, the area from where senders are able to reach the vicinity of the receiver within time $T_{\max}$ is curved. This is caused by the consideration of a circular path movement as described in Section 3.2. Second, the areas above and below the center of the upper plot have a significantly lower relevance value. This effect is caused by the minimum curve radius implementation. Senders originating in these areas cannot reach the vicinity of the receiver on a circular path at their current speed and, therefore, their relevance is low.

Figure 3(b) shows the impact of a positive absolute sender speed $|\mathbf{v}_\alpha| = 30\ \frac{\mathrm{m}}{\mathrm{s}}$. As the relative speed $|\mathbf{v}_\alpha^{\mathrm{rel}}|$ is set to $30\ \frac{\mathrm{m}}{\mathrm{s}}$, this means that the receiver is standing still. The plot shows higher relevance values in the right half, as the senders are moving initially and approach the receiver faster than in Figure 3(a). The corridor is extended to the right. This is because senders driving towards the receiver can reach it within $T_{\max}$ from larger distance than in Figure 3(a) due to their initial positive speed. We also observe that the areas above and below the center of the plot are now wider. Due to the higher initial speed compared to Figure 3(a), a larger maximum speed can be reached which leads to a larger minimum curve radius.

Figure 3(c) depicts a relative speed $|\mathbf{v}_\alpha^{\mathrm{rel}}|$ of 0 $\frac{\mathrm{m}}{\mathrm{s}}$, while the sending vehicles' speed $|\mathbf{v}_\alpha|$ is set to 30 $\frac{\mathrm{m}}{\mathrm{s}}$, i.e., both vehicles are driving with 30 $\frac{\mathrm{m}}{\mathrm{s}}$ in the same direction. We observe a corridor of highly relevant senders in the left half of the plot. This results from the fact that senders may brake (and slowly driving backwards) while the receiver is approaching them with constant speed. The corridor to the right of the receiver is shortened. This is caused by the fact that fast driving cars have lower acceleration values than standing vehicles so that only senders in a smaller area behind the receiver can reach its vicinity within short time.

4.3 Impact of Minimum Distance $d_{\min}$

The parameter $d_{\min}$ denotes the near vicinity of the receiver in which all senders have the same maximum relevance. Figure 3(d) depicts the output of the relevance function of a changed value for minimum distance $d_{\min}$ of 20 m. We changed the scale of the coloring in this particular plot because the maximum relevance value is now $\frac{1}{20} = 0.05$. We observe that the area around the receiver with maximum relevance values grows with $d_{\min}$ and also the surrounding area has slightly changed relevance values.

4.4 Impact of Time Penalty Exponent γ

In Figure 3(e) we change the time penalty exponent such that $(1+\frac{T_{\max}}{\mathrm{s}})^{-\gamma} = 0.6$ holds, which yields $\gamma = 0.233$. We observe more abrupt transitions at the border from high to low relevance values and an overall increase for high relevance values. In comparison to Figure 3(a) a short corridor of relevant senders appears to the left of the center. These senders approach the vicinity of the receiver by driving slowly backwards. Due to the lower γ, senders in this area are now more relevant.

4.5 Impact of Extrapolation Duration $T_{\max}$

In Figure 3(f) the extrapolation duration $T_{\max}$ is set to 16 s, i.e., the time interval for movement extrapolation $T_{\max}$ is doubled. Compared to Figure 3(a), the corridor of high relevance grows to the right, and we observe a bigger area of low relevance above and below the center of the plot; the latter is due to a larger minimum curve radius which needs to be respected if $T_{\max}$ is longer because then a higher extrapolated speed can be reached. A short corridor of senders to the left of the receiver also gains enough negative speed to approach the receiver, which leads to high relevance values for these senders.

5 Conclusion and Future Work

Each vehicle equipped with VANET technology will receive Cooperative Awareness Messages (CAMs) from neighboring vehicles and infrastructure. Series vehicles have to be able to process high rates of CAMs if the technology's penetration rate rises and local traffic is dense. In an earlier work we proposed a relevance estimation function which determines a relevance value for each received CAM based on basic information like position and movement without a map. This approach utilized static movement extrapolation which may not be realistic enough to estimate good relevance values. In this paper, we proposed a more sophisticated relevance estimation function that considers changes in heading and speed of the sending vehicles.

Before the improved relevance estimation function can be integrated into a series system, one has to evaluate the functions' results for real or simulated traffic and its ability to predict relevance via extrapolation. We may have to augment the improved function with further effects such as potential movement changes of the receiver which are not yet considered in this work. The used parameters have to be tuned to conform to typical vehicular behavior. To facilitate an efficient implementation, we propose to determine relevance values in a vehicular implementation by using a characteristic diagram.

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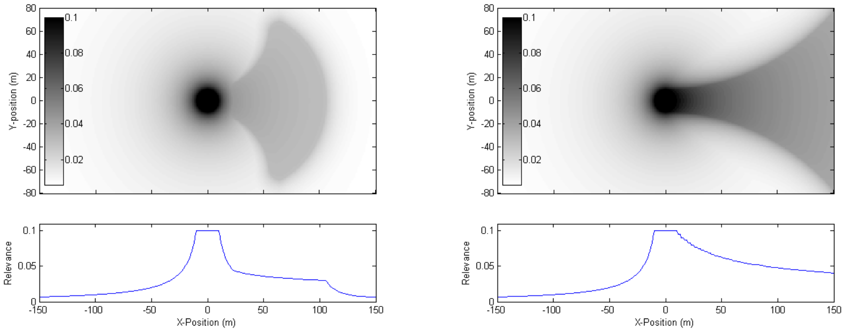
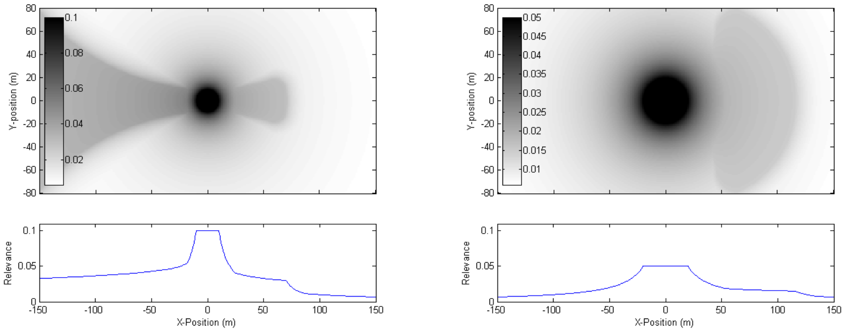
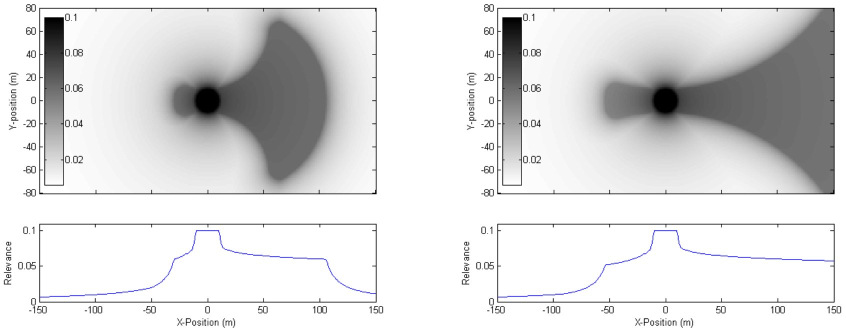


(a) $|\mathbf{v}_\alpha^{\mathrm{rel}}| = 0\ \frac{\mathrm{m}}{\mathrm{s}}$, $|\mathbf{v}_\alpha| = 0\ \frac{\mathrm{m}}{\mathrm{s}}$ (b) $|\mathbf{v}_\alpha^{\mathrm{rel}}| = 30\ \frac{\mathrm{m}}{\mathrm{s}}$, $|\mathbf{v}_\alpha| = 30\ \frac{\mathrm{m}}{\mathrm{s}}$



(c) $|\mathbf{v}_\alpha^{\mathrm{rel}}| = 0\ \frac{\mathrm{m}}{\mathrm{s}}$, $|\mathbf{v}_\alpha| = 30\ \frac{\mathrm{m}}{\mathrm{s}}$ (d) $|\mathbf{v}_\alpha^{\mathrm{rel}}| = 0\ \frac{\mathrm{m}}{\mathrm{s}}$, $|\mathbf{v}_\alpha| = 0\ \frac{\mathrm{m}}{\mathrm{s}}$, $d_{\min} = 20$ m, changed color scale



(e) $|\mathbf{v}_\alpha^{\mathrm{rel}}| = 0\ \frac{\mathrm{m}}{\mathrm{s}}$, $|\mathbf{v}_\alpha| = 0\ \frac{\mathrm{m}}{\mathrm{s}}$, $\gamma = 0.233$ (f) $|\mathbf{v}_\alpha^{\mathrm{rel}}| = 0\ \frac{\mathrm{m}}{\mathrm{s}}$, $|\mathbf{v}_\alpha| = 0\ \frac{\mathrm{m}}{\mathrm{s}}$, $T_{\max} = 16$ s

Fig. 3. Relevance values for senders moving from right to left depending on position and speed relative to a sender at the origin. The upper parts of the figures show the spatial results, whereas the lower parts are a cross-section for y-position 0 m (default values $\gamma = 0.548$, $T_{\max} = 8$ s, and $d_{\min} = 10$ m).