Daniel Bischoff and Tobias Meuser. *Geo-based Backend Dissemination for Safety-relevant V2X Applications*. In: Proc. of the AmE 2019 - Automotive meets Electronics, VDE Verlag, ISBN: 978-3-8007-4877-8

Geo-based Backend Dissemination for Safety-relevant V2X Applications

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***Abstract*—Safety-relevant V2X applications can be enhanced using communication, such that even objects out of the vehicle's sensor range are known by the vehicle. This communication congests the communication channel, which is relieved by reducing the dissemination of these messages. However, this decreases the performance of safety-relevant V2X applications, as the knowledge of the vehicles is limited.**

In this work, we increase the awareness range of vehicles by distributing information over larger distances without increasing the channel load. Our approach is based on the assumption, that only those messages should be exchanged, which are of value for the application. Thus, we develop a utility function for a V2X Intersection Collision Warning application which aims at capturing the relevance of a location-message for a specific vehicle. For this application, the relevance is defined as the probability that two vehicles meet at the intersection. Based on this utility, location-messages are exchanged stochastically.

In the evaluation, we show that our approach reduces the channel utilization by up to 68 % in the downlink channel, while similarly increasing the awareness range of vehicles. Additionally, the update frequency of vehicles meeting at the intersection is comparable to the baseline dissemination strategy.

***Index Terms*—Cellular vehicular communication, Geoserver, intersection collision application, C-ITS, V2X**

I. Introduction

The increasing number of vehicles on the road causes traffic jams and more complex situations for the driver. To relieve the driver and increase traffic safety, safety-relevant driver assistant systems are deployed to today's vehicles. Nowadays, these systems rely mostly on the vehicle's sensors like cameras and radars to sense the environment around the vehicle. To improve the environmental view obtained by local perception, communication between vehicles (V2V) as well as vehicles and the infrastructure (V2I) has been introduced. Due to the early detection of potential risks, existing safety and efficiency applications can be further enhanced [1]. At intersections, V2X-enabled vehicles share their current geographic position and speed information, which is known as Floating Car Data (FCD). Crossing vehicles, shadowed by surroundings, can be localized and tracked even before the driver or other sensors recognize them. Hence, the system and the driver have additional time to prevent an alleged accident [2].

The wireless communication channel limits the area in which these FCD messages can be distributed. To further increase the reaction time for the system and the driver, this communication area needs to be increased further. Unfortunately, a larger communication area will also induce additional channel load to the communication network. That is, perceiving information from more vehicles at long distances increases the total number of received messages. As the channel bandwidth physically limits the capacity of the communication channel, the communication channel will start to congest near intersections [3].

Preventing alleged accidents requires the system to predict the moving path of other vehicles based on the current position and vehicle speed and coordinate with potentially colliding vehicles. As the uncertainty of prediction at long distances is high [4], the provision of highly accurate information in terms of update frequency has no added value. That is, the prediction error is assumed to be much higher, than the error caused by the less frequent provision of data.

In current approaches, the dissemination rate of FCD messages only depends on the receivers dynamic data [5]. In cellular communication systems, messages can either be distributed to a set of vehicles (Multimedia Broadcast Multicast Service (MBMS)) or each vehicle separately (Unicast). MBMS exhibits the delay constraints for session setups [6], which is required to group a set of vehicles. Due to the high mobility of nodes, the session groups are very dynamic. Thus, MBMS would require continuous session setups, which would increase the latency and overhead. In unicast transmission mode, the aforementioned dissemination approach will congest the communication channel [2]. For an Intersection Collision Warning (ICW) application, we propose to adapt the FCD message dissemination rate in the downlink channel for each vehicle individually using unicast transmission mode. The FCD message dissemination rate for each vehicle is derived from the ICW application's relevance in this information. Hence, the communication channel load can be significantly reduced while maintaining equal application performance.

Therefore, our contributions are as follows: (i) We derive the utility function of information for a V2X ICW application, (ii) we develop a message dissemination adaptation approach for an ICW application based on the aforementioned utility function, and (iii) perform a comprehensive performance evaluation in terms of message rate, awareness time and relevance rate for an ICW application.

II. Related Work

Cellular communication networks aim at addressing vehicles based on their geographical position. Key challenges are the identification of relevant receivers and efficient message dissemination. In the following, we briefly summarize existing dissemination strategies for cellular vehicular networks.

In [7], a GeoCast service is described, where vehicles continuously send their geo-position to a Geocast server (Geoserver). To save overhead in the uplink channel, only the Cluster Head (CH) is connected to the Geoserver. With the location information of each CH, the Geoserver can forward geo-specific information. This information is disseminated via ad hoc broadcast communication.

In [8], a map is divided into a set of cells. The number of cells and the size of each cell depends on the respective application in the Geoserver and can be modified. Vehicles will report *leaving the current cell* to the Geoserver. In turn, the Geoserver informs the respective vehicle about the boundaries of the next cell. Hence, the Geoserver can forward information to all members of one or multiple cells. This approach was extended by a graph-based routing in [9].

To improve latency and throughput of cellular networks, the authors in [10] propose to combine unicast and multicast transmission modes based on the channel load. If the number of unicast connection with the same information increases, a Temporary Mobile Group Identity (TMGI) together with the Group Radio Network Temporary Identifier (G-RNTI) is assigned to the eNodeB and forwarded to all cell members via unicast. After the setup phase is finished, the channel load can be improved using multicast transmission mode and vice versa. TMGI and G-RNTI are assigned to specific geo-locations and used for the multicast session group. A similar approach is described in [11], where the G-RNTI and TMGI refer to specific geographical areas, called Geo-G-RNTI. As the Geo-G-RNTI are known to the vehicle's application, the application will join and leave multicast session groups without a dedicated assignment using their self-positioning system.

In [12] the authors determine the relevance of information for vehicles in route segments. The approach aims at ensuring the reception of an event for each vehicle once. The vehicle, which approaches the concerned route segment next, is prioritized.

To the best of our knowledge, an application-specific adaptation of FCD message dissemination rate in cellular networks for an ICW application has not been proposed yet.

III. Scenario

In this chapter, we provide an overview of our scenario and summarize our assumptions. In the following, we will focus on an intersection, which is depicted in Figure 1. At this intersection, vehicles are crossing the lane of each other and could potentially collide without interference. We investigate the relevance assessment for an ICW application, which aims at improving the traffic flow at the intersection.

The ICW application aims at informing vehicles of each other if they might collide at the intersection. Thus, our relevance assessment in section IV considers information as relevant, if it can be used to prevent a collision.

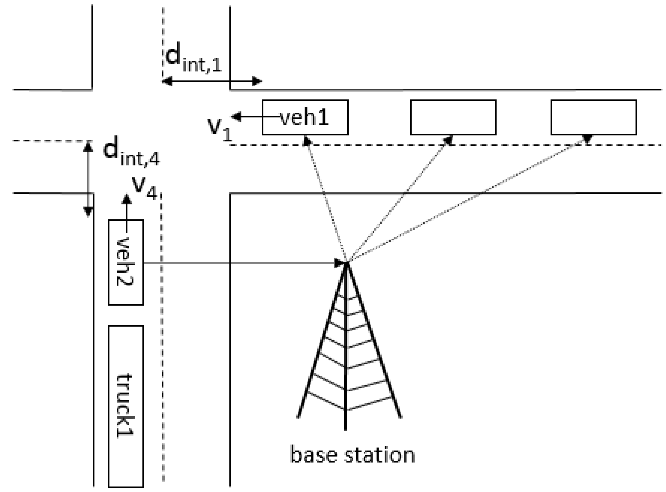

Fig. 1. Intersection scenario

For the remainder of this paper, we assume the following:

a) Assumption 1: We assume an error-free and low-latency communication, as we are using cellular communication. Therefore, the communication coverage is ensured for all vehicles within the scenario. Safety-critical intersections are often characterized by infrastructures blocking the line-of-sight path to crossing vehicles. Hence, the driver's reaction time to mitigate a collision with a crossing vehicle is significantly reduced. A similar problem applies to direct communication. The infrastructure shadows the communication path to crossing vehicles and hence the communication quality degrades severely. Using cellular communication, we leverage the height of base station antennas in cellular communication networks and the efficient routing capabilities to vehicles at long distances.

b) Assumption 2: We assume that all vehicles are equipped with an ICW application and have a self-positioning mechanism with an error-free accuracy. In addition, we assume that all vehicles are connected to the base station. Vehicles will provide location updates and their current driving speed to the Geoserver with a constant frequency of $10\,\mathrm{Hz}$ within our scenario. This assumption follows the interval adjustment approach within an intersection in [13].

c) Assumption 3: We assume that the upper and lower value for the vehicle's deceleration a_{dec} for safety-critical applications are $a_{\text{dec,min}} = 3\,\mathrm{m/s^2}$ and $a_{\text{dec,max}} = 10\,\mathrm{m/s^2}$, respectively. The minimum required time to trigger a warning is defined in [13] as $TTI_{\text{min}} = MLT + MDRT + MAT + \epsilon$, where MLT, $MDRT$, MAT and ϵ denote the maximum latency time, maximum driver reaction time, maximum action time and margin time, respectively. For simplicity, we assume a latency-free processing of messages in the application. Further, following assumption 4, the level of accuracy of the self-positioning system is error-free. Hence, we get $MLT = 0$ and $\epsilon = 0$, respectively. The reaction time of the driver is assumed to be $MDRT = 1\,\text{s}$. Using $a_{\text{dec,min}}$, $a_{\text{dec,max}}$ and $v = 50\,\text{m/s}$, we get $MAT_{a_{\text{dec,min}}} = 4.63\,\text{s}$ and $MAT_{a_{\text{dec,max}}} = 1.39\,\text{s}$. Finally, we obtain the boundaries of the Time To Interesection (TTI) with $TTI_{a_{\text{dec,max}}} = 2.39\,\text{s}$ and $TTI_{a_{\text{dec,min}}} = 5.63\,\text{s}$, where $TTI_{\text{min}} = TTI_{a_{\text{dec,max}}}$.

The Geoserver manages the received information and sends the vehicles' data to other vehicles, which are also approaching the same intersection and are potentially colliding with this vehicle. To relieve the load in the downlink channel, the Geoserver obtains the relevance in the received information for each vehicle separately and hence, only forwards the required number of messages.

We characterize the relevance of information by an utility function. That is, the relevance of information of vehicle *veh1* will vary for each receiver. The utility mainly depends on the vehicles current position and speed. By dividing the distance to the intersection $d_{\text{int},1}$ by the vehicle speed v_1, the TTI for *veh1* can be calculated. The utility and the TTI are also reciprocal. That is, the relevance in information increases while approaching the intersection. We derive the utility function for the ICW application described herein in the next section.

IV. Information Assessment

As mentioned above, the available communication channel bandwidth is limited and costly. Thus, the shared information between vehicles should be as minimal as possible. To lower the load on the network, information might be dropped by the server or not even transmitted by vehicles. Deciding which information to discard is a challenging topic and requires knowledge of the applications running on the vehicles. In this work, we assess the relevance of information for an application managing the vehicles' behavior near an intersection. For this application, the vehicles share their current location among each other to optimize the traffic flow. Thus, we define the relevance of FCD as the probability that two vehicles will meet at the intersection. Additionally, we assume the following: (i) A vehicle requires less accurate information, when it is distant to the intersection, as its possible reactions have more impact and do not negatively influence the driver. (ii) The closer the vehicle gets to the intersection, the more accurate information is required, as the driver's/vehicle's reactions are quite limited at this point. (iii) The relevance is commutative, i. e., the relevance of the position of vehicle *veh1* to vehicle *veh1* is the same as the relevance of the position of vehicle *veh2* to vehicle *veh1*. In the following, we will focus on the assumptions (i) and (ii), while (iii) is considered in subsection IV-B.

A. Modeling of Vehicle Arrival Times

To investigate the information requirements of a vehicle, we need to model the TTI for each vehicle. As we are unaware of the future behavior of the vehicle and all other vehicles in the system, we model the arrival times using a probability density function. In future work, prediction approaches considering information-specific properties like in [14] might be used to increase the accuracy of the prediction. This function needs

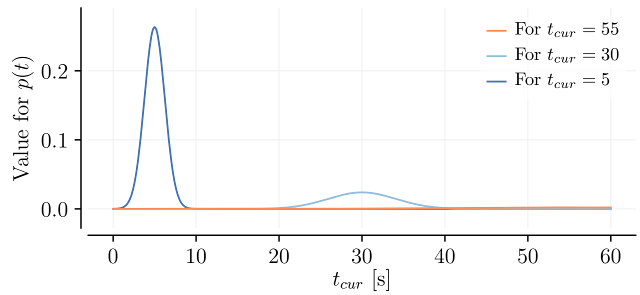

Fig. 2. Distribution of TTI for $\alpha = 1000$ and $TTI_{\text{max}} = 60$. The $\sigma(t_{\text{cur}})$ decreases with decreasing t_{cur}

to provide more accurate results if the vehicle is near the intersection and less accurate results the farther the vehicle is away from the intersection. At a predefined time TTI_{max}, no prediction (not even an inaccurate one) should be possible. We model this requirement based on the standard deviation $\sigma(t_{\text{cur}})$ of the probability density function, where t_{cur} is the expected TTI based on the vehicle's current speed and distance to the intersection. According to our previously stated requirements, $\sigma(0) = 0$, i. e., the vehicle's arrival time is known, and $\sigma(TTI_{\text{max}}) \rightarrow \infty$, as no knowledge of the vehicle's TTI is available at TTI_{max}. Thus, we model the distribution of $\sigma(t_{\text{cur}})$ as shown in Equation 1, where $\alpha \in \mathbb{R}^+$ is the scale factor that depends on the expected behavior of the vehicle and $\beta \in \{\mathbb{R}^+ | \beta \geq 1\}$. If a vehicle is expected to continually change its speed, its α should be high to account for the uncertainty in its arrival time. Similarly, α should be low if the vehicle is expected to change its speed less frequently. β improves the performance of the approach while similarly increasing the number of transmitted messages. In this work, we have assumed $\beta = 2$.

$$\sigma(t_{cur}) = \alpha * \left[\frac{1}{\beta * TTI_{\text{max}} - t_{\text{cur}}} - \frac{1}{TTI_{\text{max}}} \right] \tag{1}$$

Using Equation 1, we determine the distribution of the TTI t, which should have the standard deviation $\sigma(t)$ For this purpose, we utilize the modified Gaussian function as depicted in Equation 2. In this equation, t_{cur} refers to the average TTI of the vehicle, which is calculated dividing the remaining distance to the intersection by the current vehicle speed.

$$p(t, t_{\text{cur}}) = \frac{1}{\sqrt{2 * \pi} * \sigma(t_{\text{cur}})} * \exp\left[\frac{-(t - t_{\text{cur}})^2}{2 * \sigma(t_{\text{cur}})} \right] \tag{2}$$

We utilize Equation 2 to predict the possibility of two vehicles colliding, i. e., to determine the importance of FCD for a vehicle.

B. Relevance of Location-based Messages

As stated previously, we define the relevance of FCD with the probability of two vehicles meeting at the intersection. Otherwise, none of the vehicles requires the location of the other vehicle, as this information would not influence their driving behavior and thus would not bring any benefit to the vehicle.

To calculate the probability of two vehicles meeting at the intersection, we need to analyze their respective TTI functions for their current TTIs $t_{\text{cur},1}$ and $t_{\text{cur},2}$. For this purpose, it is essential how probable each of the two vehicles is at the intersection at a particular time. However, we need to consider the vehicles' length in the calculation: Even though a vehicle's forefront might have already passed, the vehicle might still be at the intersection due to its length. We consider each vehicles' length using the vehicle specific value $t_{\text{l},1}$ and $t_{\text{l},2}$, which refer to the duration the vehicle needs to travel its length. Based on this, we derive the collision probability p_{c} as shown in Equation 3. This equation resembles as follows: The outer integral captures the possible arrival times of the first vehicle. According to its TTI function, it might arrive between 0 and TTI_{max}. Thus, we use these two values as the boundaries for our integral. The probability of the first vehicle arriving at t_1 is then multiplied by the probability of the second vehicle colliding with it. For this to happen, there are two possibilities: First, the second vehicle arrives before the first one, in which case the first vehicle would crash into the rear of the second vehicle. Second, the second vehicle arrives while the first vehicle is still at the intersection, in which case the second vehicle would crash into the rear of the first vehicle. Based on this equation, we can derive the collision probability of the two vehicles.

$$p_{\text{c}} = \int_0^{TTI_{\text{max}}} \left[p(t_1, t_{\text{cur},1}) * \int_{t_1 - t_{\text{l},2}}^{t_{\text{l},1}} p(t_2, t_{\text{l},2}) dt_2 \right] dt_1 \quad (3)$$

Figure 3 displays an example distribution of the collision probability for two vehicles with their respective TTIs. It can be observed, that in the area for any TTI smaller than $2.4\,\text{s}$, the relevance is 1 to provide all necessary information in case of an unavoidable collision. Previously to that, our approach aims at predicting the collision probability of the two vehicles based on their current TTI. Thus, the collision probability is high if the two TTIs are similar. The width of the part where the collision probability is high, depends on α. A high α leads to a wide curve with a lower height, while a low α leads to a high curve with a low width.

We use this distribution to determine the relevance of a message for a vehicle. If the collision probability is high, the relevance is high and vice versa. In the next section, we will show the performance of our approach and analyze the impact of the different parameters.

V. Evaluation

In this section, we evaluate the performance of our approach. In the following, we introduce our simulation setup, the baseline approach and the metrics used.

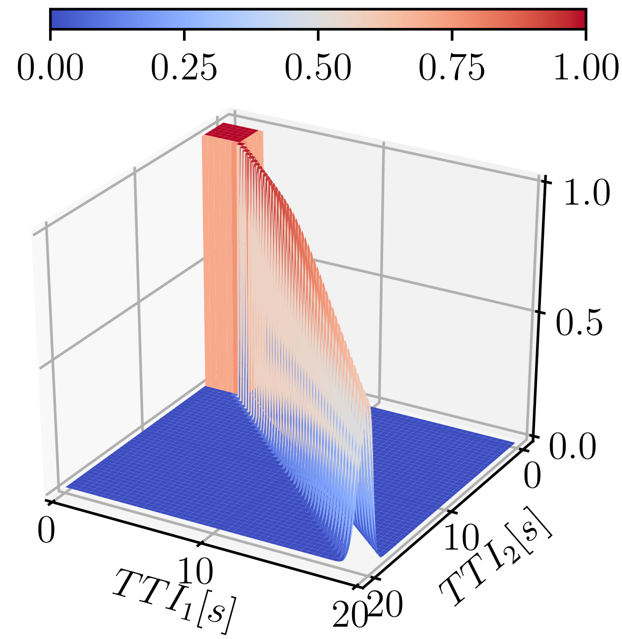

Fig. 3. Relevance function for two vehicles with their respective TTIs. The relevance is highest if the vehicle both vehicles are close to the intersection.

A. Simulation setup

For the evaluation of the communication network, we use the event-based Simonstrator framework[1] [15]. The Simonstrator supports ad hoc and cellular communication. SUMO [16] is used for the representation of the traffic flow and mobility models. The TraCI interface is used to couple both simulators. We assume a continuous traffic flow from two directions of the intersection with mixed traffic as depicted in Figure 1, where vehicles and trucks approach with an average speed of $50\,\text{km/h}$. Our scenario is $450 \times 450\,\text{m}^2$ in size.
In addition, crossing traffic will physically collide when occupying the center of the intersection at the same time, as we assume single-lanes. Thus, there is not enough space to mitigate the accident with a steering intervention. Furthermore, vehicle drivers will not mitigate a collision in the intersection. Hence, drivers will not follow the right-of-way rule.

B. Baseline approach

We compare the performance of our proposed approach with a simple forwarding approach. For the simple forwarding approach, the server forwards all incoming location updates to all vehicles in the intersection with the received frequency. Under our assumption 5, the server starts forwarding messages to crossing vehicles with a $TTI_{\text{max}} = 5.63\,\text{s}$ and an update rate of $10\,\text{Hz}$ as defined in assumption 4.

C. Metrics

For performance comparison evaluation, we introduce the following metrics:

[1] https://www.dev.kom.e-technik.tu-darmstadt.de/simonstrator/

- **Number of FCD messages** This metric describes the number of FCD messages forwarded to vehicles within the intersection scenario in the downlink channel. The FCD message rate indicates the data traffic caused by different approaches. We aim at reducing the number of messages to relieve the channel load.
- **Awareness Time** This metric describes, at which TTI the vehicle is notified about a potential colliding vehicle for the first time. The earlier a vehicle is aware of other vehicles, the earlier countermeasures can be taken.
- **FCD Update Rate** This metric defines the received FCD message rate. We limit this metric between the lower and upper TTI bound. Within this interval, very frequent data updates are required for the movement prediction.

D. Simulation Results

We evaluate the performance of our approach compared to the baseline by varying the scale factor α and the maximum TTI TTI_{max}.

Figure 4 displays the produced data traffic of our approach. It can be observed that the amount of produced data traffic is reduced between $20\,\%$ and $68\,\%$ compared to the baseline approach. This reduction of traffic is mostly caused by the application-aware distribution of information by our approach. For the intersection scenario, only information of vehicles with a similar TTI is necessary, as those vehicles might need to interact with each other. Thus, only information of these vehicles is required and sent to the vehicles. We exclude the approaches at $TTI_{\text{max}} = 5.6\,\text{s}$ and $\alpha \geq 1000$ from this consideration, as the approaches did not achieve a $100\,\%$ notification of vehicles. Although our approach cannot guarantee a message delivery before $t_{\text{cur}} = 2.4\,\text{s}$, there are no unknown vehicles for $\alpha \leq 100$.

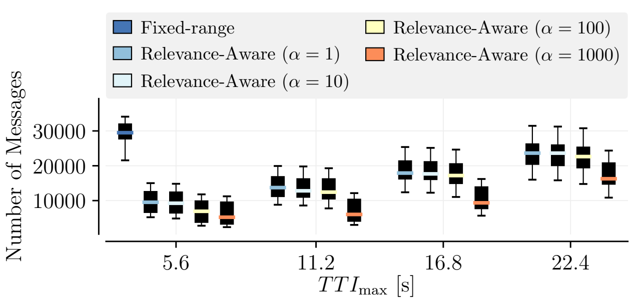

Fig. 4. *Number of Messages* depending on the scale factor α and the maximum TTI TTI_{max}. On the left, the baseline approach is displayed. Our approach uses significantly less bandwidth.

This observation is supported by Figure 5, which shows the update frequency of two colliding vehicles between $t_{\text{cur}} = 2.4\,\text{s}$ and $t_{\text{cur}} = 5.6\,\text{s}$. Notice that these TTIs are chosen such that the driver of the vehicle can still react to the opposing vehicle. The highest update rate is achieved by the baseline approach, as this approach forwards all information of vehicles with $t_{\text{cur}} \leq 5.6\,\text{s}$. However, our approach only provides information of vehicles with a similar TTI. If the update rate is lower than $10\,\text{Hz}$, this is justified by the inaccuracy of the predicted TTI. A higher TTI_{max} generally increases the update frequency for all α. For $\alpha \leq 10$, our approach even achieves a high update rate if $TTI_{\text{max}} = 5.6s$. The performance for $\alpha = 100$ depends on TTI_{max}, as the inaccuracy of the prediction increases with increasing α. For $\alpha > 100$, the update frequency seems to be inefficient for our considered intersection application, though it might be reasonable for other applications with lower requirements on information freshness.

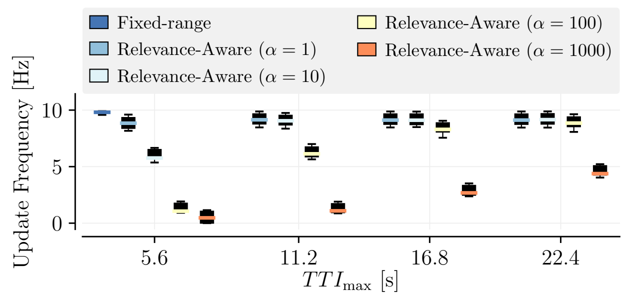

Fig. 5. *FCD Update Rate* depending on the scale factor α and the maximum TTI TTI_{max}. On the left, the baseline approach is displayed. The Update Rate of our approach depends on the parameters, but is always slightly lower compared to the baseline.

Another aspect of our approach is depicted in Figure 6. Even though our approach consumes less bandwidth compared to the baseline approach, it can notify vehicles of possible collisions much earlier compared to the baseline approach. For $TTI_{\text{max}} = 22.4\,\text{s}$, vehicles are notified up to $20\,\text{s}$ before a potential collision of the other vehicle. This early knowledge enables more efficient coordination between vehicles and can improve the driving behavior of the vehicle. It can be observed that the vehicles are notified much later if $\alpha > 100$. This late notification is justified by the lower collision probability, which is induced by a lower certainty of the vehicles' movement. However, the vehicles have received a more general overview of other vehicles, but only with a lower update rate. As the vehicles' speed in our SUMO-based simulation does not fluctuate, our approach performed better if α is low. However, it needs to be considered, that in our setting, the changes in traffic flow have been rather low due to the use of a traffic simulator. When applying our approach to real vehicles, it might be necessary to choose a higher α to account for changes in the vehicles' driving behavior.

Summarizing, our evaluation shows the versatility of our approach, which can adapt to different applications by changing the parameters accordingly. A low α reduces the uncertainty in FCD message dissemination, which makes the dissemination more efficient while reacting more slowly to changes in a vehicle's behavior. A high α already considers these changes and thus provides a broader view of the environment. However, this broader view leads to less information received by one individual vehicle.

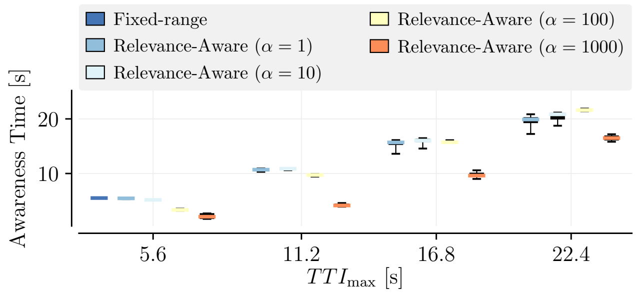

Fig. 6. *Awareness Time* depending on the scale factor α and the maximum TTI $TTI_{\max}$. On the left, the baseline approach is displayed. Our approach provide information about potential collisions much early, which can improve the decision-making of the vehicles.

$TTI_{\max}$ impacts the produced network traffic significantly, as the number of vehicle positions changes. A high $TTI_{\max}$ increases the produced network traffic, while similarly increasing the awareness range of the vehicles. This early notification enables a prior coordination of vehicles, which might be required depending on the application requirements.

VI. Conclusion

In this paper, we presented a novel cellular dissemination strategy for an ICW V2X application. Our dissemination strategy makes use of a relevance assessment approach, to distribute only necessary information to the vehicles within an intersection scenario. Our relevance assessment approach obtains the collision probability of two crossing vehicles and uses the relevance in the information dissemination.

We compared the performance of our approach with a straightforward forwarding approach, where the message frequency is fixed. In our evaluation, we showed that our approach significantly reduces the number of FCD messages and also increases the awareness time. This is achieved as our approach obtains the collision probability of two vehicles and adapts the message frequency accordingly. This adaptation leads to few messages when a vehicle is far from the intersection and increases with decreasing distance to the intersection.

We also showed that the FCD message rate right in front of the intersection is almost equal to the baseline approach for colliding vehicles which allows for a highly accurate movement prediction. The reduction of data traffic is achieved by only providing information of vehicles that will probably collide. Our approach allows the adaptation to different scenarios by changing the parameter values. In our future work, we will investigate relevance-aware dissemination for different safety-relevant V2X applications. Additionally, we want to make use of heterogeneous communication approaches to lower the load on the cellular network further.

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