Can Mobility Prediction be Compatible with Cooperative Active Safety for VANET?

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ABSTRACT

Cooperative Active Safety applications for VANET require an up-to-date knowledge of a vehicle's immediate surrounding (awareness) obtained by all vehicles broadcasting their status information (position, speed). Periodically transmitted, it leads to wireless congestion, while adapting the rate of its transmission to some predicted motions impacts the accuracy of this knowledge and the reliability of the safety application. In this paper, we investigate whether a trade-off can be found to this critical and challenging issue. As initial answer, we propose an enhanced particle filter prediction model based on bio-inspired glow-worms clustering capabilities. It is designed to react quicker to sudden traffic changes typically found in traffic safety situations (such as sudden breaks or sudden direction changes) to provide a high surrounding knowledge precision with less required transmissions. Simulations conducted with calibrated urban traffic in Bologna showed that we can ensure on the one hand a suitable adaptation of the channel load, and on the other hand, a high precision of awareness prediction and a capacity to detect traffic changes adapted to VANET traffic safety applications.

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Keywords: VANET, Traffic safety, Awareness, Mobility Prediction, Transmit Rate Control, Swarm Intelligence.

1. INTRODUCTION

Cooperative Active Safety represents a major VANET application domain, where traffic danger either mobile or static should be detected and avoided through cooperative communication between vehicles. Such detection is reached by the periodic exchange of status information (position, speed) on Cooperative Awareness Message (CAM) or beacons of each surrounding vehicle on a simultaneously shared wireless medium. The expected high number of vehicles simultaneously sharing the wireless channel assuming the high periodic transmission rate required by safety applications is expected to lead to congested wireless conditions and accordingly to a degradation of the performance of the wireless medium, an awkward situation for traffic safety applications. To reduce the load on the channel and accordingly increase its reliability, the transmission rate of such CAM/beacon cannot blindly be reduced. Rather, several studies, such as [4, 5], considered the observed regularities behind vehicular mobility to predict future vehicular positions and reduce the number of unnecessary CAM/beacon transmissions. Although showing a significant capability to lower the wireless channel congestion, these approaches have not been optimized with traffic safety requirements in mind. Yet, they should become the primary source of awareness used by cooperative safety applications. Recently, authors in [2] attempted to jointly address safety requirements at a reduced CAM/beacon transmit rate but limited its study to stable mobility. Unfortunately, most of the safety-related situations will be generated from unstable traffic, which in turn is hardly predictable. This led us to our research question: **can mobility prediction be compatible with cooperative active safety for VANET?**

In this paper, we attempt to provide an initial answer to this question and propose the *Glow-worm swarm filter (GSF)*, a prediction model adapted to sudden traffic changes. Observing that given a particular context, unexpected situations could be modeled as alternative hypotheses from the expected regular traffic, we extend a Particle Filter (PF) with bio-inspired patterns observed in glow-worms. We reproduced them in our swarm optimization algorithm (GSO) [3], which allows a PF to cluster particles in various multiple hypothesis. We illustrate how GSF is (i) capable of detecting unexpected traffic changes, and accordingly spontaneously trigger the transmission of CAM/beacons, (ii) reducing the channel load (# bits/s offered on the channel by CAM/beacons) below that of regular PF and periodic transmissions, and (iii) providing a tighter prediction precision compared to PF. The rest of this paper is as follows: Section 2 formulates our research problem, while Section 3 describes our GSF prediction filter. We then provide initial performance evaluations in Section 4, before providing the direction of our future work in Section 5.

2. PROBLEM FORMULATION

VANET Cooperative Active Safety applications require each vehicle to be aware of its surrounding (awareness),

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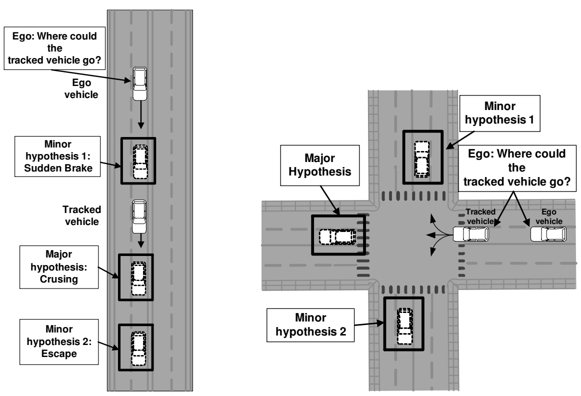
in particular neighboring vehicles. The awareness can be schematically defined as a circular area of range R in which the location of all neighboring cars are known with probability p to the ego vehicle, where both R and p are strongly dependent to a specific application. To this, we should add the *awareness freshness* corresponding to the time during two updates of a neighbor's location provided by CAM/beacons. We focus in this work on the awareness freshness as it is critical to traffic safety applications. Transmitting CAM/beacons based on the result of a prediction model conceptually makes a **periodic** awareness become an **aperiodic** awareness and accordingly reduce the *awareness freshness*. First, such reduced awareness might be too low for the various traffic safety applications running in parallel on each vehicles. Second, mobility prediction schemes are usually based on the hypothesis that the future motions will not vary much from the previous ones. Yet, as illustrated in Figure 1(a) and Figure 1(b), typical traffic situations leading to potential safety issues are generated by sudden changes of mobility patterns. Accordingly, *aperiodic* awareness schemes will have a high change of failing to detect a potential danger.



(a) Potential sudden break or escape

(b) Potential left or right turn

Figure 1: Illustration of multi-hypotheses commonly found in VANET scenarios - The tracked vehicle should be found in the major hypothesis, but considering unexpected changes, it could also be found in minor hypotheses.

The proposed solution we describe next is not only to consider a single potential future location (illustrated as *Major Hypothesis*) but also to consider vehicles in various other locations due to unpredictable motion changes (illustrated as *Minor Hypothesis*), and although being conceptually an *aperiodic* awareness approach, is capable of temporarily switching to *periodic awareness* upon detection of unexpected traffic situations.

3. GLOW-WORM SWARM FILTER (GSF)

The main feature of GSF is its capability to consider not only major but also minor hypothesis in the mobility prediction problem (as shown in Figures 1(a) and 1(b)). Thus, the swarm-based algorithm GSO has been applied to the basic concept of PF. GSO is inspired by the behavior of the glow-worms in nature where the female glows to attract a male for mating, a probabilistic approach is used to select and to move towards neighbors with brighter glow. This decentralized approach leads to the clusterization of the search space and thus to multiple local optima. Integrated to PF, as shown in Algorithm 1, where the search area is represented by a set of weighted particles corresponding each one to an eventual position estimate, the clusterization procedure is performed to generate sub-groups in the solution space by moving particles towards neighbors with high weights. Then, particles resampling is performed for each sub-group. Only particles with highest weights in each sub-group will survive. This results in a great improvement of the solution space providing both high and low probable hypotheses.

Algorithm 1 Pseudo-code of the GSF

```
Initialization: Deploy particles randomly
State update: Apply mobility model
Weights update
Normalization
Create clusters according to GSO algorithm
Resampling taking into account the several clusters
```

4. PERFORMANCE EVALUATIONS

A set of simulation runs has been carried out using the VANET simulation platform iTETRIS [1]. We have considered an urban traffic scenario (in Bologna city with 2,126m x 2,117m of size) modeling the unpredictable and the uncertain context knowledge due to the brutal change that can occur in the vehicle trajectory in such environment. First, we examine the level of accuracy of GSF prediction model and compare it with the generic PF schema. Moreover, we evaluate their convergence time. These two aspects are decisive for active safety applications. We aim to ensure a prediction precision of $1.5m$. The number of particles is an important parameter for both prediction systems has been varied. Table 1 shows the average prediction error obtained for both GSF and the basic PF. We deduce that the performance of both filters is enhanced when increasing the number of particles. GSF gives better estimation results less than $1.4m$. However, basic PF exceeds $2m$ of position error. An improvement on the awareness prediction error (43.8% than basic PF) is provided by GSF.

Particles #	10	100	500
GSF(iTETRIS-Urban)	$1.36m$	$1.31m$	$1.27m$
PF(iTETRIS-Urban)	$2.42m$	$1.79m$	$1.69m$
%improvement	43.8%	26.8%	24.8%

Table 1: Prediction error (in meters) of GSF and basic PF.

In order to evaluate the real-time performance of the prediction algorithms, the execution time has been measured for different numbers of particles. Table 2 illustrates the real execution time in seconds of $100s$ of simulation in iTETRIS for some scenarios. Basic PF ensures the lowest run time compared to GSF which is due to the extra computation that GSF algorithm introduces. However, to respect the reactivity requirements of VANET active safety applications and at the same time preserve a certain level of accuracy, 10 particles shows to ensure a trade-off between fast convergence and high precision.

In the following, we analyze the applicability of GSF to the transmit rate congestion control policy. Figure 2 plots the channel load using different awareness transmission decision

Particles #	10	100	500
GSF(A-Urban)	$1.37s$	$33.76s$	$934.64s$
PF(A-Urban)	$0.67s$	$8.22s$	$158.24s$

Table 2: Convergence time (in seconds) of GSF and basic PF.

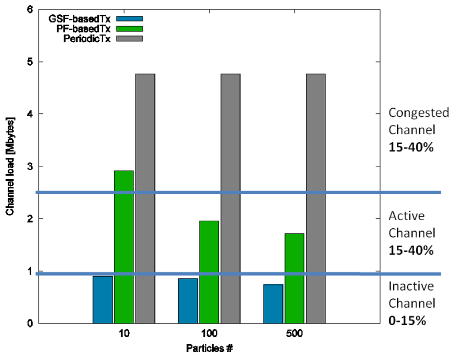


Figure 2: Channel load vs. particles number when applying different awareness transmit rate policies.

schemes: based on PF, GSF and periodic transmission. Periodic transmission shows the worst results, more than 80% of channel usage may lead to a severe problem of network congestion. GSF ensures the best performance by maintaining the channel load to less than 15% which corresponds to the inactive status (0%-15%) of the wireless channel. On the other hand, PF exceeds 15% of channel load. We conclude, here, that the control of the awareness transmission rate using prediction proves to help reducing the network congestion. Results show that it is even better enhanced when applying GSF.

Using such congestion control approach, the awareness transmission procedure stops being periodic and therefore may miss event-based awareness, such that sent by a collision avoidance application. Accordingly, we see that we have to evaluate the capabilities of an awareness prediction system to detect unexpected event in such circumstances. It has to be reactive (the sooner the better) and precise enough. The effectiveness of this application depends on the efficient transmission of the awareness to approaching vehicles at a given distance. For instance when a vehicle stops, the awareness should be received by approaching vehicles immediately to avoid accidents from happening. In worst case, when the information could not be received, the prediction system must ensure a minimum level of prediction error. Here, we consider an urgent braking scenario and we evaluate the capability of the prediction system to detect such events. Figure 3 plots the evolution of the speed of the emergency braking scenario. The prediction precision of both GSF and PF is also illustrated. We deduce from the figure that GSF ensures the lowest prediction error with average $1.4m$ compared to PF. Particularly, at braking time (around $31s$), PF, in turn, fails to track accurately the awareness and gives an error that goes up to $3m$. We can notice here that the effectiveness of awareness prediction for active safety applications is ensured by GSF since it is able to detect an abrupt context change and maintain a stable prediction error. It is worth noticing that GSF is capable of reducing the number of transmissions when it is not needed, up to 80% of periodic transmission has been

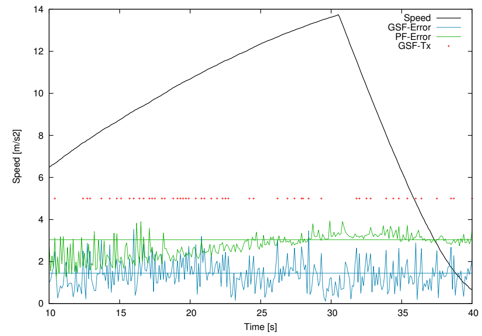


Figure 3: Speed vs. simulation time. Impact of deceleration on prediction performance and on safety collision warning application.

suppressed by our GSF algorithm, only 11% for PF. We conclude, here, that PF algorithm even being almost the time periodic can not ensure good prediction performance. However, as we can see from Figure 3, apart from insuring precise awareness prediction, GSF can switch from its aperiodicity to being periodic once it detects the context change.

5. CONCLUSIONS AND FUTURE WORKS

In this paper we showed that mobility predictions was compatible with cooperative active safety applications in VANET. We developed a bio-inspired prediction model capable of detecting sudden traffic changes typically found in traffic safety contexts and ensuring the trade-off between:

1. *Reducing channel load by an aperiodic transmit rate control policy.*
2. *Fulfilling the requirements of active safety applications by preserving a high level of awareness freshness.*

Although being at its early step, it addresses a conceptual change, as it describes a framework for event-based rather than periodic CAM/beacons transmission. In future work, we plan to conduct a larger evaluation of our GSF prediction model and also extend the framework to also dynamically adapt the transmit selection criteria.

6. REFERENCES

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