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Context-aware Gossip in Ad hoc Vehicular Networks

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Abstract

The purpose of this paper is to quantify and highlight the effects of how contextually guided gossip in ad hoc dynamic vehicular networks during emergency situations perform. Two traffic scenarios are simulated, each one of the scenarios was simulated with the effect of contextual filtering and without any filtering (broadcast gossip). Our environment assumes the minimum specifications available, which is the presence of an on-board unit only in each car. We also analyze the effect of applying such filtering and if it is worth applying in such a critical environment that has human lives at stake. The simulation results show that our proposed concept could be applied safely without much affecting the time that the gossip takes to reach other vehicles. The amount of redundant and unneeded messages transmitted is reduced drastically with higher road traffic.

Keywords: Gossip Algorithms, Vehicular Ad Hoc Networks, Wireless Sensor Networks, Network Performance

1. Introduction

The internet of things (IoT) is on the rise and that is not something new, but the applications that are coming out of it are still in their infancy stage. One of IoT's biggest sectors is the vehicle sector, which has been a topic of focus by numerous papers and studies. Studies also predict an increasingly larger development and evolution of this sector [1]. Vehicle to vehicle(V2V) communication is becoming a reality rather than a concept and vehicles exchanging messages with each other of road aggravations were discussed in academic magazines since 2013 [2]. Hence

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implementing improvements certainly will contribute in a positive way for it to function in a more efficient way. Recent advances in technology have also enabled us to add more features that would make vehicles a safer mode of travel, but it also added in a lot of distractions as well [3].

According to Litman [4], autonomous vehicles are regarded as vehicles that drive themselves. In other words, self-driving cars. In other definitions, they are called driverless or robotic. They operate with a set of programmed instructions enabling them to navigate streets, highways, and freeways like normal human beings do [5]. This sort of technology is similar to the autopilot mode pilots engage airplanes while flying. While planes cannot take off and land on autopilot mode, autonomous vehicles can start the engine, maneuver to prescribed locations, stop and turn off the engine. Many automobile manufacturers have produced autonomous vehicles and have carried out a series of test runs over 500,000 miles on major highways [5]. Levels of Autonomous Vehicles

Autonomous vehicles have been categorized into five different levels according to the National Highway Traffic and Safety Administration (NHTSA). Level 0 is called No- Automation, where the driver is in complete control of all functions of the vehicle (brake, steering, throttle, and motive power) at all times. Level 1 autonomous vehicles are called Function-specific Automation. This is the lowest level of advancement in autonomous vehicles. They perform only certain control functions such as automated parallel parking, lane guidance, and cruise control. The rest of the controlling functions are performed by the driver including acceleration, brakes, steering, and overtaking. Level 2 autonomous vehicles are more advanced and automated than level 1 autonomous vehicles. NHTSA refers to them as Combined Function Automation. In Level 2 autonomous vehicles, feet can be off the pedal and hands off the steering wheel under certain conditions. There is integration of multiple control functions such as lane centering and adaptive cruise control. Like level 1 autonomous vehicles, drivers are responsible for the overall monitoring of the vehicle on the roadway.

Level 3 autonomous vehicles are referred to as Limited Self-Driving Automation and are far more advanced than the previous two [4]. Drivers can sit back and relax while the automation takes control of the vehicle. A driver will only monitor the roadway when the automation triggers a transition back to the driver. All safety-critical functions are under automation. Fully Self-Driving Automation is the level where vehicles can fully drive themselves without needing human presence in the vehicle. The car can effectively undertake all functions of monitoring roadway conditions [4].

Road accidents are one of the leading causes of deaths when compared to other disasters as noted by the world health report. The cumulative number of reported deaths from disasters since 2006 to 2015 lists road accidents as ranking second after victims of flooding [6]. This is a problem that autonomous vehicles are expected to solve using sonar collision detection technologies and image recognition [7]. Many solutions have also focused on monitoring the driver's behavior rather than the previously mentioned methods [8].

What we are trying to implement in this study however is to inform the vehicles that have not reached an accident/anomaly scene yet of what to expect as early and fast as possible while causing minimum disturbance to the vehicular ad hoc network (VANET). Algorithms that are used to spread specified information throughout the network are called gossip algorithms. While there are a lot of randomized [9] and deterministic [10] forms of gossip, our proposed gossip scheme is context-aware (based on the vehicle network situation). This study will also analyze the simulation effects of the context-aware gossip algorithm on different scenarios so that its advantages could be quantified.

Context-aware solution is not a new idea [11] to the roadside problem, but the approach that we take is unique in itself since it only requires the usage of the on-board unit (OBU) and it does not need the roadside unit (RSU) nor an application unit (AU) installed in the vehicle. This makes the solution a more robust one and is based on situations that should happen more often since it requires fewer conditions to meet. Meaning, vehicles talking to each other without the help of an external foundation or infrastructure as other papers require. The network will be decentralized and dynamic, which in turn gives an advantage when it comes to spreading gossip by distributing it over the different nodes.

Section 2 will be about the formulating the model and the problem statement along with the scenarios that our simulation is to be implemented based upon. Section 3 describes the problem that we are trying to solve in this paper. Sections 4 proposes a solution to the problem mentioned in section 3 while also discussing the different elements in the system. Section 5 is going to discuss the simulation and analyze its results. Section 6 references the related work and how it differs from our study. The paper will conclude in section 7 with a summary of what this paper is all about.

2. MODEL FORMULATION

Our model is a mostly decentralized dynamic graph, since it is an ad hoc network and based on vehicles with no RSUs involved. It is a modified version of the prioritized gossip in vehicular networks paper [12] which is also based on the distributed networks graph model [13]. The main difference from [12] is that our nodes are not static in the sense that they can cease to exist in our simulated area of gossip activity. Likewise, there are new nodes being created or added to the area of gossip activity in a randomized way.

Dynamic graph $G = (V, E)$ will constitute a variable set of nodes V and a dynamic set of undirected edges, such that $E{:}\ N\ \{\{u, v\}\ ||\ u,v\ \in V\}$. Location is a crucial matter; hence it is marked by $x, y \in N$ being the dimension that our algorithm is concerned with. Our model takes geography and the context of into account; therefore each node has an x and y geolocation position such that: $\forall V \exists\ \{x, y\}$. Geography will be a major factor in determining the $E \forall V$, hence: $E_v(x, y)$.

This is a defining factor in our ad hoc dynamic graph model, where E_v is a variable that changes with time. All nodes (represented with vehicles in our case study) in this graph have a fixed circular coverage area, with radius r. If two nodes overlap in their coverage area, it is assumed that they communicated and established a link E with each other, keep in mind that this link E is not static or permanent. This type of data communications transfer is called beaconing [14] and is used by previous papers as well [15].

Each V should have another parameter A, to mark activeness. It is a binary variable that changes value to 1 if it received and is concerned with gossip g, and 0 if it has either not received it yet or has received but contextually irrelevant to gossip g. When $A_u = 1$ connects with a new node v it sends gossip g to the node via the newly established link. If node v is contextually relevant then A_v will change from 0 to 1, otherwise rumor has no effect on node v. Gossip g also includes a list of conditions in which A_v should switch from 0 to 1. The total network traffic ρ that is comprised of both ρ_N and ρ_T which represent network traffic in non-target nodes and targeted nodes respectively, and are both arbitrated depending on context. Not all network traffic in ρ_T is positive since some messages could be redundant, a good example would be sending the gossip message to a node that already has already received it.

Therefore, we shall define our own parameter that would differentiate the essential network traffic from junk or unneeded traffic. Junk network traffic ρ_J, which is composed of redundant sent messages in ρ_T and ρ_N added together.

3. PROBLEM DESCRIPTION

The main problem that our paper is planning to tackle is limiting the unneeded network traffic while maintaining efficiency when it comes to gossip spreading speed, this filtering needs to be done based on a context. Hence our algorithm will minimize total network traffic ρ and network traffic in non-target vehicles ρ_N. This is our prime objective in this study. Network traffic ρ is measured based on the number of data transmissions that were done during the duration of our simulation. Let us assume that if every vehicle received an emergency gossip message that it is going to forward to all of its neighbors, the ρ_u for each node u will equal to the number of vehicles that entered its network coverage after receiving the message. Sending gossip to non-target nodes is not the only network traffic that is to be minimized in our case. Sending the gossip message to nodes that already have received it is another factor that has to be minimized. The ρ_T would also enable us to determine if our context-aware gossip algorithm is as efficient as the regular broadcast gossip method.

Our simulations are implemented in two scenarios where we think that they would be more relevant when it comes decreasing the network traffic. The two scenarios are as follows:

1) First is a double three-lane highway, where the first three lanes on the left go from north to south and the other three lanes go from the south to the north. An accident is simulated to happen as pictured in figure 1. We will be referring to it as the highway scenario for the sake of simplicity.

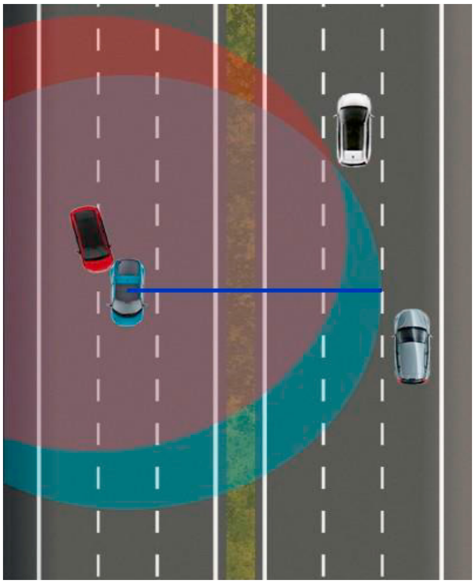

Fig. 1. How the highway scenario looks

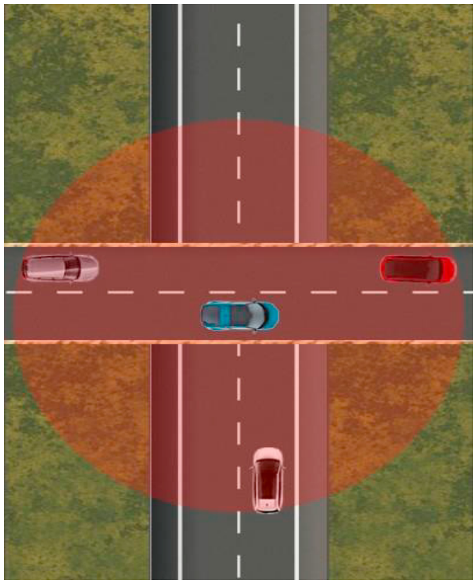

Fig. 2. How the bridge scenario looks

2) Second is a scenario involves a bridge with two lanes going over a road with two lanes. The accident in the simulation takes place right after the cars go down from the bridge as pictured in figure 2. We will be referring to it as the bridge scenario for the sake of simplicity. One of the simulation's considerations is that: In what way will contextually filtered gossip affects the speed of information spreading that is supposed to reach the targeted vehicles? This is a crucial point that may cause a dilemma for contextually filtered information broadcasting since the field that we are tackling is tied to human mortality.

4. APPLYING CONTEXT-AWARE GOSSIP

Our model requires that the on-board vehicle unit contain a GPS such that when it recognizes that it is in an emergency situation, it analyzes the context of the emergency and composes a list of conditions. This list is attached to the GPS coordinates of the emergency event and is to be broadcasted to all other vehicles passing within its coverage. Now if we put this into a purely simplistic way: The source node is going to be the vehicle that is facing the emergency. Hence the gossip message that we are going to send is composed in the following way:

$$g = \{(x_s, y_s), C, B\} \quad (1)$$

$$C = \{c_1, c_2, c_3 \ldots c_n\} \quad (2)$$

Where x_s and y_s are the GPS coordinates of the emergency and C is a list of conditions that constitute if the received vehicle the gossip message should discard it or keep it. While inside area boundary B (geographically placed polygon), if the node (vehicle) that received the message meets one c then it will keep sending gossip g to all the other nodes on its edges. As soon as the node exits area B it will stop transmitting the gossip and discard it. The algorithm for a receiving node will be as follows:

Data: Gossip g
Result: Gossip g is sent to neighboring nodes Gossip message g is received;

Gossip message g is received;

if g is *not already received* $\wedge \exists\, c_x \in C$ = *this node's circumstances* **then**
  Set **while** current (x, y) is inside B **do**
    if New E is established **then**
      Send g through E;
    else
    end
  end
else
  Discard g;
end

Algorithm 1: How gossip message g is processed in non-source nodes

The spreading behavior of this gossip scheme greatly depends on how it is implemented and the conditions of road traffic. To demonstrate the algorithm's effectiveness, we will base the flow of traffic based on probability. For example, P_x *represents* the probability of a vehicle entering the area of the simulation on lane x while λ_x represents the flow of vehicles on the previously mentioned lane. When we apply this to our two case study scenarios where the lanes are the main conditions that we have to check, lane x: l_x will be the main factor in deciding whether the vehicle drops gossip g or continues sending it throughout the boundaries given in the gossip message.

If t represents time then:

$$E[N_x] = (\lambda_x \times t) + \varepsilon \tag{3}$$

Equation 3 would give us the mean number of vehicles passing through lane x during period of time t, with a lane switch factor ε that vary according to the situation. The lane switch factor accounts for all vehicles that switched lanes.

5. The Simulation

5.1. Method

Based on previous studies conducted on 802.11p[16] we have adjusted the radius r of vehicles to perform under the worst conditions so that they would only establish a link with other vehicles within 100 meters. While boundary B in which our proposed gossip algorithm will remain active in is a circle with a 2500 m radius. Vehicles are spawned at the beginning of a particular lane based on a numerical probability to simulate different states of traffic congestion levels. The vehicles in this simulation are spawned randomly in sizes ranging from 2 to 5 meters. Vehicles that are in a collision course with the vehicle in front of it turn to their left lane to overtake the vehicle that is in front of it if there is no other vehicle present on its side. If there is no left lane available then it would adjust its velocity to match the vehicle that is in front of it. The spawned vehicles are more likely to be higher in velocity the more left situated they are on the road. The maximum velocity possible is 42 m/s(approximately 150 km/h) and the lowest being 12 m/s (approximately 43 km/h). Since the probability of spawning vehicles is random, the results may yield fringe values when it comes to the average gossip reception time, the median of 5 simulations was be taken as the result that is displayed on the graphs shown in the next section. The amount of junk traffic does not vary, so we just took the average of the 5 performed simulations that were done to take the median result of the gossip reception time.

For our highway scenario two vehicles blocking the first and second leftmost lanes to simulate an accident, they will also act as the source nodes (as shown in fig. 1). In our bridge scenario there will be only one vehicle that acts as a source node, it will be placed right before the bridge begins, which will simulate and out of order vehicle that has stopped there. Both scenarios are simulated under with context-aware algorithm and with regular broadcast to measure the efficiency of reducing junk network traffic. We measured the average time that it took for a vehicle to receive the gossip message after spawning. The average gossip receiving time plays an important role since it gives us a picture of the latency of transmitting such valuable information in situations that are critical.

Our implementation of the context-aware gossip algorithm in the highway scenario permits only the first three lanes from the left to retransmit gossip message g within the simulation boundaries. While in the bridge scenario, only the two lanes that could lead to the source node would be allowed to retransmit the gossip message. Our simulator is programmed from scratch and uses the main classes of Java without relying on any of the preprogrammed frameworks.

5.2. Results

Our concept worked better when applying it to reducing ρ_J in the highway scenario than the bridge scenario. Although ρ_J is always lower, as expected, in both cases. When it came to the average time for gossip reception, all cases had roughly very similar results. This makes our proposed concept secure since it has very little effect on the time to receive gossip message g. The junk traffic comparison chart can be shown in fig. 3 while fig. 4 shows the average time for a vehicle to receive the gossip message.

The average time for a gossip to reach a vehicle is high in the early stages because the simulated vehicles took some time to reach the source node (named as the transient phase by most simulators), but with the progression of time, the average reception time converges to a threshold of which almost no change is noted to it. The P in our graphs represents the probability of a vehicle to spawn per interval. The simulation results shown in figures 4 and 5 are set so that the interval would equal 0.25 seconds. In other words, if P10 is shown then it would mean that for every quarter of a second there is a 10% chance of a car spawning/entering our simulation environment.

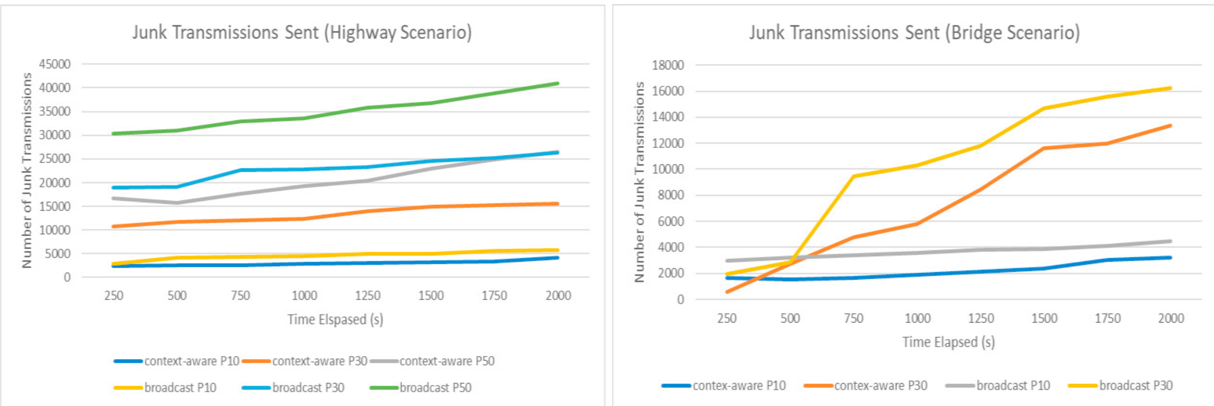

Fig. 3. Displayed is the amount of junk traffic recorded

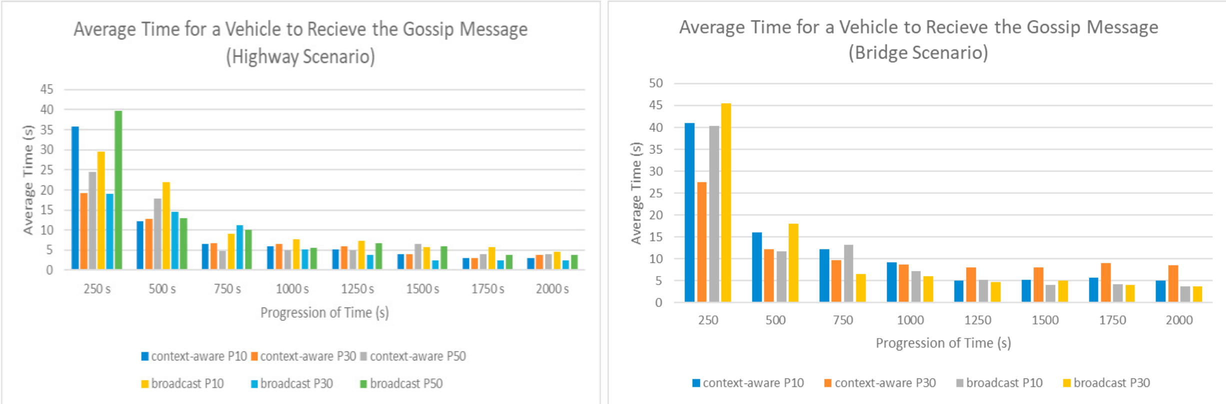

Fig. 4. The average time for the gossip to reach a vehicle

Applying context-aware filtering does not do much of a difference in junk network traffic reduction when there is low road traffic, but it really shows drastic network traffic reductions in high road traffic. At the end of the highway scenario simulation (on the 2000s marker), our proposed concept reduces junk network traffic by 25%-40%. While in the bridge scenario the traffic reduction ranges between 20% and 30%. The average gossip reception time varies according to the time period regardless of the gossip algorithm used or road traffic intensity, it always seems to decrease with the progression of time.

6. Related Work

There have been many VANET simulators developed, the most prominent of them have been compared summarized in a published paper [17] [18], but none of them suited the purpose of our case. We should differentiate between 3 things when it comes to simulators:

- Mobility generators: that simulate moving nodes/traffic in general.
- Network simulators: which is an extension to the mobility generators that add network functions to mobile nodes.
- VANET simulators: are an extension of network simulators that customize the network specifications and parameters to match the road vehicle's environment.

We decided to program our own simulator from scratch since the already existing simulators were not customizable enough for us to tinker with them to suit the conditions in our paper. Our paper is not the only study that assumed that only on-board units are used. A similar study [19] tried to optimize VANET routing by taking into account the direction and position of the vehicle to send out more reliable data packages. Another study that focused on content distribution [20] also used the peer-to-peer vehicular network as we did, but the purpose of it was relaying internet connectivity rather than anything else. There have been other VANET study models [21] that relied on real-time data to provide optimal connectivity that predicts link duration and quality to get a more reliable expectation of the VANET paradigm. The simulation was even performed on real-life city maps and compared to the actual traffic recorded.

7. Conclusion

We have highlighted how gossip algorithms in vehicular networks is not studied extensively. In our study, we explained how redundant and irrelevant messages can flood the VANET. Therefore, we developed a simulator that emulates vehicle traffic and covers the basic functions of a VANET under two scenarios: the first being a highway accident scenario and the other being an out of order vehicle in an over-bridge scenario. We have also devised our own deterministic gossip spreading algorithm to limit the amount of junk network traffic that would flood the VANET if conventional broadcast gossip is used. The proposed algorithm was put under a simulation to monitor if it would have any significant effect on the gossip latency time and if the junk traffic reduction was really worth it. The results of our simulations showed that implementing such a context-aware filtering gossip algorithm will not result in any significant reduction of gossip latency. The reduction of junk network transmissions results varied according to the scenario. The highway scenario got a 25% to 40% reduction in junk network transmissions when we applied our context-aware gossip algorithm. While the Bridge scenario yielded a 20% to 30% reduction in junk network transmissions.

While this study is not sophisticated enough to scope intricate parameters such as signal quality and loss, it does demonstrate that there are many measures that can be implemented to reduce VANET flooding. Vehicles are in a major transitionary period and it would not take took long for VANETs to dominate the industry. More rigorous studies are needed in this field to refine the results and make them more closely resemble the real-life results of implementing such an enhancement.

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