Collaborative Data Dissemination Methods in VANETs for Identifying Road Conditions Zone boundaries

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Abstract: Vehicle to vehicle communication (V2VC) is a modern approach to exchanging and generating traffic information with (yet to be realised) potential to improve road safety, driving comfort and traffic control. In this paper, we present a novel algorithm which is based on V2V communication, uses in-vehicle sensor information and, in collaboration with other vehicles' sensor information, can detect road conditions and determine the geographical area where these road conditions exist e.g. an area where there is traffic density, unusual traffic behaviour, a range of weather conditions (raining), etc. The built-in automatic geographical restriction of the data collection, aggregation and dissemination mechanisms allows warning messages to be received by other cars not necessarily sharing the identified road conditions, which may then be used to inform them of the optimum route to take (to avoid bottlenecks or dangerous areas including accidents or congestion on their current routes).

We propose two approaches in this paper that are simple, flexible and fast and do not rely on any kind of roadside infrastructure equipment. They will offer live road condition information channels at – almost – no cost to drivers and public/private traffic agencies and have the potential to become an indispensable part of any future intelligent traffic system (ITS).

Keywords: Networking, VANET, Protocols, Routing, Dissemination, Broadcasting,

1 Introduction

Currently used traffic information systems are centralised vehicular applications using technologies like Traffic Message Channel (TMC), which provides information about road traffic conditions. However, it (i) lacks short delay times (due to the centralised approach), (ii) averages information for large geographical areas (due to cost-sensitiveness of detailed sensor networks and limited radio resources) and (iii) does not have the opportunity to provide services for locally interesting and time-critical applications [1]. Moreover, as discussed in [2], implementation for complete coverage would require new infrastructure that is cost-sensitive, as shown in [3] through a case study. Such systems would, for example, not meet the requirements of an accident avoidance application, because they have long delays and would require large capacity due to the large geographical area of service. In contrast, VANET-based systems can have short delays and the capacity can be reused more efficiently. Moreover, the structure o f VANET can be distributed, which improves the level of independence, scalability and stability.

The vehicular application can be classified based on the improvement of safety and the time-critical nature of the service. Examples of application categories are safety applications (e.g. avoidance of collision, information about loss of control of the vehicle), which can improve road safety significantly (a new level of road safety assistance), but are highly time-critical. In comparison, a service about traffic condition information is less time-critical, as discussed in [4], due to the low level of variation of traffic conditions in a short time (traffic jams have to build up) and it has a lower impact on improvement of road safety than, for example, traffic accident assistance applications. This categorisation can be extended with expected improvement of safety or comfort level e.g. (example for safety) intersection collision avoidance; (for comfort) dissemination of free parking places in large parking lots [5].

This important to note the importance of understanding the requirements of vehicular applications. Different applications might have significantly different needs for information-spreading properties (e.g. delay, distance). Therefore different dissemination strategies (including technology employed) need to be employed for various vehicular applications. We aim to find model to study the effect of these diverse dissemination strategies on information spreading and how we can employ those strategies to identify the boundaries of sensed road conditions.

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2 Dissemination strategies

Most VANET-based systems assume *a priori* knowledge about the underlying road network, which is usually interpreted as a weighted graph [6]. A common approach is to divide the roads into sections with different weights, but certainly not with the same length. The weights are given according to a certain property, which can be physical like a message traversal delay [7] or stochastic probability based on the distance between vehicles [8].

Vehicles are assumed to be equipped with sensors that provide data about the status of the vehicle e.g. speed, geographical position, temperature or even sensors to detect bumps, acceleration [9] or honking [10]. This status represents local information about a geographical area at a certain moment. Distribution of local information needs to be detailed within closer vicinity, and coarser with the increase of distance, as proposed in [11]. For example, a driver would be interested in the average speed of vehicles way ahead, but the exact speed of a vehicle 100 metres ahead to be able to avoid a collision.

Based on the ***type of communication*** three main categories can be introduced. First are vehicles sending their messages via a cellular system – and/or Road-Side Unit (RSU) – to a central server or to another peer as described in [12]. The disadvantage of such systems is the high cost of construction and maintenance of the infrastructure.

Second is the group of systems that do not use cellular systems, but another dedicated system like Urban Multi-hop Broadcast Protocol, as suggested in [13], or more general communication technologies for VANET (e.g. Wi-Fi) [14]. Last, a hybrid solution, a combination of both systems, seems to be the most powerful but most complex approach.
The fundamental idea of information dissemination for VANET is to have ***periodic broadcast*** messages for routine information, and event-driven messages for causes of emergency situations. Most of the time vehicles send messages about their current status (velocity, heading) and/or knowledge about the network performance (e.g. delay of certain links, density of cars at a road section). Data from multiple inputs are processed and a new message calculated and transmitted if the routing protocol requests it. The aforementioned information should be aggregated to fulfil scalability requirements.

Flooding, as a distribution method (where each message is sent to all) however, is not scalable, consumes large amount of energy, bandwidth and memory space while being inefficient. Therefore, techniques to reduce network load are required. The main goal is to provide less information with a higher distance to keep the system scalable, as shown in [15]. Atomic information (e.g. velocity) is aggregated with information from other nodes [1] or about road sections [7] to have aggregated messages. The message has to be aggregated with new information from the current node before another broadcast takes place.

For ***aggregation***, geographically hierarchical approaches are being introduced. The level of hierarchy can, for example, be represented in different resolutions of the road network between landmarks, as suggested in [13]. Another approach is to form grids of different sizes based on various sizes of geographical area, as shown in [16]. In both cases the amount of information about a faraway geographical area is reduced, therefore data needs to be maintained as well. Dynamic store and forward approaches are used to maximise the probability that two messages are going to be present at the same time at the current node and it will have a chance to aggregate them into a single message and transmit it.

We have also identified an evolution in flooding and directed broadcast transmission to the target area to a distributed (Content Addressable Network (CAN)-based) subscriber/publisher approach [17]. The nodes subscribe to certain groups of information (for example, information about certain road sections on the route ahead) and push out messages in a distributed fashion (dissemination is distribution as well as the location of the stored data). Vehicles send (push into the network) information about their observations and abrupt events.
Data is preferably stored in a distributed fashion like CAN, which has a *d* dimensional key space that is used to give the address of a certain area based on its geographical position. It allows the possibility of reaching nodes that are responsible for storing data about a certain area without knowing their address

3 Dissemination characteristics

3.1 Keeping information alive

Information must migrate and be kept alive. This is achieved by retransmission. A message that is received and retransmitted gains two things. It survives a period in time, and it might migrate to new receivers. A retransmission can be done in two ways: either it retransmits to specific addresses, or it retransmits to everyone.

Transmission to specific addresses is most effective if the environment and receivers are static or motionless. Once the discovery and determination of neighbours is finished, each message needs to be sent only once, which saves capacity and time. This solution might demand special hardware such as directive antenna and controllers.

Flooding is like opening a door with a sledgehammer instead of a key. It is big, noisy and brutal, but it gets the job done. The biggest problem with flooding is the sheer number of messages that are received, when each node transmits all new messages to any receiver within reach.

If there are *n* receivers within reach (Figure 1), this will cause the sender to receive nine messages that are of no value. If all the other receivers can reach nine nodes, 90 messages are wasted. This will unfortunately introduce interference, and possible loss of each other's messages; the message will be received n*(n-1) times.

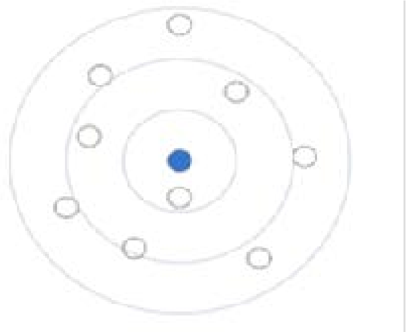

Figure 1: Flooding to nearby nodes (n=10)

The problem that presents itself is that we do not have a master in the network. Then who is going to be responsible for updating the information in the system? With no master the responsibility lies within each vehicle. An approach to this is presented in this paper.

3.2 Keeping the information consistent

The mechanisms used to keep messages alive might cause problems with keeping the information consistent and updated. Retransmissions and replication might produce duplicate messages. This introduces the need for telling the messages apart.

The information in the system depicts the real environment as truthfully as possible. As time passes, the conditions – once observed in the environment – might have changed, moved or disappeared.

A major issue is that there might be many different interpretations about what the 'truth' is. Each vehicle, or node, in the system might have a slightly different perception of what is the overall status in the network.

A bigger problem is the arrival of new vehicles. How can they get an impression about what the status is?

The vehicles most likely to have the most complete picture of what the status is in the network are probably those that are closest to the centre of the network. These vehicles have the highest probability of having received all messages that have migrated through the network.

A new vehicle will have difficulties discovering these centrally located vehicles, so an easier solution might be to rely on the nearest vehicle instead. Due to the many interpretations about status, it is not enough to ask just one neighbour. A majority vote between any vehicles within reach would provide a fairly good estimate about what the status is at this part of the network. This is definitely a 'best-effort' task.

3.3 Infrastructure

The goal is to produce a robust, self-configuring and autonomous network. If the network is reliant on infrastructure the network might be limited to operations in areas where the infrastructure is in place.

It is better for the network to be independent of existing infrastructure, but use whatever resources are available. A lamppost equipped with the same communications equipment as the vehicles might be regarded as a very slow-moving vehicle (as seen from the network). This permanent equipment can be used to supply the network with important information from 'the outside' (i.e. traffic information or congestion warnings) and might gather information for some centralised services (statistical information about troublesome areas).

Permanent infrastructure might be helpful to cover 'black holes' or difficult positions (i.e. can cover both sides of a difficult corner). The directivity and mounting height of the antenna plays a major part in the connectivity [9]. On a vehicle the most natural choice is an omni-directional antenna. The mounting height of this is limited by the vehicle and aesthetic concerns. On a permanent structure it is possible to use very different equipment depending on the location, and needs, of the area.

There is another type of infrastructure that might be useful. Buses and trams use a predictable route at predictable times. The bus or tram might work as a buffer, they get information from a source, and they can release this information when they get to new areas. A moving infrastructure comes in handy for gathering statistical information, as it covers a large area at regular intervals.

3.4 Applications built on Inter-Vehicle Communication (IVC)

The vast class of IVC applications can make driving safer and more comfortable for vehicle occupants [18][19]. IVC services can be achieved through different methods by exchanging data between vehicles and sometimes through roadside infrastructure units. Figure 2 shows the classification of vehicular communication applications. It helps us to focus on specific equipment to fulfil services and solve diverse problems.

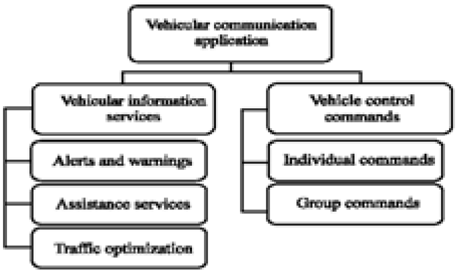

Figure 2: Classification of vehicular communication applications

To clarify the exchange approaches we propose in this paper, it will be useful to present some examples of the possible road situations (conclusions) we can come up with based on sharing individual car sensor data (the numbers quoted in (table 1) are representative rather than conclusive for the condition and represent a matter for future investigation in real-life experiments).

	Individual Car sensors data	Optimum Num example/case	Possible Conclusion
1	Windscreen Wipers	30% of cars = ON	Rainy
2	ABS Control.	5 cars = ON	Slippery (snow)
3	Slippery Oil Spot.	2 cars	Slippery spot
4	Fog light.	50% of cars ON	Foggy
5	Traffic flow Speed.	(60%) Slow/Stop	Traffic Jam
6	Reduce Speed.	5 cars within 1sec	Hazard Ahead

Table 1:Examples of some situations

We can consider that column two contains, in effect, Search Condition Limitation numbers. Assuming that this Search Condition Limitation is reached then a zone with the condition (third column) is identified and the information system can tell other nearby cars to be aware of the situation within that zone if they plan to pass through it.

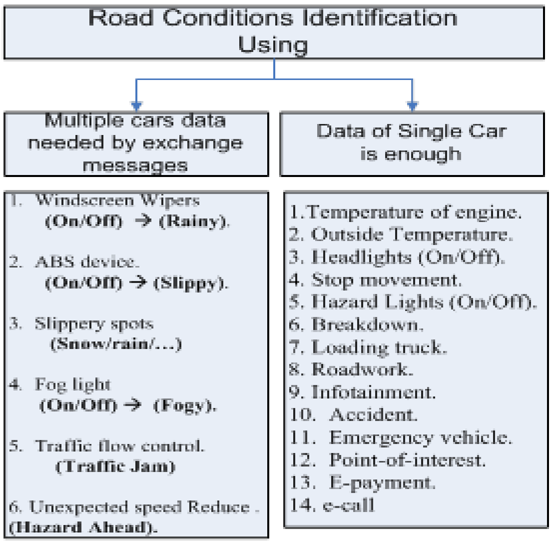

Figure 3: Aggregate data

Each message needs to be in a format that is small in size and rich in content. Two methods of collaboratively collecting data by exchanging messages based on vehicle-to-vehicle communication have been identified.

Figure 3 classifies the recognisable road conditions based on the number of cars needed for it. The examples are of discoverable road situations that need just a single car to identify the road condition/problem to generate a warning message and broadcast it to all nearby cars, and of road conditions that need multiple cars' information by exchanging messages (their data) to identify the conditions of the road they are on. So, two stages are needed: first, exchange of messages to discover whether the road has a certain condition or not; and second, generation of a warning message to inform all nearby cars of the discovered condition, if any.

4 Schemes for road condition zone boundary identification

In both proposed approaches we consider a scenario in which multiple cars' data is needed to identify a road situation. So, exchange information between nodes (cars) is needed in a way that each node requests/sends information from/to the other vehicles to collectively identify the conditions of the road. This is gathering information about how many vehicles have sensed the same specific conditions. It can be something like 'How many cars have their fog light ON?', 'Are there any queues in front of me?'. The answers to such questions should be extracted from the conclusion of the aggregated data for the cars in the zone. In the following section the mechanism for the proposed approaches to data collection from nearby nodes is given.

4.1 Blind Zone Scan Scheme (BZS)

This is two phases approach. First phase is to scan the region for any detected traffic conditions (using discovery message generated by nodes who sensed that situation) to identify the boundaries of the situation zone. The second phase is to issue warning message broadcasts to inform all nearby nodes for the situation and its boundaries. By using this approach, we investigate and identify the optimum value for two parameters: ① The number of hops used by the discovery message (How large the scanned area is), and ② the best possible delay time used in each node before rebroadcasting (to reduce the noise in the network) This mechanism involves the following steps:

1) If <u>*a node detects or senses any identifiable road conditions*</u> it becomes an *active node* (AN).

a. If it has not received other nodes' SDMs (*Situation Discovery Message*) with the same condition discovery requests within a certain past time-out period, it generates an SDM and broadcasts it to all nodes in its range as a first wave (called first hop) to inform all nodes of its current situation (Figure 4a) and to enquire if other nodes have the same condition.

b. Periodic regeneration and rebroadcasting of SDM after the time-out expires will be performed, until either the situation disappears (becomes a Non-Active Node (NAN)), or a new, different, SDM is received which shows another node has sensed the same situation (become AN) and it recognizes the current one as AN.

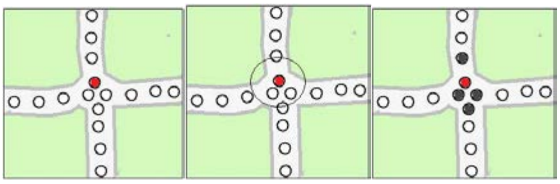

Figure 4a: Crossroad scenario – first hops

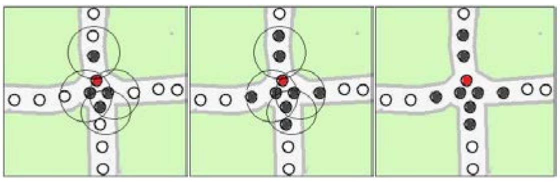

Figure 4b: Crossroad scenario – second hops

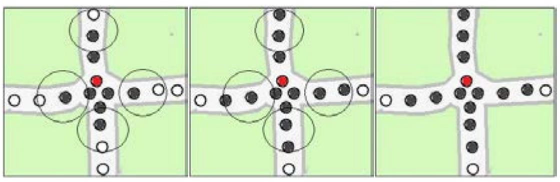

Figure 4c: Crossroad scenario – third hops and so on …

2) <u>*In each node that receives the SDM*</u>,

a. If the maximum hops number is not reached (an SDM reaches the maximum number of hops if the pre-set number of hops are transmitted by nodes) and if none of the nodes have the same situation, they forward the same SDM to the next neighbour nodes as a second wave (second hop) to inform the others of the current situation (Figure 4b).

b. However, if one of its neighbours has a new situation at the same time as receiving the message, it will generate a new SDM that contains its current condition and also all the information it has previously identified about the nearby nodes.

c. Again, all nodes forward the same SDM to the next neighbour as a third hop (Figure 4c) after they have updated the message on the current situation. These steps are repeated until the Conditions Search Limitations (CSL) become true or the maximum number of hops is reached.

3) <u>*Each node is capable*</u> of:

a. Keeping track of all seen messages, which allows it to discard all redundant messages. Also each node keeps all the information it has about all 'seen' nodes – all nodes contained in the messages received in the node – in two different lists: the first for ANs and the second for NANs.

b. If any node – at any hops – has the same/new situation, a new SDM will be generated containing additional information as well as the information it holds about the other surrounding nodes and broadcasts it to all nearby nodes. Previous steps will be repeated until – again – the CSL becomes true.

4) <u>*After a short period*</u> of exchanging SDMs:

a. Nodes will have got all about the surrounding nodes' information. Each node should hold three lists: a seen messages list (to reduce redundancy), an active node seen list and a non-active node seen list.

b. Each time a node receives a message it updates its lists and checks whether the optimum number for each detectable situation is achieved or not. If it is not, it will forward an SDM to the next hops.

5) In the case of an optimum number being achieved, the car which got this information will *calculate the boundary of the situation zone* based on the information it already has about the surrounded cars (Figure 5). Then, a new Situation Warning Message (SWM) will be generated and sent to warn all nearby cars by the situation and its position. Also, a new CSL will be set up for an SWM to determine the lifetime.

Figure 5: Situation Zones has been identifier

4.2 Cloud Zone Scan Scheme (CZS)

Based on real life, road conditions occur in certain places that will affect groups of nearby cars inside that zone. For instance, usually if a car discovers foggy weather (fog light goes ON), mostly, all nearby cars have the same condition. Or, if a car senses rain (windscreen wipers go ON), often, all nearby cars have the same situation or – at least – will sense the same very soon.

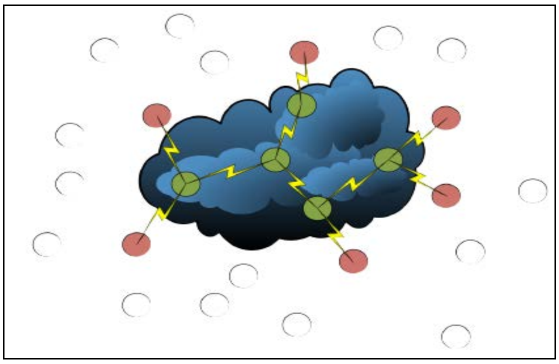

Figure 6: Raincloud

CZS scheme is based on this assumptions and *<u>the cars which sense a situation (AN) will trigger SDM</u>*:

1) This SDM will travel from car to car, until reaching the first node that does not have (sensed) the same situation, which will not retransmit the SDM (stopping the forwarding of the SDM).
2) It will reply toward the source node of the SDM message with its geographic position to inform all nearby cars that the boundary of the situation is here (its position), meaning, that this approach looks for the nodes (cars) located on the borders of a situation zone (e.g. raincloud).

Figure 6 illustrates five vehicles inside a raincloud. These vehicles communicate with each other, and with the vehicles just outside the cloud. The vehicles on the outside of the cloud respond by returning their positions, and information that they don't sense rain, to the vehicles inside the cloud. The vehicles inside the cloud update their information tables, and pass this information to the other vehicles inside the cloud. Based on the data in the information tables the vehicles can calculate the area that the cloud covers, generate SWM and broadcast it to the cars in the region.

5. Results & Conclusion

We propose in this paper schemes that are using 'intelligent flooding' instead of blind flooding broadcasting (selected nodes will retransmit the messages). These were tested using an NS2 simulator, these experiments showed that 'intelligent flooding' was faster and less resource consuming than 'pure flooding', thereby confirming our hypothesis. The results of the simulator were as expected, and the simulation proved that 'intelligent flooding' produced far fewer messages, and is significantly faster than 'pure flooding'. It also showed that 'intelligent flooding' is vulnerable to interference, and because of that important packets could be lost. Resolving these issues the focus of further research..

As aforementioned, The BZS scheme attempts to identify the optimum value for two parameters: *the number of hops* and *the delay time* needed to scan the area and identify the boundary of the situation zone. The assumption is that different situations are detected by different numbers of recognised ANs/NANs (e.g. the situation is rainy if 33% of nodes are AN, while, a slippery spot can be detected by three ANs regardless the number of NANs).

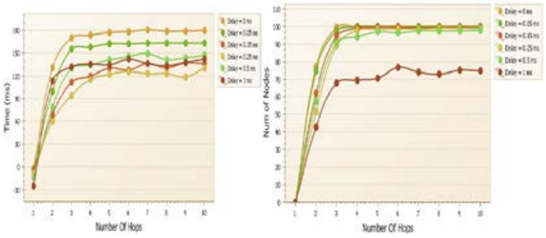

Figure 7: Message Exchange Time

And # of Nodes Saw more than 50% of AN

Analysis of the graphs' trends (the results simulate this scheme–Figure 7) indicates that:

a. There is no fixed optimum number either for delay time or number of hops. Consequently a range of numbers for these two parameters must be considered dependent on the detection cases. Based on these assumptions, we are looking for the best results that can recognise from 50% up to 100% active nodes (ANs), which will be enough to cover all cases.

b. Also, the graphs present the point of saturation i.e. where an increase in the value of the investigated parameter gives relatively small improvement in the quantity of sent/received/discarded messages. The results show clearly that using from three up to five hops is optimum to detect any traffic condition if we consider the abovementioned indicators.

c. The results show that the greatest delay time will reduce the number of exchanged messages, but will increase the total time needed to recognise the biggest possible number of ANs/NANs. This is a difficult compromise between time and noise, though a figure between 0.01 and 0.1 seconds seems to be indicated.

There is much work to be done in calculating the specific details based on the information gathered from 'intelligent flooding'. The migration of the common status is also an interesting aspect that would benefit from further study. A study of behaviour with different technologies could provide useful information.

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