TMDA: A Broadcast-Based Message Delivery Algorithm for VANETs

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***Abstract*—The challenges Intelligent Transportation Systems (ITS) address have only increased in time as, along with fast and cost-effective route planning, environmental sensibilities are nowadays also prominent. Currently, many ITS related studies focus on studying Car-to-Car (C2C) and Car-to-Infrastructure (C2I) communications in Vehicular Ad-hoc Network (VANET) environments. The utilization of such infrastructure-less and flexible topology networks poses several challenges for the routing mechanism aiming to achieve effective and efficient message delivery, specifically through broadcasts. This paper presents a new broadcast-based message delivery approach termed the Traffic Message Delivery Algorithm (TMDA) optimized for a city-based VANET setting. TMDA considers urban traffic travelling patterns and has been designed to exploit the route properties of different vehicle types such as cars and buses. In the case of the latter, TMDA adjusts its message propagation strategy so that bus routes, which intuitively involve elements (buses) with predictable routes, help propagate broadcast messages to a whole region which may otherwise have been disconnected. We investigate and compare the communications performance of vehicle groups under TMDA against other broadcast protocols through a set of experiments using NS-2 to simulate communications and SUMO to create representative mobility patterns. The simulation outcomes show that TMDA outperforms its competitors in efficiency and reliability while avoiding the deteriorating effects of a broadcast storm.**

Keywords- ITS; Car-to-Car (C2C) communication; VANET; broadcasting protocol; NS-2; SUMO

I. INTRODUCTION

Traffic demands in urban environments have been growing in recent years, following the proliferation of vehicles in the developing world and increasing worker mobility in modern economies. Utilising technology to help optimise existing traffic patterns and anticipate future demands has been a perpetual goal of Intelligent Transportation Systems (ITS). The availability of in-car wireless capabilities as well as the definition of interoperable vehicular communication standards worldwide has allowed for practically deployable decentralised ITS solutions alongside the more traditional centralised approach. As future trends indicate that in the near future urban centres will keep growing in importance and size, traffic coordination fuels and is fuelled by this growth, thus failing to manage it could stunt city development.

The importance of ITS in urban environments has been highlighted several times in the literature, with many developments helping define and expand its role [2-4]. A major theme in such works is decentralisation in the sense that traffic participants can be used as a practical tool to achieve efficient and reliable message propagation. Intuitively, vehicles are mobile entities with both predictable and unpredictable paths and so can be transports of messages to different sections of a city even if these are not covered by fixed ITS infrastructure. Further, fixed infrastructure facilities that can help propagate messages may be used in a complementary fashion helping the overall network to achieve an acceptable degree of connectivity. As a result of their great potential Car-to-Car (C2C) and Car-to-Infrastructure (C2I) solutions have received much attention [2], [5-8].

Several ITS related completed and on-going projects can be found in the seventh EU Framework Programme for Research and Technological Development [2], such as the Cooperative Vehicle-Infrastructure Systems (CVIS) project [5], which investigates interactions between vehicles and transport infrastructures for road safety. Another noteworthy and influential project is SAFESPOT [6], which considers intelligent information exchanges between vehicles and roadside units to realize safe and efficient transportation. Other works such as [7] recommend the deployment of roadside stations as it considers that infrastructure is a prerequisite for particular transportation monitors such as speed advisories and route navigation. These projects, among others, attempt to integrate C2C and C2I applications to achieve a combined benefit whilst highlighting that C2I can help improve ITS outcomes by utilizing roadside units (RSU), access points (AP) and cellular base-station information.

Even though C2I applications are broadly deployed compared to C2C applications, they exhibit well-studied weaknesses such as higher cost of infrastructure deployment [8], lower speed of connections [9] and smaller volume of handled data [10]. Importantly, C2C communications in Vehicular Ad-hoc Networks (VANETs), which are by definition infrastructure-free, self-governing and self-organized, can help effectively address such issues.

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This study contributes to the C2C communication potential in a VANET architecture deployed in an urban (city) environment. It proposes a novel and efficient broadcast-based message dissemination algorithm termed the Traffic Message Delivery Algorithm (TMDA) which makes use of known travel route information for public (buses) or private vehicles (considering route intentions declared via Sat-Nav devices) to efficiently spread messages of interest through the network. The proposed algorithm is evaluated via extensive simulation, as opposed to testbed assessment [11-13], using the Network Simulator 2 (NS-2) [14] to model communications and the Simulation of Urban Mobility (SUMO) [15] to model the mobility pattern based on the topography of the city centre of Nottingham in the UK.

The rest of the paper is structured as follows. The next section presents a literature review of existing broadcasting techniques in ad-hoc networks outlining their respective strengths and weaknesses. Section 3 describes a VANET-based C2C communication architecture proposed in previous work, which works in tandem with existing fixed infrastructure features to more effectively accommodate ITS functions. Section 4 contains an in-depth description of our novel message delivery algorithm termed TMDA, intended for use in the VANET C2C setting described in the previous section. Section 5 describes the simulation parameters used in the subsequent evaluation of TMDA. Then, Section 6 presents the simulation results and an in-depth discussion of TMDA performance. Finally, Section 7 concludes the paper and offers suggestions for future work.

II. Related Work

Flooding is a classic broadcasting method used in ad-hoc networks [3], [16], [17]. In this method, each of the nodes broadcasts or rebroadcasts a packet to all their neighbouring nodes the first time they receive it; if it has been received before they discard the packet to avoid redundant retransmissions. Ho et al. [18] state that simple flooding, also known as blind flooding [19] provides minimal state and high reliability, which are suitable for high mobility networks such as MANETs and VANETs.

Broadcast-based protocols suffer from high redundancy and transmission congestions, known as broadcast storms. Presently, several different broadcasting mechanisms are implemented in routing protocols to address this problem. Based on in-depth overviews of different protocols in [3] and [20], we only concentrate on those studies which are directly related to our area of focus, specifically those that propose delay-based, position-based and probability-based methods to mitigate broadcast storms.

A. Delay-based Protocols

In order to alleviate the negative effects of simultaneous broadcasting collisions, different methods have been adopted to generate forwarding delays.

In [21], the authors suggest a Vehicle-Density-based Emergency Broadcasting (VDEB) protocol which takes into account the sender-receiver distance. It obtains the distance from the interaction of neighbouring nodes, i.e., from acknowledgement (ACK) packets, and assigns a waiting time-slot for the rebroadcast action so that simultaneous forwarding can be avoided. The Beaconless routing algorithm (BLR) [22] applies a similar idea. Here, the delay is defined as deferring time which represents a relationship between transmission range and one-hop distance between the last sender and the current receiver. In Urban Multi-hop Broadcast (UMB) [23], which functions over IEEE 802.11, the farthest vehicles forward the received data first and then inform other nodes in between. Furthermore, Zhang et al. suggested a Neighbor Coverage-Based Probabilistic (NCPR) protocol [4], which defines a rebroadcast delay. The difference between NCPR and other protocols is that the delay is calculated based on a uncovered neighbour set $U(n_i)$ and covered neighbour sets of node s and $n_i - N(s)$ and $N(n_i)$.

B. Position-based Protocols

There exists a set of protocols which work with the position of nodes. In such cases, the nodes within or towards a particular area are the only ones that can rebroadcast messages. For example, the BLR [22] protocol specifies a Forwarding Area (FA). The nodes positioned inside the FA are the only ones that can rebroadcast the message. The shape of FA, which is defined as a sector in BLR [22] is considered as an issue. Position-based Opportunistic Routing (POR) [24] is another example of Position-based protocols and it defines the shape of FA as an area with positive progress towards a terminus.

C. Probability-based Protocols

Probability-based forwarding is another widely adopted approach to address the problem of broadcast storms. For example, Ni et al. [25] assume that the nodes should rebroadcast the received packet by following predetermined probabilities. So, if the probability is 100%, the scheme will be identical to blind flooding. The aforementioned NCPR [4] protocol uses a probability scheme to control the forwarding candidates. The authors in [25] introduce additional coverage ratio and connectivity factors to calculate the rebroadcast probability for each node. Higher coverage ratio means that there are more nodes that should be covered in the rebroadcast and therefore, the rebroadcast probability needs to be set to a high value (e.g., 0.75), allowing more nodes to dispose of Route Request (RREQ) packets. Meanwhile, although the connectivity factor increases the rebroadcast probability for the node in a sparse network with poor connectivity, it decreases the rebroadcast probability for nodes located in a dense network.

Current broadcasting protocols have improved the communication performance in terms of transmission efficiency and reliability. However, as Ros et al. [26] present, there are other factors such as uneven distributions of vehicles and their travelling speeds which are specific to

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VANET networks. In sparse network scenarios such as VANETs, appropriate protocols should be applied to deal with the high number of disconnections and their impact on message exchanges. Many existing approaches [21], [24], [27] utilize acknowledgement packets for this purpose. For example, Lee et al. [28] introduce a method for periodically broadcasting to neighbouring nodes. In this approach, neighbouring nodes of one-hop distance will be able to disperse the message to higher distance hops when they are in one-hop distance with them because of their mobility freedom. As another method, Kitani et al. [29] suggest the concept of 'message ferrying' in inter-vehicle communications, introducing bus as the ferry rather than a vehicle. Message ferrying is proposed to improve the efficiency of information sharing in sparse areas by relying on buses' regular routes and their ability to help with collecting more traffic information.

In VANETs, there are diverse and changeable communication demands and traffic problems can occur at any time in different areas. These characteristics make it very difficult for a communication protocol to perform adequately in typical communication scenarios and, it would be fair to state, there has not yet been any comprehensive and popular message delivery algorithm to do so. Researchers have proposed algorithms which include particular traffic information, such as the inclusion of the acknowledgments into the periodic beacons for high reliability in [28] and the inclusion of vehicles' status and surrounding information in [30]. So far, on the basis of studies in the literature, explicitly utilising scheduled routes information has not been considered as a means to improving network coverage or message dissemination; the proposed TMDA algorithm in this paper addresses this void.

III. A VANET FRAMEWORK

In previous work, we introduced a VANET architecture [31] which accommodates spontaneous wireless communications occurring within a group of wireless mobile nodes, as shown in Figure 1. The architecture integrates features of traditional ad-hoc networking and VANET technologies allowing for both intra-network and inter-network connections with gateway functions providing access to the Internet [32].

In this setting, we focus on the aspect of the communication system which utilizes vehicles (roaming agents) for routing purposes via the inclusion of traffic route information. To better utilise the potential of the vehicle/node as a message forwarding device when communications occur, the system distinguishes them in three types: mobile, semi-mobile and static nodes.

Mobile nodes, such as private vehicles, are defined as common ad-hoc nodes without pre-conceived routes that are able to consume and forward messages. As these are the most prolific in public road networks (privately owned vehicles outnumber publically or state owned ones in most settings), they form the majority group in acting as message forwarders and consumers. As vehicles can be generally equipped with highly capable electronic devices for message storage, they can also act as long-storage and dissemination agents for relevant messages through the network. The routes of such nodes cannot easily be predicted as it depends on the will of the owner at the time - i.e., the routes are largely unpredictable and cannot be known in advance.

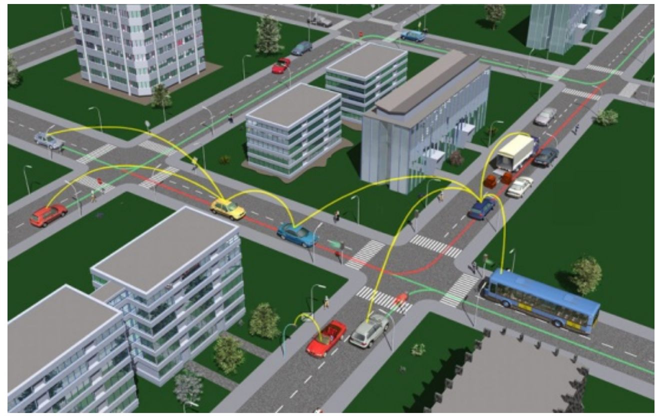

Figure 1. A VANET Scenario – city traffic communications [33]

Semi-mobile nodes, on the other hand, have predetermined routes which they follow at particular times; the most characteristic example of such vehicles is a bus following a particular bus route. In the particular case of buses, which is the semi-mobile node type considered in this study there is opportunity of including more powerful devices with greater storage than in cars due to the larger physical size of the bus vehicle. As such messages can be cached for longer before they are propagated (due to increased storage space), the communications range may be greater with the use of directional antennas (the cost of additional antennas is small compared to the cost of the bus) and more messages may be processed at the time (due to the availability of greater processing power). The presence of semi mobile nodes allows the predictable re-connection of possibly disconnected network segments and allows message propagation to reach, with predictable delay, areas in the road network where mobile node traffic is sparse. Further, in many cities there are dedicated bus-lanes or bus-priority lanes which help guarantee travel times for commuters even in times of peak traffic; as such the scheduled travelling times of semi-mobile bus nodes are more reliable than the predictable travelling time of other semi-mobile vehicles (such as police patrol cars).

Static nodes are fixed infrastructure units with the ability to relay and consume messages. These cannot ensure road network coverage on their own due to their high expense of deployment but instead cooperate with the other two node types to aid communication in the network. Broadly, these are termed roadside units and, in general, have few processing power and storage limitations.

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The message delivery algorithm described in the next section is specifically designed to meet the requirements of C2C communications in this VANET framework by taking advantage of the three types of traffic participant mentioned above. We generally assume a sparse presence of static nodes (due to their cost) and mostly rely on mobile and semi-mobile vehicles to achieve message dissemination.

IV. TMDA – Novel Message Delivery Algorithm

Traffic Message Delivery Algorithm (TMDA) is a novel broadcasting-based algorithm designed for improving communication performance in the VANET network configuration described in the previous section. The TMDA version used here is identical to that used in previous work [1]; however, it is examined here more thoroughly. The main difference between TMDA and previously proposed broadcast methods is that it does not implement only a single broadcasting approach - such as simple flooding, delay-based, position-based or neighbourhood-based methods [34] - but also adopts intelligent broadcasting strategies by utilizing pre-existing travel information for semi-mobile vehicles. Specifically, every participating vehicle is aware of the route and schedule of semi-mobile nodes in the road network; this is used in the manner described below to disseminate a message to a single or several recipients. Initial route information of semi-mobile vehicles could be downloaded each day from the vehicle owner's smartphone or through some other means.

Overall, TMDA aims to take advantage of the arbitrary, but presumably law abiding, route patterns of mobile nodes (cars) and exploits the benefits of controllable, scheduled, and predictable bus-nodes; it does not only use the simple broadcasting behaviours of cars, but also makes use of the higher processing power of bus-nodes to persistently store and forward messages. As well as handling local message delivery, TMDA allows for the possibility of Internet access through the static nodes infrastructure with road sign units acting as gateways.

A. Algorithm Description

TMDA is a receiver-oriented broadcasting protocol, meaning that receivers are solely responsible for determining re-broadcasting behaviour. The process can be distinguished in four sequences, namely (1) redundancy check; (2) position check; (3) distance check and (4) delay assignment. Algorithm I shows the pseudo-code of TMDA operations when a message reaches a receiver.

When a message is received by a receiver *R* but *R* is the originator *S* for this packet, then a broadcasting loop occurs (lines 2-3 in Algorithm I), so, in this case, *R* needs to discard the message. Each message has a unique message id *msg_id*. When a message reaches any receiver *R*, the *msg_id* is recorded into a broadcast table *brd_table* that every receiver *R maintains*. If the *msg_id* is found in *brd_table*, the redundant packet is directly discarded (lines 5-6); otherwise, *R* continues processing the message (lines 8 to 19).

ALGORITHM I. PSEUDO-CODE OF TMDA IN MESSAGE RECEIVING

```
1 Event: the message received by R
2 if R = S then
3 |   discard the message;
4 else
5 |   if {msg_id ∩ brd_table} ≠ Ø then:
6 |   |   discard the message;
7 |   else
8 |   |   if P_r is on I-Routes or R is a static node then:
9 |   |   |   assign a WD_1;
10|   |   |   forward the message at T_1;
11|   |   else
12|   |   |   if P_s is on I-Routes then:
13|   |   |   |   discard the message;
14|   |   |   else
15|   |   |   |   if D_r = D_s then:
16|   |   |   |   |   assign a WD_2;
17|   |   |   |   |   forward the message at T_2;
18|   |   |   |   else
19|   |   |   |   |   discard the message;
20|   |   |   |   endif
21|   |   |   endif
22|   |   endif
23    endif
24 endif
25 END Event
```

In this VANET configuration, nodes are assumed to be equipped with GPS enabled devices. The location information derived from GPS allows the node to discover whether it is located in a special geographic location termed the *I-Route*. The term *I-Route* refers to predetermined routes on the map which are distinguished from regular road segments in that they are bus lanes where, normally, only buses travel, i.e., bus movement there is independent from normal traffic flow. If *R* is on an *I-Route* or it is a *static node* (e.g., bus stop), then *R* forwards the message to be propagated at time T_1 after a waiting delay WD_1. Another waiting delay WD_2 is defined with some value, which is inversely proportional to the distance between *S and R*. That is, the farthest *R* forwards the message first (because the calculated added delay will be smaller compared to that of other Rs). On the other hand, if *R* is not on the *I-Route* but the last-hop *S* is, then *R* discards the message so that redundant messages can be limited to a certain degree. With this method we attempt to guarantee that transmissions on an *I-Route* have higher priority to others. If the last-hop *S* is a non *I-Route* node, then *R* reads the message and knows that the position of last-hop sender (P_s) is not on the *I-Route*; it then compares the direction of the last sender (D_s) and itself (D_r). When they move towards the same direction, then the message is forwarded at T_2 after adding a delay of WD_2. WD_2 is always greater than WD_1 which in turn means that the resulting T_2 is greater than T_1. If the nodes move in opposite directions no propagating transmission takes place.

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B. Main Mechanisms

1) I-Route: In TMDA, *I-Route* is a novel concept of assigning special importance to some linked road segments. The term implies a set of special routes considered in the message delivery algorithm that are used to determine the next operation of nodes. If a message reaches an *I-Route* receiver, the receiver forwards the message quickly using the pre-configured directions of the *I-Route*; otherwise, they follow the regular broadcasting strategy outlined in the algorithm. *I-Routes* are meant to represent locations where nodes will often be present and traffic will be dense. *I-Routes* also exist in sparse traffic places where there is a greater chance that a bus will be present compared to other parts of the network. In any case, *I-Routes* are predefined and they exist to attempt a best effort at finding an intermediate to propagate the message to its destination.

2) Farthest Node First Send: The final forwarding behaviour is defined by the Farthest Node First Send (FNFS) paradigm. This can be defined as follows; when a sender broadcast a message to all neighbours, the farthest one within the transmission range will retransmit the message before the others. This is represented by a probability value, as defined in (1):

$$P_{dis} = \frac{d_{<s,r>}}{d_{max}} \tag{1}$$

where P_{dis} is a probability of distance; $d_{<s,r>}$ represents a distance between last-hop sender and current receiver, as shown in (2); d_{max} is a maximum value of transmission range, e.g., 150 meters - this value depends on the signal propagation configuration.

$$d_{<s,r>} = \sqrt{\Delta x^2 + \Delta y^2} \tag{2}$$

where Δx and Δy is the difference of the x and y coordinates of the last sender and current receiver.

The above equations indicate that, if a receiver is positioned closer to the boundary of its last-hop sender, a larger P_{dis} is obtained, which contributes to a faster rebroadcast. In general, FNFS limits data collisions somewhat by reducing the number of transmissions along a transmission path.

3) Direction vector: The direction vector of the nodes is considered when both the sender and the receiver are not on any I-Routes. This is because nodes in such case are prone to broadcasting collision and congestion, and taking the direction of traffic into account can possibly reduce packet collisions. However, as described in Algorithm I the direction vector is not considered when the receiver is an I-Route node (a node located on an I-Route). The I-Route scheme includes a suppression mechanism to reduce the number of broadcast collisions - additional utilization of the direction vector may limit the quantity of forwarding candidates, resulting in lowering message reachability. Thus, the direction-based strategy is not essential for I-Route nodes. In (3), the direction vector is applied as:

$$P_{dct} = \frac{\pi - SR°}{\pi} \tag{3}$$

where P_{dct} is termed a direction based probability; $SR°$ represents the difference of direction vector of sender and receiver in degrees; π is equal to $180°$. In TMDA, when the angular distance between sender and receiver is less than $180°$, we consider these two nodes to move in the same direction, i.e., $D_r == D_s$.

4) Waiting Delay: In TMDA, the waiting delay WD is the most influential parameter used to control the time of forwarding. In generating a delay WD, the position and direction of senders and receivers as well as the distance between last hop and current receiver are the main factors. Forwarding with a WD strategy somewhat addresses the problem of broadcast storms. As mentioned before, VANET nodes are assumed to be equipped with GPS devices so they can detect their own positions and directions in a timely fashion and could place that information in the forwarded packets. So, when a receiver R receives the message, it is possible to deduce the distance between it and the sender (or last hop node). In TMDA, WD is calculated via (4) which adapts it for different node conditions:

$$T_{wd} = \begin{cases} (1 - P_{dis}) \times T_{hop} & RIR = 1 \\ (1 - P_{dis}) \times 2T_{hop} & RIR = 0, SIR = 0 \end{cases} \tag{4}$$

where T_{wd} is a waiting delay; T_{dis} is an minimum interval time of one-hop transmission.

According to the above equations, the waiting delay varies due to the position and direction of senders and receivers. The waiting delay is smaller when the receiver is an I-Route node than when both sender and receiver are non-I-Route nodes. In the latter condition, only communicating pairs facing the same directions have a chance to forward the message after some waiting delay. The predominant reason for this is to assign nodes different waiting delays before transmission, aiming to avoid or reduce the negative effects caused by simultaneous broadcasts.

V. Simulation Setup

To evaluate the proposed TMDA broadcasting protocols, we employ simulation and in particular use the NS-2 v.2.35 to create VANET network model for different scenarios. Further, we use SUMO to simulate real traffic flows in Nottingham (UK) city centre. Figure 2 depicts an overview of the simulation structure.

The NS-2 modules in the simulation structure consist of mobility information and broadcasting protocols. The raw

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data output from NS-2 is used to evaluate the network performance in Section 6.

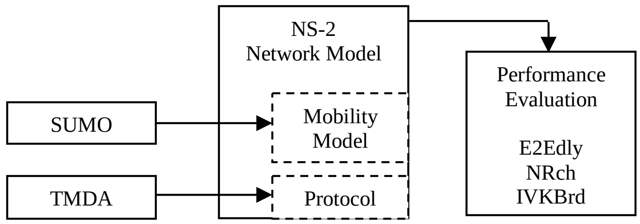

Figure 2. Simulation and evaluation modules

A. *Simulation Scenario*

In this study, the simulated area is chosen to be the city centre of Nottingham as shown on the map in Figure 3. Compared with T-shaped patterns [31] and #-shaped patterns [1] reported in our previous papers, this scenario contains more realistic elements such as road distributions, vehicle movements and the layout of bus lanes. Important elements in the simulation scenario are described as follows.

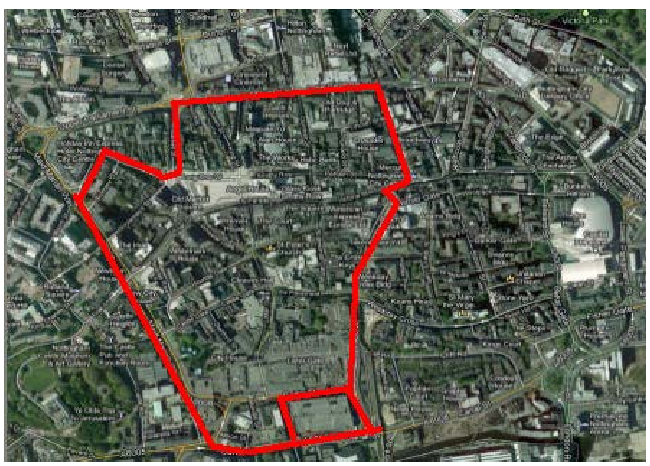

Figure 3. Nottingham (UK) City Centre with bus lanes

1) Nottingham City Centre: This is a medium scale traffic area consisting of intersections, roads in various shapes, buildings and so on. In this scenario, we need to find whether I-Routes provide efficient decisions for message delivery; whether different types of nodes can cooperate to provide high reachability under various network densities ;and whether broadcast storms can be alleviated effectively.

2) I-Route: This is a term used for a set of special routes in a target system. In I-Routes, the message transmission mechanism can process rebroadcasts based on their priorities and improve communication performance. In this simulation, we take advantage of buses in the city traffic by adopting bus lanes to shape the I-Routes; this is shown as red lines in Figure 3.

3) Network density: It represents the number of nodes in the network. In reality, the traffic density in an area can vary at different times and different days. Therefore, we consider simulation results for scenarios containing a number of mobile nodes, ranging from 50 to 200. We define terms ‘very low density’, ‘low density’, ‘medium density’, and ‘high density’ to represent networks with 50, 100, 150 and 200 nodes respectively. Density examples are shown in Figure 4.

Figure 4. Simulation models for very low and high density of networks

B. *Simulation Parameters*

The simulation parameters are shown in Table I. Further important simulation parameters are outlined below.

TABLE I. SIMULATION PARAMETERS

Network Simulator	NS-2 (version 2.35)
Traffic Simulator	SUMO
Channel	WirelessChannel
Bandwidth (Mbps)	6
Propagation	TwoRayGround
Network Interface	WirelessPhyExt
MAC Type	IEEE 802.11p
Protocol	TMDA, Flooding
Mobile vehicles	50, 100, 150, 200
Message size (byte)	128, 256, 512, 1024
Transmission range (meter)	150
Maximum Velocity (km/h)	30
Number of observation	50
Simulation time (second)	1500

1) Distance: In this work, the nodes are distributed following the topography of urban lanes. SUMO generates vehicular traffic using the car following model and the transmission is set to approximately 150 metres given that the signal propagation model (TwoRayGround) is deterministic.

2) Speed: The speed of vehicles can vary in different traffic conditions and in accordance with the traffic rules such as the road speed limit, etc. In this simulation, the speeds of nodes in city centre area are set to vary randomly with the limit of 30 km/h.

3) Time: The total simulation time is set to be 1500 seconds. NS-2 allows messages to be generated or sent by any nodes at any random time during the simulation time.

4) Message: Message contains three elements: message size, message id and other information such as the source node, current sender, the position, speed and direction of

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senders, the message expiry and current time. The size of message can vary for different communication purposes. In this paper, we observe message sizes from a minimum of 128 bytes to a maximum of 1024 bytes. We assume that only one message is transmitted per observation time.

VI. SIMULATION SETUP

In order to assess communication performance of TMDA by comparing it to conventional flooding protocol methods, we first introduce the performance metrics considered as follows, before presenting and discussing the simulation results.

A. Network Communication Performance Metrics

1) End-to-End delay (E2Ed): This metric refers to the time needed for a message from an originator to be received at the intended destination over the network, as in (5) and (6). E2Ed represents a capability of the network communication from a source to its possible destinations via one-hop or multi-hop transmissions.

$$\Delta T = T_e - T_0 \qquad (5)$$

$$T_{e2ed} = T_{WD} + \Delta T \qquad (6)$$

where T_e and T_0 stand for the time that the ultimate destination receives a packet and the first transmission time respectively.

2) Network Reachability (NRch): This parameter represents a ratio of network nodes receiving a message as in (7). In a broadcast storm, the NRch theoretically decreases due to more packet collisions or when link disconnections occur.

$$R_{NRch} = \left(\frac{N_{recv}}{N}\right) \times 100\% \qquad (7)$$

where N_{recv} is the number of reached nodes and N is the total number of network nodes, i.e., vehicles and bus stops in this study.

3) Invoked Broadcast (IVKBrd): This metric measures the number of invoked broadcasts in the whole network. The particular goal of the metric is to observe how effectively the protocol can control the forwarding process.

B. Compared Protocols

1) TMDA: The proposed traffic message delivery algorithm in this study delivers messages using the concept of pre-configured routes (I-Routes) in the city scenarios. On the basis of general broadcasting methods, TMDA reduces broadcast storms via a selective forwarding mechanism, coupled with geographic information such as positions and directions.

2) Flooding: Flooding is the simplest broadcasting approach used in VANETs for data disseminations. This has been reviewed and further discussed in Section 2. Although there are obvious problems caused from the broadcast storm, flooding is a protocol with very high reachability in a particular range of networks. By comparing with this broadcasting protocol, we can clearly identify whether TMDA addresses broadcast storm and how effectively it does so.

Table II shows the anticipated features of TMDA, being given in advance, and these advantages and disadvantages are investigated through simulation results in the following sections.

TABLE II. ANTICIPATED CHARACTERISTICS OF TMDA

Advantages	**Disadvantages**
1) Simple broadcasting mechanism 2) No network topology maintenance 3) No complex route discovery algorithm 4) I-Routes are set up for controlling packet forwards 5) Broadcast storm is controlled and reduced by particular mechanism	1) Tolerate certain delays if nodes are not on pre-configured routes 2) Not suitable for emergency message exchanges in sparse networks based on C2C communications only

C. Results Evaluation and Analysis

This section compares the communication performance under the TMDA and flooding protocols with respect to E2Ed, NRch and IVKBrd. In this paper, the in-depth evaluation and analysis is presented in two parts: the effect of networks density and the effect of message size.

1) Effective of network density

Network density, as introduced earlier, represents the number of nodes in the network. In our target VANET scenario, both mobile vehicles and static bus stops are involved. In C2C communications, a dense network usually maintains good connectivity at the cost of serious broadcast storms. Therefore, our first investigation point on how to overcome heavy packet collisions and transmission congestions, which is closely related to the reachability performance metric. We compare the reachability of TDMA with the high reachability of flooding protocol to identify whether TMDA can exhibit an acceptable message delivery ratio.

A number of studies [2], [35], [36] have attempted to use infrastructures in C2I technology to reduce the problem of large disconnections and consequently lower reachability in sparse networks such as C2C. However, if we consider resource consumption and costs the C2C approach is more effective. At this stage, we are using TMDA to improve C2C communication performance without any connected infrastructure node. TMDA's capability to maintain C2C message delivery in both dense and sparsely connected

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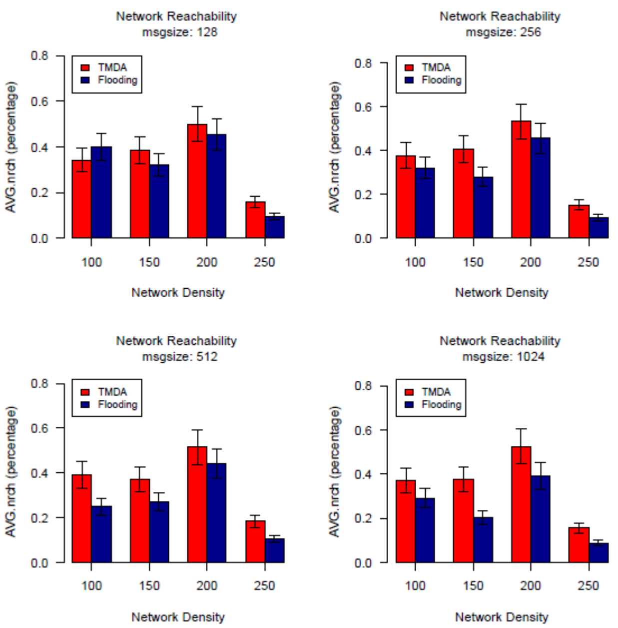

Figure 5. Reachability with the effect of density
(message size fixed)

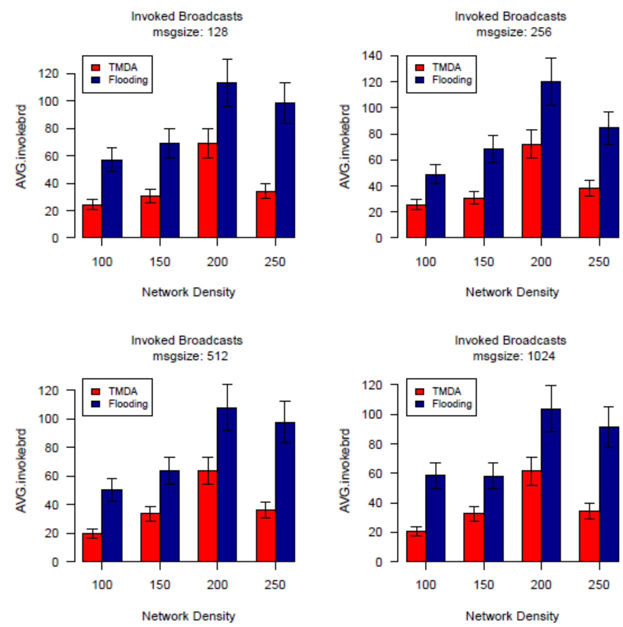

Figure 6. Invoked broadcasts with the effect of density
(message size fixed)

communication environments is investigated. This can become the basis for C2C and C2I communications in a more advanced TMDA in future work.

In Figure 5, TMDA's network reachability shows an upward trend of 0.35 to 0.5 when the number of nodes increases and then shows a significant decrease to approximately 0.15 when the network density exceeds 200 nodes. On the other hand, flooding protocol shows a slight network reachability fluctuation (0.4 to 0.32 to 0.48) when the number of nodes is less than 200. Flooding shows a significant decrease for network reachability similar to TMDA for a denser network (over 200 nodes). For fixed size of the messages, TMDA leads to around 5% to 20% higher reachability than flooding as the network becomes denser, except in the case where 128-byte messages are delivered in the 100-node network.

The reduction of rebroadcasts is a credible reason for TMDA's higher reachability. In Figure 6, TMDA shows a lower number of invoked broadcasts compared to the flooding protocol as the number of nodes in the network increases. For a fixed message size of 128 bytes, the IVKBrd is approximately 22, 30, 70 and 35 for TMDA and 58, 70, 115, and 98 for flooding, as network density increases. The range of difference in performance between the two protocols varies from about 30% to 60%. This outcome suggests that the concept of I-Route priority forwarding has reduced the number of redundant packets and thus alleviated broadcast storm.

The reachability results exhibit an unexpected trend when the size of the network increases from 200 nodes to 250 nodes. In most cases, TMDA controls the forwarding process adequately so we expected that the NRch in 250-node network should be higher than that in smaller networks. This is in contrast with the results for the 250 node case. Similarly, the flooding protocol results suffer from this descent. Here, we notice that the mobility model of 250-node network includes a large number of vehicles with short trips. In other words, many vehicles can leave the simulation

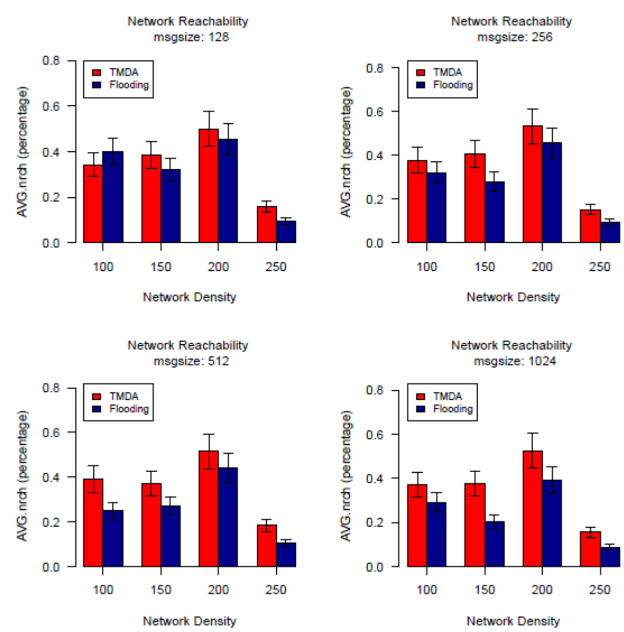

Figure 7. Delay with the effect of density
(message size fixed)

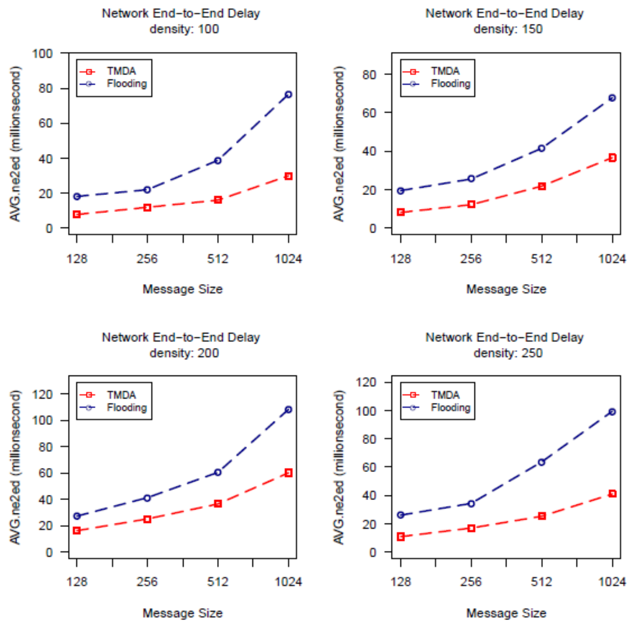

Figure 8. Delay with the effect of message size (network density fixed)

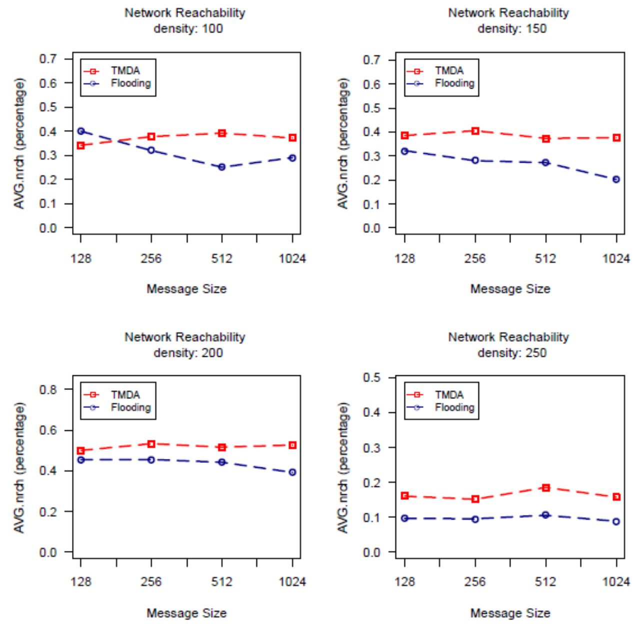

Figure 9. Reachability with the effect of message size (network density fixed)

region during simulation time. In this case, according to equation (7), the N_{recv} presents significant small value against the *N*. However, IVKBrd and EDT are not affected by this. This observations concludes our discussion of network reliability for TMDA compared to the flooding protocol. Now, we focus on the efficiency of message delivery.

In Figure 7, for both protocols the E2Ed metric generally increases as the number of nodes increases. Intuitively, if two protocols lead to similar or even the same level of message reachability, then the one with smaller E2Ed achieves more efficient transmissions. Results presented in Figures 5 and 7 show that TMDA can outperform flooding protocol with better NRch and E2Ed.

The best case for communication performance takes place in the 200-node network case where NRch is around 0.5 for TMDA and 0.42 for the flooding protocol when the message size is fixed to 128 bytes; in this case, E2Ed is 17ms and 27ms respectively. The differences between the two protocols vary in other cases. We can summarize that the schemes such as prior forwarding on I-Routes and waiting delay in TMDA work as anticipated in Table II. These schemes provide new optimisations addressing packet collisions caused by simultaneous forwarding.

Despite the fact that TMDA outperforms flooding for E2Ed, NRch and IVKBrd metrics, there is need and scope for further improvements addressing disconnections. In a sparse network (e.g., 100 nodes), if we were to observe high reachability, that would indicate that the network has an effective mechanism for addressing intermittent disconnections. In this case, TMDA shows rather better outcomes than the flooding protocol. However, it can be noticed that the value is still low over a C2C communication network – at around 0.35 regardless of the message size. We aim to address this in a future proposed improvement for TMDA.

2) Effect of message size

A critical factor effecting communication is not just the number of transmissions, but also the volume of data contained per message. To investigate the effect of the latter, in this paper, we set observed message sizes as 128

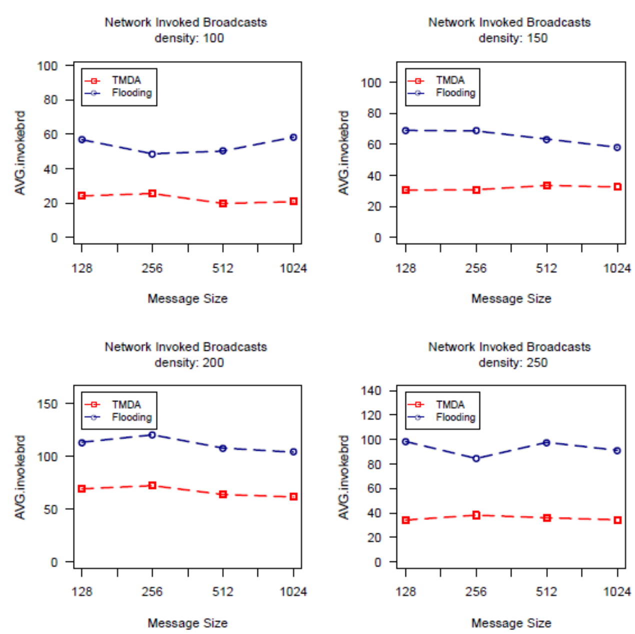

Figure 10. Invoked Broadcast with the effect of message size (network density fixed)

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bytes, 256 bytes, 512 bytes and (at maximum) 1024 bytes. The effect of message size is represented in Figure 8 for E2Ed , Figure 9 for NRch and Figure 10 for IVKBrd.

There is an obvious impact on E2Ed as shown in Figure 8. Generally, for both protocols, E2Ed increases as the message size increases. This can be justified by the fact that the larger packets require longer time to be received by neighbouring nodes for a limited channel capacity. However, we consider more notable the fact that the E2Ed of TMDA is considerably less than that of flooding and the speed of growth under TMDA is much smaller (no more than 30ms) than that of flooding (up to approx. 75ms). The differences can be approximately 4ms to 60ms for very low density network, 5ms to 40ms for low density network, 11ms to 60ms for medium density network, and 15ms to 60ms for high density network. As shown above, TMDA outperforms flooding in terms of transmission delays and, in fact, the observed delays recorded are well acceptable for several VANET traffic applications. It then becomes of interest to examine whether packet size increase has an unacceptable deteriorating effect on reachability or observed end-to-end delay. In Figure 9, it can be seen that NRch for TMDA is not significantly affected by the increase in packet size at a given network density. Further, measurements of NRch in flooding show some notable decrease. This trend becomes less prominent when the network density increases to 250 nodes. As evinced in Figure 9, the best NRch performance noted in flooding is when the message size is 128 bytes and the number of nodes over the network is 100, i.e., the network is sparse. With regard to the number of IVKBrd shown in Figure 10, the impact of message size is not too significant as is the case with TMDA.

According to the above presented results, C2C communications in our chosen city scenario can only be reasonably achieved using the TMDA method when considering realistic packet sizes, such as 512-1024 bytes; flooding only exhibits reasonable performance at small packet sizes (128bytes) and in sparse networks. Overall, TMDA is a competent performer able to broadcast messages within acceptable delay and reachability margins, suitable for typical ITS applications.

VII. Conclusion and Future Work

This paper presented a new broadcast based Traffic Message Delivery Algorithm (TMDA) for VANETs and compared its communication performance to popular broadcast-based protocols in scenarios modelling road traffic of the centre of the city of Nottingham in the UK. TMDA adopts several principles of existing broadcast algorithms, such as delay-based and position-based forwarding techniques and, further, incorporates urban traffic route information. With respect to the latter, TMDA considers the concept of different node types in the VANET, such as cars and buses, and exploits the fact that some nodes' routes, termed the I-Routes, are predetermined and predictable. In TMDA nodes in such I-Routes are given higher transmission priorities so that propagation of messages, ultimately, occurs in areas where traffic is likely and predictably present. The broadcast techniques used in TMDA aim to alleviate the impact of the broadcast storms by controlling dissemination as opposed to indiscriminately re-transmitting broadcast messages.

We measured the performance of TMDA against flooding broadcast in sparse, medium and heavy traffic densities, measuring end-to-end delay, reachability and the number of broadcasts in the network with different packet sizes. Our results indicate that the end-to-end delay observed is always 25%-68% less when using TMDA in all traffic density and packet size configurations. The difference is in the higher range as the packet size used increases (from 128b to 1Kb). The same holds true with the number of invoked broadcasts; TMDA typically exhibits 30-60% less broadcasts than flooding for similar or higher network reachability. The latter is only observed to be less than flooding by 10% in a sparse network and at a very small packet size; in any other case reachability is observed to be higher than flooding by 12-45%. Overall, we observe that in all interesting use cases, i.e., medium packet/message size and across all network topology configurations, TMDA outperforms flooding in all metrics.

In the near future, we aim to examine TMDA performance against more modern flooding techniques, in particular, probabilistic and counter-based message dissemination methods because the advanced protocols show high capability to control the broadcast storm during message propagations. We also aim to consider other road topologies from different cities in the UK to extend our case study and observe if our results hold in different settings. Finally, we will study the offered broadcast load more thoroughly by examining TMDA behaviour when the number of simultaneous broadcasts increases.

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