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Study of a geo-multicast framework for efficient message dissemination at unmanned level crossings

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Abstract: Collisions among trains and cars at road/rail level crossings (LXs) can have severe consequences such as high level of fatalities, injuries and significant financial losses. As communication and positioning technologies have significantly advanced, implementing vehicular *ad hoc* networks (VANETs) in vicinity of unmanned LXs, generally LXs without barriers, is seen as an efficient and effective approach to mitigate or even eliminate collisions without imposing huge infrastructure costs. VANETs necessitate unique communication strategies, in which routing protocols take a prominent part in their scalability and overall performance, through finding optimised routes quickly and with low bandwidth overheads. This article studies a novel geo-multicast framework that incorporates a set of models for communication, message flow and geo-determination of endangered vehicles with a reliable receiver-based geo-multicast protocol to support cooperative level crossings (CLXs), which provide collision warnings to the endangered motorists facing road/rail LXs without barriers. This framework is designed and studied as part of a \$5.5 m Government and industry funded project, entitled 'Intelligent-Transport-Systems to improve safety at road/rail crossings'. Combined simulation and experimental studies of the proposed geo-multicast framework have demonstrated promising outcomes as cooperative awareness messages provide actionable critical information to endangered drivers who are identified by CLXs.

1 Introduction

Over 630 crashes occurred at road/rail level crossings (LXs) between motor vehicles and trains in Australia between 2001 and 2009 [1]. Other than the severe financial losses involved in LX accidents, they have also been catastrophic leading to numerous fatal casualties who were 70 in Australia between 1997 and 2002 [2]. Driver errors and behaviour, signalling difficulties and environmental conditions are the major factors accounted for LX collisions [3]. Both less-effective economical passive and expensive active warning and signalling systems are the existing approaches to improve safety at LXs.

The study conducted by the Australian Transport Safety Bureau (ATSB) [4] confirmed more than 80% of LX fatal accidents occurred in excellent driving conditions in daylight with fine weather on straight dry roads. At least 50% of the LXs involved in the ATSB study were equipped with some types of active warning systems such as boom gates, flashing lights or barriers. The study revealed the fact that 46% of all incidents were commonly occurred because of driver errors. Therefore as adverse weather and/or road conditions are not the absolute reasons for LX incidents, the presence of active warning systems is also not the utter safety provider. A few intelligent level crossing systems (ILXs) have been proposed using signal and sensors, sonic–ultrasonic devices and/or cellular–radio communications in the literature such as [5–8], nevertheless none of them is cooperative, which is the most critical approach to assure situational awareness. In this regard, cooperative intelligent transportation systems (C-ITS) can offer a set of rich and fresh technologies to further improve safety at LXs.

Vehicular *ad hoc* networks (VANETs) provide vehicles with ubiquitous connectivity, which improves safety and efficiency not only on roads, but also on rail and in the vicinity of LXs. An inter-vehicle communication (IVC) system served for safety at unmanned LXs, generally LXs without barriers, may be named as cooperative level crossings (CLXs), which are a warning system to provide situational awareness and safety warnings to drivers approaching an LX by exchanging safety messages between cooperative trains and vehicles. This paper presents a framework including dedicated geo-multicast models for communication, message flow and geo-location determination as well as a routing protocol in the challenging environment of CLXs. This study is part of a multi-million dollar project [http://www.latrobe.edu.au/technology-infusion/innovation/transport/improving-safety-at-level-crossings] aiming to develop a cooperative ITS to improve safety at rail–road crossings [3].

CLXs support various safety applications such as approaching train warning and LX safe traverse, in which like other ITS safety systems, such as cooperative collision warning systems, can exchange both routine and event safety messages [9]; however the present paper focuses on event-driven safety messages. CLXs utilise wireless communication technologies such as 5.9 GHz dedicated short range communications (DSRC) to facilitate vehicle-to-vehicle/infrastructure (V2V and V2I) communications, global positioning system (GPS) for positioning and differential GPS (DGPS) or real-time kinematic (RTK) techniques to provide more accurate positioning services to communicating nodes. Other than these fundamental technologies and systems, the two critical mechanisms of a CLX are the identification of endangered vehicles and message routing.

Most of the routing protocols utilised for safety message dissemination in IVC systems are classified as broadcast such as those projected in [10–13], nevertheless these schemes are not efficient enough for CLX message routing purposes. The reason for their inefficiency is that a warning message is sent to a large number of vehicles existed in the designated areas rather than only the endangered nodes. The receivers also cannot be prioritised based on their critical location to avoid collision by the broadcast routing schemes. The geocast scheme, which was first revealed in [14] as an addition to the Internet, but not for mobile *ad hoc* networks (MANETs), is designed to overcome some of the shortages seen in the broadcast strategy by providing a more dynamic message delivery experience. Geo-multicast, a variant of geocast, is a dedicated location-dependent multicast scheme, where messages are disseminated to particular user groups within selected geographical areas.

The rest of this paper is organised as follows: Section 2 provides an overview of the CLX system, the essential models supporting the proposed framework, and position-based routing protocols. Section 3 identifies routing challenges in CLXs and outlines the geo-multicast framework's details including a geo-determination model for identifying the endangered vehicles. A few numeral demonstrations of the geo-determination model as well as result discussions are elaborated in Section 4. Then, Section 5 demonstrates the performance of the proposed cross-layer algorithms through simulation studies. Finally, Section 6 concludes this work.

2 Fundamentals of the framework

2.1 CLX warning system

CLXs support several cooperative warning applications such as warnings for the existence of a train at LXs, safely traversing LXs, and a second approaching train. All of these applications employ the situation awareness capability of the system facilitated by positioning and communication systems. Vehicles' state data including precise position coordinates, velocity, acceleration and heading can be obtained from the onboard positioning units. It is feasible to assume that all nodes can obtain their position solutions with lane-level accuracy (1–2 m) since CLX is supposed to utilise DGPS/RTK corrections provided by continuously operating reference stations widely available in many countries, including Australia.

The communication system, in addition to the positioning system, consists of at least one 5.9 GHz DSRC transceiver on-board unit (OBU) for each vehicle and a 5.9 GHz DSRC transceiver road-side unit (RSU) at each LX. Installing a DSRC RSU at LX provides more communication reliability especially in urban scenarios. In addition, RSUs located at LXs can actively contribute to lessen stop sign and traffic signal violations at both controlled and uncontrolled LXs. Based on a series of field experiments carried out in open field conditions where no roadside furniture existed, the coverage range of 5.9 GHz DSRC radios slightly exceeded 1000 m in line-of-sight using the transmission power of +20 dBm. DSRC transceivers typically employ omni-directional antennas for V2V and V2I communications. Fig. 1 presents a schematic view of the CLX environment.

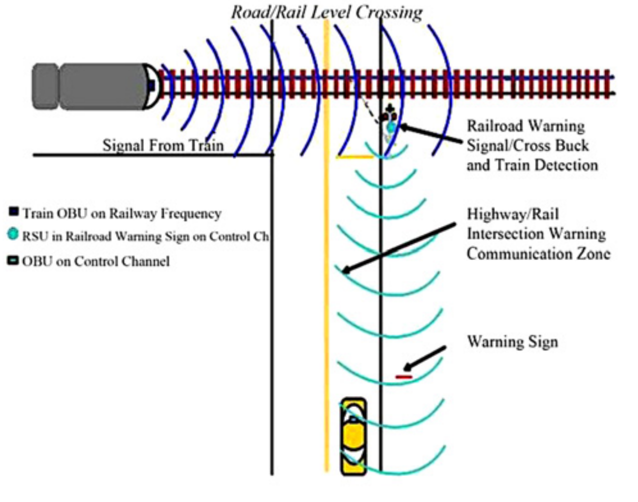

Fig. 1 *CLX warning system (courtesy of the centre for technology infusion – La Trobe university [15])*

The positioning component of the system uses point positioning recomputed every GPS epoch, although trains have substantial lengths, which are more minatory to road users. Hence, two measures can be considered to make the safety provided by CLXs more effective. In the first approach, messages constructed at senders are included with the dimensions of the sender similar to the basic safety message (BSM) of SAE J2735 to provide adequate information to vehicles approaching a LX. For the second approach, a second set of on-board positioning/communication unit (OBU), other than the one installed on the nose of train, can be installed on the tail of train. The first approach is used throughout this study.

The CLX vision in respect to communication and positioning is to connect trains, vehicles and road infrastructure simultaneously via continuous wireless communications and provide precise positioning on motorways in vicinity of LXs. Exchanging data and information relevant to a specific LX is carried out to increase the overall road/rail safety and enable cooperative traffic management. Likewise, the CLX mission in respect to communication and positioning is to define, develop and test new safety related communication and positioning services and applications using two-way communications among the road infrastructure, trains and vehicles from a technical perspective.

2.2 Communication model: unit disk graph

Topology features play a significant role in message routing within VANETs. To support these features, most of the CLX safety applications may enjoy topological advantages from multi-hop packet relaying over VANETs. Among the objectives of this study is to design and test a receiver-based geo-multicast (RBGM) framework to enable a fast and reliable message forwarding mechanism for quality performance implementation. To this end, the unit disc graph (UDG) communication model, which is widely

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used in design of network-layer-allied routing protocols for *ad hoc* and sensor networks [16], is applied; however detailed study of UDG is beyond the main goals of this research and can be found in the literature, for example, in [17].

2.3 Relevant routing protocol strategies

Although geocast-based routing protocols, unlike other position-based routing protocols, aim to disseminate messages to selective geographic areas [18], this category of protocols utilises location information of nodes in a similar manner as the other position-based routing protocols. A position-based routing protocol may consist of several components such as location service, location server, beaconing, recovery strategy and forwarding strategy [19, 20]. The location of destination nodes is taken from the location service and location server. The state information of each neighbour can be obtained from beaconing using SAE J2735 BSM. The recovery and forwarding strategies may be applied to effectively forward packets from source nodes to destination nodes. Earlier research in the field of VANET involved strategies to use topology-based routing protocols, such as ad hoc on demand distance vector (AODV) presented in [21], instead of the location services. However, some routing strategies combining position-based routing together with a simple reactive location service had been introduced in [22, 23].

This paper distinguishes between position-based and geocast routing schemes, which have a one-way relationship. Geocast-based routing protocols can be categorised as a position-based routing method, but not vice versa. Geocast routing [18] is fundamentally defined as a location-based multicast routing. Minimally identifying the multicast group and delivering packets from a source node to all identified nodes located inside a particular geographical region, known as zones of relevance (ZOR), is the objective of a geocast routing protocol. In order to avoid unnecessary and hasty reactions by vehicles that are not endangered, nodes outside the ZOR are not alerted, whereas the source node may be inside or outside of the ZOR. This class of protocols can be beneficial to many ITS applications.

Maihofer in [18] provides a taxonomy considering flooding, directed flooding and no flooding categories for geocasting. Directed flooding is the category that contains most of geocast routing methods such as location-based multicast, Voronoi, GeoGRID and Mesh. The directed-flooding-based methods try to define a forwarding zone and restrict the flooding inside the zone to limit the message overhead and network congestion. In contrast, non-flooding approaches such as unicast routing with area delivery and GeoTORA which are typically based on unicast routing, utilise regional flooding inside the destination region.

Multicast-based routing protocols typically rely on creation of routing trees requiring each individual node to maintain the state information of other nodes. In MANETs, network topology faces frequent changes because of the mobility feature of nodes and therefore the communication links among nodes (source and sink) vary dynamically and even end-to-end routings do not exist at certain periods of time. Consequently, conventional end-to-end routing protocols are inefficient to be applied in VANETs. A novel data forwarding protocol is the receiver-based routing technique, which does not require establishing global routing between source nodes and sink nodes. This category of routing protocols allows the sender's one-hop neighbours to contend for the forwarding right on the basis of their status information and under certain rules (unlike the sender-based scoping that senders actively appoint a specific forwarding node). Eventually the only node having the right to forward data is the contention winner (for each hop). The concept of receiver-based scoping as Internet additions was initially presented in [24]. This concept was also introduced to routing protocols used in mobile sensor networks, such as [25, 26].

3 Formulation of a routing protocol for CLX

The performance evaluations of the IEEE 802.11p standard in [27] signify that the 5.9 GHz DSRC technology used for V2V and V2I communications cannot ensure timely message dissemination in dense traffic environments or high channel-load scenarios [28] in the absence of an effective and efficient routing scheme. Considering exclusive characteristics of VANETs, a different type of routing protocol is required other than conventional protocols of *ad hoc* or wireless networks. This paper presents a more efficient geo-multicast routing protocol, named 'receiver-based geo-multicast' (RBGM), so as to reduce unnecessary transmissions, channel-load and routing overheads, and to optimise the transmission routes while at the same time a high level of accuracy is maintained. The geo-multicast framework includes direction-based geocasting, methods to identify the coordinates of desired geocast regions, known as ZOR, involving endangered vehicles by the approaching train and the latest time for each ZOR to receive the warning message in order to avoid the danger.

Implementing endangered-vehicle-identification mechanisms and efficient routing protocols is one of the main challenges in IVC environments because of the unique characteristics of VANETs. This uniqueness refers to as frequent topology fragmentation, relative high speed of mobile nodes, frequent disconnections and dynamic information exchange. Since CLXs contain trains as a second type of vehicle, its vehicular network has exclusive characteristics over any conventional VANET. Therefore effective implementation and close cooperation of a CLX greatly relies on IVC and roadside to vehicle communication systems to distribute messages from one node (OBU or RSU) to another [20]. However, nodes may adjust their transmission range based on packet traffic conditions experienced by the network. So, multiple hops may be required to exchange data among the communicating nodes because of the limited radio transmission range of transceivers.

3.1 Need of CLX to geo-multicast

Efficient dissemination of warning messages to all vehicles located in endangered areas in a timely manner is the foremost purpose of the geo-multicast routing scheme. This scheme incorporates two strategies for utilising the wireless channels in the most efficient approach. The first strategy is the reduction of avoidable transmissions by sending warning messages only to the endangered areas. For example, Fig. 1 illustrates a scenario where the forthcoming train may endanger vehicles approaching the LX. In such a scenario, the train is only required to send a warning message to vehicles inside the determined ZOR and drive towards the LX. Other vehicles (either outside ZOR or inside ZOR and leaving the LX) are excluded because they are not in immediate danger of the approaching train. The second strategy is to reduce radio interference leading to increase the network communication capacity. This strategy requires the transmission range of nodes to be minimised, which results in more hops for message transmission. However, a trade-off needs to be reached between the transmission range and number of hops to reduce the end-to-end delay. The problem of finding the minimal routing paths for timely delivery is modelled as an UDG and addressed by the receiver-based routing approach.

Position-based routing schemes have been recognised as a promising strategy for disseminating data in VANETs within research projects such as FleetNet [http://www.neclab.eu/Projects/fleetnet.htm], GeoNet [http://www.geonet-project.eu/], CarTALK 2000 [http://www.cartalk2000.net/] and NoW [http://www.network-on-wheels.de/]. The geographical destination of a packet, as additional information, is used by geo-multicast routing protocols to make forwarding decisions and disseminate messages. Position-based routing protocols including geo-multicast do not essentially require maintaining explicit routes, which scale well the dynamic nature of CLX environments. This is a key benefit for CLXs, where the topology receives frequent changes [19, 20]. Moreover, ad hoc networks can be scalable via routing protocols that do not necessitate fixed infrastructures to achieve scalability in high mobility networks. To reach an acceptable point of scalability, nodes within a network may adjust their radio power levels based on the density experienced by the network [20], which also results in reduction of radio interferences.

The objective of the proposed geo-multicast framework and its embedded RBGM protocol is to ensure a reliable and timely delivery of packets to vehicles within endangered areas. RBGM contains two main phases, firstly, path finding (delivery phase to transmit a message to ZOR) which uses the 'receiver-based' scheme in the case that the determined ZOR is not directly reachable by the sender. Secondly, packet forwarding (or regional delivery inside of ZOR) which uses the 'direction-based flooding' scheme in the case the transceiver range is smaller than the radius of ZOR. RBGM is a receiver-based cross-layer protocol (data link, network and application layers) that performs geo-multicasting based on the location information of geo-multicast members.

There are some assumptions in the design of RBGM. A location service module exists inside the protocol stack, which performs real-time relative-position mapping as proposed by Ansari *et al.* [29]. The location service module returns the two-dimensional coordinates of one-hop neighbours. It is also assumed that only the locations of the sender and destination (both provided in the media access control (MAC) packet) are required by the receiver-based link layer to decide the next hop route. It is further presupposed that the 'void/hole problem' in geographic routing is implicitly solved in the MAC layer with solutions similar to those studied in [30, 31].

3.2 Correlation of the geo-determination model and RBGM routing protocol

In order to deliver messages using RBGM, the shape of ZOR has to be predetermined. Closed polygons can represent the geographic address of a destination such as ZOR. These polygons include 'point', 'circle (centre point and radius)' and 'n-gon (point$_1$, point$_2$, …, point$_n$, point$_1$), $n > 2$' [14, 32]. If the polygon is considered as a point, the RBGM will actually act as a geo-unicast protocol. The circular form has been considered as the shape of ZOR in design and implementation of RBGM for simplicity as only two parameters, centre point and radius, have to be transmitted.

The key strength of the proposed geo-multicast framework is that an approaching train solely targets vehicles endangered by its existence at the LX. For this purpose, a method is proposed to identify ZOR by the approaching train. The train's OBU returns the speed of the train (s_t) and the speed limit of the crossing roads (s_r) intersecting with the rail tracks, where no vehicle is assumed to exceed the speed limit. At each transmission cycle when the train tends to

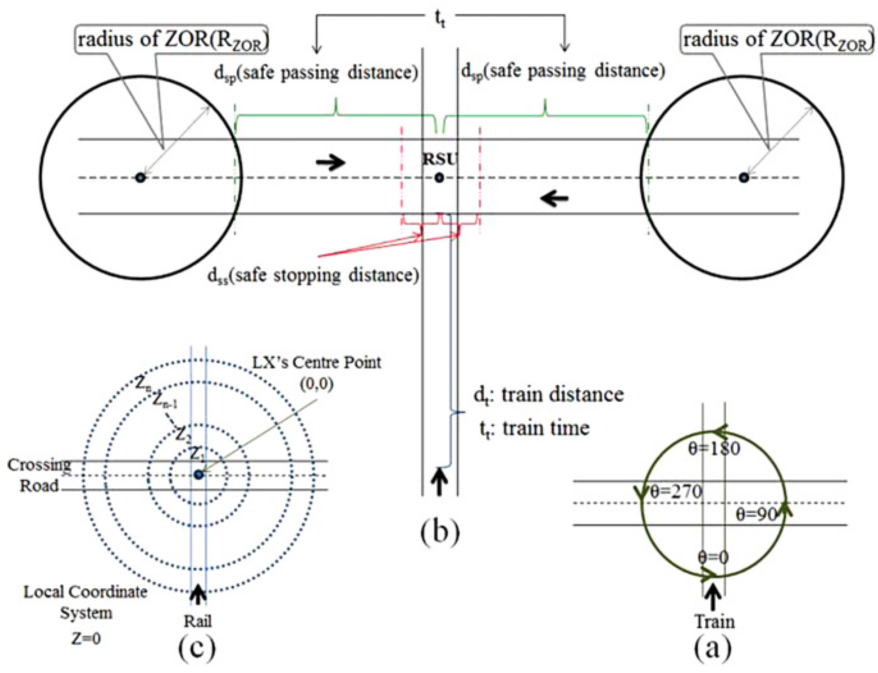

Fig. 2 *ZOR determination model*

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disseminate a warning message, the distance of the train to the LX (d_t) is obtained using the location information of the LX stored on the onboard digital-map, which also includes exclusive safe stopping distances (d_{ss}) for each particular LX calculated based on crossing roads' limits. Using this information, the train is able to calculate the time, which takes it to reach the LX (t_t) based on its dynamics as reflected in Fig. 2. The sender is then able to calculate the safe passing distances (d_{sp}) on the approaching roads, where vehicles can traverse the LX safely.

The interval of d_{sp} is considered to allow the traffic not directly endangered by the train to pass over the LX. The train transmits warning messages at a fixed frequency, for example, 1 Hz, while $d_{sp} > d_{ss}$. Finally, the sender calculates the coordinates of the centre point for each ZOR by using the values of d_{sp} and the radius of ZOR (R_{ZOR}). Two approaches can be employed for determination of R_{ZOR}. First, the sender can calculate R_{ZOR} based on its own dynamics and the speed limit of the crossing road. Second, a fixed R_{ZOR} may be assumed in the calculations. The second approach is used in this study for evaluations. Fig. 2*b* shows a simplified view of the ZOR determination model, although this method is able to cope with more complex situations as well.

To augment the model, the angle of each road than the LX rail tracks (θ) has to be a known property of each LX, where $0° < \theta < 360°$. The θ for the rail tracks is equal to 180°. An illustration of the θ determination is shown in Fig. 2*a*. Furthermore, LXs have to be classified based on the number of their crossing roads (note that each road direction is counted as a separate crossing road; so the LX degree will be added by 1 for each direction). For instance, Fig. 2*b* shows a LX of degree 2. Consequently, a LX of degree n will have n ZOR centre points associated with it. Finally, the absolute coordinates (x, y) of each LX's centre point should be available, where (0, 0) is considered as the coordinates of the LX for illustrations of this study. To predict the centre point of ZOR_i, $1 \le i \le n$, $[\sin(\theta_i) \times (d_{sp} + R_{ZOR})]$ is used to calculate the distance variation of the ZOR_i centre point from the

Algorithm1

- The sender node (sn) checks its coordinates against the ZOR
- **If** $sn \notin ZOR$ (the sender is not in the ZOR)
  - **If** ZOR centre point is NOT within the transmission range
    - The sender sends a Request-to-Send (RS) packet including the location information of itself and the ZOR center point
    - All the receivers calculate their suitability (rank) for forwarding and send Ready-to-Forward (RF)/Received packet back to the sender after a certain delay
      - The delay is calculated based on various parameters: the relative-position of node to its neighbors using relative-positioning map, distance to the destination, availability of relaying nodes, network traffic at the node, node movement pattern, etc.
    - The first node sending the RF packet back is selected as the relaying node
    - The sender transmits the data packets to the selected node
    - **Exit**
  - **If** ZOR centre point is within the transmission range
    - Geo-Multicast the data packet
    - **Exit**
- **If** $sn \in ZOR$ (the sender is inside the ZOR)
  - **If** the packet is received previously
    - Discard the data packet
    - **Exit**
  - **Else**
    - Run the RBGM receiver algorithm
    - **Exit**

Fig. 3 *RBGM send*

LX centre point on the x-axis and similarly $[\cos(\theta_i) \times (d_{sp} + R_{ZOR})]$ is used to calculate the distance variation on the y-axis, although the model can be easily modified to calculate the geocentric coordinates.

When a user intends to send a warning message, a request is passed to the application layer of the protocol stack to determine the ZOR centre points as virtual nodes. The concept of virtual node is used to eliminate the unpredictable nodes' motion and availability difficulties and make the process of devising routing algorithms in VANETs easier. RBGM then appends a header consisting of a list of virtual nodes, time-to-live (TTL) value and a checksum value to packets in the network layer. Subsequently, RBGM passes all packets for all ZOR to the MAC layer to broadcast them to one-hop neighbours using the RBGM send algorithm. This emerging protocol uses the receiver-based technique in its path-finding phase to identify the next relay node, if the endangered vehicles are not directly reachable from the sender, instead of creating and maintaining costly routing tables. In receiver-based schemes, transmission of packets is initiated by a sender without specifying the next hop node. This approach facilitates routing of packets as the result of a cooperative decision-making between all participating nodes (receivers) for each hop using the receiver-based contention mechanism of the MAC layer. In the other words, the potential receivers of each transmission make the decision of forwarding in a distributed manner considering the relative-position of node to its neighbours using the relative-positioning map, distance to destination, availability of relaying nodes, network traffic at the node and node movement pattern. Therefore costly routing tables are not required to be maintained by the sender node, as a valid route is chosen by receivers. Algorithm 1 (see Fig. 3) summarises the procedures for transmitting packets in pseudo code.

When a packet is received by a node, the packet is passed to the RBGM protocol from the Link layer to examine the checksum in the packet header and drop any corrupted packet. If TTL is greater than a threshold, RBGM then retrieves the list of the virtual nodes from the received packet. RBGM may perform multi-hop data disseminations, if the receiving nodes are outside of the ZOR. RBGM also utilises 'LX vicinity fragmentation', illustrated in Fig. 2*c*, to allow vehicles obtaining their directions. Vehicles are tagged either as 'approaching' (group-A) or 'leaving' (group-L). If a vehicle travels from zone Z_n towards zone Z_{n-1}, the vehicle is considered as a group-A member, otherwise is a member of group-L. Vehicles process a data packet if and only if they belong to group-A, otherwise they may only participate in the packet relaying procedure. The notion of LX fragmentation needs to be projected on the digital maps utilised by road vehicles' OBUs. Note that stationary nodes such as RSUs are always tagged as group-L members. Algorithm 2 (see Fig. 4) summarises the procedures for receiving packets in pseudo code.

Algorithm 2

- The receiver node (rn) checks its coordinates against the ZOR
- **If** $rn \notin ZOR$ and the packet is NOT received previously
  - Run the RBGM send algorithm
  - **Exit**
- **Else**
  - The receiver node (rn) obtains its direction
  - **If** $rn \in groupL$ (the receiver does not approach the level crossing)
    - Discard the data packet
    - **Exit**
  - **If** $rn \in groupA$ (the receiver approaches the level crossing)
    - The receiver checks its coordinates against the ZOR
    - **If** $rn \notin ZOR$ (the receiver is not in the ZOR)
      - Discard the data packet
      - **Exit**
    - **If** $rn \in ZOR$ (the receiver is inside the ZOR)
      - Process the data packet – Take action
      - **Exit**

Fig. 4 *RBGM receive*

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4 Demonstration of the geo-determination model

4.1 Numerical study of the model

To study and analyse the performance of the proposed ZOR_i centre point determination model, a few geographical plots on a local coordinate system are provided here to demonstrate the behaviour of the model. These plots are prepared in MATLAB for a LX of degree 2 with $\theta_1 = 90°$ and $\theta_2 = 270°$, where is located at the coordinates of (0, 0) on the local coordinate system. Various scenarios with dissimilar characteristics are considered for this numerical study. To implement the scenarios, it is assumed that the train's speed and speed limit of roads are constant in vicinity of the LX and R_{ZOR} = 0.5 km. The time interval (δt) between message disseminations is set to 1 s.

Scenario1: If the CLX is provided by the following set-up

- $s_t = 70$ km/h (the train travels 0.019 km/s)
- $s_r = 50$ km/h ($d_{ss} = 60$ m)
- $d_t = 1$ km at $t_0 = 0$.

Then, Table 1 shows the results for the ZOR centre points' coordinates.

Fig. 5*a* projects the coordinates shown in Table 1. The train moves on the *y*-axis, while the ZOR centre points are selected on the *x*-axis. Figs. 5*b* and *c* demonstrate the coordinates related to the other two set-ups provided here as Scenarios 2 and 3 for model verification purposes.

'Scenario 2':

- $s_t = 100$ km/h (the train travels 0.027 km/s)
- $s_r = 50$ km/h ($d_{ss} = 60$ m)
- $d_t = 1$ km at $t_0 = 0$.

'Scenario 3':

- $s_t = 70$ km/h (the train travels 0.019 km/s)
- $s_r = 70$ km/h ($d_{ss} = 75$ m)
- $d_t = 1$ km at $t_0 = 0$.

Fig. 5 testifies the fact that as the train gets closer to the LX, the ZORs are also chosen closer to the LX regardless of the scenario's characteristics, so the endangered vehicles are precisely selected based on their critical positions and the position of the train than the LX. Since the transmission range for DSRC transceivers is considered to be 1 km and the CLX includes one RSU at each LX, the train is therefore able to notify all the endangered vehicles as soon as it is 1 km away from the LX; so all road users have sufficient reaction time, while $d_{sp} > d_{ss}$ in all different scenarios. Fig. 5 also exemplifies that the ZOR centre points are always selected far behind the LX to enable vehicles to take adequate reactions; however, from Fig. 5*b*, it is advisable to trains to increase the frequency of message dissemination if the speed of the train than crossing roads increases. The illustrations seal the effectiveness of the proposed ZOR centre point determination model.

Table 1 ZOR centre points – scenario 1

$\delta t = 1$ s	d_t, km	Train location coordinates	ZOR_1 centre point coordinates	ZOR_2 centre point coordinates
$T_0 = 0$	1	(0, −1.000)	(1.2143,0)	(−1.2143,0)
$T_5 = 5$	0.903	(0, −0.903)	(1.1450,0)	(−1.1450,0)
$T_{10} = 10$	0.806	(0, −0.806)	(1.0757,0)	(−1.0757,0)
$T_{15} = 15$	0.709	(0, −0.709)	(1.0064,0)	(−1.0064,0)
$T_{20} = 20$	0.612	(0, −0.612)	(0.9371,0)	(−0.9371,0)
$T_{25} = 25$	0.515	(0, −0.515)	(0.8679,0)	(−0.8679,0)
$T_{30} = 30$	0.418	(0, −0.418)	(0.7986,0)	(−0.7986,0)

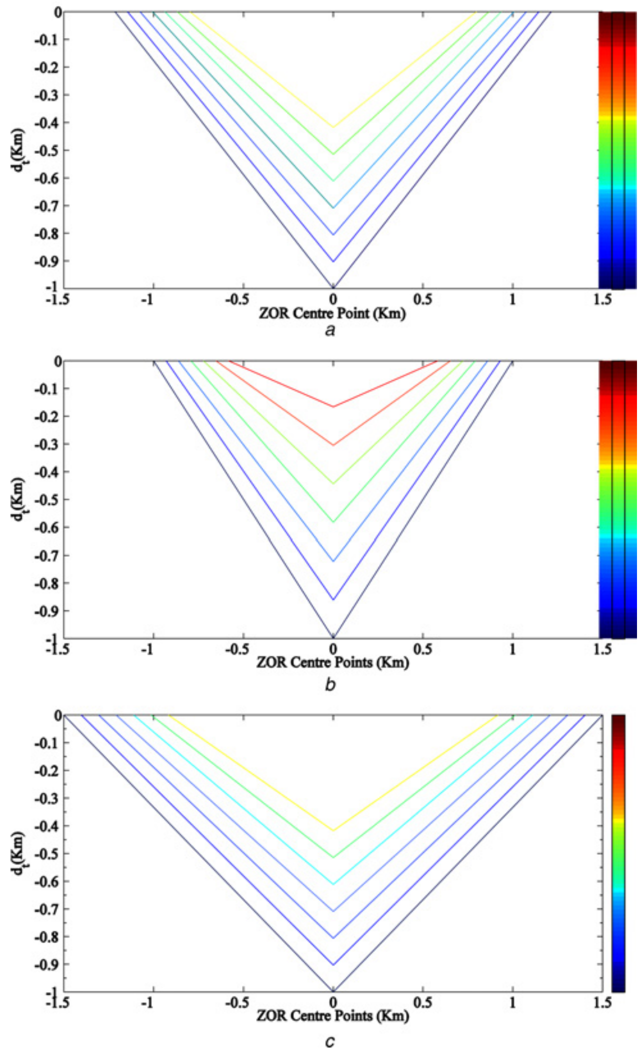

Fig. 5 *ZOR centre points against train position*
a Scenario 1
b Scenario 2
c Scenario 3

4.2 Model behaviour

This section presents results for some examples of dissimilar LX layouts than the initial LX position situation ($\theta_1 = 90°$ and $\theta_2 = 270°$) for performance comparison purposes. A second and third LX layouts are considered with [$\theta_1 = 45°$ and $\theta_2 = 225°$] and [$\theta_1 = 120°$ and $\theta_2 = 300°$] to highlight the contrasts caused by the LX layout. Tables 2–4 summarise the ZOR centre points for these proposed LXs. These substitutes $R_{ZOR} = 0.5$ km and $s_r = 50$ km/h are considered in the following demonstrations.

Furthermore, Table 5 demonstrates the results for the first LX/road layout ($\theta_1 = 90°$ and $\theta_2 = 270°$), where this time the train speed is kept constant at $s_t = 70$ km/h, while the model is examined for various road speeds.

As illustrated in Tables 2–4, the distances of ZOR centre points to the LX in comparable situations, for example,

Table 2 ZOR centre points in the first LX/road layout ($\theta_1 = 90°$ and $\theta_2 = 270°$)

	LX layout	$S_t = 30$ km/h (low)	$S_t = 70$ km/h (med)	$S_t = 100$ km/h (high)
$d_t = 1$ km	$\theta_1 = 90°$	(2.1667,0)	(1.2143,0)	(1.0000,0)
	$\theta_2 = 270°$	(– 2.1667,0)	(– 1.2143,0)	(– 1.0000,0)
$d_t = 0.5$ km	$\theta_1 = 90°$	(1.3333,0)	(0.8571,0)	(0.7500,0)
	$\theta_2 = 270°$	(– 1.3333,0)	(– 0.8571,0)	(– 0.7500,0)

Table 3 ZOR centre points in the second LX/road layout ($\theta_1 = 45°$ and $\theta_2 = 225°$)

	LX layout	$S_t = 30$ km/h (low)	$S_t = 70$ km/h (med)	$S_t = 100$ km/h (high)
$d_t = 1$ km	$\theta_1 = 45°$	(1.5321, – 1.5321)	(0.8586, – 0.8586)	(0.7071, – 0.7071)
	$\theta_2 = 225°$	(–1.5321, 1.5321)	(–0.8586, 0.8586)	(–0.7071, 0.7071)
$d_t = 0.5$ km	$\theta_1 = 45°$	(0.9428, – 0.9428)	(0.6061, – 0.6061)	(0.5303, – 0.5303)
	$\theta_2 = 225°$	(–0.9428, 0.9428)	(–0.6061, 0.6061)	(–0.5303, 0.5303)

Table 4 ZOR centre points in the third LX/road layout ($\theta_1 = 120°$ and $\theta_2 = 300°$)

	LX layout	$S_t = 30$ km/h (low)	$S_t = 70$ km/h (med)	$S_t = 100$ km/h (high)
$d_t = 1$ km	$\theta_1 = 120°$	(1.8764, 1.0833)	(1.0516, 0.6071)	(0.8660, 0.5000)
	$\theta_2 = 300°$	(–1.8764, –1.0833)	(–1.0516, –0.6071)	(–0.8660, –0.5000)
$d_t = 0.5$ km	$\theta_1 = 120°$	(1.1547, 0.6667)	(0.7423, 0.4286)	(0.6495, 0.3750)
	$\theta_2 = 300°$	(–1.1547, –0.6667)	(–0.7423, –0.4286)	(–0.6495, –0.3750)

Table 5 ZOR centre points in the first LX/road layout ($\theta_1 = 90°$ and $\theta_2 = 270°$) – constant train speed

	LX layout	$S_r = 40$ km/h (low)	$S_r = 70$ km/h (med)	$S_r = 100$ km/h (high)
$d_t = 1$ km	$\theta_1 = 90°$	(1.0714, 0)	(1.5000, 0)	(1.9286, 0)
	$\theta_2 = 270°$	(–1.0714, 0)	(–1.5000, 0)	(–1.9286, 0)
$d_t = 0.5$ km	$\theta_1 = 90°$	(0.7857, 0)	(1, 0)	(1.2143, 0)
	$\theta_2 = 270°$	(–0.7857, 0)	(–1, 0)	(–1.2143, 0)

same d_t, s_t etc., with different LX/road layout are equal. For instance, this Euclidean distance is calculated as 3.8333 for both ZOR_1 and ZOR_2 of all three LX/road layouts, where $s_t = 30$ km/h and $d_t = 2$ km. These same results indicate the fact that the LX/road layout does not influence the performance of the model.

4.3 Result discussion

This section provides comparisons on the model's performance for various situations in a typical LX layout. Fig. 6, derived from Table 2, confirms that as the train speed increases, the ZOR centre points are chosen closer to the LX. Tables 3 and 4 verify the fact that this trend is not influenced by the LX layout. It is also understood from Fig. 6 that the greater the speed of the train, the lesser the movements of ZOR centre points. It reveals the fact that the speed of the train has a direct influence on the closeness of ZORs to LXs.

Fig. 7 illustrates the results extracted from Table 5. As the speed of road vehicles increases, the distance of ZOR centre points to the LX are increased consequently. Tables 3 and 4 confirm the fact that the LX layout does not affect this trend. Conversely to the train movement, the greater the speed of road vehicles, the larger the movements of ZOR centre points. This manner indicates that the road speed limit has a converse effect on distances between the ZOR centre points and the LX.

Fig. 8 compares the distances of ZOR centre points to the LX against speed for various velocities of both train and road vehicles, where $d_t = 2$ km in the first LX/road layout. This trend for the train is descent, whereas the road vehicles have an ascending trend; therefore the speed of train and the road speed limits have contradictory effects on the

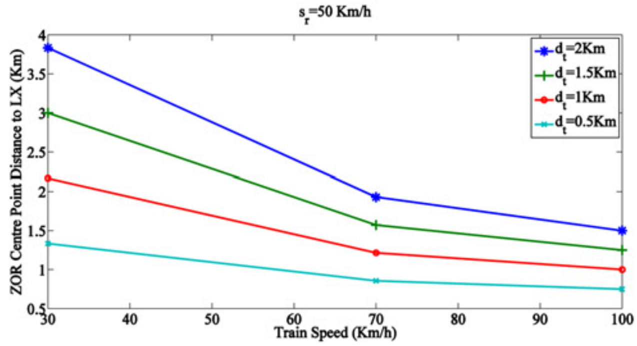

Fig. 6 *ZOR centre point against speed for train movement (s_r = 50 km/h)*

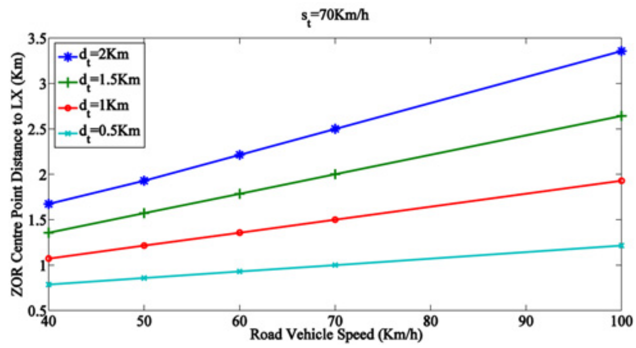

Fig. 7 *ZOR centre point against speed for road vehicle movement (s_t = 70 km/h)*

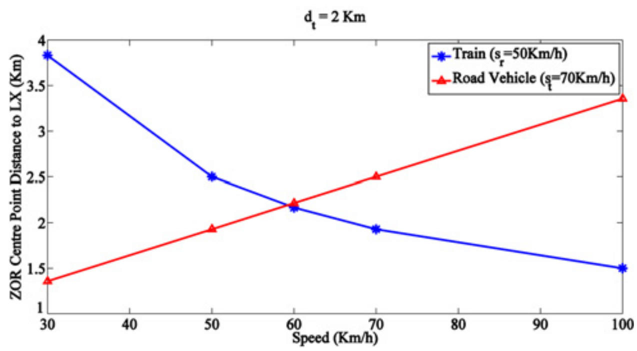

Fig. 8 *ZOR centre point against speed (d_t = 2 km)*

IET Intell. Transp. Syst., 2014, Vol. 8, Iss. 4, pp. 425–434
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coordinates of ZOR centre points. The graph confirms that the distance between the ZOR centre point and the LX is a linear function of the road speed limit; however this distance is a non-linear function of the train's speed.

5 Performance evaluation of the framework

One of the experimental tools for the study and analysis of communication protocols in computer networks such as MANETs is simulation. Various types of simulation environments are available for simulation of MANETs. Veins that is an open source IVC simulation framework composed of OMNET++ as an event-based network simulator and SUMO as a road traffic micro-simulation model is used for the purpose of RBGM performance evaluation.

5.1 Simulation model and set-up

A CLX consisting of 50 vehicles in one study and 100 vehicles in another study that are placed randomly on roads within a playground of size 1000 by 1000 m is modelled for the purposes of this research. One geo-multicast source node (train) is used where the circular ZORs with different radiuses are selected using the model provided by the framework. It is assumed that the train (as the communication initiator) is not in any of the ZORs. The speed and the direction of nodes are uniformly distributed, with speed range of 0–50 km/h for road vehicles and 0–70 km/h for train.

It is assumed that each vehicle knows its precise location information, velocity and direction. Each stationary node also knows its precise location. Each mobile node moves continuously without pausing at any location. Each vehicle is equipped with at least one 5.9 GHz DSRC transceiver with a standard transmission range for all equipments. All wireless links are assumed to have the same bandwidth.

5.2 Performance evaluation metrics

To evaluate the performance of RBGM, a performance metric is proposed and applied to determine the accuracy of the geo-multicast application delivery, termed the geo-multicast packet delivery ratio (GPDR). This metric is defined based on the works carried out in [33, 34]. Two fundamental ratios have to be defined prior the introduction of GPDR. First, PDR of the approaching vehicle group in ZOR_i (PDRA_i) refers to the ratio of the number of approaching group members who actually received the packets and the number of approaching group members that were in the ZOR_i at the time of packet dissemination. Second, PDR of the leaving vehicle group in ZOR_i (PDRL_i) refers to the ratio of the number of leaving group members who actually did not receive the packets and the number of leaving group members that were in the ZOR_i at the time of packet dissemination.

$$\mathrm{GPDR}_i = \frac{\mathrm{PDRA}_i + \mathrm{PDRL}_i}{2}, \quad i \in N$$

$\mathrm{GPDR} = \left(\left(\sum_{i=1}^{n} \mathrm{GPDR}_i\right)/n\right)$, where n refers to the total number of geo-multicast regions.

$$\mathrm{GPDR} = \sum_{i=1}^{n} \frac{\mathrm{PDRA}_i + \mathrm{PDRL}_i}{2n}$$

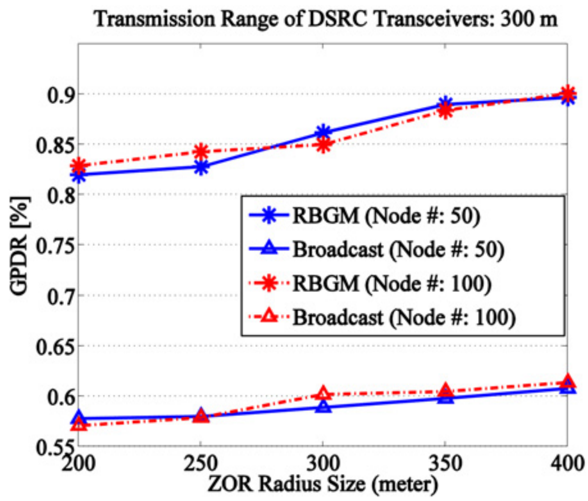

Fig. 9 *GPDR as function of ZOR size*

From the GPDR equation, it is understood that GPDR is a real number ($\mathrm{GPDR} \in \Re$) which $0 \leq \mathrm{GPDR} \leq 1$. Consequently, GeoError can be derived from GPDR as GeoError = 1 − GPDR, which can be interpreted as the delivery error percentage.

5.3 Simulation results

Fig. 9 presents GPDR in relation to various geo-multicast zone sizes (i.e. radius of ZOR), when the transmission range of DSRC transceivers is considered 300 m. As the figure shows, the GPDR remains relatively constant for both RBGM and broadcast methods if the number of nodes increases; however the optimum performance of RBGM is achieved when the ZOR size is chosen just above the transmission range of devices. The analysis shows that RBGM outperforms the broadcasting scheme by reducing the routing overheads by at least 25% in delivery of safety messages as it prioritises the endangered vehicles.

Fig. 10 plots the results for GPDR corresponding to various transmission ranges where the ZOR radius size is set to 300 m. The figure shows that RBGM performs more accurately as the transmission range increases. However, this accuracy increment does not necessarily improve the overall network

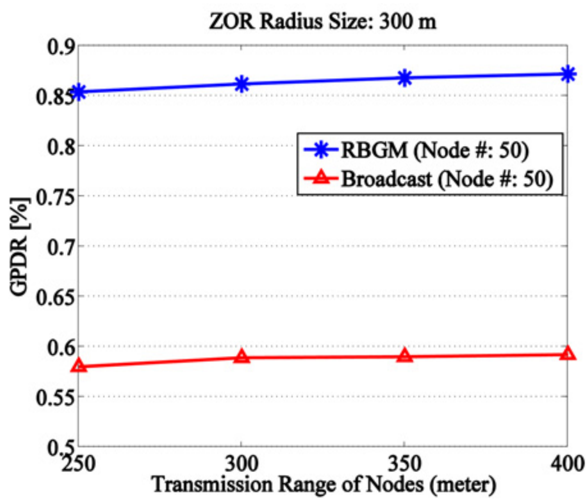

Fig. 10 *GPDR as function of transmission range*

performance as the amount of data delivery overhead raises when transmission range is increased. As a result, a built-in mechanism for RBGM deserves further research attention to dynamically set the transmission range based on the network characteristics.

6 Conclusion

Although LXs, which are very dangerous in terms of vehicular injuries and fatalities in many countries such as Australia, can benefit from VANETs, currently IVC-based systems are widely studied for road applications. The present paper suggests a framework for safety increment dedicated to CLX systems. Although the proposed framework has been merely designed for CLXs, it may be adopted by similar safety systems as well. The framework includes two main elements, namely geo-location determination model for endangered vehicles as well as a RBGM routing protocol. Location determination of the endangered vehicles is a vital task in order to keep more motorists safe and keep the traffic flow fluent as much as possible in vicinity of LXs. Such a model was not proposed previously. In addition, hence trains usually travel at faster speeds than cars, having an efficient, reliable and swift routing protocol is necessary for CLX systems. The notion of receiver-based routing is considered to satisfy these required characteristics since this technique does not rely on tree structures, and therefore nodes do not maintain costly routing trees. The simulation studies proved that the proposed cross-layer routing protocol reduces the routing overheads of the system by at least 25% as compared with the broadcast scheme, also the mathematical modelling and experimental results confirmed that the proposed framework augments the safety provided by CLX systems.

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