Performance analysis of dedicated short range communications technology and overview of the practicability for developing countries

Vandana Bassoo, Doorgesh Sookarah

Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Mauritius, Reduit, Moka, Mauritius
E-mail: v.bassoo@uom.ac.mu

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Abstract: Vehicular communication is a widely researched field and aims at developing technologies that may complement systems such as the advanced driver assistance systems. It is therefore important to analyse and infer on the performance of vehicular technologies for different driving and on-road criteria. This study considers the dedicated short range communications technology and more precisely the IEEE 802.11p standard for a performance and practicability analysis. There is also the proposal of a new classification scheme for typical driving conditions, which includes the main categories of Emergency and Safety scenarios while sub-classifications of Critical and Preventive Safety also exist. The scheme is used to build up scenarios as well as related equations relevant to developing countries for practical network simulation. The results obtained indicate that the relative speed of nodes is a determining factor in the overall performance and effectiveness of wireless vehicular communication systems. Moreover, delay values of low order were observed while an effective communication range of about 800 m was calculated for highway scenarios. The research thus indicates suitability of the system for an active use in collision avoidance even though independent factors such as climatic conditions and driver behaviour may affect its effectiveness in critical situations.

1 Introduction

In the recent years, the world has entered a new era where the conventional way to travel is gradually being replaced by technologically enhanced automotive systems. The concerned industry has long been researching the field of intelligent transportation systems (ITSs) and with the advent of efficient wireless communication standards and protocols; newer and more efficient systems are rapidly being developed. Since, the first motor vehicles were introduced, transportation systems have greatly evolved and today intelligent and quasi-autonomous systems are a reality. In fact, legislation is being amended in Europe and the United States to cater for the specificities of ITSs [1]. The need to provide safety and elevate basic driving comfort through the utilisation of technology is essential for proper advancement of transportation systems. At user level, added security and safety while driving is required through systems that allow real-time communications to support en-route choice decisions [2]. Dedicated short range communications (DSRCs), which is the state-of-the-art technology for the concerned field of interest, relies on the idea of vehicle-to-vehicle and vehicle-to-infrastructure communications for its practical implementation [3]. Both of these sub-categories of vehicular communications involve vehicular ad hoc networks (VANETs) for the process of inter-vehicular communication that is required to set up certain smart driving systems. Such types of networks are generally self-organising and primarily make use of vehicles, usually cars, as the nodes for the wireless forwarding, exchange and dissemination of information.

The current technologies that can be classified as intelligent driving systems need to alleviate traffic congestion and also provide suitable responses to driving hazards independently of the implementation sites or the regional road configuration. As an example, the motorisation rate is rapidly increasing in various areas of the world, especially in developing countries where road networks are often poorly planned and where the capacity of the physical infrastructure is not rising proportionately to the country’s socio-economical progress [4]. Hence, technologically aided systems should contribute to minimise the challenges faced in these particular regions such as significant traffic delays, inefficient fuel consumption and financial losses which usually arise due to extended traffic jams [5]. Over the past few decades, quick urbanisation as well as the population growth in developing countries has indirectly contributed to a surge in the number of on-road collisions, accident-related injuries and collateral human fatalities [6]. In fact, it has been estimated that over 90% of fatal crashes take place in low- and middle-income countries where pedestrians and cyclists are the most vulnerable and common casualties [7]. Therefore, the practical implications of technologies such as DSRC not only account for enhancement of driving comfort but also for serious issues such as the avoidance and control of collisions which in turn may help to stabilise the insecurity of driving in specific countries such as developing states.

The performance analysis of DSRC-based systems can become repetitive as it often involves the study of previous models for wireless communication in vehicular environment. However, works that aim to diversify the approach of vehicular technologies are important as they help to solidify concepts that may not have been considered in the past and help to understand future advances as well as contributions in the field. The main aim of this document is to analyse and evaluate the performance of DSRC’s IEEE 802.11p standard through the simulation of different network topologies. A number of performance metrics including throughput, delays and the communication range of the system will be discussed to properly indicate the overall system reliability and effectiveness under several conditions. The study further extends its aim to replicate road networks and driving conditions that are typically present in developing states and similar countries. Consequently, it will be possible to develop specific scenarios which give a practical overview of the implementation of DSRC-based technologies and how they may contribute to collision avoidance.

2 Related works

Over the past few years, several researches have been conducted on the performance and implementation of DSRC-based technologies. Most publications focus on evaluating the efficiency of the IEEE 802.11p standard and determining how performance metrics such as the throughput or delays in the system vary according to certain topological parameters [8, 9]. Moreover, surveys and studies have previously been performed to investigate the intricacies of ad hoc networks and [10] is a precise and detailed report of the network characteristics shown by such topologies. The
speed of nodes, the inter-vehicular distance (IVD), the regional vehicle density, and other related notions have been previously studied and many suggestions from such works are now accepted as factual. Documents such as [11–13] have investigated the essential parameters of ad hoc or vehicular networks and will be used as a means of comparison during the interpretation of results obtained.

DSRC is a promising technology as it shows the most prospects for collision avoidance, traffic management and control in the near future. There have even been earlier publications such as [14] have investigated similar systems where global positioning system/global system for mobile on-board units were tested and analysed. However, this work will distinctively consider a DSRC-based system where the IEEE 802.11p standard is simulated for performance and practicability in real-life scenarios. Additionally, this paper bases itself on previous researches which have been conducted on the performance of IEEE 802.11p standard [15] and also compared it with others such as the IEEE 802.11a [16]. Other publications such as [17, 18] did not only limit their research to comparison between the two previously mentioned standards but also analysed and compared routing protocols for vehicular environments.

Another recurring aspect of several works is the limitation of the investigation scope to extended and well-developed regions of the world such as the United States or members of the European Union [19, 20]. Typically, these countries have extensive and excellent road infrastructures which do not exist in developing countries. As opposed to the latter, highly industrialised and developed regions have much larger vehicle fleets in circulation and possess better quality road networks where the road surface is of higher grade. Moreover, the distribution ratio of urban and rural environments is more pronounced in developed countries where dense traffic areas are spread throughout the country.

Studies carried out mainly in developing regions of Africa and Asia have shown other differences which include larger roads and a much lower probability of occurrence for accidents (up to 24 times less) in developed countries [21]. It should also be noted that several developing countries such as India and Egypt are well known for their impractical driving behaviour where the non-respect of driving standards and codes is ubiquitous [22, 23]. Even at the level of governmental agencies, the trend is only to alleviate congestion by increasing available road infrastructure rather than optimising their efficiency of operation or through the sensitisation of road users to practical driving. In fact, developing countries are already in possession of basic commodity components which may easily be used to implement simple vehicular warning systems in unlicensed bands as presented by Song et al. [24]. Hence, the several benefits those developing countries would gain from the deployment of ITS systems are achievable for the concept of sustainable vehicular communities and for standardisation purposes [25].

This paper in particular seeks the use of information from related documentation such as [10, 15, 16] to first come up with a proper problem definition, before creating localised and realistic scenarios using proper routing algorithms for developing countries with average road networks. The work of certain academics such as [26] will also be used as a reference for some parts of the simulation-based evaluation of certain scenarios further explained in the next section. On the whole, the aim is to study the performance and practical aspects of the DSRC technology but also to add to a few concepts that previous academic publications may not have fully considered. The possibility of system performance depending on relative speed of nodes rather than simple velocity is investigated and the research is performed in accordance to the specificities of a developing country as described by the numerous aforementioned literatures.

3 System models

The methodological process used can be broadly separated into a problem definition and a mathematical modelling phase. This paper specifically proposes new classifications for on-road situations that can be regrouped under three distinct classes: emergency, preventive safety and critical safety. The following Table 1 gives an overview of the different parameters and characteristics associated to each class.

| Table 1 Comparison of the proposed classification schemes |
|----------------------------------------------------------|
| probability occurrence | Emergency | Preventive safety | Critical safety |
| number of vehicles involved | very low daily | high hourly small | high hourly small |
| configuration primary concern | highway rapid transportation | urban mostly lateral collisions material | urban head-on collisions human and material |
| possible losses | human and material | | accident black-spots |
| examples | ambulance dispatch or political delegations | blinker-off incidents | |

Locations where each one of these situations regularly occur have been selected and used in the scenario development process. The differences that exist in the driving conditions between developed and developing countries were examined (Section 2) to have a better understanding of driving particularities. One of these main differences is the length of the road coverage in developing countries which is short due to either a limited geographical area of the country or possibly due to financial limitations which make road development a low priority concern. Additionally, the highways if present in such countries have a low number of traffic lanes (typically three) and the road network consists of numerous narrow tributary roads which are used to provide access to specific locations such as villages or small towns. The local speed limitations are different from those applied in several European countries and there is the absence of dedicated lanes for buses or similar heavy vehicles to ease flow of traffic around the major road networks.

3.1 Scenario 1: critical situation with imminent head-on collision risk

According to Najm et al. in [27], most head-on accidents occur due to over speeding and inattentive driving. While this is the case for any region around the globe, the uniqueness of road networks present in developing countries makes users more prone to critical crashes. As mentioned in the introductory part of this section, countries where road networks are of average standard often include low number of lanes and narrow roads. Together these two simple aspects add up to the poor driving codes present and eventually result in a high number of critical situations [21, 28]. The purpose of this scenario is to give an overview of how critical situations may be controlled in order to avoid collisions and eventually help to lower the traffic-related fatalities in developing countries.

To illustrate a critical situation properly the highly curved road present at Macondé, Mauritius (Figs. 1 and 2) was selected and two vehicles are assumed to be travelling in opposite directions with one vehicle moving at reasonable speed while the second one exceeds the lawful limit.

To obtain faithful simulation for the identified location, the following mathematical model was used

\[
R_c = \frac{(R_x + R_y)}{2}
\]
The road curvature radius $R_c$ is obtained as a mean of the outer and inner road radii. The length of path for the simulation, $L_s$ is evaluated from the value of $R_c$ and the curvature factor $\alpha$.

The different performance metrics studied in this paper follow mathematical models that were developed to have a better understanding of the system functioning. The throughput is generated after computation of the symbol broadcast rate, $\lambda_s$ and the number of packets transmitted, $P_t$ (3) with $t_s$ being the simulation time

$$P_t = \lambda_s \times (n - 1) \times t_s$$

(3)

The average end-to-end delay is formulated as a sum of the individual delays between the oncoming vehicle, $V_{on}$ and the control vehicle, $V_{cn}$ scaled up to match the number of successfully received packets, $P_t$

$$\tilde{E} = \frac{1}{P_t} \sum \tilde{D}(V_{on} - V_{cn})$$

(5)

Following to (5) which gives an indication of $\tilde{E}$, a comparison is made with respect to the total reaction time, $t_r$ and the reaction factor, $F_r$

$$F_r = \frac{2}{P_t \lambda_s} \sum P_l \tilde{D}(V_{on} - V_{cn})$$

(6)

### 3.2 Scenario 2: non-critical situation with preventive safety

The deployment of ITS aims at improving the human aspect of driving by aiding or complementing common behaviour patterns [29]. One particularity of driving in developing countries is the casual attitude of drivers toward traffic and pedestrians. A common example of this driving particularity is the usual pick and/or drop which can be observed at bus stops or any similar location. This phenomenon is often seen during the morning or afternoon rush in these countries and with inattentive passengers, lateral collisions are highly probable. The scenario assumes that one vehicle stops to drop a passenger and another vehicle right behind the stopped one accelerates to overtake it. The aim is to simulate the topology and investigate how effective DSRC may be at reducing the risks of having open-door or flank collisions. The set up for this scenario is a strip of road which is located in an urban setting and where these pick and drop events are highly possible. Once more, the problem addressed is related to the driving specificities of developing countries and the aim is to determine how DSRC technologies may help in daily at-risk traffic situations.

### 3.3 Scenario 3: emergency situation with dedicated service vehicle

In this scenario, an emergency situation whereby a dedicated service vehicle needs to intervene ahead of relatively dense traffic is simulated (Fig. 3). The set up chosen is a section of a motorway and hence can be assumed to have a rapid and high traffic rate. Such sites typically encounter these emergency cases as for most developing countries only one highway path exists to move in and out of the capital cities. The largest and main agglomerations of a country typically draw in the major share of daily traffic and statistically have a higher probability of having traffic accidents whereby emergency intervention is required [30]. The overall thought here is that the emergency vehicle needs to communicate and exchange information with vehicles found along its route so that it may travel freely and deliver a rapid response. The main issue is to manage and monitor the traffic flow and hence be able to control and remedy congestion problems.

The throughput computation is same as shown by (4) except for cases where more than two nodes are involved. Equation (7) illustrates how the average throughput is evaluated whenever the number of nodes is relatively large

$$\bar{P}_t = \frac{1}{n} \sum n_{\text{links}} \frac{P_l \geq P_{\text{lost}}}{n!}$$

(7)

The estimated communication range can also be evaluated by computing the distance at which communication fails in the system. The mean value $D_k$ is obtained after different runs of the simulator
Table 2 Summary of simulation parameters

|                     | Scenario 1     | Scenario 2    | Scenario 3     |
|---------------------|----------------|---------------|----------------|
| X dimension, m      | 200            | 10            | 20             |
| Y dimension, m      | 500            | 1000          | 1600           |
| number of nodes     | 2              | 3             | 12             |
| routing protocol    | AODV           | AODV          | AODV           |
| transmission        | PBC            | PBC           | PBC            |
| radio frequency-model | Nakagami     | Nakagami     | Nakagami       |
|                     | urban variant: urban | safety          | highway         |
|                     | estimated collision time | estimated collision time | 50             |
| classification       | critical       | preventive    | emergency       |
| traffic type         | two way        | two way       | one way         |
| monitoring and delays | throughput     | throughput, delays and packet size | communication range |
|                      | and delays     |               |                |

AODV, ad-hoc on-demand distance vector
PBC, periodic forecast

\( (N_s) \) for varying settings of speed and initial distance of separation.
Equation (8) shows this formulation while (9) follows as the variation in the estimated communication range value

\[
\Delta D_R = \frac{\sum_{s=1}^{N_s} D_R(s)}{N_s}, \quad N \neq 0 \quad (8)
\]

\[
\Delta D_R = \frac{1}{N_s} \sum_{s=1}^{N_s} \Delta D_R(s) \quad (9)
\]

3.4 Summary of the simulations

Table 2 shows the different parameters and settings used for the simulation of each case study and along with their classification.

4 Results and analysis

4.1 Scenario 1

The following plots show the variation of the average end-to-end delay and average throughput for increments in the oncoming vehicle’s speed. The simulation time was set to the estimated value for which a head-on collision or an off-road collision might occur.

Fig. 4a shows a decrease in the transmission time between the \( V_{on} \) and \( V_{on} \) from 0.27480 to 0.27466 ms as the vehicles move in opposite directions and gradually approach one another. The extent of the changes in the delay value is small enough for it to be considered insignificant in realistic situations. The analysis of Fig. 4b shows a better performance for high speed of the oncoming vehicle. On comparing the initial average throughput of 1.97 kbps for a relative speed of +10 km/h and the final value of 2.39 kbps at a relative speed of +80 km/h, the increase is of about 21.3%. This value is noteworthy that as it gives a clear indication of how relative speed or the rate of change of IVD may affect performance of a DSRC system. The determining factor is in fact not the speed of \( V_{on} \) or \( V_{on} \) but rather the relative speed of both the vehicles.

4.2 Scenario 2

The results which follow show the variation of the average end-to-end delay and the average throughput for increments in the speed of \( V_{ov} \). Moreover, the plots show results for different message sizes (250, 500 and 1000 bytes) transmitted. The simulation time was set to the estimated time for which an open-door or lateral collision might occur.

Fig. 5a shows little to no variation in the delay for different values of \( V_{ov} \)’s speed and again the order of the delays observed is relatively small. The speed of \( V_{ov} \), even when varied over the set range, does not affect the delay substantially and thus confirms that the delay is not affected by the speed of a particular node. If the larger packet size of 1000 bytes is considered, the approximate delay value is 0.8 ms. This is far below the mean of available manoeuvre time and needed manoeuvre time \([31]\) required by typical drivers. The driver and vehicle response time usually fits in a

![Fig. 4 Decrease in the transmission time](image)

*a* Average end-to-end delay against oncoming vehicle speed

*b* Average throughput against oncoming vehicle speed

![Fig. 5 Little to no variation in the delay](image)

*a* Average end-to-end delay against vehicle speed

*b* Average throughput against vehicle speed
time frame of 1.3 s and if it is assumed that in case of a collision prone eventuality both drivers’ contribution are essential to prevent damage; a value of 2.0 ms (with 10% variance) will be the delay offered by the DSRC system. This value represents only 0.15% of the required total manoeuvre time and hence it can be safely assumed that technologies which make use of DSRC will be suitable at a practical level. Fig. 5b indicates that the throughput is more or less constant except for a packet size of 1000 bytes. The maximum change of 10% in the average throughput is observed for the larger packet size itself which compared with the first case is two times lesser. However, this drop in value occurs for a difference of 30 km/h between the stopped car and the overtaking car which is the largest possible in the simulation performed.

4.3 Scenario 3
The first part of the results that follow show the different plots that were obtained for the throughput and delay parameters when considering several node pairs while always considering the emergency vehicle as a reference. In the second part, the graphs are used as a measure of comparison for either the initial distance or for the real-time throughput observed in the simulated set up.

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Fig. 6 Average end-to-end delay against vehicle index
Fig. 7 Average throughput against vehicle index
Fig. 8 Pattern occurring for the throughput
a Throughput variation between $V_0$ and other vehicles
b Comparative throughput variation
4.3.1 Part I: Fig. 6 shows that there is practically no variance in the delay parameter between the emergency vehicle and any other vehicle forming the node pair. Since the principal parameter which acts as the control variable is the speed of the nodes, it can be safely considered that the latter does not considerably impact the overall performance of the VANET system. Moreover, the order of the generated delay during transmission is small enough to prevent any manoeuvre problem during real operational and driving conditions.

However, when considering the throughput between the same vehicles as in the previous case, it is observed that the system is underperforming for one particular vehicle pair. The vehicles $V_0$ and $V_1$ show a distinct drop in the communication efficiency and this result is complementary to expectations as the emergency vehicle ($V_0$) is the fastest moving node, whereas $V_1$ is a parked bus and consequently acts as a static node. Though the distance between these two nodes is initially decreasing, the average throughput only gives an indication of the performance for the whole duration of the simulation (Fig. 7). As the fire truck overtakes $V_1$, the distance gap keeps increasing at a fast rate and this hints to the fact that the performance is dependent on the IV. Another finding is that there is a key change in the performance when varying the packet size. The packets sent in this scenario proportionally increase the end-to-end delay and throughput. The larger messages require longer periods for transmission and that the throughput increases as the packet size increases. When the results were compared for the 250 and the 1000 bytes samples, both the average throughput and the delay were up to three times their initial values.

4.3.2 Part II: Fig. 8a shows the pattern occurring for the throughput which is initially higher but drops to $\sim$ 2 kbps a few seconds into the simulation. The initial drop which occurs during the time interval of 2.0–3.6 s corresponds to the time at which the emergency vehicle approaches the denser traffic ahead. This phenomenon may be due to the initial data load gradually encountering the effects of transmission in a dense vehicular environment which results in the drop of the performance [32, 33]. The second drop in the throughput which occurs only for communication between $V_0$ and $V_1$ clearly shows that at 25.9 s, there has been a complete loss of transmission between the two aforementioned vehicles. This event helps to determine a possible optimum communication range of the DSRC system that has been simulated. Through calculation, the communication range was estimated to be 775 m which according to [34] still lies in the range of what is qualified as short range communications ($\sim$ 1 km). To further investigate whether this value was acceptable and reflected the actual simulation, the developed scenario was modified to first increase the initial distance of separation between $V_0$ and $V_1$ by 400 m and then reducing this distance by 500 m. The resulting composite plot Fig. 8b shows that the communication now fails at 25.2 and 36.1 s for the decrease and increase in the distance, respectively. Once more the range of communication was evaluated and the average of these values was 800 m which is a 3.2% deviation from the first computed value.

5 Conclusion

This paper successfully presented a novel way to classify several on-road and driving patterns into distinct classes and both safety and emergency issues were addressed through a simulation process. Furthermore, the differing particularities of developing countries and high standard road networks were considered to fill this missing aspect of previous works and studies. The results give an indication of the performance metrics of a DSRC system and also give an insight into the quality of service offered by this type of technology. Scenarios 2 and 3 effectively demonstrate that the variation in average end-to-end delay and average throughput are nearly independent of the individual nodal speed. However, at a relative speed of $\sim$80 km/h, an increment of 21.3% in the throughput was observed. This result indicates that the relative speed of both nodes is the determining factor for performance and not individual speed. The IVD which is dependent on the relative speed is undeniably a parameter which greatly affects performance. Besides, the message size is critical in the delay measurements and successful communication. Scenario 3 indicates that DSRC systems will eventually need flexible resource utilisation schemes as well as relatively complex transmission algorithms to manage message exchange in a vehicular environment. Other notion to consider is the downgrade of system effectiveness in regions of dense traffic even though short range communications holds for a radius of $\sim$800 m. A radius of this value implies that the warning system present in vehicles can successfully alert other road users of any forthcoming hazard with ample time for reaction. The case of a fire truck requiring a clear path ahead of its path exemplifies this particular eventuality. Scenario 1 coupled with Scenario 2 confirms the assumptions on the practical implications of a DSRC-based system. The order of the delay values represents only a factor of 0.15% compared with what is required in real driving conditions and this validates the thought that DSRC is indeed suitable for active use. However, there is still the possibility that factors such as road visibility or at-risk driver behaviour impact on the effectiveness of the system for practical applications. For the case of developing countries, a certain ambiguity in the practical usefulness of DSRC systems exists though it is limited to specific scenarios such as critical situations. This is mainly due to the particular nature of driving in such countries as well as their road networks not matching the best structures available in highly urbanised regions. As a general note, it can be safely assumed that for most cases the DSRC system will be efficient at collision avoidance, traffic management and addressing the main traffic issues in developing countries.

6 References

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