

V2V-Intersection Management at Roundabouts

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ABSTRACT

More than 44% of all automotive crashes occur in intersections. These incidents in intersections result in more than 8,500 fatalities and approximately 1 million injuries each year in USA. It is also established that roundabouts are safer than junctions. According to a USDOT study, when compared with the junctions they replaced, roundabouts have 40% fewer vehicle collisions, 80% fewer injuries and 90% fewer serious injuries and fatalities.

In earlier work, we have proposed a family of vehicular network protocols, which use Dedicated Short Range Communications (DSRC) and Wireless Access in Vehicular Environment (WAVE) technologies to coordinate a vehicle's movement through intersections. We have shown that vehicle-to-vehicle (V2V) communications can be used to avoid collisions at the intersection and also significantly decrease the trip delays introduced by traffic lights and stop signs. In this paper, we investigate the use of our proposed V2V-intersection protocols for autonomous driving at roundabouts. We have extended our hybrid emulator-simulator called AutoSim to implement realistic map and mobility models to study traffic flow at roundabouts and have implemented our V2V-intersection protocols on roundabouts. Using a simulated environment, we quantify the benefits of our proposed intersection protocols in terms of safety and throughput enhancements while negotiating roundabouts.

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1. INTRODUCTION

Based on the statistics collected from the Federal Highway Administration (FHWA) and National Highway Traffic Safety Administration (NHTSA), approximately 3 million vehicle crashes occur at intersections which are currently managed by stop signs and traffic lights [1,18]. The future of transportation points towards autonomous driving as a way of reducing fatalities and optimizing traffic flow management. Within this context, we advocate the use of vehicular networks to design distributed protocols in which vehicles are able to interact with each other using vehicle-to-vehicle (V2V) communications. The goal is to enhance safety while decreasing the delay introduced by stop signs or traffic-lights using our proposed V2V-based intersection management protocols.

In the past few years, a series of related work has addressed the management of the traffic at intersections using Vehicle-to-Infrastructure (V2I) [3,4,5,6,7,19,20,21]. The cost

of installing the infrastructure required for the V2I approach on each and every intersection is significantly high, and makes it somewhat impractical. Another drawback is that V2I is based on a centralized system in which the infrastructure is the single point of failure and in the case that it fails, autonomous vehicles may not find other means of coordination. To address these shortcomings, we propose that Vehicle-to-Vehicle (V2V) communications can be used as a part of a distributed system in which all the approaching vehicles are interacting with each other and make decisions about when to cross the intersection safely and efficiently. Our focus in this paper is to (a) improve our V2V-based intersection management protocol and introduce a new Collision Detection Algorithm for Roundabouts (CDAR), (b) extend our hybrid emulator-simulator AutoSim, by introducing Route Network Definition File (RNDF) files and constructing roundabout routes based on the GPS coordinates extracted from digital map databases, and (c) compare the operational efficiency of the proposed protocols on

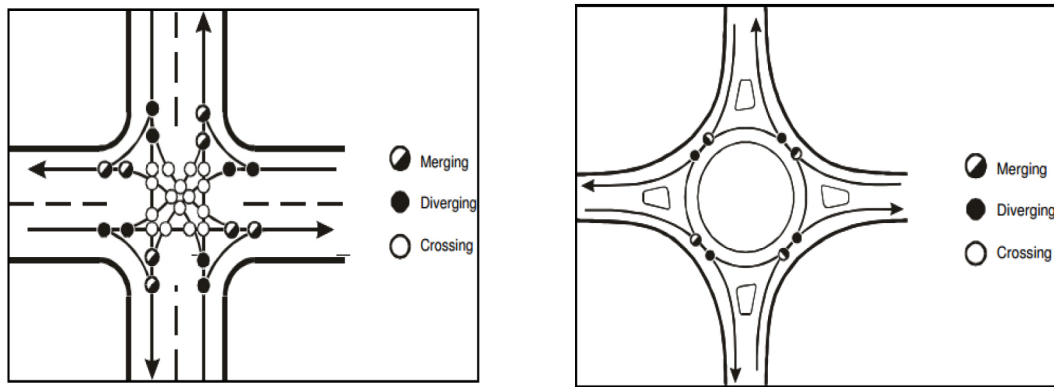


Figure 1. Traffic conflicting points at a simple cross intersection and a 1-lane roundabout

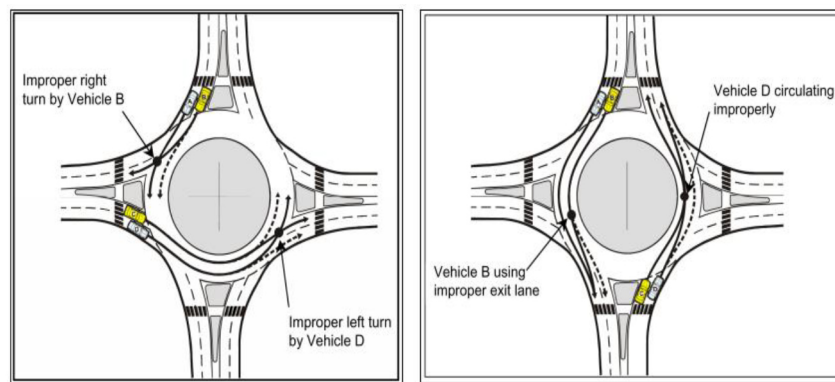


Figure 2. Additional conflicting points at multi-lane roundabouts

roundabouts with our previous work and conventional traffic lights.

The rest of this paper is organized as follows. Section 2 presents the *Collision Detection Algorithm for Roundabouts (CDAR)* used in our new intersection protocol. Section 3 describes the characteristics of roundabouts. Section 4 contains a brief summary of our V2V-based protocols: *Concurrent Crossing-Intersection Protocol (CC-IP)* and *Maximum Progression-Intersection Protocol (MP-IP)* and the modifications to make them suitable for managing the traffic through roundabouts. In Section 5, we present the evaluation of our protocols using AutoSim. Section 6 presents our concluding remarks and future work.

2. ROUNDABOUTS

A roundabout is a channelized intersection with one-way traffic flow circulating around a central island. Roundabouts are also considered as “traffic-calming” devices since all traffic is slowed to the design speed of the one-way circulating roadway. The average velocity allowed at roundabouts is between 25 and 40 km/hr. These slower speeds reduce the severity of crashes, and minimize the total number of all crashes inside the roundabout area. Roundabouts are small, generally from 25 to 50 meter in diameter compared to 100 to 150 meter and more for traffic

circles and rotaries. Roundabouts have a distinct feature of raised entry splitter islands which constrain vehicle speeds just before entry [13,14].

The Federal Highway Administration reports that, in recent years, approximately one death occurred every hour nationwide relating to intersections [22], and over nine thousand people lost their lives in traffic intersections, equaling nearly one quarter of all traffic fatalities and amounting to a financial loss of over \$96 billion [22]. In addition to slower speeds, roundabouts have fewer conflict points than traditional intersections. Figure 1 shows a comparison of conflict points between a single-lane roundabout and a single-lane perfect cross intersection. Note that the cross intersection includes 32 conflict points while the number of conflict points at the roundabout is only a quarter of that number, meaning 8 points [16].

Figure 2 shows that in multiple-lanes roundabouts, the number of conflict points increases, but it is still much less than the number of conflict points compared to a 2-lane cross intersection.

In addition to the safety benefits of roundabouts, the slower circulating speeds at roundabouts allow the entering vehicles to accept smaller gaps in the circulating traffic flow, meaning more gaps are available, increasing the volume of traffic processed. Coming to a complete stop only happens

when there is not enough gap due to the high density of traffic. However, when dealing with lower traffic volumes, due to the continuously flowing nature of yielding only until a gap is available, roundabouts outperform traffic lights with regard to total throughput and capacity.

3. COLLISION DETECTION AT INTERSECTIONS

We currently define the roundabout as a channelized intersection, in which four roads converge towards a central island from different directions. Each road includes predefined *entry and exit points* for each lane connected to it. The roundabout area is considered to be a grid which is divided into small *cells*. Each cell in the roundabout grid is associated with a unique identifier. Figure 3 shows a 1-lane roundabout. Note that the roundabout grid is divided into eight small cells and each of them is large enough to fit an average sized vehicle ($4.5m * 2.5m$) in it. The cell geometry and number of cells is unique for each particular roundabout and depends on physical parameters of the roundabout area, such as the radius of the intersection and the size of its central island. Cell geometry is also determined based on the number of lanes entering the roundabout from each direction.

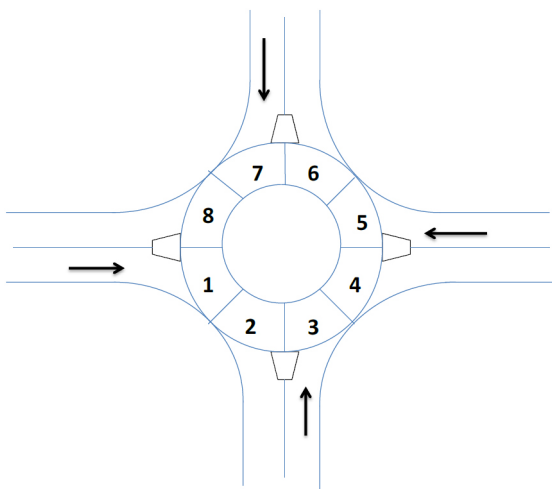


Figure 3. Roundabout grid divided into small cells

We make the following assumptions: i) each vehicle has access to a digital map database that provides road and lane information, ii) intersections are identified by unique identifiers (IDs) on this map, iii) intersections have well-defined approach and exit lanes, and iv) vehicles have access to a global positioning system (GPS) with locally generated Radio Technical Commission for Maritime (RTCM-104) corrections to obtain a Real-time Kinematic (RTK) solution in order to achieve reliable lane-level vehicle positioning. Such GPS augmentation can be made available by local base stations or through commercial service providers.

We define the **current road segment (CRS)** as the road segment that a vehicle is on *before* the roundabout, and the

next road segment (NRS) represents the road segment that the vehicle will be on *after* crossing the roundabout.

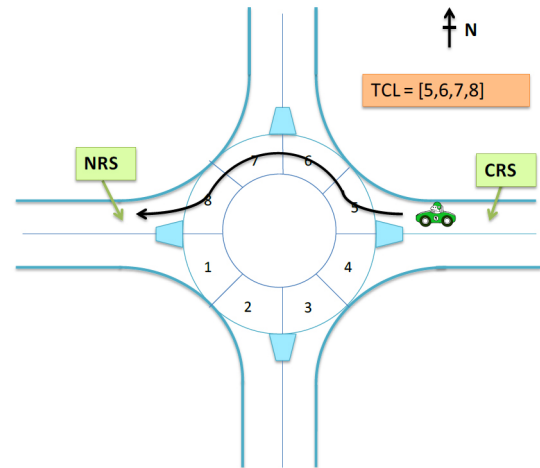


Figure 4. Illustration of TCL, CRS and NRS

Each vehicle uses the information about the CRS, NRS and the roundabout's cell geometry to create a list including the cells that will be occupied by the vehicle while crossing the roundabout. This list is called the Trajectory Cells List (TCL). The TCL is sorted based on the order of cells that are entered by the vehicle. Figure 4 shows the scenario in which the vehicle is entering the roundabout from the East and going to the West. Based on the CRS, NRS and the cell geometry, the vehicle builds its TCL using {5,6,7,8} cells. As mentioned, all the vehicles are supposed to be equipped with GPS devices and have access to the digital map database as well as the roundabout's coordinates. Therefore, each vehicle is able to use this information to map the current GPS coordinates to its current cell number. The current cell number will be then used to update the TCL and will be broadcast to surrounding vehicles as part of the basic safety message (BSM) [11]. Each vehicle uses the information about its current cell to update the TCL while crossing. Specifically when the vehicle leaves one cell and enters a new cell, the previous current cell gets deleted from the TCL. The updated TCL is useful for neighboring vehicles as it gives them explicit information about the cells which are not occupied anymore and might be used by other vehicles to cross the roundabout.

The proposed **Collision Detection Algorithm for Roundabouts (CDAR)** runs on all vehicles, using the information obtained from received safety messages, which are broadcast by surrounding vehicles. The algorithm uses the Trajectory Cells Lists of the sender and the receiver of the safety messages, and by comparing the two lists, it determines if there is any common cell along their trajectories while crossing the roundabout. If a potential collision is detected by CDAR, the algorithm returns the first conflicting cell number which we refer to as the **Trajectory-Intersecting Cell (TIC)**.