CohdaWireless™
Mobile Broadband

DSRC Field Trials

Overview

Cohda has performed more than 300 Dedicated Short Range Communications (DSRC) field trials, comparing DSRC radios from multiple manufacturers, on three continents around the globe.

It is the prevailing wisdom that WiFi chipsets can be used to build DSRC radios. However the field trial results consistently show that such radios are fundamentally limited in safety critical vehicle-to-vehicle applications. Such radios also fail to meet the heavy data transfer requirements of many vehicle-to-infrastructure applications.

The Cohda DSRC Radio demonstrated the potential to reduce collisions through increased warning time in all vehicle-to-vehicle safety scenarios, and the ability to support data intensive commercial and infotainment applications. Rather than relying upon stationary indoor WiFi technology, the Cohda Radio has been designed from the ground up for harsh mobile outdoor conditions, providing a unique and robust foundation for DSRC applications.

Introduction

Cohda Wireless has completed more than 300 DSRC field trials, for 15 distinct DSRC use-case scenarios, in the USA, Italy and Australia. These trials covered over 3000 km, during which 40GB of random data was transmitted. The trials were conducted on public roads, providing real world traffic conditions.

The following vehicle-to-vehicle and vehicle-to-infrastructure scenarios were executed [1]:

- *Intersection Collision Warning*: Warns drivers of potential side impact when entering an intersection. This scenario was executed in closed intersections (buildings on all corners) and blind corner intersections (buildings on one corner only, between the approaching vehicles);

- *Left Turn Assistant*: Warns drivers of an oncoming vehicle if turning across its path. This scenario was executed in closed intersections and open intersections;

- *Lane Change Warning*: Warns drivers of oncoming vehicle when overtaking or drifting. This scenario was executed on blind urban and hillside corners, blind corners in cuttings, and on an open highway with a truck blocking the view ahead;

- *Pre-Crash Sensing*: Harm minimization in unavoidable collisions. This scenario was executed in closed intersections and blind corner intersections; and

- *Road Side Unit*: Vehicle-to-infrastructure communications. This scenario was executed with the RSU mounted in closed intersections and open intersections.

The trials compared the performance of the Cohda Radio to radios using WiFi chipsets configured for DSRC operation from several different manufacturers. The performance metric used was Physical Layer packet error rate and a link was considered to be robust when the packet error rate was better than 10%.

GPS data and video were also recorded during the trials, providing a complete record of radio performance, vehicle position, speed, and environmental conditions. The range at which each radio was able to close the communications link was then determined.

Field Trial Results

Left Turn Assistant Scenario

This scenario recreates the situation where one vehicle may attempt to follow another into a turn when there is oncoming traffic, as shown in Figure 1. The Red Car waits to turn behind a truck on an open intersection with a turning lane. The Green Car is oncoming at 90 km/h (56 mph).

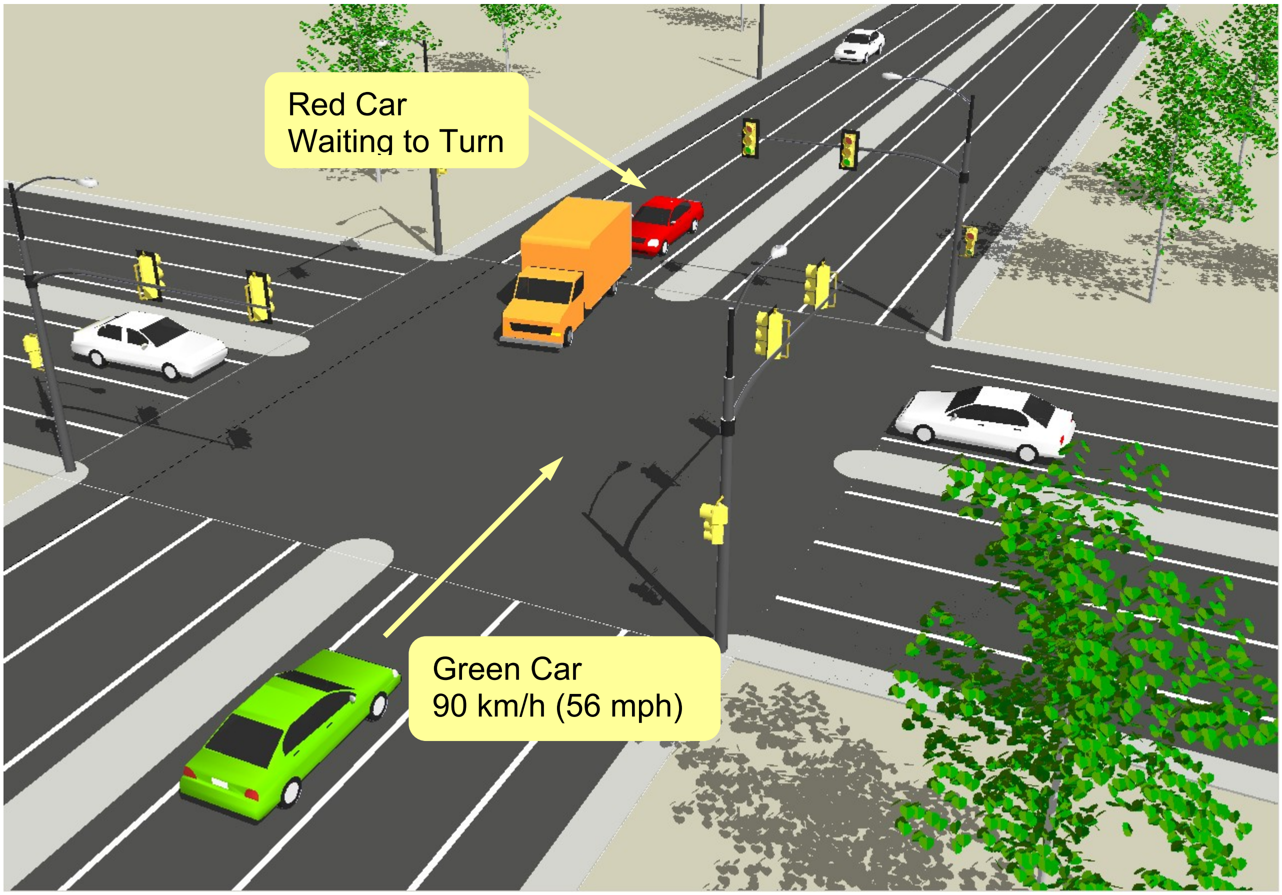

Figure 1: Left Turn Assistant Scenario

The danger is that the driver of the Red Car will blindly follow the truck around the corner. This places the Red Car in the path of the Green Car, creating a potential collision.

In this scenario the DSRC *Left Turn Assistant* application aims to warn the driver of the Red Car that it is not safe to enter the intersection [1]. The warning may be initiated based upon the state of the car's left turn signal, and/or control parameters such as steering wheel angle or yaw rate. The Green Car transmits packets containing its location, speed and heading. When the DSRC receiver in the Red Car begins receiving these packets it is able to interpret them and warn the driver if necessary.

In order to understand how this scenario can result in collision, and how a DSRC system can be used to avoid it, we work backwards from the collision point shown in Figure 2.

The Green Car is traveling at 90 km/h (56 mph) and requires at least 58 m to stop [2]. An additional 2.5 seconds must be allowed for the driver of the Red Car to react to the warning [3], during which time the Green Car travels 63m. Hence, in order to warn the driver of the Red Car and avoid the collision, a reliable communications link must be established before the Red Vehicle enters within 121 m range. The distinction between avoidable and unavoidable collisions about this point is highlighted in Figure 2.

When performing field trials for this scenario, the radio using a WiFi chipset was unable to close the communications link until a range of 14 m. This range is significantly less than that required to avoid a collision. During the same trials, the Cohda Radio closed the link at 214 m range. This range exceeds the requirements for collision avoidance by 93m, providing an additional 3.7 seconds of warning time. The range provided by each radio is compared in Figure 2[1].

These results show that DSRC systems using WiFi chipsets are severely challenged by the combination of mobility and multipath, due to the presence of a truck and other traffic, in Left Turn Assistant applications [5]. This susceptibility leaves such radios unable to provide sufficient warning for collision avoidance. In contrast, the Cohda Radio provides a robust communications link with range well beyond that required for collision avoidance, and offers additional warning time.

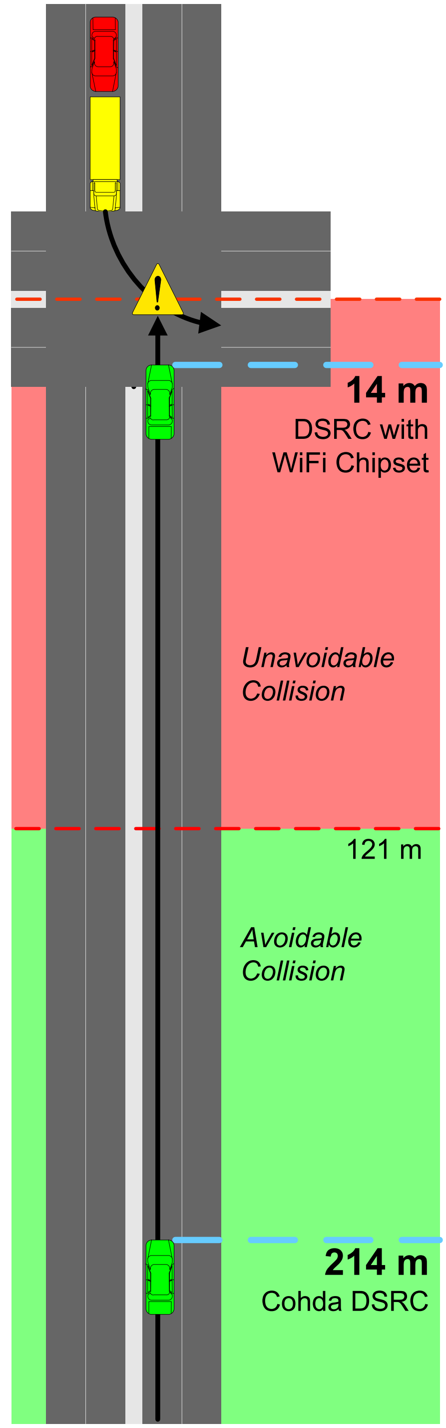

Figure 2: Left Turn Assistant Field Results

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[1] Ranges in this paper are drawn to scale. However, to aid clarity vehicles are drawn larger than scale.

Pre-Crash Sensing Scenario

This scenario recreates the situation where two vehicles approach a built up intersection on alternate legs and impact is imminent. Both cars approach the intersection at 60 km/h (37mph) as shown in Figure 3. In order to safely recreate the scenario in the field the Red Car comes to a halt at the stop bar, however in the true scenario the Red Car would enter the intersection without stopping.

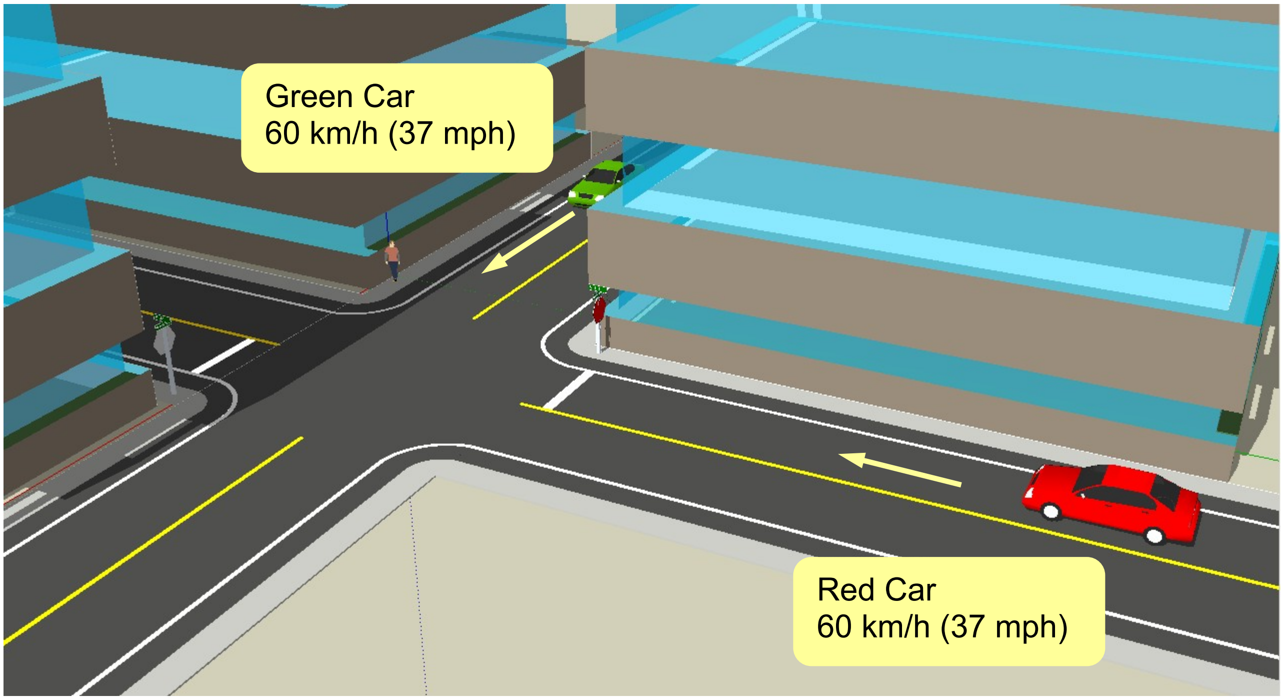

Figure 3: Pre-Crash Sensing Scenario

In this scenario there is insufficient time to warn drivers. Instead, the DSRC *Pre-Crash Sensing* application aims to prepare the vehicles and occupants for a collision [1]. The DSRC safety system aims to mitigate the severity of the crash using countermeasures such as:

- Pre-tightening of seat belts;
- Occupant repositioning;
- Pre-arming of airbags;
- Pre-deployment of side-impact airbags;
- Front bumper extension;
- Front bumper height adjustment for vehicle compatibility; and
- Emergency Brake Assist (EBA) – increasing applied brake level to maximum [4].

As soon as a reliable link is established, each car can begin processing information about the other and prepare for impact. Available data includes vehicle dimensions, mass, position, speed, acceleration, heading, steering wheel angle and yaw rate.

When performing field trials for this scenario, the radio using a WiFi chipset was unable to close the communications link until a range of 25 m. During the same trials, the Cohda Radio closed the link at 65 m range. The range provided by each radio is compared in Figure 4. At 60 km/h (37mph), the 40 m range extension from the Cohda Radio provides 2.4 seconds of additional link connectivity, adding significant value for countermeasure deployment. Furthermore, at this speed each car requires at least 28 m to stop [2], as shown in Figure 4. Hence, the range provided by the Cohda Radio may enable Emergency Brake Assist systems to bring the car to a halt, thus avoiding a collision. However, the range provided by the radio using a WiFi chipset falls short of the minimum stopping distance requirement.

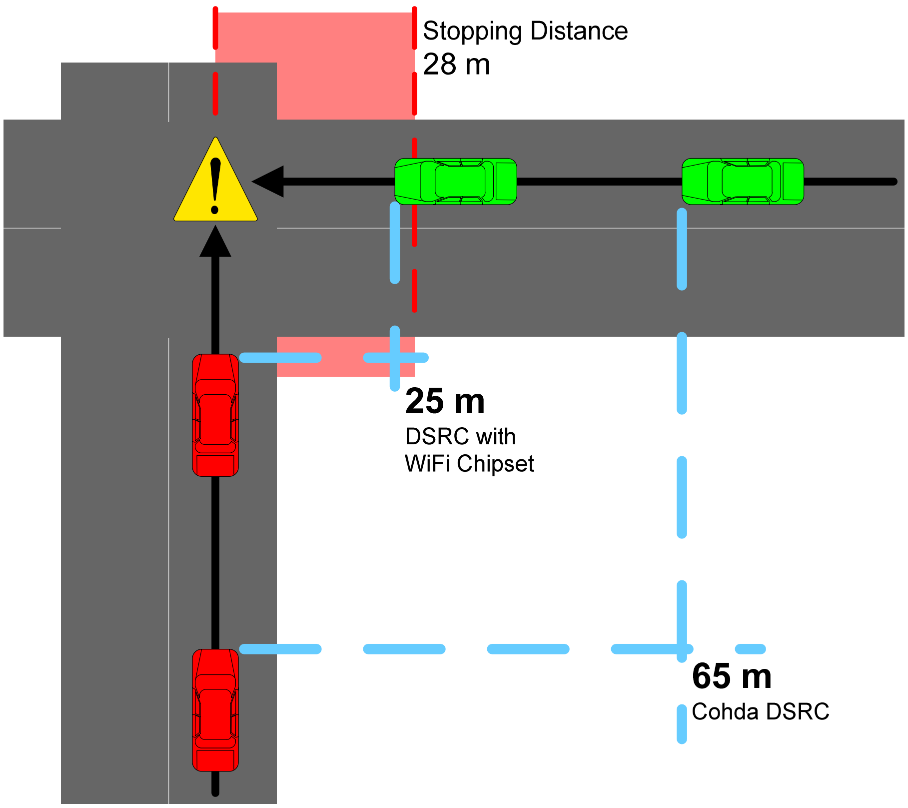

Figure 4: Pre-Crash Sensing Field Results

These results show that DSRC systems using WiFi chipsets are severely challenged by the combination of mobility and multipath [5]. However, even in non line-of-sight conditions the Cohda Radio provides a robust communications link with valuable time to deploy countermeasures, and the potential to avoid a collision altogether.

Road Side Unit Scenario

This scenario recreates vehicle-to-infrastructure communication between a mobile On Board Unit (OBU) and a Road Side Unit (RSU). Example applications include:

- Vehicle safety, e.g. traffic signal violation warning;
- Traffic Management, e.g. traffic probing, congestion control;
- Commercial, e.g. toll collection, map downloads; and
- Infotainment.

In this scenario the Car travels at 60 km/h (37mph), through and beyond an intersection with buildings on all corners. The RSU antenna is mounted at 3m height, as shown in Figure 5.

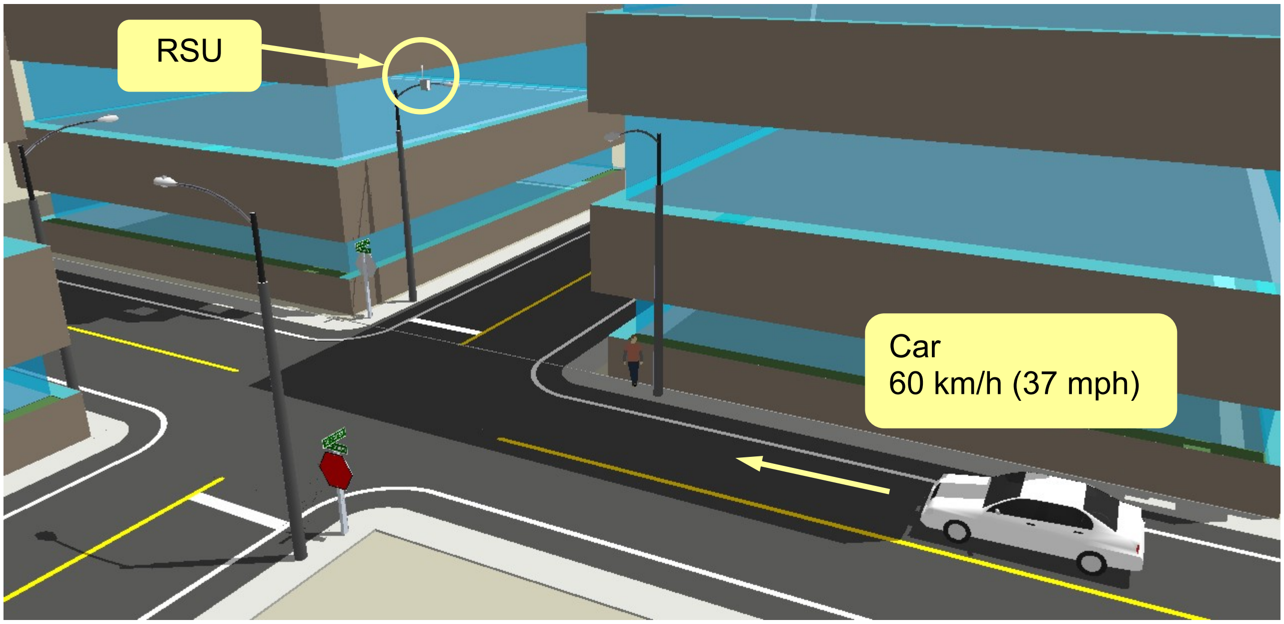

Figure 5: Road Side Unit Scenario

When performing field trials for this scenario, the radio using a WiFi chipset was able to maintain communications between RSU and OBU over only a 16 m range. During the same trials, the Cohda Radio maintained the link over a 342 m range. The range provided by each radio is compared in Figure 6.

At 60 km/h (37mph), the radio using a WiFi chipset provides 1 second of connectivity, allowing 0.6 Mbytes of data to be transferred between the RSU and OBU. However, the Cohda Radio provides a robust connection for 21 seconds, allowing 13.7 Mbytes to be transferred.

The Cohda Radio provides more than 20 times the upload/download capacity of the radio using a WiFi chipset. This adds significant value for traffic management, commercial and infotainment applications. For example, the NAVTEQ map data file for Rome is 3.8 Mbytes. This represents less than 30% of the Cohda Radio link capacity and would be easily transferred in a single RSU pass. However, at least seven RSU passes would be required to perform a fragmented download using the WiFi chipset based radio.

The connection provided by the radio using a WiFi chipset is limited in range and capacity, making it unattractive for multiple user access. However, the Cohda Radio offers sufficient capacity to support concurrent connections to multiple users.

These results again demonstrate that DSRC systems using WiFi chipsets are severely challenged by the combination of mobility and multipath. In contrast, the Cohda Radio provides sufficient range and capacity to support multiple mobile users, even in the most demanding data intensive vehicle-to-infrastructure applications.

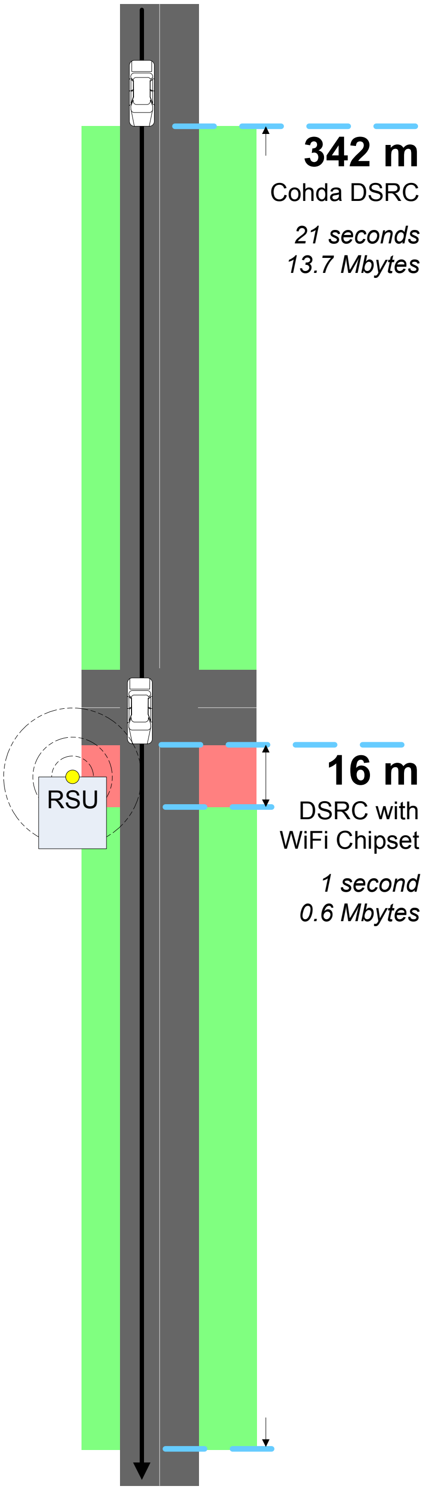

Figure 6: Road Side Unit Field Results

Summary of Results

Cohda has performed comparative field trials for twelve vehicle-to-vehicle safety applications [1]. Results from these trials are summarized in Table 1. The collision avoidance range requirement is calculated from stopping distance and driver perception-reaction time, as described for the Left Turn Assist scenario above[2]. In each case where the radio provides sufficient range for collision avoidance the result is highlighted in green, otherwise it is colored red.

Scenario	Environment	Speed (km/h)	Range to Impact (m)		
			Avoidance Requirement	DSRC using WiFi Chipset	Cohda DSRC
Intersection Collision Warning	Closed Intersection	50	55	17	102
Intersection Collision Warning	Blind Corner	60	69	33	169
Pre-Crash Sensing	Closed Intersection	60	28	25	65
Pre-Crash Sensing	Blind Corner	60	28	29	59
Lane Change Warning (overtaking a truck)	Highway	90	120	16	504
Lane Change Warning (overtaking a car)	Hillside	60	69	87	120
Lane Change Warning (overtaking a car)	Cutting	60	69	69	201
Lane Change Warning (lane drift)	Blind Corner	50	55	32	55
Lane Change Warning (lane drift)	Highway	90	120	16	602
Left Turn Assistant	Open Intersection	90	120	14	214
Left Turn Assistant	Closed Intersection	60	69	13	293
Cooperative Forward Collision Warning	Highway	90	120	9	159

Table 1: Vehicle-to-Vehicle Safety Scenario Results Summary

[2] Pre-Crash Sensing applications automatically deploy countermeasures rather than relying upon driver reaction. In these scenarios stopping distance is used as the collision avoidance range requirement.

These results consistently show that DSRC systems using WiFi chipsets are severely challenged in real world DSRC scenarios, meeting collision avoidance range requirements in only three out of twelve cases. Given that these chipsets were designed for stationary indoor applications, their failure in the combined presence of mobility and multipath outdoors is expected [5].

In all safety scenarios the Cohda Radio provides sufficient range to meet the collision avoidance requirement. Unlike WiFi based systems, the Cohda Radio has been designed from the ground up to provide robust wireless communications in mobile outdoor urban environments [6]. This is achieved using advanced receive-side signal processing, while remaining 100% compliant to the IEEE 802.11p standard. This design makes the Cohda Radio a unique and robust foundation for DSRC applications.

Range that is additional to the collision avoidance requirement translates to surplus time for slower driver perception-reaction and poor environmental conditions. Conversely, any shortfall will increase the speed at which the vehicles collide. This is highly undesirable, as impact energy increases as a quadratic function of speed. Figure 7 summarizes the surplus/shortfall in time offered by each radio, for all collision avoidance scenarios.

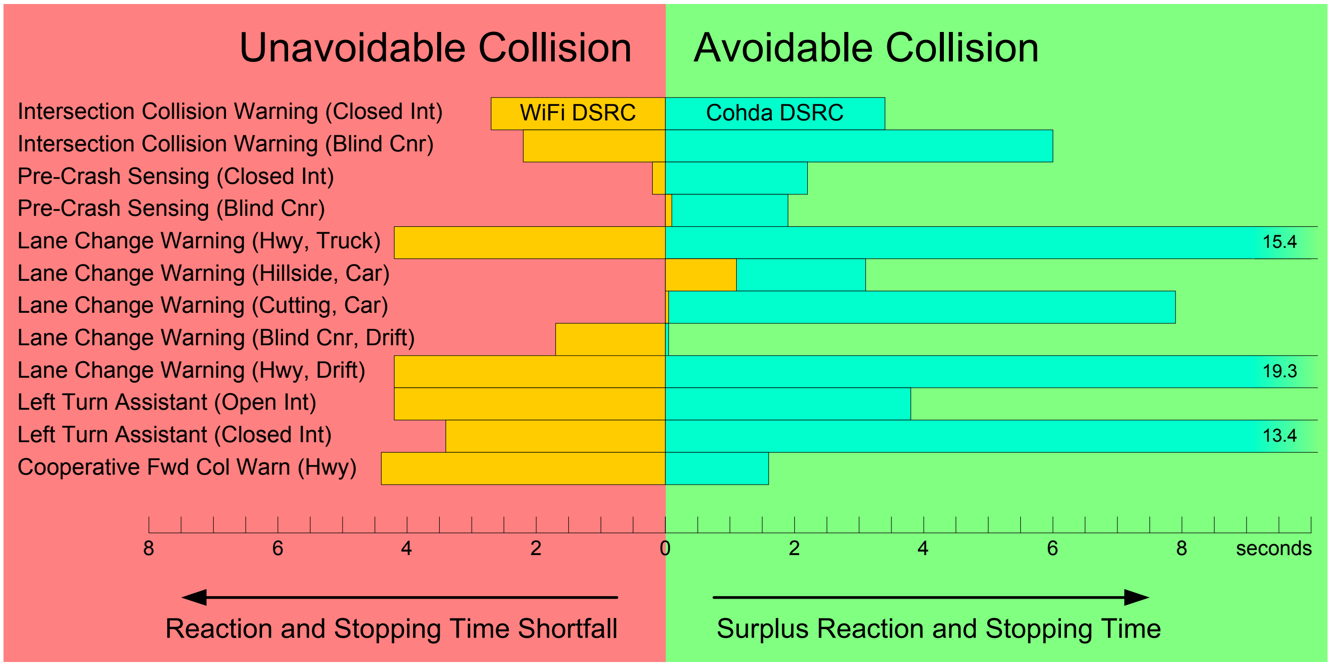

Figure 7: Collision Avoidance Time Summary

These results show that DSRC radios using WiFi chipsets can fall short of collision avoidance by several seconds. This will result in higher speed of impact. However, the Cohda Radio allows collision avoidance in all scenarios and provides significant surplus connection time, adding a further safety buffer for suboptimal conditions.

Results from vehicle-to-infrastructure scenario field trials are summarized in Table 2.

Scenario	Environment	Speed (km/h)	Data Transfer (Mbytes)	
			DSRC using WiFi Chipset	Cohda DSRC
Road Side Unit	Closed Intersection	60	0.6	13.7
Road Side Unit (OBU in car behind a truck)	Closed Intersection	60	0.3	9.5
Road Side Unit	Open Intersection	60	1.2	21.5

Table 2: Vehicle-to-Infrastructure Scenario Results Summary

DSRC radios using WiFi chipsets demonstrate consistently poor performance in vehicle-to-infrastructure scenarios. Upload/download capacity is limited, making them unattractive for high throughput applications and multiple user access.

Cohda Radio performance excels in all vehicle-to-infrastructure scenarios, providing up to 20 times the capacity of WiFi chipset based radios. This allows the Cohda DSRC Radio to support concurrent connections, each running data intensive commercial and infotainment applications.

Conclusions

Cohda has performed more than 300 comparative DSRC field trials, in real scenarios at many locations around the world. DSRC radios from multiple vendors were tested, with performance results consistent across manufacturers, and between geographic locations.

The field trials tested DSRC radios in challenging real world scenarios, including non line-of-sight environments such as closed intersections and blind corners. Danger can arise in such environments, as drivers cannot see vehicles approaching on other intersection legs. Several scenarios used the controlled inclusion of vehicles, in addition to traffic present on public roads, recreating potentially dangerous situations with impeded driver visibility. The trials were carried out at speeds consistent with the intended application and environment. In several cases vehicles closed at high relative speeds, such as 180 km/h (112 mph). Danger increases significantly with speed, since both stopping distance and impact energy increase as quadratic functions of speed.

Physical Layer performance is fundamental, as this layer forms the foundation upon which DSRC applications are built. However, of all DSRC radios tested, only the Cohda Radio has a Physical Layer designed specifically for mobile outdoor applications. All other radios rely upon the performance of WiFi chipsets that were designed for stationary indoor use.

Results from the field trials consistently show that WiFi chipset based DSRC radios are severely challenged in non line-of-sight environments such as blind corners and closed intersections, and in the presence of other traffic. These radios also demonstrated a failure mode consistent with a susceptibility to mobility. Hence, as danger increases, due to reduced driver visibility and increased speed, DSRC systems using WiFi chipsets become more likely to fail. In all but three safety scenarios these radios failed to meet the requirements for collision avoidance. Furthermore, they provide very limited support for the heavy data transfer requirements of many vehicle-to-infrastructure applications.

The Cohda DSRC Radio demonstrated the potential to make a collision avoidable in all twelve vehicle-to-vehicle safety scenarios. Sufficient support was also demonstrated for data intensive commercial and infotainment applications. This performance is achieved through receive-side signal processing, remaining fully compliant to the IEEE 802.11p standard. The Cohda Radio is built upon a unique Physical Layer that provides robust support for DSRC applications, in even the harshest real world conditions. This will allow DSRC to work in more places, more of the time, and will result in more lives saved.

References

[1] SAE International, "Dedicated Short Range Communications (DSRC) Message Set Dictionary," J2735, December 2006.

[2] Federal Motor Carrier Safety Administration, "Federal Motor Vehicle Safety Standards, Part 571 - Standard No. 135; Light vehicle brake systems".

[3] American Association of State Highway and Transportation Officials, "A Policy on Geometric Design of Highways and Streets (The Green Book)," 2001.

[4] http://www.rospa.com/roadsafety/advice/motorvehicles/brake_assist.htm

[5] Cohda Wireless, "Mobility and Multipath: Challenges for DSRC," 2007.

[6] P. Alexander, D. Haley and A. Grant, "Outdoor Mobile Broadband Access with 802.11," IEEE Communications Magazine, vol. 45, no. 11, pp. 108-114, Nov. 2007.