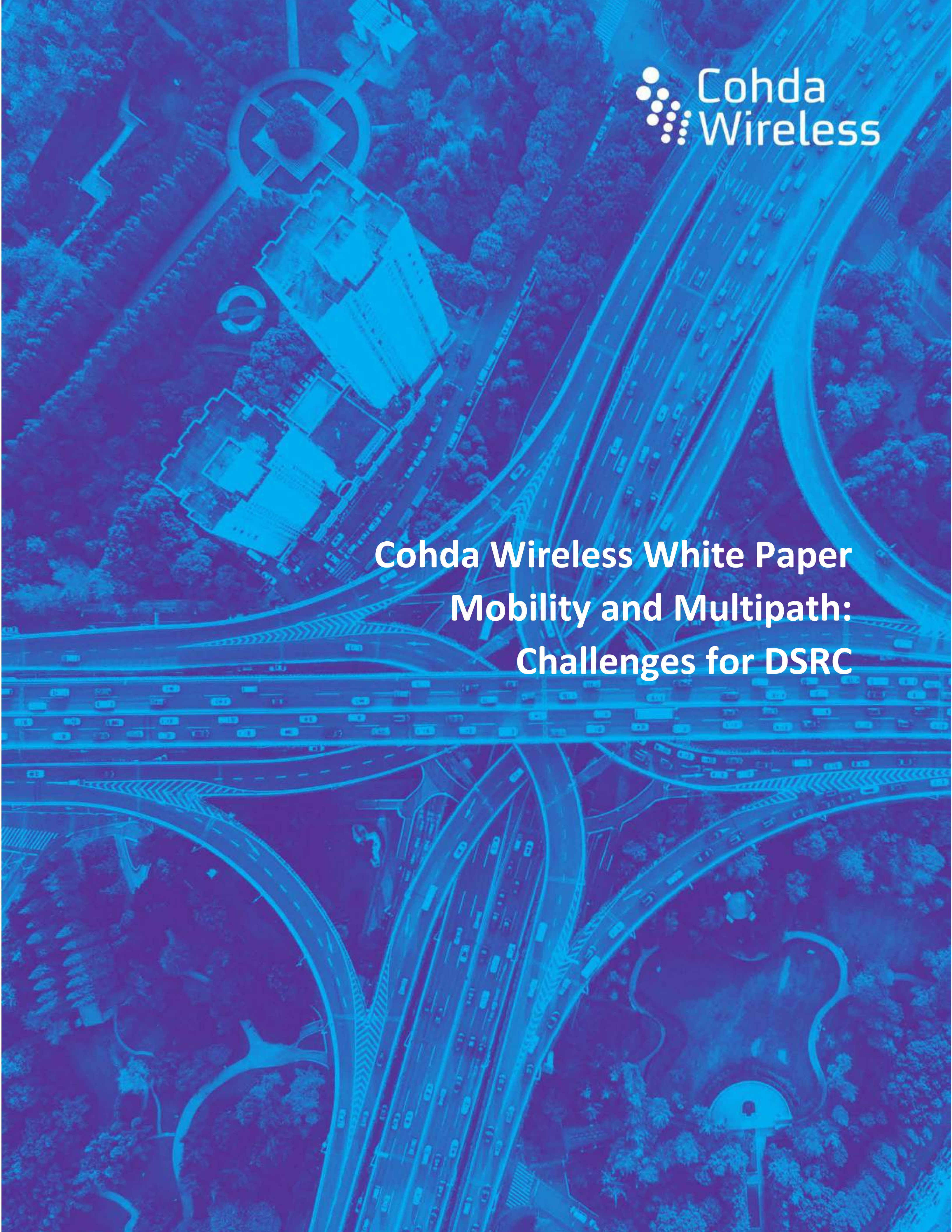

# Cohda Wireless White Paper
# Mobility and Multipath: Challenges for DSRC

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## 1.0 Overview

Dedicated Short Range Communications (DSRC) is the communications standard for radios that will be the foundation upon which future Intelligent Transport Systems (ITS) will be built. It is anticipated that DSRC-based ITS systems will play a critical role in saving lives on the road and reducing traffic congestion.

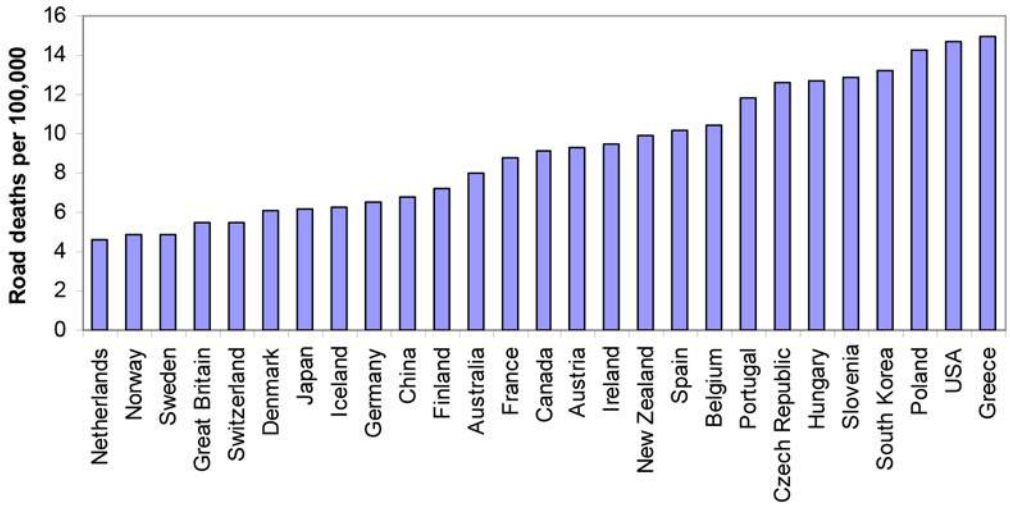
DSRC standards are based upon WiFi standards, and it is the prevailing wisdom that WiFi chipsets can be used to build DSRC radios. However, DSRC radios must perform extremely well under harsh outdoor, mobile conditions, and WiFi chipsets have been designed with benign indoor, stationary conditions in mind. In order for DSRC radios to deliver on their promise of saving lives they must be designed from the ground up to perform exceptionally well in the conditions expected out on the road.

## 2.0 DSRC Motivation

The primary motivation for developing Intelligent Transport Systems is to reduce traffic fatalities. Globally, traffic accidents are a leading cause of death – in 2004 the World Health Organization estimated that 1.2 million people lost their lives in traffic accidents around the world. This made it the ninth leading cause of death worldwide and it is projected that traffic accidents will grow to be the third leading cause of death in the world by 2020.

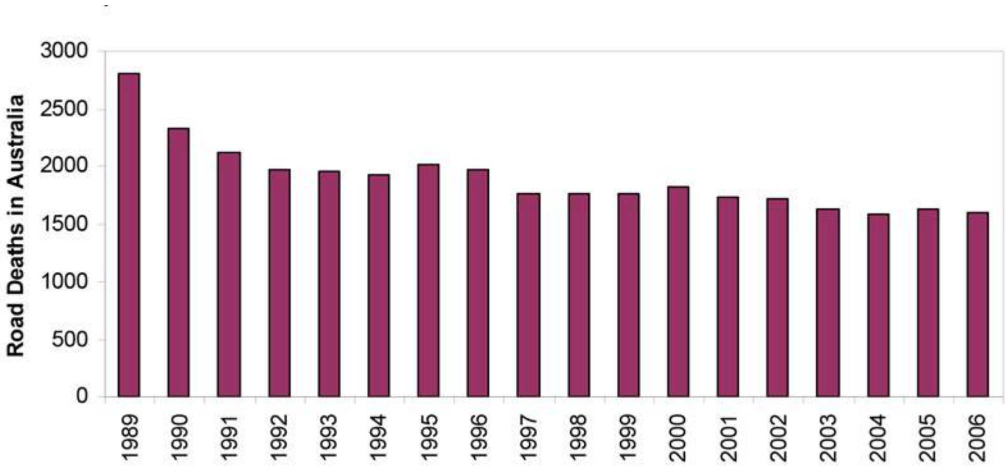
Currently, 42,000 people die annually on US roadways nationwide – this is 115 deaths every single day. Traffic accidents are the leading cause of death in the US for people between ages 4 and 33, and fifty percent of the deaths occur from intersection collisions and vehicles leaving the roadway.

Likewise in Australia 1,601 persons were killed in 1,456 road crashes in 2006. In order to compare these two figures consider the following graph that shows the number of traffic fatalities per 100,000 people in 2005. The number of fatalities in the US was very high globally with 14.7 road deaths per 100,000 people, and Australia was in the middle of the global range with 8.0 road deaths per 100,000 people.




As well as the human cost, there are also economic impacts of both traffic accidents and traffic congestion. For example, traffic crashes cost the US economy $230 billion annually, and traffic congestion costs $63 billion. There is also increasing concern about the impact of traffic congestion on carbon emissions, with 56 billion gallons of fuel wasted annually in the US alone due to traffic congestion.

There have been efforts around the world to reduce traffic fatalities. For example, in the last decade in Australia mandatory airbags have been introduced and speed limits have been reduced. However, these efforts are having diminishing returns. The following graph shows traffic fatalities in Australia over the last 16 years. While there is evidence of a long term downward trend in Australian road deaths, the number of deaths per annum has not changed markedly since 2003.

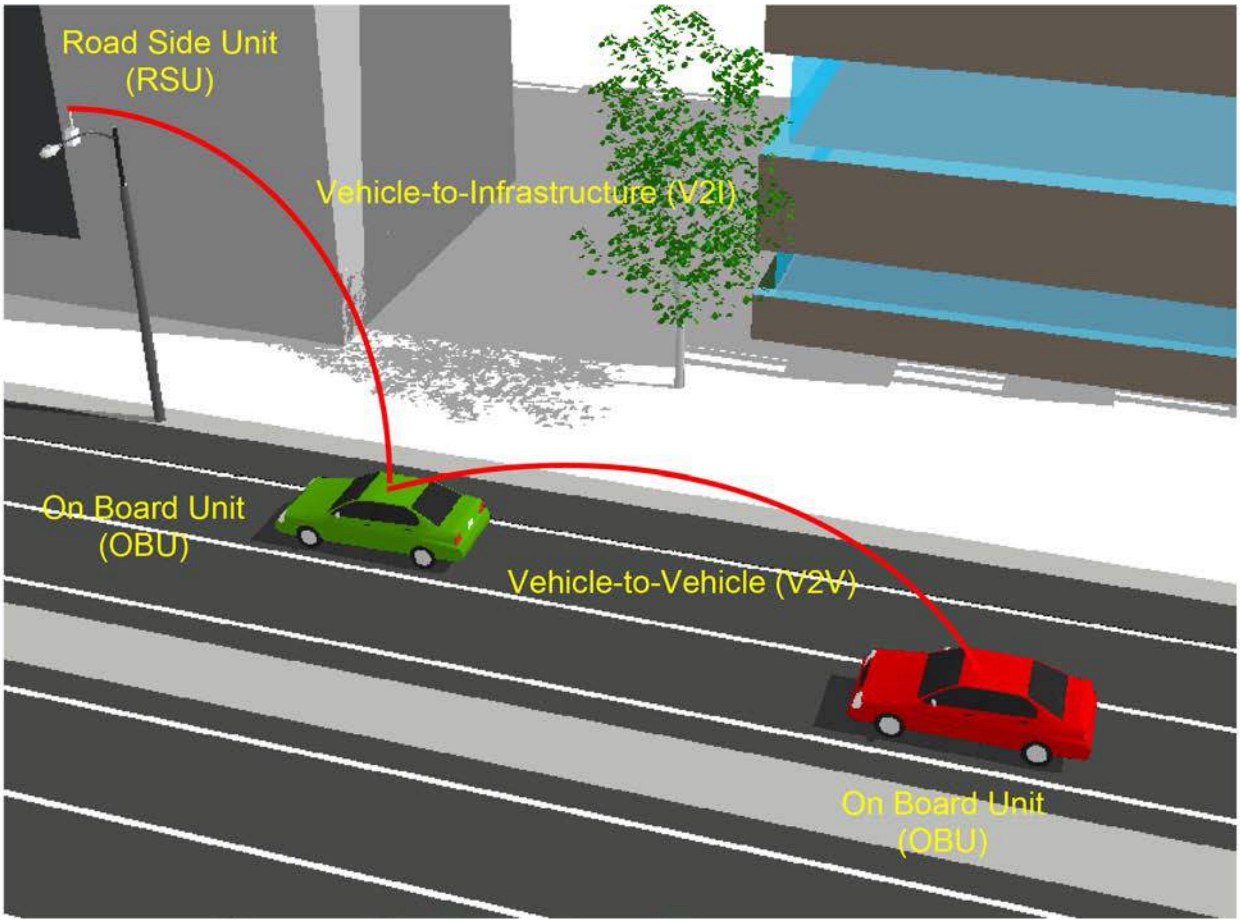



This experience is being reflected around the world, and countries are looking for new techniques to reduce traffic fatalities. DSRC-based ITS has the potential to save significant numbers of lives on the road.

## 3.0 DSRC Overview

DSRC-based ITS systems consist of a network of road-side units (RSUs) – typically mounted at intersections on traffic lights – and on board units (OBUs) mounted in vehicles. These on board units will consist of a DSRC radio, GPS receiver, interfaces to vehicle sensors, and a human-machine interface.

DSRC will be used to allow communications between the vehicles and the roadside unit, known as vehicle-to-infrastructure communications, and between the vehicles, known as vehicle-to-vehicle communications.




Vehicles on the road will constantly be transmitting data such as their position, speed, and heading. This will allow other vehicles to determine if a collision is likely and to take appropriate action. For example: imagine two vehicles approaching a blind intersection. By analyzing the transmissions from the other vehicle, a vehicle can determine if a collision is likely and warn the driver.

DSRC also allows vehicles to communicate with the ITS infrastructure, permitting traffic flow monitoring and congestion mitigation. For example: vehicles will take snapshots of road and traffic conditions as they travel, and upload these snapshots when they are in range of a road side unit. The traffic control centre will then have a very good near-real time picture of conditions throughout the road network.

DSRC-based ITS systems can also go beyond safety and traffic control applications. They will also enable commercial applications such as toll collection, and infotainment applications such as driving directions.

DSRC is defined by the IEEE 802.11p and IEEE 1609 standards.

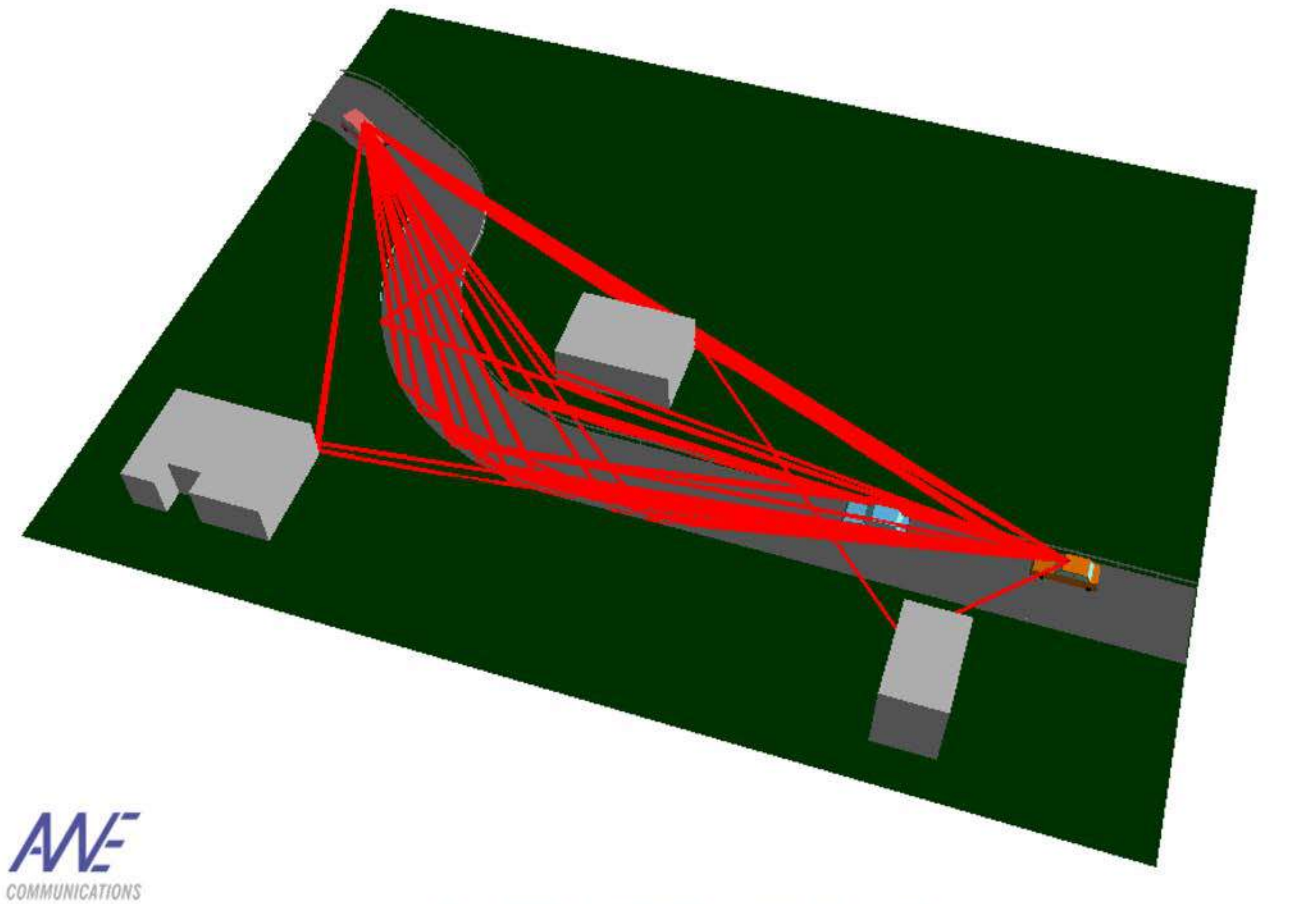
## 4.0 Challenges for DSRC

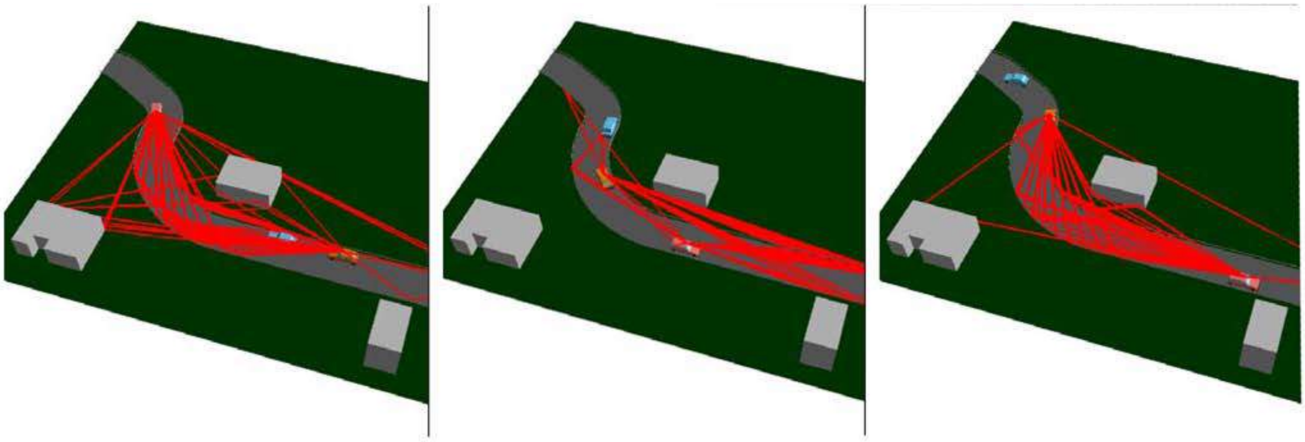
The biggest challenge for DSRC is that it must work well under very harsh conditions, due to the nature of outdoor radio channels and the fact that the vehicles are moving.

The following diagram was generated using a 3D ray tracing tool from AWE Communications, and shows the radio paths for communications between the red car and the orange car. The signal from the transmitter to the receiver travels along multiple paths which are combined at the receiver. These paths result from reflections off of buildings, guard rails, and even other vehicles. Diffraction over and around these objects is also possible. Each of these paths has a different length, and the paths combine both constructively and destructively at the receiver.

Furthermore, these paths are changing in time as the vehicles move. The film strip below the diagram shows how these paths evolve over time – each time the position of either vehicle changes then so do the paths that the radio waves travel between the two vehicles.

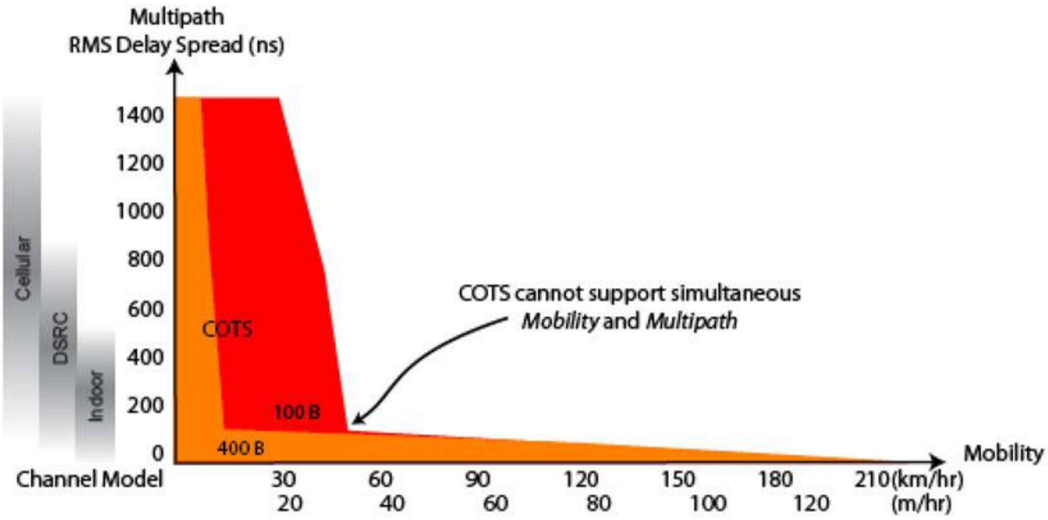
This combination of *multipath* and *mobility* results in time-varying frequency-selective fading, which the receiver must be able to cope with.





Now, how does this multipath and mobility affect a DSRC radio in practice? In the following plot we show the results of bench tests of a typical commercial off-the-shelf (COTS) DSRC radio using a channel simulator. Channel models with differing RMS Delay Spreads – a measure of multipath – were tested at a variety of different vehicle speeds.

The orange area shows the regions of operation where the COTS radio achieved acceptable performance for long packets (400 bytes), and the red regions shows the same for short packets (100 bytes). As can be seen, the COTS radios can cope with *some* multipath, as long as the mobility is low, and *some* mobility, as long as the multipath is low. However, the COTS radios fail when there is *simultaneous* multipath and mobility.

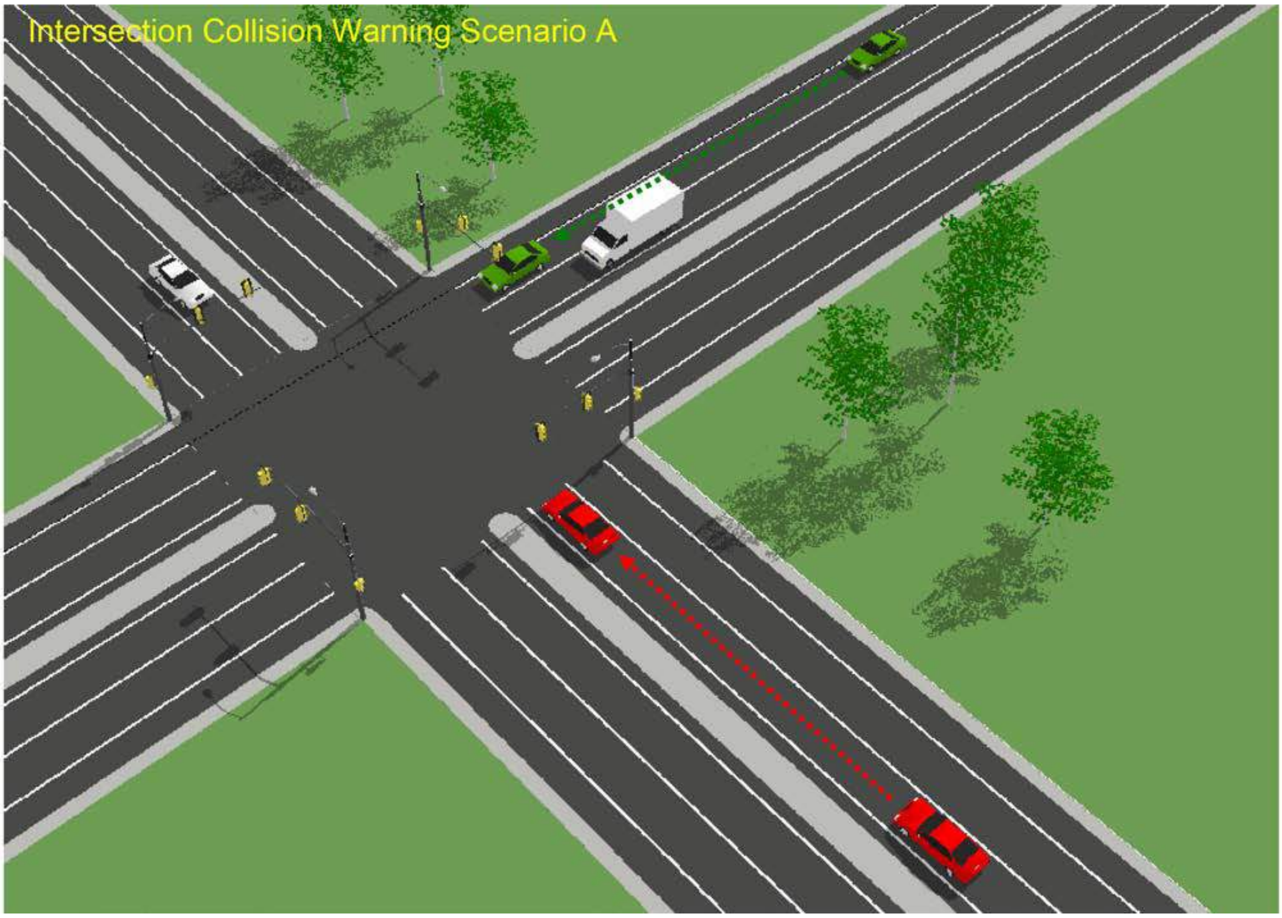


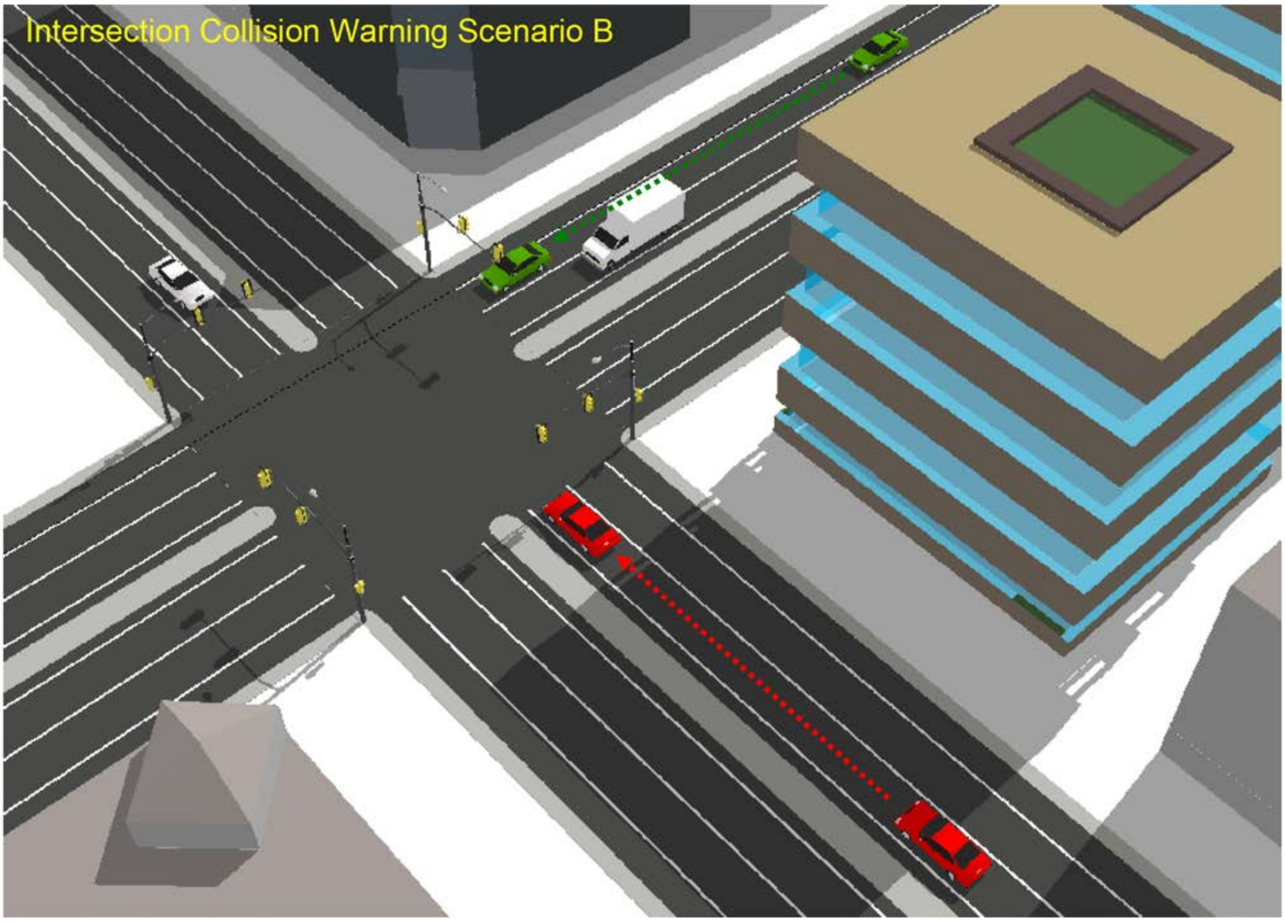

3 Mbps, 400 Byte Packets, 10% PER Threshold, No Additional Noise, -78 dBm Rx Power, 10 MHz, 5.9 GHz

## 5.0 Scenarios That Challenge DSRC Radios

Consider an Intersection Collision Warning scenario, as illustrated below. Here the green vehicle is traveling along the road with a green light, and the red vehicle is approaching the intersection on a side road with a red light and *should* stop at the stop line. However, if the red vehicle is traveling too fast it will not be able to stop in time. In this case the earlier that the green vehicle can successfully receive a DSRC transmission from red vehicle the earlier the driver of the green vehicle can be warned and the more likely a collision can be averted.

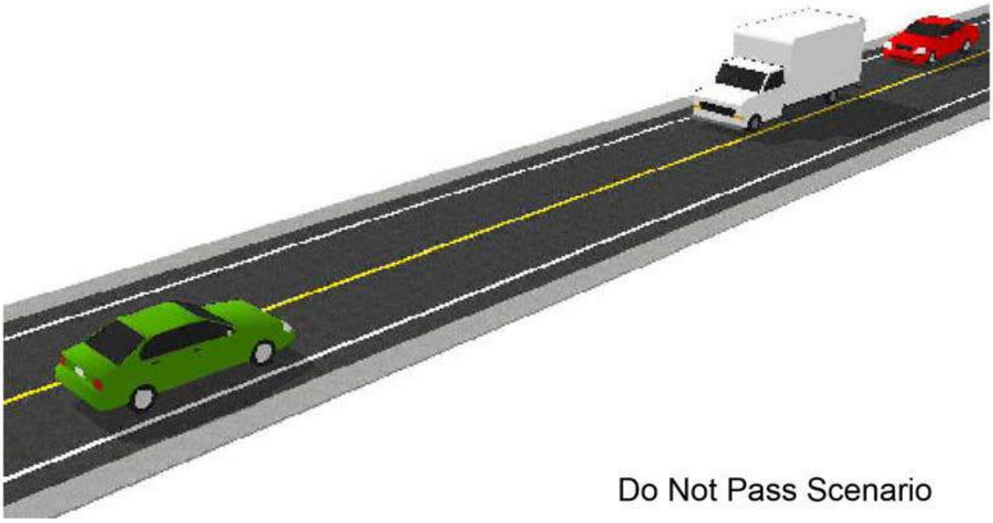
In Scenario A the intersection is open. In this case the delay-spread of the multipath will be low, and a COTS DSRC radio may be able to close the link (although in this case the drivers will also be able to make visual contact with the other vehicle, so the DSRC radio may not be necessary to avert a collision). However, in Scenario B the intersection is surrounded by buildings and the harsh combination of simultaneous multipath and mobility will exist everywhere outside of the intersection itself. In this case the COTS DSRC radio may not be able to close the link and generate a warning to the driver until both vehicles actually enter the intersection, by which time it is too late to avoid a collision.





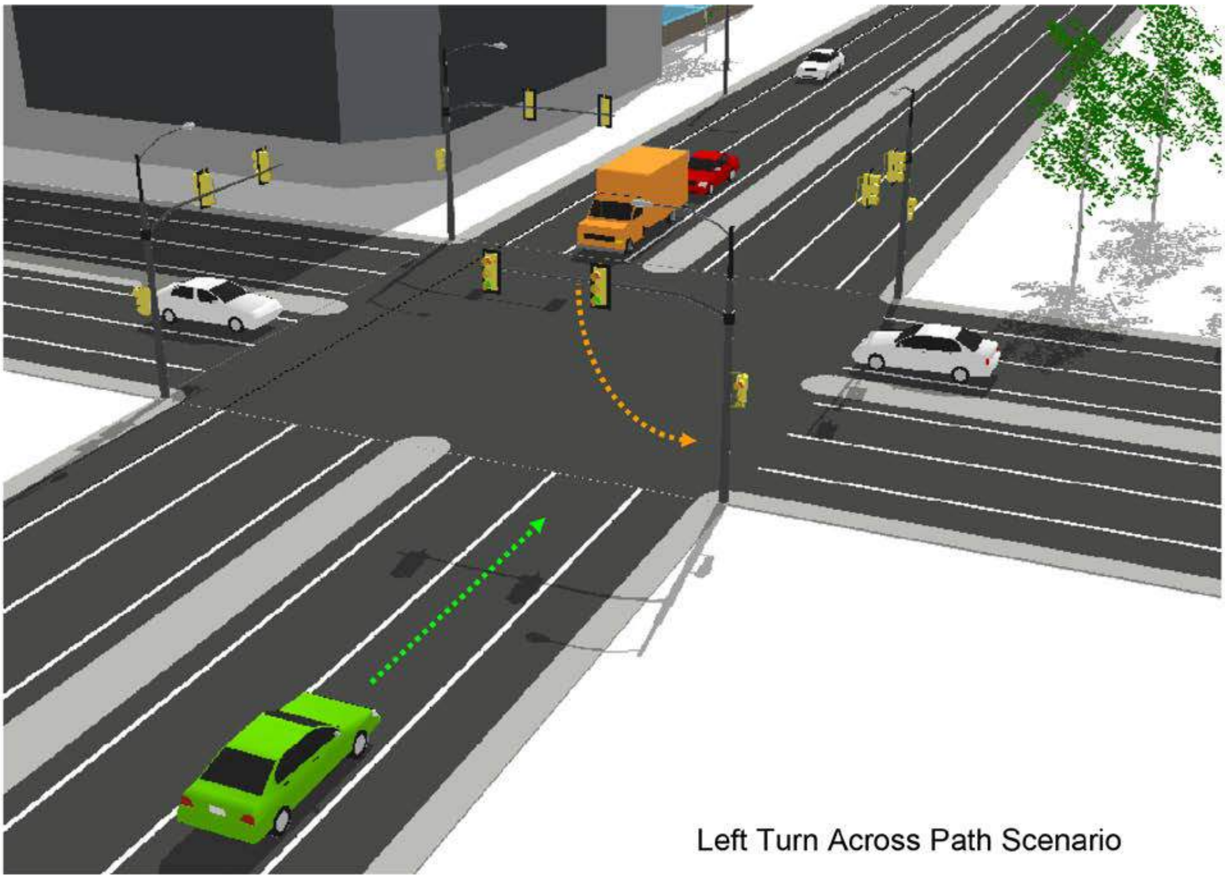

Next consider the Do Not Pass scenario, shown below. Here the red vehicle is traveling along a two lane road, and wishes to pass the vehicle in front. If the view of the oncoming traffic is blocked then the driver may attempt to overtake when it is not safe to do so. However, if the OBU in the red vehicle is aware of the green vehicle as a result of receiving its DSRC transmissions then the driver of the red vehicle can be warned if an attempt to overtake is made.

In this scenario the view of the oncoming traffic is blocked by a large truck and conditions of simultaneous multipath and mobility exist. The COTS DSRC radio in the red vehicle may not be able to close the link and detect the presence of the green vehicle. This is a particularly harsh scenario as the vehicles are traveling towards each other, doubling their apparent speed, while halving warning times.



Do Not Pass Scenario

Finally consider the Left Turn Across Path scenario, as shown below. Here the red vehicle is waiting to turn left across the path of oncoming traffic, and its view is blocked by a large truck. If the red vehicle is unaware of the green vehicle approaching from the opposite direction then the driver may be tempted to follow the truck around the corner, placing the red vehicle directly in the path of the green vehicle. Again, conditions of simultaneous multipath and mobility exist in this scenario, and the COTS DSRC radio may be unable to close the link between the red vehicle and the green vehicle, and the driver of the red vehicle cannot be warned of the oncoming traffic.

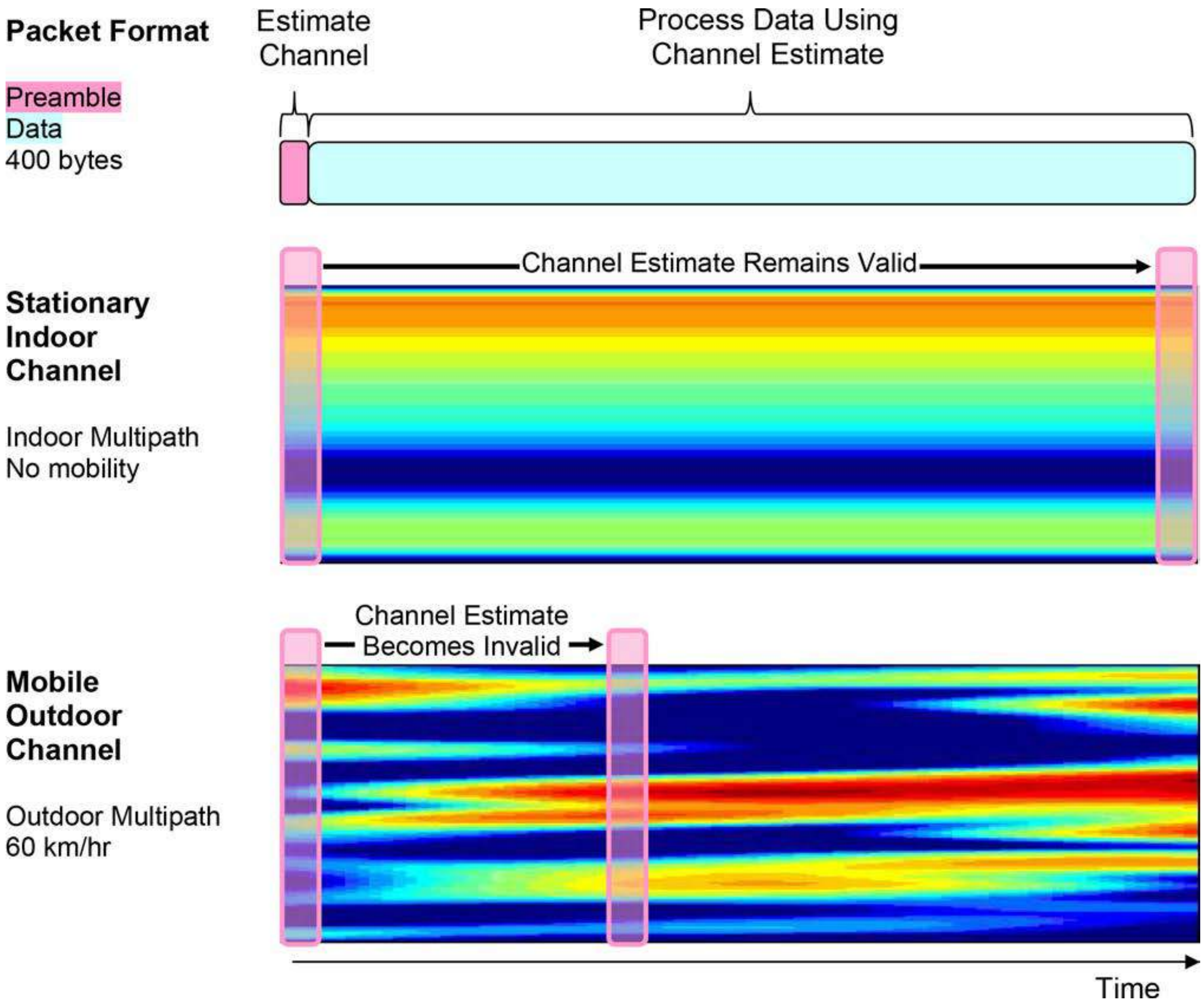


Left Turn Across Path Scenario

## 6.0 WiFi Chipsets in DSRC Radios

Standards for DSRC radios are based upon the standards developed for WiFi radios, and it is a commonly held belief that WiFi chipsets can be used in DSRC Radios. However, WiFi chipsets were developed for indoor conditions, where the multipath is low and the mobility is at worst walking pace. COTS DSRC radios are built around these WiFi chipsets, and as we have shown they do not perform well in outdoor conditions, where multipath and mobility abound.

Every WiFi (and DSRC) packet transmission is preceded by a preamble. The purpose of the preamble in the WiFi standard was to provide a known signal that the WiFi receiver could use to estimate the multipath channel. This is exactly what WiFi chipsets do and, because they are designed for indoor operation, these chipsets assume that the channel is static for the duration of the packet and use this channel estimate throughout the packet However, under the conditions of simultaneous multipath and mobility often experienced in DSRC applications, the channel will change significantly from the start of the packet to the end of the packet and this channel estimate will become invalid before the end of the packet. This is illustrated below. This diagram shows how both an indoor channel and an outdoor channel evolve over time.



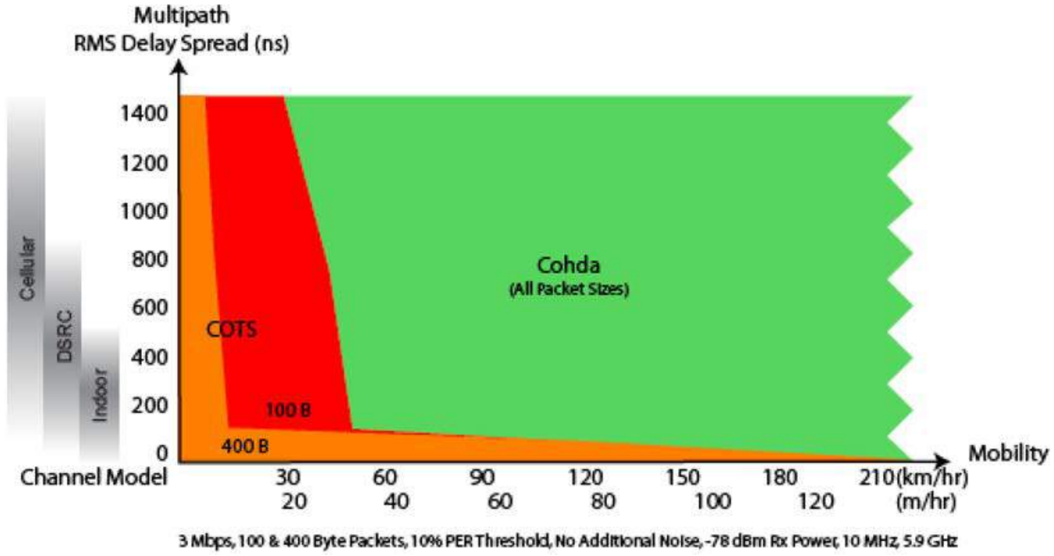
This is what causes the COTS DSRC radios to fail under conditions of simultaneous multipath and mobility. It also explains why the performance of the COTS DSRC radios is worse when the packets are longer – the packets spend more time on the air and channel estimate made during the preamble is more likely to become invalid before the end of the packet.

So what is the source of this belief that WiFi chipsets can be used for DSRC radios? Largely it is the result of overly simplistic testing. Consider the following photograph on the left from a series of tests conducted by ARINC at Maryland International Raceway during the development of the DSRC standards. The purpose of the test was to validate that a DSRC radio based on WiFi chipsets could be used at high speed. The tests succeeded at a speed of 120 mph, but note the absence of other traffic or sources of multipath reflection. This meant that the test conditions lay close to the x-axis in the multipath vs. mobility plot on page 6, and it is not surprising that the test succeeded. Contrast this to the photograph that depicts the real-world conditions under which DSRC radios will be expected to perform. In these conditions simultaneous multipath and mobility will occur often.

## 7.0 Cohda's DSRC Solution

What is needed for DSRC applications is an IEEE 802.11p compliant radio that has been designed from the ground up to cope with simultaneous multipath and mobility. Cohda Wireless has built such a radio and tested it in the field under real-world conditions.

The following plot revisits the performance of the COTS DSRC radio and compares it to Cohda's DSRC radio. The green region shows the range of conditions over which the Cohda DSRC will meet the performance requirements of DSRC. As can be seen, Cohda's radio is virtually impervious to mobility, and its performance is independent of packet length. The key to this performance is our proprietary techniques that do an excellent job of estimating the channel and tracking it as it evolves throughput the packet. This means that Cohda's DSRC radio will perform extremely well under the DSRC scenarios discussed on page 6.




In addition to being robust under conditions of simultaneous multipath and mobility, Cohda's DSRC radios also have improved receiver sensitivity and increased tolerance to interference.

## 8.0 Conclusion

Existing WiFi chipsets cannot cope with the combination of multipath and mobility expected in DSRC use-case scenarios under real-world conditions. This is inconsistent with the prevailing view that existing WiFi chipsets can be used to build DSRC radios.

However, these chipsets were designed for indoor, stationary operation, and as we have shown they do not perform well under harsh mobile, outdoor conditions. (This not to say that DSRC radios based on these chipsets will fail completely. Rather, the range of conditions under which they will perform satisfactorily will be greatly reduced).

On the other hand, Cohda's DSRC radio has been designed from the ground up to perform extremely well under all conditions anticipated by DSRC use-case scenarios, and we have proven this advantage in the field. Note also that we achieve this while remaining 100% compliant to the standard – our improvements are all in the receiver.

In short, Cohda's DSRC radios will allow DSRC to work in more places, more of the time.

And this will result in more lives saved.