802.11p(DSRC) in V2V communication

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***Abstract*—Every year, roughly 6.75 million vehicle accidents occur. Every day, around 18,510 vehicle accidents occur. That equates to around 3,700 deaths every day on a worldwide scale, with an additional 20-50 million wounded or handicapped (CDC). If there was a means to prevent accidents, if vehicles (autonomous or non-autonomous) could communicate with each other and notify the driver of potential hazards, the number of accidents on the road would be considerably decreased. There is, thankfully, a protocol (IEEE 802.11p) that can be utilized to create vehicle-to-vehicle communication. The goal of this paper is to introduce the DSRC; an IEEE 802.11p application for vehicle to vehicle communication, that solves this problem with great efficacy and minimal overhead. This paper discusses the use case, implementation, and simulation of 802.11p, which serves as the foundation for Dedicated Short Range Communication (DSRC).**

***Index Terms*—dedicated short range communication, vehicle-to-vehicle communication, IEEE 802.11p**

I. INTRODUCTION

It is true that sensors are being included in automotive vehicles to reduce accidents on the road, by warning drivers of potential hazards that may or may not be visible to the driver. One limitation in this regard is the inability of this sensors (i.e. cameras, lidars or radars e.t.c) to warn drivers out of the traditional line of sight scenarios, and their limitations in certain conditions, for example the camera and lidar performance are affected by the weather, radars have high noise interference and inadequate classification (see Figure 1) [8].

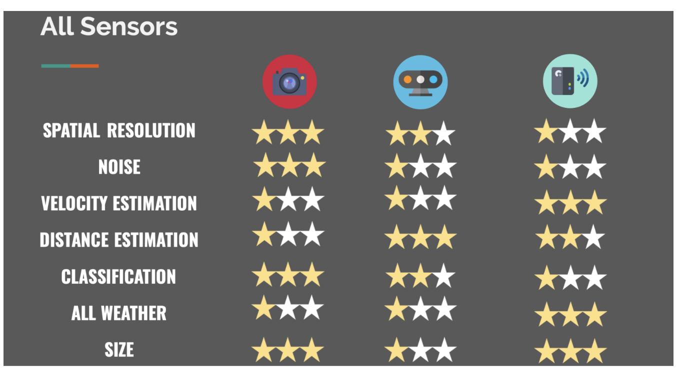

Fig. 1. Sensor Limitations [8]

Even in autonomous vehicles where two or more of this sensors combine their data (i.e. sensor fusion) to compensate for each others weakness, the DSRC control information can be shared between vehicles within a certain range to avoid redundant calculation for each vehicle, and information such as vehicles wanting to overtake or vehicles coming from blind spot will increase the accuracy, performance and efficiency of this fully autonomous vehicles. There are three types of DSRC broadcast messages that are based on the 802.11p communication protocol, these messages are independent of the underlying wireless technologies; and are used in different countries/regions independently. For example the **Cooperative Awareness Message**(CAM) and **Decentralised Environment Notification Message**(DENM), are both used in EU member states, the key difference between CAM and DENM is CAM broadcast vehicle status information all the time, and DENM broadcast information about specific events. In the U.S. and China the **Basic Safety Message**(BSM) which broadcast vehicles status information is used, the key difference between the U.S. BSM message is the inclusion of optional event flags (Figure 2) [9].

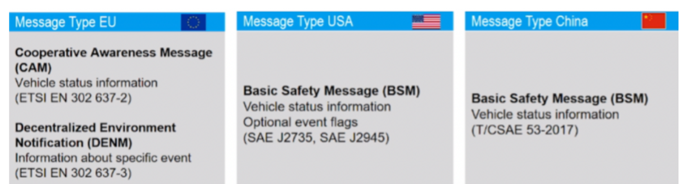

Fig. 2. Type of broadcast messages [9]

V2V communication exchange this information directly between vehicles without intermediaries such as cell-phone infrastructure or WiFi hotspot. DSRC-V2V does not require infrastructure to facilitate the communication between vehicles.

II. BSM MAKEUP

An On-Board Unit (OBU) is required for a vehicle to establish V2V communication with other vehicles, an OBU is used for collecting data. BSM is a broadcast message that is normally sent up to 10 times per second. BSM content comprises vehicle information such as vehicle speed, position(location), and brake condition. Safety applications use the remote vehicles (RVs) data from BSM and Host Vehicle(HV) data from the OBU interfaces like CAN and

GNSS to predict a potential crash and alert the driver. Potential car crashes (i.e collisions/accidents) can be avoided with six safety applications, Figure3 gives scenarios where these safety application are applied [1].

Pre-crash scenarios	Pre-crash group	Associated safety application
Lead vehicle stopped	Rear-end	Forward collision warning
Lead vehicle moving	Rear-end	Forward collision warning
Lead vehicle decelerating	Rear-end	Forward collision warning/emergency electronic brake light
Straight crossing path without traffic light	Junction crossing	Intersection movement assist
Left-turn across path/opposite direction	Left turn at crossing	Left turn assist
Opposite direction/no maneuver	Opposite direction	Do not pass warning
Opposite direction/maneuver	Opposite direction	Do not pass warning
Change lane/same direction	Lane change	Blind spot warning/lane change warning
Turning/same direction	Lane change	Blind spot warning/lane change warning
Drifting/same direction	Lane change	Blind spot warning/lane change warning

Fig. 3. Safety applications [1]

From Figure 3 the safety applications are: (1) Forward Collision Warning (FCW), (2) Electronic Emergency Brake Light (EEBL), (3) Intersection Move Assist (IMA), (4) Do Not Pass Warning (DNPW), (5) Blind Spot Warning/Lane Change Warning (BSW/LCW), and (6) Left Turn Assist (LTA). These applications proved to mitigate and prevent potential crashes in the Connected Vehicle Safety Pilot Deployment Program conducted by University of Michigan Transportation Research Institute (UMTRI). The National Highway Traffic Safety Administration(NHTSA) in the U.S. has come up with some performance requirements for V2V devices. V2V devices must be capable of broadcasting V2V messages in an interoperable way in order to prevent crashes. NHTSA has recommended performance standards for DSRC-based V2V communication to guarantee interoperability. These requirements are: (1) maximum 300 m transmission range , (2) Transmission in all directions (360○) , (3) Elevation angle +10○ to 6○, (4) Packet error rate of nothing less than 10%, (5) Required Data rate of 6Mbps, and (6) A Transmission frequency of 10 times per second under non-congested conditions.

A. Contents of a BSM

The content of a BSM must be properly specified to ensure that application designers understand the specific collection of information that will be provided, their unit, and the level of accuracy that each information element will have. The SAE J2735 standard defines a message set, data frames, and data components to allow interoperability across DSRC applications. The Abstract Syntax Notation One (ASN.1) form of a BasicSafetyMessage as established in the SAE J2735 Standard is illustrated in figure 4.

Notice the two optional event flags in Figure 4 that are present in American BSM and absent in the Chinese BSM.

1) Part I of a BSM: Part I data of the BSM (BSM Core Data) is included in every message and transmitted at all time. ASN.1 representation of the Part I data is shown in figure 5.

```
BasicSafetyMessage ::= SEQUENCE {
   -- Part I, Sent at all times with each message
coreDataBSMcoreData,      -- Part II Content
partII          SEQUENCE (SIZE(1..8)) OF
PartIIcontent{{ BSMpartIIExtension }} OPTIONAL,
   regional       SEQUENCE (SIZE(1..4)) OF
RegionalExtension {{REGION.Reg-BasicSafetyMessage}} OPTIONAL,
   ...
   }
```

The two optional flags of the American BSM, that diffrentiates it from the Chinese BSM

Fig. 4. Basic Safety Message(BSM) content [6]

```
BSMcoreData ::= SEQUENCE {
msgCntMsgCount,
   id              TemporaryID,
secMarkDSecond,
lat             Latitude,
   long            Longitude,
elev            Elevation,
   accuracy        PositionalAccuracy,
transmission    TransmissionState,
   speed           Speed,
   heading         Heading,
   angle           SteeringWheelAngle,
accelSet        AccelerationSet4Way,
   brakes          BrakeSystemStatus,
   size            VehicleSize
   }
```

Fig. 5. Part I of a BSM [6]

For more information look at the SAE International, “Dedicated Short Range Communications (DSRC) Message Set Dictionary” SAE J2735 Standard, March 2016 edition or see reference [6].

2) Part II of a BSM: BSM Part II data is optional and included when needed, figure 6 gives an overview of it’s content.

```
-- BSM Part II content support
PARTII-EXT-ID-AND-TYPE ::= CLASS {

&id      PartII-Id UNIQUE,
&Type
   } WITH SYNTAX {&Type IDENTIFIED BY &id}
PartIIcontent  { PARTII-EXT-ID-AND-TYPE: Set} ::= SEQUENCE {
partII-Id      PARTII-EXT-ID-AND-TYPE.&id( {Set} ),
partII-Value   PARTII-EXT-ID-AND-TYPE.&Type( {Set}{@partII-Id} )
   }
PartII-Id ::= INTEGER (0..63)
vehicleSafetyExtPartII-Id::= 0  -- VehicleSafetyExtensions
specialVehicleExtPartII-Id::= 1  -- SpecialVehicleExtensions
supplementalVehicleExtPartII-Id::= 2  --
SupplementalVehicleExtensions
   -- NOTE: new registered Part II content IDs
will be denoted here
-- In a given message there may be multiple extensions present
-- but at most one instance of each extension type.
BSMpartIIExtension  PARTII-EXT-ID-AND-TYPE ::= {
{ VehicleSafetyExtensions       IDENTIFIED BY vehicleSafetyExt} |
{ SpecialVehicleExtensions      IDENTIFIED BY specialVehicleExt} |
{ SupplementalVehicleExtensions IDENTIFIED BY
 supplementalVehicleExt} ,
   ...
   }
```

Fig. 6. Part II of a BSM [6]

III. DSRC PROTOCOL STACK

The DSRC protocol stack and related standards are depicted in Figure 7. The standards specify how data from one V2V device to another is exchanged and analyzed [1].

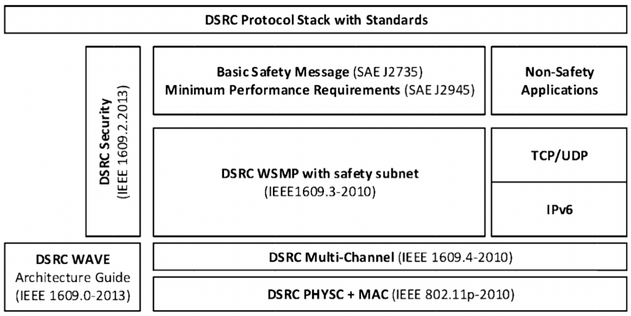

Fig. 7. DSRC protocol stack [1]

The IEE 1609.0 protocol layer serves as an architecture guide. It explains the links between the 1609 standards and other related standards such as IEEE 802.11p and SAE J2735 [2]. The IEEE 1609.3: Network Services standard layer, defines network and transport layer services, such as addressing and routing, It defines how various message types (such as WAVE Short Messages, WAVE Service Advertisements, and WAVE Routing Advertisements) are built, packed, and managed for transmission or reception between an application and IEEE 1609.4. It also explains how to construct, route, process, and analyze WAVE low-latency messages, as well as messages based on other well-known protocols like User Datagram Protocol (UDP)/Transission Control Protocol(TCP)and Internet Protocol Version 6 (IPv6) [3]. Multi-channel radio operations for WAVE(Wireless Access in Vehicle Environment) are described in IEEE 1609.4: Multi-Channel Operations Layer. It explains how to implement features like user priority access to the media, data packet routing on the correct channel with the necessary transmission parameters, and coordinated switching between the control and service channels [4]. The IEEE 802.11p: Medium Access Control and Physical Layer Specifications for WAVE defines enhancements to 802.11 required to support V2V safety applications. It specifies the physical layer for implementing DSRC operating at 5.9 GHz. For V2V applications, exchange of information between vehicles travelling at high speed needs to be considered. To accommodate for the rapid exchange of information between vehicles, IEEE 802.11p is an amendment to 802.11 to enable operation without setting up a basic service set [5]. The SAE J2735: DSRC Message Set Dictionary layer specifies message sets, data frames, and data elements, specif- ically for use by applications intended to utilize the 5.9 GHz DSRC for WAVE communications systems. The purpose of this standard is to support interoperability among DSRC applications [6]. The SAE J2945/1: On-Board System Requirements for V2V Safety Communications layer, specifies the system requirements for an on-board vehicle-to-vehicle (V2V) safety communications system for light vehicles, including standards profiles, functional requirements, and performance requirements. It addresses the on-board system needs for ensuring that the exchange of BSMs in V2V safety communications provides the desired interoperability and data integrity to support the performance of the envisioned safety applications [7].

IV. V2V IMPLEMENTATION

Figure 8 gives an overview of the DSRC based V2V on-board system requiremnts

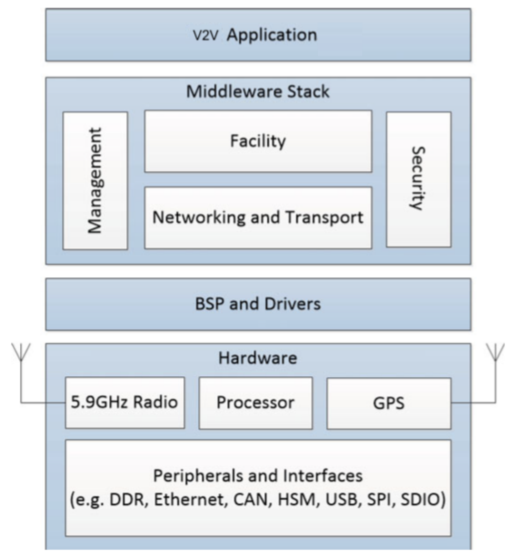

Fig. 8. DSRC based V2V on-board system architecture [1]

The system architecture of a typical DSRC-based V2V On-Board System is shown in Figure 8. A processor, a DSRC radio for transmitting and receiving V2V communications, a GPS module for receiving location information, and a few peripherals and interfaces are required at a minimum to support the entire system. The On-Board Unit(OBU) collects vehicle data such as speed, yaw rate (i.e. the angular velocity of the rotation, or rate of change of the heading angle when the vehicle is horizontal), and steering-wheel angle via CAN modules. Another critical item required by OBU is the Hardware Security Module (HSM), which manages a vehicle's security certificates and protects against equipment tampering and bus probing. Some GPS systems have an Inertial Management Unit (IMU) or an interface to connect an IMU, which can offer information such as velocity, roll, pitch, and heading. The Board Support Package (BSP) is the software that handles the hardware specific tasks necessary to get the operating system up and running. The BSP and drivers offer support for the hardware components as well as a means for the Middleware Stack to access them. Middleware Stack takes care of the upper layer standards to provide message encoding and decoding, signing and verifying BSMs, network and transport services and so on. It provides the data from received V2V message to the application layer in a way that can be understood by an application developer. It also provides Application Program

Interfaces (API) to the application layer for using the lower layer services and makes it easier and straightforward for an application engineer to do the development [1].

V. V2V SIMULATION

In this section INET and Veins are going to be used together to simulate a V2V network using Omnet++.

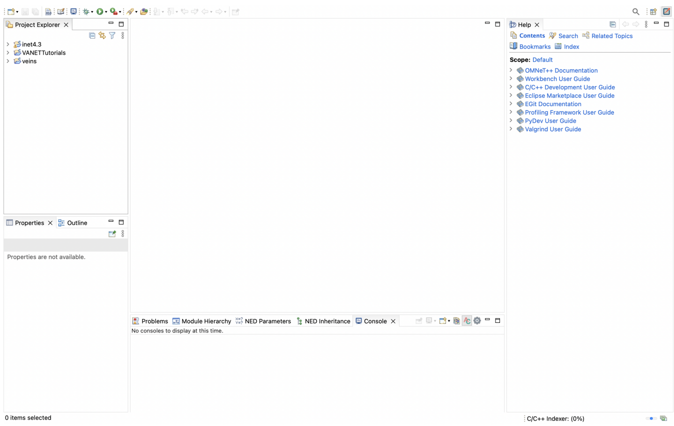

Fig. 9. Simulation Tool

With this we are able to access all the protocol stacks listed in section III, needed to create the DSRC application layer that will be used for the V2V communication. The simulation starts by first building the vines folder, after that the omnetpp.ini file in the veins sub folder that is in the veins folder is run.

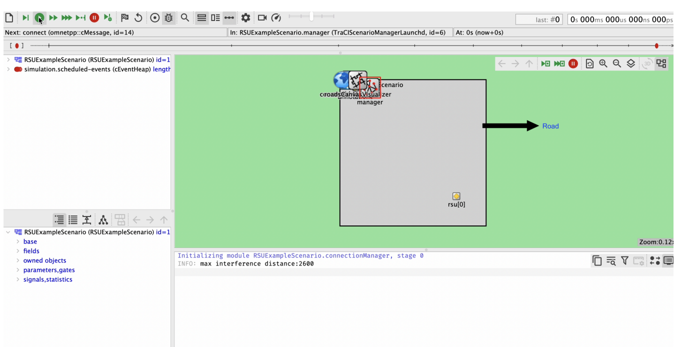

Fig. 10. Simulation environment

When the green play button is pressed, the simulation starts and the vehicles are placed on the road as nodes

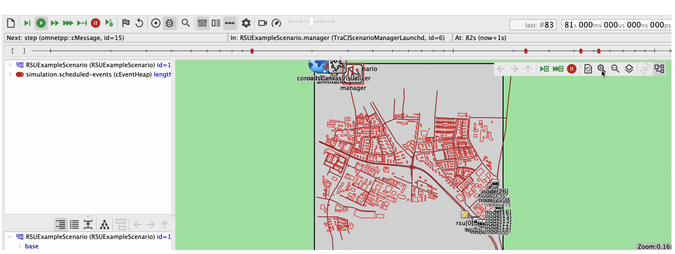

Fig. 11. Deployment of nodes (i.e. vehicles) to the simulation environment

Node 0 (vehicle 0) send DSRFC (i.e BSM) messages to there surrounding vehicles using the IEEE 802.11p as the PHY + MAC layer.

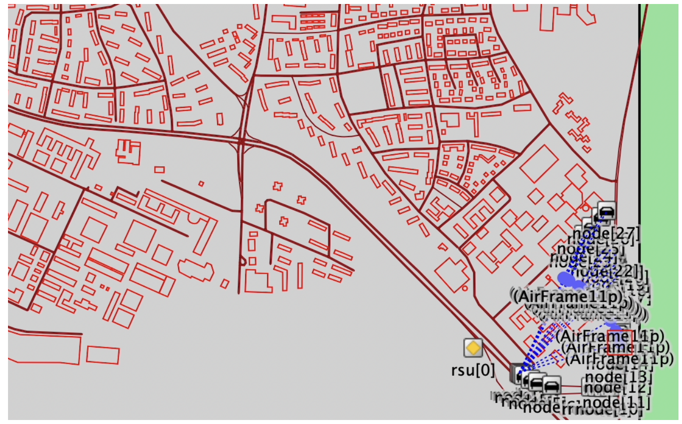

Fig. 12. Sending BSM messages using IEE 802.11p

From the simulation (figure 13) it is shown not all vehicles on the road got the DSRC message, only the nodes (i.e. vehicles) that turned green, in the simulation received the DSRC message. This reinforces the statement that DSRC messages using the IEEE 802.11p layer have a maximum range of 300m.

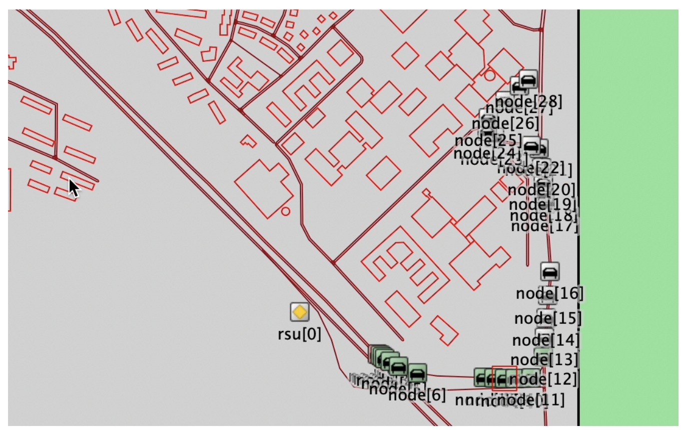

Fig. 13. DSRC maximum range

How the DSRC message moves from one layer of the protocol stack to the next level is shown in the simulation environment (figure 14). Also the sender of the BSM message is also received by the receiver vehicle; this is gotten from the id section of the BSM message, that was discussed in section II and shown in figure 5 of this paper.

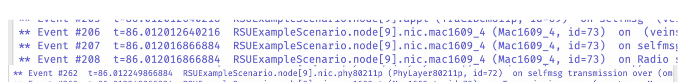

Fig. 14. How messages are sent from vehicle to vehicle through the protocol stack visualisation

VI. PACKET ERROR RATE

In V2V communication we deal with mobility(fast moving vehicles), that is is to say in V2V communication speed is of upmost importance. Because the data packets that are been sent to the vehicles on the road need to sent at a relative high speed the User Datagram Protocol (UDP) is used; The UDP protocol accelerates transfers by allowing data to be transferred before an agreement is granted by the receiving side. Unfortunately, User Datagram Protocol (UDP) is a communications protocol that is primarily used to build low-latency and loss-tolerant connections between internet-connected applications.Due to this reason there are usually errors in packet delivery during transmissions: such as the loss of packets during transmission. This section involves end to end simulation used to determine the packet error rate of IEEE 802.11p transmission. In this section MATLAB is used for the simulation. Multiple packets are sent across a V2V channel for each **signal to noise ratio** (SNR) point, demodulated, and the **Physical Layer Convergence Procedure Service Data Unit** (PSDUs) retrieved. To assess the quantity of packet mistakes, the PSDUs are compared to those sent. The receiver performs packet detection, timing synchronisation, carrier frequency offset correction, and phase tracking for each packet. The figure below shows the processing chain with channel tracking [10].

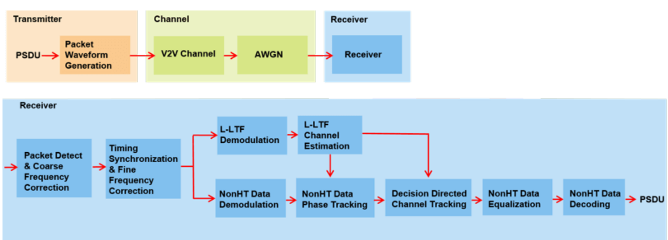

Fig. 15. Packet error rate processing with channel tracking. [10]

The MATLAB code for determining the packet error rate (PER) is in figure 16, 17 and 18 respectively.

```
% Link parameters
mcs = 2;       % QPSK rate 1/2
psduLen = 500; % PSDU length in bytes

% Create a format configuration object for an 802.11p transmission
cfgNHT = wlanNonHTConfig;
cfgNHT.ChannelBandwidth = 'CBW10';
cfgNHT.PSDULength = psduLen;
cfgNHT.MCS = mcs;

% Create and configure the channel
fs = wlanSampleRate(cfgNHT); % Baseband sampling rate for 10 MHz

chan = V2VChannel;
chan.SampleRate = fs;
chan.DelayProfile = 'Urban NLOS';

snr = 15:5:30;

maxNumErrors = 20;   % The maximum number of packet errors at an SNR point
maxNumPackets = 200; % The maximum number of packets at an SNR point

% Set random stream for repeatability of results
s = rng(98);
```

Fig. 16. Setting up the Waveform Configuration, Channel Configuration and Channel Configuration [10]

```
% Set up a figure for visualizing PER results
h = figure;
grid on;
hold on;
ax = gca;
ax.YScale = 'log';
xlim([snr(1), snr(end)]);
ylim([1e-3 1]);
xlabel('SNR (dB)');
ylabel('PER');
h.NumberTitle = 'off';
h.Name = '802.11p ';
title(['MCS ' num2str(mcs) ', V2V channel - ' chan.DelayProfile ' profile']);
```

Fig. 17. PER visualisation [10]

```
% Simulation loop for 802.11p link
S = numel(snr);
per_LS = zeros(S,1);
per_STA = per_LS;
for i = 1:S
    enableChanTracking = true;
    %802.11p link with channel tracking
    per_STA(i) = v2vPERSimulator(cfgNHT, chan, snr(i), ...
        maxNumErrors, maxNumPackets, enableChanTracking);

    enableChanTracking = false;
    % 802.11p link without channel tracking
    per_LS(i) = v2vPERSimulator(cfgNHT, chan, snr(i), ...
        maxNumErrors, maxNumPackets, enableChanTracking);

    semilogy(snr, per_STA, 'bd-');
    semilogy(snr, per_LS, 'ro--');
    legend('with Channel Tracking','without Channel Tracking')
    drawnow;
end

axis([10 35 1e-3 1])
hold off;

% Restore default stream
rng(s);
```

Fig. 18. Simulation loops for the IEEE 802.11p link [10]

When the code is run two graphs are plotted; the first graph figure 13 shows the difference in PER with and without channel tracking.

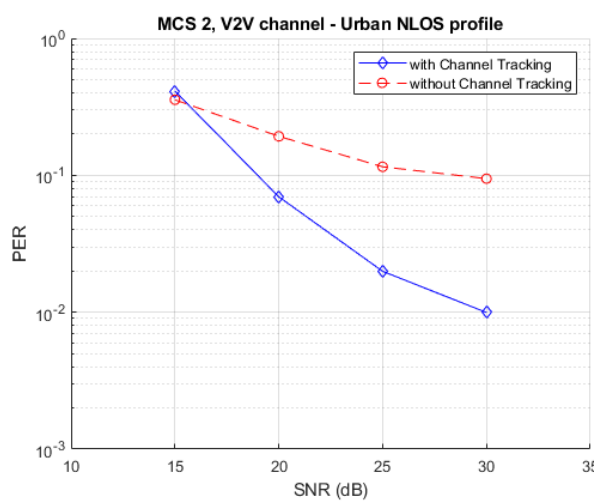

Fig. 19. PER plotted graph

From figure 13 it can be inferred after 51 packets, the signal to noise ratio (SNR) is 15 dB with channel tracking, with a packet error rate (PER) of 0.41176. After 59 packets, the signal to noise ratio (SNR) is 15 dB without channel tracking, with a packet error rate (PER) of 0.35593. After 201 packets, the signal to noise ratio (SNR) is 20 dB with channel tracking, with a packet error rate (PER) of 0.069652. After 109 packets, the signal to noise ratio (SNR) is 20 dB without channel tracking, with a packet error rate (PER) of 0.19266. After 201 packets, the signal to noise ratio (SNR) is 25 dB with channel tracking, with a packet error rate (PER) of 0.0199. After 182 packets, the signal to noise ratio (SNR) is 25dB without channel tracking, with a packet error rate (PER) of 0.11538. After 201 packets, the signal to noise ratio (SNR) is 30dB with channel tracking, with a packet error rate (PER) of 0.0099502. After 201 packets, the signal to noise ratio (SNR) is 30 dB without channel tracking, with a packet error rate (PER) of 0.094527.

VII. DSRC TECHNICAL CHALLENGES

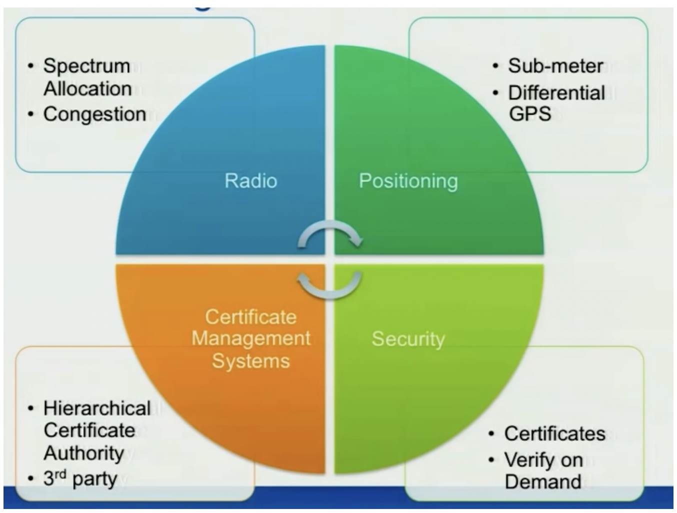

Fig. 20. DSRC Technical Challenges [11]

There are some challenges facing DSRC in V2V communication. This challenges include: security, positioning, radio and certificate management system. This challenges are hindrances to the application of V2V communication worldwide. For example in a scenario where the Radio channel is full (i.e. Radio channel congestion) no more messages can be sent; the improvement of congestion algorithms improves channel utilization by 50% to 75%. Security is a key challenge in DSRC V2V communication, the possibility of tracking vehicles, drivers/passengers, as well as the possibility of sending false messages to mislead vehicles is one of the major reasons why V2V communication is not been widely adopted in industries; the inclusion of public, private keys, and digital certificates to DSRC V2V communication mitigates the security concerns [11]. Positioning: In section IV, figure 8 we see the inclusion of GPS for V2V application, we need GPS to be able to locate the position of vehicles, but the problem facing this implementation is the inaccuracy of GPS; the position gotten from GPS is not accurate and this leads to huge problems due to the fact we are dealing with moving systems (i.e. constantly changing positions). To solve this problem differential GPS is used in place of the traditional GPS.

VIII. CONCLUSION

The benefits of V2V communication in today's world can not be over emphasised due to an increasing number of vehicles on the road, DSRC can prevent a large percentage of road accidents and mitigate the road congestions that are predicted to increase; by sharing vehicle information such as: the information of a vehicle wanting to overtake or the position of a vehicle we can have a safer, cleaner and efficient transport system.

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