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An Empirical Study to Investigate the Effect of Air Density Changes on the DSRC Performance

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Abstract

The primary role of Intelligent Transportation Systems (ITS) system is to implement Advanced Driver Assistance Services (ADAS) such as pedestrian detection, fog detection and collisions avoidance. These services rely on detecting and communicating the environment conditions such as heavy rain or snow with nearby vehicles to improve the driver's visibility. ITS systems rely on DSRC to communicate this information via a Vehicle-to-Vehicle (V2V) or Vehicle-to-Infrastructure (V2I) communications architectures. DSCR performance may be susceptible to environmental changes such as air density, gravitation (gravitational acceleration), air temperature, atmospheric pressure, humidity, and precipitation.

The goal of this research is to investigate whether the DSRC performance persist with respect to air density changes in a foggy environment. Simulation experiments are setup using PreScan to study the influence of changing the air density on the DSRC performance in a foggy environment using V2V communications. The PreScan simulation experiments are carried out over a wide range of air density levels that start from an extremely low value of (0.05 kg/m^3), a normal air density level of 1.28 kg/m^3 to a high altitude with air density level of (50 kg/m^3). The study uses this wide range of air density levels to allow us to determine the influence of the air density on the DSRC performance and explore any performance inconsistency if there is any. The research findings proved that the DSRC performance can persist through air density changes, which helps to make up for lost human visibility on roads during foggy times. This finding aims to promote safe highway operations in foggy conditions.

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Keywords: VANET; ITS; DSRC; Fog and Smoke; Air Density; Visibility

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1. Introduction

Self-driving vehicles are the next generation of the auto industry and they will be used all of the over the world by 2025. Moreover, IEEE predicts that up to 75% of vehicles will be driverless by 2040. This will lead to a dramatic change in the Intelligent Transportation Systems [1]. Therefore, as future driving becomes more autonomous (driver-less), vehicles will be equipped with a wide variety of sensors such as the ones shown in fig. 1 [2]. These sensors are used to observe, collect different types of information such as vehicle's speed, dimensions, heading, braking status and environmental conditions such as fog, cloud and amount of rain. This data will be collected using short range sensors such as: (1) Radars (Radio Detection and Ranging) for detecting nearby objects including human body or other vehicles, (2) 360 degrees camera system for mirroring 360 degrees around the vehicle, and (3) LIDARs (Light Detection and Ranging) for detecting objects by sending out a laser beam and measuring the reflected signal to determine the distance between the vehicle and surrounding objects.

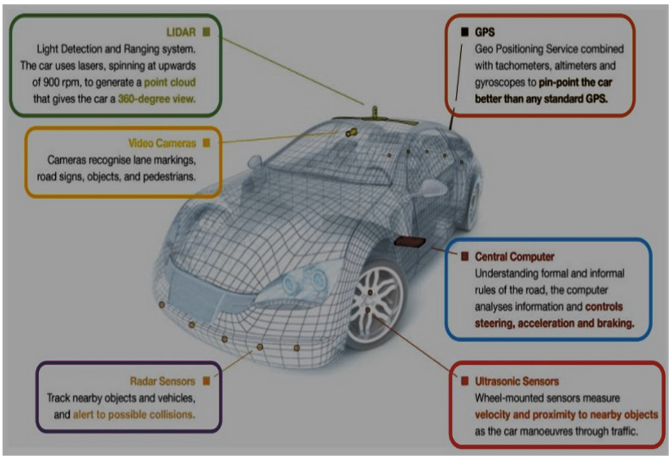
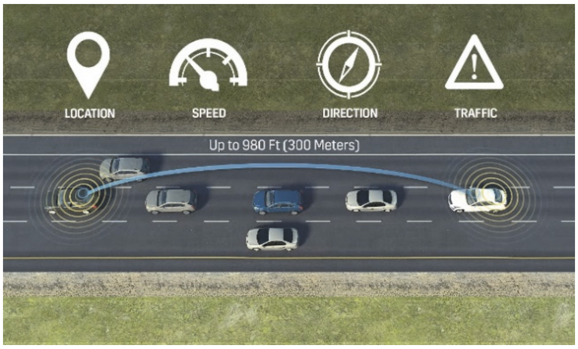


Fig. 1. On-Board Vision-based Sensors in Autonomous Vehicles [2]

Therefore, sharing the collected data with other vehicles via V2V Communication is vital for road and public safety. It is found that the driver's visibility varies from 0.1km up to 1km in foggy weather conditions [3]. Consequently, the inclement weather conditions should be communicated to nearby drivers within this visibility range (0.1km-1km) for the sake of drivers' safety. Therefore, V2V messages are designed to support a communications range of approximately 0.3km, which is beyond the capabilities of the on-board short-range sensor systems. Different technologies such as Dedicated Short Range Communication (DSRC) or Millimeter Wave Vehicular Communication (MmWave) are needed for such kind of short communications range. Although DSRC is the technology of choice for V2V communications right now, authors in [4] argued that DSRC may not be an effective V2V communication solution to support high speed data rates for sensor generated raw data exchange among vehicles and therefore millimeter wave (mmWave) communication will be a viable solution in the future.

Fig. 2. shows that V2V DSRC based communications technology can communicate various Advanced Driver Assistance Services (ADAS) such as car crashes or collisions at a rate of 1,000 messages per second, which is much earlier than the short range sensors [5, 6, 7]. Therefore, it is essential for the short range communication technologies (Radars, camera system and LIDARs) to be augmented with the V2V communications technologies (DSRC or Mmwave) to provide an effective information dissemination solution rather than using either approach alone.

(a) road hazard warning message



(b) DSRC communication link range

Fig. 2. Vehicle-to-Vehicle (V2V) ADAS services [5]

National Highway Traffic Safety Administration (NHTSA) set guidelines on how different levels of vehicle automation may reduce vehicles crashes and how the use of on-board short-range sensors coupled with V2V technologies can help in facilitating communication among vehicles [6, 7]. Authors in [8, 9] are among the researchers who have responded to NHTSA's recommendation of using DSRC in V2V communications and evaluated the DSRC performance in foggy environment. Authors' research work aims to study the influence of foggy environments on the drivers' visibility. Their research findings proved that the DSRC performance can persist through fog density changes, and vehicles are still able to maintain connections over the DSRC link range. This confirms that relying on the DSRC system to communicate V2V messages can help compensate for lost human visibility and consequently, driver safety is improved in foggy conditions.

Moreover, DSCR performance may be susceptible to environmental changes such as air density, gravitation (gravitational acceleration), air temperature, atmospheric pressure, humidity, and precipitation. None of the research work presented in [3, 4, 8, 9] addressed these environmental changes.

In this paper, we will focus on exploring the effect of the air density on the performance of a V2V DSCR based communication system in a foggy environment. In this study, we will investigate whether the use of DSRC communication protocol is a safe choice to disseminate road traffic conditions in a foggy environment under different levels of air density. In order to answer this question; simulation experiments are setup using PreScan and Simulink simulation engine [10] that supports DSRC enabled vehicles communications.

The remainder of the paper is organized as follows. Section 2 provides an overview on how environmental conditions such as fog, cloud affects the DSRC signal loss in the microwave frequency range, where DSRC belongs. Section 3 describes how the simulation experiments are setup and executed. Sections 4 and 5 conclude the paper and outline the future work.

2. Background and related work

In general there are two main sources contributing to radio wave power attenuation (1) atmospheric gaseous absorption and (2) environmental characteristics such as, rain droplets, cloud, fog, ice, snow, aerosol, dust, etc.,. These losses were ignored at lower frequency bands such as 1.4-2.4GHZ. However, as the frequency increases, it is essential to consider the signal power attenuation that might be existed in the microwave range of 3-30GHZ. In [11], authors conducted a study to estimate the power margin losses in the microwave band (12–24 GHz) due to earth's atmosphere and weather conditions such as clouds and fog. Authors' findings indicated that the signal loss due to the atmospheric gaseous absorption and environmental characteristics attenuation are the two contributing factors for signal loss in the frequency range (12–24 GHz). Also, the study showed that as the signal frequency increases, additional power loss is introduced to the transmitted signal due to atmospheric absorption caused by clouds and fog. Authors in [11] calculated the signal power attenuation using a modified version of the Friis Equation that supports the microwave frequency range such as follows:

$$P_r = \frac{P_t G_t}{4\pi d L_a} A_r = \frac{P_t G_t G_r}{L_a}\left(\frac{\lambda}{4\pi d}\right)^2 = \frac{P_t G_t G_r}{L_{FS} L_a} \quad (1)$$

Where:

P_r: power received; P_t: power transmitted

G_t: transmitter antenna gain; G_r: receiver antenna gain

A_r: effective area of receiver antenna (λ2Gr/4π)

L_{FS}: free space loss = (4πd/λ)2;

d: radio link distance between transmitter and receiver

λ: radio wave signal wavelength

L_a: signal power loss to account for atmospheric gaseous absorption and environmental characteristics such as, rain droplets, cloud, fog, ice, snow, aerosol, dust.

The power received (P_r) can be represented in dB such as follows:

$$P_r\,(dB) = P_t + G_t + G_r - (L_a + L_{FS}) \quad (2)$$

$$L_{FS}\,(dB) = 92.45 + 20\log f + 20\log d \quad (3)$$

Where:

f: frequency in GHz;

d: distance in km.

The value of L_a attenuation component is dependent on the environmental contribution to the signal loss. So, in a foggy environment, the signal attenuation component (L_a) depends mainly on the relationship between the water droplet size of the fog cloudbank and the signal wavelength. The signal attenuation (L_a) can be expressed in terms of the water content per unit volume based on Rayleigh Approximation model such as follows:

$$L_a^{'} = K_l\, M \quad (4)$$

Where:

$L_a^{'}$: attenuation in (dB/km) within the fog cloudbank

K_l: specific attenuation coefficient [(dB/km)/(g/m^3)] - (constant value dependent on the signal frequency and the air temperature)

M: fog droplet water density (g/m^3)

Based on the results presented in [11], it is likely that V2V DSRC based systems, operating in the lower band of the microwave range at 5.9GHZ, to suffer slightly from signal attenuation as signal moves through foggy air buckets with various air density levels. Therefore, we'll study the DSRC power loss due to the changes in the environmental characteristics such as air density. Therefore in this research, we will build our work based on our previous contribution in [8, 9] and the necessity to study the performance of the DSRC system running in the lower band of the microwave range as suggested in [11].

3. Building simulation experiments and results analysis

3.1. Prescan simulation engine

PreScan is a simulation development environment that is used to simulate realistic driving conditions and allow for testing users' algorithms and ADAS services. It supports communications using various sensor technologies such as built-in vehicle camera, LIDAR, RADAR, and GPS in V2V and V2I architecture. PreScan supports three design paradigms: model-based controller design (MIL), real-time tests with software-in-the-loop (SIL) and hardware-in-the-loop (HIL) systems [10]. PreScan provides a GUI that enables us to build a simulation scenario and model sensors, while the Simulink and MATLAB interface allows us to add a control system to define the simulation building blocks to test the ADAS application or the user algorithm. There are four steps to build and run a simulation scenario such as described below and in fig. 3.

a. Building the simulation scenario

A dedicated GUI is used to build and modify traffic scenarios using an existing database of road sections, trees, buildings, traffic signs, different vehicles such as cars, trucks and various weather conditions such as rain, snow and fog.

b. Modelling sensors

Various types of sensors such as radar, laser, camera, ultrasound, infrared, GPS and antennas for vehicle-to-X (V2X) communication can be added with various parameters to adjust the simulation scenario.

c. Adding control system

A Matlab/Simulink interface enables us to control the vehicle movement algorithm as well as sensor fusion and add any user custom module to perform a mathematical operation such as calculating the inter-vehicle distance in a simulation environment and exporting collected data to output files.

d. Running the simulation experiment

A 3D visualization viewer allows users to monitor the progress of the simulation experiment as well as analyse the obtained results.

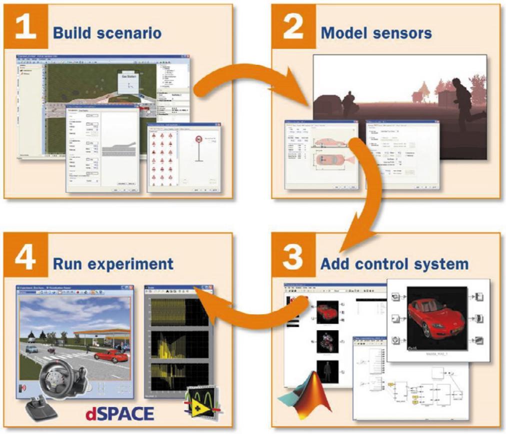


Fig.3. PreScan simulation engine life cycle [10]

3.2. Building simulation experiments

The goal of our simulation experiments is to test the persistence of the DSRC performance in a foggy environment under different air densities by observing any changes in the inter-distance between the DSRC vehicles as a result of changing the air density level in a foggy prone environment. To do so, we setup and ran the PreScan simulation experiments in two phases that allowed us to change the air density level such as follows:

3.2.1. Phase I: Monitor the inter-distance between the two DSRC vehicles under different levels of air density

The simulation scenario includes the following elements such as shown in fig. 4.:

Two Vehicles Moving in Opposite Direction:

Rx Vehicle: sedan vehicle- Audi A8

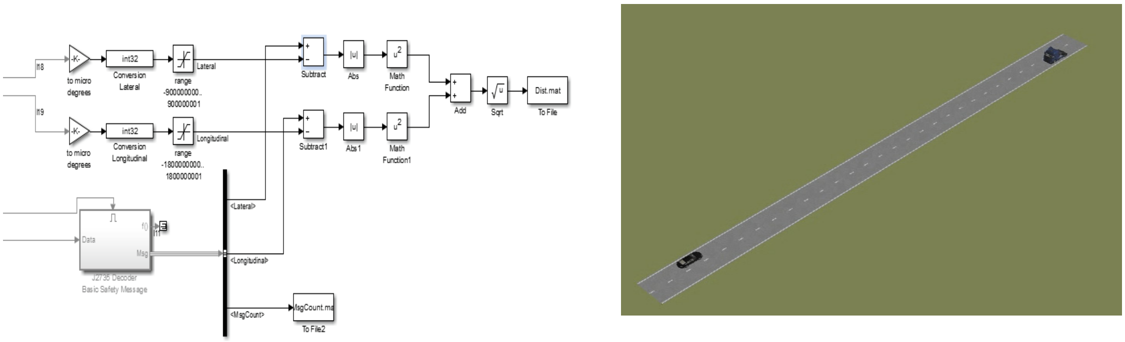
Tx Vehicle: sedan vehicle- Audi A8

Vehicle Trajectory:

Road Length: 120 meter

Number of Lanes: 2 opposite lanes

The simulation circuit was designed using the PreScan environment along with the Simulink software as shown in fig. 4. PreScan was chosen to implement the simulation environment because it supports DSRC communications.



(a) Simulink block diagram (b) Real Time View of the Simulation Environment

Fig. 4. Simulation circuit and real time environment

In this phase, we setup and ran the experiments by changing the air density level such as follows:

1. Experiment #1: an experiment with the air density 1.28 kg/m^3 (normal air density at sea level and at 15°C),
2. Experiment #2: an experiment with unlikely value of the air density 50 kg/m^3, and
3. Experiment #3: an experiment with a very low value of the air density 0.05 kg/m^3.

In these experiments, the receiving vehicle is our reference vehicle from which we will observe the inter-distance between the two DSRC vehicles. In another way, at the receiving vehicle's location, we observed the transmitted DSRC packets and extracted the transmitting vehicle's location in order to be able to calculate and observe the inter-distance between the two vehicles. The receiving vehicle's DSRC interface decodes the incoming fog-attenuated DSRC signal under different levels of air density. The goal of experiments 2 and 3 is to stress the V2V DSRC based system running under unlikely values of air densities (50 kg/m^3, and 0.05 kg/m^3) and accordingly monitor any changes in the DSRC performance.

Obtained results are shown in fig. 5. They do not suggest that changes made in the air density levels affect the DSRC performance because the graphs for all three experiments are almost the same. In terms of driver safety, knowing that DSRC performance can persist through foggy environments with variable levels of air density helps to confirm that it can help make up for lost human visibility.

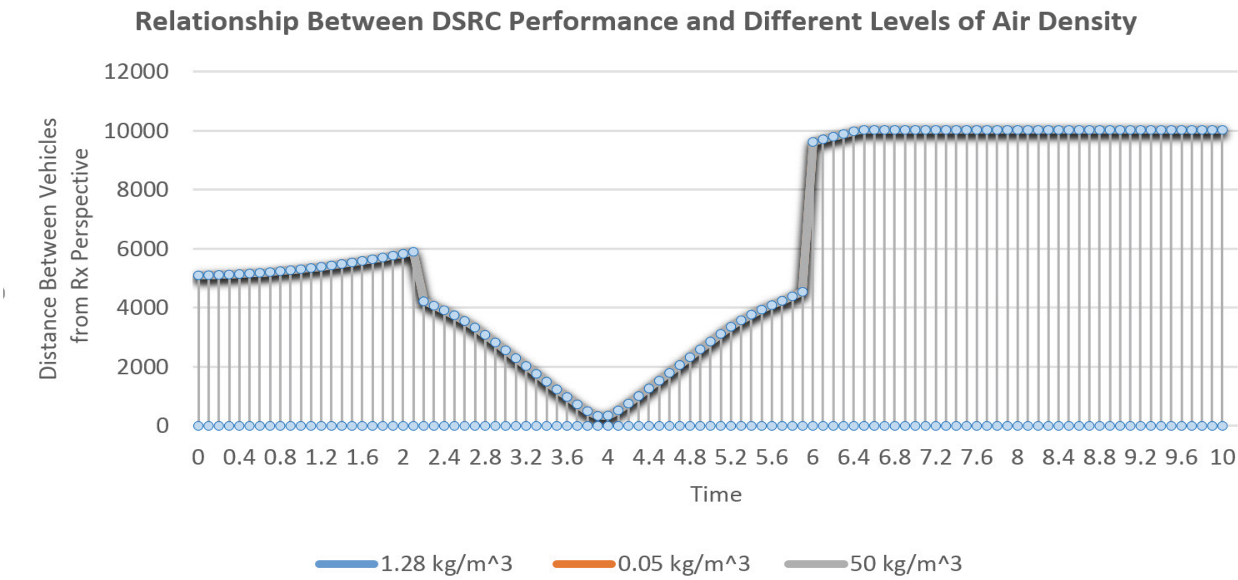


Fig. 5. DSRC performance under different levels of air density

3.2.2 Phase II: Monitor the received signal strength between two different types of DSRC vehicles under different levels of air density and vehicle dimensions

In the second phase of our experiments, we explore the effect of the vehicle type in conjunction with various levels of air density on the DSRC performance. Therefore, we have run four experiments simulating sensor streaming by transmitting a counter integer from the transmitting vehicle (Tx) to the receiving vehicle (Rx). Then we have recorded the transmitted signal strength (the counter integer), measured the received signal strength from the Rx vehicle (counter integer received) and calculate the total signal loss. The four experiments are characterized as follows:

1. Experiment #1: an experiment with the air density 1.28 kg/m^3 (normal air density at level sea level and at 15°C)- (this is our control experiment and benchmark),
2. Experiment #2: an experiment with unlikely value of the air density (128.00 kg/m^3; 100 times the normal air density value 1.28),
3. Experiment #3: an experiment with the air density 1.28 kg/m^3 and changing the vehicle type to (Mercedes Actros 1860),
4. Experiment #4: an experiment with unlikely value of the air density (128.00 kg/m^3 and changing the vehicle type to (Mercedes Actros 1860).

We observed the DSRC signal loss over an interval of time from T=3.9 sec to T=4.6 sec for all these four experiments. The data observed during this interval is still almost identical in all experiments as shown in fig. 6. Therefore, the obtained results in phase-II are consistent with the results obtained in phase-I. The results demonstrate that the DSRC performance still persists through foggy environments with variable levels of air density and it is independent of the vehicle type/dimensions.

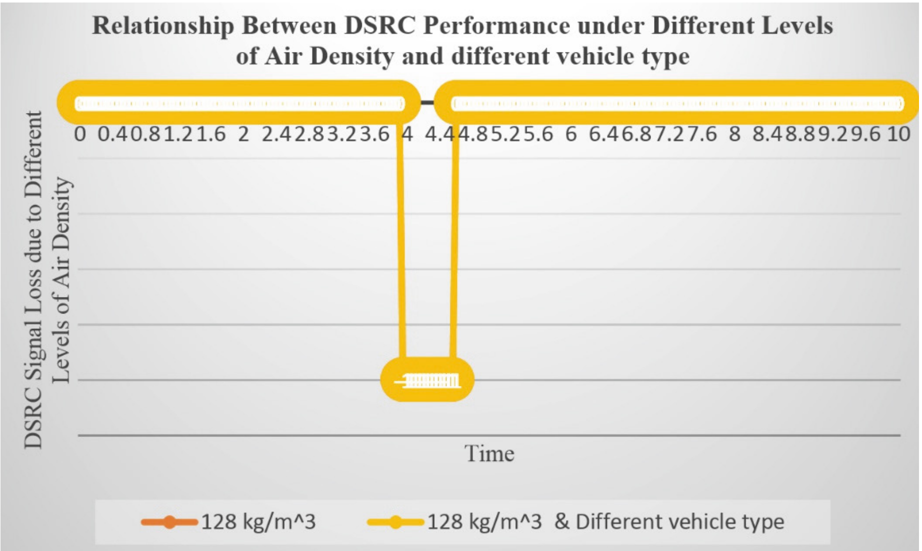


Fig. 6. DSRC performance under different levels of air density and different vehicle types

4. Future work

Authors would like to investigate the streaming of collected environment characteristics using Technology-Independent Sensor (TIS) over DSRC link supporting V2V and V2I infrastructure. In addition, authors would like to monitor the DSRC performance in response to changes in the sensor location placement of the vehicle system.

5. Conculsion

Authors focused on studying the effect of the air density on the propagation characteristics on the DSRC signal generated by the vehicle's DSRC sensor. Simulation experiments are carried out using PreScan and Simulink software to analyze how air density affects the DSRC system's performance. Experimental studies addressed the extreme cases for environmental conditions as it is related to air density fluctuation (Very low: air density = 0.05 kg/m^3 and Very high: air density = 128.00 kg/m^3). We also studied the influence of the vehicle type/dimensions on the DSRC performance.

We found that the DSRC performance would be the same in both extremely high and very low air density in a foggy environment regardless of the vehicle size. Our results are similar with results presented in [11], where authors noticed that there is a slight reduction in the signal power at the frequency range of 12GHZ due to environmental changes such as fog and clouds buckets. Since DSRC signal falls below the 12GHZ range (in the 5.9GHZ), then, DSRC signal will exhibit the same behaviour and may not suffer significantly from the air density changes in a foggy environment. Therefore, DSRC performance persists in severe weather conditions under different levels of air density.

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