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DSRC Based Sensor-Pooling Protocol for Connected Vehicles in Future Smart Cities

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Abstract

Smart cities are racing to create a more connected Intelligent Transportation Systems (ITS) that rely on collecting data from every possible sensor such as a smart utility meter or a smart parking meter. The use of more sensors resulted in generating a lot of information that maps the smart city environment conditions to more real time data points that needed to be shared and analyzed among smart city nodes. One possibility, to carry and share the collected data, is in autonomous vehicles systems, which use the Dedicated Short Range Communications (DSRC) technology. For example, in a Car-to-Parking-Meter or a Vehicle-to-Vehicle (V2V) communications, short-range embedded sensors such as Bluetooth, Cameras, Lidar send the collected data to the vehicle's Electronic Control Unit (ECU) or to a road side gateway for making collaborative decisions and react to the environment's surrounding conditions.

The goal of this research is to develop and test a DSRC based *sensor-pooling* protocol for vehicles to cooperatively communicate inclement weather or environment conditions. Five simulation experiments are setup using PreScan and Simulink to validate and study the scalability of the proposed solution. PreScan is an automotive simulation platform that is used for developing and testing Advanced Driver Assistance System (ADAS). The research findings proved that the DSRC can be used to effectively stream the short range sensors' collected data over a long distance communications link.

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Keywords: Smart Cities; Autonomous Vehicles; VANET; ITS; DSRC; Sensor Streaming

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1. Introduction

The main challenge behind building smart cities is to reduce roadway congestion, ensure drivers' safety, respond to climate change, and support economic development using Intelligent Transportation Systems (ITS) technologies [1 and 2]. ITS technologies encompass various constituents such as Vehicular Sensor Networks (VSN), which is designed to collect, process and make smart decisions. In VSN networks, the nature and quality of the collected data depends on the vehicle's underlying wireless access methods and the communications paradigm V2V, V2I and V2X. In a V2V system, data is collected and disseminated using the vehicle on-board sensors infrastructure such as Technology Independent Sensor (TIS), DSRC, Wi-Fi., Radars (RAdio Detection and Ranging), 360 degrees camera and LIDARs (Light Detection and Ranging) sensors [3]. In this paper, we will focus on the *TIS and the DSRC* sensors.

Building smart cities continues to be steadily on the rise and rooted on maintaining a safe driving experience. This goal initiates a strong interest among the ITS industry partners to develop a wide range of Advanced Driver Assistance Systems (ADAS) applications such as alerting a driver for possible danger due to bad weather conditions, hacking activity, unsafe nearby drivers or pedestrians crossing the road suddenly [1, 2 and 3]. To develop such a functional ADAS application in a V2V system, a quick reliable feedback on the conditions around the vehicle's surrounding is necessary [4]. To achieve this goal, a significant contribution towards this end was presented in [3, 4, 5, 6 and 7].

In [3], authors studied the efficiency of using DSRC as a long distance data dissemination protocol. Authors' findings proved that DSRC performance is not susceptible to environmental changes such as air density or fog density changes. In [4], authors introduced a cooperative distributed system that supports the creation of safety applications. Their solution was based on estimating the positions of nearby vehicles and account for any estimate errors using the Central Limit Theorem. This method can be easily exploited and create settings for security threats in autonomous vehicles such as performing GPS Spoofing attack. In [5], authors introduced a warning defence system to alert the driver in case a potential GPS spoofing attack is underway. The proposed system was based on real time cross-comparing the estimated value of the nearby vehicle position to what the nearby vehicle is periodically broadcasting about its location. Moreover, in [6 and 7], authors introduced various vehicle detection techniques using on-board sensors to assist in creating a driver assistance solution to alert a driver about the nearby vehicles. Work presented in [6 and 7] classified the vehicle's short-range on-board sensors into three categories, depending on the relative location of the target vehicle compared to the host vehicle, such as shown in fig 1.

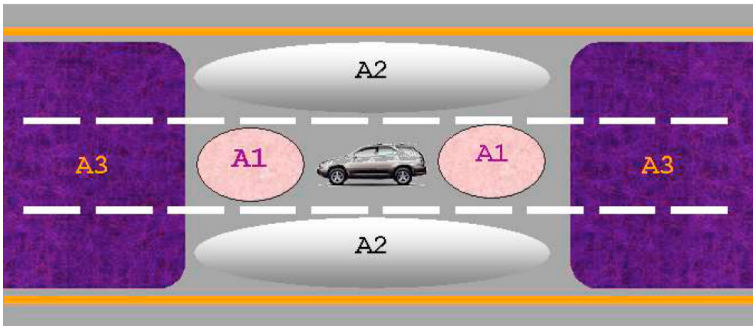


Fig. 1. Detecting vehicles in different regions requires different methods. A1: Close by regions; A2: Overtaking regions; A3: Mid-range/distant regions. [6 and 7]

If the target vehicle is located in the *close-by region (A1)*, only some parts of the vehicle may be seen and multiple sensors' readings will be required with sensor fusion to make a better classification and detection decision. On the other side, if the vehicle is located in the *overtaking region (A2)*, a vehicle's side view is visible to the reading sensors and its visible side is also dynamically changing. Finally, detecting vehicles in the *mid-range or distant region (A3)* depends on the vehicle's available view given that its presence is more stable.

In reality, on-board short-range sensors are not only used in vehicle detection but also used to collect road conditions such as car crashing information or weather conditions. For safety reasons, this info must be shared with other vehicles as quick as possible and as far as it can reach. In [8], authors found that the driver's visibility-range varied from 0.1km up to 1km when fog conditions is present. Therefore, any reliable V2V communications technology should be able to cover a link with a range up to 1km (drivers' visibility range). Unfortunately, this communications range is beyond the capabilities of the short-range on-board sensors and a new medium to long range on-board sensor technology is needed. Therefore, it is essential for the short-range on-board sensors (for example TIS Sensor) to be augmented with a medium/long-range sensor technology (for example DSRC) to disseminate the collected data. Additionally, authors' research work presented in [3] aims to study the influence of foggy environments on the drivers' visibility when DSRC is used in communications. 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. DSRC is the technology of choice by the National Highway Traffic Safety Administration (NHTSA) for medium/long range V2V communications and to carry safety messages [2, 11 and 12].

The use of DSRC as a carrier protocol to transport the collected data via short range sensors received minimum to almost no attention from the research community. Therefore, in this research, we are building upon the work presented in [3 and 9] and will develop a DSRC based *sensor-pooling* protocol for vehicles to cooperatively communicate road conditions as needed. Additionally, our study will investigate the sensor orientation effect on the quality of the sensor streaming protocol. The proposed work is significant in such a way of:

- It is among the original attempts to support sensor streaming in autonomous vehicles systems.
- It provides an essential step towards managing on-board sensor streaming, possibly participating in a sensor streaming relay or P2P distributed architecture, which ultimately would pave the road to create smart V2V application opportunity.

It is important to note that DSRC sensor by itself isn't able to interpret environmental conditions around the vehicle directly [2, 3]. However, in this work, we plan to extend the DSRC sensor's functionality to share its *host vehicle's short range on-board sensor data* with other nearby DSRC-enabled vehicles in some coordinated manner.

The remainder of the paper is organized as follows. Section 2 describes how the simulation experiments are setup and executed. Sections 3 and 4 conclude the paper and outline the future work.

2. Building simulation environment, experiments and results analysis

2.1. 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 in realistic simulation environment. 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.

2.2. Methodology and building simulation experiments

The goal of our simulation experiments is to test the sensor streaming protocol and determine if it is possible to multiplex the *short range on-board sensor's captured data on the long range on-board sensor output.* To do so, we setup and ran the PreScan simulation experiments in two phases. In phase01, we'll test the performance of a base DSRC system and establish a system benchmarking before testing the sensor streaming protocol in phase02.

PreScan Simulation supports the default and the user-custom version of Basic Service Message (BSM) format for DSRC communications. The BSM user-custom format includes up to a ten user defined fields to carry best interest DSRC sensor data. We'll build our own custom BSM message using up to three user-defined fields that allows us to multiplex any desirable short range sensor data elements.

We organized our simulation experiments using a two-step process such as follows:

- **Step-01: Base V2V DSRC Sensor Communications**
    - In this step, we'll setup an experiment to get two DSRC based vehicles communicating with each other over a long range using on-board DSRC sensors.
    - In this experiment, the BSM's default message structure will be used.
- **Step-02: Disseminate the collected TIS sensor data using V2V DSRC over a long distance link**
    - In this step, we'll set up an experiment to superimpose and stream the collected data from the short range on-board TIS sensor on the DSRC signal.
    - The TIS sensor data elements of interest are characterized as *(target detection range, scanning beam ID and target detection azimuth)*. These elements will be carried out using the user-defined section of the BSM message.

2.2.1. Experiment #1: Base V2V DSRC sensor communication

We ran the first experiment to study the DSRC's base performance using the Simulink library with the modules shown in fig 2 and introduced in our work presented in [3]. The experiment includes two sedan vehicles passing each other on a two-lane road, both equipped with *TX/RX DSRC* hardware only. The transmitting vehicle broadcasts a periodic BSM message that includes its *GPS location* and the receiving vehicle (RX) detects the incoming message.

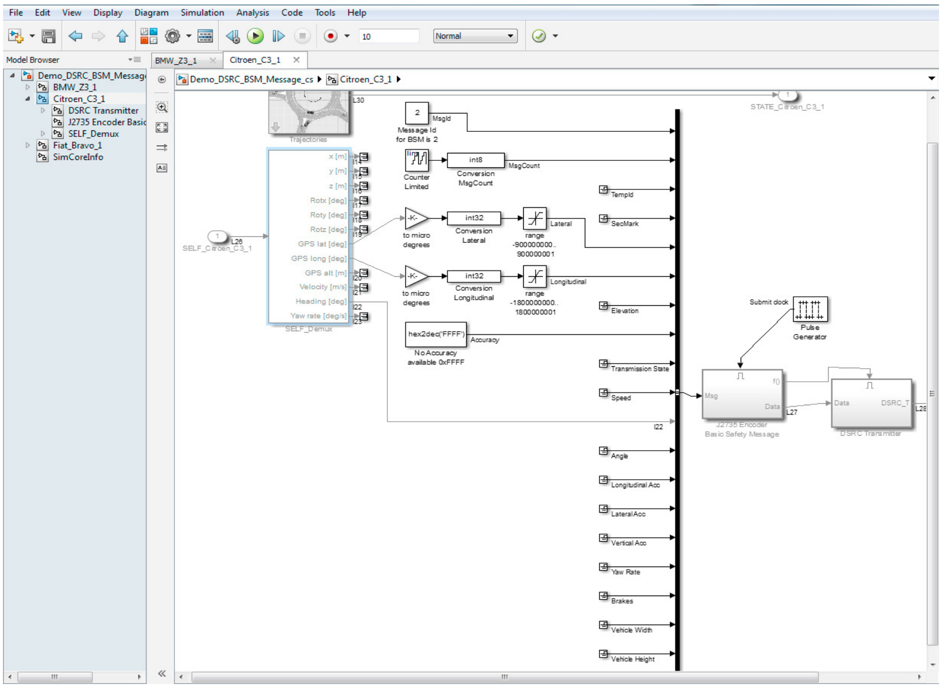


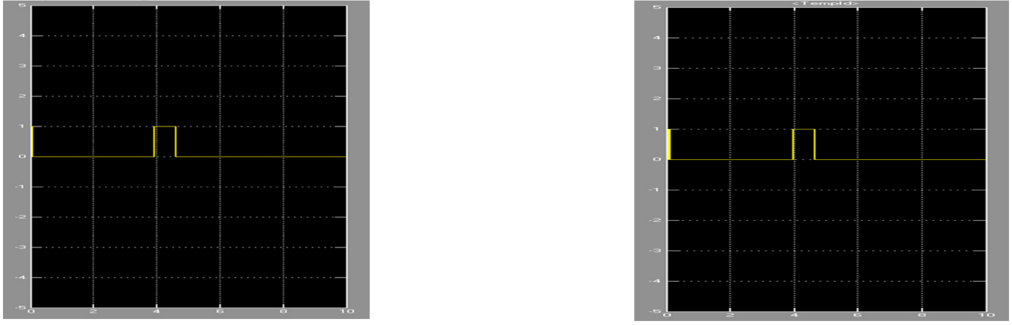
Fig. 2. PreScan simulation engine's DSRC functional diagram

The *default* structure of the BSM message contain a field called *TempID*, which is simply a transient identifier for the vehicle to track its movement and status. We are going to use this field as our data element to be exchanges between the two vehicles and monitor the vehicles' inter-distance.

Here is the description of the DSRC based V2V communication protocol that will be used in this experiment:

- The *first* vehicle - (*vehicle A*) is equipped with DSRC sensor.
- The *second* vehicle (*vehicle B*) is equipped with DSRC sensor.
- Vehicles *A and B* transmit periodically their *GPS locations* as part of their BSM messages.
- The *first* vehicle - (*vehicle A*) is monitoring the inter-distance (D) between itself and the *second* vehicle (*vehicle B*) based on vehicle B's GPS coordinates received by vehicle A.
- If the inter-distance (D) drops below *1000* microdegrees - (*1000* microdegrees is an arbitrary random threshold value):
    - *(Vehicle A)* will set the "TempID" field to a value of "1" in its periodic BSMs; otherwise
    - *(Vehicle A)* will transmit a value of "0" in the TempID field.
- The other vehicle (*vehicle B*) is listening specifically for this incoming BSM message that carries the value of the *TempID* field.

Fig. 3 displays vehicle A's BSM message that carries the TempID field value (1 or 0) and the BSM message received by vehicle B. The result shows that the TempID value over time is the same, meaning that the two vehicles (A&B) are successfully able to participate in a DSRC conversation.



(a) Vehicle A's transmitted BSM message carrying TempID field value (b) Vehicle B's received BSM message carrying TempID field value

Fig 3. Base V2V DSRC sensor communication

2.2.2. Experiment #2: Sensor streaming over DSRC link

We have modified the previous experiment by adding another on-board short range sensor *TIS sensor* beside the existing long range *DSRC sensor* in Vehicle A. Vehicle B is still the receiving vehicle and is equipped with a DSRC sensor only. Then, in the transmitting vehicle (Vehicle A), we attempted to superimpose the *TIS Sensor* data on the *DSRC signal* by feeding the TIS sensor's output as an input to the DSRC sensor such as shown in fig 4 (right hand-side). Triggering data exchange between the two vehicles is still controlled by the same condition mentioned in the above experiment, which is based on monitoring the vehicles' inter-distance value.

However, in this experiment, we used the *Beam ID* as the *TIS sensor data element* to be sent from the transmitting vehicle (A) to the receiving_vehicle (B). Beam ID indicates the ID of the current beam being captured from the scanning activity. QAM16 was used to generate the modulated DSRC signal to carry the TIS sensor data element (*Beam ID*). Here is the description of the DSRC based *sensor-pooling communications* protocol:

- The *first* vehicle - (*vehicle A*) is equipped with a *DSRC sensor* and a *TIS sensor*.
- The *second* vehicle (*vehicle B*) is equipped with a DSRC sensor.
- Vehicles A and B transmit periodically their GPS locations.
- Vehicle A's TIS sensor is periodically scanning the vehicle's surrounding and record the reflected beam's BeamID. The *BeamID* simulates the environment conditions data of our interest.
- Vehicle A is periodically monitoring the inter-distance (D) between itself and the second vehicle (vehicle B) based on vehicle B's GPS coordinates received by vehicle A.

- If this inter-distance (D) drops below *1000* microdegrees - (*1000* microdegrees is an arbitrary random threshold value):
    - Then, Vehicle A forwards the collected data (TIS sensor's current BeamID) to its DSRC sensor; otherwise (Vehicle A) will forward a value of "0" to its DSRC sensor to be transmitted instead.
    - Next, Vehicle A's DSRC sensor multiplex the (TIS sensor's BeamID) with the unmodulated DSRC signal and generates a new DSRC modulated signal to be transmitted.
    - Finally, Vehicle A's DSRC sensor transmits the new DSRC signal to Vehicle B's DSRC sensor.
- The other vehicle (*Vehicle B*) is listening specifically for this incoming BSM message that carries the value of the BeamID field.
- Then, Vehicle B's DSRC passes this info to its ECU Unit for further processing to alert the driver.

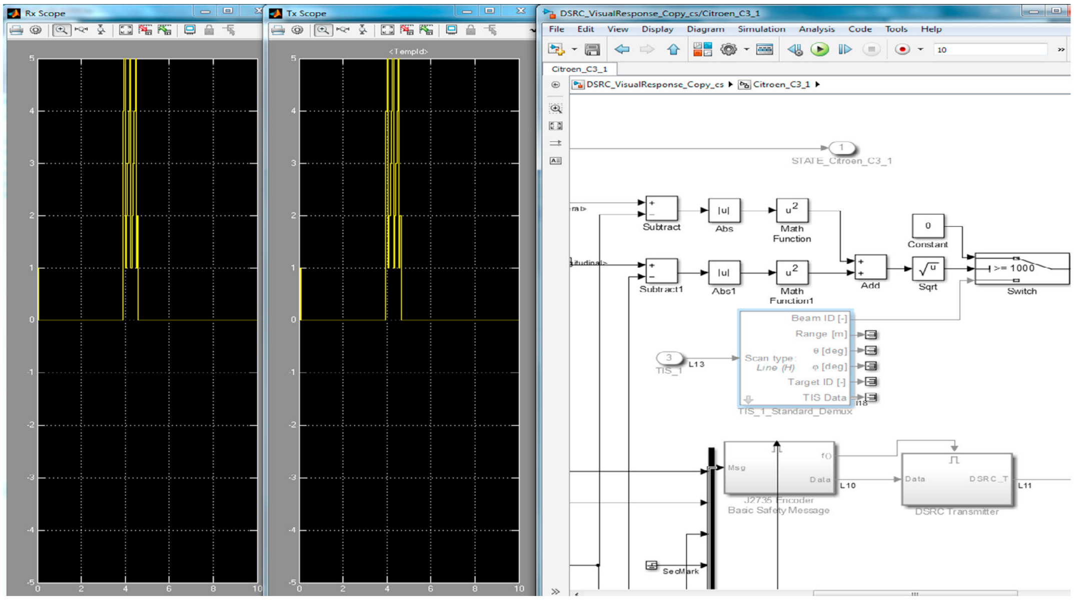
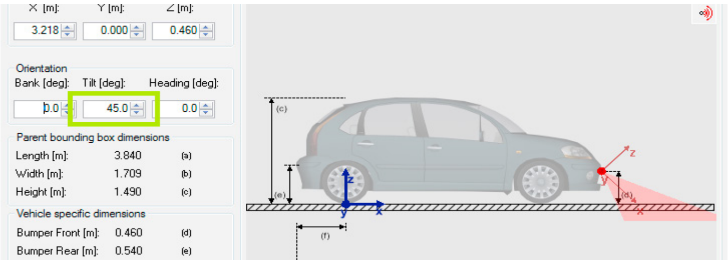


Fig. 4. Sensor streaming (Beam ID) over DSRC link

Fig. 4 shows that the Beam ID value over time is the same at the transmitting and receiving vehicles, meaning that the two vehicles are still able to participate in a successful communications session over a long DSRC link.

2.2.3. Experiment #3: TIS sensor orientation effect on the quality of the DSRC sensor streaming protocol

While still transmitting the *Beam ID*, we changed the TIS sensor's tilt to 45 degrees instead of 0 degree such as shown in fig. 5.


X [m]: 3.218
Y [m]: 0.000
Z [m]: 0.460

Orientation
Bank [deg]: 0.0
Tilt [deg]: 45.0
Heading [deg]: 0.0

Parent bounding box dimensions
Length [m]: 3.840 (a)
Width [m]: 1.709 (b)
Height [m]: 1.490 (c)

Vehicle specific dimensions
Bumper Front [m]: 0.460 (d)
Bumper Rear [m]: 0.540 (e)

Fig. 5. TIS sensor orientation setup to 45 degrees

We recorded the DSRC signal's transmitted energy level as well as the received one in two cases of setting the TIS sensor up to point to 0 and 45 degrees. Then we calculated and compared the DSRC energy loss in each case. The results in fig 6 showed that the received DSRC signal strength in the two cases is the same regardless the sensor orientation, which means that the sensor streaming quality is unaffected by adjusting the sensor orientation. These results confirmed that the DSRC sensors are responsible for the quality of the sensor streaming, while the orientation of the TIS sensor is only responsible for collecting the data from a specific scanning zone. Adjusting the TIS sensor orientation will certainly affect the usefulness of the data (scanning zone), however, as the later experiments have shown, data dissemination is dependent on the DSRC.

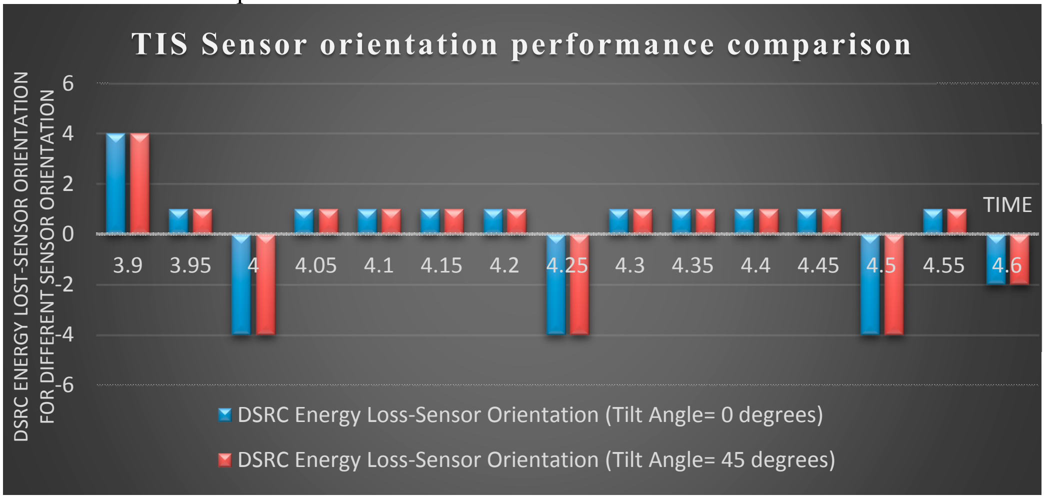


Fig. 6. TIS Sensor orientation performance comparison

2.2.4. Experiment #4: Scalability of the DSRC sensor streaming protocol

Then, we decided to expand our previous experiment #2 and transmit more TIS sensor data elements (*Beam ID, Target detection range, TempID)* instead of just the *Beam ID* to determine the robustness and scalability of the streaming protocol. So, we constructed a *three* field user-defined BSM message that contains these *three* data elements provided by the TIS sensor. In this experiment, the receiving activity is continuous (vehicle B's DSRC sensor is always listening) while the sending activity is not because the transmitting vehicle (vehicle A) is only including these *three* fields when the inter-distance is within 1000 micro degrees of the other vehicle (B). Obtained results in fig. 7 suggested that the *range*, B*eam ID* and the TempID were interpreted correctly by the receiving vehicle.

(a) TX Vehicle Range

(b) RX Vehicle Range

(a) TX Vehicle Beam ID

(b) RX Vehicle Beam ID

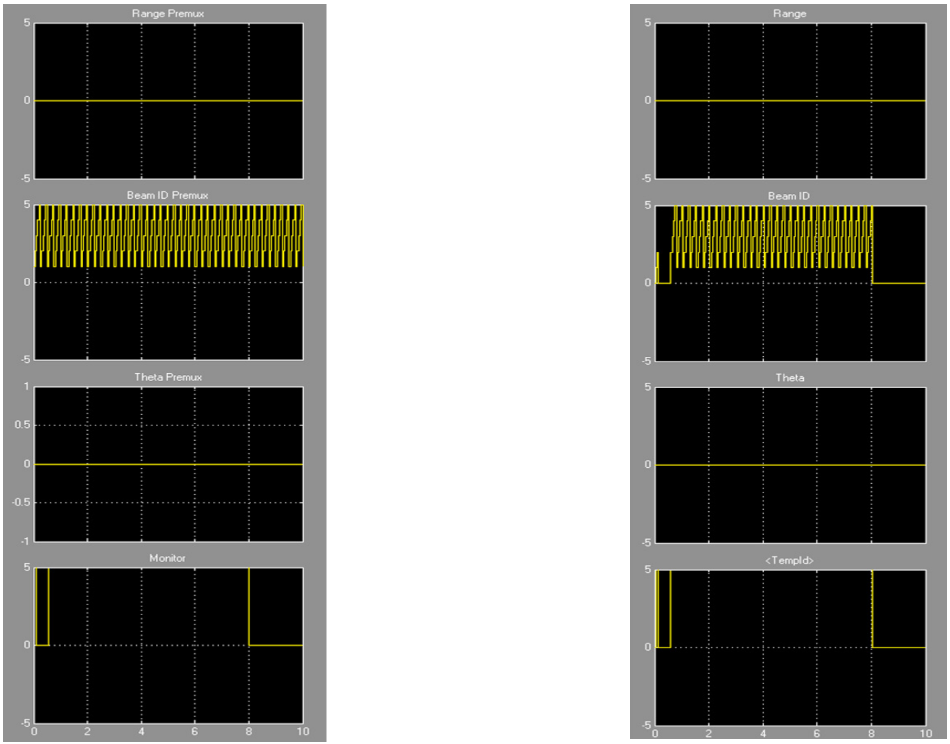
(a) TX Vehicle Temp ID

(b) RX Vehicle Temp ID

Fig. 7. Sensor streaming data (range, beam ID, and TempID) over DSRC link with sensor tilt =0 degree

2.2.5. Experiment #5: TIS Sensor Orientation effect on the quality and scalability of the DSRC sensor streaming

Also, we wanted to explore whether a change in the sensor orientation (45 degrees) from its default setting (0 degrees) may affect the sensor streaming quality and scalability when sending too many data elements (*Beam ID, Target detection range, TempID)* at the same time. Therefore, we combined experiment #3 and #4 together and set the TIS sensor to point down at 45 degrees. Experiment results are shown in fig. 8. It shows that neither range nor azimuth were reported because the sensor was pointed at the ground. However, the *beam ID* and the TempID were interpreted correctly by the receiving vehicle.



(a) TX Vehicle (range, beam ID, azimuth and TempID)

(b) RX Vehicle (range, beam ID, azimuth and TempID)

Fig. 8. Sensor streaming data (range, beam ID, azimuth and TempID) over DSRC link with sensor tilt =45 degree

Results in Figs (4-8) confirmed that it is possible to stream multiplexed scalar sensor data between vehicles, and that the TIS sensor is insensitive to orientation changes in a realistic way.

3. Future work

Authors would like to compare the sensor streaming protocol among different types of active and passive short range sensors and determine the applicability of each sensor for different types of ADAS applications. In addition, authors would like to study the DSRC performance while making changes in the sensor placement and considering various sensor features including environmental features, object dimensions and shape.

4. Conculsion

Authors proposed the use of two different types of on-board sensors that are augmenting each other; one is used to capture the data of interest *(TIS Sensor)* and the other one is used to disseminate the captured data *(DSRC Sensor)*. We focused on studying the quality and scalability of the DSRC streaming protocol in a V2V system by creating custom user defined BSM messages carrying different data elements. Sensor orientation was a focus in our investigation of the DSRC quality. Five simulation experiments were carried out using PreScan and Simulink software to analyze the performance of the DSRC sensor streaming protocol using different TIS sensor data elements and various sensor orientation settings. Also, we confirmed that the DSRC sensors are not designed to collect or respond to changes in the environment because it is just a carrier protocol for what can be observed by other short range sensors such as TIS or LiDAR.

The obtained results proved that (1) it is possible to stream multiplexed scalar sensor data between vehicles such as what it is collected by TIS sensor and (2) the TIS sensor is insensitive to sensor orientation changes.

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