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# Using Bluetooth and Sensor Networks for Intelligent Transportation Systems

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*Abstract*— Safety of road travel can be increased if vehicles can be made to form groups for communicating data among themselves. The Bluetooth protocol can be used for inter-vehicle communication among vehicles equipped with Bluetooth devices. This paper presents a novel approach to increase the safety of road travel using the concepts of wireless sensor networks and the Bluetooth protocol. We discuss how vehicles can form mobile ad-hoc networks and exchange data sensed by the on-board sensors. The fusion of these data could give a better understanding of the surrounding traffic conditions. The feasibility of using Bluetooth for data exchange among vehicles is evaluated. Coverage area and probability of detection plots for isotropic and non-isotropic sensors are analyzed to study their use to avoid potential dangerous situations in traffic. As the simulation results show, Bluetooth and sensor networks can be used collaboratively to increase the safety of road travel.

## I. INTRODUCTION

Vehicle crashes in the U.S.A. account for more than a staggering 40,000 deaths, 3,000,000 injuries, and $150 billion in financial losses annually [1]. The automobile industries are working hard to enhance the vehicles' safety features by taking advantage of on-board sensor technologies. Drivers will be able to purchase vehicles with certain advanced safety features to assist them to drive safely; such as, collision avoidance, obstacle detection, range detection [2], reversing sensors, automatic braking [3], intelligent headlights [4], etc. The concept of these driver-aid systems is that, by using the information collected by the sensors on the vehicle, potential unsafe situations could be captured on time; and these captured data could alert the driver or help the driver with appropriate actions.

Insufficient data about the surrounding vehicles often leads to misjudgment on the part of the driver leading to an accident. Hence, sensors, such as the millimeter-wave radar, have been used on vehicles to assist the driver. The millimeter-wave radar is a type of sensor which can be mounted on vehicles and has been efficiently used for providing safety services like collision avoidance and obstacle detection [5]. It is based on the FM-CW (Frequency Modulated-Continuous Wave) radar system, and can detect targets even during stormy conditions. It can simultaneously measure both the target's distance and its relative velocity. It can, hence, be used in driving conditions with poor visibility such as driving in a fog [6]. In addition, a visual sensor or a camera can also be mounted on board the vehicle for classification of sensed objects. A sensor based control system (SBCS) can be put on the vehicle for periodic monitoring of the vehicle. Such an SBCS should be able to interpret the readings taken by the various vehicle sensors and warn the driver of any possible malfunction or a potentially dangerous situation. Also, the SBCS should be capable of communicating with other similarly equipped vehicles over a radio interface. Vehicles need to be informed about the dynamic characteristics, for example, speed, acceleration, turn indication, etc., of their surrounding vehicles. This will ensure that a vehicle is aware of the movements of the vehicles around it. For this to be accomplished, vehicles traveling on the road need to form mobile ad-hoc networks among themselves if they have the capability of wireless communication. In this paper, we have utilized the concepts of coverage area and probability of detection of isotropic and non-isotropic sensors to avoid potential dangerous situations in traffic. We have discussed the use of Bluetooth for inter-vehicle communication. Bluetooth is a wireless protocol for wireless communication in the 2.4 GHz industrial, scientific and medical (ISM) band [7]. Vehicles equipped with Bluetooth radios can communicate wirelessly with each other.

As the early demonstration of intelligent vehicle technologies, the California PATH program [8] focuses on creating a complete Autonomous Highway System (AHS) in which vehicles travel together in platoons. However, it requires major changes to the existing highway infrastructure to implement such a system. Also, in the real world, the idea of forming platoons is practically infeasible in everyday traffic which follows random patterns which vary depending on the type of vehicle and its driver. Compared with the scheme presented in [8], our scheme requires no changes to the existing infrastructure of highways. Using our approach, one vehicle can benefit from the data sensed by other vehicles. Hence, only one sensor per car, like the millimeter wave radar, is essential. This can cut down the overall cost and can reduce the complexity of the overall sensor system.

The DEMO 2000 [9] driving program discusses the implementation of an autonomous distributed communication system among vehicles. Our paper follows

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this approach and assumes that vehicles can form ad-hoc networks among themselves for the exchange of data.

The rest of the paper is organized as follows. In section II we investigate the characteristics of the Bluetooth protocol for the formation of ad-hoc networks among vehicles. In Section III we discuss the concepts of coverage area and probability of detection of wireless sensor networks. In section IV we present our simulation results and we conclude the paper in section V.

## II. BLUETOOTH FOR INTER-VEHICLE COMMUNICATION (IVC)

A number of wireless network protocols, such as IEEE 802.11, Bluetooth, can be used for communication among vehicles. In this paper, we discuss the use of Bluetooth technology to form ad-hoc networks among vehicles in the traffic. Bluetooth is an open specification for short-range communications of data and voice between both mobile and stationary devices. Bluetooth has a raw bandwidth of 1 Mbps. It also provides three levels of security. A Bluetooth device can discover other Bluetooth devices in its communication range by the process of *inquiry*. During inquiry, the listening and the sending nodes hop using the same sequence. A sender can *inquire* more than one listener and collect data about them, such as, their clock offsets. In the paging procedure, messages are unicast by the sender to a specific listener. On receiving an acknowledgment message, the sender becomes the *master* while the listener becomes the *slave*. In this way, Bluetooth devices can form *piconets* and communicate among themselves. A *piconet* can contain up to seven *active* slaves and one master. Figure 1 shows vehicles in a piconet. If a master device has more than seven slaves then some of the slaves have to be *parked*. Hence, to communicate with a parked slave a master has to *unpark* it first, consequently, parking some other active slave. Two or more piconets can be joined together to form a scatternet. The Bluetooth standard allows a device to have multiple roles. It can be master in one piconet while it can be a slave in one or more other piconets. But, a device can be active only in one piconet. To become a member of another piconet, a device has to switch to the hopping frequency sequence of the other piconet. Communication among slave devices has to be performed through the master. Using such piconets and scatternets, vehicles can communicate their sensed data with other vehicles in the network and can travel safely along the road aware of the surrounding traffic movements.

In the following sub-section, we discuss a typical traffic scenario at a traffic intersection which may lead to potential accident and then show how the potential accident can be avoided , if the vehicles involved in such a situation are equipped with sensors and have communicating capabilities to exchange data with others in the network.

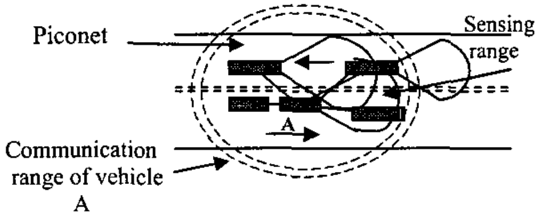

Figure. 1 The communication range and the sensing range of vehicle A

Even though the common ITS infrastructure based safety system may exist at certain intersections, still, a networked approach for communication among vehicles can increase the level of safety as we discuss below. Accidents at highway intersections can account for almost thirty percent of all the road accidents in the USA [10]. In figure 2, we have shown a traffic scenario at a road intersection. Assume that the signal for the horizontal lanes has been turned green and consequently the signal for the vertical lanes is red. Vehicle B wants to make a right turn while vehicle A wants to proceed straight from left to right. Neither of the vehicles can see each other due to vehicle C.

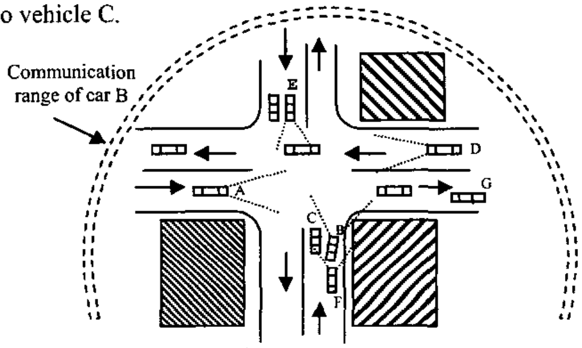

Figure 2 Vehicles at an intersection

If the vehicles are able to communicate with each other, then vehicles A, B, D, E and F could form a sensor network and could communicate with each other. We show in Section IV how vehicles A and B can use their sensed data and data from other vehicles to avoid a collision even though vehicle C is blocking the direct line-of-sight view between them. Based on the scheme discussed in Section IV, each vehicle would know the position and the velocity of the other vehicle using area coverage techniques and would take appropriate measures to avoid the accident and cross the intersection safely.

We can see in figure 2 that the communication range of vehicle B can cover all the vehicles at the intersection. The major challenges in such cases are that, there being many vehicles in its communication range, vehicle B should be able to obtain only those data which are useful while neglecting data from other vehicles. In figure 2, vehicle G has already turned right, so its information is not useful for vehicle B and hence should be neglected. Another challenge maybe that, at intersections in urban areas, the Bluetooth signals may experience some interference due to any buildings surrounding the intersection

Overall, our scheme proposed a method to exchange data among vehicles in real-time situations while traveling on the road. This data is obtained by various sensors mounted on the vehicles. Every vehicle contains the data gathered by different sensors on it. We also proposed that the Bluetooth technology should be the major data exchanging media protocol among vehicles. These data can be fused with data sensed by other vehicles and the driver can have a better knowledge of the surroundings.

## III. AREA COVERAGE IN SENSOR NETWORKS

The sensing range and the communication for a vehicle are different. Generally, the sensing range is smaller than the communication range, and it is generally non-isotropic. By exchanging sensed data, via the wireless network, the area of coverage of each vehicle will be enlarged. The area of coverage is a measurement of the quality of service of a sensor network [11]. Coverage can be used to find weak/strong points in the sensor field, which could be used in future deployment schemes to improve quality of service. The sensor network coverage is also one of the metrics for energy preserving, node scheduling and self-organization of sensor networks. In this paper, the coverage of a vehicle in the traffic is discussed. In the area covered by the sensors, we use the probability of detection over the area to describe the performance of the inter-vehicle sensing.

### *A. Sensor Detection Model*

A vehicle may be equipped with different sensors. The detection models are different for different sensors. For example, the pedestrian detection sensor uses the energy emitted by the object. The signal from the target decays as a polynomial of the distance. The sensor detection model can be described as: $p(d) = K / d^k$, where $K$ is the energy emitted, $k$ is the decay coefficient, and $d$ is the distance between the sensor and the object. The sensor intensity of a network of sensors can be defined based on the detection model [12].

Vehicles can also be equipped with ranging sensors such as millimeter-wave radar. The sensing area of the millimeter-wave radar resembles a sector of a circle. Each vehicle equipped with such a sensor can detect objects or other vehicles in this area. However, radar has a certain field of view, from 150° to 270° and is generally non-isotropic.

The sensing range of a sensor is the area in which it can sense the data. The communication range of a sensor defines the area in which it can interact with other devices which are often sensors. The Sensing Model for the sensors such as the millimeter-wave radar is given by Equation (1):

$$p(d \mid \mu, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp(-\frac{(d-\mu)^2}{2\sigma^2}) \qquad (1)$$

where $d$ is the distance between the sensor and the sensed object. Equation (1) shows that the sensing model follows a Gaussian distribution with variance $\sigma$ and mean $\mu$.

Figure 3(a) shows the sensing model plot for an isotropic sensor while Figure. 3(b) shows the same for a non-isotropic sensor. An isotropic sensor can sense data all around itself i.e. it has a complete 360° of sensing ability. Whereas, a non-isotropic sensor, like the millimeter wave radar, can sense data around itself in a direction ranging from 150° to 270°. Figure 3(c) and 3(d) show the sensing model plots for three isotropic and three non-isotropic sensors, respectively. We can see considerable overlap among the sensing models of the three sensors. The sensing strength in the overall area around the vehicles also increases. This in turn increases the probability of detection of any other sensors or obstacles or other vehicles without sensors which may enter that area. Hence, this leads to the overall increase of sensing ability of the sensors in that area. This can be effectively used for the collaborative exchange of data among the vehicles. The probability of detection at the overlap area is defined by Equation (2) as:

$$p = 1 - (1 - p_1)(1 - p_2)(1 - p_3) \qquad (2)$$

where $p$ is the total probability of detection and $p_1$,$p_2$ and $p_3$ are the probabilities of detection of individual sensors.

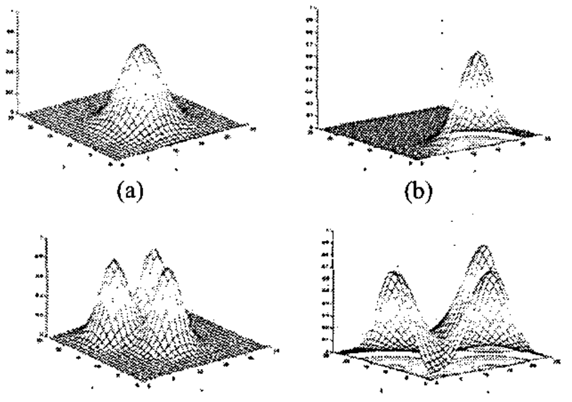

Figure 3 Sensing model for (a) A single isotropic sensor (b) A single non-isotropic sensor (c) Three isotropic sensors (d) Three non-isotropic sensors

It means that the vehicles can effectively use data from other vehicles to gain a wider perspective of their surroundings. In the above detection fusion scheme, the distance between two sensors/vehicles is important. For this purpose, sensor localization can be used. Sensor localization is a mechanism for discovering spatial relationships among sensor nodes. To localize itself, a sensor node first calculates its distance from its immediate neighbors which is called ranging and then it estimates its location using the ranging data and beacon node data. Ranging, finding the distance between two sensor nodes, can be done using the millimeter-wave radar which measures the distance between the nodes using the signal strength of the received signal.

### *B. Analysis of the topology of the network and coverage of a network of sensors*

The sensors need to be aware of their neighboring sensor nodes to decide about which data are relevant to them and which is to be discarded. For this purpose, they need to make use of a global positioning model based on the other sensors in the network. Voronoi diagram and Delaunay triangulation [13] are used to establish relationship among neighboring sensor nodes. Figure 4 shows a Voronoi diagram and the Delaunay triangulation for a group of vehicles traveling in the network. Each point in the Voronoi cell around a vehicle is closer to that vehicle than any other vehicles in the group. The Voronoi diagram thus gives us an idea of the coverage of each sensor in the network. There is a link between any two immediate neighboring vehicles in the network having sensors. This link represents the flow of data between two vehicles.

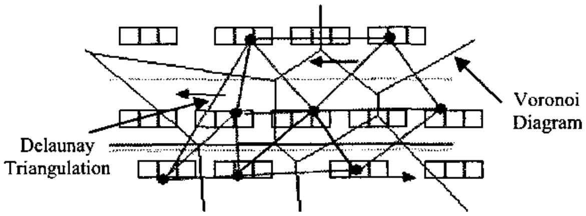

Figure 4 Neighboring vehicles in traffic

## IV. SIMULATION RESULTS

### *A. Sensor coverage area and probability of detection plots*

In this section, we apply our coverage based sensor network principles to the intersection scenario which was shown in Figure 2. The sensor area coverage plot for vehicle B at the intersection is as shown in Figure 5(a). As compared to the area coverage plot for a single sensor, we can see that more area is covered when more sensors are used. This is because of the significant overlap in the coverage areas. But, not all the data that can be obtained at the intersection are relevant to vehicle B (as discussed in Section II). Hence, for this plot, we have considered the sensed data only from vehicles A, D, E and F along with the data of vehicle B.

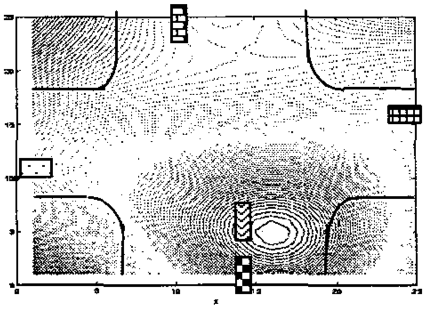

Figure 5(a) Coverage area map for vehicle B at an intersection

▭ -- Vehicle A ▨ -- Vehicle B ▦ --Vehicle D
▤ -- Vehicle E ▩ -- Vehicle F

Figure 5(b) shows the plot for the probability of detection for vehicle B. For this plot too, we have considered the data from vehicles A, D, E and F along with the data of vehicle B. As is seen in Figure 5(b), the probability of detection becomes more uniform than when a single sensor is used as in Figure 3(b). This means that the probability of detection of data (i.e. in this case another vehicle) increases due to the overlap in the sensor signals of the four vehicles.

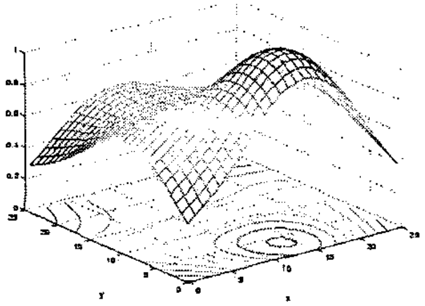

Figure 5(b) Plot of probability of detection for vehicle B

To detect the changes in these plots we consider that vehicle B turns right while the other vehicles remain at their original positions. Figure 6(a) depicts the area coverage map for this case after vehicle B has turned right. It can be observed from figure 6(a) that the coverage area contours are different from those in figure 6(a). The sensor based control system (SBCS) should be able to interpret these changes in real-time and generate the appropriate alert messages.

Figure 6(b) shows the probability of detection plot after vehicle B has turned right. We can see that the peak probability areas shift towards the right. This is because the sensed data of vehicle B now gets added with the data of vehicle D.

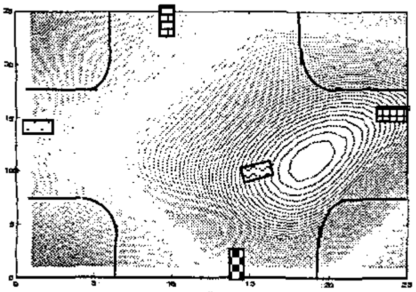

Figure 6(a) The changed coverage area map after vehicle B turns right

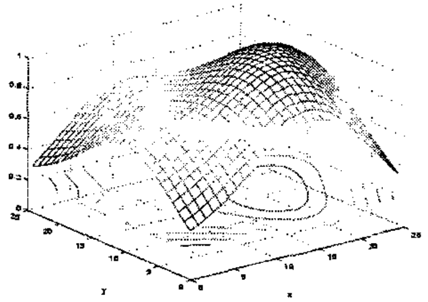

Figure 6(b) The changed plot of probability of detection after vehicle B turns right

Based on our scheme each of these vehicles can exchange its area coverage map with the other vehicles at the intersection that are part of the network. Using these maps vehicles A and B can predict that their paths will cross each other and can take appropriate action to avoid any collision. Thus, vehicle sensor systems can be programmed to recognize changes in coverage area and probability of detection plots and can use these sensed data to decide whether the path of the vehicle is safe.

### B. *Bluetooth simulator*

To evaluate the performance of the Bluetooth protocol we used the Blueware simulator [14]. The Bluetooth devices that can be simulated using the Blueware simulator are equipped with different modules which implement many aspects of the Bluetooth protocol. In inter-vehicle networks, vehicles equipped with Bluetooth radios need to discover other such vehicles in their communication range to establish communication with them. The simulated environment was 25m by 25m. The Blueware simulator places the specified number of Bluetooth nodes in the simulated environment randomly. Each node has a communication range of 10 meters.

Figure 7(a) shows the plot of connection setup delay against the number of Bluetooth devices. The connection setup delay is the time taken for a Bluetooth device to establish its first communication link with another Bluetooth device. It indicates the time taken for a Bluetooth node to discover other Bluetooth devices in its communication range. As can be observed from figure 7(a), the connection setup delay is fairly constant when the number of nodes is increased from 10 to 50. This indicates that Bluetooth devices can be used for communication in inter-vehicle networks to provide fairly consistent performance even when the number of vehicles is not constant or is changing; as is inherent in vehicle traffic networks.

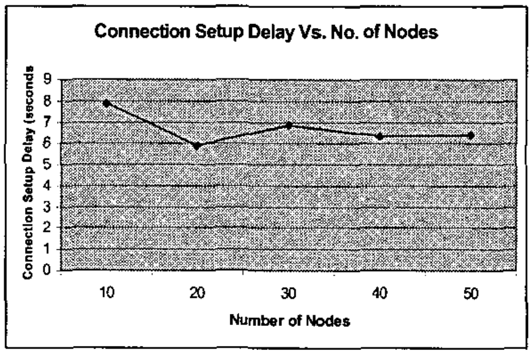

Figure 7(a) Average connection setup delay for different number of Bluetooth nodes

Figure 7(b) shows the plot for the time taken for the formation of a connected scatternet consisting of all the simulated Bluetooth devices against the number of Bluetooth devices. It can be seen that a slight decrease is observed in the scatternet formation time with the increase in the number of nodes. As the number of nodes increase, there is more overlap in their communication ranges since the simulated area is kept constant.

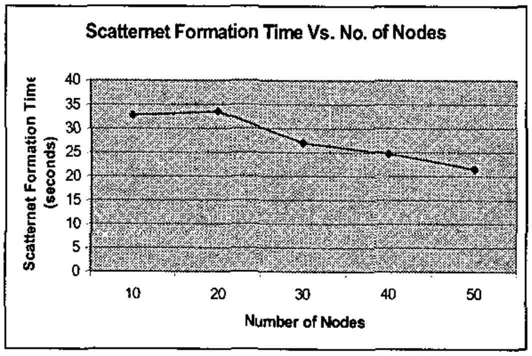

Figure 7(b) Scatternet formation time for different number of Bluetooth nodes

The results obtained clearly indicate that Bluetooth can be efficiently used for inter-vehicle communication. But, these results will vary when such a Bluetooth based inter-vehicle network is actually implemented in the real world. Vehicle mobility will play an important part in inter-vehicle communication. The type of scatternet formation algorithm used will also affect the network formation time.

## V. CONCLUSION

This paper addressed the approach of sensor networks to increase the safety of road travel. Our scheme does not require any changes to the existing highway infrastructure. We showed, using various examples, that the exchange of sensed data among vehicles can be beneficially used to avoid accidents. Isotropic and non-isotropic sensors were studied with respect to the coverage area and the probability of detection. In our simulation, we considered a typical highway intersection and plotted the sensor coverage area and the probability of detection for various vehicles equipped with non-isotropic sensors. As the first step study of this concept, this paper does not consider several issues, which should be considered as the further research directions, such as, the potential communications overhead and its effect on the communication efficiency, the integration of the vehicle-based ad hoc wireless sensor networks with road side infrastructures, which will involve the vehicle-to-roadside sensor communications. The future challenges lie in designing effective sensor based systems which can interpret such changes and can take appropriate actions to avoid accidents. We plan to implement our approach using robotic vehicles equipped with Bluetooth devices. Such an implementation will give us the opportunity to study inter-vehicle communication under realistic scenarios.

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