Assessment of Positioning Errors on V2V Networks Employing Dual Beamforming

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***Abstract*—In this paper, we present an analysis of Vehicle-to-Vehicle (V2V) Networks employing beamforming at both the transmitter and the receiver when positioning errors are present. Specifically, we will examine the performance of this system setup when the source of the positioning errors are from the Global Positioning System (GPS) measurements as well as from variations in the delays due to the overhead communication channels. To achieve adequate performance, beamforming requires precise location information of the transmitter and the receiver, and when accurate information is unavailable the system performance can potentially deteriorate. This is especially challenging in highly mobile vehicle networking environments where the operating conditions and location information varies rapidly in time. Simulation results are obtained showing Bit Error Rate (BER) values increasing by 99.9% when the exact GPS locations are known by the vehicles when compared to a 6.6m error in GPS location.**

***Keywords*—Beamforming, Directional Antenna, Positioning errors, GPS errors**

I. Introduction

Vehicle-to-Vehicle (V2V) communications are designed to transmit information without the need from a centralized networking architecture in order to provide safety messages to other vehicles. In the United States alone, almost 90% of all crashes were due to human negligence, resulting in 37,461 fatalities in 2016 [1]. To improve road safety, one promising approach is to wirelessly connect vehicles to support greater communications and increase situational awareness for all drivers and vehicles. Consequently there has been a significant amount of activity by car manufacturers, university researchers, and government agencies to create more secure and efficient driving conditions using wireless communications and networking.

The objective of the connected vehicle environment is to create the ability to receive a warning message when there is a risk of an accident, as well as enable the vehicle to take preventive action in order to avoid collisions. To mitigate the worst case scenarios on the road, it is possible to send information to drivers at a frequency of 5.9GHz using the IEEE802.11p standard. The Dedicated Short range Communications (DSRC) standard employs two main components: On Board Units (OBU) and Road Side Units (RSU). Note that both OBUs and RSUs are often equipped with omnidirectional antennas [2], thus resulting in decreased signal quality at the receiving vehicles due to signal power loss in undesired directions [3]. In order to overcome this issue, electronic beam-steering using directional antennas is implemented in order to improve the quality of V2V links [4]. The benefits of using beamforming antennas to improve the network capacity in wireless ad hoc network was evaluated in [5].

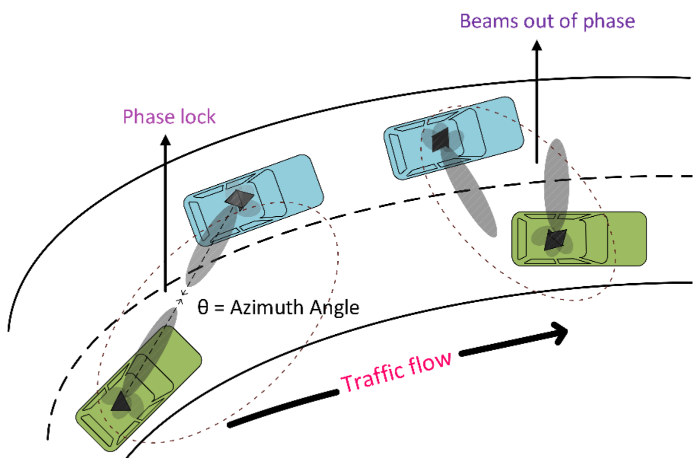

Figure 1: The figure shows beamforming between two autonomous vehicles with perfect and imperfect beam lock

Obtaining accurate locations of the vehicles on road is very important in order to form a functioning V2V network. Location accuracy mainly depends on frequent updates regarding the vehicle's state, speed, and trajectory. The localization accuracy of the GPS signals can be affected by its surrounding environment, such as buildings, forests, or any other sources of interference for electronic systems. This can be improved by sending basic safety messages (BSM), which includes position information or any other required data to assist in determining the location of the vehicle. In Reference [6], the author considered an Intelligent Driver Model (IDM) to compensate for location errors in the cloud. In Reference [7], the author proposed a method to verify the GPS assisted location information provided by the V2V equipped target vehicle. The authors in Reference [8] used a centroid localization (CL) approach for Vehicular Ad Hoc Networks (VANETs), where the receiver's location can be tracked based on the location of its neighboring vehicles.

In this paper, we focus on improving the communication between vehicles within a network for using beamforming, as well as access the impact when the receiver is not present at the calculated location due to various topological errors. By using a beam-steering technique, we can maximize the signal strength of the transmission in one specific direction in order to obtain the maximum antenna transmit and/or receiver gain *directivity*. The Bit Error Rate (BER) is employed as a performance measure in this paper. By identifying the coordinates of the transmitter and the receiver, the beams are locked such that they establish a signal connection possessing maximum Signal-to-Noise ratio (SNR). However, when there is a phase shift in the beam due to changes in the receiver's location, and when the update is not sent to the transmitter due to delay, the effect on the BER is significant, as will be discussed in this paper. Figure 1 illustrates a simple scenario consisting of two cars with one as the transmitter and the other as the receiver with beams locked when: (i) there is no shift in the beam, and (ii) there is a shift and the beams are out-of-phase.

The primary objective of this paper is to investigate how positioning errors and the overhead information delays affect the V2V network utilizing a beamforming architecture. The contributions of this paper are:

- A dual beamforming architecture for V2V networks where one vehicle acts as the transmitter whose location is assumed to be precise and the other vehicle acts as the receiver.
- An analysis of the positioning errors due to GPS and overhead channel updates on the system performance of a V2V network employing dual beamforming.

The paper is organized as follows: In Section II, we describe the beamforming setup and the mathematical expressions used for this spatial signal processing algorithm. In Section III, we discuss V2V architecture model when beamforming is employed within the network. In Section IV, we propose a model for beamforming when positioning errors are considered. In Section V, simulation results are presented and performance characteristics are evaluated. In Section VI, several concluding remarks regarding this research is provided.

II. Beamforming Implementation

Smart antennas vary from simple switched-beam configurations to fully adaptive arrays. Switched-beam arrays use beamforming techniques that yield multiple, fixed, simultaneously available beams. These beams are found to possess higher gains and with lower side lobes [9]. One example of a phased array performing beamforming is the Uniform Linear Array (ULA), which possesses L elements with uniform spacing d. All the elements of the ULA have uniform amplitudes but different phase shifts γ [10]. The Array Factor (AF), is the factor by which the directivity function of an individual antenna must be multiplied to get the directivity of the entire array. The response for each individual antenna as a function of its direction is given by the array pattern [11]. For isotropic sources, the AF is given by the expression:

$$AF(\theta,\gamma) = 1 + e^{(j(d\cos(\theta)+\gamma)} + e^{(j2(kd\cos(\theta)+\gamma)} + \ldots . \quad e^{(j(L-1)(kd\cos(\theta)+\gamma)}, \tag{1}$$

where AF is the Array Factor, k is the wavenumber magnitude that is equal to $\frac{2\pi}{\lambda}$, d is the distance between the array elements, θ is the azimuthal angle, and γ is the phase shift.

The expression can also be represented as:

$$AF(\theta,\gamma) = \sum_{l=1}^{L} e^{(j(l-1)(kd\cos(\theta)+\gamma)}. \tag{2}$$

In ULAs, the amplitude and the phase of the AF can be controlled by properly choosing the phase shift between the elements. As the number of array elements increases, the beam becomes more narrower achieving the maximum gain [12]. For an ULA, the center of the array is at the origin of the coordinate system. In this case, the AF can be further reduced to:

$$AF(\theta,\gamma) = \frac{1}{L}\left(\frac{\sin(\frac{L}{2}\chi)}{\sin(\frac{1}{2}\chi)}\right), \tag{3}$$

where χ is represented as $kd\cos(\theta)+\gamma$. The 3-db beamwidth, also known as half power beamwidth, is the measure of the beamwidth at AF = $\frac{1}{\sqrt{2}}$. The array factor for the 3-db point is given by the expression:

$$\theta_p = \arccos\left(\frac{\lambda}{2\pi d}\left(-\alpha \pm \frac{2.782}{L}\right)\right). \tag{4}$$

Assuming line-of-sight conditions between the transmitter and the receiver, in this paper the path loss is predicted by the Friis Free Space Propagation Model [13]. The received power is calculated as:

$$\Gamma_r(d) = \Gamma_t\left(\frac{\lambda}{4\pi d}\right)^2 g_t g_r, \tag{5}$$

where $\Gamma_r(d)$ is the received signal power in watts, d is the distance between the transmitter and the receiver, λ is the transmitted wavelength = $\frac{c}{f}$, c is the velocity of light, f is the frequency involved in transmission, Γ_t is the power transmitted in watts, and g_t and g_r are the gains of the transmitter and the receiver, which are dimensionless quantities. The power transmitted and the power received is usually represented in terms of dBm. In this case, the above equation is represented as:

$$\begin{aligned}\Gamma_r(d) = \Gamma_t dBm + 10\log_{10}(g_t) + 10\log_{10}(g_r) + \\ 20\log_{10}(\lambda) - 20\log_{10}(4\pi d) - 10log_{10}(L).\end{aligned} \tag{6}$$

III. V2V Architecture Model

In order to make the location of the vehicles known to each other, the vehicles exchange two types of messages: (i) Cooperative Awareness Messages (CAM), where the beacon messages are transmitted periodically, and (ii) Decentralized Environmental Notification Message (DENM), which contains data related to road obstacles or an abnormal traffic condition including its type and status [14]. Beacons contain the state of the vehicle as well as its current position. To reduce packet loss and to make sure the packets transmissions are up-to-date, beacon messages are sent frequently. However, occasionally the information sent is lost due to collisions on the communication

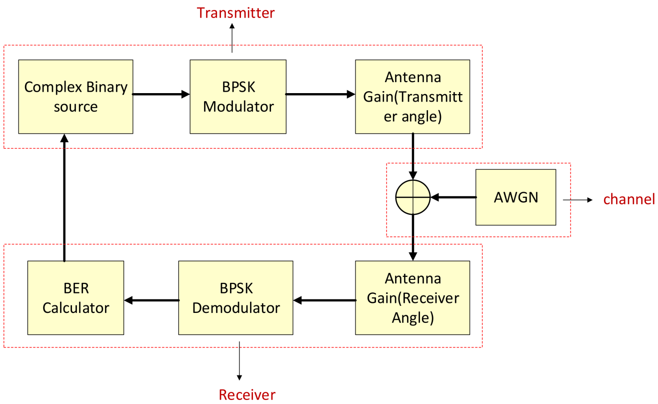

Figure 2: Block diagram of simulation environment through AWGN using BPSK.

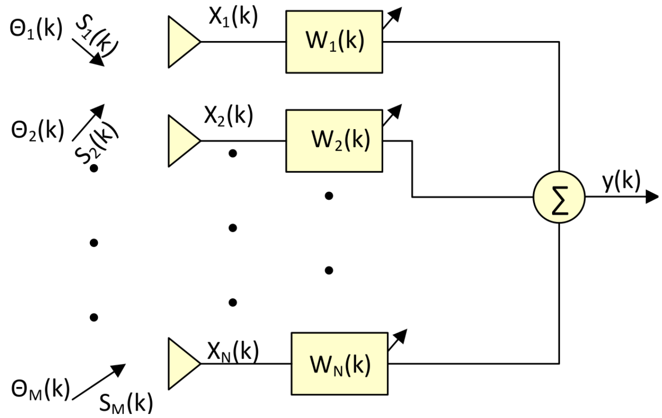

Figure 3: A beamformer with a linear combination of sensor outputs with each sensor output multiplied by a complex weight and then added.

overhead channel. This mostly occurs in traffic scenarios when there exists a large number of vehicles that are actively communicating and the channel becomes overloaded [15]. One of the major challenges of vehicular networks is the dynamic topology and high mobility of the environment. The topology of the vehicles change due to high speed of the traffic occurring on the freeways and other road environments [16]. Therefore, maintaining wireless connectivity between vehicles in real-time is a non-trivial problem to resolve. Therefore, there exists a need for a distributed protocol that only relies on local network information exchanges instead of global network information sharing. Consequently, we assume the vehicular communication network possesses an overhead channel, that is capable of sharing information regarding the geographical location of all receivers (vehicles) on road at any given time. This data is vital for enabling perfect beamforming between two vehicles.

To detect nearby vehicles, the beampatterns will sweep the azimuth at a constant rate. In order to support the spatial filtering of information between two connected vehicles, directional coverage via beamforming is employed. Figure 2 illustrates the simulation environment being studied in this paper. Figure 3 shows the beamforming system being used for processing narrowband signals. In this illustration, there are M signals, $S_m(k)$, being received by $N > M$ array elements with N adjustable weights, $W_n(k)$. For zero mean Additive White Gaussian Noise (AWGN), the array output is given by [17]:

$$y_k = \widetilde{W}^T(k)\widetilde{x}(k), \tag{7}$$

where $\widetilde{x}(k) = \widetilde{a}^T(\theta_i)\widetilde{s}_k + \widetilde{n}_k$, with $\widetilde{w}(k) = W_1(k), ..., W_N(k)$. $\widetilde{a}$ is the steering vector for the angle of arrival θ_i and $\widetilde{n}_k$ is the noise at each of the array element.

IV. Proposed Positioning Error Models for Beamforming V2V

The accuracy of the vehicle's position is affected by the pseudorange measurements of the satellite that continuously orbits the earth and the geometry from which those pseudorange measurements are obtained. A timing error of 10 ns results in a location measurement difference of approximately 3 m from the actual location of the vehicle. GPS error sources that influence the location factors are the ephemeris data, satellite clock, ionosphere, troposphere, multipath reception, and receiver measurements. The total error occurring within a GPS position measurement is based on the Dilution of Precision (DOP) and user-equivalent range error (UERE). The standard deviation of the RMS error in the northeast plane is given by [18]:

$$E_{n-e,\text{rms}} = \text{HDOP} * \text{UERE}_{\text{rms}} = (1.3)(5.1) = 6.6, \tag{8}$$

where HDOP is the Horizontal DOP. Figure 4 illustrates the receiver's positional error location at one particular error coordinate. In this scenario, θ is the azimuth angle. The transmitter's beam angle should be directed towards the receiver's angle for the beam to obtain a lock in order to ensure perfect communication. With error present within the system, this information can lead to significant degradation of communication performance when the vehicles are beamforming with each other.

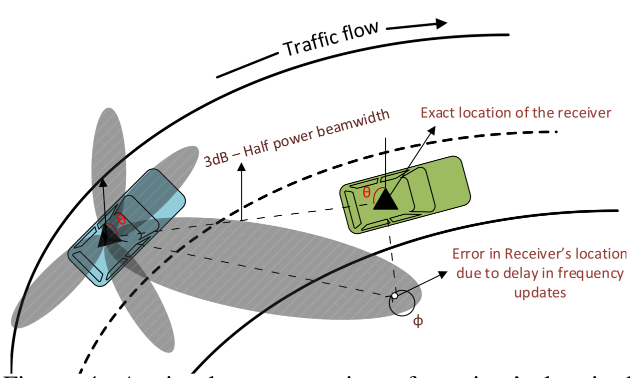

Figure 4: A visual representation of receiver's longitudinal error location with respect to transmitter at one particular error coordinate

With the standard deviation equal to 6.6m, this can be translated into GPS errors ranging from 0.1% to 1%, which can then be intentionally introduced into the actual location of the vehicle. Note that the relationship between the percentage of the error and the angular displacement between the transmitter and the longitudinal error position of the vehicle was found to be linear.

V. Simulation and Results

For this research, the performance of the proposed technique was evaluated using MATLAB simulations. To provide a baseline for our simulation results, we considered the scenario where no phase shift was present, which means the connection was established between two cars with maximum directivity. For our simulation experiments, the SNR was varied by changing the number of antenna elements, namely, $L = 2, 4, 6, 8$. This is done by using the Equation(3) and Equation(6). Figure 5 shows the beam scanning patterns for different azimuth angle orientations. Specifically, it shows the beam scenario when the transmitter and receiver possess an angular displacement of either 90°, 60°,45°, or 30° with respect to the locations of the transmitter and receiver vehicles.

In this paper, we consider the power transmitted Γ_t and path loss to be constant. With Γ_t equal to 0.01Watts (*10dBm*), we consider the scenario when the GPS errors are introduced at the receiver's location with the corresponding BER performance evaluated with respect to the constant number of linear array elements ($L = 4$). Another scenario considered in this case was when the error rates are being compared to the change in the number of linear array elements ($L = 2, 4, 6, 8$) if the azimuth angle is kept constant at θ=90°, meaning there is no phase shift between the transmitter and the receiver.

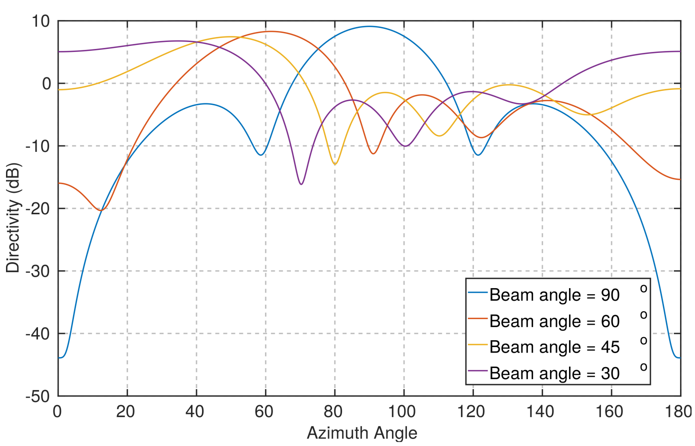

Figure 5: Beam orientation for $L = 4$ dipole antenna on a vehicular system when the beam angles are at 90°, 60°,45°, and 30°, respectively

Figure 6 shows the change in SNR in dB with respect to varying the distance in meters using *d*=100,200,300,...,1000 between the transmitter and the receiver, and also changing the number of array elements $L = 2, 4, 6, 8$. It is observed that the SNR is at its maximum when the receiver is close to the

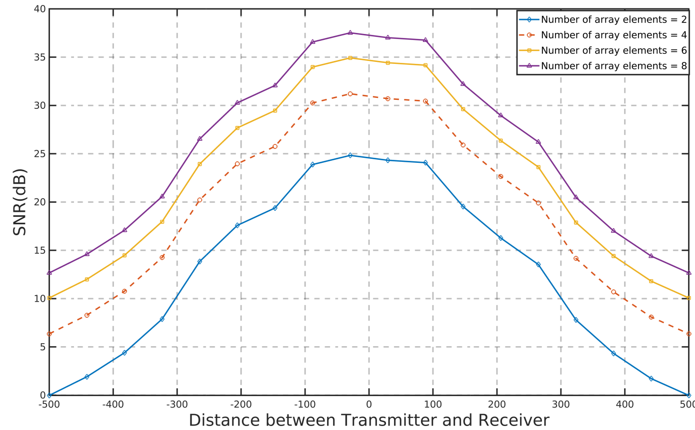

Figure 6: SNR change with respect to different distances between Transmitter and Receiver with the number of array elements varied from $L = 2, 4, 6, 8$.

transmitter. Furthermore, we observe that the SNR decreases as the distance between the transmitter and receiver increases irrespective to the number of array elements used.

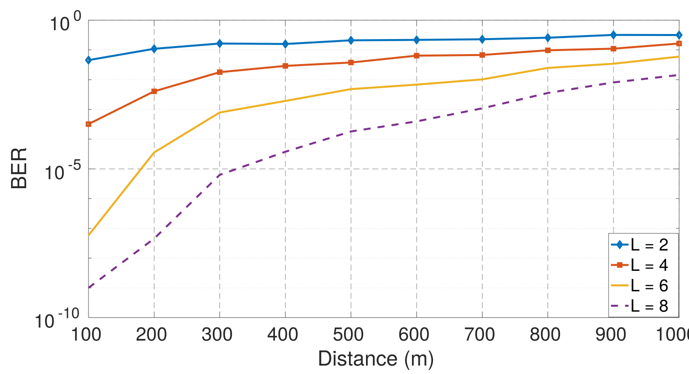

Figure 7: Distance between Transmitter and Receiver with the number of array elements varied from $L = 2, 4, 6, 8$ and the effect of bit error rate for each case.

Figure 7 shows the BER for different numbers of linear array elements ($L = 2, 4, 6, 8$). The distance between the two array elements is kept as a constant at $\frac{\lambda}{2}$. As L is increased, the beam becomes narrower resulting in higher SNR values when compared to previous cases. Figure 8 shows the BER performance for different positional errors of the receivers from the directed azimuth angle of the transmitter. In our case, we are considering the values when the receiver is 0°, 5°,10° and 15° shifted from the main beam of the transmitter. In each case, the SNR is found to degrade, implying the connection is negatively being impacted and this might lead to a broken link. It is important to note that due to the varying nature of the azimuth angles, the BER performance also varies significantly.

VI. Conclusion

In this paper, we analyzed the BER performance of directional antennas for a V2V network where the the location information of the vehicles is initially known. We also examined

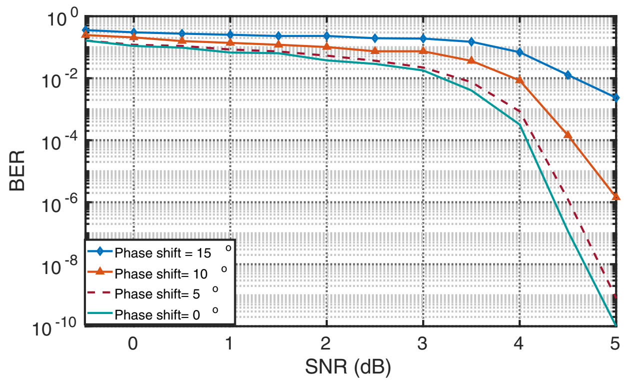

Figure 8: BER change when the gps errors in the receiver's location affect the beam having a shift of 0°, 5°,10° and 15° from the transmitter.

the transmission loss when positional errors are introduced to the system which negatively impacts the beamforming performance. We derived the probability of error function using the Friss free space channel propagation model, and we then analyzed the SNR performance using our channel model for different phase shifts due to error updates in the location and different number of array elements. We compared all the azimuth angles to both the best and worst case scenarios.

Our work is focused mainly on improving the link capacity with respect to noise quality and not the interference level. The same method is also used when the interference is considered but in that case we have to use different channel model that considers reflection, diffraction, and scattering due to local and global variables. For this paper, we have used one V2V link to establish connectivity in order to provide a straightforward assessment of dual beamforming with positional errors in vehicular network. Nevertheless, this way can readily be implemented for connecting a large number of vehicles within a network operating in for different environments using beam-steering.

VII. Acknowledgement

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