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Vehicle to Vehicle Communication using DS-CDMA Radar

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Abstract

Tremendous amount of research is going on in the area of Intelligent Transport System. The automotive companies like General Motors, Toyota, Mercedes etc have announced launch of high end vehicles with inbuilt V2X(Vehicle to infrastructure/Vehicle) systems. In this paper we have proposed a scheme to implement vehicle to vehicle communication using Direct Sequence Spread Spectrum Code Division Multiple Access radar (DS-CDMA). The system is capable of performing ranging as well as communication with multiple targets.

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1. Introduction

There is a need to obligate the vehicle manufacturers to incorporate various systems in the vehicle that will improve its safety performance and reduce the number of accidents that are taking place. The various vehicle manufacturers have responded to the call of National Highway Traffic Safety Administration (NHTSA) standards to build the safer vehicles [8]. The General Motor CEO, Mary Barra announced during her keynote address at the Intelligent Transport System (ITS) World Congress in Detroit on September 7, 2014 that Cadillac will begin offering advanced “intelligent and connected” vehicle technologies on certain 2017 model-year vehicles [3]. Daimler Trucks has given us a sight of Mercedes Benz Future Truck 2025 self driving truck. The truck will use technologies like radar sensors a stereo camera, 3D maps, vehicle to vehicle and vehicle to infrastructure communication to drive autonomously [5]. Toyota has proposed to develop vehicular system using three key technologies namely Dynamic Radar Cruise Control, Lane Trace Control, Predictive and Interactive Human Machine Interface (HMI) [13].
The report, from the DOT’s National Highway Traffic Safety Administration (NHTSA), found that V2V technology could stop up to five million crashes per year, saving many lives [8].

There is ongoing research on many technologies like VANET, CALM, WAVE, CDMA etc for implementing vehicle to X (infrastructure/vehicle) communication[6][7][9][10]. In this paper we propose to implement V2V communication using DS CDMA technique. The spread spectrum technology has been the choice for the following reasons-

- Resistance to jamming
- Resistance to fading caused by multipath effect
- Ranging Facility

The CDMA (Code Division Multiple Access) technology with spread spectrum provides multiple accesses. It allows multiple users to communicate with each other. In addition, it does not require any bandwidth allocation as in FDMA (Frequency Division Multiple Access) or any time allocation as in TDMA (Time Division Multiple Access)[4][16]. Another advantage of DS CDMA technique is that same system of transmitter and receiver can be used for ranging and communication. We are in the process of implementing the DS CDMA system in Matlab/Simulink. Simulink is a software package for modeling, simulating, and analyzing dynamic systems at any point.

Section 2 provides brief background of DS CDMA technique and scheme for ranging using DS BPSK technique which is simulated in Simulink. Section 3 gives details of the proposed scheme. Finally we conclude in section 4 by giving brief idea of the future work and the challenges we anticipate.

2. DS CDMA technique

2.1. DS BPSK based CDMA system (DS CDMA)

Multiple access is ability of a system to allow many users to communicate simultaneously using common transmission medium. The signals may be separated in time, frequency or code. In Code Division Multiple Access (CDMA), multiple users transmit signals occupying same frequency band and at the same time. However, the transmitting signals have different codes. CDMA signal can be realized using Direct Sequence Spread Spectrum [18][4].

Fig 1 shows the block diagram of a DS BPSK based CDMA system for two users. Here, each user is provided with unique and uncorrelated PN code \(c_1(t)\) and \(c_2(t)\). The data of both the users \(d_1(t)\) and \(d_2(t)\) is spread by \(c_1(t)\) and \(c_2(t)\) respectively using DSSS modulation, to obtain \(s_1(t)\) and \(s_2(t)\). Then each spread data \(s_1(t)\) and \(s_2(t)\) is carrier modulated using BPSK technique with the same carrier \(w_d(t)\). As there is no frequency or time division, the DS BPSK signal will be present at the input of each of the receivers. Hence inference caused by the other users will exist at the input of each receiver.

The data rate is \(f_d\) and chip rate is \(f_c\). The signal present at the input of coherent detector 1 is

\[
    z(t) = \sqrt{2P_0}c_1(t)d_1(t)\cos(w_0t + \phi_1) + \sqrt{2P_0}c_2(t)d_2(t)\cos(w_0t + \phi_1)
\]

The received signal \(z(t)\) is multiplied with \(c_1(t)\) and is coherently detected by the carrier \(\sqrt{2}\cos(w_0t + \phi_1)\) to get signal \(\nu(t)\) which is then applied to integrate and dump circuit which acts as a low pass filter(LPF) whose cutoff frequency is equal to bandwidth of the baseband signal \(d_1(t)\). The output of the LPF is given by

\[
    \nu_0(t) = \sqrt{P_0}d_1(t) + \sqrt{P_0}d_2(t)c_2(t)c_1(t)\cos(\phi_2 - \phi_1)
\]
Here we assume that c1(t) and c2(t) make transitions at the same time. In the above equation, the second term in RHS is a wideband signal. The LPF will pass only that part of spectrum of this wideband signal which lies within its pass band. The power spectrum of the interfering signal is given by

$$S_0(f) = P_0T_c/4$$

The probability of error is given by

$$P_e = (1/2)erfc\sqrt{2(T_0/T_c)}$$

The complementary error function is monotonically decreasing function of its argument. Hence to minimize probability of error, we have to maximize quantity under the square root, that is $f_c >> f_0$ [12][14][15][17][16].

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**Fig 1** A DS BPSK based CDMA system for two users

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2.2. **Ranging using DS BPSK technique**

The scheme for ranging using DS BPSK technique is shown in Fig 2. Here, autocorrelation property of the PN sequence aids in detection of the target and it’s ranging [1][2].
The transmitter section consists of binary data generation, spreading the data using PN sequence and its modulation (BPSK). The received signal power is calculated using radar range equation as follows

\[
P_{\text{rec}} = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}
\]

where,
- \(P_t\) is the peak transmitted power in watts.
- \(G\) is the gain of the antenna.
- \(\lambda\) is the carrier wavelength in meters.
- \(\sigma\) is the RCS of the target in square meters.
- \(R\) is the range from the radar to the target in meters.

At the receiver, the transmitted and received signal are aligned and the delay between them is calculated and accordingly target range is obtained by using the following equation

\[
R = \frac{ct}{2}
\]

where
- \(c\) = velocity of light = \(3 \times 10^8\) m/s
- \(t\) = time delay between transmitted and received signal

2.3. Simulation results of the DS BPSK Radar

Various graphs are plotted by using the data given in Table 1.
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip rate ($f_c$)</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Transmitted Power ($P_t$)</td>
<td>1 W</td>
</tr>
<tr>
<td>Antenna Gain</td>
<td>100</td>
</tr>
<tr>
<td>Wavelength ($\lambda$)</td>
<td>0.3 m</td>
</tr>
<tr>
<td>Target Cross Section ($\sigma$)</td>
<td>1 m$^2$</td>
</tr>
<tr>
<td>Minimum detectable signal power ($P_{min}$)</td>
<td>0.011 mW</td>
</tr>
<tr>
<td>Velocity of light ($c$)</td>
<td>$3 \times 10^8$ m/s</td>
</tr>
<tr>
<td>Maximum Radar Range ($R_{max}$)</td>
<td>8 m</td>
</tr>
</tbody>
</table>

Table 1: Specifications of Spread Spectrum Radar

As radar range increases, the signal power received at the receiver decreases. This is depicted in Fig 3. The minimum detectable signal power at the receiver $P_{min} = 0.000110726$ W or -39.55 dB for $R_{max} = 8$ m. The detection be varied by changing the chip rate or antenna gain [1][2].

![Range vs Prec](image_url)

Fig 3: Range versus Received Signal Power graph

For range (R) = 1 m, Eb/No Vs BER graph is plotted using Bit Error Rate Analysis Tool in Matlab/Simulink. Monte Carlo simulation results and theoretical results are in Fig.4 below. We can see that as Eb/No ratio increases, BER decreases.
Fig 4: Range versus Received Signal Power graph

Fig 5 below shows theoretical distance of the target and the distance computed by the radar model.

Fig 5: Theoretical distance versus computed distance
3. Proposed scheme of DS CDMA Radar

The DS BPSK Radar model discussed above is capable of detecting only one target at a time in one direction. In the proposed scheme, we are developing a system which will do ranging and communication with multiple targets. Fig 6 below shows a scheme for multiple target ranging.

3.1. Multiple target ranging using DS CDMA

![Diagram of DS CDMA technique used for multiple target ranging.]

DS CDMA modulator and demodulator together form a DS CDMA Radar system. By using unique data stream and PN sequence, it is possible to detect various targets. Fig 6 above shows one such scheme for ranging two target vehicles. If the target vehicle is within the set range of communication, the same system can be adapted for communication amongst the vehicles.

3.2. Communication with the target using DS CDMA

![Diagram of DS CDMA technique used for multiple target ranging.]

Fig 7 DS CDMA technique used for multiple target ranging.
In the proposed scheme, a vehicle initially will only broadcast emergency warnings like forward collision, blind spot, landslide, emergency braking, etc to the other vehicles in the prescribed range. Fig 7 shows one such scenario where Vehicle A would want to relay a message to other vehicles in its proximity. Vehicle A will locate all the vehicles in its prescribed range using scheme shown in Fig 6. In our example, Vehicle A finds out that Vehicle B and Vehicle C are within its communication range. Accordingly, Vehicle A will transmit its particulars like identification number, its location etc (ID_A) and its own PN code PN_A, encoded with common PN sequence called PN_common. PN_common is available to all the vehicles. When B and C receive this code, it can detect the information using PN_common and will recognize the location of the Vehicle A trying to communicate with them along with its PN code, PN_A. Subsequently, Vehicle A will transmit the warning message encoded with PN_A towards B and C. Vehicle B and C will decode the message with PN_A and take appropriate action.

4. Conclusion and Future work

In this paper we have proposed to implement vehicle to vehicle communication using DS CDMA technique. The advantage of using DS CDMA technique is that both ranging and communication can be achieved using the same transmitter-receiver arrangement. We have already implemented single target ranging using DS BPSK technique. Here in this design, the idea is limited just to broadcasting of a message. In future, we aspire to implement communication amongst individual vehicles in the given range. One of the challenges that we anticipate in this system is broadcasting of false messages by a fraudster, thereby misleading all the other vehicles. Hence there is a need to incorporate a system which authenticates the information before it is broadcasted. Differentiating between vehicular target and non vehicular target is another area which needs attention.

References

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