Design of Wireless Sensor Network for Intra-vehicular Communications

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Abstract. The number of sensor nodes in the vehicle has increased significantly due to the increasing of different vehicular applications. Since, the wired architecture is not scalable and flexible because of the internal structure of the vehicle, therefore, there is an increasing level of appeal to design a system in which the wired connections to the sensor nodes are replaced with wireless links. Design a wireless sensor network inside the vehicle is more challenging to other networks, e.g., wireless, sensor and computer networks, because of the complex environment inside the vehicle. In this paper, we design a wireless sensor network for intra-vehicular communications. Firstly, we discuss about the link design between a base station and a sensor node and then we design a network scenario inside the vehicle for reliable communication. Finally, the performance is evaluated in terms of network reliability. The simulation results assist to design a robust system for intra-vehicular communications.

Keywords: Controller Area Network, ZigBee, Intra-vehicular Communications.

1 Introduction

The Controller Area Network (CAN) is a serial communication protocol capable of managing high efficiency distributed realtime control with a high level of security. A CAN network is composed of a linear bus made with a twisted pair of wires and number of nodes connected to each other via the transmission medium. It is the most widespread system of communication between Sensor Nodes (SNs) inside a vehicle with wired connections. Fig. 1 is the example of a controller area networks and Fig. 2 depicts the frame format of CAN. For more information about CAN, we refer to [1,2].

The number of sensors in the vehicle has increased significantly due to the various safety and convenience applications. Since, the wired architecture is not scalable and flexible because of the internal structure of the vehicle [3]. Therefore, there is an increasing level of appeal to design a system in which the wired connections to the SNs are replaced with wireless links. To this end, several technologies, such as Radio Frequency IDentification (RFID) and Zigbee, have been investigated in literature [4,5,6].

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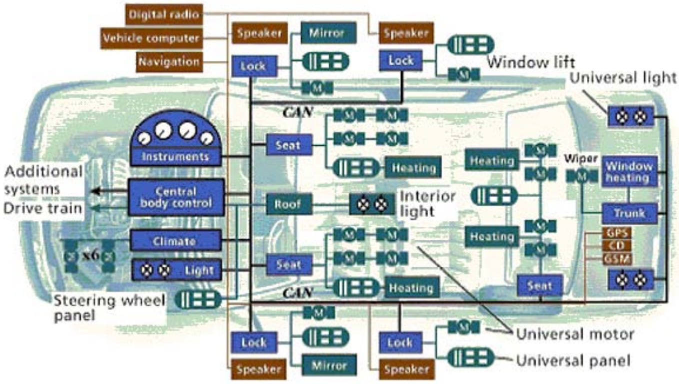
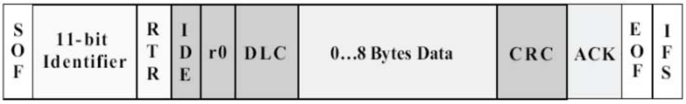


Fig. 1. Example of a Controller Area Network



S O F	11-bit Identifier	R T R	I D E	r0	DLC	0...8 Bytes Data	CRC	ACK	E O F	I F S

Fig. 2. CAN Frame Format

Wireless channels are by nature extremely complex and unpredictable systems. Several models and parameters are used to characterize wireless channel [7,8], whereas many of them are backed up by intuition and physical theory [9,10]. However, no single concrete method for determining the characteristics of a wireless channel has been established. Therefore, the most accurate method of characterizing a particular wireless channel is experimental measurements, particularly for practical purposes.

The design of an Intra-Vehicle Wireless Sensor Networks (IVWSNs) can not be separated from the study on the link between the different sensor nodes distributed in the vehicle. Therefore, link designing between Base Station (BS) an SN is an important issue in IVWSNs. The level of network performance varies with different communication parameters such as distance between BS and SN, transmission power and channel fading. From Fig. 3, we can see that the transmission power of the BS is set P_{t1} if the distance between BS and SN is d_1. When the distance is increased from d_1 to d_2 then the transmit power needs to be increased from P_{t1} to P_{t2} for receiving the same level of received signal by the SN. We also notice that due to the increasing of distance between BS and SN, the obstacles may come in the propagation path that changes the line-of-sight (LOS) to non LOS (NLOS). As a result, the fading distribution of a channel will be changed. For achieving the better performance in IVWSNs, the above parameters need to be adjusted. In fact, design a wireless sensor network inside the vehicle is more challenging to other networks, e.g., wireless, sensor and computer networks, because of the complex environment created by a large number of parts inside the vehicle. Therefore, it is an active research area to design a network for intra-vehicle communications.

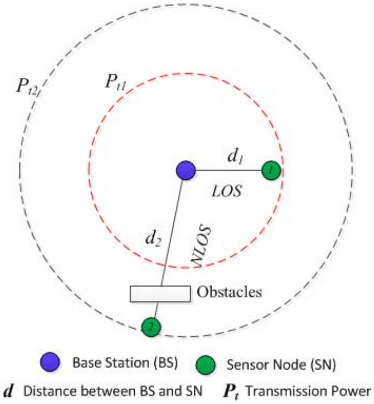


Fig. 3. Scenario is changed with the varying of communication parameters

In this paper, we design a wireless sensor network for intra-vehicular communications and evaluate its performance in terms of network reliability. More in details, firstly, we study about the link analysis between BS and SN, then based on that we design an IVWSNs by utilizing ZigBee standard instead of the traditional CAN technology. Finally, we define network reliability in terms of end-to-end delay to measure the performance of the networks. The simulation results assist to design a robust system for intra vehicular communications.

The rest of the paper is organized as follows. In Section 2, we provide the related works, while in Section 3, we describe the design of IVWSNs. In Section 4, we discuss about the network reliability, while in Section 5, we present the simulation results. Finally, in Section. 6, we conclude the paper.

2 Related Works

There have been active researches on the design of wireless and sensor networks [12,14,15,16]. For example, In [12], the authors present an empirical study based reliability estimation in wireless networks. However, there are less numbers of work have addressed particularly the design of network for intra-vehicular communications [3,11,17,18,19,20]. In [19], the authors present the viability of the optical wireless channel for use in intra-vehicular communications applications. In [20], the authors investigate the coverage area performance of multi band orthogonal frequency division multiplex ultra wide band intra-vehicular communication in the presence of plural mobile terminals.

The ZigBee is a key technology to design a wireless sensor network for various purposes. In [21,22], the authors design a monitoring and control system based on ZigBee wireless sensor network. In addition, it plays an important role in the intra-vehicle networks. However, few works have addressed this technology for intra-vehicular communications. In [3], the authors report the statistical characteristics of 4 representative intra-vehicle wireless channels on the basis of the results of received power measurements and verify the level of reliability of the channels. In [11], the authors propose another work to characterize the wireless channel for intra-vehicle wireless communication. In [17], the authors design and analysis a robust broad-cast scheme for the safety related services of the vehicular networks. In [18], the authors study the performance of ZigBee sensor networks for intra-vehicle communications, in the presence of blue-tooth interference.

Unlike all the aforementioned works, in this paper we design a ZigBee based wireless sensor network for intra-vehicular communications and evaluate its performance in terms of network reliability.

3 Design of IVWSNs

The main design of the intra-vehicle wireless sensor networks including two parts: link design between BS and SN and network scenario design. The link design presents the suitability of the communication parameters for single link in IVWSNs, such as transmit power and the distance between BS and SN. The network scenario design part presents the detailed description about IVWSNs. We are explaining them in the following.

3.1 Link Design between BS and SN

In this sub-section, we study about the analysis of single link between BS and SN, since the design of a IVWSNs can not be separated from the study on the link between the different sensor nodes distributed in the vehicle. In order to do that, we have carried out a simulation through a discrete event simulation software, OPNET, with the relative packages for the ZigBee module. A pair of transmitter (i.e., SN) and receiver (i.e., BS) communicates each other within a vehicle. The BS collects the packets that are transmitting periodically by the SN. The BS and the SN are placed at a distance d. The Transmit Power set: $\{-10, -15, -20, -25\}$ dBm, which is suitable for ZigBee, such as the Crossbow MICAz MPR2400 [24]. The Carrier frequency is 2.4 GHz (ISM band). There are two channels 1 (a, b), which are for NLOS paths with Rayleigh fading. The path loss exponent γ for channel 1(a) 3 and for channel 1(b) is 4. The values of shadowing deviation $\sigma[dB]$ is 8. The suitability of the considered parameters has been discussed elaborately in our previous work [23].

Fig. 4 shows the behavior of the average throughput with the variation of distance between BS and SN for Channel 1 (a, b). The figure clearly shows a decreasing trend of the average throughput with increasing distance. The cause of this trend is due to the low power level of the packets arriving to the antenna of BS. We know that the path loss increases with distance and the effect of the log-normal shadowing involves a fluctuation in time of the received power, which can further degrade the performance of the communication. These fluctuations may lead the level of received power below the receiver sensitivity (-95 dBm). Then, the BS evaluates the received packet as noise and consequently, the packet is lost. From this analysis, we can see that the transmit power -15 dBm (both

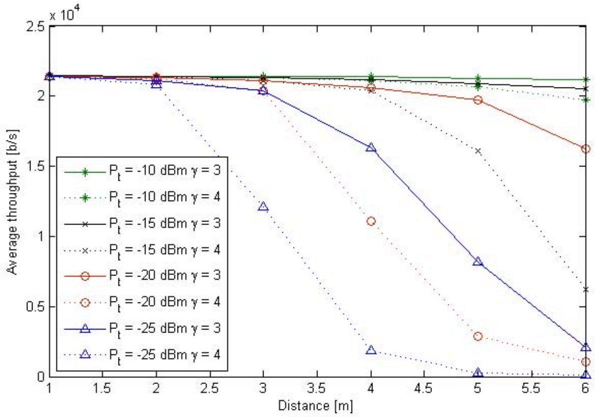


Fig. 4. Average throughput versus Distance between BS and SN with the varying of Transmit power

$\gamma = 3$ and 4) is suitable for IVWSNs. We also notice that when the distance between BS and SN is less than 4 the performance is very good, consequently, we can say the BS should be placed in the center of the car for getting good performance. The detailed analysis for single BS and SN is found in [23].

3.2 Network Scenario Design

There is only on BS that is placed in the center of the vehicle and several number of SNs are placed around it, as shown in Fig. 5. In this way, the distance between SN and BS will be less than any other scenarios where BS is set at any palace in the vehicle, as a result the BS can receive packets from the SNs with better signal strength. Two different SNs are considered: one is Green (G) and other is Yellow (Y), whose transmission period is 120 ms and 60 ms, respectively. We also consider four different cases according to traffic load in the networks. These considerations will help to measure the performance of the network while the traffic load is high. In case I, 100% Green, in case II, 70% Green and 30% Yellow, in case III, 50% Green and 50% Yellow and in case IV, 30% Green and 70% Yellow SNs will be from the total sensor nodes, see Table 1. The more number of Yellow SNs means the more traffic in the network because of its less transmission period. The number of sensor node set is {10, 30, 50, 70, 90, 110}. The communication parameters of the networks are as follows:

- Transmit Power: -15 dBM, as discussed in the previous subsections;
- Carrier frequency: 2.4 GHz (ISM band), which is used on ZigBee sensor node [24]
- Receiver sensitivity: The reception threshold of the BS is set equal to -95 dBm, typical for ZigBee [24];
- Transmission Period: 120 ms and 60 ms for Green and Yellow SN, respectively ;

Table 1. Considered Cases

Number of NS	Case I		Case II		Case III		Case IV	
	G	Y	G	Y	G	Y	G	Y
10	10	0	7	3	5	5	3	7
30	30	0	21	9	15	15	9	21
50	50	0	35	15	25	25	15	35
70	70	0	49	21	35	35	21	49
90	90	0	63	27	45	45	27	63
110	110	0	77	33	55	55	33	77

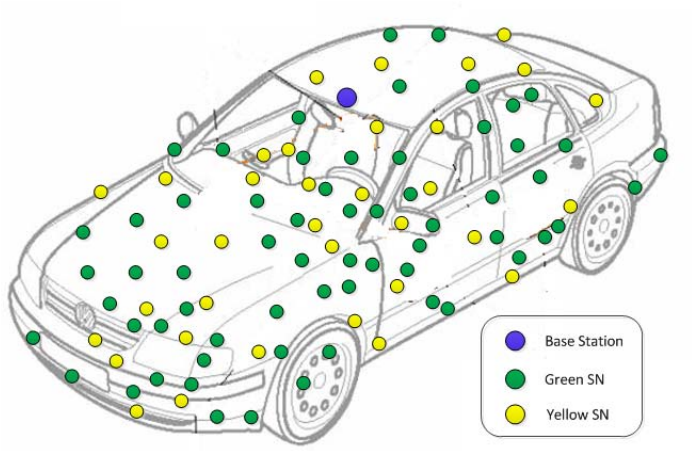


Fig. 5. Example of SNs distribution inside the vehicle

- Channel: The channel is for NLOS paths with Rayleigh fading. The path loss exponent γ is 4. The values of shadowing deviation $\sigma[dB]$ is 8. These values are suitable for intra-vehicle communication [3,11].
- Packet size: 210 bits (ZigBee packet header 120 bits + data 90 bits);

  Remark 1. 90 bits for data is selected with the reference of CAN message used in [13].

- Parameters MAC:
  - ACK Mechanism:
    - ACK Wait Duration: 0.05 second;
    - Number of retransmissions: 5.
  - CSMA-CA Parameters:
    - Minimum Backoff Exponent: 3;
    - Maximum Number of Backoffs: 4;
    - Channel Sensig Duration: 0.1 second.

4 Network Reliability

In this section, we define the network reliability, which will be utilized for measuring the performance of the network. The definition is in the following:

Definition 1 (Network Reliability R). *Network reliability is defined as the ability to deliver the packets to the destination (BS) within a certain time limit (called Deadline). The expression of the reliability can be written:*

$$R = P_r(D_{ete} \leq D) \tag{1}$$

were R is the network reliability, D_{ete} is the end to end delay (i.e., the overall delay between the time instant when it creates a package from the application layer and the time instant when it is received) and D is the deadline (i.e., the limits on the chosen end-to-end delay of the packet).

Remark 2. In this paper, we consider two deadlines: one is called restrictive deadline denoted as D_1 and other is called less restrictive deadline denoted as D_2. Note that D_1 and D_2 represent 25% and 50% of the maximum SN transmission period, i.e., 120 ms. This consideration is reasonable because less end to end delay of the packet increases the reliability of the network due to its less packet retransmission.

5 Simulation Results

In this section, we analyse the reliability of the network, varying of traffic load, by taking account of Definition 1. Due to the increasing of traffic load, the intra-vehicle network becomes congested. The effect of congestion on the network is also investigated. In order to assess the level of reliability, we have carried out a series of simulations through a discrete event simulation software, OPNET, with the relative packages for the ZigBee module. The performance of the network is measured based on this network reliability.

In Fig. 6, we report the CDF of the end-to-end delay versus the number of nodes for analyzing the reliability in the case I. From the figure, we notice that as the number of SN increases in IVWSN, the CDF shift to the right. The cause of this performance is due to the collisions among the packets, which increases with the increasing number of SN in the network. In fact, after the collision SN waits for a certain period of time (Backoff + sensing period) and then if the channel is free, it retransmits the packet that already caused collision previously. The new re-transmissions can be subjected to other collision. The repetition of the procedures is explained under the CSMA-CA protocol. It is easy to understand at this point that the increasing number of collisions results the increasing end-to-end delay experienced by the packets.

As in the first case there is only Green SN and the considered deadlines are $D_1 = 30ms$ and $D_2 = 60ms$. As it can be seen in Fig. 6, the condition on less restrictive deadline, D_2, is fully satisfied, as shown in Table 2. On the other

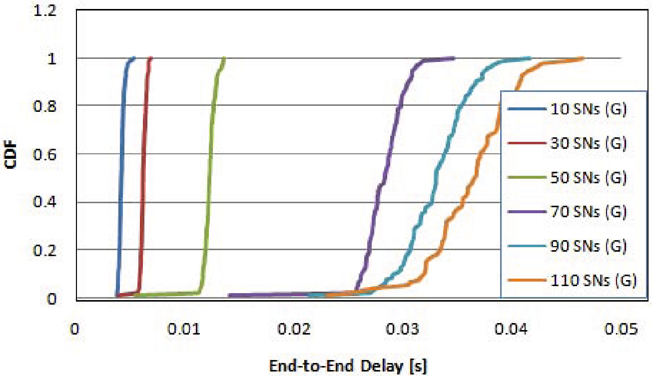


Fig. 6. CDF of end-to-end delays Vs the number of nodes in the case I

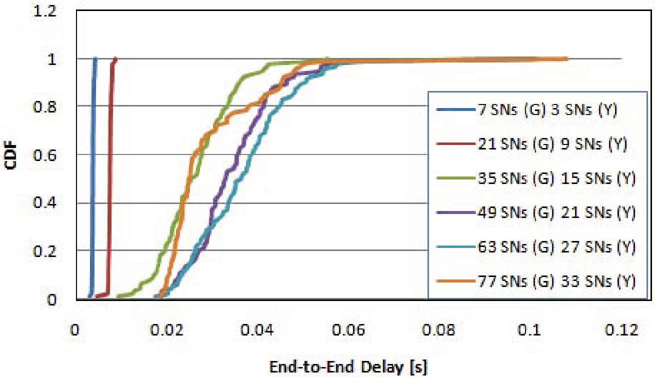


Fig. 7. CDF of end-to-end delays Vs the number of nodes in the case II

hand, the restrictive condition, $D_1 = 30ms$, it is satisfied in the case of 10, 30, 50 and 70 SNs, while in other cases (90, 110 SNs) are satisfied with a probability not adequate (about 16% in best case) in terms of reliability.

We also report the CDF of the end-to-end delay versus the number of nodes for analyzing the reliability in other cases, as shown in Fig. 7 - 9. The above figures show that the introducing of more Yellow SNs in the network, the end-to-end delay is increasing i.e., the reliability of the network decreases. In fact, in the case I with 70 NS, the reliability is 100% for less restrictive deadline. D_2, whereas in case II, this falls to about 96% and continuously falling while increasing in the number of Yellow SNs in the network.

In addition, the increasing number of SN, in particular when it increases the number of Yellow SN, in the intra-vehicle WSN is subjected to the phenomenon of congestion. In fact, increasing the traffic up to a certain point where the network is no longer able to handle the traffic then it enters into congestion. As a result a number of transmitted packets (including retransmitted packets) by SN

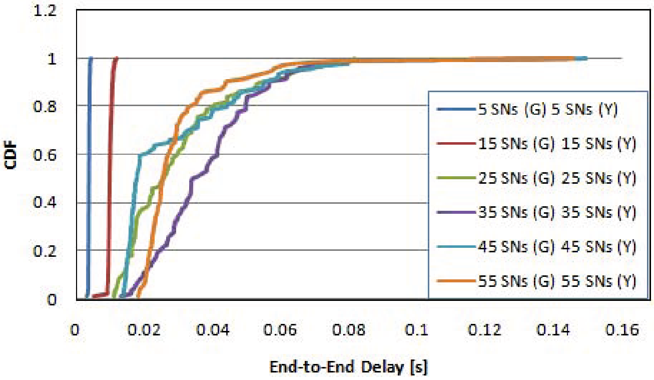


Fig. 8. CDF of end-to-end delays Vs the number of nodes in the case III

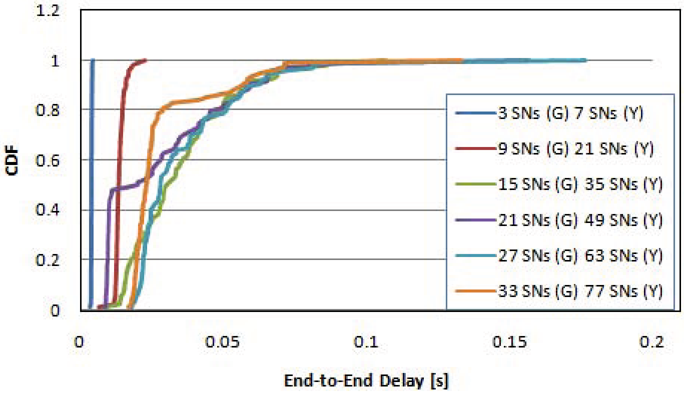


Fig. 9. CDF of end-to-end delays Vs the number of nodes in the case IV

never reaches its destination. Higher the degree of congestion of the network, the greater will be the number of packets that never arrives at the destination. The Table 2 summarizes the results obtained in four cases, the results highlighted in bold are "distorted" due to congestion of the network. The phenomenon of congestion decreases the end-to-end delay that causes the distortion of the results, since in OPNET the end-to-end delay is calculated on the basis of packets that reach to their destination.

To mitigate the problem of congestion, we introduce two BSs in the network. Each BS is consisting of 50% SNs from the total SNs. In Fig. 10, there is 90 SNs with half Green and half Yellow SNs in case of both single and double BS. We note, in case of single BS, initially the result is distorted due to the large number of packets that do not reach to the destination because of the congestion in the network. In case of double BS, there is no congestion effects because of the proper traffic load distribution. However, introducing additional BS increases

Table 2. Reliability in Different Cases

Number	R in case I		R in case II		R in case III		R in case IV	
of NS	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2
10	100%	100%	100%	100%	100%	100%	100%	100%
30	100%	100%	100%	100%	100%	100%	100%	100%
50	100%	100%	72%	97%	52%	90%	45%	87%
70	92%	100%	40%	96%	25%	88%	**66%**	86%
90	16%	100%	30%	95%	**62%**	**89%**	**63%**	**87%**
110	6%	100%	**65%**	75%	**77%**	**92%**	**82%**	**89%**

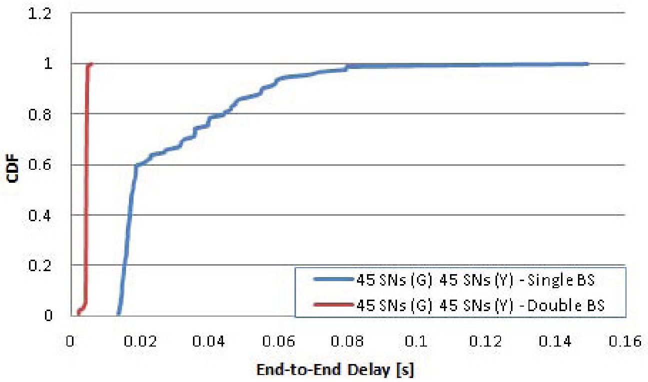


Fig. 10. Comparison between CDF in the case of single BS and double BSs

the design complexity of the networks. Therefore, a new MAC strategy can be designed for congestion network that will be the future direction of this work. We will also investigate the performance by introducing the concept of cognitive radio in intra-vehicle wireless sensor networks [25]-[30].

6 Conclusion

In this paper, we design a wireless sensor network for intra-vehicular communication. We define the network reliability in terms of end-to-end delay to measure the performance of the networks. After the analysis, we note that, the phenomenon of congestion plays an important role in the network while the traffic load is high. To mitigate the congestion problem, we could increase the number of BS in the network. In fact, introducing additional BS increases the design complexity of the networks. Therefore, a new MAC strategy can be designed for congestion network that will be the future direction of this work. The simulation results assist to design a robust system for intra vehicular communications.

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