V2I Technology and Energy Efficient Solution using Zigbee
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Abstract— Vehicle communication provide useful information from networks to vehicle such as road traffic, car accident and road construction to avoid delays and accidents. It also provide useful information from vehicle to information networks for usage in road traffic calculation and accident warning, and help in better traffic management for Intelligent Transportation System. In this paper, we overview the communication as it is probably the next generation communication for vehicles to communicate. We propose the prototypes of the road side equipment (RSE) and the on-board equipment (OBE) for communication between vehicles and road side stations based on and Zigbee wireless technologies. The experiments and results of the prototype under various vehicle operation tests are shown. The results have shown the possibility of using Zigbee as the communication protocol and device for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Key words: Energy Efficient Solution, V2I Technology

I. INTRODUCTION

The continuous increase of traffic volumes and the limitation of road network extension, especially in dense urban areas lead to the necessity of introducing and continuously improving complex traffic management systems (TMSs). Intelligent systems, containing traffic detectors, adaptive control and user information services increase the efficiency of the road network, in terms of capacity management and level of service. Infrastructure development and new technologies are now integrated with communications and allow for collecting useful on-board information, assisting drivers on the route. In urban areas, TMSs may integrate public transport management or emergency management in order to provide faster routes for special vehicles, considering that, in congested peak hours, the usual TMS algorithm cannot provide enough improvement for vehicle delays. There are some ways to provide a faster vehicles' transit through junctions, the most frequent being the extension of green time, if the vehicle approaches the junction during green period, or reducing red time if the vehicle approaches the junction during red period. For the public transport vehicles (PTVs), priority may be given at all times (this being usually possible if there is provided a dedicated PTV lane) or the PTV should receive priority only if it is running late. The situation is different for emergency vehicles in mission. The Vehicle to Infrastructure interaction, Similarly to V2V, is based on wireless communication technologies. The main traffic safety goals of such systems are well summarized by USDOT's (U.S. Department of Transportation) Connected Vehicles Program. V2I is the wireless exchange of critical safety and operational data between vehicles and highway infrastructure, implemented formally to avoid accidents and also to enable lots of safety measures. V2I communications apply to all vehicle types and all roads, and transform infrastructure equipment into “Smart Infrastructure”.

A. Architecture

Several V2I architectures can be found in the different research papers. But generally these systems consist of the same key components, on the basis of which a general framework can be defined. The minimal V2I system should contain the following parts:
- Vehicle On-Board Unit or Equipment (OBU or OBE)
- Roadside Unit or Equipment (RSU or RSE)
- Safe Communication Channel

Fig. 1: Minimal V2I system

B. Wireless Technologies

1) DSRC
2) Bluetooth
3) WiFi
4) Mobile networks
5) Short range radio

C. Applications

As mentioned above the V2I systems are closely related to the V2V communications. Most of the V2I applications rely on the V2V on-board units, so these applications can commonly called Intelligent Transportation System (ITS) applications. Naturally several applications currently exist which based only on roadside sensors, typically which require only observation (e.g. toll control, speed measurement etc.).
D. Safety
The safety applications aim to decrease the number of accident by prediction and notifying the drivers of the information obtained through the communications between the vehicles and sensors installed on the road.

![Example safety applications with the integration of DSRC and roadside sensors](image)

Fig. 2: Example safety applications with the integration of DSRC and roadside sensors

The typical safety applications could be the following:
- Warning for hazardous situations (such as congestions, accidents, obstacles etc.),
- Merging assistance,
- Intersection safety,
- Speed management,
- Rail crossing operations,
- Priority assignment for emergency vehicles.

E. Efficiency

1) Zigbee
The possibility of employing ZigBee communications for vehicle-to-infrastructure (V2I) communications is possible. Such communications require less energy consumption, compared to other technologies and are recommended for dense urban areas, where the density of infrastructure equipment reaches higher levels and involves significant power consumption. A prototype for vehicle identification using ZigBee protocol is presented as a solution to test V2I communications in laboratory conditions. For all applications it appears that the first step in the process of granting priority in a junction is to detect or identify these special vehicles. In the following sections of this article, several detection solutions are analysed and a ZigBee communication solution based on detection is presented.

2) Vehicle Identification
Optical identification this technical solution employs a high intensity light beam (e.g. white light for emergency vehicles or white light with infrared filter for other transmitting vehicles) that is sent by a device placed on the vehicle. The light is programmed to illuminate using a very high frequency code, to be distinguished from other light sources in the area. Different codes may be associated with different vehicles. As specific vehicles categories are identified, the system may implement different priority measures depending on the emergency type and other specific traffic factors.

Magnetic signature detection another method to identify vehicles is taking advantage of inductive loops. The solution is based on a transmitter placed under the vehicle requiring priority, an inductive loop and a standard detecting unit, with an additional frequency demodulator. The device on the vehicle continuously broadcasts a code representing a unique vehicle identifier. The detection unit decodes the signal received from the vehicle, and identifies its category. This information is then sent to the traffic controller, which decides the proper TMS response. Magnetic signature may be detected also with magnetic sensors, which evaluate the unique influence of each vehicle on the Earth’s magnetic field. These variations are identified and, hence, vehicle counting and even classification is possible. There are some debates regarding the efficiency of such method in jam conditions, but some solutions have been proposed to overcome this downside. V2I communication Many modern improvements in traffic management and information systems include communications between vehicles and vehicle to infrastructure communications. As the infrastructure communication system already is in place adding vehicle detectors in the road network are usually a simple task. The device may be active or passive (only being detected, without the capability of transmitting radio signals). The V2I communication system for this application may be based on a large variety of data transmission protocols. The basic features that must be considered in the implementation of the network are:
- Communication does not include critical data: the impossibility of transmitting proper data or the delays in communication do not directly imply the occurrence of traffic events.
- Data rate is very low: only the vehicle ID, along with encryption coding is transmitted, hence the communication speed is ensured by all the available protocols.
- Communication range is usually provided, especially for public transport vehicles, as they travel on the first lane, very close to the devices installed near the road. However, some elements must be additionally considered such as interferences from other communication networks that may be already implemented and which can significantly reduce the usual communication distance. From the considerations above, we conclude that all of the most frequently used wireless protocols (WiFi, DSRC, Bluetooth, ZigBee etc.) may be used for V2I communications for vehicle identification purposes.

Due to the fact that all the above features are provided no matter the choice made, we shall introduce a new criterion in order to be able to decide what may be the optimal solution: the energy efficiency. From the list above the only protocol that was especially designed to be energy efficient is ZigBee.

3) The Zigbee Protocol
The Zigbee protocol represents an alternative to Bluetooth and WiFi communications, being developed to ensure better energy consumption, even with the downside of lower data rates. Its specifications were set in back in 2004. After more revisions, ZigBee PRO was defined in 2007. The newest version of the protocol is ZigBee 3.0, being set in 2015. The ZigBee standard is built on forpacketbased wireless communication and enhances its functionality by providing flexible, extendable network topologies with integrated setup and routing intelligence to facilitate easy installation and high resilience to failure. ZigBee networks may co-exist with Bluetooth and Wi-Fi, as they incorporate listen-before-talk protocol and rigorous security measures. The ZigBee
standard operates in the 2.4 GHz band worldwide, but has various implementations, such as 784 MHz (China), 868 MHz (Europe) or 915 MHz (USA and Australia). For 868 MHz and 915 MHz bands binary phase shift keying (BPSK) is used, and for the 2.4 GHz band offset quadrature phase-shift keying (OQPSK), that transmits two bits per symbol, is employed. The data rate has a wide variation depending on the implementation, ranging from 20 kbit/s to 250 kbit/s. Related to road traffic communications purpose, the ZigBee technology has the advantage of being more flexible and allowing networks to be easily adjusted to changes by adding, removing or moving network nodes. The protocol is designed such that nodes may appear in and disappear from the network, making it very adaptable and proper for V2I communication. Another big advantage of a ZigBee network is that it can easily be installed and configured.

There are three methods to create a ZigBee network: preconfigured, self-configuring and custom.

- Pre-configured system: all parameters are configured by the manufacturer, and the system cannot be modified or extended.

- Self-configuring system: installed and configured by the end-user. The network is set up by "discovery" messages sent between devices. After that, the system can be easily modified or extended, due to detection of nodes added, removed of moved and automatic system adjustment. This solution is even employable in automatic configuring and self-repairing networks.

- Custom system: is adapted for specific applications/locations. It is designed and installed by a system integrator using custom network devices. The system is usually configured using a software tool.

F. Case Study: V2I Communication Test

A prototype system for vehicle identification using ZigBee protocol was implemented in the laboratory using an Arduino Uno module with XBee shield. The system had two components: - A subsystem in the vehicle - consisting of an on-board computer that manages on-board components and ensures data transmission to ground equipment, a GPS receiver that allows the on-board computer to determine vehicle’s position, and a ZigBee communications device. This subsystem may include a database that contains the timetable in order for the vehicle to request priority only if it’s late, but for the demonstration purpose it was considered that the system is able to provide priority for all the vehicles.

- A subsystem installed on the road side, which is in connection with the traffic controller (or is directly placed into the traffic controller cabinet – depending on its position) that receives vehicle information and, based on the data, decides the proper signalling plan that minimises the vehicle's delay. For the decision process all the vehicles that need to pass through the intersection must be considered in the minimization algorithm, so there will be no direction receiving an disproportionate green time while for other entrances the waiting time become excessive where TMC represents the Traffic Management Centre. The test was aimed to verify the capability of a mobile device to determine its location and, if the process of detection may be carried on in a pre-determined area (in the proximity of a fixed access point), to send a message to the traffic controller. The configuration employed a master-slave architecture (with a Coordinator and an End Device). Typical Arduino modules were used, one being connected to a PC and the other one being programmed and functioning as a mobile device.

![Fig. 1: Communication test diagram](image)

For the PC connection

An XBee Explorer module is connected to the PC using an USB cable. X-CTU application is started. The main window of the application, which presents some explanations regarding possible actions is shown in Figure 2. The XBee module previously connected is added using "Add devices" button. The communication parameters (that are used in the process of new modules detection) are set as shown in Figure 3.

![Fig. 2: X-CTU software](image)

![Fig. 3: ZigBee configuration dialog box](image)
After the module is properly identified, the module parameters window is shown (Fig. 4).

Fig. 4: ZigBee module parameters dialog box

The efficiency applications can support the better utilization of the roads and intersections. These functions can operate locally at an intersections or a given road section, or in an optimal case on a large network, such as a busy downtown. It is important to note that the efficiency applications also have a beneficial effect on safety in most cases.

The following typical applications can enhance the traffic efficiency:
- Traffic Jam Notification,
- Prior Recognition Of Potential Traffic Jams,
- Dynamic Traffic Light Control,
- Dynamic Traffic Control,
- Connected Navigation

Fig. 5: Dynamic traffic control supported by DSRC (Source: http://www.car-to-car.org/)

G. Payment and Information

The number plate recognition serves as base for the payment applications, which is well-tested and reliable camera-based technology. The payment applications could be the following:
- Parking control,
- Congestion charge,
- Highway toll control.

The information services can be typically the conventional variable traffic signs or temporary road signs supplemented with a DSRC beacon.

II. CONCLUSION

From the tests performed it resulted that the mobile device’s positioning is hardly dependant on environmental conditions (location of the Coordinator and the End Device, number of satellites that may be seen by the GPS receiver) as well of weather conditions (also influencing the signal from GPS satellites).

The next step will be to define, including all the potential influencing factors, the conditions in which such system can be implemented in order to provide a proper data transfer. ZigBee’s main intended advantage against other wireless communication devices was the lower energy consumption. The rough comparison with Bluetooth reveals that Zigbee-based devices may have 1mW RF output power, while Bluetooth Smart (low energy version of Bluetooth) specify 0.01 ... 0.5W energy consumption (1W for classic Bluetooth). The difference in energy consumption is multiplied in a complex urban network by the number of devices, thus result a significant energy efficiency of such system compared to others. Additional tests are intended to be performed in various (outside) environments, also implying data transfer in order to evaluate data rate, as well. The future research may also focus on employing an ad-hoc network of V2V to extend locally the communication range, where only selected vehicles transmit data, and nearby vehicles are used exclusively to relay data transmission to access points in the roadside. But this remains a subject for another development.

REFERENCES


