Sensor Communication in Automotives

Wireless Automotive Sensor Network-ZigBee

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***Abstract*—Today, Sensors are found every where in an automobile. The sensors are integral parts of an automobile. The uses of sensor modules are rapidly increasing, and are finding extensive application today - also will do more in the future, generating a lot of data. The data sensed by these sensors have to be efficiently communicated to the corresponding ECUs and/or sensor nodes. Placing of the ECUs and the sensor modules is in itself a challenge; this is compounded with the increasing number of sensors used in today's automobiles making it a big challenge to design a communication system for them.**

Further, the automobiles have to abide by strict rules, legalities and regulations based on environmental safety, human safety, comfort requirements, energy consumption requirements, media and entertainment requirements and many more applications. This further complicates the already existing design challenge. The existing communication systems and standards in the automobiles are largely wire based, entailing the wiring system in the automobiles very complex, bulky and expensive. Imperatively, the solution for this would be the use of Wireless Automotive Sensor Networks (WASN). Here, the Wireless Automotive Sensor Network is discussed in detail with significance to ZigBee. Currently, the use of ZigBee is made in many fields especially where sensors are being used. Since, ZigBee can be implemented in small sized sensor nodes; it forms a promising alternative to the sensor communication systems in the automobiles.

Keywords*—Zigbee; sensor communication; communication in automotives; automotive sensors; wireless automotive communication network; WASN;

I. INTRODUCTION

Communication has been an active area of research in the field of automotives since the last decade. The automobiles today have to adhere to several rules and regulations conforming to safety and pollution standards. Several of these are extremely strict in nature. There are several other features built in order to satisfy the market demands, where in the energy consumption and comfort plays a major role. Some of these features are the Anti-lock braking system, Tire pressure monitoring system, Oil pressure monitoring system, Exhaust gas monitoring system, and many more types of systems like weather tracking, GPS communication, or road conditions etc. All these system contain sensors which sense the data and communicates to other sensor modules or the Electronic Control Units (ECUs) for further processing and usage. By every passing day a large number of features are being added in the automobiles & is increasing at a rapid pace. The addition of new features is stressing the communication system currently in use. The figure 1 below depicts the different locations where sensor nodes are generally placed in an automobile.

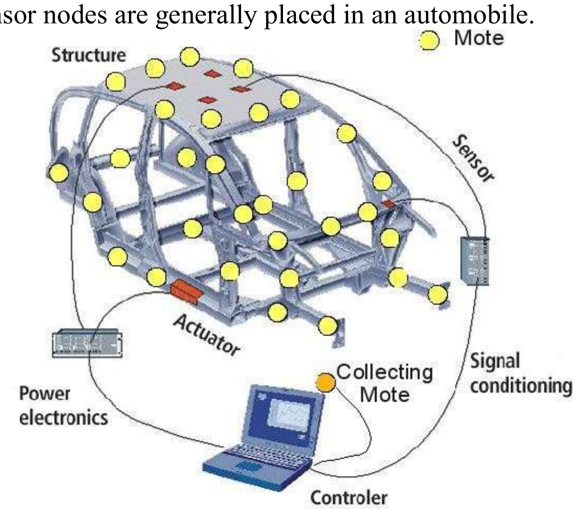

Figure1:Sensor position in an automobile Source[6]

Most commonly used communication system in the automotive domain is the CAN bus system, along with other bus system like Flex Ray and the LIN. Media Oriented Systems Transport (MOST) is used for multimedia application due the requirement of high throughput. Majority of these busy stems are wired with an exception of MOST, which may be optical fiber cable. Whether metallic or optical, these systems need kilometers long cables to be installed in the automobile. The different kinds of communication systems used in the automobiles are shown in the figure 2

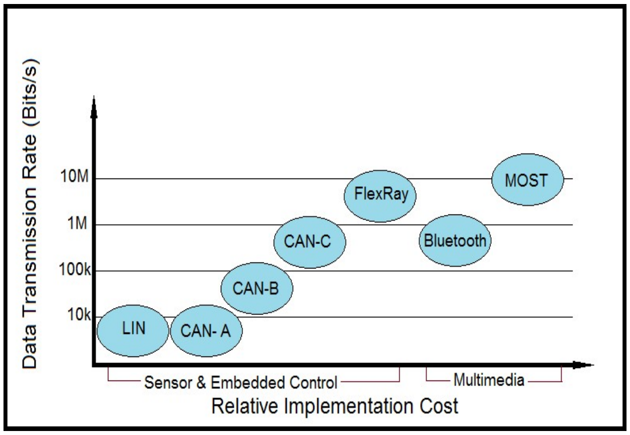

Figure 2: Different kinds of automotive communication system Data Source [5]

The presence of more than 150 kinds of sensors, and switches requires highly complex, bulky and expensive wiring system. It is estimated that the wiring system alone adds around 50kg to the vehicle's weight.

II. AUTOMOTIVECOMMUNICATIONSYSTEMS

A. *Traditional Automotive Communication Systems*

The Society of Automotive Engineers (SAE) in 1994 has classified the automotive communication protocols into Class A, Class B & Class C based on the data transmission rates. Class D was added later with increase in transmission rate.

Class A consists of low data rate with a speed of up to 10kbps e.g. CAN A, LIN etc. This is normally found in application of less criticality and simple systems such as window control, seat control. Class B consists of a data rate greater than 10kbps to 125kbps and found in non- critical communication, emission data systems e.g. CAN B (low speed CAN). Class C consists of a data rate from 125kbps to 1Mbps and generally found in high data rate and real time application including safety critical applications e.g. CAN C (high speed CAN) [1].

B. *Wireless Automotive Communication Systems*

As discussed earlier, the wired communications have several challenges and drawbacks including the weight, complexity of design, the placing of ECUs and sensor modules among many others. To overcome these challenges, wireless communication forms the solution. In the recent years, several wireless technologies have been invented, based on which different kinds and versions of wireless sensor devices have been designed. Some of these technologies include the Bluetooth, WiFi and ZigBee [7].

Bluetooth is an IEEE 802.15.1 standard communication protocol, which is currently one of the highly used technologies for intra-vehicle communication and inter-device communication. It has a bandwidth of 12Mbps with a range of 100m. It operates in the ISM frequency band (2.4GHz). Its special features are the dominating PAN and easy synchronization. It is based on Master-Slave architecture wherein one master can communicate with 7 slave devices. WiFi is primarily used in vehicle to vehicle and vehicle to infrastructure communication. It operates in the frequency band of 2.4GHz. It has a bandwidth of 54Mbps with a range of 100m.MainadvantageofWiFiisthedominatingWLAN and the wide availability. The gap left by these technologies can be filled by ZigBee especially in the inter-vehicle and the vehicle to infrastructure field. It was originally released in 2004. It has a bandwidth of 250kbps with a range of around 100m. It operates in the frequency range of 2.4GHzin most regions of the world, while in Europe it is 868MHz (the bandwidth is 20kbps) and 915MHz (the bandwidth is 40kbps) in US and Australia. It can connect up to 255 devices. Unlike Bluetooth and WiFi, which are high power consuming devices and expensive, ZigBee devices consume very less power and is a low cost device. This low power feature of ZigBee makes it the ideally suited communication protocol for a wireless sensor module, which is highly power efficient in its functioning.

III. ZIGBEECOMMUNICATION PROTOCOL

ZigBee is low cost, low power communication standard designed for devices such as sensor modules. It operates in the ISM frequency band. ZigBee provides a data rate ranging from 20kbps in 868 kHz band to 250kbps in 2.4GHz frequency. ZigBee can be used in devices and networks where high data rate is not required. It can have star, mesh or P2P topology. A networkmayhaveupto65,535 ZigBee nodes. ZigBee is based on IEEE standard 802.15.4 and build upon its physical and medium access control layers. A ZigBee device can change from sleep mode to active mode in just 30ms (while a Bluetooth device takes at least 3s). Currently, ZigBee standards are developed and available for eight domains, which include Building Management, Consumer Electronics, Energy Management, Health Care, Home management, Retail Management and Telecommunications.

CSMA (carrier sense multiple access) is used in ZigBee for communication. Low power consumption, longer battery life and elimination of polling are achieved due to CSMA. The chief driver for using ZigBee for sensor nodes is that it is developed mainly for sensors and control application, it uses less power and it is low cost. The time needed for mode change from sleep to active is also extremely low. These factors make it ideal for wireless sensor nodes.

A. ZigBee Stack Architecture

The ZigBee protocol stack extends the physical layer and the Medium Access Control defined in the IEEE standard 802.15.4 by building upon it. The ZigBee stack architecture is made up of blocks called layers, consisting of Application layer, Network layer, Medium Access Control, and Physical Layer. The figure 3 shows the typical architecture of the ZigBee protocol stack.

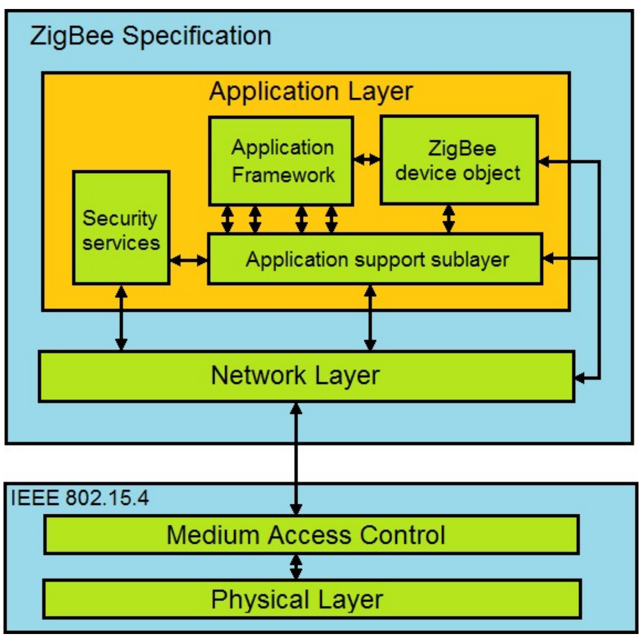

Figure3:ZigBeeprotocolstackarchitecture
Data Source[8]

The Application layer is highest layer defined by the ZigBee specifications. It includes the Application Framework, ZDO (ZigBee Device Object), Security services and the Application support sub-layer. The Application sub-layer is responsible for maintaining the binding tables, which helps in connecting different devices and transferring messages from one device to another. Another major role of Application sub-layer is to identify devices operating within its network. ZigBee Device Object(ZDO) defines the role advice plays in a network like coordinator or end device etc. Its responsibilities also include, initiating a request, responding to requests and establishing communication between different devices in the networks.

Network Layer provides an interface between the Application layer and the Medium Access Control (MAC). It enables the proper usage of the MAC sub-layer. It helps in the routing of the messages. Its responsibilities include, establishing a network, join a network or leave a network and configure the stack for the required operation .It is this layer that assigns address to the new devices that joins the network. It synchronizes one device with the other either by tracking the beacons or by polling. Adding security frames to the messages while sending and removing them when receiving is also the job of the network layer and also routing the messages to their destination nodes.

Two Physical layers (PHY) are defined in the IEEE standard 802.15.4. One PHY layer is responsible for the communication in the lower frequency bands of 868kHz (Europe)and915kHz(US and Australia).The other PHY layer serves the higher frequency band of 2.4GHz used virtually in the rest of the world. The MAC sub-layer is responsible for transmitting the beacon frames, providing the synchronization mechanism and also reliability in transmission. It controls the channel using CSMA/CA mechanism.

B. ZigBee Device Types and Topology

The ZigBee specifications define three types of devices, the ZigBee Coordinator, the Full Function Device (FFD) - also called the ZigBee Router (ZR) and the Reduced Function Device (RFD) – the ZigBee End Device (ZED). The IEEE 64-bit addresses are used in these devices with an option of shorter addresses. This reduction helps in the operation of the device in either addressing modes- star or P2P.

The ZigBee Coordinator is the most important and capable device. In a tree it forms the root. The Coordinator is the device which can bridge one network to the other. There can be only on coordinator in one network. This coordinator is the device which stores the information about the network. It is the one which initiates a network. It is generally the first component in a network. It is a fully functioning device which can route messages from one node to another and also perform actions for the application.

The ZigBee Router is a full function device which can act as an intermediate device passing data from one neighboring device to another. It also runs the application function. The ZigBee End Device has functionality enough only to communicate to its parent node (which may be ZC or ZR) and run the application. Hence, it may go to sleep mode whenever it is not required to be active. This helps it to retain the battery power, in turn increasing life time of the device. Unlike the Coordinator or the Router, an End Device cannot pass on the messages from other nodes. It can only function as a sensor module communicating with its router or coordinator. These devices form a network in the form of a mesh or star.

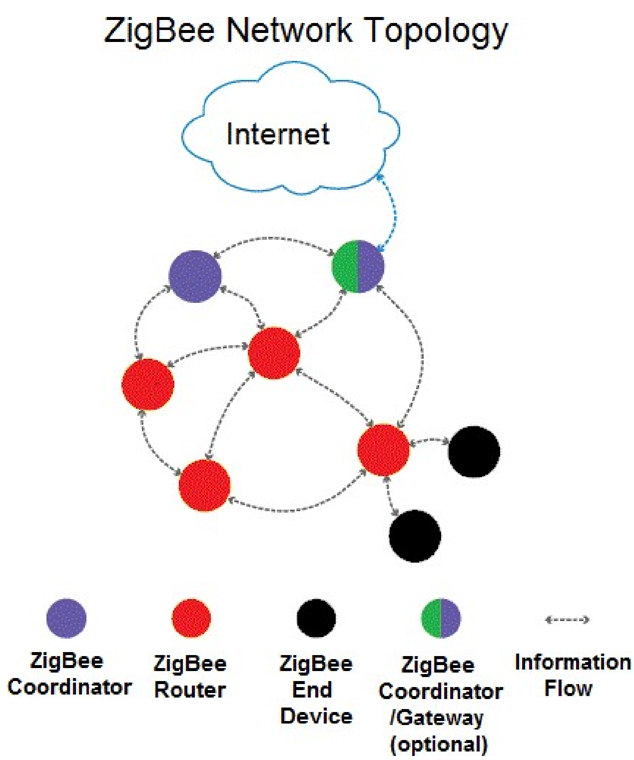

Figure4:The ZigBee devices in a Network Source[3]

C. Formation of a ZigBee Network

The first device in a network is the ZigBee Coordinator. Whenever a node wants to form a network, it first scans the available energy and channel. Then it scans if other networks are already present in the channel. The ZC selects the best channel available. Once the channel is selected the Coordinator assigns a PAN ID (Personal Area Network ID) to the network. This PAN ID is sometime pre-determined and sometimes allotted dynamically based on the other networks, making sure that a conflicting ID is not used. Then the coordinator assigns a short address in order to identify it self to other Nodes within its network.Thisgenerallyis0x0000.Then the coordinator completes self configuration and becomes the coordinator of the network, after which it is ready to accept other nodes into its network.

When a new node wants to join this network, it first scans the channel and checks for the available networks and decides which network it has to join. Many networks may be operating on the same channel, but are differentiated using their PAN Ids. The new node may notice more than one Router along with a co coordinator in a given network. Then it has to select anyone of them as a parent node. After choosing a particular router node as parent node, this new child node sends a request to join message to the router/coordinator. The router/coordinator node decides whether or not to allow the new node to join its network. This is dependent on whether the coordinator is allowing new nodes to join at the given time, and has enough address space to allocate for the new node. The coordinator then allocates an address to this new child device.

When leaving the network, the node must remove all the associations with other nodes, especially the children nodes before leaving the network.

D. ZigBee Data Traffic Types

IEEE 802.15.4can accommodate different kinds of data types. The data can be periodic, intermittent or repetitive. ZigBee employs two kinds of modes, beaconed and non-beaconed for data communication. Beaconed is generally used when the coordinator has high power resource constraint, while non-beaconed mode is used when the power availability is not a constraint.

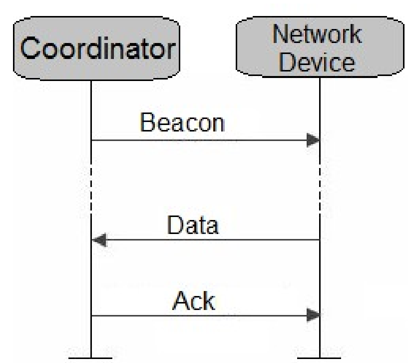

Figure5: Beacon enabled source[8]

In the beaconed enabled mode, the end device and the routers keep waiting for the beacon message from the coordinator, which is transmitted periodically and checks for the messages addressed to it. After completion of the transmission of the message the coordinator sets and informs the schedule for the next message, so that the device can go to sleep mode till then. In some cases even the coordinator itself may go to sleep mode. In beaconed mode, almost all the nodes know the time when to communicate with other nodes. Hence, it has complex timing circuitry in order be accurate, if not the nodes will have to be awake a little earlier. This may increase the power consumption of the coordinator.

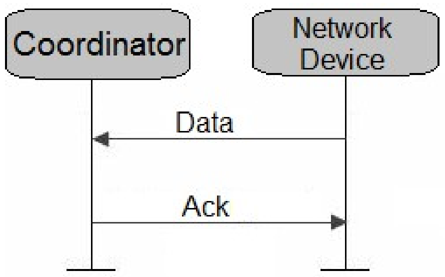

Figure6:Non-beaconenabledsource[8]

In the non-beaconed mode the nodes are almost always in the sleep mode. They wake up in random intervals and inform the network about its presence. When evera message/data is detected, the nodes wakeup and transmit to the coordinator which is continuously awake. In case the channel is busy then the node will miss its chance to send. However, this is a very rare occurrence.

E. Comparison with other technologies

There different popular wireless technologies available for use in automobiles. Prominently among them are the ZigBee, Bluetooth and WiFi. Table 1 gives a brief comparison of all these technologies. It can be noticed from the table that the range of all the technologies is around 100m. However, the difference lies in the Bandwidth, data throughput, the power efficiency and the number of devices that can be connected in a network.

It can be seen that ZigBee is the technology which requires the least power and hence most suitable for the sensor nodes and network in the automotive domain [7]. However, ZigBee cannot be used when high speed data throughput is required as in multi-media applications. For such applications Bluetooth or WiFi forms an alternative solution.

It has now been proved by de Fransico et al. that ZigBee and Bluetooth can coexist in an automobile without much effect on the operation[10].However, Further research is needed to confirm the same in all conditions.

Standard	**ZigBee (802.15.4)**	**Bluetooth (802.15.1)**	**WiFi (802.11)**
Application in vehicles	In vehicle & vehicle to infrastructure	In vehicle& inter device	In vehicle & vehicle to infrastructure
Range	100m	70m	100m
Bandwidth	250kbps	12Mbps	54Mbps
Frequency of operation	2.4GHz*	2.4GHz	2.4GHz
Features	Low power Low overhead Multiple devices	Dominating PAN Easy synchronizatio n	Dominating WLAN Widely available
Drawbacks	Low Bandwidth	More Power Limited number devices	High Power

Table1:Comparison of different wireless technologies
Data source[7]

IV. APPLICATIONS

The use ZigBee can seen in several applications, found in many different domains. However, in automotive field ZigBee is quite new and hence very few applications have been developed as on date. This slow pace of development may due to the high reliability requirement of the automotive field, even though ZigBee is one of the most suitable technologies for automotive sensor modules. Here, one such successful implementation of this technology is discussed.

A. Tire pressure monitoring system

There are several drawbacks in the traditional Tire Pressure Monitoring System (TPMS). In traditional TPMS, challenges are faced in the transmission of the data collected. The reliability of these systems is also low. In order to overcome these challenges a team of students Wang et al. have developed ZigBee based TPMS. This new program monitors the automobile tire parameters dynamically and also transmits them wirelessly to a meter via wireless communication. ZigBee is used for the communication here. Star topology is used here in order to increase the speed ofthe data transmission and also increase its stability.

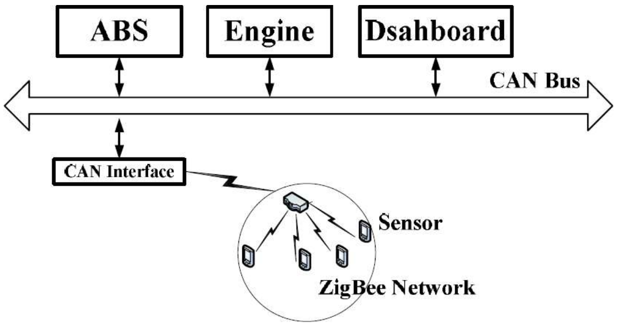

Figure7:ZigBeebased TPMS source[10]

This system is fixed in the tire and uses lithium batteries for power requirements. It uses ZigBee wireless technology for communication. The communication takes place between the ZigBee based TPMS module and the CAN bus. Hence, an MCU, ZigBee modules, and sensors are present in tire modules and is as shown in figure 9.

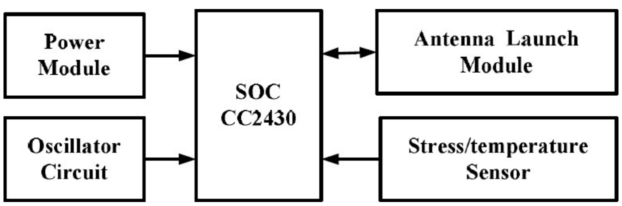

Figure8:TireModuleArchitecture source[10]

This system has several advantages, among which are the improvement of the anti-jamming ability and reduction in the problems faced by wireless transmissions. This further improves the reliability of the system. The TPMS and the ECU can be integrated together, reducing the number of wires used along with reliability and flexibility increase of the control system. This system also helps in the reduction of the cost and makes it easier for installation and maintenance.

V. CONCLUSION

ZigBee, no doubt forms one of the best option and an alternative for wired communication system, but none the less we need to consider certain points before we use ZigBee in an automotive communication system. Firstly, the data rate in the ZigBee is limited. Then followed by this is that, ZigBee may experience interference with other kinds of network like the Bluetooth and the WiFi, which use the same frequency band for the intercommunication. Even though it has been proved otherwise in some experiments, it is felt better to be skeptic about this fact, as only more experiments and research can clarify this. However, it has been reiterated in many texts that ZigBee is not an alternative to Bluetooth but is complementary. Further, it is to be noted that ZigBee standards for automotive domain is yet to be established. Also, since ZigBee is a new technology for automotive domain, it will require more work and more time for it to become ubiquitous.

Increasing requirements in vehicle functions is making the use of more and more sensors inevitably. This drastic increase in sensors is resulting in more and more wiring for communication. As discussed in the previous chapters, this increased wiring is making the design of the communication system a challenge. Hence, the solution is Wireless Automotive Sensor Network. Currently, with the constraints in costs and power consumption in a wireless sensor module, only ZigBee, being low cost and low power technology, can be one of the best options for automotive communication.

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