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Zigbee for intelligent transport system applications

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About the author

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Suggested keywords

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ZIGBEE FOR INTELLIGENT TRANSPORT SYSTEM APPLICATIONS

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Keywords: Middleware, Wireless sensor networks, ZigBee, Smartdust, and Intelligent Transport Systems.

Abstract

Wireless communication technologies are expected to be widely employed in the near future in Intelligent Transport System applications. The important innovations in wireless and digital electronics will support many applications in the areas of safety, environmental and emissions control, driving assistance, diagnostics and maintenance in the transport domain. It is evident that wireless communication technologies can be used in-vehicle, inter-vehicle and between vehicle and infrastructure in transport applications. Among the different possibilities, Bluetooth is currently the most widely used automotive wireless technology for in-vehicle communication while Wi-Fi is used for vehicle to vehicle communication by several pilot research projects. ZigBee also has a role, mainly in the interconnection of wireless sensor with vehicles and infrastructure.

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1 Introduction

A recent study by the UK Government's Office of Science and Innovation, which examined how future intelligent infrastructure would evolve to support transportation over the next 50 years looked at a range of new technologies, systems and services that may emerge over that period [1] [2]. One key class of technology that was identified as having a significant role in delivering future intelligence to the transport sector were wireless sensor networks and in particular the fusion of fixed and mobile networks to help deliver a safe, sustainable and robust future transport system based on the better collection of data, its processing and dissemination and the intelligent use of the data in a fully connected environment [3]. As future intelligent infrastructure will bring together and connect individuals, vehicles and infrastructure through wireless communications, it is critical that robust communication protocols are developed.

Mobile Ad-hoc Networks (MANETs) are self-organising mobile networks where nodes exchange data without the need for an underlying infrastructure. In the road transport domain, schemes which are fully infrastructure-less and those which use a combination of fixed (infrastructure) devices and mobile devices fitted to vehicles and other moving objects are of significant interest to the ITS community as they have the potential to deliver a 'connected environment' where individuals, vehicles and infrastructure can co-exist and cooperate, thus delivering more knowledge about the transport environment, the state of the network and who indeed is travelling or wishes to travel. This may offer benefits in terms of real-time management, optimisation of transport systems, intelligent design and the use of such systems for innovative road charging and possibly carbon trading schemes as well as through the CVHS (Cooperative Vehicle and Highway Systems) for safety and control applications. Within the vehicle, the devices may provide wireless connection to various Information and Communications Technologies (ICT) components in the vehicle and connect with sensors and other nodes within the engine management system.

There is growing consumer demand for wireless communication technologies in transport applications from point-to-point to multiplexed communications. Advances in portable devices (mobile phone, personal digital assistant and

GSM devices) may exploit the possibility of interconnection using in-vehicle communications. Also advances in wireless sensor networking techniques which offer tiny, low power and MEMS (Micro Electro Mechanical Systems) integrated devices for sensing and networking will exploit the possibility of vehicle to vehicle and vehicle to infrastructure communications [4]. The important innovations in wireless and digital electronics will support many applications in the areas of safety, environmental and emissions control, comfort and entertainment, driving assistance, diagnostics and maintenance in the transport domain.

The Controller Area Network (CAN) was first introduced by BOSCH in the 1980s with the clear intent to serve communication systems for automotive applications and it is still dominant in automotive networks. The CAN is not fully satisfying requirements such as predictability, performance and dependability which are mandatory in automotive communications [5]. To overcome the limitations of the current CAN, a number of technologies have been developed for designing automotive networks such as Time-Triggered Protocol (TTP), Time-Triggered CAN (TTCAN) [6], Byteflight and Flexray [6] [7]. Wireless communication technologies such as ZigBee, Bluetooth and Wi-Fi are also expected to be widely employed in the near future in the transport domain. It is evident that wireless communications can be used in-vehicle, inter-vehicle and between vehicle and infrastructure in automotive applications.

Over the last few years, many different versions of wireless sensor devices (motes) have been designed and built by various companies and institutions. The size of these motes varies from the size of a box of matches to the size of a pen tip. The ultimate aim is to implement a mote that fits into a volume of one cubic millimeter [8]. These motes have been nicknamed as *Smartdust*. Most current motes communicate in the ISM bands using proprietary protocols but standards are emerging (e.g. IEEE 802.15.4 ZigBee [9]) which will eventually allow motes and sensors from different manufacturers to be combined within the same network. Smartdust with ZigBee technology has enormous potential both within and without the transportation arena. Fundamentally, it provides a convenient and economic means of gathering and disseminating information about the environment. With appropriate sensors and signal processing technologies, a wide variety of environmental variables and transport related variables such as motorway traffic data, vehicle speed and vehicle emissions could be monitored.

2 ZigBee Technology

The ZigBee standard [9] has evolved since its original release in 2004 and it is a new low cost low power wireless networking standard for sensors and control devices. ZigBee provides network speeds of up to 250kbps and is expected to be largely used in wireless sensor network applications where high data rates are not required. ZigBee uses the media access control layer and physical layer of IEEE 802.15.4 for communication between devices. ZigBee offers a short range wireless networking capability with low cost, low data rate and low power consumption.

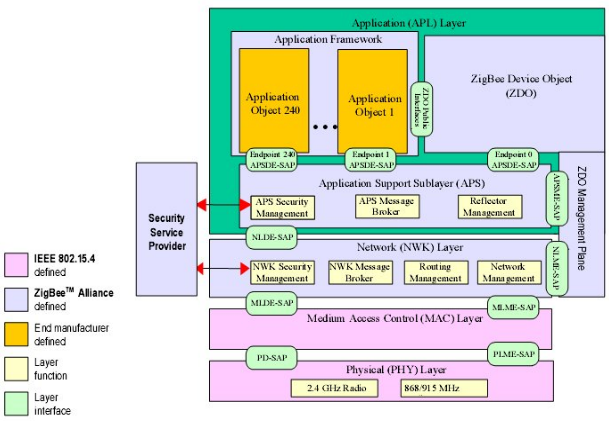

Figure 1: Outline of the ZigBee Stack Architecture [10]

Figure 1 shows the ZigBee stack architecture which is made up of blocks called layers. Each layer performs a specific functions in the ZigBee protocol architecture. A data entity provides a data transmission service and a management entity provides all other services. Each service entity exposes an interface to the upper layer through a service access point (SAP) and each SAP supports a number of service primitives to achieve the required functionality [10].

The IEEE 802.15.4 standard defines the two lower layers which are the physical layer (PHY) and the medium access control layer (MAC). The ZigBee protocol builds upon on this foundation by providing the network layer (NWK) and the framework for the application layer. The application layer framework consists of the application support sub-layer (APS) and the ZigBee device objects (ZDO). IEEE 802.15.4 has two PHY layers that operate in two separate frequencies: 868/915 MHz and 2.4 GHz. The lower frequency PHY layer covers both the 868MHz European band and the 915 MHz band, used in United States and Australia. The higher frequency PHY layer is used virtually worldwide. The IEEE 802.15.4 MAC sub-layer controls access to the radio channel using a CSMA-CA mechanism. Its responsibilities may also include transmitting beacon frames, synchronization and providing a reliable transmission mechanism [10].

The ZigBee network layer supports star, tree and mesh network topologies. The ZigBee coordinator is responsible for initiating and maintaining the devices on the star network topology. A star network topology is controlled by the coordinator and all other devices directly communicate with the coordinator. In the mesh and tree network topologies, the ZigBee coordinator is responsible for starting the network and for choosing certain key network parameters. In tree networks, routers move data and control messages through the network using hierarchical routing strategy.

ZigBee employs carrier sense multiple access (CSMA) as its protocol. The advantages that ZigBee derives through CSMA adoption is the reduced current drain, longer battery life elimination of waiting time for polling. ZigBee has been developed to suit the sensor and control applications. Basically, ZigBee shall cater to wireless personal area network (WPAN) applications that cover short distance communication and control requiring low data rates. A prime propelling factor promoting the ZigBee cause is the significant reduction in power consumption provided by this wireless standard which thereby facilitates in improving the battery life from hours to months and even to years. ZigBee technology has therefore evolved as an innovative standard for a market that stands highly fragmented today by the presence of a multitude of proprietary solutions creating numerous inter-operability issues. Its simplified implementation combined with the very low power consumption and limited cost of implementation shall drive the early adoption and acceptance of the standard. The active development of ZigBee chipsets and complete solution development by various companies globally stand witness to the expected boom of the ZigBee standard in the very near future in several applications including ITS.

3 EMMA Project

The Embedded Middleware in Mobility Applications project (EMMA) [11] is funded under the Information Society Technologies (IST) Priority of the 6th Framework Programme of the European Commission and has an overarching goal of utilising new embedded middleware to support the underlying logic and communications required for future cooperating wireless objects and the applications they may support in the automotive and road transport domains. This trend in the widescale deployment of digital processing into the environment – what is variously called ambient intelligence, ubiquitous computing, the internet of things, or just 'smart' technology – goes well beyond transport and will impact on almost every aspect of our lives. Just as the World Wide Web was a one-time transition in the technology landscape, bringing information into a globally integrated system, so we are just at the start of another one-time transition, linking up things through embedded intelligence and communications.

The EMMA project is committed to deliver a middleware platform and a development environment which facilitates the design and implementation of embedded software for cooperative sensing objects. The ultimate aim that the project will focus on delivering is to hide the complexity of the underlying infrastructure whilst providing open interfaces to 3rd parties enabling the faster, cost-efficient development of new cooperative sensing applications. This end-product will be accompanied by a publicly available specification (PAS) that will help to facilitate its wider adoption.

The EMMA project strategic goal will be achieved by means of number of specific objectives:

1. To build a middleware platform and development environment which facilitate the design and implementation of embedded software for WIreless COoperative sensing objects (WICOs)
2. To lab test this middleware on a number of wireless cooperative objects

   a. With an automotive subsystem
   b. At a vehicle level
   c. At the supra-vehicle level
3. To validate EMMA wireless cooperative objects in the context of a number of applications.
4. To feed the project results into the relevant standards, particularly in those of the automotive industry.
5. To facilitate the access of SMEs (Small and Medium Enterprise) to the market of cooperative sensing systems by means of specific middleware and targeted dissemination and awareness actions.

These objectives will be achieved in 30 months by a consortium of two SMEs (ETRA Research and Development, Spain and Institute of Communication and Information Technologies, Poland) and two big automotive industries (TRW Conekt, UK and Fiat Research Centre, Italy) and two Universities (University of Newcastle, UK and University of Stuttgart, Germany) and the Korean Electronics and Telecommunications Research Institute (ETRI). ETRI provides the NanoQplus operating system for sensor networks and the Qplus operating system for PowerPC and these operating systems will be used in EMMA WICOs [12].

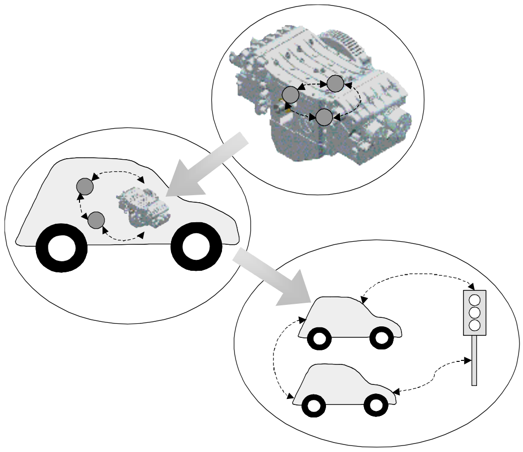

Figure 2: EMMA Hierarchical Network Architecture

The EMMA network architecture can be considered at three levels (Figure 2): Within an automotive subsystem, at a vehicle level and at the supra-vehicle level. Recently, many wireless micro sensor network applications are being developed for a variety of applications including transport monitoring and control. However, there are still numerous challenges to be overcome if wireless sensor devices are to communicate with each other in an intelligent, cost effective and reliable way. It is necessary to find suitable technologies to support and coordinate WICOs at all three levels. The following sections will focus on the middleware and communication technologies for the EMMA project.

4 Communication Technologies for EMMA Project

Among the different possibilities, Bluetooth is currently the most widely used automotive wireless technology for in-vehicle communication and Wi-Fi is used for vehicle to vehicle communication by several pilot research projects, e.g., the Car2Car consortium [13]. ZigBee will be able to fill the gap left by these other technologies, mainly in the interconnection of wireless sensor with vehicles and infrastructure. The ZigBee standard has evolved since its original release in 2004 and it is a new low cost low power wireless networking standard for sensors and control devices. ZigBee provides network speeds of up to 250kbps and is expected to be largely used in typical wireless sensor network applications where high data rates are not required.

The EMMA project needs to discover which communication technologies are more suitable and how the networks are formed by WICOs from different levels. The following Table 1 shows a comparison of three different wireless communication technologies such as ZigBee, Bluetooth and Wi-Fi.

Standard	ZigBee 802.15.4	Bluetooth 802.15.1	Wi-Fi 802.11g
Automotive application	Inter-vehicle and vehicle to infrastructure communication	In-vehicle communication and device connectivity	Inter-vehicle and vehicle to infrastructure communication
Network range	Up to 100m	Up to 70m	Up to 100m
Network method	Mesh	P2P	P2P
Bandwidth	250 kbps	12Mbps	54Mbps
Frequency	2.4 GHz	2.4 GHz	2.4 GHz
Advantages	Low power Many devices Low overhead	Dominating PAN Easy synchronisation	Dominating WLAN Widely available
Disadvantages	Low bandwidth	Consume medium power	Consume high power

Table 1: Comparison of wireless communication technologies

ZigBee, Bluetooth and Wi-Fi have been designed for short-range wireless applications with low power solutions and can be used at the EMMA infrastructure level. Table 1 shows a comparison between those three technologies relating to the most important factors which need to be considered in the ITS application domain.

ZigBee can accommodate larger numbers of devices than Bluetooth. On the other hand, Bluetooth offers high bandwidth with relatively high throughput. EMMA wireless sensor network applications do not require high data rate communication technology as it is based on data exchange. ZigBee provides 250 kbps data rate and is expected to be enough for the EMMA sensor network applications. Notably, ZigBee uses low overhead data transmission and requires low system resources which are vitally important factors for embedded sensor networks. Also mesh networking features in ZigBee protocol allow devices to extend its coverage and optimize its radio resources. The features show that ZigBee is the suitable communication technology for the EMMA project applications.

5 Smartdust for EMMA Project

Smartdust is a new concept for wireless sensor networks which offers tiny, low power and MEMS integrated devices for sensing and networking. It is not only interesting for the low power sensing technologies but also the low power communication and networking capability which it has demonstrated [8]. Smartdust devices have extremely large potential within the EMMA project. Fundamentally, it provides a convenient and economic means of gathering and disseminating environmental and other useful information in the EMMA validation process. Normal sensors need a complete system interface to communicate with other devices in the validation process where Smartdust has the required interface itself. Existence of ZigBee based networking capability between the Smartdust devices will benefit the EMMA validation process. The Smartdust devices also have sensors attached to them to monitor the physical environment in some way. These sensors can be built directly onto the mote or can come as daughter-boards which can be connected in some way to the motes main motherboard. Sensors can measure a wide range of environmental parameters, such as pollution, noise, temperature, humidity as well as vehicle speed, vehicle direction and vehicle presence.

Initial studies suggest environmental monitoring, vehicle to vehicle, vehicle to infrastructure and infrastructure to infrastructure applications may exist for Smartdust in the transport domain. Indeed the vital application of the devices is beginning to be tested in the road vehicle environment. Smartdust devices are suggested to have a future application in smartcards and RFID, whilst the use of the technology to support location based services and personalised mobile information delivery is clearly one of the future major markets for ad-hoc sensor networks and may feed in well to the future Intelligent Transport Systems Applications.

Even though a range of Smartdust platforms are available in the market, Crossbow Mica [14] family motes will be used for EMMA applications due to their commercial success in many wireless sensor network applications. Mica family motes use TinyOS which is an open source operating system designed for embedded systems with very limited resources [15]. Also, Micaz mote will be the most suitable platform for the EMMA project since it features sensing and networking capabilities with low power consumption using ZigBee as communication protocol. Figure 3 shows Crossbow a Micaz mote.

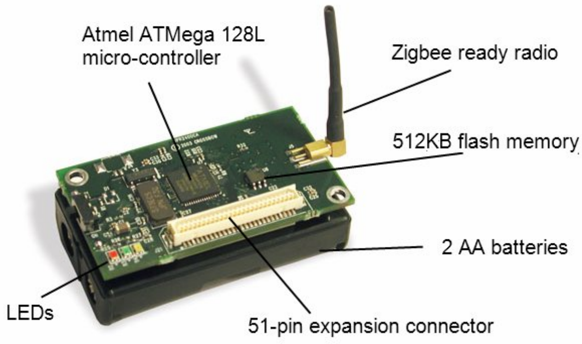

Figure 3 – The Crossbow Micaz Mote

Micaz mote is a family of the Crossbow Mica motes where the radio transceiver uses the Chipcon CC2420 IEEE 802.15.4 (ZigBee) compliant chipset. This will allow the Micaz to communicate with other ZigBee compliance equipment. The software stack includes a Micaz mote-specific layer with ZigBee support and platform device drivers, as well as a network layer for topology establishment and single / multi-hop routing features. It is mainly used for research and development of low power wireless sensor network applications.

The Micaz mote platform is built around the Atmel AtMega128L processor which is capable of running at 7.37 MHz. The Micaz motes have 128 Kbytes of program memory, 512 Kbytes of flash data logger memory, and 4 Kbytes of SRAM. Power is provided by two AA batteries and the devices have a battery life of roughly 1 year depending on the application (very low duty cycle assumed). Sensor boards can be attached through a surface mount 51 pin connector, Inter-IC (I2C), Digital Input Output (DIO), Universal Asynchronous Receiver Transmitter (UART) and a multiplexed address/data bus.

6 Experiments

An experiment has been carried out in order to explore the feasibility of using Micaz [14] motes for the vehicle to infrastructure communication. The experiment focussed on the effect of vehicle travelling at higher speed with the Micaz using ZigBee as a communication technology. Earlier experiments have demonstrated that motes can be used for communication between a fixed infrastructure and a moving vehicle up to a speed of 50 mph [16]. This experiment focused on the higher speeds (60 and 70 mph) to asses the suitability of Micaz in the fast moving vehicle to communicate with Micaz in the infrastructure (e.g. motorway applications). The experimental setup is described below:

- Two Micaz motes (Mote A and Mote B) were used
- Mote A was placed on the dashboard of a car, connected to a laptop which was used to store the received data packets
- Mote B was suspended on a motorway bridge, approximately 6 Meters over the centre of the motorway
- Mote A broadcasts a packet every 250 milliseconds. Upon receiving this packet, Mote B re-sends it back to Mote A. Mote A records the number of packets communicated between the two motes
- The experiment was conducted on a section of the A1 motorway near Newcastle upon Tyne (UK) in bright clear conditions
- The vehicle was travelling at the speed of 60mph or 70mph when passing under Mote B on the motorway bridge.

Several passes were made and the results can be seen on Table 2. On average, 7.75 packets were successfully communicated when the vehicle was travelling at 60 mph, and 6.17 packets at 70 mph. Since the packets were broadcast every 0.25 seconds, it can be calculated that the communication windows are 1.94 seconds and 1.54 seconds respectively.

	Speed			
	60mph		70mph	
Pass	No. of packets	Transaction time (s)	No. of packets	Transaction time (s)
1	4	1	5	1.25
2	10	2.5	6	1.5
3	8	2	7	1.75
4	9	2.25	12	3
5			4	1
6			3	0.75
Average	7.75	1.94	6.17	1.54

Table 2: Results from the experiments

These experimental results demonstrated that Micaz motes can be used for communication between a fixed infrastructure WICO and fast moving vehicle-based WICOs. This is an important finding which proves that the Micaz using ZigBee communication technology do not suffer from any Doppler effects at normal motorway speeds. Based on the information gathered from these experiments, it can be calculated that the effective communication range of motes when used with a fast-moving vehicle to be around 50 meters (± 5 meters). It is also noted that there is no significant signal degradation when the vehicle travels at a higher speed.

6 Conclusions

The paper has presented on-going research being undertaken to investigate the suitability of using ZigBee technology for the intelligent systems applications. A selection of the results from experiments carried out to systematically characterise the ZigBee technology in the road domain were presented here. The ability to communicate between vehicle and roadside illustrates that well designed networks will enable efficient and discrete communications between vehicle and roadside – as the unit cost of motes will continue to go down – this is a significant contribution to the ITS domain.

The paper has introduced the EMMA project which will deliver a middleware platform and a development environment, prototypes of wireless cooperating sensors incorporating EMMA embedded software. Then, the potential transport applications of Smartdust and ZigBee in the EMMA project were discussed. It is clear that the next generation of vehicles will be required to have increased safety, lower emissions and more entertainment with higher performance than those of today. The innovations in wireless sensor devices electronics will enable novel automotive applications which will become very common in future ITS. The challenges such as integrating Smartdust devices for specific ITS application can be achieved by developing EMMA like middleware technologies

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