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Wireless communication in cooperative urban traffic management

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ABSTRACT

The possibility to enable cooperative concept in urban traffic systems is challenging because of large amount of traffic data that must be collected, processed and distributed to end users. The main objective is to establish communication between three main subsystems of traffic system: driver, vehicle and infrastructure so that they can cooperate in real time traffic environment. This paper describes various wireless communication technologies that can be used to achieve real time data exchange, and potential problems and limitations. Internet of Things (IoT) concept can be used as supportive concept for collection, processing and distribution of traffic data with one main goal – to increase urban traffic system quality in overall.

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1 Introduction

Cooperative approach includes communication among three main factors in traffic and transport system – vehicle, infrastructure and driver. So, basically, there are two main communication channels: vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication [1]. In urban areas vast amount of traffic related data can be collected in order to increase the quality of urban traffic system. One approach for data storage and processing is usage of Internet of Things (IoT) concept, especially because communication performance (speed, bandwidth, etc.) is enlarged with every new stage of development of the communication technology. In order to achieve efficient and effective communication between vehicles and infrastructure, different communication technologies can be used for various scenarios. The development of this concept is influenced by previous development of certain areas of engineering sciences such as connecting devices in motion, wireless sensor networks, processing large amounts of data [2]. In the field of intelligent transportation systems (ITS), several EU funded projects have been conducted (SAFESPOT, CVIS, CAPTIV, etc.) where improved cooperative concept and possible communication scenarios were defined [3], [4], [5], [6]. Also, with the development of ITS and cooperative concept several frameworks and communication standards were defined like WAVE IEEE 802.11p [7], [8], CALM [9], etc. This paper describes possible usage of IoT as a support concept for traffic data collection and processing, various possible communication scenarios and system architecture for the urban traffic system. Also, security issues regarding data transmission will be presented.

2 IoT basic concept

Basic concept of IoT is connection of physical objects from the environment into the global network based on IP protocol which can be the basis for development of smart traffic system in large scale. Because of vast amount of traffic data that can be collected from traffic (number of vehicles, speed, travel times, etc.), IoT concept can be the suitable platform for development of traffic management centers. Development of IoT concept is triggered by research within certain areas of engineering sciences such as connection of entities in motion, processing large amounts of traffic data, IPv6 standard development and deployment, etc. All developed and independent technical areas can be linked through an intermediary program layer [10].

IoT can be perceived as continued development of M2M (machine-to-machine) communication which supports data transmission between machines and automated means of information transfers and orders without human intervention [11]. Opposed to M2M communication, IoT affords interaction with objects in human environment by extending their interaction with different information (current location, speed, estimated travel times, etc.). Two basic modes of communication within IoT concept can be defined [12]:

– *person – object communication:* users generate communication with available devices get certain information,

– *object – object information:* information is exchanged between two or more objects with or without human intervention.

From the IoT standpoint, object are things from the physical environment (traffic entities, sensor data) or from a virtual environment (virtual items). Such objects have the ability to integrate within the network of information and communication and become active participants in terms of information exchange, recognition of events and changes in the environment as well as autonomic reactions to the same events and changes [12], [13].

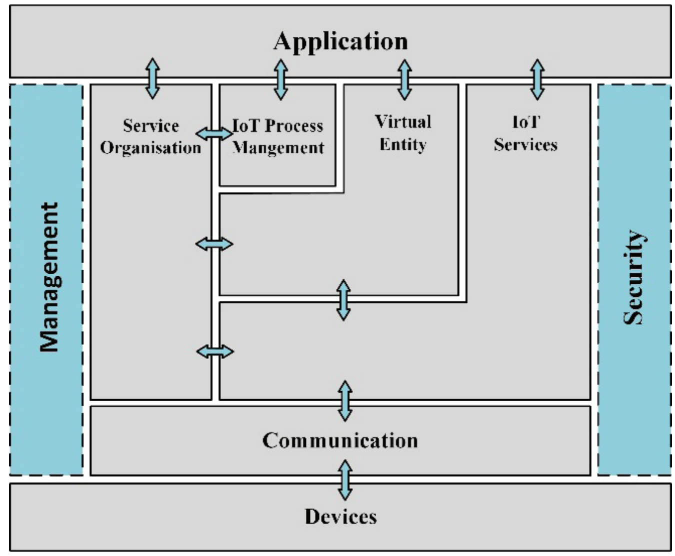

Figure 1 IoT functional model [14]

2.1 IoT functional model

In order to offer a unique concept regarding IoT implementation, functional model was developed (**Figure 1**). Functional model describes the functional components, interfaces and interactions between the components.

The IoT functional model contains longitudinal and transversal functionality groups. These transversal groups provide functionalities that are required by each of the seven longitudinal groups. The policies governing the transversal groups will not only be applied to the groups themselves, but to the longitudinal groups as well. Since the transversal functional groups (management and security) interface with most of the other functional groups, their interactions with are not explicitly depicted [15].

Functional group "devices" contains all the possible functionality of the physical devices that are used for instrumenting the physical entities and include: sensing, actuation, processing, storage and identification components. The "communication" functional group derives all possible communication mechanisms used by defined "devices" (in the actual environment where IoT will be implemented) in order to enable communication between devices.

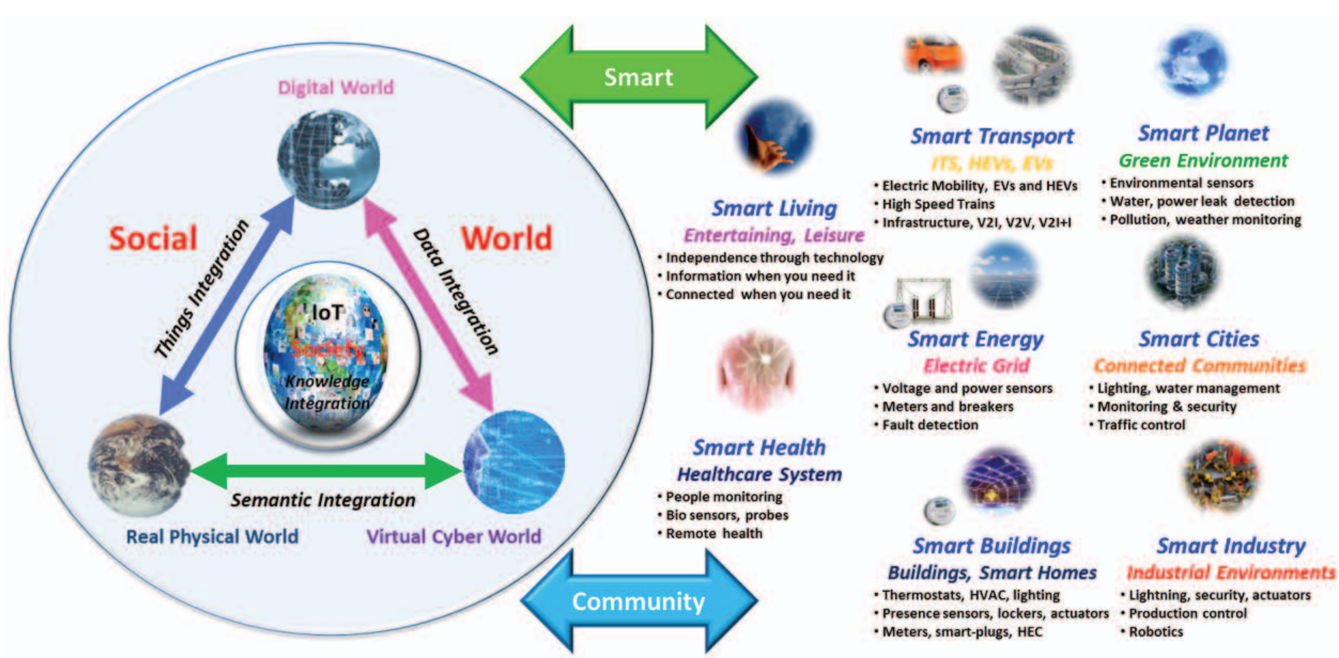

Figure 2 Application of IoT concept

2.2 Environments for IoT application

Because of great potential and specific defined concept, IoT can be applied in various areas – private, business and social aspects. Internet of Things Strategic Research Agenda identifies main application environments: cities, energy, health, buildings, life and transportation. Integration of communication capabilities and capabilities of collected data processing can be the basis for creation of new environment with large number of new available services. Within IERC – European Research Cluster on the Internet of Things, "Internet of Things – Pan European Research and Innovation Vision", October, 2011 the main objectives for IoT is the creation of smart environment and self-aware things (smart transport, smart cities, etc.). Possible IoT application on higher level is presented on **Figure 2**.

At the city level, the integration of technology and quicker data analysis will lead to a more coordinated and effective civil response to security and safety, greater urban traffic city management quality, reduction in travel times, emissions, etc. Vast amount of traffic data can be collected and processed so that traffic control can be upgraded to a new level. Within this paper cooperative traffic management in urban environment is presented, with communication establishment between three main subsystems of traffic system – vehicle, driver and infrastructure. Main features of cooperative traffic management is presented in the next chapter.

3 Urban cooperative traffic management concept

Urban traffic management systems are mostly based on real-time traffic data collected from traffic infrastructure. With the implementation of intelligent transportation systems (ITS) services it is possible to achieve better urban traffic system quality with providing accurate and real-time traveler information, advanced traffic control on signalized intersections, etc. That leads to reduction in traffic congestions, travel times and improvement of safety and passenger comfort. The main disadvantage of existing ITS services is that there is no achieved communication between different components of a traffic system (traffic management center, public transport management center, public transport vehicles, etc.).

The next possible step in the improvement of public transport management system could be the expansion with cooperative concept, mostly in the field of dynamic traffic control (at signalized intersections). Cooperative

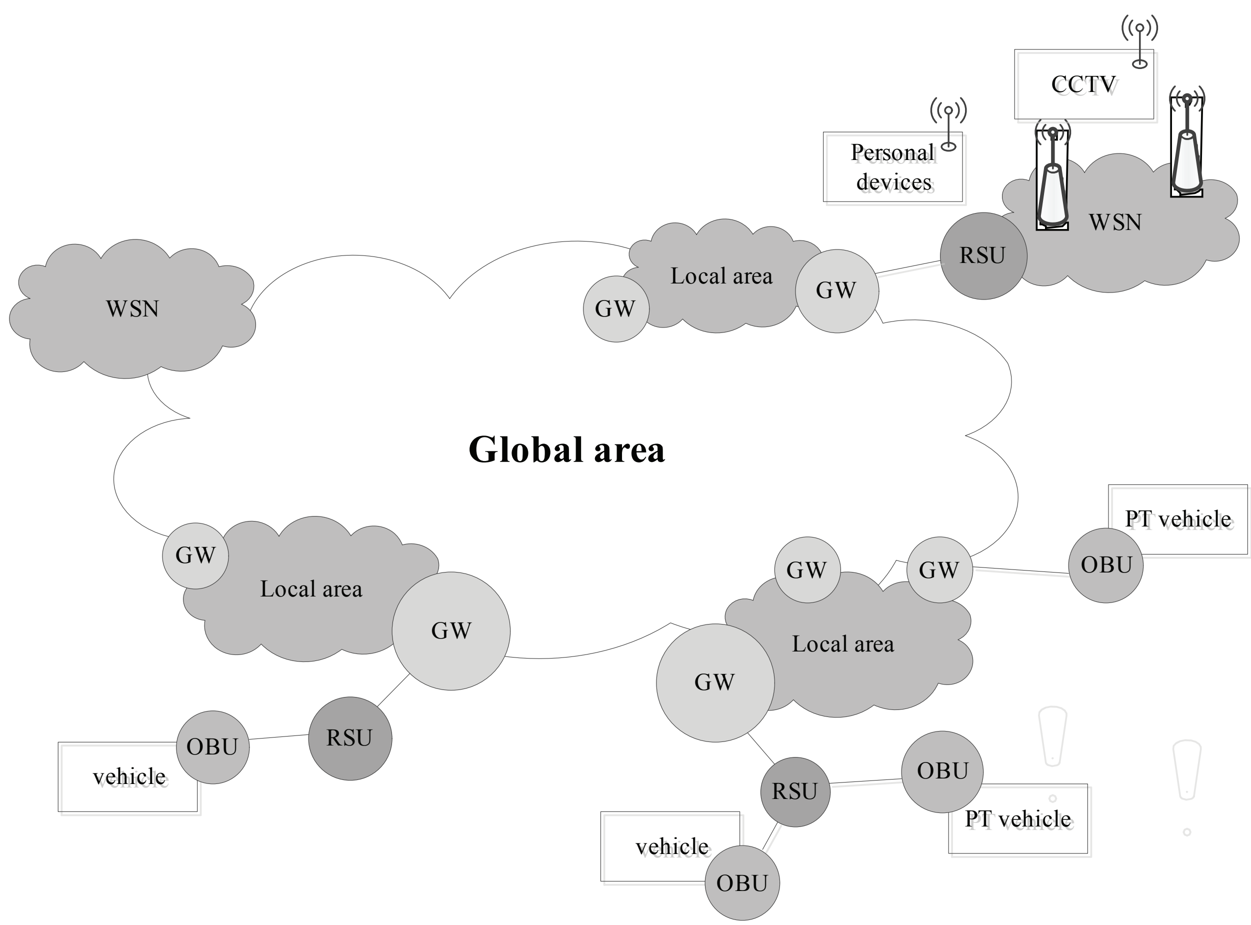

Figure 3 ICSI system architecture [16]

approach includes communication among three main factors in traffic and transport system – vehicle, infrastructure and driver. So, basically, there are two main communication channels: vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication.

This research includes conceptual cooperative model for future applications of urban traffic management as part of EU FP7 STREP project *Intelligent Cooperative Sensing for Improved Traffic Efficiency – ICSI* [16]. System is based on Wireless Sensor Networks (WSNs) and vehicular networks. This implies that it should be able to collect and process a large amount of sensed data in scalable and reliable way. The ICSI system is composed by heterogeneous components (**Figure 3**):

- *Control Centres.* Control centres are able to collect, store and process big amount of data coming from the other components of the system. They can also provide feedback/actions to act on the transport system,
- *Road-Side Units (RSU).* RSUs are positioned along the road for collecting measurements through sensors (e.g. flow sensors, park sensors, etc.) and cooperative ITS nodes using ITS communication standards. RSU can be able to actuate feedbacks (e.g. by means of variable message signs), and can be wired or wirelessly interconnected to each other in order to extend network coverage,
- *On-Board Units (OBU).* The OBU resides in the car and can be equipped with sensors and wireless networking equipment for V2V and V2I communications,
- *Personal devices*. User equipment like tablets, smart phones, etc., consists of portable devices used by pedestrians and citizens which are involved in collecting news, travel information and other kinds of information.

Information and collected data are processed in a cooperative manner performing content aggregation since the earliest stages, e.g. information about traffic flows can be collected through WSNs based on low-cost camera sensors and stored locally, sending statistical data to the Control Centre, for long-term evaluation. In order to do that ICSI defines two key concepts:

- *ICSI gateway (GW)* – it hosts the Data Distribution Platforms and the high level applications in charge to enable local intelligence in the system. GWs allow data exchange with attached sub-systems such as WSNs and vehicular networks, and can share data with other GWs achieving collaborative sensing and events notification,
- *ICSI areas*. The concept of area is related to the context in which the gateway works. Areas can be classified in local and global areas:
  - *A local area* is a set of gateways that cooperate in order to offer cooperative sensing to services and applications. A gateway can join one or more local areas. Gateways that join an area are selected according to geographical, urban or strategic considerations in order to make it possible for each gateway to take local decisions based on the input provided by its attached subsystems (e.g. vehicular subsystem, wireless sensor network subsystem) and by other ICSI gateways in the same area.
  - *Global area* is the overlay network connecting all the ICSI gateways in the system. The global area allows long-term and statistical data collection and remote monitoring capabilities to control centers.

After the complete architecture of the proposed cooperative traffic management was defined, it is necessary to select the most suitable wireless technology for different communication levels and scenarios which is presented in the next section.

4 Wireless technologies for cooperative ITS application

In the field of ITS the most important information is vehicle state which includes position, speed and direction. The main problem in traffic is collection, distribution and exchange of real-time traffic information. There are many different wireless technologies that can be used (DSCR, Bluetooth, ZigBee, WLAN, etc.) regarding information exchange speed and range. For example, 3G/4G covers the longest range, followed by WLAN, etc. which will be presented in advance. Basically, wireless access technologies in ITS services are divided in three main categories [17]:

1. short range/ad-hoc: CEN DRSC 5.8GHz based on CEN EN 12253-2004, European 5.9GHz ITS based on IEEE 802.11p, DSRC based on IEEE 1609, ZigBee based on IEEE 802.15.4, etc.
2. cellular: Wi-Fi at 2.4GHz based on IEEE 802.11a/g, UMTS at 800MHz and 2GHz based on 3GPP,
3. digital broadcast.

Regarding ITS services, within CVIS (Cooperative Vehicle-Infrastructure Systems) FP6 project, CALM (Communication Access for Land Mobile) architecture is defined. CALM architecture comprises of standardized set of air interface protocols and parameters for medium and long range, high speed ITS communication using one or more communication technologies and networking protocols [18]. The architecture is standardized under specification

within ISO's Technical Committee 204 Working Group 16 (TC204 WG16). The set of CALM International Standards include specifications for [19]:

- ITS station management,
- ITS communications security,
- ITS station facilities layer protocols,
- ITS station networking and transport layer protocols,
- communication interfaces (CIs) designed specifically for ITS applications and services,
- interfacing existing access technologies into ITS stations,

- distributed implementations of ITS stations, and
- interfacing ITS stations to existing communication networks and communicating with nodes.

This International Standard describes the common architectural framework around which ITS stations are instantiated and provides references to relevant International Standards, including access technology support standards, various networking and transport protocol standards, facilities standards, and ITS station management and security standards.

Because of the stochastic nature of traffic systems (V2I and V2V communication), cellular technologies are more important and useful than ad-hoc technologies for information exchange on wider range of traffic system (i.e. traveler information distribution). For detection of vehicles on signalized intersections short range/ad-hoc technologies are more suitable. Table 1 presents comparison of wireless communication technologies used in the field of ITS.

According to **Table 1** it is visible that various technologies can be used for various communication scenarios. The most important phase of development of extended cooperative ITS architecture (except good definition of user needs) is definition and development of communication ITS architecture because it is essential to define commu-

Table 1 Comparison of wireless communication technologies suitable for ITS services [20]

Standard	ZigBee	Bluetooth	Wi-Fi	CALM
ITS application	In-vehicle and V2I	In-vehicle and device connectivity	V2V and V2I	V2V and V2I
Network range	Up to 100m	Up to 70m	Up to 100m	Up to 1000m
Network method	Mesh	P2P	P2P	P2P
Bandwidth	250 kbps	12Mbps	54Mbps	54Mbps
Frequency	2.4GHz	2.4GHz	2.4GHz	5.8GHz
Advantages	Low power and overhead, many devices	Dominating PAN Easy sync	Dominating WAN, Widely available	Wide coverage
Disadvantages	Low bandwidth	Consume medium power	Consume high power	Consume high power

Table 2 Active road safety applications [22]

Use case	Communication mode	Minimum transmission frequency	Critical latency
Intersection collision warning	Periodic message broadcasting	10 Hz	< 100 ms
Lane change assistance	Cooperation awareness between vehicles	10 Hz	< 100 ms
Overtaking vehicle warning	Broadcast of overtaking state	10 Hz	< 100 ms
Head on collision warning	Broadcasting messages	10 Hz	< 100 ms
Cooperative forward collision warning	Cooperation awareness between vehicles associated to unicast	10 Hz	< 100 ms
Emergency vehicle warning	Periodic permanent message broadcasting	10 Hz	< 100 ms
Co-operative merging assistance	Co-operation awareness between vehicles associated to unicast	10 Hz	< 100 ms
Collision risk warning	Time limited periodic messages on event	10 Hz	< 100 ms

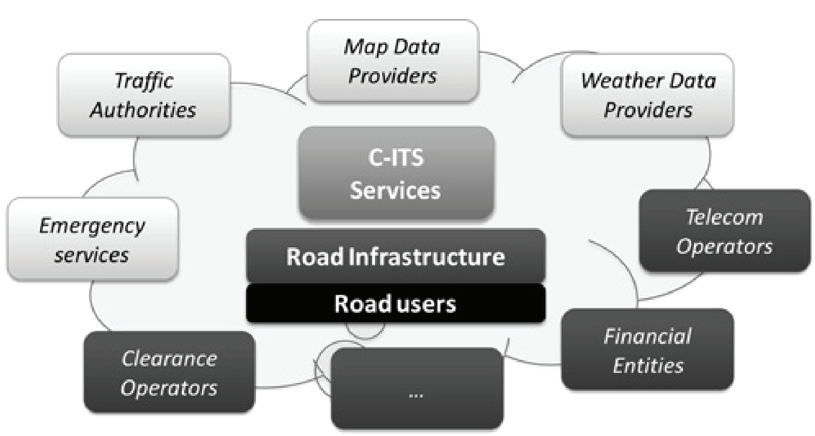

Figure 4 Links and environment in cooperative concept [21]

nication links among three main traffic subsystems. Figure 4 represents simplified scheme of cooperative services environment.

Different types of cooperative services demand different support communication technologies. Table 2 shows active road safety application requirements for different use cases and different scenarios of V2V and V2I communication.

The coverage distance associated with this type of application varies from 300 meters to 20000 meters depending on the use case.

5 Conclusion

In the growing trend of ITS services and cooperative concept (especially in urban areas) where large amount of traffic data can be collected and processed, strong communication links must be achieved. In order to achieve reliable and fast information exchange (especially in V2V communication scenario) various communication technologies were processed. Wi-Fi and CALM can be used for V2V communication because of high bandwidth and coverage, but in urban environment the main problem could be registration of every vehicle, and possible interference of signals. For V2I communication (for example, registration of public transport vehicles on signalized intersections), ZigBee and Bluetooth technologies can be suitable because of synchronization speed and low energy consumption. Also, regarding cooperative concept in urban traffic systems, basic architecture is defined with two main areas – local and global area, but IoT as a supporting concept can be used for data collection and processing. Further research in this field will be focused on real time examination of selected communication technologies to ensure possible difficulties in communication establishment and data exchange speed.

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