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WIRELESS SENSOR NETWORKS : THEIR PROGRAMMING AND TRANSPORT IMPLEMENTATIONS

In the paper the Wireless Sensor Networks their operations frameworks, architecture and topologies are presented. A great attention is paid to programming in these networks. Two levels of programming are distinguished: low level programming of data sensors and distributed high language level programming addressed to dedicated applications. The transport implementations of wireless sensor networks are demonstrated in two areas: the intelligent road implementation and the logistics.

BEZPRZEWODOWE SIECI SENSORÓW: ICH PROGRAMOWANIE I ZASTOSOWANIA W TRANSPORCIE

W pracy prezentowane są bezprzewodowe sieci sensorów: ich zasady pracy, architektura i topologie. Duża uwaga poświęcona jest programowaniu w tych sieciach. Wyróżniane są dwa poziomy programowania: niski poziom programowania danych sensorów i rozproszony poziom w językach wysokiego poziomu adresowany do dedykowanych aplikacji. Zastosowania w transporcie bezprzewodowych sieci sensorów pokazane są w dwu obszarach: inteligentnych zastosowań drogowych i logistyce.

1. INTRODUCTION

Wireless Sensor Networks (WSN) grown up on the base of general purposes wireless computing networks. They make distributed systems usually composed of embedded devices, each equipped with a processing unit, a wireless communication interface and sensors or actuators. The implementation of such networks is determined by type of sensor and type of implementations, hardware requirements and programming methods used. Recently, an attention is focused on the Web oriented distributed programming methods, related data communication and data coordination among the WSN nodes [1-2].

The transport is one of possible application the Wireless Sensor Networks, mainly, in the area of intelligent road systems and logistics where mobile and wireless communication technology allow to manage a global interconnecting, even in real-time. In these systems the SQL (Structure Query Language) stream computing platform can be used for

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information coming from many different data sources and formats. The SQL-stream solution reduces the time and cost to deploy sensor network systems, which easily can integrate a given application with existing databases. Usually, for these purposes the Relational Asynchronous Messaging (RAM) technology is implemented for which SQL stream provides powerful platform for processing real-time streams of the data. RAM technology enables any number of data sources to be connected in real-time, mainly, using middleware solution making a standard of scalable sensor network applications. The example can be the Intelligent Transportation systems improving road safety, optimize transportation efficiency, reduce pollution, and providing data to support the national security issues. Data exchange among in-vehicle and road side sensors produces a huge amount of real-time information which can be processed as a result of a progress in wireless technology. Thus, speeding vehicles or traffic congestion can be identified enabling to improve e.g. traffic congestion under local weather and braking distances.

SQL stream computing platform aided by sensor technology enables :

- to process in real-time a big amount of information from many different inputs,
- to combine sensor data, with GPS and data of other transportation databases,
- to integrate various mobile applications of the transport.

Recently, related such system operate in real-time and multi-technology environment using the Mobile Resource Management (MRM) standard. It incorporates GPS and location information, wireless network technology with the Internet and mobile applications by combining geospatial sensor data with intelligent applications. They are referred to the sensor matrices, Internet portals and mobile applications combining verity sensor data with enterprise data of logistic supply chains and ERP management systems. By this, the wireless sensor networks can support the business cross of the globe with the data taken from remote places regardless of their physical location.

2. PROGRAMMABLE WIRELESS SENSOR NETWORKING

Wireless Sensor Networks applications can be categorized in regards of application goal, interaction pattern, mobility, space and time. Application goal resolves itself to sense only or to sense-and-react under condition interacting one-to-many, many-to-many, many-to-one. The mobility covers distinguishing the static or mobile nodes and sinks, space distinguishes global and regional operations, it can be based on periodic or triggered sensor operations. Typical sensor systems consists of hardware, operating system assuring routing, localization, time synchronization, storage, reprogramming as well as application software. So, sensor node is supported by Volatile Memory, External Storage, CPU, Program, Radio Ports, Power Source, Actuators, Sensors. Capacity of volatile memory range from 2 KB to 512 KB and is used to store run-time data during program execution. Program code is stored in a dedicated memory ranging of 128 KB supported, if needed, by the external memory ranging several gigabytes. The sensor node wireless operations are usually arranged in the 2.4 GHz band by the use of the communication protocols of second layer of the OSI model. In contrary to standard computing, in the WSN operating system a key role plays a library of which data codes combine with the application code to produce

a binary execution codes. This allows to sent the required data directly to the end user keeping under consideration the power supply energy allocated to each node as power supply energy makes here the critical issue node managing.

In the WSN systems the programming is addressed to distributed processing among the nodes and single nodes. It can be managed e.g. by the SQL like node interfaces referred to relational tables allowing to avoid the inter-node interactions.

Thus, programming manner has to be considered in two areas: communication and implementation. First one covers mainly addressing and data accessing, while second one covers functional, sequential, rule-based, even driven, SQL-like or special purposes operations. The WSN nodes can't perform any useful task if they left alone; to accomplish a higher-level implementation goal a given WSN system has to assure collaboration and coordination of numerous devices. In communication this is referred to node operations: mainly, multi-hop connected and multi-hope disconnected WSN group of the nodes. So, the communication scope can be defined as the node set to data exchange accomplishing a required process in which application is dependent on the nodes making:

- physical neighborhood,
- multi-hop group: connected or non-connected.

For such purposes frequently so called Active Messages approach is used, it makes a set of interfaces providing basic communication primitives described in the nesC event-driven language derived from C language for WSN purposes. Applications are built in nesC by interconnecting components that interact by providing interface data. An example of such simple nesC Active Message interface is shown below

```
interface AMSend {
  command error_t send ( am_addr_t addr, message_t * msg, uint8_t len );
  command error_t cancel ( message_t * msg );
  event void sendDone ( message_t * msg, error_t error );
  command uint8_t maxPayloadLength ();
  command void * getPayload ( message_t * msg, uint8_t len );
}
```

The Active Message interfaces fulfill conditions of the MAC-sublevel of the OSI model and make a platform to single-hop cast or broadcast operating. In such platform to overcome the limitations, the multi-hop protocols for data collection and distribution have to be developed in the form of special Active Message interfaces.

Other one programming approach is addressed to Connected Multi-hop groups called the EnviroSuite group. This makes an object-based programming framework used to monitoring and tracking a given application. In specified by this manner the environment the objects represent the physical entities dynamically created when the corresponding physical entities are detected. They are automatically destroyed when the same entities move out of sensing range. Following approach is addressed to non-connected multi-hop group. The objects allow creating the Logical Neighborhoods - programming abstraction that allows redefining a node's neighborhood according to logical properties of the network nodes, independently on their physical location. For those purposes a declarative

programming language called Spidey Neighborhoods can be used, it makes extension of existing WSN languages and operates by using Application Programming Interfaces associated with given nodes.

Besides of shown above the WSN programming the system-wide, so called, the TinyDB system also is used. It makes possible to optimize energy consumption by controlling **where**, **when**, and **how** often data are sampled. Then, at the base station in the form of "injection" into the network the user is allowed to submit SQL-like requirement on the optimized data. This allows to the users to pay attention just to the data without specifying how to do so, as "injection" is equivalent to build a routing tree spanning all nodes across of given network. In consequence, at the base station the data to be processed are reduced.

Important roles in the WSN implementations play the data communication and related to it addressing. Two classes of addressing are distinguished:

- physical addressing: the given nodes are identified by statically assigned identifiers,
- logical addressing: the given nodes are identified by application program.

Similarly, for program purposes the communication can be classified as the explicit communication or implicit communication described by the possibility of used language.

In each WSN application independently on communication the data processing (data computing) makes important issue referred to local, group and global data of the nodes. This used to be described by the Data Access Model of the WSN, which covers processes of:

- databases: WSN data are referred to a relational database and SQL operations,
- data sharing: WSN data are shared as the remotely accessible variables,
- mobile codes: WSN data are accessed locally to a node,
- message passing: among the nodes the WSN data are exchanged in the form of communicates.

In this environment, the most frequently the basic application WSN programming is referred to the use of objective network programming related to the Java language and SOAP / WebSevices programming approach e.g. [2]. In this approach the low level oriented languages play a role of pre-processing adjusted to further processing the sensor data in dedicated application using the high-level languages. Thus, in the WSN systems two types of programming can be distinguished, first one covering low level language pre-programming and second one covering the real application done by the use of high level languages.

3. WSN TRANSPORT IMPLEMENTATIONS

For transport purposes main areas of the WSN implementations the Intelligent Transport Systems and Logistics the make.

3.1 Intelligent transport implementations

In this area of application the WSN are mostly addressed to the automobile sector [3]. They make the car's onboard communication units to register real-time data on traffic and road conditions from a variety of onboard sensors. The great interest is paid to the data referred to traffic control, especially, real-time traffic re-routing by intelligent traffic management systems, and safety warning systems. In these implementation the systems and the networks are distinguished, they are built ad hoc for dedicated purposes. The most challenging, however, is building the Web based wireless Grid systems able to aggregate and to process data in much more wider range determining the ubiquitous traffic monitoring and managing. They make the new road oriented application area called the **Ubiquitous Traffic Telematics - Traffmatics**.

Various types of vehicles can be equipped with short and medium range wireless communication systems to keep communication with other vehicles and fixed gateways built in along of the road [3]. Then, the data are collected on traffic and road conditions from a variety of onboard sensors. Services based on such data are addressed to safety purposes, mainly, warning systems including collisions, driver assistance and information systems. Besides of that, these data allow to perform the traffic analysis and dynamic traffic simulations. In the US, in relation to such purposes a standard of inter vehicle Dedicated Short Range Communication (DSRC) was developed, similar standards are soon expected in Europe and Japan. In such systems the WSN applications, mainly, register vehicle speed in reference to GPS parameters: the car sensors provide wanted information referred to instantaneous and time-averaged vehicle speeds at defined geographical position.

Thus, the used sensors can provide an information on local traffic density referred to some registration pattern the actual front and back headways e.g. by the use of the VANET communication standard [3]. The VANET meets requirements of traffic monitoring as well as traffic safety and management. The data are exchanged among sensors placed into cars and allow to keep the security distance by the warnings, which are sent to road neighboring cars [3-4].

Other road application can make the sensors embedded in the car engine to provide the data facilitating preventive maintenance minimizing the road breakdowns but no question, the most important the road application makes the sensor traffic monitoring and management systems. E.g. the wireless network sensors can replace too expensive current loop detectors and cameras along the roadside, as they can improve sensing reaction time and maintenance expenses. An alternative can be also to support each vehicle in onboard sensors to transfer via wireless link the data to managing points on local traffic situation, density, speed etc. An example such system is the Vehicle Information and Communication Systems (VICS) to register the data of dynamic traffic, packet routing and distribution via wireless communication the driver timely reliable information on changeable inter-vehicle gaps, vehicle clusters etc.[4]. One such system mode operation makes the servers and gateways along the road with backbone interconnections to public networks or the message relay boxes to store vehicle messages for further processing. This system operates as ad hoc made WSN network with dynamically changed topology. Those system network topology requires the special routing protocols, namely, the topology and position based protocols. The traffic is monitored by passing the information from car to

car until information is able to reach a vehicle with access to an Internet to transfer the data to the monitoring center [5].

For presented dynamic WSN networks a big challenge makes keeping end-to-end network connectivity based on the position routing, which allow to cooperate the system parts without route setup and route maintenance. Pattern standard for such wireless inter-vehicle communication is referred to the IEEE 802.11 standards guarantying operations up to 1 km, if proper antennas are used. To optimize this and other communication parameters the extensive research works have been undertaken, they cover modeling and simulation techniques increasing the systems intelligence. This later is assured mainly by the data aggregation by mean of WEB systems to build the GRID systems for the traffic management purposes [6]. A goal is programmable dynamic simulation forecasting of undesirable traffic conditions: stop-and-go waves, congestion etc. Then, on the road the simulation results can instantaneously adjust the traffics management to dynamically changing situation on the road via traffic signal control, traffic re-routing etc., Unfortunately, actually such systems are still at an early stage and their development in regards of their sophistic character.

3.2 WSN in Logistic Application

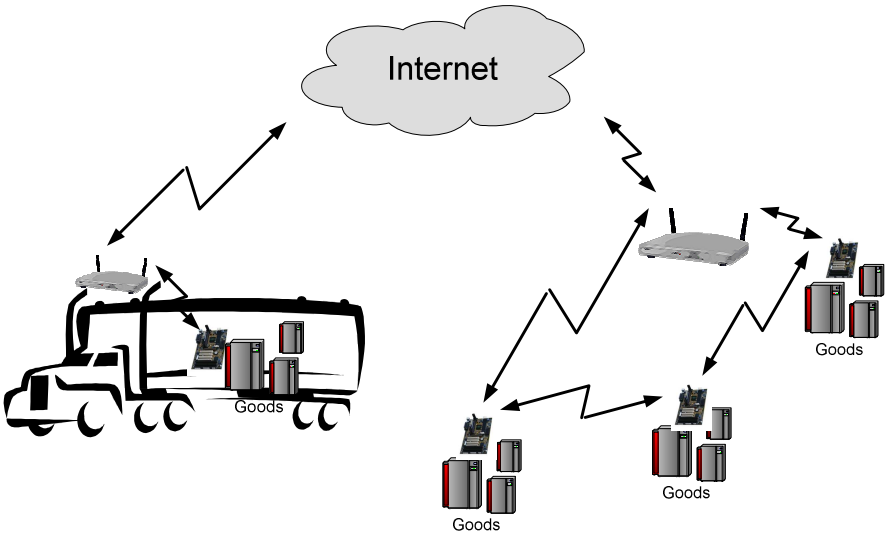
Recently, for transport logistic services the challenge makes growing competition at increased atomization of goods to be transferred imposed by:

- changes in delivery chains,
- operating by mean the virtual enterprises allowing just-in-time management,
- increasing traffic and congestion on the transport routes,
- increased environmental awareness.

In such service environment using traditional central planning is difficult and inefficient, so the WSN technology becomes an important alternative to solve a problem of effective logistic services. Other one area to implement the WSN technology the advanced CRC systems are [7].

For these purposes the **intelligent transport goods** are introduced. They are marked up by choosing the transport vehicles under condition of expected arrival time at given destination, risk not to arrive in time, suitability of transport vehicle for the dedicated transport purposes and transport expenses. All these factors can be easily monitored and controlled using the WSN technology, especially, if used system solutions are supported by the RFID tags or more advanced JavaCards recognized by the computers with access to Internet e.g. [8].

The purpose using the WSN technology for such application is to assure to intelligent goods mutual communication and communication with the vehicle's board computer. Schematically this is shown in fig. 3.1.



Rys.3.1 An idea to use the wireless sensors in logistic management

Shown in fig.3.1 the transport goods will "advise" to the vehicle's board computer how to configure the sensors to monitor the best transport conditions. On the transport vehicles this can be done as the transport goods can identify themselves by intercepting the transport requirement commands from the Internet. A given number of vehicle sensors identifying the transport goods can be configured into the WSN dedicated network assuring monitoring the required transport conditions.

Other manner to handle logistic operations by the use of the WSN is so called **Agent Representation of Transport Goods**. In computer networks this approach is referred to the goods represented by autonomous program agents, which possess the attributes defined by mean an unit program able migrate cross of the network. For logistic purposes such agents usually fulfill condition of the FIPA standard [9], in which the agents are combined with wireless sensor networks and allow to transfer the agent codes into agent platform covering the transport vehicles and the goods. In transport environment under correctly specified conditions such mobile agents are able to migrate to the goods data bases facilitating the data processing over computer networks. Advantage of such solution is high speed of operations, disadvantage really advanced programming supported the computer network system.

4. CONCLUSIONS

In the paper the principles, system architecture and topologies of the Wireless Network Sensors (WNS) were presented. Especial, attention was paid to the programming methods possible to be used in the sensors implementations. Related programming was categorized into two groups the low level language programming addressed to managing the data of the sensor networks and the high language level programming addressed to service implementations based on aggregated sensor data. In the service sensor network

programming implementations there were shown a key role of distributed programming in the Web environment. It is based on using the Java language and more universal approaches referred to the SOAP / WebService.

Last part of the paper is addressed to the Wireless Sensor Networks transportation service implementations. They are demonstrated by the service implementations in intelligent road controlled systems and logistics. Both of these areas characterize the wireless service operating environment, which if supported by the Web oriented sensor networks significantly upgrades the level of services.

This allows to state that the wireless sensor networks make powerful technology with the potential to be truly universal computing environment. However, despite of the advancements bringing smaller devices, more computation and communication power, and the new sensor application, programming of WSN systems remains the weakest point of wider deployments. So far, the WSN programming platforms can be as much advanced as sensors assure acceptable and predictable levels of performance and reliability.

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