ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

Performance Evaluation of Large-Scale Wireless Sensor Networks Communication Protocols that can be Integrated in a Smart City

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ABSTRACT: In the past few years the Smart City concept is a very topical issue being addressed by many research centres around the world. This paper presents the WSN communication protocols used as part of the smart city concept. Thus, we have analyzed the communication means that can be integrated in such a smart city concept, by taking into account the advantages and disadvantages of each particular technology.

KEYWORDS: Smart City, Wireless Sensor Networks, large-scale, IEEE 802.15.4, the 6LoWPAN, Internet of Things, Jennet.

I.INTRODUCTION

In the past few years the Smart City concept city is a very topical issue being addressed by many research centres around the world. One of the main problem addressed in many scientific papers in the selection of the communication protocols that can be integrated in a Smart City as to obtain the highest level of performance. The main contribution of this paper is the performance evaluation of the communication protocols that can be used in the Smart City Concept.

II.COMMUNICATION PROTOCOLS THAT CAN BE USED IN A SMART CITY

This section presents a comparative analysis of the communication protocols that can be used in a Smart City concept. The purpose of this study is to evaluate the performance level so as to select the best candidate. The structure of a Smart City has a series of particular features that must be taken into account, so that the performance level reached can be as high as possible. The WSN nodes are distributed over a large geographical area and the network is of long-thin, large scale.

There are two communication means in the Smart City concept:

- local communication, on short distances (hundreds of meters) between the various WSN nodes within the same system;
- long distance communication, between the control centre, where the information is collected, and the sink node.

The systems used in the Smart City concept and presented in the professional scientific literature suggest the protocols presented in Table 1 for transmitting information.

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Table 1. Communication protocols that can be integrated in a Smart City

Long distance communication	• Wi-Fi (802.11 b\g\n\ac); • Ethernet (TCP/IP); • GPRS (General Packet Radio Services); • 3/4G; • WiMax.		
Local communication	WSN	IEEE 802.15.4	ZigBee [1]; ZigBee Pro [2]; ZigBee IP [3]; JenNet [4]; Light Link [5].
		Internet of Things	6LoWPAN [6]; JenNet-IP [7];
		Proprietary protocols	Ant [8]; Dust Networks [9]; Z-Wave [10]: Simply TI [11].

As can be observed, most WSN protocols can be classified as follows: protocols based on the IEEE 802.15.4 standard, WSN networks that belong to the concept of Internet of Things and a series of proprietary communication protocols. In order to ensure the long distance transfer of information, the protocols that can be considered are: Wi-Fi, Ethernet, GPRS, 3/4G and WiMax.

Other criteria that can be considered are: recommended network topologies, maximum number of nodes, complexity in developing applications, presence of the Self Recovery function, the standard of reference the protocol is built on, additional license costs and, last but not least, whether the IP communication is supported (Table 2). This support for IP communication entails the presence of a certain advantage, when the TCP/IP protocol is used for the long distance transfer of information and it requires that the IP data packet is sent within the WSN network after a series of adjustments.

Table 2. Performance evaluation of the WSN that can be integrated in Smart City

	Recommended network topologies	**Maximum number of nodes,**	**Complexity in developing applications**	**Self Recovery**	**Reference Standard**	**Additional license costs**	**IP Support**
IEEE 802.15.4	Star Point-to-point	50	Medium	No	-	No	No
ZigBee	Star Tree Mesh	50	High	Yes	IEEE 802.15.4	Yes	No
ZigBee Pro	Star Tree Mesh	>50	High	Yes	IEEE 802.15.4	Yes	No
ZigBee IP	Mesh	≈250	High	Yes	IEEE 802.15.4	Yes	Yes
JenNet	Star Point-to-point Tree	>500	Low	Yes	IEEE 802.15.4	No	No
Light Link	Star	50	High	No	IEEE 802.15.4	Yes	No
6LoWPAN	Star	-	High	No	IEEE	No	Yes

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	Mesh				802.15.4		
JenNet-IP	Star Point-to-point Tree	>500	High	No	IEEE 802.15.4	No	Yes
Ant	Star Mesh	-	Medium	No	-	Yes	No
Z-Wave	Mesh	Max 50.	High	Yes	-	Yes	No
Simply TI	Star	Max.50	High	Yes	IEEE 802.15.4	Yes	No

The following is a brief description of the protocols that ensure the highest performance level.

III.THE IEEE 802.15.4 STANDARD

The IEEE 802.15.4 standard regulates the communication of WSN (wireless sensor networks). This standard defines the MAC (Medium Access Control) and the physical layer, as can be seen in Fig. 1. Beyond the physical and the MAC layers, the ZigBee or other protocols define the network layer (NWK) and the application (APL) layer.

In a WSN network that complies with the IEEE 802.15.4 standard, the physical layer is found on a lower level. This layer controls the radio transmitter and is directly responsible for activating radio transmissions or receiving packets, by selecting the communication channel. The MAC layer secures the interface between the physical layer and the network layer, being responsible for generating packets and synchronising devices.

The network layer ensures the connection between the MAC layer and the three layers associated with the application: the application framework, the application profiles and the application layer defined by the user. The network layer is responsible for network development, security, power management, network topology development and routing the packets.

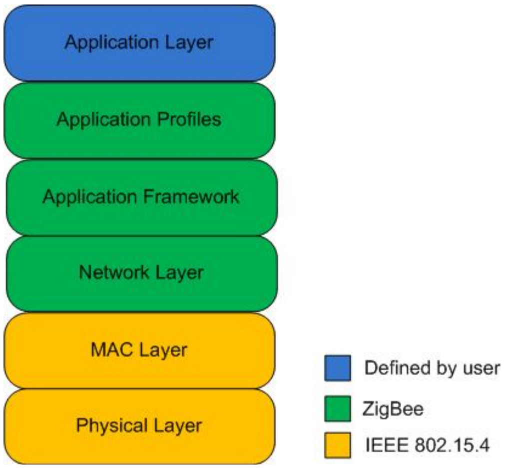

Fig. 1 The IEEE 802.15.4 communication standard and the ZigBee protocol

In the case of the ZigBee protocol, the application layer is developed by the user by means of the application profiles and the framework defined by the ZigBee Alliance. The disadvantage of using this protocol is the presence of certain additional license costs and the possibility to integrate a limited number of nodes. Thus, the ZigBee protocol does not ensure a high performance level in the Smart City concept.

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IV.THE 6LOWPAN STANDARD

Another way to implement the Smart City concept may consist in using the 6LoWPAN standard (IPv6 over Low Power Wireless Personal Area Networks) that entails the adjustment of the IPv6 protocol to the IEEE 802.15.4 standard. Since the length of the payload supported by IPv6 (Internet Protocol) is exceeding, 6LoWPAN suggests an adaptation layer that connects the NWK network layer to the MAC layer by compression, fragmentation and rearrangement as can be seen in Fig. 2.

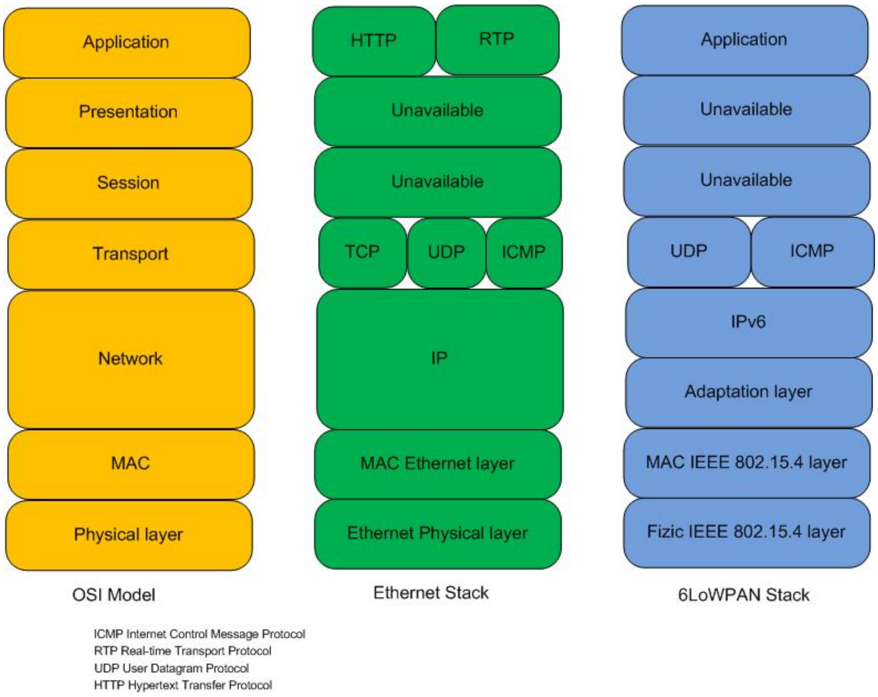

Fig. 2 The IEEE 802.15.4 communication standard and the ZigBee protocol

Fig. 2 also show an analogy between the OSI (Open Systems Interconnection) model, the Ethernet communication stack and the 6LoWPAN standard.

Thus, one can identify the seven layers of the OSI model and their correspondence in the Ethernet and 6LoWPAN protocols. The 6LoWPAN standard uses UDP (User Datagram Protocol) and ICMP (Internet Control Message Protocol) technologies at the transport layer.

This adjustment of the IPv6 packet to the packet defined by the IEEE 802.15.4 standard entails the occurrence of certain problems that the group Internet Engineering Task Force (IETF) [12] is trying to settle. The JenNet-IP and ZigBee-IP protocols are based on this standard.

We will next present some of the difficulties encountered when translating the IPv6 packet in an EEE 802.15.4 network.

1. Compression of the IPv6 packet to the size of an IEEE 802.15.4 packet entails the development of compression algorithms that would also allow keeping the same address used in WSN networks.

2. Developing new routing algorithms that:
- Would not cause the expansion of the size of the packet, given that the WSN communication is of the multi-hop type;
- Would take into account the fact that the nodes have memory and limited power resources;
- Would reduce the routing tables as much as possible.

3. The limited size of the packet.
The 6LoWPAN protocol entails using small sized packets. Adding the IP connectivity should first allow communication in a single frame, with no need for excessive fragmentation and then rearrangement. One of the main problems is caused by the small RAM memory of the WSN nodes that are not able to store packets of 1280 bytes in size. Mention must be made of the fact that the maximum size of an IEEE 802.15.4 packet is of 127 bytes.

4. Number of nodes
The Smart City concept entails the presence of a large number of nodes, spread across a wide geographical area, and, therefore, the introduction of the IPv6 capabilities should not increase the delays, limit the self-healing ability of the network or increase the cost of the devices.

5. Security
The encrypting algorithm used in WSN networks is AES (Advanced Encryption Standard). It ensures a high security level and is implemented in the IEEE 802.15.4 communication stack. However, the IEEE 802.15.4 standard does not mention any other additional details on how to manage the keys or the security provided on the other communication levels. In contrast, the 6LoWPAN protocol entails high confidentiality and data integrity protection, and such an increased security level can generate certain problems. The major disadvantage of this standard is the high cost of the devices and a rather low performance level, since various problems are yet to be addressed and thus we cannot yet speak of a mature standard.

V.INTERNET OF THINGS

Even though the term Internet of Things (IoT) is often mentioned in the professional literature, there is a certain degree of confusion associated with it, due to the large number of concepts it includes, and also due to its given name. [13]. Thus, a number of definitions have been assigned to this concept, for instance, according to [14] IoT refers to a global network (WWW- World Wide Web) of interconnected objects that can be addressed in a unique way, based on standard communication protocols. Paper [15] defines IoT as a concept that encompasses services that allow the interfacing of devices with virtual identities and personalities, operating in a virtual environment and using intelligent interfaces to communicate with the social environment and to the user. Professional literature includes a series of papers [16]-[20], that present various conceptual models and applications where WSN modules evolve using the Internet's IP infrastructure as communication environment.

The architecture of a Smart City is also part of the IoT concept (Fig. 3) as the long distance transfer of information uses the infrastructure of the Internet, and WSN sensors are used for implementing various systems.
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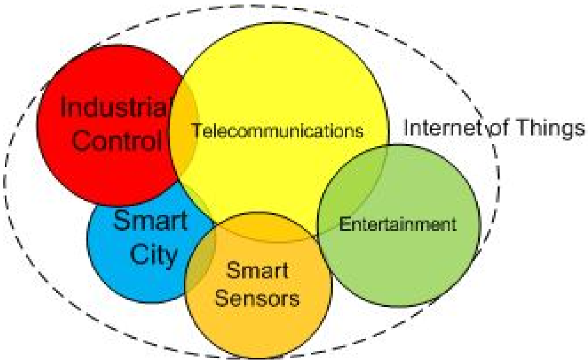

Fig. 3 The Internet of Things concept

Thus, there is a close connection between the Smart City concept (SC) and the Internet of Things concept, as they use the same communication environment. Additionally, intelligent cities implicitly integrate the concept of IoT, thus contributing to the development of intelligent WSN networks. [21]. The long distance transfer of information in an SC, the efficiency and advantages of an Internet connection are used.

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VI.JENNET PROTOCOL

Another protocol that could be used in a Smart City is the JenNet, developed by NXP/Jennic. JenNet is based on the IEEE 802.15.4 standard, over which the NXP/Jennic has developed the network layer, as can be seen in Fig. 4.
JenNet meets the requirements entailed by the need for a high performance level, such as: large number of nodes, reduced complexity in developing the applications and the lack of additional license costs, being thus recommended for integration in a long-thin large-scale WSN network that covers a very wide geographical area.

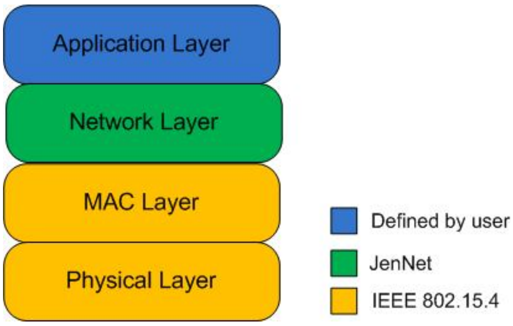

Fig. 4 The JenNet protocol

VII.CONCLUSION

After this brief summary of the advantages and disadvantages of the main WSN protocols that can be integrated in the Smart City concept, we can conclude that, in order to reach a high performance level, the employment of a WSN communication protocol based on the IEEE 802.15.4 standard is recommended. The IoT concept still has the highest advantage, consisting in the transmission of the data packets over the already existing infrastructure.

ACKNOWLEDGMENT

This paper has been financially supported within the project entitled ***„SOCERT. Knowledge society, dynamism through research”***, contract number POSDRU/159/1.5/S/132406. This project is co-financed by European Social Fund through Sectoral Operational Programme for Human Resources Development 2007-2013. **Investing in people!**

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