Comparative Study of Performance for 804.15.4 ZigBee and 6LoWPAN Protocols

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Abstract. This paper addresses the low power mechanisms provided by the ZigBee and the 6LoWPAN Protocol, providing comparative assessments based on the results obtained by different researchers and available in specialized literature, running through experimental measurements on digital test banks. For a performance comparison, the parameters of each protocol have been adjusted so that it is able to function properly in low power mode and make the measurement scenarios equivalent in terms of traffic and energy efficiency. The comparison focuses on the impact of the mechanisms of low power in the performance of the network. Experimental evaluations mentioned, show strengths and weaknesses of both protocols when working in a low power mode.

Keywords: ZigBee, 6LoWPAN, network protocols, efficiency

1 Introduction

The gravitational nucleus formed by the concepts of Web 2.0 and the Internet of things (IoT) is moving towards Web applications and concepts of services looking for greater integration and greater accessibility, in the light of new paradigms of "at any time" and "at anywhere". The future of the Internet is based on these "bricks" willing to form a dynamic entity, producing new means of interaction with the services, other users and the environment [3, 5]. Networks of wireless sensors (WSN) have been recognized as a very important part of the concept of interconnected network, which aims to monitor the environment or any situation that you want to control, allowing an interaction with a remote control device in the same field. Data sampling can be carried out over a large area through the distribution of sensors. For years, wireless technology has been the new means of communication of this type of network. However, to meet the current and the future standards and to ensure the accessibility of all nodes in a network of sensors, the use of the IP and in particular IPv6 seems inevitable. From the fact that a node must be economic, the calculation of the power and energy storage capacity is limited. In order to overcome the fact that the classical IP are the limiting factor, two new protocols have been developed, they are called

6LoWPAN (about IPv6), Low - Power Wireless Personal Area Networks, and Zigbee [11].

The present study aims to compare the performance of the modes of low consume operation of IEEE 802.15.4 / ZigBee and 6LoWPAN, for a wireless network of industrial sensors - WSN. Therefore the first part describes the two protocols with an approach to low power mechanisms that are implemented and their capabilities. As it follows we cited the results of actual comparisons of both protocols in a digital test bank, focusing on the impact of the mechanisms of low power on the performance of the network. Since these mechanisms of low-work power put some nodes at rest in order to decrease their cycle, the protocol comparison is made by making them work on the same platform HWSW, under the same workload and using the same cycle. To accomplish this, we need a preliminary adjustment of the operating parameters of the two protocols. Such tuning is not simple, just as the mode of low power consumption implemented by the two protocols, and therefore, the relevant parameters are significantly different [14].

2 Related Work

WSN Internet interconnection has been widely investigated in recent years. At the beginning of the WSN era, the researchers focused on the development of dedicated systems, then very specialized, but non-standardized protocols were designed. Although these systems were generally efficient in specific application scenarios, they lacked flexibility: the development of new applications required much time and it was a very cumbersome job. As a remedy to this, the standard 6LoWPAN is proposed as a viable method to carry IPv6 WSNs [4]. This has obvious advantages, such as the fast connectivity and compatibility with existing architectures, plug - and - play, rapid development of applications as well as the possibility of integration with existing web services developed for the IF standard for networks [3]. Several studies of performance of the IEEE 802.15.4 / ZigBee exist in the literature, carried out by experimental measurements, simulations and analytical models. A detailed analytical assessment of the performance of IEEE 802.15.4 network is provided in [1], they consider both saturated as unsaturated traffic scenarios. Both models, the analytical and the simulation for the analysis, are used in [6], to evaluate the performance of the low-power IEEE 802.15.4 Protocol ZigBee. All of these works, however, only provide some parameters, without any comparison with other protocols. This document aims to compare the performance of the low consumption operating modes of the ZigBee and 6LoWPAN protocols.

The 6LoWPAN Protocol is attracting the attention of the market and the researchers, thanks to the new possibilities with the integration of WSN and Internet technologies. In [12], it discusses the main decisions in the design of 6LoWPAN, together with the issues and challenges that must be addressed to achieve further development. In [16], it proposes a method for 6LoWPAN inside IPv4 networks, so that IPv4 can also take advantage of the WSN integration.

An adaptation of a stage 6LoWPAN routing algorithm is presented in [2] and its experimental validation in a real test bank, in order to allow simple transmissions in real time. A comparison of the capabilities provided by some protocols which are competing in the home automation technologies is offered in [9]. However, it is a theoretical approach and not quantitative, without a quantitative assessment of the performance of protocols.

3 Protocols Under Evaluation

3.1 IEEE 802.15.4/ZigBee

The IEEE 802.15.4 standard [7] defines physical layers and the wireless Medium Access Control (MAC layer) of low power consumption in wireless personal area (WPAN) network. It is a protocol for low rate and power of communications, especially suitable for small embedded devices, such as sensors nodes. The Protocol allows varying the nodes work cycles from 100 up to a minimum of approximately 0.1 [14]. The IEEE 802.15.4 MAC Protocol has two operating systems: one without the management framework, in which the channel access nodes use a classical mechanism (unslotted) CSMACA (Multiple Access with listening to carrier and collision avoidance) and a mode with enabled Administration frame, which uses a slotted CSMACA mechanism which supports the duty cycle to save energy. This Protocol is based on a superplot, structure which is bounded by guides, which are submitted by a coordinator in order to synchronize the associated nodes [7].

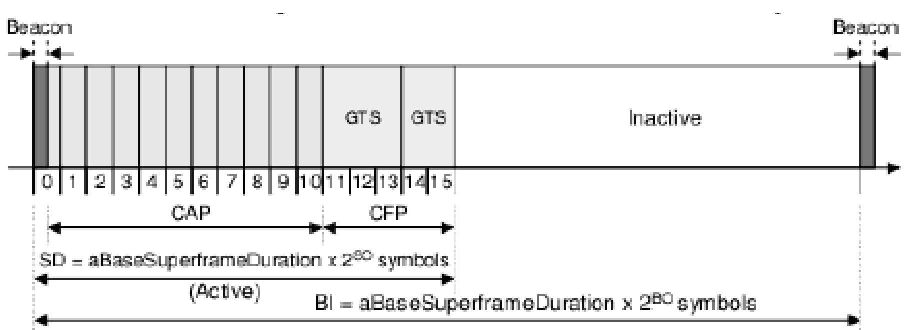

Fig. 1. Superplot of IEEE 802.15.4

The superplots which are shown in Figure 1 are divided into two parts: the active part and the inactive part. The active part is divided into 16 connectors of the same length, and by the limit of these nodes, the channel can be accessed to transmit information. This is divided in turn into two subparts: the Containment Access Period (CAP, for its acronym in English), in which the media access is regulated by the CSMACA, and the Proof period of containment (PPC, for its acronym in English), in which you can access the channel without dispute. In the inactive part, on the other hand, there is no communication and therefore the nodes can turn their radios out and enter (Suspension) energy saving mode. The timing of the superplot is governed by two parameters:

- The order between the Bacons (BO) or guidelines, which define the interval between two guides, which consequently define the duration of the superplot. This interval is called interval between guides (BI) and is defined as BI= 2BO
- The order of the superplots (SO), which defines the active period of the same duration. In accordance with the IEEE 802.15.4 standard, must be defined in the following order: 0≤SO≤BO≤14.

As the nodes sleep in the period of inactivity of the superplot, the duty cycle (DC) of this only depends on the structure of the superplot, and it can be specified as:

$DC = \frac{SD}{BI} = 2^{(IO)}$ (1)

Where IO = SO − BO is called the order of inactivity.

When using IEEE 802.15.4 devices in their low-power protocols with the Guide element enabled, two data of different transfer protocols are used to achieve communication between a coordinator and its devices. In the case that a packet must be sent from a device to which the one that acts as Coordinator, it is used a direct-drive mechanism. In this Protocol, the device waits for the plot Guide, sent by the Coordinator, to synchronize with the superplot. Then, it sends data from one of the slots of the superplot. To run the reception of the package, the Coordinator sends an acknowledgement of receipt to complete the transmission. This last point, however, is optional. Two different forwarding protocols are defined by the ZigBee specification: a protocol for routing based on the Ad hoc on - demand distance of the Vector (AODV, for its acronym in English), and a routing protocol tree which forwards the packets to the following hierarchy of coordinators. Topologies of star and group of trees can take advantage of the feature of low power consumption. However, the star topology can only be used for small networks, while tree cluster topology is suitable for larger sensor networks. For this reason, this document focuses on the topologies of the trees with tree routing cluster [14]. The ZigBee Networks used on its enabled guide mode, allow deterministic cycles of service nodes, since they depend on parameters of the superplot, according to equation (1). These parameters can be set at design time in order to comply with the requirements of the network in terms of energy consumption. However, the waiting time for the next active superplot and the increase of the complexity and the overhead expenses of indirect communication can affect the performance of sensitive data transmissions at the same time, especially in the case of multi-hop networks cluster of trees.

3.2 6LoWPAN

The 6LoWPAN [10] protocol specification allows IPv6 communications over low-power wireless devices. In particular, the RFC 6LoWPAN standard defines the network layer of WPAN based on IP, using the IEEE 802.15.4 standard in layers of physical access. The main reason for developing 6LoWPAN was that common IPv6 standard is too bulky for small embedded devices, such as sensors nodes. The standard IP protocol could not fit for WSN for several reasons. For example, the standard IPv6 header is 40 bytes, which is comparable to (or even larger), the data from the sensor that is transmitted through a WSN. An additional overload of 20 bytes is introduced by the TCP Protocol respectively.

Taking into account that the maximum size of plot in the MAC layer is 102 bytes, or even smaller when the link layer security is enabled, just a few bytes would be available for data transmissions. On the other hand, IPv6 minimum maximum transfer unit is 1280 bytes (RFC 2460), which is much larger than the maximum for the IEEE 802.15.4. Therefore, it needs a little fragmentation. Another of the problems raised by the support of IP over IEEE 802.15.4 MAC and physical are the scheme of addressing and the routing mechanism. In fact, IP and IEEE 802.15.4 have different protocols for address and routing that cannot handle nodes in sleep mode. Therefore, 6LoWPAN introduces an adaptation layer between the MAC and the network layer, which compresses the header to a few bytes, keeping the main features of IPv6. The guarantee of adaptation of 6LoWPAN layer, introduces support mechanisms to the fragmentation and to the reassembly, when compressing the headers, and carries out the assignment of addresses between IPv6 and IEEE 802.15.4. The details of these mechanisms, however, are outside the scope of this work.

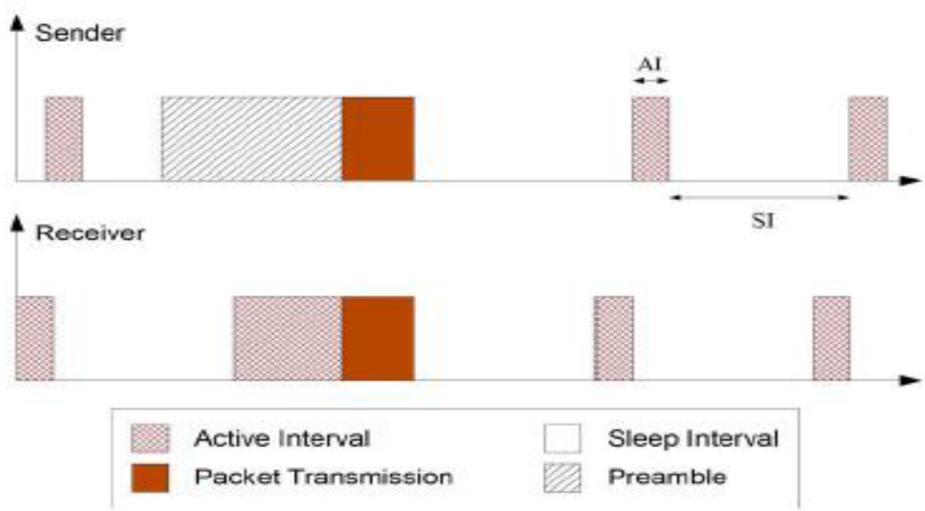

Fig. 2. Low Power Listening

The 6LoWPAN specification does not provide any specific mechanism to achieve low-power communication, but it depends on the bottom layer approaches.

The simplest solution to achieve energy efficiency in 6LoWPAN networks could be the exploitation of the low-power capabilities of the IEEE 802.15.4 protocol with enabled Guide. However, while the MAC layer could theoretically work both in enabled mode as in not enabled, all 6LoWPAN current implementations only support the Protocol not enabled. The main reason for not applying the communication without a guide in 6LoWPAN is that IP protocols assume that the link is always active. This is for the sake of simplicity, so that IP protocols do not need to program transmissions of datagrams. Therefore, 6LoWPAN uses techniques that give the illusion that the upper layers in the receiver are always active, although actually it only happens part of the time. Most of 6LoWPAN implementations use low powers of listening to power (LPL), a technique that allows the nodes to access channel asynchronously in a fully distributed network.

The Operation behind LPL is as follows. A node periodically wakes, lights and so do the activity controls. If no activity is detected, the node turns off the receiver and returns to its state of rest, or otherwise, the rooms stay turned on until the packet is received or, in the case of a false positive, until a timer expires. A graphical representation of the LPL operations is shown in Figure 2.

4 Performance Evaluation

Benchmarking is done in two different test scenarios, in which the nodes have the same configuration, but the sending node transmission period (and therefore workload) is different. The first scenario emulates an application of detection of low power where the monitored phenomenon has slow dynamics, and where the sensor node sends packets of data with a period of 20s. The second scenario emulates a WSN application with a faster dynamics, where the shipping period is 400ms. It should be noted that the difference in shipping period also changes for the 6LoWPAN‘s working cycles. The topology of the network, as in the scenarios is the same as shown in Figure 3. All nodes in the IEEE 802.15.4 ZigBee network share the same superplot settings and, therefore, the same working cycle. Four different settings of superplot have been used for the net IEEE 802.15.4 ZigBee, with different working cycles and, therefore, different energy saving capabilities. The first setting uses a BO of 3, which is a smaller guide, which offers sufficient security of transmission, with this BO we use an OS, which in turn is the smallest SO that provides sufficient reliability of transmission. We get a cycle of 0.25. To further reduce the duty cycle, the superplot is set using a Guide order of 5. In

Table 1. Superplot Settings for the IEEE 802.15.4 / ZigBee Networks

Name of the Setting	BO	SO	DC
ZigBee 1	3	1	0,25
ZigBee 2	5	1	0,06
ZigBee 3	5	2	0,12
ZigBee 4	5	3	0,25

this way, we have been able to work down to 0.06 cycles. The details of these configurations are shown in Table 1.

The 6LoWPAN settings (BI and SI) have been selected to provide the emitter node with the same working cycle as the IEEE 802.15.4 / ZigBee network. It also depends on the shipping period, so we use different configurations in the two scenarios.

4.1 Scenario 1 - Tsend = 20s

By solving the following equation:

$$DC = \frac{\mathrm{AI}}{\mathrm{SI} + \mathrm{AI}} + \frac{\mathrm{SI} + \mathrm{Tpkt} + \mathrm{Dtx}}{\mathrm{Tsend}} \quad (1)$$

With SI (interval of inactivity) as unknown and the value specified for the other parameters, according to [14], achieves a SI of 162 and 492ms allows a cycle of work of 0.12 and 0.25, respectively, with a period of shipment of 20s and the AI (activity interval) of 51.2ms standard. However, with the use of these LPL parameters is not possible to achieve a work of 0.06 cycle such as the stage 2 with ZigBee. For this reason, after tried to reduce the AI parameter to half the value of the MAX LPL, the CCA executes permanent control. In this way, by designing an AI of 25.6ms, we are able to achieve a duty cycle of 0.06, through the use of a SI of 606ms. The settings that were used in the LPL for this scenario are summarized in Table 2.

Table 2. LPL Settings for 6LoWPAN IEEE 802.15.4 Networks

Config Name	AI *(ms)*	SI *(ms)*	DC
6LoWPAN-1	25.6	606	0.06
6LoWPAN-2	51.2	492	0.12
6LoWPAN-3	51.2	162	0.25

The experiment consisted of sending 1300 packages and record the times of transmission and reception of each packet. The log files are then used to calculate three performance metrics:

- The delay from end to end, calculated as the difference between the date and time of an event of reception and the date and time of the event of corresponding transmission.
- The time of update is the time interval between two consecutive events for the reception of packages.
- The relationship of delivery, which is the percentage of received packets over the total number of sent packets successfully.

4.2 End-to-end Delay

The cumulative distribution function (CDF) of the experiments in delays from end to end for all measurement activities are represented in Figure 3, while the average delay and standard deviation are shown in Table 4. Here it is possible to see that the delay from end to end of the 802.15.4 / ZigBee IEEE network is strongly influenced by the beacon interval. In fact, the ZigBee configuration - 1 with a Guide order of 3 has less delay than in the ZigBee - 4 configuration that has the same working cycle but with a Guide order of 5. The delay from end to end of the 6LoWPAN configurations are also very influenced by the cycle of work regarding the network configurations with 0.25 and 0.12 duty cycle, we can see that 6LoWPAN has a smaller average delay, but with a considerably larger standard deviation than IEEE 802.15.4 ZigBee.

In Figure 3 you can see that, taking into account the ZigBee - 1 and 6LoWPAN - 3 scenarios with a duty cycle of 0.25, although the average delay is smaller, in this last protocol is larger, the ZigBee delay - 1 is approximately of 200 MS, which is much smaller than the 6LoWPAN - 3. However, when considering the scenarios that have a cycle of 0,12 (ZigBee - 3 y 6LoWPAN-2), the 6LoWPAN Protocol provides a smaller delay than IEEE 802.15.4 / ZigBee most of the time. Finally, from Table 4, it is possible to observe that the decrease in the length of the AI in the 6LoWPAN - 1 configuration, has a serious negative impact on the performance of the network, since both, the delay and the increase in the standard deviation of some of them will mean an order of magnitude. As a result, the ZigBee - 2 configurations with the same cycle of 0.06 clearly exceeds 6LoWPAN - 1.

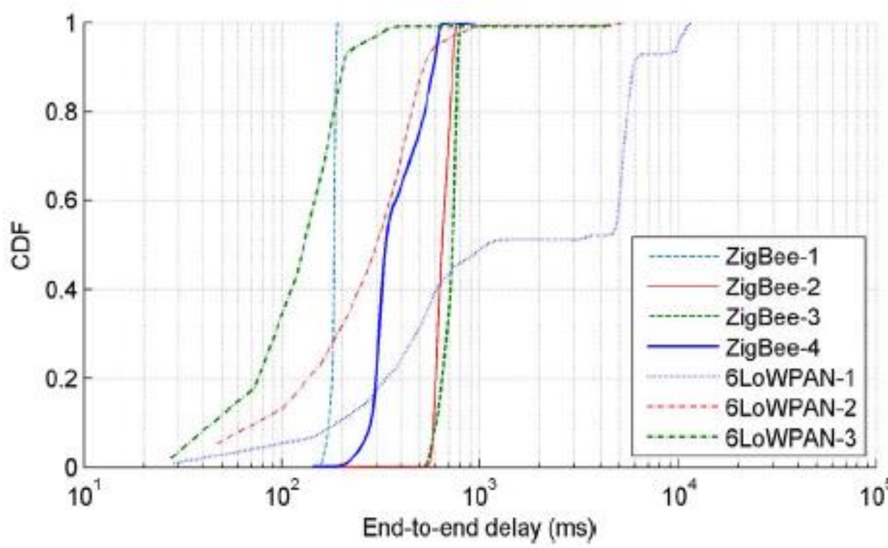

Fig. 3. CDF Delay from End to End

4.3 Time Update and Distribution Relationship.

In terms of the CDF of the times of update, in Figure 4, we see that IEEE 802.15.4 / ZigBee achieves smaller time intervals between consecutive packets receptions. Due to the fact that TelosB nodes have a slightly shorter symbol time than the expected by the standard, the actual shipping period is shorter than 20s, and in particular is about 19, 07s. Therefore, the smaller update times of the IEEE 802.15.4 / ZigBee configuration are closer to the 6LoWPAN. Once again, the 6LoWPAN - 1 configuration shows much better performance than the other configurations. Finally, we see in the ZigBee – 1 configuration, that there are some sporadic cases where the update time is twice the theoretical value. A closer look at Figure 4 reveals that this also occurs for the other configuration of IEEE 802.15.4 / ZigBee, but with a lesser probability.

This result is due to packet loss, if a packet is lost, the update time is recorded in the next reception of packets, and therefore doubled the time of update. Regarding the relationship of distribution, in Figure 5, we see that the 802.15.4 / ZigBee IEEE network experiences some loss of packets, which increases when the order guide decreases. One possible explanation for this behavior is that this packet loss is due to some problems of synchronization due to the variability of real beacon intervals. In the figure we see also that 6LoWPAN with the default value of IA (51.2ms) has the best performance in terms of packets received (but the ZigBee with BO = 5 configuration is just marginally less). On the Opposite, the 6LoWPAN -1 with the smaller AI settings has better performance in all aspects.

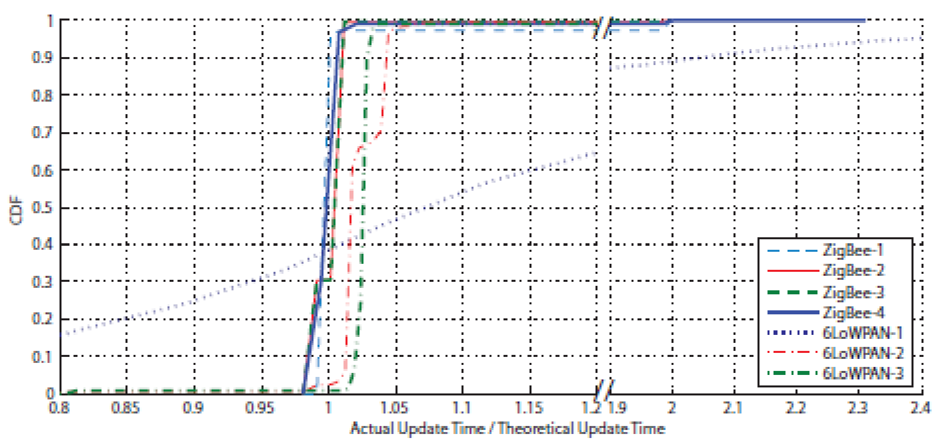

Fig. 4. Update Times CDF

4.4 Scenario 2 – Tsend = 400ms

The smaller shipping period of this scenario makes the 6LoWPAN- 1 configurations and 6LoWPAN - 2 to be unusable, because their sleep intervals are comparable to the shipment times, and this would lead to congestion in the network. Configuration 6LoWPAN - 3 is still usable, but the comparison with the other networks would be unfair, since the cycle of this configuration is 0.7 considering the 400ms of shipping in each period. It is possible to see that 0.25 or smaller working cycles are not reachable at all with this period of shipping and with the IA by default. On the other hand, it was seen that the decrease in the duration of active intervals causes a degradation of performance, for this reason, it was decided to compare the performance of the same configuration of 802.15.4 / ZigBee IEEE stage 1 against the 6LoWPAN settings that provides the smallest work cycle for the shipping, it is possible to see that the optimum is a SI of 92ms which provides a 0.64 duty cycle with the default value of AI 51.2ms. We refer to this network configuration such as 6LoWPAN - 4. The same performance data observed for stage - 1 were also calculated for the stage - 2.

In the CDF of end-to-end delay in packets, we see basically the same trends that were observed for the stage - 1 the delays of the IEEE 802.15.4 / ZigBee are almost identical to those shown in Figure 3.

5 Discussion of Results

Several authors have examined the performance of 6LoWPAN and ZigBee protocols independently. A project os IETF 15 assesses the ZigBee Protocol whereas several routing scenarios of real-life. Malisa Vucinic, Bernard Tourancheau and Andrzej Duda, made a comparison of the performance of the RPL and LOADng protocols proposed by the IETF for low-power and high-complexity based networks on the IPv6/6LoWPAN.

ZigBee is a network layer built on the IEEE MAC 802.15.4 standard, designed to provide a protocol based on the standards for the interoperability of the sensors networks. 6LoWPAN, the new buzz word, seems to be competing heavily with ZigBee.

In essence, 6LoWPAN products have entered the market as the ZigBee direct competition, since they can use the mentioned standard (802.15.4), and even better, they can work with other PHY and allows seamless integration with other IP-based systems. 6LoWPAN is an acronym of IPv6 via Low-Power Wireless Personal Area Networks; the name originated in the Working Group in the IETF.

– 6LoWPAN vs. ZigBee: Wireless Protocol Interoperability

ZigBee defines communication between 802.15.4 nodes (Layer2 in the IP World), and then defines new upper layers for all the way to the application. This means that ZigBee devices can interoperate with other ZigBee devices, assuming that they use the same profile (similar to Bluetooth). Besides the 6LoWPAN Protocol provides interoperability with other wireless 802.15.4 devices as well as devices in any other IP network link (for example, Ethernet or Wi-Fi), with a simple bridge device. To build a bridge between non-ZigBee and ZigBee networks requires a more complex gateway at the application layer.

The key requirement for IPv6 on 802.15.4 is that the Maximum Transmission Unit (MTU), must be at least 1280 bytes packages (by RFC 2460). Since the IEEE 802.15.4 standard packet size is 127 bytes, an adaptation layer must be implemented to allow the transmission of IPv6 datagrams.

– 6LoWPAN vs. ZigBee: Size of Stack / Overload of Packages

When comparing ZigBee and 6LoWPAN over 802.15.4, the professional should be familiar with the package format and general costs, since this is directly related to the ease of scaling the network and the available space for payload data. Although there are alternative ways, typical configurations are shown below.

The IP routing over 6LoWPAN links, does not necessarily require additional header information in the 6LoWPAN. Layer. This reduces the overload of packets and allows more room for the payload data. Moreover, the size of the typical code of a pile with all the functions is 90 KB for ZigBee and only 30 KB for 6LoWPAN.

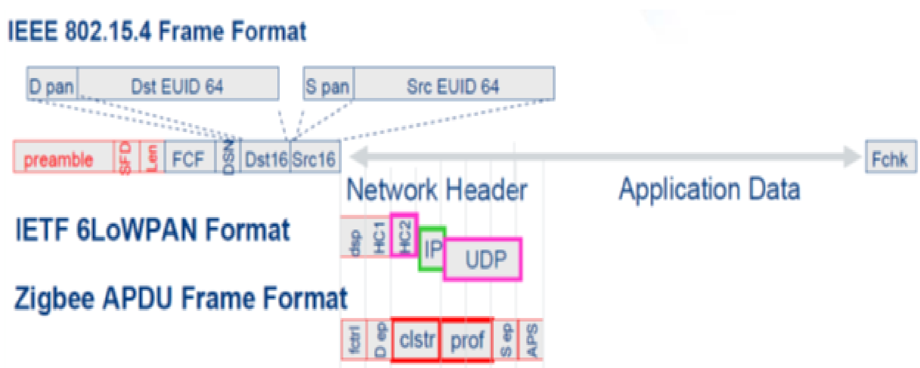

Fig. 5. Diagram of Archrock Supply

Fctrl: Frame control bit fields; Dep: Destination endpoint; Clst: Cluster identifier; Prof: Profile identifier; Sep: Source endpoint and APS: APT counter (for the prevention of duplicate sequence).

– 6LoWPAN vs. ZigBee: Availability and Cost

The major players in the industry of semiconductors, such as Texas Instruments, Freescale and Atmel, promote, and provide 802.15.4 tabs that can be used, either for ZigBee or 6LoWPAN. These same companies even offer free ZigBee stacks. The Support for 6LoWPAN stacks seems to be behind ZigBee. There is at least one available open source stack, and some companies such as Archrock and Sensinode licensed their own 6LoWPAN stacks. In summary, 6LoWPAN is quite attractive, since it is based on IP - the standard work of Internet Protocol. However, ZigBee seems to be more popular and has been adopted by the main actors in multiple industries.

6 Conclusions

This work was directed to an evaluation of the comparative performance of the IEEE 802.15.4 / ZigBee and 6LoWPAN protocols for industrial WSNs. The document offers several contributions. First, a theoretical analysis of the low-power characteristics of the two protocols, which are used as the basis of a methodology to tune the configuration parameters of low-power of the two protocols (it means., the BO and SO for 802.15.4 / ZigBee, and the AI and SI for 6LoWPAN) in order to achieve a working cycle in a realistic test bank built with COTS Hardware and open source software. And seconds, the experimental comparative evaluation in a digital test bank, that allow to highlight the strengths and the weaknesses of both protocols when working in the mode of low consumption. From these assessments arise tips for the designer of the network, allowing him to select the technology that best suits the purpose of performance, to properly achieve a given duty cycle, or a maximum delay.

The 802.15.4 IEEE protocol allows a network designer to carry out energy planning by adjusting the cycle nodes work, but the implementation has to be carefully done because of the possible problems superimposed on the superplot. On the other hand, 6LoWPAN does not require any synchronization between nodes, but their cycle should depend on the general effectiveness of the load, and this makes it more difficult to plan the working cycle and therefore the power consumption. The results of experimental evaluations show that the 802.15.4 / ZigBee IEEE network is able to support smaller working cycles and provide minor final delays with updating times that are a little closer to the theoretical value than the 6LoWPAN. On the other hand, the 6LoWPAN network shows that average delays are minor from end to end and thus, provides greater reliability; this is a lower percentage of packet loss.

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