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Hybrid Wireless Protocols for the Internet Of Things

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***Abstract*—The development of new communications protocols in the Internet Of Things aim low power embedded systems. Protocols are designed to be reliable and not to have a large bandwidth. These technologies have each their specificities and try to become the reference standard. This article explain how researchers and manufacturers need to create new hybrid and multi-technologies networks in order to develop complex systems which can adapt themselves to the constraints.**

I. Introduction

We are in height in the revolution of wireless sensor networks: The Internet Of Things. The export of a large number of real-time informations on a particular environment is a value-added to an ageing product. This emergence of the Internet of Things is perceived by the manufacturers as a breath of fresh air which allows to give a youthful boost to their products and to imagine new uses. Certain uses more serious as the monitoring and the supervision of datacenters or rescue in high mountain requires a study more thorough and more optimal technologies to satisfy the degree of reliability and required performances. The energy saving, the range, the increase of nodes, the safety, the bit rate, the latency are so many parameters as any standard radio manages to satisfy at the same time. We are going to analyze pros and cons of these standards and to offer interesting combinations for these cases of uses.

The sections of this article are going to resume the main current technologies for wireless sensors network and to demonstrate that there are industrial application needs where it is necessary to have several technologies. In the second part, the notion of hybridization of the low layers is present in the form of three possible architectures. The last part shows cases of uses of the hybridization and exposes the necessity of identifying the performances needed by the application to choose the technologies and to create a correct model.

II. State of the art of the radio technologies

In this chapter, we present a quick state-of-the-art of the most popular technologies used in the context of our study.

A. Sigfox

The Sigfox [7] technology is the property of a Toulousian company in France and aims at the market of the energy-efficient objects which want to send very few data towards Internet. This technology has the originality to be very narrow band (UNB, Ultra Narrow Band), with a bandwidth of about ten hertz wide against several hundreds to several thousands for the other technologies.

Sigfox uses ISM bands which allows him to be used world wide and to have not to buy frequency band in every country. It is essentially the technical reason which explains its fast deployment these last years. The frequency efficiency allows not to consume too much energy during the transmission and to get more range.

The very long range require only 1 to 3 fixed basic antennas to cover 1000m^2 against 20 antennas for a classical short-range cellular network. The low frequency efficiency and the low rate of emission of objects allows to have a higher success rate of the transmission and decrease the pollution of the free ISM band. These few advantages are thwarted by the locking of the technology by the Sigfox company which detains all the rights.

Sigfox is actually the biggest network for the Internet Of Things in term of cover in the world, however it has to show its ability against the LoraWAN technology and particularly the 5G. Indeed the Sigfox technology is Ultra Narrow Band what make difficult the communication from the gateway to the object is the dispersal in frequency. The lack of acknowledgment strongly undermines the reliability. The limitation of Sigfox tranceivers is 140 packets of 12 bytes per day. The offer in term of tranceivers is limited to the main partners of Sigfox as Telecom Design[8], Radiocrafts, Adeunis, Atim and Nemeus.

B. LoRa and LoRaWAN

LoRa alliance is a grouping of several large companies of the sector of semiconductors, telecoms and computing. This consortium is mainly carried by Cisco and IBM. LoRaWAN is considered as the main opponent of Sigfox because it is on the same market but remains free. This allows everybody to spread his own gateway for example the network "The Thing Network" [12] which aims to be a community network.

LoRaWAN is a protocol which includes some safety whith a double encryption [3]. An application encryption which allows to guarantee the data privacy of the sensor up to the application server. The second encryption allows the operator to recognize the data packet and to send the data towards the good application server without being able to decipher the application payload. This double encryption is visible on the figure 3. These two encryptions are symmetric with AES keys of 128bits.

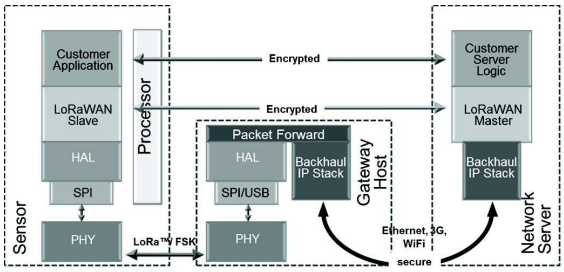

Fig. 1. LoRaWAN Architecture - source: LoRa Alliance

This technology allows to reach the same performances as Sigfox in term of range, with a beam of 20km in line of sight and 5km in urban area. The available bandwidth of the signal are 125kHz, 250kHz and 500kHz, with the management of several modes, following the distance in which the object is of the gateway.

C. Zigbee/802.15.4

The standard IEEE 802.15.4 [10] is aimed at the embedded systems low consumption, short range and with low bit rate. It is a standard older than other technologies presented here, but that remains a reference for numerous protocols. It bases itself on the principle of nodes having a 16 bits address (short address) and which can be a Full Function Device (FFD) or a Reduce Fonction Device (RFD). This standard allows to create LRWPAN networks (Low Range Wireless Personal Area Network) in star or meshed.

The technique of access to the medium is CSMA/CA. The Zigbee protocol is not a standard but a technology defined by a consortium of companies: the ZigBee alliance. This protocol was mainly used at the moment in home automations applications as the detection of smoke or intrusion, as well as in the industrial environment for example the range Harmony XB5R[13] of Schneider Electric.

D. 6LoWPAN

The workgroup 6LoWPAN bases itself on the principle to spread the use of ipv6 to the LPWAN. These networks as we said are very constrained in energy and in bandwidth and this requires some limitations for the use of ipv6. The workgroup drafted several standards, in particular at the level of the fragmentation of an IP packet as well as compression of the header.

This comes because the PSDU of the standard IEEE 802.15.4 which is the MAC layer of 6LoWPAN is too low. Furthermore it is difficult to respect the Maximum Transmission Unit of ipv6, the size of the largest protocol data unit that the layer can pass onwards. The applications of the 6LoWPAN are almost the same as Zigbee because both are based on IEEE 802.15.4. However the fact of being reachable directly from a network IP allows to have access to a lot of protocols as the SNMP directly on end devices.

Today, numerous works are in progress as the standardization of 6TISCH [14] which adapts the works of 6LowPAN on a IEEE 802.15.4e [11] layer. These works aim at creating ipv6 wireless sensor networks with strong industrial constraints.

E. BLE

Bluetooth Low Energy is an extension of Bluetooth for the WPAN. The BLE allows to have lower consumption to the detriment of the bit rate and to the detriment of the range. However the BLE has a bandwidth of 1Mbps and Bluetooth 3Mbps what is very interesting because the energy consumption was divided by 10. The typical electrical consumption of a single Bluetooth chip is about 1 watt, while a BLE chip needs from 0,01 to 0,5W. BLE is a recent technology which wants to win some places on the market of LPWPAN by promising a much higher bit rate with the same order of consumption.

F. Comparative technologies

None of these technologies is fulfilling and requires to make choice following the targeted application.

TABLE I
COMPARATIVE DIFFERENTS TECHNOLOGIES

	BLE	Zigbee	Sigfox	LoRaWAN	6LowPAN
Bit Rate	++	+	-	-	++
Range	-	+	++	++	+
Price	+	+	–	-	+
Autonomy	+	+	++	++	+
Free Standard	+	–	—	++	++

The table I above allows to compare the technologies among them. We can notice that it is difficult to have very long range and a high bit rate. Sigfox is not planned to be bidirectional because the receiver is often of much better quality to be able to identify a signal and to extract it out of the noise.

A lot of applications require to have a very active Mesh, for example in ZigBee, and to have the possibility of extracting data more punctually by a LoRa network or Sigfox. ZigBee and 6LowPAN share the same MAC layer standardised in the IEEE 802.15.4 standard. It is possible to make a hybridization of the network layer to be compatible with both technologies.

In the following section, we present various cases of uses which can require to have hybrid nodes.

III. INDUSTRIAL CONSTRAINTS

A. Datacenter Monitoring

The supervision and the monitoring of datacenters is a current problem with a high demand of technical solutions by the administrators. A great deal of metrics are watched as the temperature of the servers, the temperature of the water in the air conditioning system, the electric consumption, the generators, the tanks etc. All these data must be collected and handled in real time. The network and electric wiring is very dense in these rooms and the addition of hundreds of sensors is impossible. It is necessary to imagine solutions of networks of autonomous sensors in energy which communicate with a gateway.

The datacenter environment is very centred around networks IP and around supervision of equipment in SNMP. The technical solution which occurs is 6TISCH which allows the access to these two technologies.

B. Mountain forecasts and rescue

The mountain environment is a very poor zone in telecommunication networks. It is also a high-risk area where it is very important to have an emergency calling service and prevention of an imminent thunderstorm for example 2. Wireless Sensor Networks can easily be implemented to satisfy this need. With LoRaWAN for example, we can have a high radio range and supply a service of localisation.

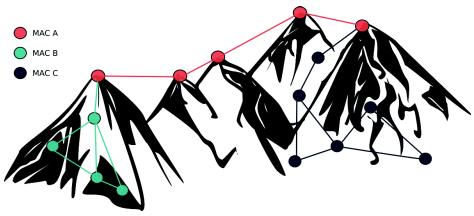

Fig. 2. Mountain hybrid mesh network

The ranging is going to be very dependent of the ground, it is necessary to place antennas to have a maximum of visibility in valleys which allows to have a range in order of 5km in line of sight. LoRaWAN offers the localization service via the calculation of the Time of Flight (ToF). Base stations indicate their GPS address to make some triangulation.

IV. Hybridization radiofrequency of embedded systems

The hybridization of a node of wireless network has to allow to increase its reliability, its bit rate and its agility in the network. It also allows to have an available node for several applications without having to change it. This hybridization can be by the addition of a second one tranceiver to have the possibility of emitting on several bands at the same time or with several modulations. Another possibility is to use the only one tranceiver who possesses several modulations and several available frequency bands. During the design of the node it is important to make technological choice on the hybridization, according to the application, to optimize some parameters such as the energy consumption as well as the unit price.

A. Hybrid Architecture

1) Multi physical layer node: The addition of two physical layers allows to have two tranceiver in parallel. From there, it is possible to make two formal stacks or to merge the network layer for example to have a hybrid network. It becomes possible to have sensor Mesh network able to communicate using narrowband with low range on a local application as a row of servers or a mountain chain but also of having the possibility to send some datas at high range.

To give the possibility to every node to be able to trace directly an information allows to decrease strongly the latency

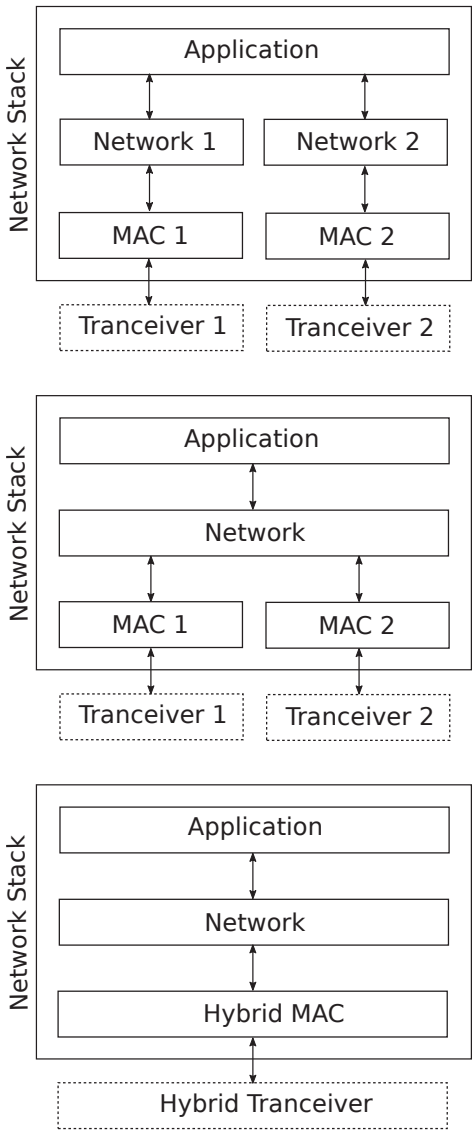

Fig. 3. Three forms of hybridization of the lower layers

and the global consumption of the mesh. This also allows to win in reliability because there is no Single Point of Failure. An example with two physical layers is presented here but it is naturally generalizable to 3 or 4.

2) Node whith an adaptative MAC layer: The cheap equivalent solution which allows to have a diminished energy consumption is to conceive an hybrid MAC layer and an hybrid tranceiver (capable to manage several modulations and/or several channels in a not simultaneous way). This technical solution is the most difficult to implement because it requires to have two compatible technologies, whith the need to respect both standards of the MAC layer simultaneously.

V. Hybridization model

The modelling of one formal hybrid stack requires the deepened analysis of each of the technologies. It needs that

the basic mechanisms of the technologies are compatible[5]. For example, a hybridization of the MAC layer requires that it is capable of respecting several standards simultaneously.

In these works on the WSN with multiple formal stacks, Alexandre Guitton moreover warns on the looping up of data packets within these models [4]. The model of hybridization is the logical result of the technological choice of protocols to be assembled. The purpose has to be to optimize the bit rate, the latency, the energy consumption or the reliability to answer impossible specifications with a single technology. The hybridization can allow to answer wider problems as the use of owners protocols in ultimate recourse or to keep easy compatibility with the existing equipment.

VI. Example of an hybrid node

Imagine a mesh network with hybrid wireless sensor nodes 4. For several years, the results of the studies on protocols for meshed networks show the necessity of having nodes which can have metrics on their influence in the network. These nodes also require to be agile to re-configure if they have a bad influence. A hybrid wireless sensor node can bring this feature. A group of close nodes can activate a MAC layer and a physical layer which allows to have much more bandwidth with equal consumption. This group of knots can elect a node which acts as gateway towards other groupings by activating a hybrid MAC layer between its two transmitters. For these exchanges with lower bit rate but longer distance, it is possible to use a LoRa MAC.

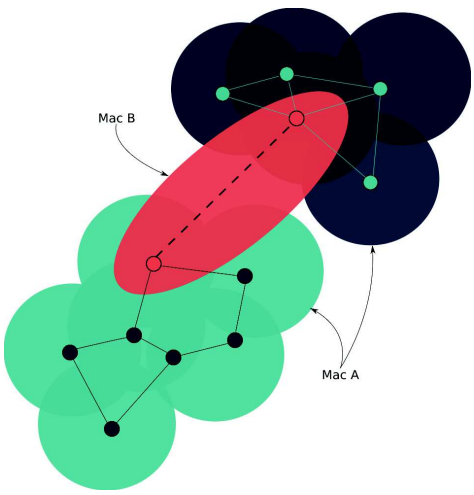

Fig. 4. Example of en hybrid mesh network

VII. Conclusion

The applications manufacturers with strong constraints need to develop networks of hybrid sensors to optimize the various technologies and succeed the constraints of specifications. This hybridization of the low formal layers, allows to win in reliability and in performances. It requires however a very precise choice of the hybridization to find a compatible coupling with a cost and an energy consumption adapted to the application. The hybridization of a formal stack asks of thorough knowledge in the various protocols and the compatibilities among them. The design of a formal hybrid stack bases itself on models which must be experienced. To facilitate the deployment of these technologies, it is important to design several theoretical models and to test them to highlight the earnings of this technological choice.

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