Bizkaiko Foru Aldundia
Diputación Foral de Bizkaia
Berrikuntza eta Ekonomi Sustapen Saila
Departamento de Innovación y Promoción Económica

Programa Ekinberri 2007

SmartMotes

Semantic wireless sensor nodes

D2.1 Comparative analysis of wireless sensor network platforms

Tecnológico Fundación Deusto — Teknologikoa Deustu Fundazioa

robotiker tecnalia

ABSTRACT

This document presents a comparative analysis on several different wireless sensor network platforms, which are the main candidates for hosting the middleware to be developed in the SmartMotes project.

The process involves several steps. First, several evaluation criteria are identified in order to analyse the candidate platforms under the light of these criteria. Second, the different platforms are evaluated and given concrete scores for the criteria. Third, the criteria are given a weight depending on the target application to be tested in the SmartMotes project. Finally, the analysis is completed by applying the weights to the obtained scores in order resulting in the final evaluation.

The selected platforms are: Mica2, XBee/XBee Pro, MicaZ/MicaZ OEM and Imote2.

CHANGE HISTORY

Version	Description	Author	Date	Comments
V0.9	First draft of the document	Leire Muguira Asier Arruti	23/10/2007	
V1.0	First review	Iñaki Vázquez	23/11/2007	
V1.1	Changed Programming Characteristics (2.3)	Iker Larizgoitia	01/02/2008	
V1.2	Second review	Asier Arruti	06/02/2008	
V1.3	Added comments for revision	Iker Larizgoitia	06/02/2008	
V1.4	Third revision	Asier Arruti Leire Muguira	08/02/2008	
V1.5	Added comments for revision	Iker Larizgoitia	08/02/2008	
V1.6	Fourth revision	Asier Arruti Leire Muguira	13/02/2008	
V1.7	Completed comparison Added comparison charts	Asier Arruti Leire Muguira Iker Larizgoitia	18/02/2008	
V1.8	Added conclusions and some small corrections	Asier Arruti Leire Muguira	22/02/2008	

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1 INTRODUCTION TO WIRELESS SENSOR NETWORKS

During the last years, protocols and architectures development for Wireless Sensor Network (WSN) has become on a very important investigation field, due to the apparition of new wireless standards that have allowed new paradigms to appear, as environmental intelligence.

Today, the most extended standards are Bluetooth (IEEE 802.15.1) and WiFi (IEEE 802.11). Each one of them was born with different goals; so, they have more suitable application fields and characteristics for them. In addition, more wireless technologies have appeared as time passes. That way, many daily devices have been introducing in our lives, as Bluetooth connections for mobile phones or car communications, home phones, Internet access, PDAs, car keys, radiofrequency controls…[Doamo07]

In this document, different WSN candidate platforms that can be used in the SmartMotes project are going to be evaluated. The candidate platforms are in great-hype nowadays. Manufacturers are continuously developing these technologies to design optimum products. Let us take the Motes platform as an example. The product has evolved remarkably over time, and in 2007, a new product lime, the iMotes2 family, has been released.

In the next sections, general information about the candidate platforms (Mote2, XBee/XBee Pro, MicaZ and iMote2), prior to the comparative analysis, is presented.

Specific information related to these platforms has been extracted from their respective datasheets. [XBee/XBee-Pro802.15.4D], [XBee/ XBee-ProZigBeeD], [CrossbowD07].

1.1 Crossbow motes platform

The Crossbow motes are a family of embedded sensor nodes sharing roughly the same architecture [Crossbow]. There are a lot of different kinds of motes, from Mica2 and Mica2Dot to WeC and more. The main versions (most used up to now) are compared in the next table, presenting their principal characteristics. In spite of being different evolutions of previous models, each one would be more appropriate depending on the interests of each concrete WSN-based project.

Mote type		IMote2	Iris	MicaZ	Mica2	Mica2Dot [1]	TelosB
Example picture							
MCU	Chip	Marvell PXA271	XM2110CA	MPR2400CA	ATmega128L		MSP430
	Type	13-416 MHz,	8 MHz, 8 bit		8 MHz, 8 bit		8 MHz, 16 bit
	Program memory	32 MB	128 KB				48 KB
	RAM (KB)	256	8	4			10
External nonvolatile storage	Chip	-	-	-	AT45DB014B		AT45DB41B
	Connection type	I2C	-	I2C, SPI	SPI		I2C, SPI
	Size (KB)	-	-	-	512		
Default power source	Type	3xAAA	2xAA			Coin cell	2xAA
	Typical capacity (mAh)	500	2850			1000	2850
RF	Chip	CC2420	-	-	CC1000		CC2420
	Radio frequency	2.4 - 2.4835 GHz			868/916 MHz, 433, or 315		2.4 - 2.4835
	Raw speed (kbps)	250			38.4		250

Figure1. Comparison of some development platforms for Motes devices

Using these devices, very challenging projects have been developed in different universities and research centres worldwide.

An example of a very active application field is telemedicine. There are pervasive examples of data acquisition systems based on motes for real time health monitoring. For example, motes have been integrated with portable electrocardiogram (ECG) systems. The goal was to develop an integrated sensor-based, wireless-enables ECG device using analog/digital signal acquisition circuitry and a TCP-enabled interface to log, analyze and monitor home based heart patients. It was intended to provide an alternative to the current limited-in-purpose wired-based ECG devices for monitoring patients. [Bobbie06]

Some research lines explore alternatives for creating enhanced versions of the platform. For example, engineers from Berkeley University wanted to increase the reliability of distributed wireless networks by introducing two watchdog designs on the Mica mote. These watchdogs detect errors through monitoring aspects of the system and then take steps, so that, the mote recovers from these errors. After finishing the project, they concluded that the distributed wireless network would benefit from these watchdogs by the additional error detection and recovery that was not previously available. In this way, it is possible to conclude that the

[1] Mica2 and Mica2Dot data's have been completed with [Feng04], in addition to datasheets. The other datasheets are [IMote2D07], [IrisD07], [MicaZD07], [TelosBD07].

benefits of increased overall system reliability greatly outweigh the costs [Iben02].

1.2 XBee and XBee-Pro platform

MaxStream is a provider of wireless device networking solutions. It was founded in 1999 and it provides wireless modem modules, RF design services, stand-alone radio modems and supporting software. Solutions operate within the ISM 900 MHz and 2.4 GHz frequencies, with different power output and interfacing possibilities.

MaxStream's RF solutions are embedded into thousands of products worldwide. Some application, where reliable wireless solutions are being integrated, are commercial, industrial, residential, environmental or military and government applications. One example of medical application is the use of these modules to take care of the health, like in "imPulse". It is a modular design object that senses pulse and allows users to wirelessly transmit their heartbeat rhythms [Croft07]. Another example is the development and application of a miniaturized impedance sensor node for structural health monitoring [Mascarenas07].

These modules have been used to develop the communication network to measure the quality of the power line, using sensors [Rodríguez06] and to develop gestural interface to support music pedagogy [Bevilacqua07].

Further information can be obtained from MaxStream's website [MaxStream].

MaxStream is a member of the ZigBee Alliance. Among all the products of Maxtream we have chosen Xbee and Xbee-pro RF modules because they are Zigbee/IEEE 802.15.4 compliant solution [Hyncica06]. This technology offers the possibility to build cost effective, low-power and reliable wireless products. The most important benefits that Zigbee offers are that it is standard based, self healing, secure and easy to deploy. To access the ZigBee Specification it's necessary to fill out the ZigBee Specification Download Request form on the ZigBee Alliance web site [ZigBeeAlliance].

XBee and Xbee-Pro operate in ISM 2.4 GHz operating frequency, with a transmit power output of 0dBm for XBee and 20dBm for Xbee-Pro. They have different antenna options like U.FL connector, chip antenna or integrated whip antenna. Modules support industrial operating temperature ratings, from -40° C to 85° C. Another relevant characteristic is their dimension and weigh, they are small and light modules.

The XBee ZigBee modules are available in two classifications, XBee Series 1 and XBee Series 2 modules. Although they are similar, they are not interoperable, they use different application profiles. XBee Series 1 comes standard with 802.15.4 firmware and ZigBee firmware in beta, which has limitations, based on Freescales's ZigBee stacks. XBee Series 2 runs ZigBee mesh firmware based on the EmberZNet stack. To know more about the differences visit the knowledgebase of MaxStream website.

2 SELECTION OF CRITERIA

In this section, different evaluation criteria for the analysis of wireless sensor network platforms are considered. Each criterion is accompanied by a description and a scale for interpreting the possible values. This scale ranges from 0 to 3, which must be interpreted, in a general sense, as:

Condition	***Points***
Very good	3
Good	2
Bad	1
Very bad	0

All the different value ranges for each criterion are mapped to the specified scale, except for some of them that add the range values if they are considered exclusive, so, the final value must be the addition of all implemented characteristics.

Five different groups for the criteria have been identified: general, power requirements, programming characteristics, performance and community support.

2.1 General

2.1.1 Standard

Standardization is the process of establishing a technical specification, called a standard, among competing entities in a market. It refers to the standard that the modules were engineered to operate with.

A product supporting one standard offers several advantages like the interoperability between different manufactures that operate within the same standard.

A standard can be open or proprietary. An open standard is a standard that is publicly available and has various rights of use associated with it. Proprietary standards have restrictions on using, copying and modifying it. For this kind of devices, today most commons standard is Zigbee, versus others like WiFi or Bluetooth which are used for other different applications.

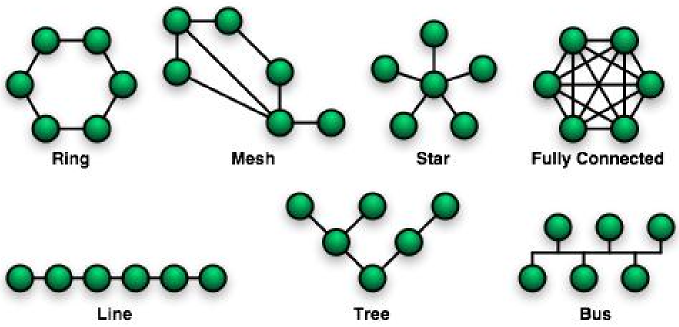
Condition	***Points***
ZigBee	3
ZigBee (Beta)	2
802.15.4	1
Proprietary standard	0

2.1.2 Logical Topology

It is important to understand the difference between logical and physical topology. The first one is how devices appear connected to the user, and the second one refers to the interconnection with wires and cables.

Logical topology is the study of the logical interconnections between nodes. The choice of topology is dependent upon type and number of equipment being used, planned applications and rate of data transfers, required response times and cost.

Network topologies are categorized into different types like bus, ring, star, tree, mesh. It is possible to create complex networks as hybrids of two or more topologies.



In this case, if the platform implements different types of networks, points must be added for each type.

Condition	***Points***
Mesh or Hybrid	1.5
Star or Ring	0.75
Tree or Bus	0.5
Line	0.25

2.1.3 Max number of nodes

This refers to the maximum number of nodes that can be added to the network. Depending on the characteristics of each module, the network can support more or less number of nodes. The number of nodes required depends on the application, but obviously it is better to support a bigger number of nodes to be able to increase them later.

Condition	***Points***
>80,000 nodes	3
(60,000-80,000] nodes	2
(40,000-60,000] nodes	1
<=40,000 nodes	0

2.1.4 Price

This refers to the price in euros of each module. Wireless sensor networks can be composed of a lot of nodes, thus the unitary price is very important.

Condition	***Points***
< 10 €	3
[10 – 50) €	2
[50 – 100] €	1
> 100 €	0

2.1.5 Maximum data load per packet

The maximum data load is the maximum numbers of bytes that can be send in one packet.

Condition	***Points***
>150 bytes	3
[100 - 150] bytes	2
[50 – 100) bytes	1
<50 bytes	0

2.1.6 Interfaces

This point is referred to the different buses or interfaces that the module has to connect with other modules. *Especially interesting interfaces: DIO, Analog input, Uart*

Condition	***Points***
Three interesting interfaces or more	3
Two interesting Interfaces	2
One interesting Interface	1
No interesting interfaces	0

2.1.7 www.Security

No truly computer network is completely secure, but some networks are built more securely than others. Wireless networks add extra security complexity because the signals propagate through the air, so they are easier to be intercepted. This characteristic refers to security features that scramble network traffic so that contents can't easily be deciphered by snoopers, because of the security methods the module has implemented.

Condition	Points
It implements a high level of security, using well-defined protocols	3
It implements several security protocols, but it has some design aspects that can create problems	2
It implements some protocols, but it has serious security problems	1
It doesn't implement any security protocol	0

2.1.8 RF Data Rate

Radio Frequency data rate is the average bits number transferred among modules per second. Higher data rate permits to transfer more bits in the same time, so it means faster speed.

To measure this characteristic the unit used is bps, bit per second.

Condition	Points
>200 kbps	3
[100-200] kbps	2
[50-100) kbps	1
<50 kbps	0

2.2 Power requirements

2.2.1 Power consumption

To develop wireless sensors network it is important to know the power consumption of each module of the network.

If we use the same battery to support two modules and the power consumption of one of them is bigger than the other, the battery will spend faster on it.

One benefit of lower power consumption is the financial benefit. Lower power consumption involves smaller costs. The energy saving is another important advantage. Moreover, lower power consumption can result in smaller size, and it is important when we are developing a wireless sensor network.

To determine the power consumption, the current consumption is measured in different states during a concrete period of time and with the minimal transmition power. Comparing this information with a typical rechargeable battery capacity, it is possible to define how much time in years battery life can last for one concrete module. The typical capacity for a battery is about 2.100 mAh, and it is going to be measured for a transmission rate of 1 message per day. Comparing power consumption according to battery lives is a good way to compare them, due to the similarities of this pattern. Power scales change between platforms, so battery life can be a suitable parameter for comparison.

The possible states are transmit, idle/receive, and sleep and, according to typical scenarios, the percentage in each state is:

Transmit: 0.03%

Idle/Receive: 0.27%

Sleep: 99.71%

Condition	**Points**
> 3 years	3
[2-3 years]	2
[1-2 years)	1
< 1 year	0

2.2.2 Supply Voltage

Supply voltage is the voltage that the module needs to work correctly.

Supply voltage is related to power consumption and it is measured in volts.

Condition	**Points**
<= 2 V	3
(2-3] V	2
(3-4] V	1
> 4 V	0

2.2.3 Indoor Distance Range

Indoor Distance Range refers to the maximum distance required between two modules to work correctly, while they are inside a building. It is measured in metres and to evaluate correctly the distance range, all the modules have to work with the maximum transmission power.

Condition	**Points**
>100	3
[65-100] m	2
[35-65) m	1
<35 m	0

2.2.4 Outdoor Distance Range

Outdoor Distance Range refers to the maximum distance required between two modules to work correctly, while they have line of sight between them. It is measured in metres and to evaluate correctly the distance range, all the modules have to work with the maximum transmission power.

Condition	***Points***
>200	3
[100-200] m	2
[50-100) m	1
<50 m	0

2.3 Programming characteristics

2.3.1 Learning Curve

The learning curve is related to the easiness for the developers to master the environment that is needed to program the modules. It can be based on other platforms or standards, which make it easier or can be a proprietary system which should be learnt from scratch or might need a license to work with.

Condition	***Points***
Standard language	2
Standard environment	1

2.3.2 Programming Environment

A good programming environment should have a certain set of tools and applications that enables the developers to program the modules as easier and reliable as possible.

Condition	***Points***
Programming IDE	1.5
Emulator	0.75
Debugging utilities	0.50
Simulator	0.25

2.3.3 Language capabilities

Each programming language has different characteristics that may have influence on the easiness, performance or the time of the development.

Condition	*Points*
Simple I/O access to the hardware	1
Large set of external libraries	1
Automatic memory management (garbage collector)	0.5
Error management with exceptions	0.25
Object oriented programming paradigm	0.25

2.4 Performance

2.4.1 Size without battery

It is the dimension of the module without considering the battery. The size refers to the wide, height and length dimensions and it is measured in cubic centimetres.

Depending on the size of the module it will be easier to embed the modules in the environment.

Condition	*Points*
<5 cm^3	*3*
[5-20) cm^3	*2*
[20-50] cm^3	*1*
>50 cm^3	*0*

2.4.2 Weight without battery

It is the weight of the module in grams, without the battery.

The weight can influence the manageability of the module, lower weight means higher manageability.

Condition	*Points*
< 5 g	*3*
[5-10] g	*2*
(10-20] g	*1*
> 20 g	*0*

2.4.3 Operating Temperature

Operating temperature is the temperature range where the modules work as expected. It is measured in Celsius degrees. Depending on the applications it could be necessary to support different temperature ranges, for example:

Military: From -55ºC to 125ºC

Industrial: From -40ºC to 85ºC

Commercial: From 0ºC to 70ºC

Condition	***Points***
Military Range	*3*
Industrial Range	*2*
Commercial Range	*1*
Less than Commercial Range	*0*

2.4.4 Electromagnetic compatibility

The electromagnetic compatibility refers to the unintentional generation, propagation and reception of electromagnetic energy with reference to the unwanted effects that such energy may induce.

Interference may be caused by another system on the same frequency range, external noise, or some other system.

The goal of this characteristic is to assess the correct operation of different modules in the same electromagnetic environment, so avoiding any interference effects.

To analyze this characteristic it is important to know the frequency band that the module uses because the frequency has direct effects on the interferences.

Condition	***Points***
It works in one unlicensed frequency band different from ISM, as 900 MHZ or 5.8 GHz bands for example, which are less used than ISM, and implements several protection techniques	*3*
It works in ISM band with some logical and physical protection techniques	*2*
It works in one unlicensed band with some logical and physical protection techniques	*1*
It works in one unlicensed band with any protection technique	*0*

2.4.5 Expansibility

Expansibility refers to the existence of different add-on boards that can be easily plugged to the module.

(If the modules meet the condition the correspondent mark is added)

Condition	***Points***
The different add-on boards and communication interfaces are quite developed.	*1*
There are communication interfaces.	*1*
There are add on boards.	*1*

2.5 Community resources

2.5.1 Community support

Community support refers to the different sources of information that can be checked when we are working with each module, for example, the manufacturer’s web site, different projects or forums.

Condition	***Points***
When there is a lot of information, easy to find and access. There are interesting forums where people can comment and resolve different problems related to the module. A lot of people works with the module and it is well documented.	*3*
There are interesting forums and people working with it but it is not so easy to find and access the information.	*2*
There are information related to the module, but there are not forums.	*1*
There are almost no people working with the module.	*0*

2.5.2 Documentation

It refers to the quality of the datasheet and other specific documents.

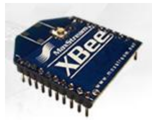
Condition	***Points***
Documentation is clear and complete and there is enough information about the module to work with it without problems, with examples...	*3*
Documentation is clear, but not complete. Not enough examples.	*2*
Documentation is neither clear nor complete.	*1*
Documentation is scarce.	*0*

3 PLATFORMS COMPARISON

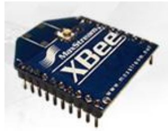
The next sections contain the comparisons of the selected platforms using the criteria defined in section 2.

At the end of the section there is a graphical summary of all the characteristics.

3.1 General characteristics

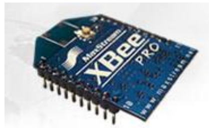
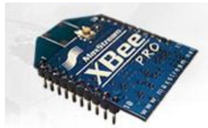
CRITERION	MOTE MICA2	MICAZ	IMOTE2	XBEE 802.15.4 OEM RF Modules v1.xAx	XBEE-PRO 802.15.4 OEM RF Modules v1.xAx	XBEE ZigBee OEM RF Modules v8.x17 Beta	XBEE-PRO ZigBee OEM RF Modules v8.x17 Beta
Photo							
Standard	Proprietary of Xbow	IEEE 802.15.4 (CC2420)	Zigbee	IEEE 802.15.4	IEEE 802.15.4	ZigBee (beta)	ZigBee (beta)
	0	**1**	**3**	**1**	**1**	**2**	**2**
Logical Topology	Star Mesh Hybrid	Star Mesh	Star Tree	Star Tree	Star Tree	Mesh, Star	Mesh, Star
	2.25	**2.25**	**1.25**	**1.25**	**1.25**	**2.25**	**2.25**
Max. number of nodes	max. 65,533 nodes	max. 65,533 nodes	max.65,533 nodes	max. 65,533 nodes	max. 65,533 nodes	46,656 nodes, due to limitations in the network structure	46,656 nodes, due to limitations in the network structure
	2	**2**	**2**	**2**	**2**	**1**	**1**
Price	107.99 €	90.16 €	275.73 €	13.39 €	22.54 €	13.39 €	22.54 €
	0	**1**	**0**	**2**	**2**	**2**	**2**
Maximum data load per packet	248 bytes	102 bytes	100 bytes	100 bytes	100 bytes	72 bytes	72 bytes
	3	2	2	2	2	1	1
Interfaces / Buses	Analog Inputs, Digital I/O, I2C, SPI, UART	Analog Inputs, Digital I/O, I2C, SPI, UART	Opios 2x, SPI 3x, UART, I2C, SDIO, USB host, USB client,AC´97,Camera	Analog Inputs (7), Digital I/O (9), UART	Analog Inputs (7), Digital I/O (9), UART	UART	UART
	3	3	3	3	3	1	1
Security	Identifiers for motes, remote border security, occupancy monitoring and acknowledgement protocol…[Cullinan05]	802.15.4 Default Security Protocol MAC encryption (AES-128).	802.15.4 Default Security Protocol MAC encryption (AES-128).	128-bit AES encryption	128-bit AES encryption	128-bit AES encryption	128-bit AES encryption
	2	3	3	3	3	3	3
RF Data Rate	38.4 kbps	250 kbps	250 kbps	250 kbps	250 kbps	250 kbps	250 kbps
	0	3	3	3	3	3	3
TOTAL	***12,25***	***17,25***	***17,25***	***17,25***	***17,25***	***15,25***	***15,25***

3.2 Power requirements

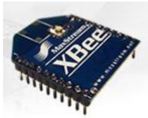
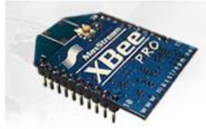
CRITERION	MOTE MICA2	MICAZ	IMOTE2	XBEE (802.15.4)	XBEE-PRO (802.15.4)	XBEE (Zigbee)	XBEE-PRO (Zigbee)
Photo							
Transmit Power (dBm)	5, 0, -10, -20	0, -1, -3, -5, -7, -10, -15, -25	0, -1, -3, -5, -7, -10, -15, -25	-10, -6, -4, -2, 0	10, 12, 14, 16, 1	-10, -6, -4, -2, 0	10, 12, 14, 16, 18
Operating Current	(@ 3.0 V & 5 dBm) Tx: 27 mA Rx/Idle: 10 mA CPU current: 8 mA	(@3.0 V & 0 dBm) Tx: 17.4 mA Rx/Idle: 19.7 mA CPU current: 8 mA	(@4.5 V & 0 dBm) Tx: 44 mA Rx/Idle: 31 mA CPU current: 31 mA @13 MHz. It is possible to scale it till 416 MHz.	(@3.3 V & 0 dBm) Transmit: 45 mA Receive/Idle: 50 mA Processor current: 6.5 mA	(@ 3.3 V & 18 dBm) Tx: 215 mA Rx/Idle: 55 mA CPU current: 6.5 mA	(@ 3.3 V & 0 dBm) Tx:: 45 mA Rx/Idle: 50 mA CPU current: 6.5 mA	(@ 3.3 V & 18 dBm) Tx: 215 mA Rx/Idle: 55 mA CPU current: 6.5 mA
Sleep Current	(@ 3.0 V) < 1 µA CPU current: < 15 µA	(@ 3.0 V) 1 µA CPU current < 15 µA	(@ 4.5 V) at 13 Mhz 390 µA CPU current: 290 µA	(@ 3.0 V) < 1 µA CPU current < 70 µA	(@ 3.0 V) < 1 µA CPU current < 70 µA	(@ 3.0 V) < 1 µA CPU current < 70 µA	(@ 3.0 V) < 1 µA CPU current < 70 µA
Receiver sensitivity	-98 dBm	-94 dBm	-94 dBm	-92 dBm	-100 dBm	-92 dBm	-100 dBm
Battery lifetime average power consumption[2]	3.244 years 0.0665 mAh.	2.34 years 0.0922 mAh	0.457 years 0.4721 mAh	1.563 years 0.1381 mAh	1.26 years 0.1712 mAh	1.563 years 0.1381 mAh	1.26 years 0.1712 mAh.
	3	2	0	1	1	1	1
Supply Voltage	3.0 V	3.0 V	4.5 V	3.4 V	3.4 V	3.4 V	3.4 V
	2	2	0	1	1	1	1
Indoor Distance Range	Up to 150 m with line of sight	Indoor/Urban: up to 30 m	30 m with line of sight	Indoor/Urban: up to 30 m	Indoor/Urban: up to 100 m	Indoor/Urban: up to 30 m	Indoor/Urban: up to 100 m
	2	0	0	0	2	0	2
Outdoor Distance Range	Up to 150 m with line of sight	Outdoor: Up to 100 m	30 m with line of sight	Outdoor: Up to 100 m	Outdoor: Up to 1.5 km	Outdoor: Up to 100 m	Outdoor: Up to 1.5 km
	2	1	0	1	3	1	3
TOTAL	9,00	5,00	0,00	3,00	7,00	3,00	7,00

[2] Numbers have been calculated with a spreadsheet, located in same website that this document, and named *"Power balance_SmartMotes project.xls"*.

3.3 Programming characteristics

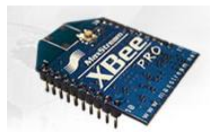
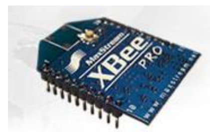
CRITERION		MOTE MICA2	MICAZ	IMOTE2	XBEE (802.15.4)	XBEE-PRO (802.15.4)	XBEE (Zigbee)	XBEE-PRO (Zigbee)
Photo								
Learning curve	Standard Language (2)	nesC language	nesC language	c# micro framework	C	C	C	C
	Standard Environment (1)	linux-like	linux-like	Visual Studio	CodeWarrior	CodeWarrior	CodeWarrior	CodeWarrior
Programming environment	Programming IDE (1.5)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Emulator (0.75)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Debugging utilities (0.50)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Simulator (0.25)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Language capabilities	Simple I/O access to the hardware (1)	Yes	Yes	Yes	No	No	No	No
	Large set of external libraries (1)	Yes	Yes	No	No	No	No	No
	Automatic memory management (0.5)	No	No	Yes	No	No	No	No
	Error management with exceptions (0.25)	No	No	Yes	No	No	No	No
	Object oriented programming paradigm (0.25)	No	No	Yes	No	No	No	No
TOTAL		6	6	8	5	5	5	5

3.4 Performance

CRITERION	MOTE MICA2	MICAZ	IMOTE2	XBEE	XBEE-PRO	XBEE	XBEE-PRO
Photo							
Size without battery	5.8 x 3.2 x 0.7 = 12.992 cm^3	5.8 x 3.2 x 0.7 = 12.992 cm^3	3.6 x 4.8 x 0.9 = 15.552 cm^3	2.438 x 2.761 x 0.656 = 4.416 cm^3	2.438 x 3.294 x 0.656 = 5.268 cm^3	2.438 x 2.761 x 0.656 = 4.416 cm^3	2.438 x 3.294 x 0.656 = 5.268 cm^3
	1	1	0	3	2	3	2
Weight without battery	18 g	18 g	12 g	3 g	4 g	3 g	4 g
	1	1	1	3	3	3	3
Operating Temperature	-5 to 55 ºC	-40 to 85 ºC	0 to 85 ºC	-40 to 85 ºC	-40 to 85 ºC	-40 to 85 ºC	-40 to 85 ºC
	1	2	1	2	2	2	2
Electromagnetic compatibility	Frequency Band: 300 – 1000 MHz Module Frequency Range: ISM 868 – 916 MHz Modulation: FSK Spread Spectrum Type: DSSS	Frequency Band: ISM 2.4 - 2.4835 GHz Module Frequency Range: 2.405 - 2.480 GHz Modulation: QPSK Spread Spectrum Type: DSSS	Frequency Band: ISM 2.4000 - 2.4835 GHz Module Frequency Range: 2.405 - 2.480 GHz Modulation: OQPSK Spread Spectrum Type: DSSS	Frequency Band: ISM 2.4000 - 2.4835 GHz Module Frequency Range: 2.405 - 2.480 GHz Modulation: QPSK Spread Spectrum Type: DSSS	Frequency Band: ISM 2.4000 - 2.4835 GHz Module Frequency Range: 2.405 - 2.480 GHz Modulation: QPSK Spread Spectrum Type: DSSS	Frequency Band: ISM 2.4000 - 2.4835 GHz Module Frequency Range: 2.405 - 2.480 GHz Modulation: QPSK Spread Spectrum Type: DSSS	Frequency Band: ISM 2.4000 - 2.4835 GHz Module Frequency Range: 2.405 - 2.480 GHz Modulation: QPSK Spread Spectrum Type: DSSS
	1	2	2	2	2	2	2
Expansibility	*MTS101CA:* Thermistor, conversion to the engineering units, light sensor, prototyping area. *MTS300/MTS310*: Microphone, sounder, light and temperature, 2 axis accelerometer, 2 axis magnetometer, turning sensors on and off. *MTS400/MTS420*: Humidity and temperature sensor, barometric pressure	*MTS101CA:* Thermistor, conversion to the engineering units, light sensor, prototyping area. *MTS300/MTS310*: Microphone, sounder, light and temperature, 2 axis accelerometer, 2 axis magnetometer, turning sensors on and off. *MTS400/MTS420*: Humidity and temperature sensor, barometric pressure	*ITS400 Basic Sensor Board*: 3d accelerometer, advanced temp/humidity sensor, light sensor, 4 channels A/D. IIB2400 Interface Board: code loading and debugging.	XBee\XBee-Pro Adapters: RS-485 Adapter, RS-232 Adapter, Sensor Adapter, USB Adapter, Analog I/O Adapter, Digital I/O Adapter, RS-232PH Adapter.	XBee\XBee-Pro Adapters: RS-485 Adapter, RS-232 Adapter, Sensor Adapter, USB Adapter, Analog I/O Adapter, Digital I/O Adapter, RS-232PH Adapter.	XBee\XBee-Pro Adapters: RS-485 Adapter, RS-232 Adapter, Sensor Adapter, USB Adapter Available Oct07: Analog I/O Adapter, Digital I/O Adapter, RS-232PH Adapter.	XBee\XBee-Pro Adapters: RS-485 Adapter, RS-232 Adapter, Sensor Adapter, USB Adapter Available Oct07: Analog I/O Adapter, Digital I/O Adapter, RS-232PH Adapter.

	sensor, light sensor, 2 axis accelerometer, GPS(MTS420 only), turning sensor on and off. *MDA100CA/MDA100CB*: Conversion to engineering units, light sensor, prototyping area. *MDA300CA* & MDA320CA: General measurement platforms. Sensor boards Gateways: MIB510, MIB520 or MIB600.	sensor, light sensor, 2 axis accelerometer, GPS(MTS420 only), turning sensor on and off. *MDA100CA/MDA100CB*: Conversion to engineering units, light sensor, prototyping area. *MDA300CA* & MDA320CA: General measurement platforms. Sensor boards Gateways: MIB510, MIB520 or MIB600. Molded housings					
	3	3	2	1	1	1	1
Total	7	9	6	11	10	11	10

3.5 Community resources

CRITERION	**MOTE MICA2**	**MICAZ**	**IMOTE2**	**XBEE**	**XBEE-PRO**	**XBEE**	**XBEE-PRO**
Photo							
Community support	**This section is explained in 3.6.1			**This section is explained in 3.6.2			
	2	2	2	1	1	1	1
Documentation	See [CrossbowD07]			See [XBee/XBee-Pro802.15.4D] [XBee/ XBee-ProZigBeeD]			
	3	3	2	1	1	1	1
Total	5	5	4	2	2	2	2

3.6 Remarks

3.6.1 Motes platform

The main support source is going to be always the enterprise itself who manufactures the platform, Crossbow, whose web site, (www.xbow.com/Home/HomePage.aspx) puts contact techniques and problem query services at your disposal, as well as documentation that IEEE sets out as referred to Motes platform (http://standards.ieee.org/getieee802/download/802.15.4-2003.pdf).

Additionally, an assistance distribution list exists for help people who work with TinyOs system, where it is possible to expound all kind of doubts and problems. It is possible to enrol in it with the next URL: www.mail-archive.com/tinyos-help@millennium.berkeley.edu/info.html. More specifically, there is another distribution list for Imote2 community, available in http://tech.groups.yahoo.com/group/intel-mote2-community/.

Separately for interest of these entities, which are motivated by sale desires and expansion of their standards, projects using this platform have been developed in lots of universities and investigation centres, who can become in query points and people to ask, like Simón Bolívar University, from Venezuela, Polytechnic University of Cartagena (Spain), or Polytechnic School of Castelldefels (Spain too), for example.

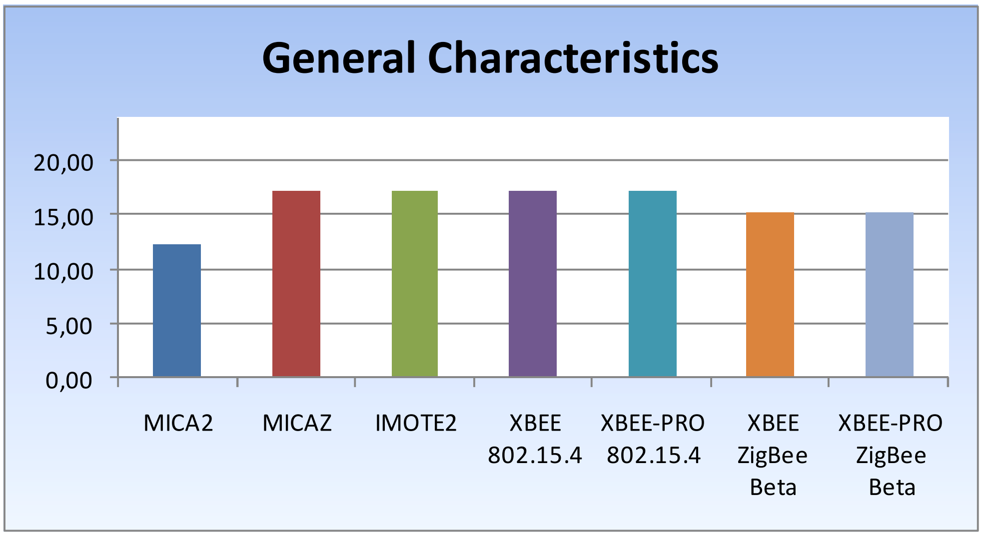
3.6.2 X-Bee platform

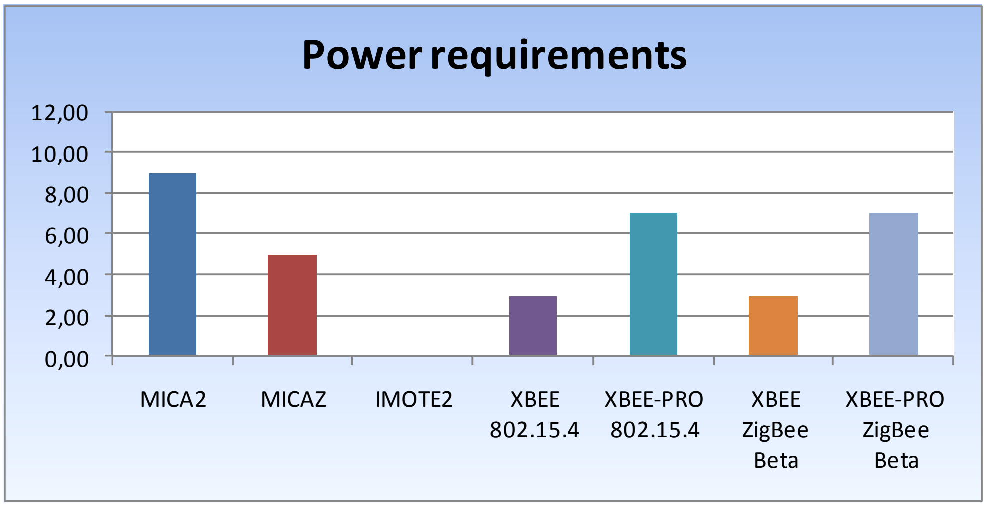
In X-Bee case, the manufacturer web site allows to find the necessary support to work with these modules. On the one hand, in downloads section it provides with the software and necessary drivers, just as X-Bee firmware proof versions. Everything in www.maxstream.net/support/downloads.php.

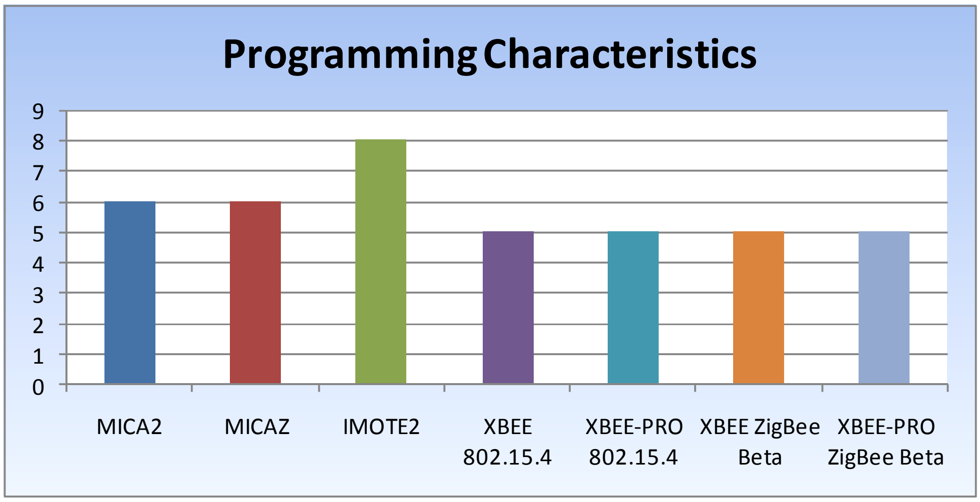
On the other hand, it places at users disposal an article collection, with little explanations and examples, with the main goal of be able to clarify all kind of dudes that could arise when somebody works with its products. It is possible in www.maxstream.net/support/knowledgebase/. If it is not possible to settle all dudes with the previous data base, manufacturer offers an electronic mail address to contact, available in www.maxstream.net/corporate/contact.php?email=support. The Maxtream web contains an actualized blog too, in which all events with relation to their products, applications or tests are published. These events have been developed by different users, and they have been filed by months. Its url address is www.maxstream.net/blog/.

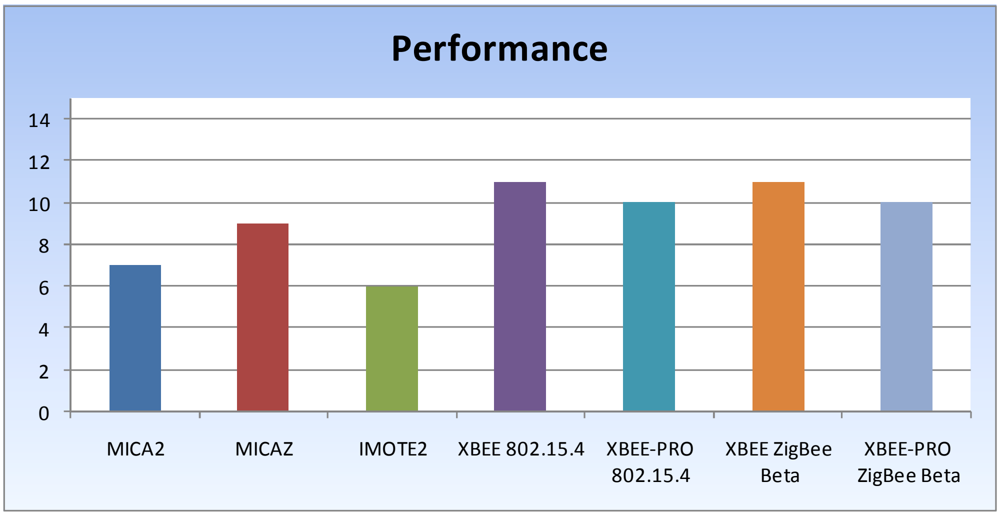
Moreover, it is possible to see a large range of applications, in which these modules have been composed, in the next link: www.maxstream.net/wireless/customer-success.php.

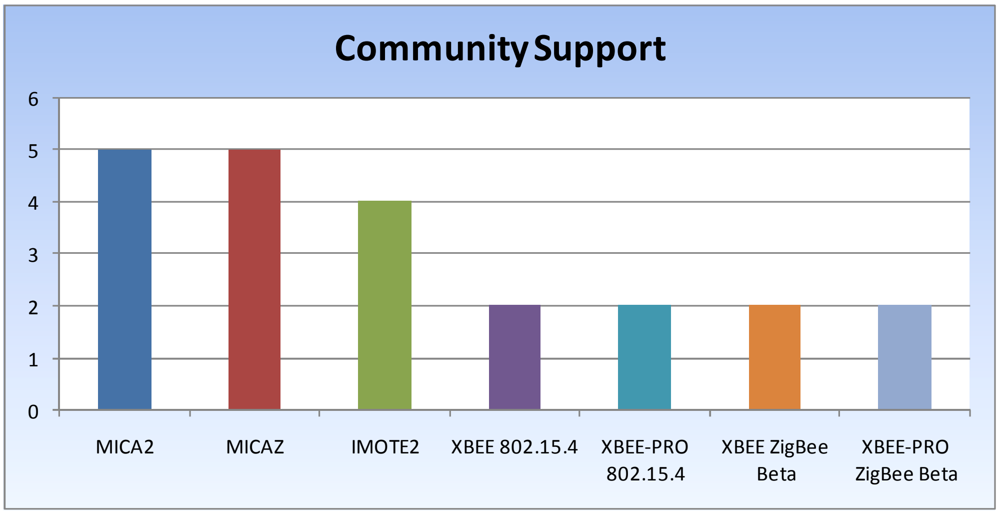
3.7 Summary


General Characteristics
20,00
15,00
10,00
5,00
0,00
MICA2
MICAZ
IMOTE2
XBEE 802.15.4
XBEE-PRO 802.15.4
XBEE ZigBee Beta
XBEE-PRO ZigBee Beta


Power requirements
12,00
10,00
8,00
6,00
4,00
2,00
0,00
MICA2
MICAZ
IMOTE2
XBEE 802.15.4
XBEE-PRO 802.15.4
XBEE ZigBee Beta
XBEE-PRO ZigBee Beta

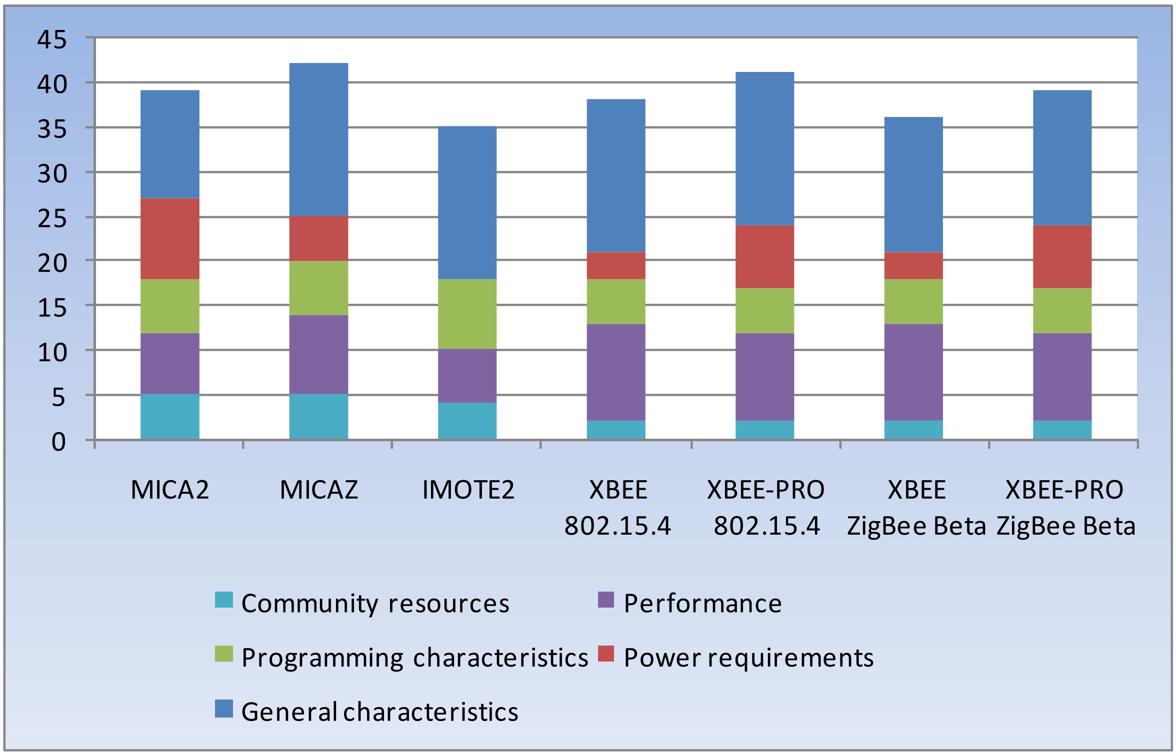

Programming Characteristics
9
8
7
6
5
4
3
2
1
0
MICA2
MICAZ
IMOTE2
XBEE 802.15.4
XBEE-PRO 802.15.4
XBEE ZigBee Beta
XBEE-PRO ZigBee Beta


Performance
14
12
10
8
6
4
2
0
MICA2
MICAZ
IMOTE2
XBEE 802.15.4
XBEE-PRO 802.15.4
XBEE ZigBee Beta
XBEE-PRO ZigBee Beta


Community Support
6
5
4
3
2
1
0
MICA2
MICAZ
IMOTE2
XBEE 802.15.4
XBEE-PRO 802.15.4
XBEE ZigBee Beta
XBEE-PRO ZigBee Beta

4 CONCLUSION

Across the document we have analyze multiple parameters to evaluate different wireless sensor network platforms. These parameters have been grouped in five clusters: general characteristics, power requirements, programming characteristics, performance and community resources. After doing the corresponding marking of all the criteria, we have developed the next summary.



As we can see, the best wireless sensor platform is Micaz. If we order all the platforms, first one is Micaz, and then XBee-Pro 802.15.4, Mica2 and XBEE-PRO ZigBee Beta, XBEE 802.15.4, XBEE ZigBee Beta, and finally IMOTE2.

But if we analyse the criteria separately, we see that MICAZ, IMOTE2, XBEE 802.15.4 and XBEE-PRO 802.15.4 are who have the best general characteristics and the worst is MOTE MICA2. Although if in our application the most important criterion is the power requirement or the existing community resource, the best platform is MOTE MICA2 because it is the oldest and as a consequence, it is the most extended and tested device. On the other hand, about the programming characteristics, the first platform is IMOTE2 and if we are interested in the performance, we have to choose XBEE ZigBee or XBEE 802.15.4 platforms.

In conclusion, in general the best platform is MICAZ but depending on the application, some criteria are more important than others. So we have to know the most important criteria in our case and choose the wireless network platform analysing them.

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