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Survey on Motes Used in Wireless Sensor Networks: Performance & Parametric Analysis

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Abstract

Wireless Sensor Networks (WSNs) are used to sense certain parameters in an environment, manipulate the acquired data and transmit/receive the information in an intra or inter communication network. Innovative researches in WSNs have resulted in the increase of application scenarios, which, at a time instant, were not even well-thought-of to be automated by WSNs. With this advent, it becomes necessary to customize sensor nodes depending on node specific characteristics and the deployment environment. Challenges for designing a WSN depend on the scenario in which it is implemented. Commercially available wireless motes are mostly generalized for usage in most of the applications. This survey work aims to provide an insight on the various wireless motes available in the market. This will enhance future researchers to select wireless modules which might be most suitable for their application needs. Various parameters related to the technical and implementation characteristics of WSNs were considered in this survey. This survey also concentrates with the survey on individual RF modules based on certain parameters like frequency of operation, transmission power, receiver sensitivity, interface mechanism, data rate, active, sleep & power-down current consumptions, range and cost involved.

Keywords

Wireless Sensor Networks, Motes, Transmission Power, Receiver Sensitivity

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1. Introduction

WSNs have proved its use in the recent years with the rising need for wireless sensing and monitoring applications [1] [2]. Innovative researches in WSNs have resulted in the increase of application scenarios, which, at a time instant, were not even well-thought-of to be automated by WSNs. WSNs are used to sense certain parameters in an environment, manipulate the acquired data and transmit/receive the information in an intra or inter communication network [3] [4]. Advancements in networking and semiconductor technologies have driven the deployment of WSNs to differ vastly from the initial strategies followed a decade ago. Lower deployment and maintenance costs, fail-safe operating conditions and diverse application scenarios have resulted in the increased usage of WSNs [5]. To corroborate the above stated fact, WSNs are now considered to be well suited for applications like traffic monitoring, air pollution sensing, habitat and environment monitoring, to name a few [6]-[8].

Challenges for designing a WSN depend on the scenario in which it is implemented. For example, a WSN deployed in military surveillance is expected to have more sufficient power requirements, increased and fail-safe connectivity within the network due to the severity involved in the application [9] [10]. An application scenario involving agricultural monitoring doesn't require much security and fail-safe connectivity as compared to that of military applications. But with regard to the power requirements, it is an obvious fact that motes deployed for agriculture monitoring are more power-hungry due to the nature of application scenario. It might be less feasible for providing continuous and adequate power supply unless a renewable power source is used. Usage of renewable power sources involves trade-off with the aesthetics and design requirements of the mote [11] [12].

One possibility of efficiently deploying and transceiving information through the motes is by involving more effective clustering and routing algorithms in a WSN [13] [14]. Most importantly, a sensor node can be possibly connected to a cluster of sensors, which streams in the sensed data to the node. The collected data are processed or just the raw data are in turn transmitted to a sink node which utilizes the received data for further manipulation. On the contrary, for the sake of a counter argument, it could be stated that the overhead in a mote may increase considerably with the involvement of more complex routing and clustering algorithms. With the availability of more commercial and custom-designed wireless motes in the market, deciding the appropriate mote for an application has become a bit tedious for researchers. To corroborate the above fact, with the inclusion of diverse application scenarios and varied environment and technical specifications to be considered, wireless motes becoming customized for a particular test bed have increased considerably [15].

The sections of this survey are organized as follows. Section 2 defines the application scenarios and respective specifications for implementing a WSN. Section 3 surveys the different motes available commercially and for research purposes. The comparison of different specifications for the available motes is also discussed in this section. Section 4 provides the conclusion of this survey.

2. Requirement Specifications and Available Motes

As mentioned earlier, WSNs have a wide range of applications. Although there are more available commercial modules, many of them may not be suited for specified applications. Some of the factors which influence the decision for selection of an application specific wireless module are discussed below.

2.1. Power Consumption

In certain applications like soil quality and agricultural monitoring, sensor nodes might be placed underground. In these scenarios, the power consumption parameter of a node plays a major role in deciding the most suitable mote for the application. When motes are deployed in a remote location or underground, the source of power has to be either from a battery or from a renewable source. This source of power has to be utilized efficiently so as to retain the residual energy in the node for a long time. This can be done by optimizing the power levels of transmitted data, sensitivity of the receiver, making at-most usage of power-down and sleep modes in the node etc. Due to the afore-mentioned considerations, power consumption factor becomes an important parameter for selecting motes for an application. There are applications where power consumption is considered less prior, for example in border security, fail-safe monitoring in air-borne systems etc. In these, the trade-off between power and operational parameters is not considered as a parameter. Thus, power consumption becomes a major factor for selecting an appropriate node for an application.

2.2. Fail-Safe and Redundant Operation

As mentioned earlier, WSNs are finding its use in applications which were not even though of to be automated by WSNs. For example, in landslide and coal-mining applications, redundancy and fail-safe operation is the most expected in nodes involved in detecting these scenarios. Though software routing of acquired data and clustering of nodes play a major role here, the dependence of the hardware module cannot be neglected. Sensor fusion is prescribed as an efficient way to counter redundancy, but the support in terms of operation speed, memory capability, and optimized data storage has to be provided by the hardware module.

2.3. Inclusion of In-Built and External Sensory Elements

Simpler interface to external sensory elements and inclusion of more in-built sensors also enhances the credibility in mote selection. Commercially available motes include certain sensing elements like temperature, humidity etc. Customizing a commercially available mote with specific sensor elements creates a trade-off between the market scope and operational need for any application. But with the increase in semiconductor technology and inclusion of more sensing elements like accelerometers, pressure sensors, light sensors etc., this trade-off is minimized.

2.4. Deployment Environment

The deployment environment also plays an important role in mote selection. For applications where the mote needs to be deployed in an open atmosphere, the hardware needs to have components with industrial standards to withstand intense temperature and environmental changes. Moreover, in certain applications, the sensors on-board the mote may get influenced due to static charges in the deployment environment. Motes like WaspMote and panStamp implement the sensing elements in the bottom layer of the hardware, thereby protecting the elements from foreign particles. Thus hardware robustness also plays an important role in mote selection.

2.5. Node Life Time

Node life time is one of the key parameters for mote selection. Different motes offer various technical specifications which directly or indirectly affect the lifetime of a node. This parameter becomes particularly important for "power-hungry" nodes deployed in remote environment. Usage of controllers in the hardware module with more low power consumption techniques will enhance the availability of residual energy in the node to a greater extent. RF modules with increased efficiency in TX and RX are obviously considered as a trade-off with the node life time. Processor and RF module selection with more power down and sleep modes will enhance the lifetime of the node. For example, TelosB uses a MSP430 family processor, which supports five power-down states. The TelosB also includes a CC242x RF module which supports power-down and sleep modes and provision is also provided to cut-off the RF module connection with the processing element. This reduces the battery drain, thereby increasing the node life time.

In the following paragraphs, different wireless motes are analyzed depending on its application usage, technical specifications etc. For improving readability and to provide a better picture, the survey is organized with specifications of the motes in an ascending fashion, starting from older to recently arrived motes in the market.

1) Mica2/MicaZ Motes

Figure 1 pictorially represents the Mica2 Mote. These motes are the second and third generation mote technologies from CrossBow Technology. Mica2 and MicaZ use an Atmega128L controller along with a CC1000/CC2420 RF Module respectively. Mica2/MicaZ are equipped with humidity, temperature and light sensors, with interface support for connecting sensors that connect directly to the mote. These motes are capable of measuring barometric pressure, acceleration/seismic activity etc. Possible uses of Mica motes lie in pressure monitoring, structural health monitoring etc.

The motes are powered from an external 2 AA batteries with an operating range of 2.1 to 3.6 V DC.

2) TelosB Motes

Figure 2 pictorially represents the TelosB Mote. TelosB mote was initially developed by University of California, Berkeley. The TelosB mote embeds an 802.15.4 compatible CC2420 radio chip from Texas Instruments. It provides onboard humidity, and temperature IC type sensors (SHT2x from Sensirion). The relative humidity reading is provided by the humidity sensor with an accuracy of 3% and temperature sensor connected through

Figure 1. Pictorial representation of a Mica2 Mote.

Figure 2. Pictorial representation of a TelosB Mote.

SPI has accuracy of 0.4˚C. The motes are powered from an external 2 AA batteries with an operating range of 2.1 to 3.6 V DC.

Apart from the TelosB, the **XM1000** wireless motesare based on the TelosB specifications but with an upgraded program and data memory. In-built light sensors are also introduced in this product.

3) Indriya-Zigbee Based WSN Development Platform

The Indriya is a hardware development environment for building ambient intelligence based WSN applications [12]. It features a low power MSP430 core with an IEEE 802.15.4 based CC2520 from Texas instruments. On-board sensors include an accelerometer and light sensors with a lot of optional add-ons. Possible applications include

a) Indoor air quality management for which humidity and/or a CO_2 sensor can be added.

b) Range measurement, direction finding and tracking, for which an ultrasonic or a magnetometer can be interfaced.

c) Image sensors can be integrated for security and surveillance.

d) Occupancy detection and human occupancy based controls with the help of a PIR interface.

The RF module offers an achievable data rates of 250 Kbps. The indoor and outdoor range of this mote varies between 20 - 30 meters and 75 - 100 meters respectively [16].

4) IRIS

Figure 3 pictorially represents the IRIS Mote. One of the available wireless node platforms which offer higher communication range (*Near to* 500 *Meters in LoS*), is the IRIS. It uses a 2.4 GHz IEEE 802.15.4 wireless module. The mote works on an open source TinyOS operating system on an ATmega1281 based low-power Micro-Controller. The IRIS mote gives developers the support of integrating sensor support boards through a standard 51-pin expansion connector. The most interesting part is the current consumption where TX current varies from 10 - 17 mA and the RX current reaches to 16 mA. The communication range varies is >300 and >50 meters for outdoor and indoor ranges (with LoS) [17].

Due to its higher communication range, the motes can be deployed underground for agriculture and soil monitoring. Though, it is an obvious fact that soil provides higher interference to RF communication, it is possible to implement a network of underground motes within a mote-mote communication range of ~30 meters underground. Moreover IRIS motes can also be integrated with a MIB600 TCP/IP Ethernet network which can act as a base station.

Figure 3. Pictorial representation of an IRIS Mote.

5) iSense Core Wireless Module

Figure 4 pictorially represents the iSense Module. The iSense core module combines the controller and an RF Transceiver in a single housing. One of the main advantages of this module is that the software resource spent on an external interface with the controller and RF module is nullified. The controller runs on a powerful 32-bit RISC core with a shared 128 Kbyte program and data memory. Higher data rates of up to 667 kBits/Sec can be achieved. The RF module provides a receiver sensitivity of −95 dBm and a transmit power of +2.5 dBm. It also support addition of an extra power module through which the receiver sensitivity is increased to −98 dBm and a transmit power level of +10 dBm [18].

Figure 4. Pictorial representation of an iSense Mote.

6) Preon32-Wireless Module

Figure 5 pictorially represents the Preon32 Sensor node. The module Preon32 is a universally usable sensor and actuator platform for realization of sophisticated applications for short-range wireless networks. With a high performance Cortex-M3 controller, it has an IEEE 802.15.4 compliant RF module. More interestingly, this module allows developers to program the wireless module with an object-oriented language like Java. It features external interfaces like the CAN, USB, and SPI, etc. [19]. Applications involve

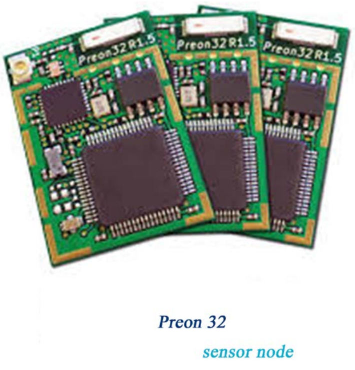

Figure 5. Pictorial representation of Preon32-wireless module.

a) Home Automation.
b) Agricultural and Habitat Monitoring.
c) Monitoring of Road Traffic.

7) Wasp Mote

Figure 6 pictorially represents the Wasp Mote. Wireless Sensing has become a needed entity to attain a "Smart Environment". One of the prevalent examples for this is the "**Smart Water Sensor**", Utilizing Wasp Mote, introduced by Libelium. Smart Water wireless sensing platform is used to simplify the monitoring process for water quality. The module is equipped with sensors to measure certain water quality parameters like pH, Conductivity, dissolved ion content and Oxygen level. The nodes can be connected to a cloud network for real-time monitoring and control. This platform uses an ultra-low-power sensor node for use in rugged environments. It is possible to connect the sensor network through long range 802.15.4/ZigBee (868/900 MHz). Most importantly, this "Smart Water" sensor can accommodate solar panels for maintaining autonomy over the power supply.

Figure 6. Pictorial representation of a Wasp Mote.

8) WiSense Mote

Figure 7 pictorially represents the WiSense Mote. An interesting platform for WSN and Internet-of-Things (IoT) implementation is the WiSense platform. Apart from providing hardware modules for developers, WiSense provides a framework through which researchers and developers can build their own mesh networks through a GUI. The software makes use of an easy-to-use Eclipse platform with an IEEE 802.15.4 protocol stack implementation. This type of interface in terms of both the hardware and software provides an extended support to the developer. The hardware platform involves a MSP430 low-power controller from Texas instruments. The mote runs on an 8/16 MHz Clock along with a CC1101 RF module. With the usage of CC1101, possible applications of this mote extends to Home automation, automated food ordering system in restaurants, campus network, industrial automation, green cities etc. The data and program memory are fixed at 4 KB and 56 KB respectively [20].

Figure 7. Pictorial representation of a WiSense Mote.

9) panStamp NRG Mote

Figure 8 pictorially represents the panStamp Mote. Recently introduced in the market, the panStamp NRG relies on a CC430F5137 processor and an in-built CC11xx RF module. The main advantage of this module is that, it has a very lesser footprint compared to the other available motes. It offers a programmable speed of 8 to 24 MHz with flash and RAM capability of 32 KB and 4 KB respectively. With the inclusion of a 3-axs accelero

Figure 8. Pictorial representation of a panStamp Mote.

meter and support for AES security encryption, this mote out-performs the standard available motes in the market. Options are provided for including a dual temperature-humidity sensor at the bottom layer. Since the bottom layer is used for the inclusion of optional sensors, it makes the sensing more efficient by reducing the effect of dust and other environmental parameters on the sensed values. Most importantly, panStamp provides the developers to integrate the mote with Raspberry Pi as a shield, making it the most supportive mote available [21].

3. Survey on RF Modules Available in the Market

This survey is also extended to analyze the RF modules available in the market with respect to the parameters detailed here. The parametric analysis is also tabulated below.

3.1. Frequency of Operation (FoP) and Range

This entity decides the type of application to be implemented. For example, a home automation network with limited deployment coverage may utilize a 2.4 GHz operated mote. The distance covered may vary from 50 - 100 Meters which will be sufficient for implementing a clustered multi-hop WSN. In applications where the range of operation is to more, like agricultural field monitoring, habitat monitoring, the need for higher range communication becomes necessary. For this purpose, the FoP can be selected to a sub-1 GHz bandwidth. Handling external interferences and packet loss in low bandwidth communication becomes an overhead, but the range limitation of higher bandwidth RF modules has resulted in research work on interference patter and reduction in Sub-1 GHz RF communication.

3.2. TX Power & RX Sensitivity

Most of the RF modules provide programmable TX power and receiver sensitivity levels. For example, CC2500 module provides a maximum of +1 dBm Tx Power and −102 dBm receiver sensitivity, whereas, MC1322x RF module from Freescale semiconductors provide a maximum of +4 dBm Tx power and −100 dBm receiver sensitivity respectively. These characteristics will directly affect the current consumption of the RF module, which in turn will affect the power levels and battery drain in the motes.

3.3. Data Rate

The data-rate can be programmed in most of the available RF modules. Data-rate directly affects the range of communication, irrespective of bandwidth of operation. This work has also surveyed the RF modules based on the available and programmable data rates.

3.4. Electrical Characteristics of the RF Module

This survey has also produced different RF modules based on the supply voltage and the current consumption in different modes of operation in the RF modules. The current consumption at different TX power levels and receiver sensitivity levels directly affects the overall power consumption of the mote. For example, the TX and RX current levels are comparatively higher in CC25xx modules than in the NRF family RF modules. On the other hand, the sleep and power down mode current levels in CC25xx modules are much lesser than in the NRF modules. Depending on the frequency of sleep and power-mode usage, the overall power consumption in CC25xx modules can be reduced. Due to the differences in programmability, algorithm design, this survey has provided the analysis for current consumption.

3.5. Package and Cost

The affordability and support for product development using the RF modules also comes into picture. For this reason, this survey has provided the details of the cost and the packaging involved for different modules.

Table 1 provides a comparative study on various wireless modules available in the market.

Table 1. Parametric analysis of available RF modules [22]-[25].

Name of the module	**NRF24L01** 	**CC1101** 	**RFM22B-S2 \SMD Wireless Transceiver-434 MHz** 	**TRM-433-LT** 	**CC2500** 	**MC1322x** 
Role	Transceiver	Transceiver	Transceiver	Transceiver	Transceiver	Transceiver
Frequency	2.4 GHz	sub-1 GHz	sub-1 GHz	433.92 MHz	2.4 GHz	2.4 GHz (IEEE 802.15.4)
TX Power	+20 dBm	Programmable output power up to +12 dBm for all supported frequencies	+20 dBm Max (RFM22B) +13 dBm Max (RFM23B)	0 dBm typical	+1 dBm (Without External Antenna)	+4 dBm Max (Without External Antenna)
RX Sensitivity	−94 dBm RX sensitivity at 250 kbps −82 dBm RX sensitivity at 2 Mbps −85 dBm RX sensitivity at 1 Mbps	−116 dBm at 0.6 kBaud, 433 MHz, 1% packet error rate −112 dBm at 1.2 kBaud, 868 MHz, 1% packet error rate	−121 dBm	−112 dBm typical	−102 dBm RX Sensitivity for 2.4 Kbps (Optimized for Sensitivity)	−100 dBm Sensitivity
Interface	SPI	SPI	SPI	serial	SPI	Equipped with a uC running on ARM7TDMI Core
Data rate	Configurable on-air data rate of 250 kbps, 1 Mbps or 2 Mbps	Programmable data rate from 0.6 to 600 kbps	0.123 to 256 kbps	65 - 10,000 bps	Configurable on-air data rate 1.2 - 500 Kbps	
Operating voltage	1.9 to 3.6 V	3.9 V Max	1.9 to 3.6 V	2.1 - 3.6 VDC 3.0 VDC typical	1.9 to 3.6 V	2.0 to 3.6 V
Supply current	11.3 mA Radio TX at 0 dBm 13.3 mA Radio RX at 2 Mbps on-air data-rate	29.2 mA Radio TX at +10 dBm RX: 17 mA typical	TX @ 20 dBm: 80 mA typical TX @ 13 dBm: 30 mA typical TX @ 6 dBm: 18 mA typical RX: 18.5 mA typical	TX @ 0 dBm: 7.6 mA typical TX @ 11 dBm: 12.0 mA typical RX: 6.1 mA typical	21.5 mA Radio TX at +1 dBm RX: 17 mA typical	29 mA TX and 22 mA RX
Power down current	900 nA deep sleep mode	200 nA deep sleep mode		11.5 µA typical	200 nA deep sleep mode	0.85 µA (Hibernation Mode)
Stand-by current	--	--		--		3.3 mA (Radio Off)
Sleep current	--	--		--		0.8 mA (uC Sleep, Radio Off)
Operating temperature	−40˚C to +80˚C	−40˚C to +80˚C	−40˚C to +85˚C	−40˚C +85˚C	−40˚C to +80˚C	−40˚C to +105˚C
Range	80 Meters	1 - 2 Km	Not mentioned	Up to 915 Meters without data loss	70 - 75 Meters in LoS **(tested by our previous research work)**	--
Package	20-pin 4 × 4 mm QFN	QFN	QFN	SMD	QFN	RoHS-compliant 9.5 mm × 9.5 mm × 1.2 mm 99-pin LGA package
Cost	~$5	~$16/Pair	$12	$15.28 - $16.24	~$14/Pair	--

4. Conclusion

WSNs have provided the best option for minimizing manual control in application scenarios. Even in applications where utmost human intervention is required, WSNs have managed to automate the processes to a greater extent. We have also surveyed on possible RF modules to be used in newer product design. The survey for RF modules was particularly concentrated about the power consumption and RF-related parameters like Tx Power and Rx Sensitivity. This will enhance the support for future developers to choose an RF module based on the need and suitability for application.

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