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PERFORMANCE COMPARISON OF CONFIGURABLE TRANSCEIVER TECHNOLOGIES APPLIED TO LONG RANGE WIRELESS SENSOR NETWORK COMMUNICATIONS OVER SEAWATER

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ABSTRACT

Two recent radio technologies were put to the test by communicating over land and seawater, to determine which performs better in harsh environments. This work focuses on the comparison of two 900MHz digital transceivers: particularly the Digi XBee Pro 900 and the Laird AC4490. Their performance was measured taking into account the data transmission Success Rate (SR%) and the relative valued Received Signal Strength Indicator (RSSI) of round trip packets. Both radios were tested at different distances transmitting at a fixed 50mW power level. Initially two rounds of experiments were carried out over land and a third round of tests was done over seawater, using a fixed offshore base station placed on a pier and a portable wireless relay node that was placed on discrete positions along the beach. From the logged measurements, mean valued RSSI and SR% were tabulated and interpreted graphically to reflect which radio outperformed the other. The best performing transceiver is intended to be deployed in long range marine environmental sensor network applications at the coasts of Baja California, México.

1. INTRODUCTION

Wireless sensor networks (WSN) are a set of new communications technologies that have been developed as an inexpensive alternative to conventional environmental monitoring technologies, which tend to be expensive and difficult to scale-up [1, 2]. WSN operate within the 900MHz and 2.4GHz unlicensed Industrial-Scientific-Medical (ISM) frequency bands [3]. Some WSN standardization efforts have been done by the IEEE Computer Standards Society [4] and later by a group effort of companies called the Zigbee Alliance [5,6]. In general, WSN have been conceptualized as low data rate wireless systems with energy saving features to extend their remote operational lifetime [7]. Many application areas have been found for WSN that replace or enhance traditional monitoring technologies, and in some cases have opened possibilities that were impractical with 20th century technologies [8, 9].

2. MODERN DIGITAL TRANSCEIVERS

Since the 70's, when digital communications started their accelerated development, the first MODEM (Modulator/Demodulator) transceiver devices were enabled with algorithms that understood the well known AT (ATtention) Protocol composed of a set of digital character commands. These AT commands are issued to initiate communications and to convey custom configurations [10, 11].

WSN transceivers interact with their host in two ways: some with binary low level commands (read and stored in an EEPROM) and others use AT style command characters. Many transceiver developers have preferred AT command interaction because it's easily understood by human operators. Here, the transceivers that are compared are the Digi XBee 900 and the Laird AC4990; both use their own type of AT commands to configure automated operations and to determine performance. Also, these radios use their own set of Application Program Interface (API) frames to do on-the-fly transceiver characteristic changes.

3. THE XBEE-PRO 900 TRANSCEIVER

The XBee manufacturer, Digi Corp., states in its literature that the low power XBee Pro 900/900 Digimesh modules were engineered to create extended range wireless sensor networks [12]. These XBees operate within the ISM 900 MHz frequency band and transmit at a fixed 50mW power level using a 2dBi antenna. Their over the air bit rate reaches 156.25Kbps using a frequency hopping spread spectrum (FHSS) scheme to avoid data collisions, an their sensitivity is at -100dBm. In general, any XBee module provides a radio frequency (RF) link with a serial interface. An XBee is then able to convert serial data to RF frames intended for other modules in the network. Furthermore, when a packet arrives at an XBee node, it is placed on its serial interface so any attached host may have access to incoming remote information. An XBee module also provides a software interface that enables user interaction and on-the-fly configuration of different device features and peripheral functions. Figure 3.1 illustrates the XBee module functionality, where an XBee by default is a simple drop-in solution enabled with a transparent data packetizer. Figure 3.2 shows the XBee module footprint, which is common to most Digi modules. In the case of the XBee Pro 900 it has only six analog to digital converters onboard (AD0 – AD5) and several digital I/O configurable pins.

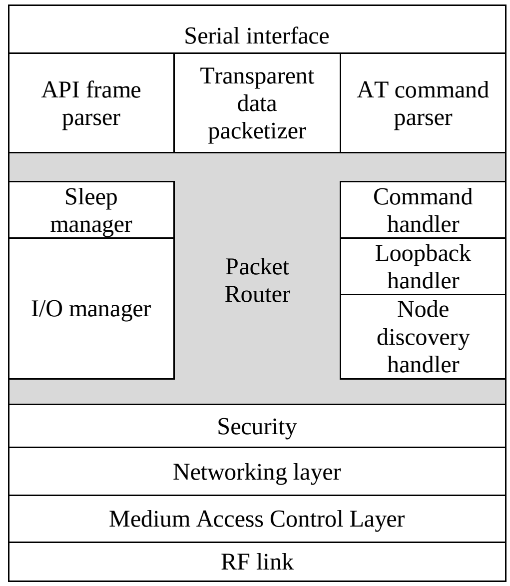

Fig. 3.1. XBee module functionality.

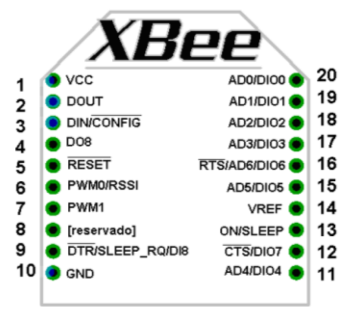

Fig. 3.2. XBee Pro 900 module footprint.

Besides transparent operation, an XBee can be configured to work in more powerful command modes of operation, such as: AT mode or in API mode. Such types of operation enable dynamic configuration of the XBee module features. By using these command modes a host processor, attached to its serial interface, can issue character commands to an XBee and process remote data accordingly. This permits outer routing control and low level access to the transceiver operation parameters. Among the XBees automated tasks, periodic analog to digital data sampling and transmission is one of the more appealing set of features. This can be done directly by the XBee by enabling any of its ADC input pins and by setting the desired sampling rate. Figure 3.3, the well documented API frame structure is shown.

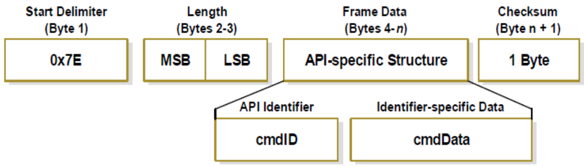

Fig. 3.3. XBee API frame model.

The API identifier, known as the command ID or cmdID in fig. 3.3, specifies what type of message is in the cmdData section of the frame. So the type of frame depends on the cmdID value, which can be a transmit frame that has to be constructed through software, or a receive frame that the XBee sends out its serial port. Another possibility is that it might be a local or remote configuration command, excluding response frames that may accompany certain API XBee interactions.

4. THE AC4490 TRANSCEIVER

Laird Technologies manufactures different digital transceivers, one of these is the AC4490 transceiver intended for long range telemetry [13]. It operates within the ISM 915MHz frequency band and transmits at a fixed 76.8 Kbps data rate using frequency shift keying (FSK) and a FHSS collision avoidance scheme. This transceiver can establish point to point and point to multipoint links, as well as master-slave and peer to peer communications. Data framing and forwarding are done at a link-layer level, it’s up to the application and algorithms on an attached host processor to deploy some sort of routing. Also, these modules have adjustable power levels, and can reach a transmission power value of up to 1000mW (with a 2dBi antenna) which is at the maximum limit allowed under the international agreement for the ISM frequency bands.

When an AC4490 starts up, it looks for an internal EEPROM table for non-volatile configuration values that specify addressing information and various other parameters that determine operational behavior. To modify these registers the AC4490 uses an AT command scheme. To enter command mode it’s necessary to place the well known sequential characters “AT+++<LF>” at the radios receive (Rx) serial line at a default 56700 bps. Also, some AT commands permit “on-the-fly” configurations and status querying.

These radio modules offer API communication and control, through which four kinds of packet exchanges can be enabled: *Receive*, *Transmit*, *Send Data Complete* and *Enhanced Receive*. In order to interact with the AC4490, when in this type of communication mode, specific packet structures are expected. Figures 4.1 to 4.4, show four API frame structures are shown.

0x83	Payload data length	Source MAC address	Payload data

Fig. 4.1. Laird API Receive packet

0x81	Payload data length	Res.	Transmit or Broadcast attempts	Dest. MAC address	Payload data

Fig. 4.2. Laird Transmit API packet model.

0x82	Reserved	Last ACK RSSI	Failure/Success

Fig. 4.3. Laird API Send Data Complete packet.

0x81	Payload Data length	Res.	RSSI	Source MAC address	Payload data

Fig. 4.4. Laird Enhanced API Receive packet.

In this mode of operation, the starting byte is the API packet identifier. Although the transmit and the enhanced receive packets start with the same 0x81code, these packets travel on opposite sides of the host/transceiver serial interface and do not interfere with each other, it’s up to the software developer not to mix them up. Contrasting this mode of operation with the XBees API operation, the XBee transceivers require that if API frames are to be used, then all interaction has to be done in this mode. Furthermore, Laird transceivers can have only some API frames enabled. In other words, an AC4490 can have one API packet feature at a time. For example, if only API receive packets are useful (or practical) then the application developer can activate only this feature and transmit without the need of constructing a Tx API packet.

5. EXPERIMENTAL FRAMEWORK

Both XBee and AC4490 radios can be acquired with an evaluation board for testing and possible technology integration. In the case of the XBee, there are many third party products available. It’s worth mentioning that the more expensive AC4490 lacks third party support, and the only available

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“off-the-shelf” hardware is the Laird Technologies’ development kit [14]. Both come with serial communication capabilities for host interaction through which initially a host computer is used to interact with them, to change operation registers and to determine their startup options. On the software side, the same situation prevails. Although both, Digi and Laird, distribute their configuration and testing software with their boards, for the XBees there are many and very well documented software examples, as well as project integration initiatives with a diverse range of microcontroller technologies [15,16].

For our tests, we used Digi and Laird proprietary evaluation interface boards and software. Both, XBee and AC4490 evaluation software have a “range test” panel that requires that one end of the communications link have a “loopback” connection [17, 18]. Any message sent from a base station to this loopback node is repeated back and a received power estimate can be viewed, successful transmissions are counted and a success percentage is shown. We set up the experiments to be as fair as possible, both radios transmitting at the same power level, with the same antenna gain (2dBi each) and so forth. The difference we didn’t change were over the air bit rate and the receivers sensitivity. For these tests, the payload that was sent was an alphanumeric string at a rate of 32 ASCII character message per second so as to visually verify outgoing and incoming messages.

6. TESTING THE DIGITAL TRANSCEIVERS PERFORMANCE

Testing was done in three different settings with both radios transmitting simultaneously in different channels to avoid collisions. For the first round of experiments, we set up a transmitting base station with a loop-back repeater at the other end of the university campus driveway known as the “circuito interno”, an aerial image is shown in figure 6.1. The total distance for this test was 800m. Our goal was to compare both radios starting in a general setting just to have an idea of their general performance. Average power readings were made and success rates were recorded at discrete points along the driveway. The repeater node was moved after 15 minute interval measurements. After several simultaneous tests at the same site, and repeating them in another occasion, we recorded the round trip percentage of good packets and we averaged the values of the *received signal strength indicators* (RSSI in -dBm) for both pairs of radios. The resulting values are summarized in table 6.1.

Table 6.1. First experiment results (fig. 6.1). Round trip % of good packets and RSSI vs. distance.

	XBee		AC4490	
Distance, m	% good packets	RSSI avg -dBm	% good packets	RSSI avg -dBm
150	100	-85	100	-46
250	100	-85	100	-52
350	100	-85	100	-66
500	66	-92	100	-70
600	25	-102	92	-79
800	0	-104	35	-91

Using these discrete distance results, in figure 6.2 a comparative line graph is presented noticing that the AC4490 outperforms the XBee 900, at the same 50mW transmission power level.

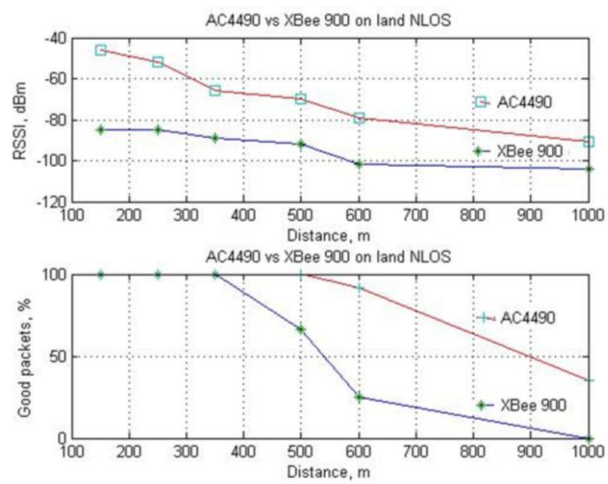

Fig. 6.2. AC4490 Vs. XBee 900 on the campus Boulevard.

The second experiment was done at the beach. In

Fig. 6.1. Transceiver test points along a strait Boulevard. Distances are in meters with respect the base stations fixed position at 0.

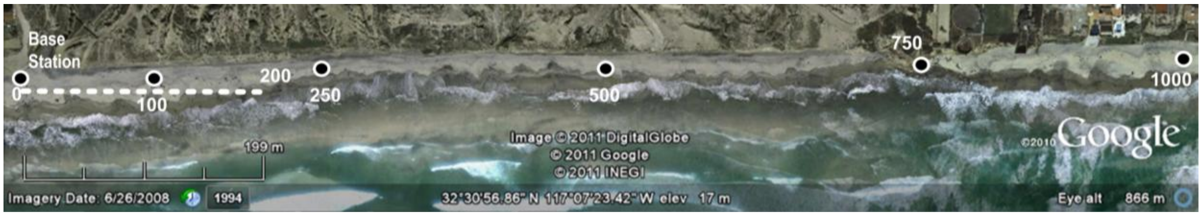

Fig. 6.3. Transceiver test points along a strait flat beach. Distances are in meters with respect the base station fixed position.

fig. 6.3 an aerial view is shown of the selected test site at Playas de Tijuana, México. Also, the resulting values are presented in table 6.2. And in fig. 6.4, a line graph serves as a visual aid in the comparison where 30dBm maximum difference is noticeable giving the AC4490 a significant advantage over the XBee 900.

Table 6.2. Second experiment results (fig. 6.3). Round trip % of good packets and RSSI vs. distance over wet sand.

	XBee		AC4490	
Distance, m	% good packets	RSSI avg -dBm	% good packets	RSSI avg -dBm
100	100	-85	100	-53
250	100	-85	100	-60
500	100	-92	100	-77
750	80	-98	100	-82
1000	0	-104	80	-90

The apparent anomaly between the first and second experiments is that the AC4490 lost more packets during the driveway trials than over wet sand. An explanation is that in the first case there were lamp posts and car circulation creating reflections and perturbing the propagation channel. Meanwhile, in the beach experiment, direct line of sight was achieved with mainly ground reflections that perhaps helped to enhance the total received signal strength.

It is important to mention that the AC4490 transmits at a lower RF bit rate, compared to the XBee 900, which makes the AC4490 RF symbols take more time to transmit (with larger symbol periods). Consequently, it is more robust against noise and interference; this results in a lower bit error probability compared to the XBee.

For our third experiment, we selected transmission over seawater. This implies a harsh environment for RF wireless communication due to water EM absorption and vapor dispersion. In figure 6.5, the Playas de Rosarito city pier stretches 300 meters from the public beach head out to sea. Table 6.3, shows the performance results in terms of RSSI and percent of packets correctly received.

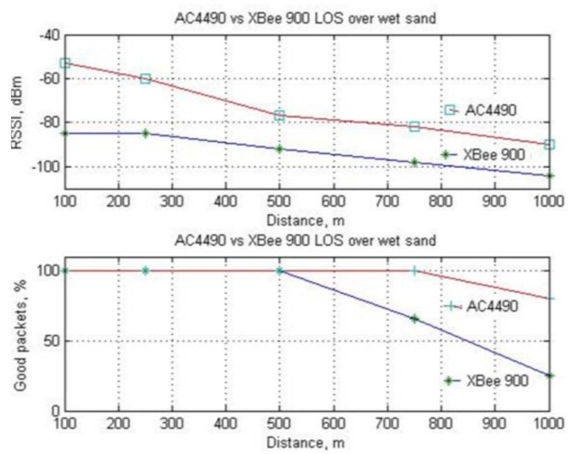

Fig. 6.4. AC4490 vs. XBee 900 over wet sea sand.

Table 6.3. Third experiment (fig. 6.5). Round trip % of good packets and RSSI vs. distance over seawater.

	XBee		AC4490	
Distance, m	% good packets	RSSI avg -dBm	% good packets	RSSI avg -dBm
300	100	-92	100	-57
500	80	-94	100	-68
920	15	-100	96	-73
1300	0	-104	80	-85
1930	0	-104	45	-97

The performance contrast between both radios was similar to the wet sand experiment, and the

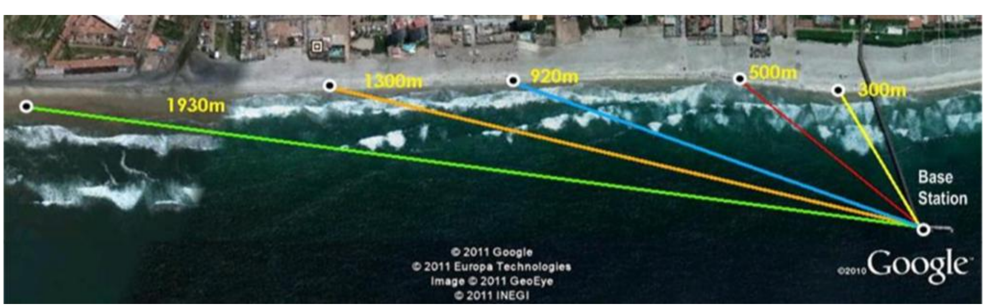

Fig. 6.5. Portable transceiver test points on a beach to a fixed base station on a pier over seawater.

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AC4490 achieved an extended range while the XBee continued to exhibit a poor % of successful received packets. Figure 6.6, illustrates the line graph comparison. On average, from the line graphs the AC4490 had 25dBm higher RSSI value compared to the XBee.

It´s important to note that the base station on the pier was situated at roughly eight meters over sea level, so this meant more radio range despite the sea shore wave activity. Either way, the results show that the AC4490 outperforms the XBee 900. One reason is that while the XBee has a good -100dBm receiver sensitivity, the AC4490 has an even larger sensitivity value of -110dBm. This means that the AC4490 is able to demodulate very weak signals with less effort compared to the XBee.

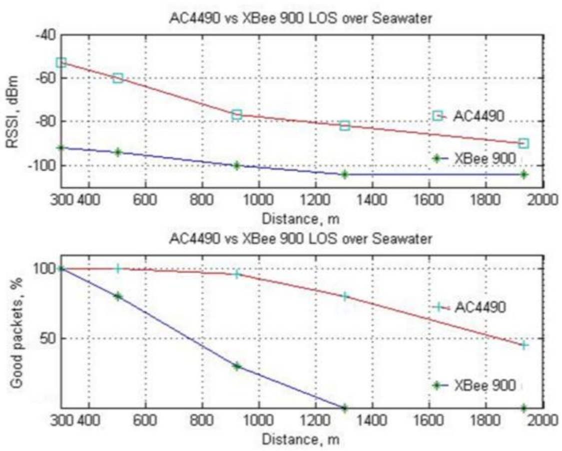

Fig. 6.6. AC4490 vs. XBee 900 over seawater.

Operating at 50mW Tx power, the AC4490 achieved a range of 1300m with an 80% round trip packet delivery success rate while at the same success rate the XBee 900 only reached a 500 meter range (table 6.3).

One last remark on the usefulness of our results is that they have proven which technology works better on land or over seawater. This means that the next step in prototype deployment is to manufacture water resistant enclosures and to install an adequate antenna setup to ensure wireless communications in the harsh environment that marine habitats pose.

CONCLUSIONS

When comparing digital radios an assumption is that the best one is the transceiver with the highest Tx bit rate. But if range is an issue, a trade-off has to be reached. In this case, the results support this claim. If more bandwidth is needed, there is a bit error rate price that has to be paid, because its probability increases exponentially. It is important to note that even if the XBee still received some signal power, this didn't guarantee bit error free data delivery. And another of the XBees disadvantages is that the AC4490 has that "extra" 10dBm sensitivity which broadens the received power gap making it extremely suitable for long range communications.

REFERENCES

[1] C.Y. Chong and S.P. Kumar, **Sensor networks: Evolution, opportunities, and challenges**, *Proceedings of the IEEE*, vol. 91, n.8, 2003, pp. 1247-1256.

[2] Kay Romer and Friedemann Mattern. **The design space of wireless sensor networks.** IEEE Wireless Communications Journal. Volume: 11 Issue:6, pp. 54 – 61. ISSN: 1536-1284. 2004.

[3] Semtech Corp. **FCC Regulations for ISM Band Devices: 902 – 928 MHz**. Application Note AN1200.04. 2006.

[4] IEEE Computer Society. http://www.computer.org last visited april/2012.

[5] IEEE Standards Committee 802.15.4. **Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (WPANs).** Institute of Electrical and Electronics Engineers. New York: IEEE Press. 2006.

[6] Zigbee Alliance. http://www.zigbee.org/ Visted april/2012.

[7] R. C. Shah and J. Rabaey, **Energy Aware Routing for Low Energy Ad Hoc Sensor Networks**. IEEE Wireless Communications and Networking Conference (WCNC), March 17-21, 2002.

[8] Yao-Jung Wen. **Smart Dust Sensor Mote Characterization.** Masters of Science at the University of California, Berkeley. 1999.

[9] C. F. García-Hernández, P. H. Ibargüengoytia-González, J. García-Hernández, and J.A. Pérez-Díaz. **Wireless Sensor Networks and Applications: a Survey**. IJCSNS International Journal of Computer Science and Network Security, VOL.7 No.3, March 2007.

[10] Conexant Systems, Inc. **AT Commands for SmartSCM, SmartACF, SmartACFL**, and SC56D Modems. Reference Manual. 2000 - 2001.

[11] MultiTech Systems. **AT Commands For GSM/GPRS Wireless Modems.** Reference guide. 2003.

[12] Digi Intl. Inc **XBee-PRO® 900/DigiMesh™ 900 RF Modules.** User's manual, 2009.

[13] Laird Tech. **AC4490 900MHz Transceiver** User's Manual. Ver. 3.2.1, 2007.

[14] Laird Tech. **AC4490 Developer Kit User's Manual.** Version 3.3. 2005.

[15] Oficial web site. **Arduino-Xbee**. http://arduino.cc/es/Main/ArduinoXbeeShield. Visted 4/05/2012.

[16] Libelium Inc. **The Waspmote**. http://www.libelium.com/products/waspmote. Visited 05/2012.

[17] Digi Intl. Inc. **X-CTU Configuration & Test Utility Software User's Guide.** Rev. 2008.08.20.

[18] Digi Intl. Inc. **How to perform a range test of Drop-in XBee series modules.** White paper, 2009.