Adaptive Packet Sizing for OTAP of PSoC Based Interface Board in WSN

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***Abstract*—Adaptive packet sizing techniques are widely used in wireless communication to enhance the link reliability. Typically, shorter packets are less error prone than longer packets. Adaptive packet size technique is used in IEEE 802.11 wireless network to enhance link reliability and packet delivery ratio. In this work, we adopt this technique to work in IEEE 802.15.4 based networks, and specifically in wireless sensor networks. A special protocol is designed to implement adaptive packet size transmission in WSN. In WSN, different mote designs and implementations are relying on the use of programmable circuits in their sensor interface boards. Delivering new firmware to these circuits by means of OTAP (Over The Air Programming) requires a reliable link between base station and target mote. Such reliable link can be achieved using the proposed adaptive packet sizing protocol. A testbed based on such scenario is constructed and the proposed protocol was tested to send new firmware update data to the target mote in its distant location under different environmental conditions.**

I. Introduction

WSN (Wireless Sensor Networks) have drawn great attention by developers all over the world. WSN have promising solutions for many fields of applications; home automation, medical monitoring, military surveying and industrial process control are just few examples [1]. A distinctive class of such applications uses programmable circuits in the sensor node/mote design [2][3]. However, for this class of motes, installing new firmware and updates is a real life challenge due to the geographically distribution of the motes over large areas of deployment. Nevertheless, the heavy traffic this firmware update process will impose to the wireless network.

In WSN, the mote to/from base station communication is not built to be fully reliable and that's mainly for the sake of power conservation of the motes [4]. Implementing acknowledgment based transfer protocols will heavily load the communication channel and decrease the battery's life time of the mote.

In this work we propose a reliable, power efficient protocol to deliver firmware updates over the air to the spatially distributed motes in their final destinations. The proposed protocol uses adaptive size packets techniques [5][6][7] to transfer new firmware over the air to motes with PSoC (Programmable System on Chip) devices on their sensor interface board. The packet size is decided prior to the actual transfer of packets carrying firmware data by means of an exploration packet. From the exploration packet, the link quality of the intended communication channel can be predicted. If the link quality is relatively high, which means a less error prone link, the packet size will be long. On the other hand, if the link quality is low, the packet size will be reduced to decrease the packet susceptibility to error. The link quality is measured through RSSI (Received Signal Strength Indicator) provided by transceiver chips manufacturer that are IEEE 802.15.4 compliant.

The rest of the paper is organized as follows. Section II details the relation between signal-to-noise ratio and packet reception rate for the IEEE 802.15.4 standard. Section III describes the proposed protocol design for adaptive size packet transmission over wireless sensor networks and section IV details the testbed built to verify the operation of the proposed protocol in different environments. Finally section V concludes the paper.

II. Background

For any given RF modulation scheme, a given signal-to-noise ratio has an expected bit error rate [8]. The PHY of the IEEE 802.15.4 at 2.4 GHz uses offset quadrature phase shift keying (OQPSK). Denote that the E_b/N_o is the ratio of the average energy per information bit to the noise power spectral density at the receiver input, in the case of an additive white Gaussian noise (AWGN) channel. Then the bit error rate (BER), P_e, can be expressed as:

$$P_e = Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \qquad (1)$$

where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\frac{u^2}{2}} du$$

E_b = Energy required per bit of information
N_o = thermal noise in 1 Hz of bandwidth

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Fig. 1 shows the relation between the bit error rate and the E_b/N_o.

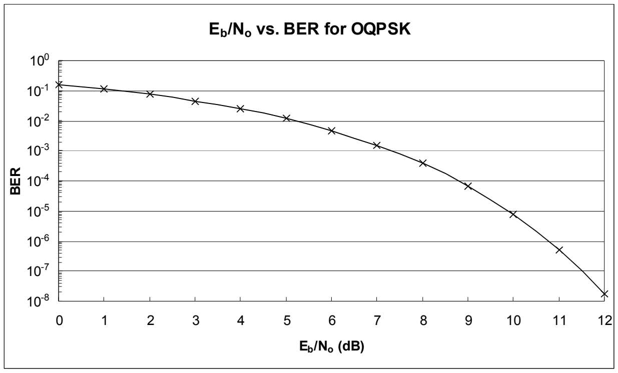

Fig. 1. Eb/No vs. BER for OQPSK Modulation

The PHY of the IEEE 802.15.4 at 2.4 GHz has a data rate of 250 kbps and channel bandwidth of 2 MHz [9]. Thus recalling that signal-to-noise ratio equals:

$$SNR = \frac{E_b}{N_o} \times \frac{R}{B} \qquad (2)$$

where

R = system data rate (250 kbps for Zigbee at 2.4 GHz)

B = channel bandwidth (2 MHz for Zigbee at 2.4 GHz)

substituting

$$SNR_{dB} = \left(\frac{E_b}{N_o} \right)_{dB} - 9.03 \qquad (3)$$

Thus redrawing graph in Fig. 1 to reflect the relation between *SNR* and bit error rate, the resultant graph is shown in Fig. 2.

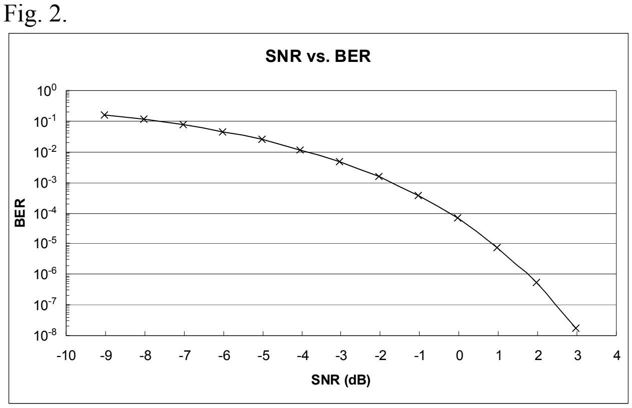

Fig. 2. SNR vs. BER for Zigbee at 2.4 GHz

During packet transmission, long packets suffer high probability of error, while shorter packets can sustain a lower *SNR* value. From [10] it is shown that the packet reception rate (PRR) is related to P_e by the following equation:

$$PRR = (1 - P_e)^{8f} \qquad (4)$$

where

PRR = packet reception rate

P_e = bit error rate (BER)

f = frame packet length in bytes (overhead + payload)

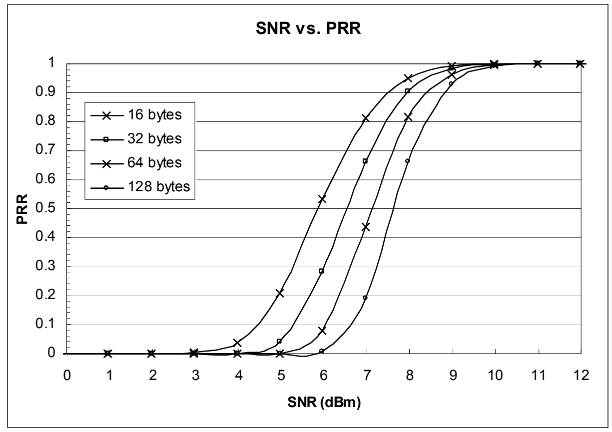

Fig. 3. SNR vs. PRR for Different Packet Lengths

Thus redrawing graph in Fig. 2 to demonstrate the relation between *PRR* and *SNR* for different packet lengths in bytes. In the intermediate region of the graph shown in Fig. 3, for every *SNR* value there are different *PRR* values according to the packet length. This means that for this region the received signal strength is an important factor that decides whether the packet will be received correctly or not. It is also shown that for a certain *SNR* level, changing the packet size will increase *PRR* thus decreasing the *PER* (Packet Error Rate) since *PER = 1 – PRR*. The proposed protocol as described in the next section based upon this fact.

IEEE 802.15.4 complied transceivers have an indicator for the signal quality typically known as Received Signal Strength Indicator (RSSI). The *RSSI* is the RF signal strength, in dBm [11]. Transceivers read *RSSI* of received packets and append this value to the packet itself. *RSSI* measurement at the receiver is including the received signal strength and the receiver noise floor.

$$\left(RSSI_{dBm}\right) = \left(P_{rx}\right)_{dBm} + \left(R_{NF}\right)_{dbm} \qquad (5)$$

where

R_{NF} = receiver noise floor

P_{rx} = received signal power at the receiver

Every transceiver has a specific and known receiver noise floor depending on its noise figure and its thermal noise, thus the *RSSI* is a direct indication to the received signal power at the receiver. For example, if the transceiver noise floor is -95 dBm, graph in Fig. 3 can be redrawn to reflect the relation between *RSSI* and *PRR*, as shown in Fig. 4. If the received signal power level is much higher than signal-to-noise ratio, the packets will be all delivered correctly. If it is much lower than signal-noise-ratio, the packets will not be delivered at all to the receiver. The transitional region in between is where the variation of the packet size will have a great impact on the packet reception rate. The proposed protocol works in this region to enhance the link susceptibility to errors.

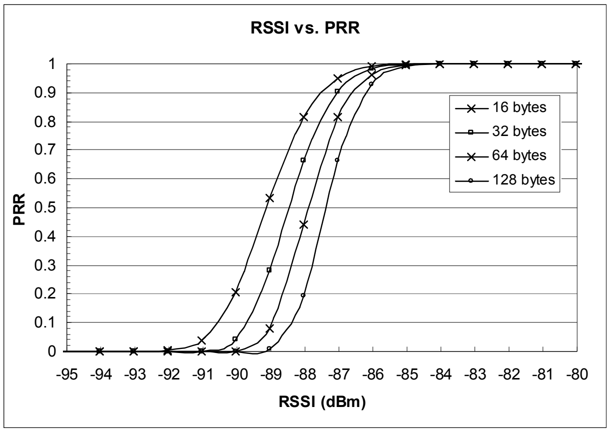

Fig. 4. RSSI vs. PRR for Different Packet Sizes

III. Protocol Design

The proposed protocol is designed specifically for situations where the base station in WSN is required to send massive data chunks to a terminal node in the wireless network. Sending new firmware to the scattered nodes is one example of this type of communication. This scenario is shown in FIG, where a PC connected to the base station will have the new firmware data that should be transferred to a specific node in the wireless network.

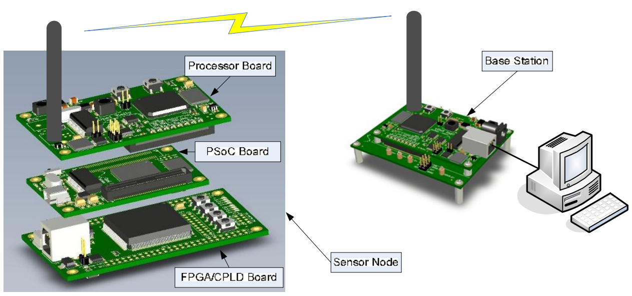

Fig. 5.WSN Example Configuration

Based on the relation between *PRR* and *SNR*, we propose the following protocol. First the protocol uses adaptive packet payload sizes (in bytes). The protocol is then divided into sender part and receiver part. The sender part is the base station and the receiver part is the sensor node. The base station sends an exploration packet to the receiver to explore the link quality. The sensor node replies with an empty packet. The base station receives this packet and extracts the *RSSI* value from it.

According to the *RSSI* value received the base station starts sending the required configuration bits dividing them into packets. Optimal packet size is based on its estimation of *SNR*; the sender adjusts its packet sizes based on the link quality with the receiver. The packet size is decided such that to retain a certain packet reception ratio as discussed in the previous sections.

The exploration packet procedure is repeated every 64 bytes of raw data. If at any point the base station didn't receive a reply from the sensor node within a specific timeout, the base station will report a link error to the associated PC and will repeat the exploration packet procedure for a defined number of retries. The receiver responds to the exploration packet with an empty packet which the sender will use to extract the *RSSI* value from. The sender then uses this *RSSI* value and accordingly sends the firmware data dividing them into packets of adaptive size. After the complete firmware update is sent to the sensor node, the node will acknowledge the successful reception within a certain timeout. If failed, the complete process should be repeated again. The protocol transactions are shown in Fig. 6.

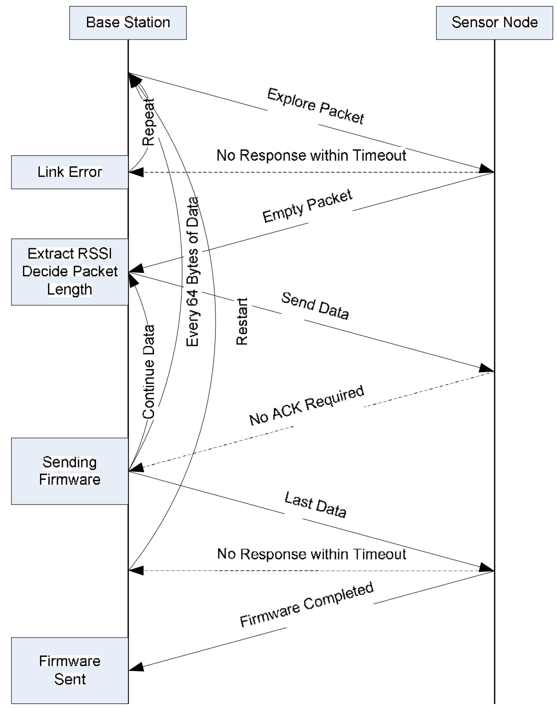

Fig. 6. Protocol Transactions

ACked communication can also be considered, instead of waiting for the complete firmware transfer to verify the operation success, acknowledge frame can be sent from the sensor node after every transaction received from the base station. However, this sort of ACKed communication if utilized in high quality channels will unnecessarily reduce net throughput of the system and increase power consumption.

IV. Testbed

A testbed is built to test the proposed protocol. The testbed consists of a base station connected to PC from one side, and wireless to target IRIS mote from the other side. Shown in Fig. 7 is the target mote which is composed of a Radio/Processor of the IRIS mote, CPLD board, and PSoC based sensor board.

The firmware update process is intended for this PSoC based sensor interface board. An FPGA board is located between the target IRIS mote and PSoC sensor interface board and is responsible of the programming procedure of the PSoC device when a new firmware is received from the mote. A special program was developed to perform the different protocol transaction. The program resides on the PC and handles the firmware transmission to target node through the connected base station.

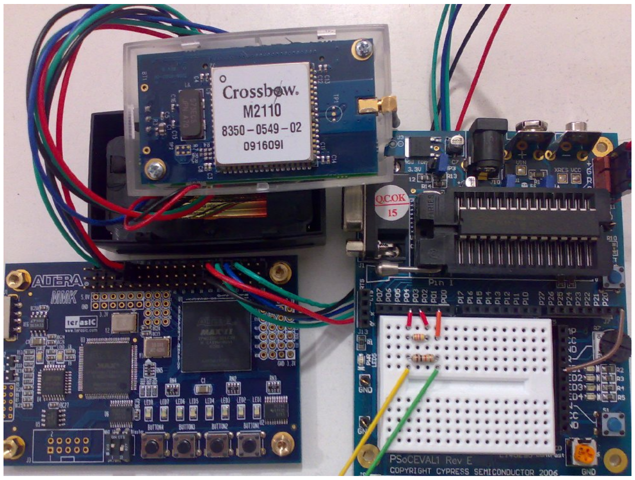

Fig. 7. Testbed Construction

Several experiments were conducted in indoor environment at different distances between the base station and the target node. The experiments were done using firmware update size of 32 kB. The outcome of the experiments are concluded in the following table which shows the optimum packet size to be used to obtain a packet reception rate of 100%. RSSI values in the table are defining the intervals used by the developed program to decide the optimum packet payload excluding overhead bytes of the IEEE 802.15.4 standard. They are obtained after several RSSI measurements at different distances and used to retain the *PRR* value at 100%.

TABLE I
SUGGESTED OPERATING PARAMETERS

RSSI (dBm)	**Payload Size (bytes)**	**OTAP Duration (seconds)**
< -75	No reception	--
> -75 and <= -70	8	130
> -70 and <= -65	16	48
> -65 and <= -57	32	15
> -57	64	5

Experiments show that, if a fixed packet size of 128 bytes was chosen to transfer the firmware update data, these packets would have suffered a *PRR* of 90%. On the other hand, if a fixed shorter packet size was chosen, the transmission of the firmware data will take unnecessary long time. Instead, using the proposed protocol, the *PRR* can reach up to 100% by the adaptive packet sizing technique. By using the proposed protocol the throughput of the transmission will be kept in its optimum range with an efficient use of the mote's battery.

It is worth mentioning that, analytically, the transitional region as shown in Fig. 4 is about 5 dBm wide, while the results deduced from the conducted measurements show that the transitional region are as wide as 18 dBm. For indoor environments this can interpreted into a distance variation of about 15 meters [13]. The deviation from the analytical value is due to different factors mainly because of the channel modeling in indoor environments which are not included in the analytical derivation.

V. CONCLUSION

In this work we presented a protocol to transfer large files in WSN built on the IEEE 802.15.4 standard. The protocol is based on predicting the link quality prior to transmission using an exploration packet between the base station and the target node. This technique allows adjusting the packet size to achieve a lower packet error rate. The protocol was tested using testbed built to allow over the air programming of PSoC's firmware inside sensor interface board connected to IRIS node. The results show that the proposed protocol enhances the firmware transfer process while maintaining optimum throughput and lower battery use.

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