A Study on Combining Power Management and Power Control for Wireless Sensor Networks

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***Abstract*—Two power saving schemes namely power management and power control have been investigated in isolation for addressing power constraint of wireless sensor networks, which is known to be the most prominent limitation in road to successful deployment of wireless sensor networks. However, combining the power saving schemes is yet to be investigated in the literature. Therefore, in this paper, we propose a power saving scheme combining power management and power control simultaneously for wireless sensor networks. We perform real testbed experiments to evaluate the performance of the proposed power saving scheme. Experimental results demonstrate that we can reduce power consumption of sensor nodes using the proposed scheme at an expense of marginal decrease in delivery ratio.**

***Index Terms*—sensor networks, power management, power control, PMaC, testbed**

I. Introduction

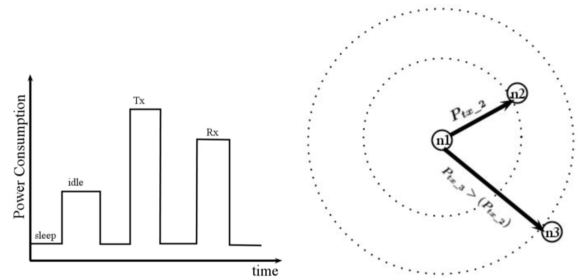
Even though the development of wireless sensor networks was motivated by military applications such as battlefield surveillance, a number of diversified applications such as industrial process and control, machine health monitoring, environmental monitoring, etc., have started using these networks now-a-days. Most of these sensor networks consist of battery-driven sensor nodes. As batteries are known to be limited-power sources and it is difficult to frequently change batteries of the nodes, power consumption of the nodes remains one of the key challenges in successful deployment of wireless sensor networks.

Many research studies have addressed the issue of power constraint in wireless sensor networks from different perspectives. These studies result in a number of energy-efficient protocols covering all the layers of the protocol stack [2], [10], [7].

These protocols exploit different power saving schemes. Of them, two most frequently used power saving schemes are power management and power control.

While using power management, sensor nodes decrease their power consumption through utilizing a ultra-low-power state called SLEEP state [4] as much as possible in addition to traditional transmit (Tx), receive (Rx), and idle states. On the other hand, while using power control, sensor nodes decrease their power consumption through adjusting its power consumption in transmit state according to its distance to the intended destination [13].

Fig. 1 presents operations of power management and power control. Here, Fig. 1a shows different states of the sensor nodes in a timing diagram. Besides, Fig. 1b shows different power consumption in transmit state based on different distances from a source node (n_1) to the destination nodes (n_2 and n_3).



(a) Power management (b) Power control

Fig. 1: Operations of power management and power control

State of the art techniques for wireless sensor networks utilize power management [3] and power control [12] schemes in isolation. However, combination of these two schemes for wireless sensor networks is yet to be investigated in the literature. Therefore, in this paper, we investigate a power saving scheme for wireless sensor networks combining power management and power control. To the best of our knowledge, we are the first to investigate the combination for wireless sensor networks. In our investigation, we find that we can reduce power consumption of a sensor node through exploiting a combination of power management and power control, however, at the expense of marginal loss in delivery ratio.

Based on our work, we make the following contributions in this paper:

- We propose a power saving scheme for wireless sensor networks combining power management and power control. We name the proposed scheme as PMaC.
- We evaluate the performance of the proposed scheme through conducting experiments over a real testbed.

II. Related Work

Different techniques for minimizing power consumption in wireless sensor networks. [6], [11], [3], [12] have already been proposed in the literature. Here, two power saving schemes namely power management [3] and power control [12] have already been investigated in isolation. However, little effort has been spent on combining both power management and power control.

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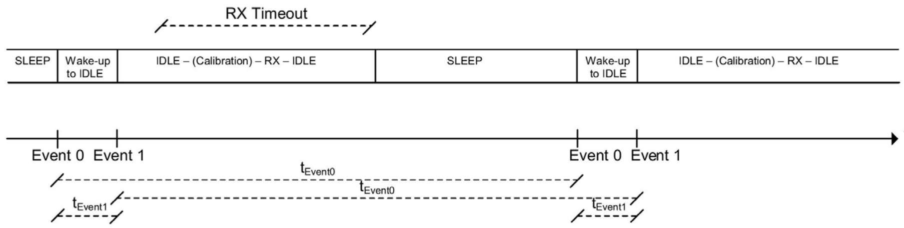


Fig. 2: Timing diagram of WOR and different radio states [8]

Few studies [6], [11] in the literature have focused on the combination. Here, the study in [6] only presents the idea of combination without any experimental evaluation, whereas the study in [11] performs experimental evaluation. However, both of these studies adopt 802.11 radio while combining power management and power control. The 802.11 radio is generally used in WLAN. It has a high bandwidth and long transmission range, which comes at an expense of high power consumption. On the other hand, the traditionally used radios in wireless sensor networks (for example, 802.15.4) exhibit a completely different behaviour of having low bandwidth, short transmission range, and low power consumption. Due to these dissimilarities, wireless sensor networks exhibit completely different behaviour [1]. Consequently, the studies [6], [11] on WLAN are not directly applicable to wireless sensor networks. Dissimilarities between our findings in this paper and the results presented in the study in [11] validates this claim.

To the best of our knowledge, combining power management and power control is yet to be investigated in the literature. Therefore, we attempt to perform the investigation in this paper. We start presenting our investigation through elaborating operational mechanism of wireless sensor networks in the ease of simultaneous presence of power management and power control in the next section.

III. Operational Mechanism of PMaC

PMaC combines power management with power control . In the case of power management, it is not desirable to keep a node in SLEEP mode all the time. In such case, it cannot detect the presence of a message in transmission, and therefore cannot receive the message. Consequently, in PMaC we use a special mechanism for enabling power control in the sensor node. This mechanism is called Wake on Radio (WOR) [8].

The WOR [8] enables the radio of a node to periodically (Fig. 2) wake up from SLEEP mode and listen for incoming packets without interaction of any other intelligent devices. After a programmable time in R_X, the radio goes back to the SLEEP state unless a packet is being received. Fig. 2 shows the relationship between WOR events and the different radio states.

Next, we consider power control as all sensor nodes, when deployed, are not at fixed distance from each other. Therefore, the power required for data transmission is not same for all data transmission. Controlling power at transmission state according to the distance between source and destination is a good approach for reducing the consumption of power. Sensor nodes generally have the capability of transmitting data with different level of dBm power and the level can be controlled easily. In PMaC we control the level through tuning transmit signal strength according to the distance between source and destination. We evaluate the performance of such tuning in accordance with power management in the next section.

IV. Experimental Evaluation

We implement PMaC over a two node wireless sensor network testbed to evaluate its performance. First, we present the testbed settings, and then we present testbed results.

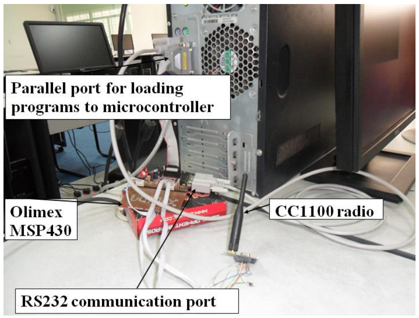
A. Testbed Settings

For transmitting and receiving data, we use wireless transceiver Chipcon CC-1100 EM [9]. This is an ultra-low-power UHF wireless transceiver, which can transmit and receive data in 868 MHz and 915 MHz. The RF transceiver is integrated with a highly configurable baseband modem. The modem supports various modulation formats and has a configurable data rate up to 500 kbps. This chip has serial peripheral interface (SPI) to communicate with any intelligent device. Using this SPI interface, we control the transmission and reception of data and transmission power.

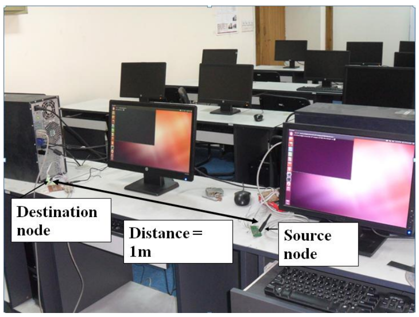
CC-1100 has a variety of features for controlling own power consumption and for going to different energy states. We achieve the control through writing pre-defined data to the registers of the transceiver.

To control operation of the transceiver, we use a microcontroller board from Olimex Limited named MSP430-PXX [5]. In this board, a microcontroller MSP430f1611 is connected with some supplementary devices. There is a RS-232 interface to communicate between computer and the microcontroller using Universal Synchronous/Asynchronous Receiver/Transmitter (USART). Besides, this microcontroller provides SPI interface that can be used with the CC-1100's SPI interface to communicate between the microcontroller and transceiver.

We interface the microcontroller with computer for controlling it from the computer. Additionally, we interface the microcontroller with the transceiver. According to the command sent from computer, the microcontroller communicates with the transceiver and the transceiver transmits or receives data. The microcontroller initializes the transceiver for PMaC.

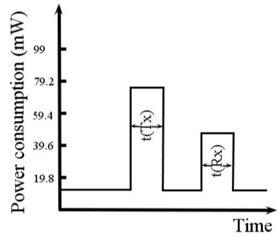


(a) Setup for single sensor unit

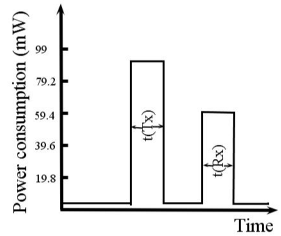


(b) Deployment of source and destination nodess

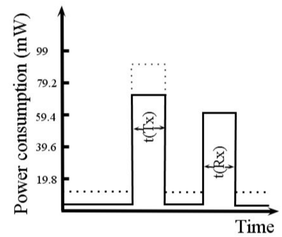
Fig. 3: Testbed settings for evaluating PMaC



(a) Power consumption of the sensor node with only power control scheme



(b) Power consumption of the sensor node with only power management scheme



(c) Power consumption of sensor node for PMaC (dotted lines show power power consumption in earlier cases)

Fig. 4: Power consumption in three power saving scheme

It enables the Wake On Radio feature and set the transmission dBm level according to the receiver's position.

The microcontroller is connected with a computer via RS-232 port. We sent our data through the computer. The computer simply sends the data to the microcontroler through RS-232 port using USART protocol with a BAUD rate of 9600. The microcontroller receives this data and generates commands for communicating with its connected transceiver. We enable the communication between microcontroller and transceiver through SPI. After receiving commands from the microcontroller, the transceiver wakes up and transmits data according to its initialized dBm level.

Another transceiver is connected with a different microcontroller at a distant place. This microcontroller is also connected with another computer in a similar fashion. This transceiver receives data from the first transceiver, and sends it to the microcontroller. After receiving, the microcontroller processes the message and sends it to the computer for display.

The microcontroller and the transceiver unit is powered by a power adapter. The internal circuitry of the microcontroller board ensures that the device is feed by a regulated stable 3.3 Volt DC power supply. Therefore, we measure only current in order to calculate the consumed power of the device. We take the measurement through connecting a digital multi-meter and measuring the average input current of the device.

We show our experimental set-up in Fig. 4. Here, Fig. 3a shows a single unit and Fig. 3b shows the two node deployment.

B. Testbed Results

In our testbed experiment, first, we implement the power control scheme independently. We collect data for several times for a fixed position of destination node while using power control and compare it with normal case. Our results show that the node consumes more power in the transmission state than in any other state. (Fig. 4a). We show an average value of the power in the figure.

Next, we implement the power management scheme independently. Here, we measure power consumption in different states. Here, we find that, the sensor node consumes less power in the SLEEP state than in other sates (Fig. 4b).

Finally, we combine the two approaches and implement PMaC. We perform the implementation in our programmable intelligent device, i.e., MSP430 microcontroller. Here, we enable the Wake on Radio of CC-1100 and control transmitting power according to dBm feature combinely. In this case, the power consumption in IDLE state gets reduced in accordance with limiting power consumption for transmission and reception (Fig. 4c).

The reduction of power consumption in the case of PMaC is intuitive as it takes the advantage of both power management and power control. However, the reduction comes at a price of reduced network performance. To analyse the trade-off, we focus on delivery ratio while using different different power saving schemes in wireless sensor networks.

First, we measure the delivery ratio without implementing any power saving scheme. We find approximately 100% delivery of data in this case as the destination node is within

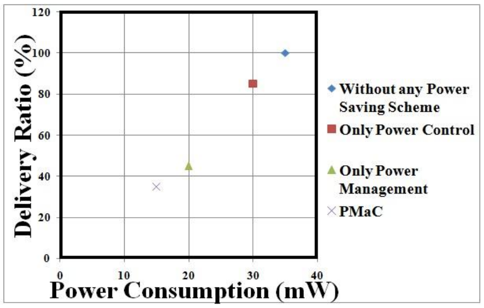


Fig. 5: Trade-off between power consumption and delivery ratios of different power saving schemes

Power saving scheme	(%) decrease in power consumption	(%) decrease in delivery ratio
Power control	15	14
Power management	55	43
PMaC	65	57

TABLE I: Impact on power consumption and delivery ratio in different power saving scheme compared to the case having no power saving scheme

the transmission range of the transmission radio, of the source node.

Next, we measure the delivery ratio in the case of implementing only power control. We observe that a very good amount of data was successfully delivered to the receiver. Here, the delivery ratio is approximately 85%. However, when we implement only power management scheme, the delivery ratio significantly degrades compared to the previous case. Here, the delivery ratio drops to an approximate value of 45%.

Finally, we observe the delivery ratio of PMaC. The delivery ratio in this case degrades a bit further compared to the previous cases. Here, we get a delivery ratio around 35%. This value is close to the value that we get through multiplying the two previous values. Again, this is intuitive as the delivery ratio in PMaC experiences effects of delivery ratios of both power management and power control.

V. Future Work

Our experiment result demonstrate a trade-off between power consumption and delivery ratio in the case of PMaC compared to other power saving schemes. Here, the value of delivery ratio is comparatively small. This happens as we enable PMaC in a naive way. There is a potential to improve the delivery ratio through using artificial intelligence in PMaC while enabling power management and power control simultaneously. We plan to incorporate the intelligence in future.

Besides, we have preferred our experiments over one-hop network testbed. However, real wireless sensor networks often experience more than one-hop data transmission. Therefore, in future, we plan to perform our experiments over testbeds having more than one-hop data transmissions.

VI. Conclusion

Wireless sensor networks are mostly equipped with low-power sensor nodes. Therefore, limiting power consumption always remains a challenge for such networks. Different power saving schemes such as power management and power control have been proposed for limiting power consumption in wireless sensor networks. However, the potential of combining the two schemes together for wireless sensor networks has yet to be investigated in the literature. Therefore, in this paper, we investigate simultaneous usage of power management and power control (named as PMaC) for wireless sensor networks. Our investigation, through performing real testbed experiments, reveals that there is a trade-off between power consumption performance of data transmission while using PMaC. To improve the performance while retaining the limited power consumption we need to introduce artificial intelligence in PMaC. We plan for such incorporation of artificial intelligence in future.

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