ODTPC: On-demand Transmission Power Control for Wireless Sensor Networks

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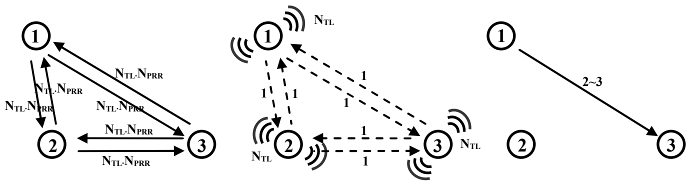
***Abstract*— Development of efficient transmission power control algorithms providing both high energy efficiency and good link quality is the current major focus in wireless sensor networks research. In the paper, we propose an efficient transmission power control algorithm for wireless sensor networks, namely, the on-demand transmission power control (ODTPC) algorithm. This new algorithm attempts to reduce the initialization overhead in determining the optimal transmission power level while providing good link qualities. Our testbed experiment results show that ODTPC consumes much less energy than previous transmission power control algorithms (PCBL [11] and ATPC [12]) and is easily implemented with routing protocols like AODV [15] and Directed Diffusion [16].**

I. Introduction

A good transmission power control algorithm for wireless sensor networks should provide an energy efficient mechanism, because sensor nodes are powered by small batteries and may be difficult or impossible to replenish frequently. The transmission energy consumption can be significantly reduced with the transmission power control algorithm and popularly used radio hardware such as CC1000 and CC2420 offer a register to specify the transmission power level during runtime. However, determining the optimal transmission power level is difficult due to the instability and unpredictability of wireless channels. There are previous studies [10-12] that propose transmission power control algorithms in wireless sensor networks. However, these algorithms have a lot of overhead in the initialization phase since a number of packets have to be transmitted to determine the optimal transmission power level. Moreover, the initialization overhead dramatically increases as the number of nodes increases and this may reduce the lifetime of the network. In this paper, we propose a simple but efficient transmission power control algorithm for wireless sensor networks, namely, the on-demand transmission power control (ODTPC) algorithm. We adapt the inner-loop transmission power control mechanism [14] of the CDMA system to our algorithm. This new algorithm dramatically reduces the initialization overhead and therefore consumes much less energy than previous transmission power control algorithms while providing good link qualities. Moreover, ODTPC can easily be implemented with routing protocols because of its simplicity. The testbed experiment results show that ODTPC can achieve much better energy consumption performance and is suitable for routing protocols.



(a) PCBL (b) ATPC (c) ODTPC

Fig. 1 Comparison of transmission power control algorithms

II. Related Works

There are a number of previous studies in CDMA [7-9] and wireless ad-hoc network [3-6] literatures, but these studies mainly focused on improving the channel capacity and the performance of the network. In wireless sensor network literature, the authors of [10] proposed topology control algorithms with transmission power control and were primarily concerned about the energy-efficient network connectivity. The authors of [11] presented valuable studies about the impact of variable transmission power on link quality and proposed a transmission power control algorithm with blacklisting scheme (PCBL).

In PCBL algorithm, each node sends N_{PRR} packets at different transmission power levels to measure the quality of the link based on the packet reception rate (PRR). N_{PRR} denotes the number of PRR packets. Among the transmission power levels that exceed a certain threshold in PRR, the minimum transmission power level is selected as the optimal transmission power level. They argue that PRR is a good indicator to determine the optimal transmission power level rather than the received signal strength (RSSI), because the link quality is significantly influenced by distance, multi-path, interference, and time. However, in PCBL algorithm, a number of packets have to be transmitted to build the PRR metric at different transmission power levels and it may reduce the lifetime of the network. As shown in Fig. 1, each node sends $(N_{NODE}-1)\cdot N_{TL}\cdot N_{PRR}$ packets in the initialization phase. N_{TL} and N_{NODE} denote the number of transmission power levels and the number of nodes respectively. Another drawback of PCBL is that when the number of active nodes increases, determining the optimal transmission power level based on PRR is difficult due to collision. In addition, PCBL also cannot adjust the transmission power level dynamically over time since the nodes can increase its transmission power level after several packet transmission failures.

The authors of [12] argue that RSSI and LQI are still good resources to estimate the optimal transmission power level, and they employ a feedback based adaptive transmission power control (ATPC) algorithm to dynamically maintain link qualities over time. In ATPC algorithm, each node broadcasts a beacon at different transmission power levels in the initialization phase, and its neighbours measure RSSI/LQI values corresponding to these beacons and send these values back by a notification packet. After the notification packet is received, the beaconing node determines the optimal transmission power level by the least square approximation method. In the runtime tuning phase, the transmission power level is adjusted based on their feedback mechanism. This scheme can reduce the initialization overhead of PCBL and can maintain good link qualities over time. However, ATPC still has overhead in the initialization phase. As shown in Fig. 1, each node broadcasts N_{TL} beacons and unicasts N_{NODE}-1 notification packets in the initialization phase. Moreover, when there are large-scale link quality variations during initialization phase due to multi-path or interfering, the approximation based on a few number of RSSI values can not be accurate [18].

We adapt the closed-loop transmission power control mechanism [14] of the CDMA system to our algorithm and modify the mechanism to be suitable for wireless sensor network devices. In this paper, we propose an efficient transmission power control algorithm for wireless sensor networks, namely, the on-demand transmission power control scheme (ODTPC). There are two main differences between the related works and ODTPC. First of all, ODTPC is an on-demand scheme. As shown in Fig. 1, a link quality between a pair of nodes is measured after the sender and the receiver exchange data-ACK packets rather than measuring link quality to every neighbour in the initialization phase. Secondly, there is no additional packet exchange to maintain good link quality and adjust the transmission power level. Therefore, because of its simplicity, ODTPC can be easily implemented with routing protocols like Directed Diffusion [16], AODV [15], and etc. The detail design of ODTPC is presented in Section 4.

III. Investigation of Relationship Between Transmission Power and RSSI

The previous study [12] presents the correlation between transmission power and link qualities. We conduct testbed experiments to confirm the correlation between the transmission power and link qualities under MICA2 platform. We use a pair of MICA2 motes for our experiments. One of the motes transmits 100 packets at each transmission power level and the other mote records the RSSI values. We vary the distance of nodes from 5 to 50 meters and all experiments are conducted in a corridor. The experiments are repeated with three different pairs of motes in the same environmental conditions to obtain statistical confidence.

Fig. 2 shows the linear correlation between the transmission power level and RSSI at different distance of nodes.

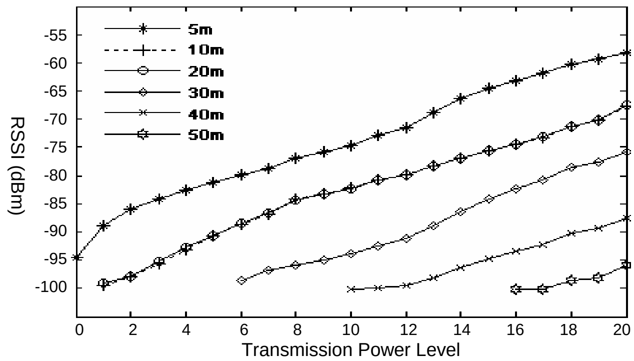


Fig. 2 Transmission power level vs. RSSI at different distance

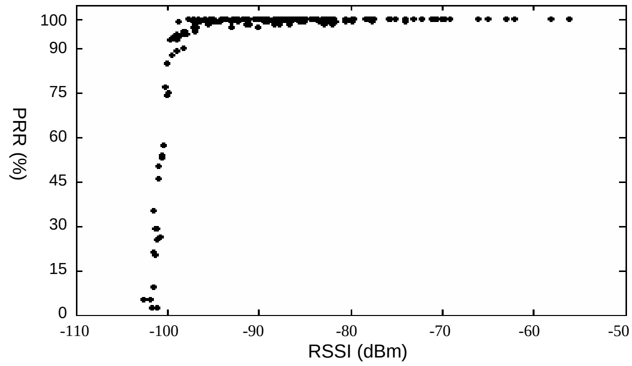


Fig. 3 RSSI vs. PRR

This result confirms that the least square approximation method of ATPC can be adapted to MICA2 platform. This result also shows that when we know the transmitted power level, we can roughly approximate the appropriate transmission power level based on the RSSI. From the experiment results, we notice that packets can not be coherently received when RSSI below a certain threshold. As shown in Fig. 3, when RSSI above -98dBm, PRR close to 99% and otherwise PRR significantly decreases; therefore, we can determine a RSSI threshold to choice the optimal transmission power level while providing good link quality. The RSSI threshold is also approximated with the analytical model which is given by [19]:

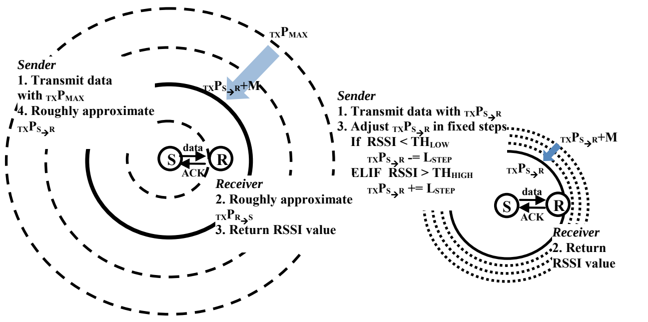
$$RSSI_{THRE}(dB) = 10\log\left(-1.28\ln(2(1-0.99^{\frac{1}{8f}}))\right) + P_N(dB)$$

Where f denotes the length of packet, 30bytes, and P_N denotes the average noise floor, -110dBm, which is derived from experiments.

IV. Design of ODTPC

ODTPC is designed with three main goals:

- providing a simple transmission power control algorithm and can be easily implemented with routing protocols;
- determining the optimal transmission power level very quickly without the initialization phase;
- to make each node dynamically adjusts its transmission power level over time and maintains good link quality without additional packet overhead.



(a) Large-scale Transmission Power Control (b) Small-scale Transmission Power Control

Fig. 4 Overview of ODTPC design

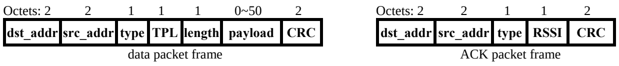


Fig. 5 MAC frame formats used in ODTPC

As shown in Fig. 4, ODTPC has two phases: the large-scale transmission power control (L-TPC) phase and the small-scale transmission power control (S-TPC) phase.

A. Large-scale transmission power control (L-TPC) phase

When a sender has a data packet to be sent, it looks at a neighbour table to find the optimal transmission power level. If the optimal transmission power level to the receiver does not exist, the data packet is sent with the maximum transmission power level, $_{TX}P_{MAX}$. The receiver measures RSSI corresponding to the data packet and roughly approximates the appropriate transmission power level, $_{TX}P_{R\to S}$, according to the measured RSSI and transmitted power level which is indicated by TPL field (see Fig. 5) as follows:

$$_{TX}P_{R\to S} = {}_{TX}P_{R\to S}^{approximated} + M$$

Where M is the margin to ensure successful communication since determining the optimal transmission power level based on RSSI is difficult [11]. Then, the receiver sends this value back by an ACK packet with the approximated transmission power level. When the sender is received the ACK packet from the receiver, it roughly approximates the appropriate transmission power level, $_{TX}P_{S\to R}$, according to the RSSI field with the margin M.

B. Small-scale transmission power control (S-TPC) phase

Next time, when the sender has a data packet to the same receiver, the data packet is sent with the approximated transmission power level and the receiver sends back an ACK packet with RSSI measurement. If the RSSI value is below than a lower threshold, TH_{LOW}, the sender increases the transmission power level in a fixed step, L_{STEP}, 1. Otherwise, if the RSSI value is above than an upper threshold, TH_{UPPER}, the sender decreases the transmission power level in the fixed step. TH_{LOW} and TH_{UPPER} are $RSSI_{THRE}$ and $RSSI_{THRE}$+6 respectively since the RSSI accuracy of the CC1000 is ±6 [1]. If the maximum transmission failure limit is reached, the transmission power level is increased in a large step. In S-TPC phase, each node precisely determines the minimum transmission power level that provides good link quality and dynamically maintains the transmission power level over time.

In our algorithm, each sender can quickly find the optimal transmission power level to its receivers, because there is no initialization phase to find the optimal transmission power level. In addition, there is no throughput overhead since a sender and a receiver exchange real-data and ACK packets without any additional packets. Moreover, our algorithm does not need complex operations and also does not use large memory to determine and maintain the optimal transmission power level.

TABLE 1
BRIEF ODTPC ALGORITHM

Step 1:	Roughly approximate an appropriate transmission power level with margin M (L-TPC)
Step 2:	Gradually decrease the transmission power level to a minimum transmission power level that provides good link quality (S-TPC)
Step 3:	Dynamically adjust the transmission power level to maintain good link quality over time (S-TPC)

V. EXPERIMENT RESULTS

A. Single Data Flow Scenario

In this subsection, we compare the performance of PCBL, ATPC, and ODTPC over single data flow scenario. In the experiments, we used two MICA2 motes and one of the motes transmits data packets at a rate of 4 packets per second. The receiver located at 30m distance from the transmitter. Before transmitting data packets, PCBL and ATPC have the initialization phase: in PCBL algorithm, the transmitter transmits 15 packets at each transmission power level; in ATPC algorithm, the transmitter transmits one packet at each transmission power level.

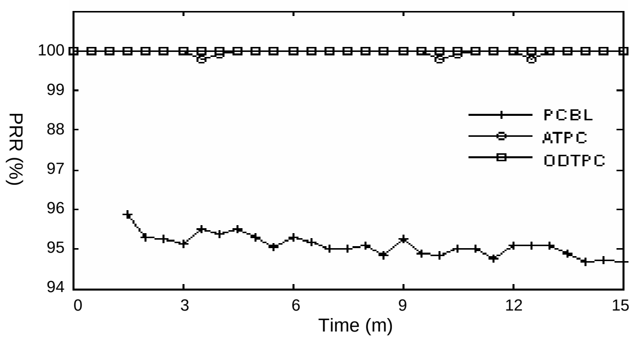


Fig. 6 PRR over time

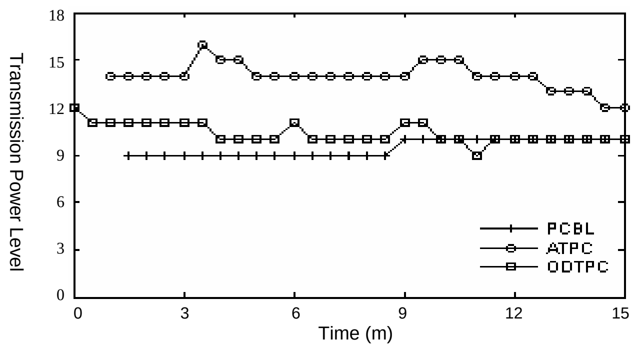


Fig. 7 Average transmission power level over time

We used fully active mode B-MAC [13] as a medium access control protocol and modified the source code of TinyOS to provide reliable transmission.

As shown in Fig. 7, we can see that PCBL selects lower transmission power level than others. The reason is that PCBL selects the minimum transmission power level which provides over 95% PRR, whereas ATPC and ODTPC select the transmission power level corresponding the pre-determined RSSI threshold which can provide 99% PRR. In Fig. 7, we can see that the transmission power level of PCBL slightly increases to 10 since the PRR of transmission power level 9 falls under 95% as shown in Fig. 6. ATPC selects a higher transmission power level than others, because it is difficult to derive the accurate correlation between transmission power level and RSSI with a few number of beacons [18]. Even though ATPC selects a higher transmission power level than OTPC, ATPC shows slightly lower PRR performance than OTPC. This means that the feedback algorithm of OTPC is more efficient than the feedback algorithm of ATPC.

B. Multiple Data Flows Scenario

In this subsection, we present the performance analysis for the proposed ODTPC algorithm over multiple data flows scenario. In the experiments, we used 7 MICA2 motes and these motes were located on the 5th floor of a building as shown in Fig. 8. Six nodes, which are numbered from 1 to 6, transmit a data packet every 30 seconds and the data packet size is 30 bytes including MAC header and CRC frame. Before transmitting data packets, PCBL and ATPC have the initialization phase: in PCBL algorithm, the transmitter transmits 15 packets at each transmission power level; in ATPC algorithm, the transmitter transmits one packet at each transmission power level. The experiments were run 3 hours and repeated 5 times to obtain statistical confidence.

Fig. 9 shows the mean transmission energy consumption on the entire network while every source node sends 500 data packets including the initialization phase. For better comparison, we take the energy consumption of the MAX scheme which every source node sends data packets at the maximum transmission power level. As shown in Fig. 9, we can see that ODTPC consumes much less energy than others. PCBL and ATPC show lower performance than ODTPC since they spend a lot of energy in the initialization phase. ODTPC dramatically reduces the energy consumption for the initialization phase and uses less than 53.48% of MAX scheme while maintains good PRR.

Fig. 10 shows the PRR on the entire network while every source node sends 1500 data packets except the initialization phase. In Fig. 10, we can see that ODTPC shows better PRR performance than PCBL and ATPC since the transmission power level is nicely adjusted based on our small-scale transmission power control algorithm. Although ODTPC shows slightly lower PRR performance than MAX, ODTPC significantly reduces the transmission energy consumption. PCBL shows the lowest PRR performance since, as we mentioned before, the transmission power level can not be dynamically adjusted over time.

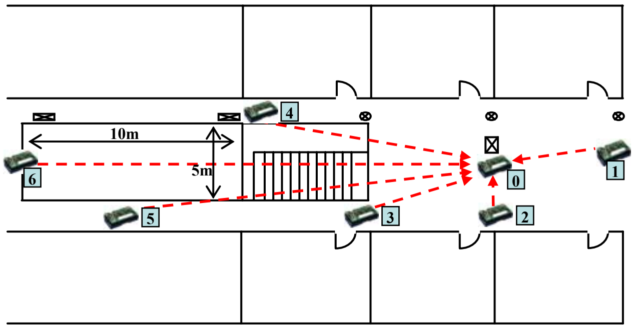


Fig. 8 Location of 7 MICA2 motes

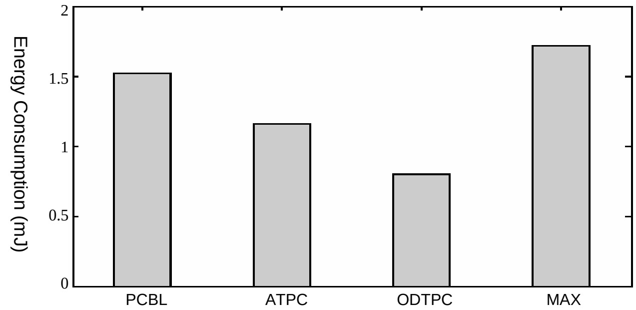


Fig. 9 Mean transmission energy consumption on the entire network

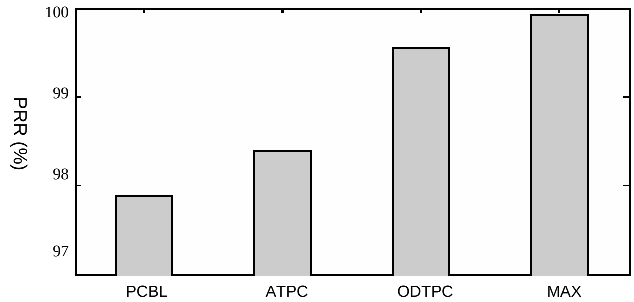
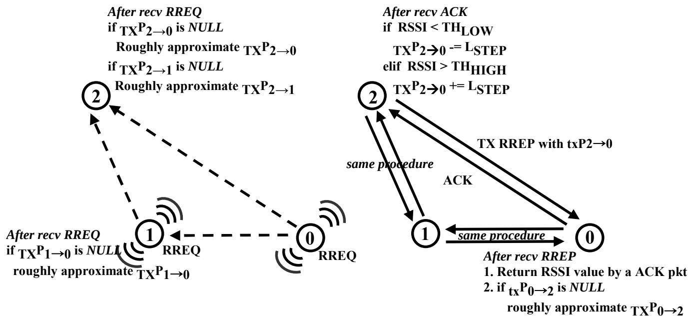


Fig. 10 PRR on the entire network

C. Ad-hoc Network Scenario

As we mentioned before, ODTPC is designed to be easily implemented with routing protocols. In this subsection, we present a combination scheme of AODV [15], which is the most popular routing protocol for wireless ad-hoc networks, and our new transmission power control algorithm, ODTPC. As shown in Fig. 11, the source node (numbered as 0) initiates path discovery by broadcasting a route request (RREQ) packet to its neighbours and its neighbours roughly approximate the appropriate transmission power level based on the measured RSSI value. When the destination node (numbered as 2) is received a RREQ, it sends a route reply (RREP) back to the source node. After the source node is received the RREP, it roughly approximates the appropriate transmission power level and returns a measured RSSI value by an ACK packet. When the destination node is received the ACK packet from the source node, it slightly adjusts its transmission power level in a fixed step, L_{STEP}.



(a) Path Discovery (b) Path Setup

Fig. 11 Combination scheme of AODV and ODTPC

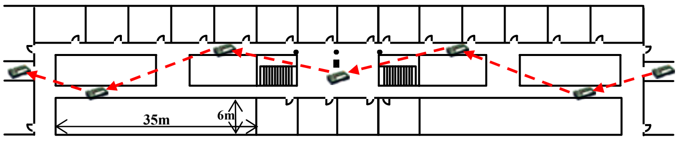
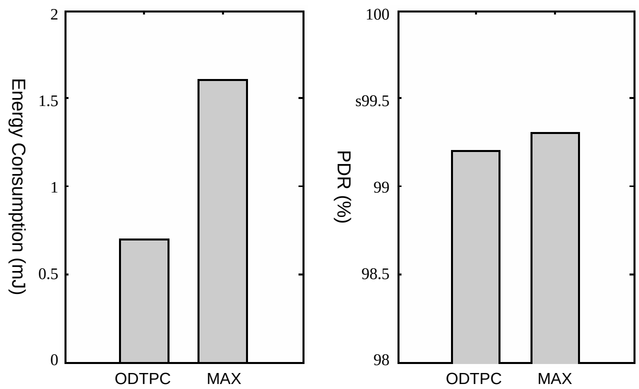


Fig. 12 Ad-hoc network scenario



(a) Mean transmission energy consumption (b) PDR

Fig. 13 Performance results

To compare the energy consumption performance over ad-hoc network scenario with AODV routing protocol, we conducted testbed experiments as shown in Fig. 12. The source node generates a 30-bytes data packet (including AODV header) every 5 second after the path discovery phase. In Fig. 13(a) and (b), ODTPC significantly reduces the transmission energy consumption while showing similar packet delivery rate (PDR) performance to MAX. This experiment results confirm that ODTPC works nicely with AODV routing protocol.

VI. Conclusions and Future Work

In this paper, we propose a new transmission power control algorithm, namely, the on-demand transmission power control (ODTPC) algorithm. ODTPC algorithm can dramatically reduce the transmission energy consumption while maintaining good link qualities. In ODTPC algorithm, each node determines the optimal transmission power level quickly without the initialization phase and dynamically maintains the transmission power level over time without additional packet overhead. In our testbed experiments, ODTPC achieves much better performance than previous transmission power control algorithms. We also present a combination scheme of AODV and ODTPC, and the testbed experiment results confirm that ODTPC works well with AODV routing protocol. We expect that our transmission power control algorithm works well with other popular sensor network routing protocols like Directed Diffusion [16] and SPIN [17], and we will propose a new energy aware routing protocol in our future work.

Acknowledgment

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References

[1] CC1000 Single Chip Very Low Power RF Transceiver http://www.chipcon.com

[2] CC2420 2.4GHz IEEE 802.15.4 / Zigbee RF Transceiver http://www.chipcon.com

[3] J. P. Monks, V. Bharghavan, W. Mei, and W. Hwu. A Power Controlled Multiple Access Protocol for Wireless Packet Networks. In Proceedings of IEEE INFOCOM, Apr. 2001.

[4] A. Muqattash and M. Krunz. Power controlled dual channel (PCDC) medium access protocol for wireless ad hoc networks. In Proceedings of IEEE INFOCOM, Apr. 2003.

[5] A. Muqattash and M. Krunz. A single-channel solution for transmission power control in wireless ad hoc networks. In Proceedings of MobiHoc, May. 2004.

[6] A. Akella, G. Judd, P. Steenkiste, and S. Seshan. Self Management in Chaotic Wireless Deployments. In Proceedings of ACM MobiCom, Aug. 2005.

[7] C. F. Kou and H. Leib. Power Imbalance Effects on Packet CDMA. IEEE Journal on Selected Areas in Communications, Dec. 1996.

[8] Kazuo MORI. Adaptive Transmission Power Control in CDMA Slotted-ALOHA Radio Communications. IEEE Universal Personal Communications, Oct. 1998.

[9] S. Niida, T. Suzuki, and Y. Takeuchi. Experimental results of outer-loop transmission power control using Wideband-CDMA for IMT-2000, IEEE Vehicular Technology Conference Proceedings, May. 2000.

[10] M. Kubisch, H. Karl, A. Wolisz, L. C. Zhong, and J. Rabaey. Distributed Algorithms for Transmission Power Control in Wireless Sensor Networks. Wireless Communications and Networking (WCNC), Mar. 2003.

[11] D. Son, B. Krishnamachari, and J. Heidemann. Experimental Study of the Effects of Transmission Power Control and Blacklisting in Wireless Sensor Networks. IEEE SECON, Oct. 2004.

[12] S. Lin, J. Zhang, L. Gu, T. He, and J. Stankovic. ATPC: Adaptive Transmission Power Control for Wireless Sensor Networks. In Proceedings of SenSys'06, Nov. 2006.

[13] J. Polastre, J. Hill, and D. Culler. Versatile low power media access for wireless sensor networks. In Proceedings of SenSys'04, Nov. 2004.

[14] TIA/EIA/IS-95. Mobile station-base station compatibility standard for dual-mode wideband spread spectrum cellular system. Telecommunication Industry Association, July. 1993.

[15] C. Perkins and E. Royer. Ad-hoc On-Demand Distance Vector Routing. In Proceedings of IEEE WMCSA, Feb. 1999.

[16] C. Intanagonwiwat, R. Govindan, and D. Estrin. Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks. In Proceedings of ACM MobiCom, Aug. 2000.

[17] W. R. Heizelman, J. Kulik, and H. Balakrishnan. Adaptive Protocols for Information Dissemination in Wireless Sensor Networks. In Proceedings of ACM MobiCom, Aug. 1999.

[18] C. Alippi and G. Vanini. Radio localization with mica2 wireless sensor network: A metrological analysis. In Proceedings of IEEE EmNetS, Nov. 2004.

[19] M. Zuniga and B. Krishnamachari. Analyzing the Transitional Region in Low Power Wireless Links. In Proceedings of IEEE SECON, Oct. 2004.