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# The effects of transmission power control in mobile ad-hoc sensor networks

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**Abstract**

Preserving energy is a very critical issue in mobile ad-hoc sensor networks (MASNETs) because sensor nodes have a severe resource constraints due to their lack of processing power and limited in power supply. Since the communication is the most energy consuming activities in MASNETS, the power use for transmission or reception of packet should be managed as much as possible. One way to reduce energy consumption is by applying transmission power control (TPC) technique to adjust the transmission power in communication between nodes. This technique has been widely studied in MASNETS. However, as MASNET applications emerge, the unique characteristics of this network such as severe resource constraints and frequent topology change suggest that TPC might be useful to reduce energy consumption in MASNETS. Therefore, we investigate different effects of TPC on Ad hoc On-Demand Distance Vector (AODV) routing protocols for MASNETs. AODV is used as a medium of communication to assist the investigation of the effects of TPC in multihop communication in this networks with Random Way Point (RWP) mobility model. Our simulation results show a noticeable effects of TPC implementation technique on MASNETS in respect to transmission energy consumption and packet received ratio at low node mobility. These results support the use of TPC technique to enhance the performance of multihop AODV routing protocol in MASNETs.

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## 1. Introduction

Recent rapid development of wireless communication technologies and portable mobile devices such as laptops, PDAs, smart phone and wireless sensors bring the best out of mobile computing particularly Mobile Ad-hoc Sensor Networks (MASNETs). MASNETs are particular types of Mobile Ad-hoc Networks (MANETs) that are designed to consider energy in mind because they have severe resource constraints due to their lack of processing power, limited memory, and bandwidth as in Wireless Sensor Networks (WSNs) [1, 2]. Hence, they have the characteristics, requirements, and limitations of both MANETs and WSNs. There are many potential applications of MASNETs,

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ranging from small networks that are constrained by power sources, to large-scale, mobile, highly dynamic networks such as real-time target tracking [3] and ocean temperature monitoring [4].

Preserving energy is a very critical issue in MASNETs because sensor nodes have a severe resource constraints due to their lack of processing power, limited memory, bandwidth and energy as in WSNs [1]. Thus, the design and development of routing protocols in MASNETs is very challenging due these characteristics that distinguish them from contemporary communication and wireless ad hoc networks [5]. Therefore, careful resource management is essential to save energy as much as possible in designing any routing protocol for MASNETs. This is because when some of the sensor nodes are mobile it is not easy to detect any broken routes and react faster to topology change. The increase of mobility in sensor nodes also affects the connection to their neighbours and the routing table update as evaluated in our previous work in [6]. Moreover, the communication process between sensor nodes when they are moving from one area to another also consumes more energy related to transmitting and receiving control packets.

Since the communication is the most energy-consuming activities in MASNETs, the power use for transmission or reception of packet should be controlled as much as possible in designing any routing protocol for this type of networks. The adjustment of transmission power through dynamic transmission power control (TPC) protocols is one of the techniques to effectively reduce energy consumption in MASNETs [7]. Therefore, in this paper we investigate different effects of TPC on MASNETs. AODV routing protocol is used as a medium of communication to assist the investigation of the effects of TPC in multihop communication in mobile environment using Random Way Point (RWP) mobility model in simulation environment.

The rest of the paper is organized as follows. In Section II, we includes the recent related work on TPC technique. Next, we briefly described transmission power control for MASNETs in Section III. Then, the AODV routing protocol description is summarized in section IV. The simulation tool and metrics are described in Section V. We present the experimental simulation results in section VI. Section VII concludes the paper and outlines the future work.

## 2. Related Work

TPC technique has been widely studied in mobile ad-hoc networks (MANETs). However, as MASNET applications emerge, the unique characteristics of MASNETs, such as severe resource constraints and frequent topoly change, suggest that TPC might also be useful in reducing energy consumption in these networks. In the IEEE802.15.4 MAC protocol, each node transmits packets at the same power level which is normally the maximum possible power level. But, if a node transmits packets at high power level it may generate too much interference to the network and consume more energy than necessary. In the case when too node pair are close to each other, a low transmission power is sufficient to communicate with each other. The power level should be high enough to guarantee the transmission and should be low enough to save energy in mobile environment.

Reducing energy consumption has always been a main focus of MASNETs research. TPC is one of the approach to conserve energy by adaptively control the transmit power of the radio. Most of proposed TPC techniques to determine the transmission power for mobile devices in MANETs [8, 9] are not applicable to MASNETs because of limited resources in MASNETs. These techniques mostly use signal strength related metrics such as signal to noise ratio (SNR) or signal to interference ratio (SIR) computed over incoming packets and compare the resulting values to static or dynamic thresholds to determine a mobile node's transmission power. While some existing TPC related work in WSNs only focus on the transmission power of resource constrained motes for static nodes [10, 11]. Their proposed techniques cannot be applied to MASNETs, because they rely on gathering extensive information about the channel environment prior to deciding the transmission power. These not possible in MASNETs because the channel conditions for mobile nodes change frequently. In [10], the transmission powers for stationary nodes are determined by instantaneous link quality indicators such as RSSI which have one-to-one correlation with the packet reception ratio (PRR). We use this technique to estimate the distance between nodes for determine the ideal transmission power for MASNETs.

## 3. Transmission Power Control for MASNETs

The transmission energy consumption can be significantly reduced with the TPC technique. A good TPC technique for MASNETs should provide an energy-efficiency mechanism to support dynamic topology changes in energy-

Table 1: Transmission power and typical current consumption for CC2420 radio [12]

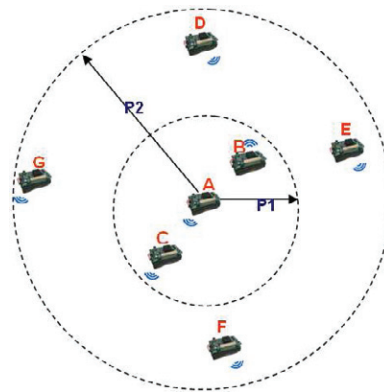| Power Level | Output Power (dBm) | Current Consumption (mA) |
|---|---|---|
| 31 | 0 | 17.4 |
| 27 | -1 | 16.5 |
| 23 | -3 | 15.2 |
| 19 | -5 | 13.9 |
| 15 | -7 | 12.5 |
| 11 | -10 | 11.2 |
| 7 | -15 | 9.9 |
| 3 | -25 | 8.5 |



Fig. 1: Ideal transmission power selection based on estimated distance between nodes

constrained networks. To achieve the best performance in MASNETs, the radio transmission power needs to be set to the right level. The radio transmission power of each sensor node can be set to fixed value or it can be adjusted dynamically based on the estimated distance between nodes. In terms of energy efficiency, Table I indicates that controlling the transmission power level can decrease the radio's current consumption by up to 51% for the popular CC2420 radio [12]. The RSSI provided by CC2420 radio is a useful link quality estimation value because it is the measured signal power of a received radio signal of each incoming packet. We can use the RSSI value to estimate the distance between nodes because it would be good indicator of distance as supported by previous research [13].

In this paper, we consider the energy consumed based on transmission power that is currently used by each node to transmit each packet towards sink. An optimization function considers the estimated distance between nodes based on RSSI values received from neighbour nodes to decide the  ideal transmission power for packet transmission towards sink. As shown in Figure 1, if node A (source) wants to transmit packets to nodes D, E, F, and G, it can do that with maximum power of 31 at P2. It is also possible for node A to transmit packets to nodes B and C with the same power of P2, but this fixed setting of maximum power for all nodes consumes more energy which is not practical for energy-constrained MASNETs.

Moreover, some of mobile nodes might moving nearer to node A like in position of nodes B and C in Figure 1 which require only low transmission power of 15 at P1 for node A to reach these nodes. Therefore, to minimize energy consumption, node A must be able to select the ideal transmission power level in every packet transmission. This can be done if node A has some knowledge about the output power needed for every packet transmission based on the estimated distance between node A and its neighbours. In our work, we propose the used of RSSI values to estimate the distance between nodes for determine the ideal transmission power to be implemented in AODV routing protocol for MASNETs.

## 4. Aodv Routing Protocol Description

AODV[14] stands for ad hoc on-demand distance vector protocol because route discovery in AODV is "on-demand". This protocol initiates a route discovery process only when it has data packets to send and it does not know any route to the destination node. It is a routing protocol designed for ad hoc networks and is one of the most popular reactive routing protocols in MANET. Being a reactive routing protocol AODV uses traditional routing tables, one entry per destination and destination sequence number (DSN) to determine the freshness of routing information and to prevent routing loops. This will greatly increase the efficiency of routing processes. AODV consists of two basic routing operations such as route discovery and maintenance. There are also various types of control messages used in the routing process of AODV [15] as follows:

- Control Messages: Route Request (RREQ) message, Route Reply (RREP) message, Route Error (RERR) message and HELLO messages are the control messages used for the discovery and breakage of route. The RREQ message is broadcasted by a node requiring a route to another node, RREP message is unicasted back to the source of RREQ message, RERR message is sent to notify other nodes of the loss of the link. HELLO messages are used for detecting and monitoring links to neighbours.

- Route Discovery: It is initiated when a source node wants to find a route to a new destination or when the lifetime of an existing route to a destination has expired. During a route discovery process, the source node broadcasts a RREQ message to its neighbors. If any of the neighbors has a route to the destination, it replies to the query with a RREP messsage; otherwise, the neighbors rebroadcast the RREQ message until the sought route. This is possible because each node receiving the RREQ message caches the route back to the originator of RREQ message. A route is said to be fresh enough when the DSN of the sought route in the recipient nodes routing table is greater than the DSN in the RREQ packet itself. A flag is set in the RREQ for establishing a reverse route between destination node and source node.

- Route Maintenance: To handle the case in which a route does not exist or the query or reply packets are lost, the source node rebroadcasts the query packet if no reply is received by the source after a time-out. A path maintenance process is used by AODV to monitor the operation of a route being used. If a source node receives the notification of a broken link, it can re-initiate the route discovery processes to find a new route to the destination. If a destination or an intermediate node detects a broken link, it can choose to repair the link locally or send an RERR packet to notify its upstream nodes. An RERR message contains the list of those destinations which are not reachable due the loss of connectivity. Whenever an end point receives RERR message it removes all the routes information of bad end point from it routing table. AODV only keeps the records of next hop instead of the whole route.

## 5. Simulation Tools and Metrics

In this section, we present the analysis of the effects of dynamic TPC technique implemented on AODV routing protocol for MASNET applications through experimental simulation. The relationship between the number of hops and transmission energy consumption and the correlation between the transmission power level and RSSI in multihop network also investigated here. All of the experimental simulation are performed using latest version (Beta 1.7.114) of Avrora simulation tool [16].

### 5.1. Simulation Tool

Avrora [16] is an open-source cycle-accurate simulation and analysis tools for WSN embedded sensing programs written for the AVR microcontroller produced by Atmel and the Mica2 sensor nodes. It is originally created to simulate Atmel AVR microcontroller-based sensor nodes with clock-cycle accurate execution of microcontroller programs, allowing real programs to be run with precise timing. It takes an object dump of in tinyos programs over AVR platforms such as mica2/micaz and is capable of single node emulation for verification of the program as well as multiple node simulation. AVRora is implemented in Java and runs code in an instruction-by-instruction fashion. However,

this simulation tool attempts to achieve better scalability and speed than TOSSIM [17] by avoiding synchronization of all nodes after every instruction. It provides a framework for program analysis, allowing static checking of embedded software and an infrastructure for future program analysis research. It simulates a network of motes, runs the actual microcontroller programs, and runs accurate simulations of the devices and the radio communication. It also provides many useful features to support the research on WSN, like control flow graph generation, energy analysis, and mobility extension model.

The Avrora's extension model of Random Waypoint (RWP) mobility model is used to simulate different mobility settings in our experiments because this model is the most commonly used mobility model in this research area. In this mobility model, a node randomly chooses a destination and moves towards it. After reaching the destination, the node stops for a time defined by the 'pause time' parameter. After this duration, it again chooses a random destination and repeats the whole process until the simulation ends.

## 5.2. Simulation Metrics

In order to analyze the effects of dynamic TPC technique implemented on AODV routing protocol for MASNET applications, we focused on two performance metrics as follows:

- Transmission Energy Consumption: Energy consumption is defined as the amount of energy consumed by nodes in the network through radio communication. So, the transmission energy consumption, given as $P_E$, can be calculated by adding all energy consumed only by source nodes (transmitter), $n$, throughout the simulation time. The equation for total energy consumption is written as below where this equation totals up the energy consumed in all source nodes when they transmit data packets which can be defined as follows:

$$P_E = \sum_{i=1}^{n} E_{Tx}^i \qquad (1)$$

- Packet Received Ratio: This metric can be defined as the ratio of data packets correctly delivered to the sink over all data packets that are generated by the source over the simulation time. The greater the packet received ratio, the more reliable the network is. The packet received ratio, $P_t$, is determined by calculating the ratio of packet successfully delivered to the sink, $P_{Rx}$, to the total number of packets sent by the source nodes, $P_{Tx}$, over the simulation time, $t$, as given below:

$$P_t = \frac{P_{Rx}}{P_{Tx}} \qquad (2)$$

## 6. Simulation Results

There are several experiments have been conducted in order to analyze the effects of TPC technique on AODV routing protocol for MASNETs.

## 6.1. Relationship between Number of Hops and Transmission Energy Consumption

The relationship between the number of hops and transmission energy consumption in multihop AODV routing protocol is investigated through simulation. The implementation of AODV routing protocol for these experiments are coding in nesC (Networked embedded system C) language . In our experiments, we simulate five MICAz motes with Avrora where one as static source node, one as static intermediate node, one as static sink node and another two as mobile nodes as shown in Figure 2. In part (a) of Figure 2, the source node (node A) transmit around 300 packets within 300 seconds of simulation time. The intermediate node (node B) then forwards the packets received from the source node to the sink node (node C). At this stage, the two mobiles nodes (node D and node E) are not within the communication range of other static nodes. Therefore, the node A requires maximum transmission transmission power level (i.e. 31) in order to reach node B, which also use maximum power level of 31 to forward the received packets

from node A to the sink node. But, as mobile nodes within the range of static nodes as shown in part (b) of Figure 2, the transmisson power level for every nodes can be adjusted as minimum as possible (i.e. 15) when forwarding the packets from source node to sink nodes within 5 hops communication. The energy consumed by source node within multihop communication of different number of hops is recorded by increasing the number of nodes involved to route the packets from source node to sink node.

As expected, the transmission energy consumed by source node is reduced as the number of hops increased especially from 2 hops to 4 hops (Figure 3). This is because of changing in transmission power levels and distance between nodes when there is an intermediate node within a range that can forward the packets towards the sink node. As can be seen in Figure 3, after 8 hops there appears to be a gradual decline in transmission energy consumption. Therefore, the total number of hops should be in range of 4 and 8 where the most transmission energy consumption can be reduced within the communication of multihop communication in AODV.
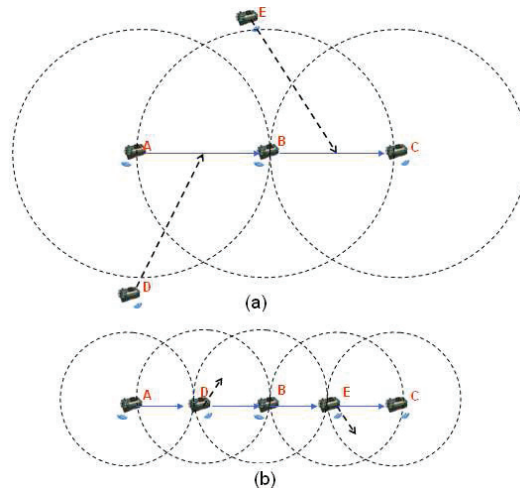


Fig. 2: (a) 2 hops communication (b) 4 hops communication when mobile nodes join in
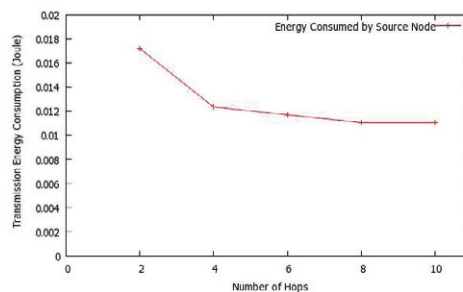


Fig. 3: Transmission energy consumption versus number of hops

## 6.2. Correlation between Transmission Power Level and RSSI

This subsection outlines the simulation experiments conducted to investigate the correlation between the transmission power level and link qualities based on RSSI in multihop AODV routing under MICAz platform. We simulate three MICAz sensor nodes in our experiments where one as the source node (transmitter), one as the intermediate node and the last one as the sink node (destination) as shown in Figure 4. The source node sends out 100 packets at each transmission power level. The intermediate node forwards the packets received from the source node to the sink node, which records the RSSI values and the number of packets received at each transmission power level. We
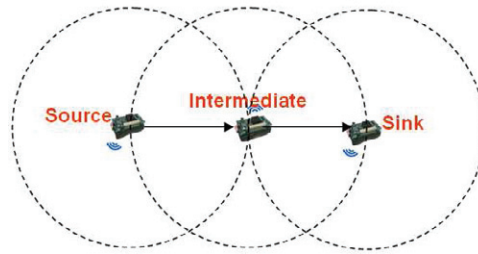
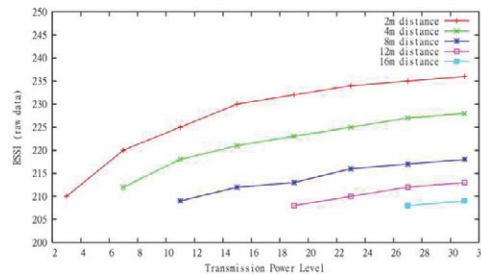Fig. 4: Multihop communication between source, intermediate and sink nodes



Fig. 5: Transmission power level versus RSSI at different distance

vary the distance between these nodes from 2 to 16 meters and all the experiments are simulated using Avrora. The experiments are repeated 5 times in the same simulation settings to obtain statistical confidence. The implementation of transmitter and receiver nodes for these experiments are coding in nesC language as in previous experiments.

Figure 5 shows our experimental data obtained from three sensor nodes in static environment. Each curve demonstrate the correlation between the transmission power level and RSSI at different distance of that pair of nodes. It is clearly shown that there is an approximately linear and strong relationship between transmission power level and RSSI. Moreover, this result shows that the transmission power control can be adapted to MICAz platform. Thus, it can be reason out 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, although the RSSI with specified transmission power and distance varies in a very small range, we still be able to identify the ideal transmission power level that the transmitter node should use to send packets toward sink in order to preserve energy as much as possible.

## 6.3. Comparison between Non-TPC and TPC

In this subsection, we evaluate the efficiency of the TPC technique on the Micaz platform in MASNETs through simulation. The main objective of these simulation experiments is to show that the proposed technique can minimize transmission energy consumption in mobile applications of MASNETs while maintain the packet received ratio. We evaluate two performance metrics outlined previously, which are transmission energy consumption and packet received ratio. The TPC technique is incorporated into AODV routing codes in TinyOS. Then, this implementation of TPC on AODV is evaluated and compared against the unmodified AODV without TPC implementation running with transmission power level of 31. We chose this value since it is the highest transmission power of the CC2420 radio, and thus must yield the best communication in terms of link quality and number of packet delivered in MASNETs.

We simulated a network of 9 nodes (6 static and 3 mobiles nodes) in 3x3 grid topology in a simulation area of 60 m by 60 m, where each mobile nodes moves according to the Random Waypoint mobility model with a maximum speed of 1 m/s. We ran six simulation scenario files twice to simulate non-TPC and TPC implementation on AODV, each of which was characterised by a simulation time. The different simulation times were: 200, 400, 600, 800, 1000, and 1200 seconds. Table II shows the simulation parameters used in this experimental simulation.

As shown in Figure 6, we can see that energy consumption of TPC slightly reduces around especially at 800 seconds

Table 2: Parameters used in Non-TPC and TPC experimental simulation

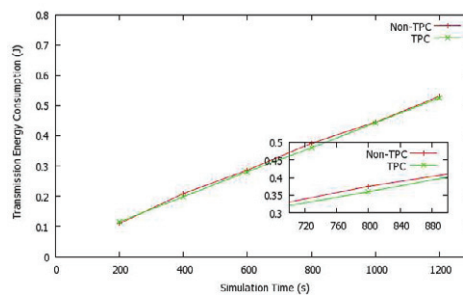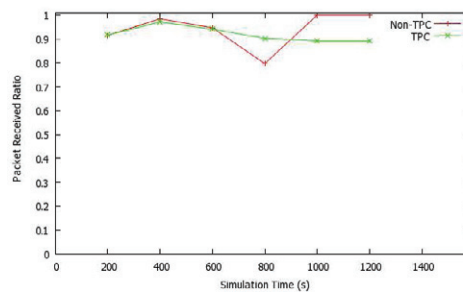| Parameters | Value |
|---|---|
| Simulator | Avrora-Beta 1.7.114 |
| Protocol | AODV |
| Simulation time | 200, 400, 600, 800, 1000, 1200 sec |
| Simulation area | 60 m x 60 m |
| Number of nodes | 9 |
| Mobile nodes | 2, 4, 6 |
| Mobility model | Random Waypoint |
| Pause time | 5 sec |
| Maximum Speed | 1 m/s |
| Packet Rate | 1 packets/sec |
| Data payload | 512 bytes/packet |



Fig. 6: Energy consumption over time



Fig. 7: Percentage of packet loss over time

of simulation time compare to non-TPC. This means that the TPC implementation on AODV is more efficient that the non-TPC. Figure 8 shows packet received ratio over simulation time. Due to the implementation of energy-aware TPC in AODV, it is able to perform better than non-TPC between 600 and 900 simulation time. We found out that when there is reduction in transmission energy consumption, the percentage of packet loss of TPC is also increased as shown in Figure 6 and Figure 7 respectively at simulation time of 800 seconds. It means that the reduction of transmission energy consumption might also increase the percentage of packet loss in MASNETs if the energy-aware TPC technique implemented on AODV routing protocol.

## 7. Conclusion and Future Work

We have experimentally investigated the different effects of TPC technique implementation on AODV routing protocol for MASNET because we believe this technique is useful in reducing energy consumption in this types of networks. Our simulation results show a noticeable effects of TPC implementation technique on MASNETs in respect to energy consumption and percentage of message loss at low node mobility. Although, there is not much reduction in energy consumption of TPC technique on AODV, but it shows that the implementation of TPC algorithm can enhance the performance of AODV in MASNETs. As a conclusion, these results support the use of TPC technique to enhance the performance of multihop AODV routing protocol in MASNETs.

There are several avenues for further studies. We can consider to implement TPC technique on the clustering protocols for MASNETs because they might have different impact on the energy consumption and percentage of packet loss. Moreover, it is also interesting to analyze the impact of TPC technique on different commonly use mobility models like Manhattan and Gauss Markov.

## References

[1] J. G.-H. J. A. P.-D. Carlos F Garca-Hernndez, Pablo H Ibargengoytia-Gonzlez, "Wireless sensor networks and applications: a survey," *International Journal of Computer Science and Network Security (IJCSNS)*, vol. 7, no. 3, pp. 264–273, 2007.

[2] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless sensor networks: a survey," *Computer Networks*, vol. 38, no. 4, pp. 393–422, 2002.

[3] Y. Zou and K. Chakrabarty, "Distributed mobility management for target tracking in mobile sensor networks," *IEEE Trans. Mob. Comput.*, vol. 6, no. 8, pp. 872–887, 2007.

[4] C. Albaladejo, P. Snchez, A. Iborra, F. Soto, J. A. Lpez, and R. Torres, "Wireless sensor networks for oceanographic monitoring: A systematic review," *Sensors*, vol. 10, no. 7, pp. 6948–6968, 2010.

[5] J. N. Al-karaki and A. E. Kamal, "Routing techniques in wireless sensor networks: A survey," *IEEE Wireless Communications*, vol. 11, pp. 6–28, 2004.

[6] M. Jambli, K. Zen, H. Lenando, and A. Tully, "Performance evaluation of aodv routing protocol for mobile wireless sensor network," in *Information Technology in Asia (CITA 11), 2011 7th International Conference on*, pp. 1 –6, july 2011.

[7] L. H. A. Correia, D. F. Macedo, A. L. dos Santos, A. A. F. Loureiro, and J. M. S. Nogueira, "Transmission power control techniques for wireless sensor networks," *Comput. Netw.*, vol. 51, pp. 4765–4779, Dec. 2007.

[8] J. Gomez and A. T. Campbell, "Variable-range transmission power control in wireless ad hoc networks," *IEEE Trans. Mob. Comput.*, vol. 6, no. 1, pp. 87–99, 2007.

[9] M. Krunz, A. Muqattash, S. ju Lee, and H. packard Laboratories, "Transmission power control in wireless ad hoc networks: challenges, solutions, and open issues," *IEEE Network*, vol. 18, pp. 8–14, 2004.

[10] S. Lin, J. Zhang, G. Zhou, L. Gu, J. A. Stankovic, and T. He, "Atpc: adaptive transmission power control for wireless sensor networks," in *Proceedings of the 4th international conference on Embedded networked sensor systems*, SenSys '06, (New York, NY, USA), pp. 223–236, ACM, 2006.

[11] D. Son, B. Krishnamachari, and J. Heidemann, "Experimental study of the effects of transmission power control and blacklisting in wireless sensor networks," in *Sensor and Ad Hoc Communications and Networks, 2004. IEEE SECON 2004. 2004 First Annual IEEE Communications Society Conference on*, pp. 289 – 298, oct. 2004.

[12] "Texas instruments. 2.4 ghz ieee 802.15.4 / zigbee-ready rf transceiver."

[13] K. Srinivasan and P. Levis, "Rssi is under appreciated," in *In Proceedings of the Third Workshop on Embedded Networked Sensors (EmNets*, 2006.

[14] C. Perkins, E. Belding-Royer, and S. Das, "Ad hoc on-demand distance vector (aodv) routing," 2003.

[15] E. M. Belding-Royer and C. E. Perkins, "Evolution and future directions of the ad hoc on-demand distance-vector routing protocol," *Ad Hoc Networks*, vol. 1, no. 1, pp. 125–150, 2003.

[16] B. Titzer, D. K. Lee, and J. Palsberg, "Avrora: scalable sensor network simulation with precise timing," in *IPSN*, pp. 477–482, 2005.

[17] P. Levis, N. Lee, M. Welsh, and D. Culler, "Tossim: accurate and scalable simulation of entire tinyos applications," in *Proceedings of the 1st international conference on Embedded networked sensor systems*, SenSys '03, (New York, NY, USA), pp. 126–137, ACM, 2003.