Interference-aware Geographical Routing for Sensor-nets in Indoor Environments

Junseok Kim and Younggoo Kwon

Department of Electronic Engineering, Konkuk University
1 Hwayang-dong, Kwangjin-Gu, Seoul, 143-701, KOREA
jskim1,ygkwon@konkuk.ac.kr

***Abstract*— In the indoor environments, the geographical routing can perform poorly because it tends to forward messages across the interference (e.g. concrete wall). Nowadays many other 2.4GHz devices (e.g. WLAN or Bluetooth) cause more interferences. Some researchers have proposed the packet-reception-rate (PRR) based geographical routing algorithms [1] [2] [3]. However, these algorithms can incur large overhead and cannot adjust to the interference changes dynamically because they have to send several messages to obtain the PRR. In this paper, we propose an interference-aware geographical routing algorithm for sensor networks (sensor-nets). The proposed algorithm estimates the link qualities fast and energy-efficiently; and selects good-link-quality neighbors accordingly. The proposed algorithm then forwards messages to the node that is closest to the destination among the selected neighbors. The experiment results show that the proposed algorithm achieves higher energy and delivery performances than the previous algorithms.**

I. Introduction

Recently, many location-based sensor-net applications have been developed and widely deployed in large buildings [4]. For examples: guiding people in unfamiliar space such as museum and airport; monitoring patients in hospital for emergency response; and tracking shipments in logistics center. If the location information is available, the geographical routing is more appropriate than the flooding-based routing in large sensor-nets [2] [5]. The Geographical routing requires the location information of sender, sender's neighbors, and destination to deliver messages to a destination. This means that each node only needs to maintain its local topology to deliver packets to any destinations.

The geographical routing uses the greedy forwarding where possible. In the greedy forwarding, sender forwards a packet to its neighbor that is geographically closest to the destination. The local minima may exist where no neighbor is closer to the destination than sender. In that case, greedy forwarding fails and the geographical routing uses the face recovery to escape from the local minima. In the face recovery, a packet is traversed around the perimeter of a face in a planar subgraph of the network. The planar subgraphs need to be constructed by using the Relative Neighborhood Graph (RNG) [6] or the Gabriel Graph (GG) [7] beforehand.

In the indoor environments, the greedy forwarding can perform poorly because it tends to forward a packet across the interference (e.g. concrete wall) [1]. Nowadays many other 2.4GHz devices (e.g. WLAN or Bluetooth) cause more interferences to the sensor-net devices because they use the same ISM-band frequency [8]. Therefore, the geographical routing protocol has to be designed carefully by considering the interferences in the real-world deployments.

In this paper, we propose an interference-aware geographical routing algorithm for sensor-nets. Our design goal is to forward messages reliably in the presence of the interference, especially in the indoor environments. In the proposed algorithm, each node estimates the link qualities fast and energy-efficiently; and selects good-link-quality neighbors accordingly. The proposed algorithm then forwards messages to the node that is closest to the destination among the selected neighbors. We conducted testbed experiments with 27 sensor-net devices in the building. The experiment results show that the proposed algorithm achieves higher delivery and energy performances than the previous algorithms.

II. Related Works

Many researchers have proposed algorithms to improve the performance of the geographical routing in the indoor environments. Seada et al. [9] and Kim et. al. [10] [11] proposed the cross-link-removal algorithms to improve the performance of the face recovery. The face recovery incurs a relatively large overhead than the greedy forwarding. Arad et al. assign the virtual coordinates to the concave (local minima) nodes to increase the efficiency of the greedy forwarding [12]. To maximize the efficiency, Kleinberg assigns virtual coordinates to all nodes in the hyperbolic plane [13]. However, this algorithm cannot adjust to the environmental changes dynamically because the construction of the hyperbolic plane is based on a (non-local) spanning tree [14].

In building, the performance of the greedy forwarding would be degraded due to the obstacles. To resolve this problem, Fonseca et al. assign the virtual coordinates of nodes based on the hop-count from a set of beacon nodes [15]. In [16], nodes forward packets based on the global link cost states and packets carry the link connectivity states. These algorithms can guarantee a reliable delivery, but they have to flood messages frequently to adapt to the environmental changes.

Another approach to improve the delivery performance is the PRR-based greedy forwarding [1] [2] [3]. In these algorithms, sender forwards a packet to its neighbor with the highest $PRR \times ADV$ [1] [2] or the highest $PRR \times ADV / E_{TX}$ [3]. ADV and E_{TX} denote the advance to the destination and

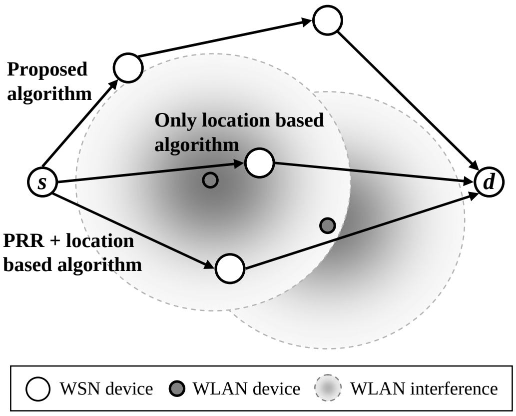


Fig. 1. Comparison of geographical routing algorithms

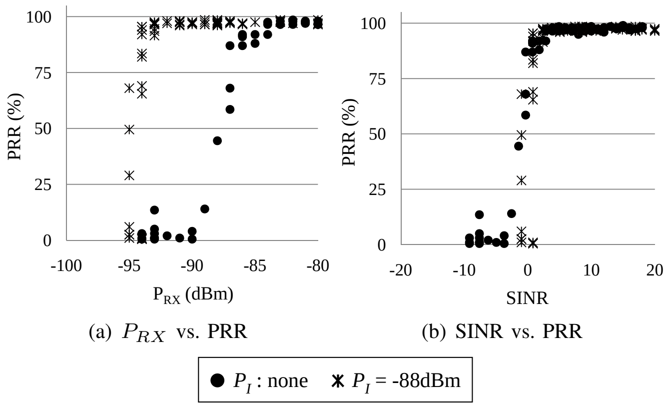


Fig. 2. Correlation of PRR for P_{RX} and SINR under different P_I conditions

the energy consumption for data transmission. To estimate the PRR, they use three methods: sending probe messages; measuring the signal to noise ratio (SNR); or overhearing periodic beacon messages. However, the PRR-based algorithms cannot adapt to the interference changes dynamically because they have to send or overhear several messages to estimate the PRR.

Recently, many other 2.4GHz devices (e.g. WLAN or Bluetooth) cause more interferences to the sensor-net devices because they use the same ISM-band frequency. Experimental studies have shown that the performance of the sensor-nets can be significantly degraded due to the various interferences [17] [18]. Dynamic channel selection can be a solution but the interference varies over time and the all frequency channels could be occupied. The proposed algorithm estimates the link-qualities with considering the interference effect and forwards messages through good-quality-links. Estimating the link-quality, therefore, is important and the main contribution of our work.

III. Interference-aware Link Quality Estimation

In this section, we present a technique to determine the minimum transmit power by considering the effect of the distance, obstacle, and interference. From our experimental results shown in Fig.2(a), the PRR is close to 100% when the received power, P_{RX}, is above a certain threshold. If the received power threshold, P_{RX}^{TH}, is known, the minimum transmit power can be determined as:

$$P_{TX}^{MIN} \quad = \quad PL + P_{RX}^{TH} \tag{1}$$

where PL denotes the path loss and the value is defined as the difference between the transmit power and the received power [19]. Note that the path loss depends on the distance and the obstacles between nodes.

As shown in Fig.2, the received power threshold varies according to the interference power and the PRR is strongly correlated with the signal-to-interference-plus-noise-ratio (SINR). The SINR, ζ, is the power ratio between the desired signal's strength to the undesired signals' strength as:

$$\zeta \quad = \quad 10log\frac{10^{P_{RX}/10}}{10^{P_I/10} + 10^{P_N/10}} \tag{2}$$

where P_I and P_N denote the interference power and the noise power. We rearrange above equation to derive the received power threshold as:

$$P_{RX}^{TH} \quad = \quad 10\log\left(10^{P_I/10}10^{\zeta/10} + 10^{P_N/10}\right) \tag{3}$$

We set the SINR target as 0.4dBm from our previous results [18]. The noise power equals the radio's receive sensitivity that is defined in datasheet [20]. The interference power can be measured by reading the received-signal-strength-indicator (RSSI) register of radio [21].

By using Eq.(1) and (3), the minimum transmission power model is defined as follow:

$$P_{TX}^{MIN} \quad = \quad PL + 10\log\left(10^{P_I/10}10^{\zeta/10} + 10^{P_N/10}\right) \tag{4}$$

We now illustrate the procedure how each node estimates the link-qualities for its neighbors. We assume that the sensor-net uses the synchronized duty-cycle MAC protocol such as IEEE 802.15.4 [20]. Each node measures the interference power (by reading the RSSI register) at the start of each active period and takes an average. To distinguish the signal from sensor-net, we first check the start of frame delimiter (SFD) pin of radio before the measuring. The SFD pin goes high when the radio receives the IEEE 802.15.4 signal [20]. By using Eq.(2), each node then determines its received power threshold.

After that, each node announces the received power threshold by broadcasting a message with the maximum transmission power. We include the transmit power value in packet header to help receiver measure the path loss. When a node received the message, it determines the minimum transmission power by using Eq.(1). In the operation, Each node measures the interference power periodically and adjusts the received power threshold accordingly. When the received power threshold is changed by a certain amount, the node broadcasts the received power threshold again. Note that the minimum transmission power depends the effect of distance, obstacles, and interference and we use this as the link-quality-indicator.

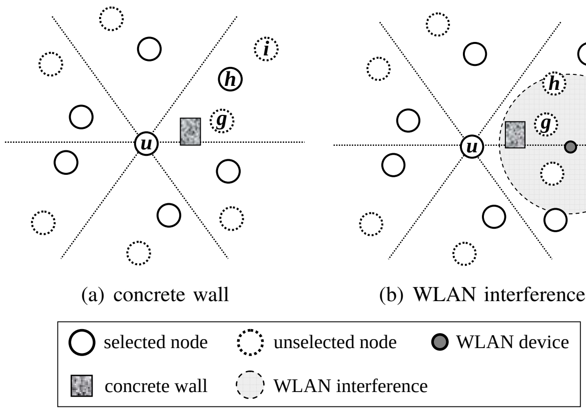


Fig. 3. Neighbor selection examples in the presence of:

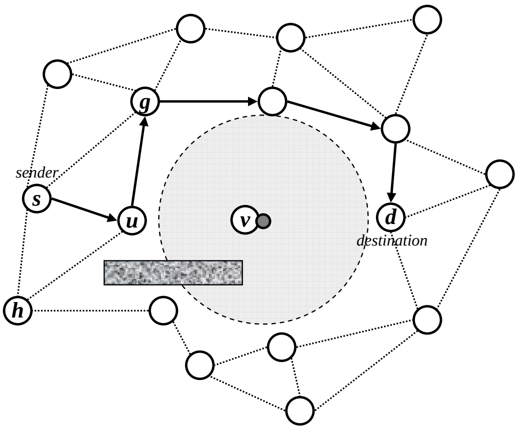


Fig. 4. Proposed geographical routing example

IV. Link Quality Based Geographical Routing

As we stated above, our design goal is to forward messages reliably in the presence of the interference. In the proposed algorithm, each node selects good-link-quality neighbors adaptively according to the interference changes. The proposed algorithm then forwards messages to the node that is closest to the destination among the selected neighbors.

A. *Link-quality-aware Neighbor Selection*

In the initialization phase, as stated above, each node determines the received power threshold and broadcasts it with the location information. When a node u received the message from a node v, it determines the minimum transmission power for node v by using Eq.(1). The node u also calculates the direction ρ to the node v as follows:

$$^{u \to v}\rho \quad = \quad \arctan\left(\frac{Y_v - Y_u}{X_v - X_u}\right) \tag{5}$$

where X_u and Y_u denote the coordinates of the node u. After the node received the messages from all neighbors, it selects a neighbor with the lowest transmission power in every $\pi/3$ cone as shown in Fig. 3. The node then broadcasts its selected neighbor list to remove the uni-directional links. For instance, $link(u, v)$ can be remained, only if both node u and v select each other.

In the operation, as stated above, each node measures the interference power periodically and adjusts the received power threshold accordingly. When the received power threshold is changed by a certain amount, the node broadcasts the received power threshold again. The node's neighbors then repeat the above neighbor selection and uni-directional link elimination if necessary. Note that, a node broadcasts the received power threshold or the selected neighbor list only when the received power threshold or the selected neighbor list is changed.

The proposed neighbor selection is based on the Yao Graph (YG) [22]. In the YG, each node selects the geographically closest neighbor in every cone. Whereas, the proposed algorithm selects neighbors by considering not only distance but also the effect of the obstacle and the interference. For example, in Fig. 3(a), node u selects node h rather than node g because the signal strength from the node g is more attenuated due to the concrete wall. In Fig. 3(b), node u selects node i rather than node h because the node h is heavily affected by the WLAN interference. That is, the proposed algorithm adjusts its local topology adaptively and thus can forward messages reliably in the presence of the interference, especially in building.

B. *Geographical Routing on Selected Neighbors*

In the general greedy forwarding, a sender forwards messages to its neighbor that is geographically closest to the destination among its selected neighbors. As we mentioned before, this general greedy forwarding can perform poorly in the indoor environments, because it tends to forward messages across the interferences [1]. In the proposed algorithm, a sender forwards packets to the node that is closest to the destination among the selected good-link-quality neighbors (except the previous node). Since each node selects its neighbors with considering the interferences, the proposed algorithm can make a detour to avoid the interferences. For example, in Fig. 4, a sender s forwards a packet to the node u that is closest to the destination. The node u encounters the local minima, because the node v can't receive anything due to the WLAN interference. The node u then selects the neighbor among the remain neighbors; except the previous node s. The node u, therefore, forwards the packet to the node g and the packet can bypass the WLAN interference.

When the network is sparse, the proposed algorithm can cause the loop. To prevent the loop, when a packet gets stuck in the local minima, the traversed-node-list are appended to the tail of the packet until the closer node to the destination is found. Figure 5 shows the example. When the node u encounters the local minima, it sets the geographical routing mode as the recovery mode. Then, the node u appends its address to the tail of the packet and forwards the packet to the node h. The packet is forwarded through node $h \to g \to i$ with appending the traversed node list. The node i forwards the packet to the node v, because it can find out that the

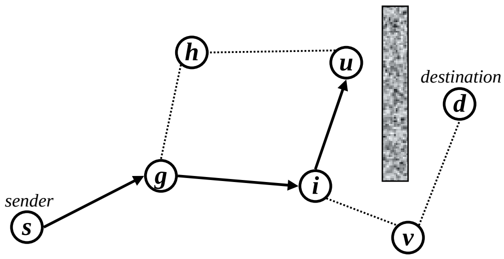


Fig. 5. Recovery operation example

node u had been traversed before. Finally, at the node v, the geographical routing mode returns to the greedy mode and the appended list is erased from the packet. When the node i received another packet destined to the same destination d, it forwards to the node v.

V. Performance Evaluation

We now evaluate the performance of the proposed algorithm and compare it with the GPSR [5] and the JDRPC [3] performance results. We use MTM-CM3000 sensor-net device [23] and N200UA WLAN device [24]. MTM-CM3000 is the clone of TelosB [25] and has CC2420 IEEE 802.15.4 radio and Titanis antenna [26] [27]. N200UA has RT2870 IEEE 802.11 a/b/g/n radio [28]. We place 27 sensor-net and 4 WLAN devices as shown in Fig. 6. In the experiments, the source node transmits 50 byte data packets to the destination node every 10 seconds. In the meanwhile, one WLAN device runs the FTP server and another WLAN device downloads files at random.

Figure 7(a) shows the packet delivery rate (PDR) performance. The GPSR shows the lowest PDR performance because it tries to forward across the concrete walls and WLAN interferences. As we mentioned before, the GPSR forwards packets based only on the geometric information. The JDRPC shows better PDR performance than the GPSR, but the performance is still very low. The reason is that the JDRPC cannot adjust to the WLAN interferences dynamically because it needs to exchange several packets to detect the interference based on the PRR. Another reason is that the JDRPC determines the minimum transmission power based on the distance without considering the interference. (they used the log-normal multi-path fading model and the SNR model) The proposed algorithm shows the highest PDR performance (PRR of each link is 98.5% on the average). The major reason is that the proposed algorithm forwards messages through good-quality-links and thus bypass the WLAN interference.

Figure 7(b) shows the energy consumption (PDR) performances. We use the energy consumption model for sender:

$$E = P_{TX}^{i} \times T_{DATA} + P_{RX} \times (T_{LIFS} + T_{SIFS} + T_{ACK}) \quad (6)$$

and for receiver:

$$E = P_{TX}^{i} \times T_{ACK} + P_{RX} \times (T_{LIFS} + T_{SIFS} + T_{DATA}) \quad (7)$$

where P_{TX}^{i} and P_{RX} denote the power consumption for the transmitting with the transmission power level i and the receiving. T_{DATA}, T_{ACK}, T_{LIFS}, and T_{SIFS} denote the durations of the data packet, the acknowledge packet, the long inter-frame space, and the short inter-frame space respectively [20]. The GPSR shows the lowest energy performance because it has to retransmit several times due to the high packet loss rate. The JDRPC shows better energy performance because its PDR is higher and it saves the energy by using the power control. The proposed algorithm shows the highest energy performance even though it forwards packets through more hops than others. The reason is that the GPSR and the JDRPC consume a lot of energy because of many retransmissions. From the results, we confirm that the proposed algorithm can efficiently mitigate the performance degradation due to the interference effect.

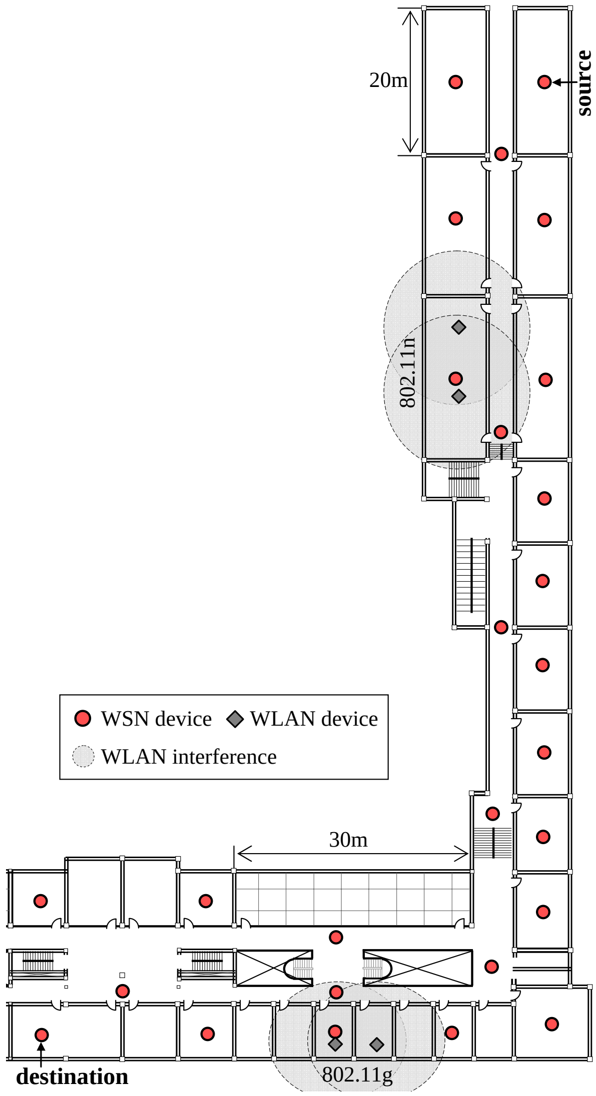
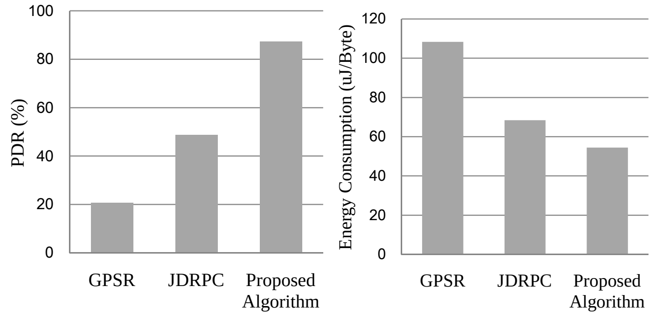


Fig. 6. Experiment scenario

VI. Conclusions

In the indoor environments, the sensor-net may suffer significant performance degradation due to the various interfer-



(a) delivery performance (b) energy performance

Fig. 7. Experimental results

ences. Recently, many WLAN or Bluetooth devices incurs more interferences. This paper proposes an interference-aware geographical routing algorithm. In the proposed algorithm, each node selects its good-link-quality neighbors adaptively with considering the interferences and forwards messages through the good-quality-links. From the experimental results, we observe that the proposed algorithm can provide the high delivery and energy performance simultaneously in the indoor environments.

ACKNOWLEDGMENT

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REFERENCES

[1] K. Seada, M. Zuniga, A. Helmy, and B. Krishnamachari, "Energy-efficient forwarding strategies for geographic routing in lossy wireless sensor networks," in *Proc. SenSys*, Baltimore, MD, USA, Nov. 3–5, 2004, pp. 108–121.
[2] S. Lee, B. Bhattacharjee, and S. Banerjee, "Efficient geographic routing in multihop wireless networks," in *Proc. MobiHoc*, Urbana-Champaign, IL, USA, May 25–27, 2005, pp. 230–241.
[3] C. Li, W. Hsu, B. Krishnamachari, and A. Helmy, "A local metric for geographic routing with power control in wireless networks," in *Proc. SECON*, Santa Clara, CA ,USA, Sept. 26–29, 2005, pp. 229–239.
[4] M. Hazas, J. Scott, and J. Krumm, "Location-aware computing comes of age," *IEEE Computer*, vol. 37, pp. 95–97, Feb. 2004.
[5] B. Karp and H. Kung, "Gpsr: Greedy perimeter stateless routing for wireless networks," in *Proc. MobiCom*, Boston, MA, USA, Aug. 6–11, 2000, pp. 243–254.
[6] G. Toussaint, "The relative neighborhood graph of a finite planar set," *Pattern Recognition*, vol. 12, pp. 261–268, 1980.
[7] K. Gabriel and R. Sokal, "A new statistical approach to geographic variation analysis," *Systematic Zology*, vol. 18, pp. 259–278, 1969.
[8] S. Shin, H. Park, S. Choi, and W. Kwon, "Packet error rate analysis of zigbee under wlan and bluetooth interferences," *IEEE Trans. Wireless Commun.*, vol. 6, pp. 2825–2830, Aug. 2007.
[9] K. Seada, A. Helmy, and R. Govindan, "On the effect of localization errors on geographic face routing in sensor networks," in *Proc. IPSN*, Berkely, CA, USA, Apr. 26–27, 2004, pp. 71–80.
[10] Y. Kim, R. Govindan, B. karp, and S. Shenker, "Geographic routing made practical," in *Proc. NSDI*, Boston, MA, USA, May 2–4, 2005, pp. 217–230.
[11] ——, "Lazy cross-link removal for geographic routing," in *Proc. SenSys*, Boulder, CO, USA, Nov. 1–3, 2006, pp. 112–124.
[12] N. Arad and Y. Shavitt, "Minimizing recovery state in geograhpic ad-hoc routing," in *Proc. MobiHoc*, Florence, Italy, May 22–25, 2006, pp. 13–24.

TABLE I
NETWORK PARAMETER VALUES USED IN EXPERIMENTS

Parameters	Values	Parameters	Values
p	95%	Δ	3dB
k	19		
P_{RX}	59.1mW	P_{TX}	≤52.2mW
T_{LIFS}	0.64ms	T_{SIFS}	0.192ms
T_{DATA}	1.6ms	T_{ACK}	0.32ms

[13] R. Kleinberg, "Geographic routing using hyperbolic space," in *Proc. INFOCOM*, Anchorage, AK ,USA, May 6–12, 2007, pp. 1902–1909.
[14] R. Flury and R. Wattenhofer, "Randomized 3d geographic routing," in *Proc. Infocom*, Phoenix, AZ ,USA, Apr. 13–18, 2008, pp. 834–842.
[15] R. Fonseca, S. Ratnasamy, J. Zhao, C. Ee, D. Culler, and I. Stoica, "Beacon vector routing: Scalable point-to-point routing in wireless sensornets," in *Proc. NSDI*, Boston, MA, USA, May 2–4, 2005.
[16] S. Lee, B. Bhattacharjee, and S. Banerjee, "Blacklist-aided forwarding in static multihop wireless networks," in *Proc. SECON*, Santa Clara, CA, USA, Sept. 26–29, 2005, pp. 252–262.
[17] R. Musaloiu-E and A. Terzis, "Minimizing the effect of wifi interference in 802.15.4 wireless sensor networks," *International Journal of Sensor Networks*, vol. 3, pp. 43–54, 2008.
[18] J. Kim and Y. Kwon, "Interference-aware transmission power control for wireless sensor networks," *IEICE Trans. on Commun.*, vol. E90-B, pp. 3434–3441, Nov. 2008.
[19] T. Rappaport, *Wireless Communications: Principles and Practice*. Upper Saddle, NJ, USA: Prentice Hall, 2002.
[20] *Part 15.4: wireless medium access control (MAC) and physical layer(PHY) specifications for low-rate wireless personal area networks (LR-WPANs)*, IEEE Std. 802.15.4, 2003.
[21] K. Srinivasan, M. Kazandjieva, S. Agarwal, and P. Levis, "The β-factor: improving bimodal wireless network," Stanford University, MA, Tech. Rep. SING-07-01, Feb. 2007.
[22] A. Yao, "On constructing minimum spanning trees in k-dimensional spaces and related problems," *SIAM J. Computing*, vol. 11, pp. 721–736, 1982.
[23] The MAXFOR website. [Online]. Available: http://www.maxfor.co.kr/
[24] The IPTIME website. [Online]. Available: http://www.iptime.co.kr/
[25] *TelosB MOTE PLATFORM*, Crossbow, 2007.
[26] *CC2420 2.4GHz IEEE 802.15.4 / Zigbee RF Transceiver*, Chipcon, 2003.
[27] *Titanis 2.4 GHz Swivel SMA Antenna*, antenova, 2007.
[28] *RT2800 MIMO Wireless Chipset Family*, Ralink, 2007.

VII. APPENDIX

From experiments, we can notice that the signal strength of WLAN device is fluctuated unpredictably. This means that maintaining the minimum transmission power only based on the analytical model is not enough. To alleviate this problem, we give a margin, M, to the transmit power as follow: $P_{TX} = P_{TX}^{MIN} + M$ and we adjust the margin as follows:

- If packet in error: $M+ = \Delta$
- Else: $M- = \Delta/k, M \geq 0$

To maintain a steady margin value, a packet error should be followed by k consecutive success. Hence, k should be $p/(1-p)$ where p is the desired PRR target. We set Δ as 3dB and k as 19 from the results of [18]. Note that we use the margin for preserving the connectivity from the temporal impact of the interference and the margin does not affect to the neighbor selection.