Hybrid Contention-Based Geographic Routing in Wireless Sensor Networks

Thanh Le Dinh
University of Engineering and Technology, VNU-HN
144 Xuan Thuy, Cau Giay,
Hanoi, Vietnam
(+84) 37547611
thanhld@vnu.edu.vn

Dai Tho Nguyen
University of Engineering and Technology, VNU-HN
144 Xuan Thuy, Cau Giay,
Hanoi, Vietnam
(+84) 37547611
nguyendaitho@vnu.edu.vn

Ho Thuan
Institute of Information Technology, VAST
18 Hoang Quoc Viet, Cau Giay
Hanoi, Vietnam
(+84) 37549329
hothuan@vast.ac.vn

ABSTRACT

Beaconless and contention-based geographic routing is an attractive approach to resource-constrained wireless sensor networks. Aggressive contention is the most cost-efficient form of contention-based geographic routing since it uses no control packet. Nevertheless, to avoid duplicated data packets, aggressive contention must set restriction on the contention area. Consequently, its packet delivery rate is limited. On the other hand, non-aggressive contention maximizes packet delivery rate by making use of full contention area. As the compensation, control packets have to be used and additional delay is introduced.

In this paper, we propose Hybrid Contention-Based Geographic Routing (HCGR) - a protocol that takes full aggressive contention and uses non-aggressive contention for recovering aggressive contention from failure. If aggressive contention succeeds, non-aggressive contention is suppressed. In cases where aggressive contention fails, non-aggressive contention is taken place to deliver data packets. Thus, HCGR can maximize packet delivery rate while keeping its overheads reasonably low. We implement HCGR and single-form protocols in the network simulator ns-2, conduct extensive simulations and present simulation results.

Categories and Subject Descriptors

C.2.2 [**Computer-Communication Networks**]: Network Protocols – *Routing protocol.*

General Terms

Algorithms, Design, Performance.

Keywords

Wireless sensor networks, geographic routing, beaconless, contention, aggressive, non-aggressive, hybrid.

1. INTRODUCTION

Geographic routing is typically comprised of greedy forwarding and recovery routing [1-3], which are used alternately. Geographic routing that does not require the prior information on the position of the neighboring nodes, which is proactively maintained by periodic beaconing messages, to forward packets is referred to as beaconless geographic routing. Many beaconless geographic routing protocols have been proposed. These protocols use contention for the selection of next forwarders. We classify these protocols into two classes/forms: *aggressive* [4-7] and *non-aggressive* [8-10]. Aggressive contention is the most cost-efficient form of contention since it uses no control packet. Nevertheless, to avoid duplicated data packets, aggressive contention must set restriction on the contention area. Consequently, its packet delivery rate is limited. On the other hand, non-aggressive contention maximizes packet delivery rate by making use of full contention area. As the compensation, control packets have to be used and additional delay is introduced.

In this paper, we propose Hybrid Contention-Based Geographic Routing (HCGR) - a protocol that takes full aggressive contention and uses non-aggressive contention for recovering aggressive contention from failure. If aggressive contention succeeds, non-aggressive contention is suppressed. In cases where aggressive contention fails, non-aggressive contention is taken place to deliver data packet. Thus, HCGR can maximize packet delivery rate while keeping its overheads reasonably low. We implement HCGR and single-form protocols in the network simulator ns-2 [11], conduct extensive simulations and present simulation results.

Related works are reviewed in Section 2. HCGR is presented in Section 3. Then, a comparative study on the performance of HCGR and single-form protocols via simulation is presented in Section 4. Finally, Section 5 gives our conclusion and future works.

SoICT 2011, October 13-14, 2011, Hanoi, Vietnam.

2. RELATED WORK

For ease of understanding HCGR, we would like to give a briefly review on geographic routing, beaconless and contention-based instance of geographic routing, two forms of contention, i.e. aggressive and non-aggressive, consecutively.

2.1 Geographic routing

Geographic routing is typically comprised of *greedy* forwarding and *recovery* routing [1-3], which are used alternately. In greedy forwarding, the neighbor the closest to the destination and closer to the destination than the current node will be selected as the next forwarder. Greedy forwarding will fail at nodes that have no

neighbor closer to the destination. These nodes are referred to as *local minima*. Recovery routing is used in order to route packets to a node where greedy forwarding can be resumed, i.e. the node closer to the destination than the last local minimum. Many recovery routing strategies have recently been proposed such as face routing [1, 2], boundary detouring [3].

2.2 Beaconless and Contention-based Geographic Routing

Geographic routing protocols in [1-3] require the prior information on the position of the neighboring nodes to forward packets. This prior information is proactively maintained by periodic beaconing messages. These messages reduce bandwidth available for data packets, and more seriously consume much energy of battery-powered nodes, thus reduce the lifetime of nodes.

Addressing the disadvantages of beaconing, many beaconless geographic routing protocols have been proposed. These protocols implement a timer-based *contention* for the selection of next forwarder. In more detail, instead of inactively being selected by the forwarding node, neighbors must take part in a contention whose *winners* will be the next forwarders. Up to date, there are two typical forms of contention which are briefly described as follows.

2.2.1 Aggressive Contention

Aggressive contention is a form of contention described as followed. (1) The forwarding node launches a contention by broadcasting the DATA packet. (2) Upon receiving DATA packet, each neighbor in the *contention area* – a sub-area in the radio range of the forwarding node - sets its own timer to some value dependent on its own position, position of the destination and that of the forwarding node. *Delay functions* are used for computing such values. (3) Neighbors with expired timers become the winners. (4) Those that overhear DATA packet from winners give up the contention.

Taking the same aggressive contention form described above, an aggressive contention-based routing protocol differs from the others only in its contention areas and delay functions [4-6].

The main advantages of aggressive contention include that it has low end-to-end latency. Moreover, no control packet is used, thus energy of nodes and bandwidth are saved. However, disadvantages of this contention form include the limitation on the success rate in choosing the next forwarder and the creation of duplicated data packets. If the contention area is too large, neighboring nodes that do not have lowest delay may not overhear data packet from the first winner and becomes winners too. Therefore, duplicated data packets are resulted. In order to reduce duplicated data packets, the contention area is restricted so that every node in the contention area overhears the data packet retransmitted from the winner and gives up the contention. This, however, reduces the opportunity of choosing the next forwarder, i.e. reduces the delivery success rate. The impact of restricted contention areas on delivery success rate is well studied in [7].

2.2.2 Non-Aggressive Contention

Non-aggressive contention is another form of contention described as follows. (1) The forwarding node launches a contention by broadcasting a REQUEST packet. (2) Upon receiving the REQUEST packet, each neighbor in the contention area sets its own timer to some value defined by some delay function. (3) Neighbors with expired timer broadcast a RESPONSE packet. (4) Those that overhear the RESPONSE packet give up the contention. (5) The forwarding node defines the winner which is the sender of the first RESPONSE packet received by the forwarding node, and broadcasts a SELECTION packet to announce the winner. In this form of contention, either REQUEST packet or SELECTION packet contains content which is being delivered.

Again, taking the same non-aggressive contention form described above, a non-aggressive contention-based routing protocol differs from the others only in its contention areas and delay functions [8-10].

Unlike aggressive contention, non-aggressive contention does not result in duplicated data packets. However, control packets are used and additional delay is introduced.

3. HYBRID CONTENTION-BASED GEOGRAPHIC ROUTING

Data packets are forwarded in two different modes: greedy and recovery. Information on the position of the destination and three previous nodes, as well as that of the last local minimum, is recorded in the header of data packets. Each data packet is generated with a greedy mode, set to recovery mode if a local minimum is reached, and set to greedy mode again at node that is closer to the destination than the last local minimum.

The key idea in HCGR is that two forms of contention, i.e. aggressive and non-aggressive, are used and that non-aggressive contention is treated as the backup routing protocol for the failure of aggressive contention so that HCGR can maximize packet delivery rate while keeping its overheads reasonably low. Aggressive contention suppresses non-aggressive contention. If aggressive contention fails, non-aggressive contention is unsuppressed and forwards the packet in place of aggressive contention. Contention area is divided in two sub-areas: Aggressive Area (AA) and Non-aggressive Area (NA). Nodes in AA sub-area follow aggressive contention while nodes in NA sub-area follow non-aggressive contention. We will describe our proposed contention areas, delay functions and the behavior of nodes taking part in hybrid contention, consecutively.

3.1 Contention Area and Delay Function

Assume that nodes have two common parameters: r is the radio range of nodes and T_{max} is a parameter used by delay functions. If the data packet is in greedy mode, the contention area is the region containing points in the transmission range of the forwarding node and closer to the destination than the forwarding node. The AA sub-area is the 60^o sector from the forwarding node towards the destination with a radius of r. The NA sub-area is the remaining regions of the contention area. These areas are visualized in Figure 1.

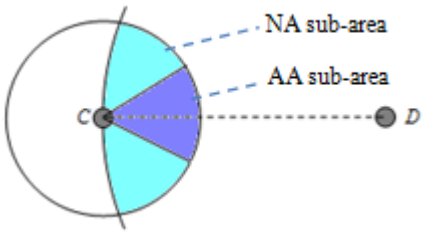

Figure 1. Contention areas in greedy mode

Contention timers for greedy data packets are set to

$$gct = \left(\frac{\theta + \frac{r-p}{r}}{360}\right) T_{max} \quad (1)$$

where θ is the angle $\widehat{OCD}$ where *C, D, O* are the forwarding node, the destination and the owner of the timer, respectively; and $p = |CD| - |OD|$ where $|MN|$ denotes the distance from node *M* to node *N*. Note from the equation (1) that the closer angle to the destination a neighbor is on, the shorter delay its timer is set. Thus, no node in NA sub-area has shorter delay than that of any node in AA sub-area. Such important property of delay function (1) ensures that no node in NA sub-area replies before nodes in AA sub-area. Thus, aggressive contention suppresses non-aggressive contention. In cases where aggressive contention fails, non-aggressive contention is unsuppressed and forwards the packet in place of aggressive contention. We also learn from the delay function (1) that among nodes on the same angle to the destination, the node closest to the destination has the shortest delay.

The contention area and delay function for recovery mode is described as follows. Let *C* be the forwarding node, *P* and *Q* are two previous nodes whose position is charged in the header of the DATA packet. Without loss of generality, we assume that *Q* is on the left of $\overrightarrow{CP}$, the contention areas are visualized in Figure 2. Let (*C, r*) be the circle centering at *C* and having radian of *r*. Let *I* be the crossing point of two circle (*C, r*) and (*P, r*), which is on the right of $\overrightarrow{CP}$. The AA sub-area is the 60° sector $\widehat{ICJ}$, which contains an empty area, where *J* is on the right of $\overrightarrow{CI}$. The NA sub-area is the remaining area in the transmission range of *C*.

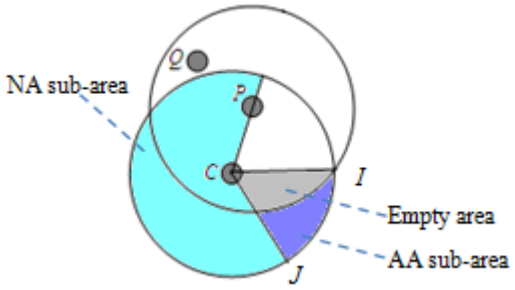

Figure 2. Contention areas in recovery mode

Contention timers for recovery data packets are set to

$$rct = \left(\frac{\sigma}{360}\right) T_{max} \quad (2)$$

where σ is the angle comprised of $\overrightarrow{CI}$ and the vector from *C* to the owner of the timer.

Note from the equation (2) that no node in NA sub-area has shorter delay than that of any node in AA sub-area. Thus, as in greedy mode, non-aggressive contention is suppressed and plays the role of backup protocol for the failure of aggressive contention. Note also that 60° sector is the largest sector in which each node can hear from the others, thus aggressive contention can avoid duplicated packets.

3.2 The Protocol

The forwarding node broadcasts the DATA packet then stores a copy of the DATA packet and sets a *monitoring timer* for that packet to T_{max}. If the DATA packet is in recovery mode and the forwarding node is closer to the destination than the last local minimum, the forwarding node set the packet to greedy mode before broadcasting it. During the monitoring period, if a DATA packet or a RESPONSE packet is returned, the forwarding node stops its monitoring timer, drops the stored DATA packet, broadcasts a SELECTION packet (in case the RESPONSE packet is returned first) whose next forwarder field is set to the identifier of the sender of the RESPONSE packet, and discards the returned packet. On the other hand, after monitoring period, if no DATA packet and no RESPONSE packet are returned, the forwarding node acts dependently on the mode of the stored DATA packet. That is, if the stored DATA packet is in recovery mode, the forwarding node simply drops the packet; otherwise, the forwarding node records its position in the header of the DATA packet as the last local minimum then set the DATA packet to recovery mode and repeats above procedure.

Upon receiving the DATA packet, each neighbor that is not in the contention area simply drops the packet; each in contention area stores the packet and sets a *contention timer* for that packet to *gct* if the DATA packet is in greedy mode or to *rct* if the DATA packet is in RECOVERY mode. When its contention timer expires, a neighbor in AA sub-area rebroadcasts the DATA packet, i.e. it becomes the next forwarder. On the other hand, when its timer expires, a neighbor in NA sub-area broadcasts a RESPONSE packet. Other neighbors that overhear the DATA or RESPONSE packet from winning neighbor stop its contention timer and drop the stored DATA packet. After broadcasting a RESPONSE packet, the neighbor sets a *waiting timer* for this packet to T_{max}. When the waiting timer expires, i.e. no SELECTION packet is received, the neighbor drops the DATA packet.

Upon receiving SELECTION packet, each neighbor stops its (non-expired) contention timer and its waiting timer (if any), rebroadcasts the DATA packet if it is selected as the next forwarder or drops the DATA packet, otherwise.

If the destination receives the DATA packet, it broadcasts a FINISH packet immediately. On the receipt of the FINISH packet, the forwarding node stops its monitoring timer, drops the DATA packet; neighboring nodes stop its contention timers and drop the stored DATA packet.

A formal description of HCGR is given in Figure 3 while the structure of packets used in HCGR is given in Table 1.

Table 1. Packet Header (Contention Related Fields)

Field	Description
cid	Identifier of contention, which may be the combination of the identifier of the node that launches the contention and a sequence number generated by that node.
launcher	Identifier of the node that launches the contention
type	Packet type, whose value is DATA, RESPONSE, SELECTION or FINISH
mode	Forwarding mode, whose value is GREEDY or RECOVERY.
resp	*cid* of another DATA packet that is being delayed.
sel	Identifier of node being selected as the next relay node
$prev_{0,1,2}$	Previous nodes traveled by the DATA packet
lastlm	Last local minimum traveled by the DATA packet

```
---------------------------------------------------------------------------------------------
Upon receiving a DATA packet p from N:
    If p is a fresh data packet received from the upper network layer then
        Set p.mode = GREEDY, p.resp = NULL,  p.prev0 = myself, p.prev1 = myself, p.prev2 = myself
        Record position of the destination to the header of p
        Call LaunchContention(p)
    Else
        Let cp be the cached DATA packet whose cid is p.resp
        If cp <> NULL then
            If I am the launcher of the contention p.resp then stop the monitoring timer for cp, else stop the contention timer for cp
            Remove cp from my cache
        If I am the destination of p then
            Broadcast a FINISH packet
            Send p to the upper network layer
        Else
            If am not in the contention area of N then discard p
            Else
                Set the contention timer for p to the value computed by (1) and (2)
                Store p in my cache
Upon receiving a RESPONSE packet p from N:
    Let cp be the cached DATA packet whose cid is p.resp
    If cp <> NULL then
        If I am the launcher of the contention p.resp then
            Stop the monitoring timer for cp
            Remove cp from my cache
            Broadcast a SELECTION packet sp which defines N as the next relay node, i.e. sp.sel is set to the identifier of N
        Else
            If the contention timer for cp has not been expired yet then
                Stop the contention timer for cp
                Remove cp from my cache
    Discard p
Upon receiving a SELECTION packet p:
    Let cp be the cached DATA packet whose cid is p.resp
    If cp <> NULL then
        Stop the contention timer for cp
        Stop the waiting timer for cp (if any)
        If I am selected as the next forwarder, i.e. p.sel is my identifier, then
            Call LaunchContention(cp)
        Remove cp from my cache
    Discard p
Upon receiving a FINISH packet p:
    Let cp be the cached DATA packet whose cid is p.resp
    If cp <> NULL then
        If I am the launcher of the contention p.resp then stop the monitoring timer for cp
        Else stop the contention timer for cp
    Remove cp from my cache
    Discard p
Upon monitoring timer for p being expired:
    If p.mode = GREEDY then
        Set p.mode = RECOVERY, p.lastlm = myself
        Call LaunchContention(p)
    Else, p.mode = RECOVERY
        Remove p from my cache
Upon contention timer for p being expired:
    If I am in the AA contention area of p.launcher then
        Set p.resp = p.cid
        Call LaunchContention(p)
    Else, I am in the NA contention area of p.launcher
        Generate a new RESPONSE packet rp
        Set rp.resp = p.cid
        Broadcast rp
        Set a waiting timer for p to Tmax
Upon waiting timer for p being expired:
    Drop p from my cache

LaunchContention(p):
    If p.mode = RECOVERY and I am closer to the destination than p.lastlm then set p.mode = GREEDY
    Set p.launcher = my identifier
    Generate a unique value for p.cid
    Set p.prev2 = p.prev1, p.prev1 = p.prev0, p.prev0 = myself
    Broadcasts p
    Store p in my cache
    Set the monitoring timer for p to Tmax
---------------------------------------------------------------------------------------------
```

Figure 3. The HCGR, code for node C.

4. SIMULATION

HCGR can be regarded as a scheme. It can take any aggressive contention such as ones in [4-6] followed by a non-aggressive contention such as ones in [8-10]. Our simulation goal is to gain a comparative evaluation on the performance of aggressive contention, non-aggressive contention and the combination of these two. HCGR can be regarded as the combination of ACGR and NCGR, where ACGR is the purely aggressive contention-based protocol with the same contention area and delay function as that of HCGR and NCGR is the purely non-aggressive contention-based protocol that uses non-aggressive contention on the whole contention area with the same delay function as that of HCGR. ACGR and protocols in [4-6] belong to aggressive family, one is slightly different from the others in delay functions. Similarly, NCGR and protocols in [8-10] belong to non-aggressive family, one is slightly different from the others in delay functions. To this end, ACGR and NCGR are adequately considered as the representatives of aggressive and non-aggressive contention, respectively.

We implement HCGR, ACGR and NCGR in the open-source network simulator ns-2 [11]. Then, extensive simulations are performed. We use four performance metrics: packet delivery rate, communication overhead, the number of duplicated data packets, and the average end-to-end delay. In order to meet our simulation goal, we use scenes varying in node density. The sensor field is the rectangle of the size 3750 x 600 m^2. Nodes have the radio range of 250 m. Each simulation lasts for 900 simulated seconds and uses 20 CBR traffic flows sending 64-byte packets at the rate of 2 Kbps. Each set of simulations (specified by a node density) contains six simulations. We use the mean of each metric over these set of simulations. Simulation results are described as follows.

4.1 Packet Delivery Rate

Figure 4 shows the packet delivery success rate of simulated protocols. Simulation results show that HCGR has the same packet delivery rate as NCGR, the packet delivery rate of ACGR is lower than and decreases faster than that of HCGR and NCGR when node density decreases. This is caused by the fact that ACGR uses only the AA sub-area while HCGR and NCGR use the whole contention area.

4.2 Communication Overhead

The simulation results shown in Figure 5 confirm that HCGR has lower overhead than NCGR. Recall that ACGR, the purely aggressive contention-based protocol, does not use control packets.

4.3 Average End-to-End Delay

From the simulation results shown in Figure 6 we learn that the end-to-end delay of HCGR converges to that of ACGR when the node density is high enough. The higher the node density is, the fewer holes are present, thus the less probability aggressive contention fails.

4.4 Duplicated Data Packet

The simulation results shown in Figure 7 indicate that HCGR and ACGR generate the same number of duplicated data packets. This is caused by the fact that non-aggressive contention, by its nature, does not result in duplicated data packets.

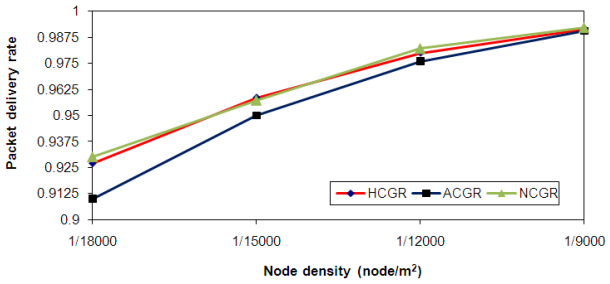

Figure 4. Packet delivery rate of HCGR, ACGR and NCGR.

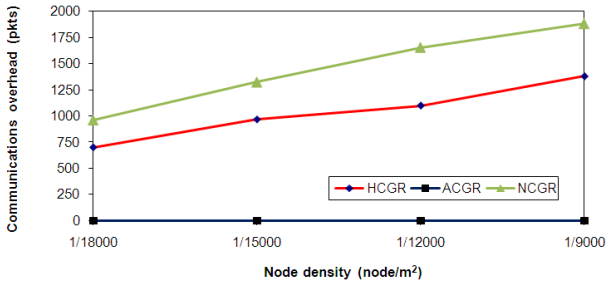

Figure 5. Communication overhead of HCGR, ACGR and NCGR.

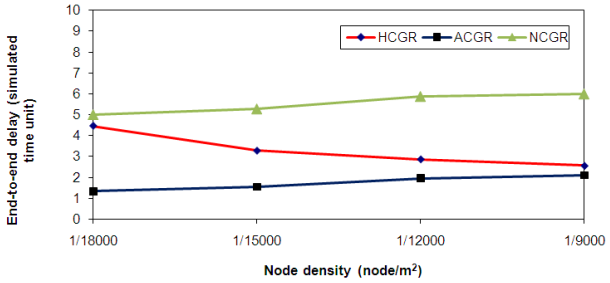

Figure 6. Average end-to-end delay of HCGR, ACGR and NCGR.

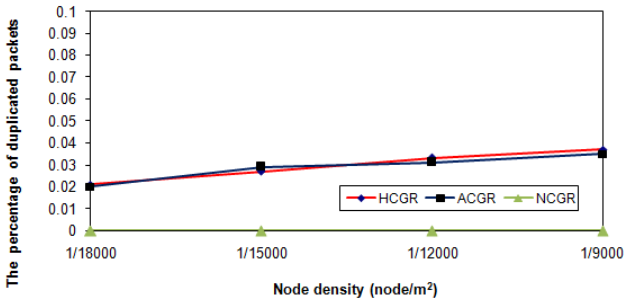

Figure 7. The percentage of duplicated data packets generated by HCGR, ACGR and NCGR.

We summarize our comparative study on the performance of HCGR, ACGR and NCGR via simulation by ranking these protocols using four above metrics. The ranking results are given in Table 2. Recall that HCGR introduces communication overhead and additional delay in comparison to that of ACGR in cases where aggressive-contention, i.e. ACGR, fails. Thus, these communication overhead and additional overhead can be regarded as the cost for recovering ACGR from failure.

Table 2. Protocol Ranking

Protocol	Packet delivery rate	Communication overhead	Average end-to-end delay	Duplicated data packets
ACGR	2	1	1	2
NCGR	1	3	3	1
HCGR	1	2	2	2

5. CONCLUSION

We have introduced HCGR, a protocol that takes full aggressive contention and uses non-aggressive contention for recovering aggressive contention from failure. If aggressive contention succeeds, non-aggressive contention is suppressed. If aggressive contention fails, non-aggressive contention is taken place in data packet forwarding. In the future, we intend design new contention areas and delay functions, evaluate the performance of HCGR with these contention areas and delay functions, and propose the best contention areas and delay functions for HCGR.

6. ACKNOWLEDGMENTS

This work was supported by the University of Engineering and Technology under the contract number CN.11.09 and partially supported by TRIG-B project currently conducted at the University of Engineering and Technology, VNU-HN.

7. REFERENCES

[1] Karp, B. and Kung, H.T. 2000. GPSR: Greedy perimeter stateless routing for wireless sensor networks. In *Proceedings of the MOBICOM* (New York, NY, USA, 2000). 243-254.

[2] Bose, P., Morin, P., Stojmenovic, I. and Urrutia, J. 2001. Routing with guaranteed delivery in ad hoc wireless networks. *Wireless Networks*. 7, 6 (Springer, Netherlands, 2001), 609-616.

[3] Fang, Q., Gao, J., Guibas, L. 2006. Locating and bypassing routing holes in sensor networks. *Mob. Net. App.* 11, 2 (Springer, Netherlands, 2006), 187-200.

[4] Heissenbüttel, M., Braun, T. 2003. A novel position-based and beacon-less routing algorithm for mobile ad-hoc networks. In *Proc. of the 3rd IEEE Work. App. Serv. in Wireless Net*. (Berne, Switzerland, July 2003), 197-209.

[5] Amadou, I. and Valois, F. 2010. Pizza forwarding: A beaconless routing protocol designed for realistic radio assumptions. In *Proc. 4th Int'l Conf. on Sensor Tech. and App*. (Venice/Mestre, Italy, July 18-25, 2010), 495-500.

[6] Witt, M. and Turau, V. 2005. BGR: Blind geographic routing for sensor networks. In *Proc. 3rd Int'l. Work. Intel. Solutions in Embedded Systems* (Hamburg, Germany, May 2005), 51-61.

[7] Chen, D., Deng, J., and Varshney P. K. 2007. Selection of a forwarding area for contention-based geographic forwarding in wireless multi-hop networks. *IEEE Trans. On Vehicular Tech*. 56, 5 (Nov. 2007), 3111-3122.

[8] Sanchez, J. A., Marin-Perez, R., and Ruiz, P. M. 2007. BOSS: Beacon-less on demand strategy for geographic routing in wireless sensor networks. In *Proc. of 4th IEEE MASS* (Pisa, Italy, 8-11 October 2007), 1-10.

[9] Watanabe, M. and Higaki, H. 2007. No-beacon GEDIR: Location-based ad-hoc routing with less communication overhead. In *Proc. of the Int'l Conf. on Information Technology* (Las Vegas, Nevada, USA, 02-04 April 2007), 48-55.

[10] Kalosha, H., Nayak, A., Rührup, S. and Stojmenovic, I. 2008. Select-and-protest-based beaconless georouting with guaranteed delivery in wireless sensor networks. In *Proc. 27th IEEE Int'l Conf. on Computer Comm., Joint INFOCOM'08* (Phoenix, AZ, USA, 2008), 346-350.

[11] The Network Simulator ns-2, http://www.isi.edu/nsnam.