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Performance of Termite-hill Routing Algorithm on Sink Mobility in Wireless Sensor Networks

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Abstract. High efficient and energy-aware routing is an important issue for the design of resource constrained environments like Wireless Sensor Networks (WSNs). Many protocols have been developed for WSN that try to overcome the constraints that characterized this type of networks. Termite based routing protocols can add a significant contribution to assist in the maximization of the network lifetime without performance degradation. But this is only possible by means of an adaptable and balanced algorithm that takes into account the main constraints of WSN. This paper presents a biological inspired self-organized routing protocol for WSN which is based on termite colony optimization metaheuristic termed Termite-hill. The main objective of the proposed algorithm is to efficiently relay all the traffic destined for the sink, and also balance the network energy. The results of our extensive experiments on Routing Modeling Application Simulation Environment (RMASE) demonstrated that with sink mobility, our proposed routing algorithm was able to balance the network traffic load and prolong the network lifetime without performance degradation.

Keywords: Swarm Intelligence, Wireless Sensor Networks, Energy Efficiency, Termite-hill, Network Lifetime, Network Throughput, Routing Algorithm.

1 Introduction

Wireless Sensor Networks (WSNs) are collections of compact-size, relatively inexpensive computational nodes that measure local environmental conditions, or other parameters and forward such information to a central point for appropriate processing. Many applications of sensor networks deals with the static nature of nodes which in most cases sense their environment and then send the measured values to a central base station through hop-to-hop (multi-hop) routing, hence leading to rapid exhaustion of energy around the sink (base station). The issue is that, sensor nodes around the sink tend to deplete faster in energy than those farther away. This is mainly because, besides forwarding their own traffic, they forward traffic on behalf of other sensors nodes that are located farther away from the sink node. Hence, the lifetime of sensor network can be improved upon if the energy spent in traffic relaying to the sink is reduced.

Social insect communities have many desirable properties from the WSN perspective as surveyed in [1, 2]. These communities are formed from simple, autonomous, and cooperative organisms that are interdependent for their survival. Such systems may be composed of simple nodes working together to deliver messages, while resilient against changes in its environment. The environment of sensor network might include anything from its own topology to physical layer effects on the communications links, to traffic patterns across the network. A noted difference between biological and engineered networks is that the former have an evolutionary incentive to cooperate, while engineered networks may require alternative solutions to force nodes to cooperate. Research on the field of swarm intelligence has been focused on working principles of ant colonies as adopted in [3], and honey bees [4]. To the best of our knowledge, little attention has been paid in utilizing the organization and behavioral principles of other swarms such as termites to solve real world problems. The study of termite behavior has revealed remarkable achievements in the communication capabilities as compared to ants and honey bees as adopted in [5]. To this end, we proposed an on-demand and probabilistic routing algorithm termed Termite-hill. In this algorithm, termite agents were modeled to suit the energy resource constraints in WSNs for the purpose of improving the network lifetime, by extensively borrowing from the principles behind the termite communication.

The rest of the paper is organized as follows. Section 2 gives an overview of related work. In Section 3 we describe our proposed algorithm. Section 4 discusses the experimental environment and results. Section 5 concludes the paper with comments for future work.

2 Related Work

The idea of using the swarm paradigm to establish routes in communication networks is not new. In [3], an ant-based algorithm was adopted to calculate the optimal paths among the nodes through an architecture called AntNet. Small agents, the virtual ants, migrate from a node to another, building the routing rules in a distributed way.

In Sensor driven and Cost-aware ant routing (SC) [6], it is assumed that ants have sensors so that they can smell where there is food at the beginning of the routing process so as to increase in sensing the best direction that the ant will go initially. In addition to the sensing ability, each node stores the probability distribution and the estimates of the cost of destination from each of its neighbors. Though, the protocol suffers from misleading when there is an obstacle which might cause errors in sensing. In their extended work, Flooded Forward ant routing (FF) [6] argues the fact that ants even augmented with sensors, can be misguided due to the obstacles or moving destinations. The protocol is based on flooding of ants from source node to the sink node. In the case where destination is not known at the beginning by the ants, or cost cannot be estimated, the protocol simply use the broadcast method of sensor networks so as to route packets to the destination.

Ad-hoc On-demand Distance Vector (AODV) [7] is a popular classical routing protocol for mobile ad-hoc networks. AODV discovers routes only when required. When a node has some data to send to a destination and it does not have the valid routing table entry, it generates a Route Request (RREQ) packet and broadcasts it to all its neighbors. When the destination node receives an RREQ packet, it generates an RREP which is unicast back to the source node. On reception of an RREP packet, each intermediate node updates its routing table to set up a forward pointer and relays the RREP message to the next hop using the reverse pointer. But in AODV, it is assumed that all nodes are mobile, in our scenario the sensor node is not a mobile node, only the sink node can be mobile when the need arise. Furthermore, our focus is on the routing packets problem, while in their work the authors focus on the optimal movement of mobile sensors.

Besides all the drawback of each of the related protocols, almost all the algorithms tends to scarifies the network performance as against the improvement of energy consumption of the nodes, and vice-versa for others. They do not consider the energy available on each path for update of routing table and also the limited memory of sensor nodes in their algorithms.

3 The Termite-hill Routing Algorithm

Termite-hill is a routing algorithm for wireless sensor networks that is inspired by the termite behaviors. The principles of swarm intelligence are used to define rules for each packet to follow which results in an emergent routing behavior. The algorithm has better performance due to reduction of control traffic, quick route discovery and repair, utilization of energy as a criterion for route selection, and reduction of memory usage along with other additional benefits. Analogous to the termite ad-hoc networking [5], each node serves as router and source, and the hill is a specialized node called sink which can be one or more depending on the network size. As in the termite hill building example, packets are biased towards strong pheromone path but the selection of next hop is always randomly decided. To prevent old routing solutions from remaining in the collective network memory, exponential pheromone decay is introduced as negative feedback. Pheromone increases linearly per packet, but decreases exponentially over time.

Termite-hill discovers routes only when they are required. When a node has some events or data to be relayed to a sink node and it does not have the valid routing table entry, it generates a *forward soldier* and broadcasts it to all its neighbors. When an intermediate node receives this *forward soldier,* it searches its local routing table for a valid route to the requested destination. If the search is successful, the receiving node (sink) then generates a *backward soldier* packet, which is then sent as a unicast message back to the source node where the original request was originated using the reverse links. If the node has no valid route to the destination, it re-broadcasts the *forward soldier* packet. On reception of the backward *soldier* packet, each intermediate node updates its routing table to set up a forward pointer and relays the *backward soldier* message to the next hop using the reverse pointer. The process continues till the *backward soldier* is received by the original source node. For Termite-hill algorithm for wireless sensor networks, *HELLO* packets are not used to detect link failures. Rather it uses feedback from the link layer (MAC) to achieve the same objective. Intermediate nodes do not generate reply (*backward soldier*) even if they have a valid route which avoids the overhead of multiple replies. As such the termite-hill is designed to function in three modules. In the course of the algorithm design, the following assumptions were also made: 1. each node is linked to one or more nodes in the network (neighbors), 2. A node may act as a source, a destination, or a router for a communication between different pair of nodes, 3. Neither network configuration nor adjacency information is known before hand, and 4. The same amount of power is required for sending a message between any pair of adjacent nodes throughout the network.

3.1 The Pheromone Table

The pheromone table keeps the information gathered by the forward soldier. Each node maintains a table keeping the amount of pheromone on each neighbor path. The node has a distinct pheromone scent, and the table is in the form of a matrix with destination nodes listed along the side and neighbor nodes listed across the top. Rows correspond to destinations and columns to neighbors. An entry in the pheromone table is referenced by $T_{n,d}$ where n is the neighbor index and d denotes the destination index. The values in the pheromone table are used to calculate the selecting probabilities of each neighbor.

When a packet arrives at a node, the pheromone for the source of the packet is incremented by γ, where γ is the reward. Equation (1) describes the pheromone update procedure when a packet from source s is delivered from previous hop r. A prime indicates the updated value.

$$T'_{r,s} = T_{r,s} + \gamma \tag{1}$$

and
$$\gamma = \frac{N}{E - \left(\frac{E_{min} - N_j}{E_{av} - N_j}\right)} \tag{2}$$

Where E is the initial energy of the nodes, E_{min}, E_{av} are the minimum and average energy respectively of the path traversed by the forward soldier as it moves towards the hill, N_j represent the number of nodes that the forward soldier has visited, and N is the total number of network nodes.

Pheromone is evaporated so as to build a good solution in the network. Each value in the pheromone table is periodically multiplied by the evaporation factor $e^{-\rho}$. The evaporation rate is $\rho \geq 0$. A high evaporation rate will quickly reduce the amount of remaining pheromone, while a low value will degrade the pheromone slowly. The nominal pheromone evaporation interval is one second; this is called the decay period. Equation (3) describes the pheromone decay.

$$T'_{n,d} = T'_{n,d} * e^{-\rho} \tag{3}$$

Though for robustness and flexibility some application needs a slow decay rate. Hence to account for the pheromone decay each value in the pheromone table is periodically subtracted by percentage of the original value as shown in equation (4).

$$T'_{n,d} = (1 - x)T'_{n,d} \tag{4}$$

Where, $0 \leq x \leq 1$

If all of the pheromone for a particular node decays, then the corresponding row and/or column are removed from the pheromone table. Removal of an entry from the pheromone table indicates that no packet has been received from that node for quite some time. If a neighbor is determined to be lost by means of communications failure (the neighbor has left communications range), the neighbor row is simply removed from the pheromone table.

3.2 Route Selection

Each of the routing tables of the nodes is initialized with a uniform probability distribution given as;

$$P_{s,d} = \frac{1}{N} \tag{5}$$

Where $P_{s,d}$ is the probability of jumping from node *s* to node *d* (destination), N the number of nodes in the network. Upon arrival at a node *s*, an incoming packet with destination *d* is routed randomly based on the amount of *d's* pheromone present on the neighbor links of *s*. A packet is never forwarded to the same neighbor from whom it was received, *the previous node*. If *s* has only one neighbor, i.e. the node that the packet was just received from, the packet is dropped. The equation below details the transformation of pheromone for *d* on link s $T_{s,d}$ into the probability $P_{s,d}$ that the packet will be forwarded to *d*.

$$P_{s,d} = \frac{(T_{s,d} + \alpha)^{\beta}}{\sum_{i=1}^{N}(T_{i,d} + \alpha)^{\beta}} \tag{6}$$

The parameters α and β are used to fine tune the routing behavior of Termite-hill. The value of α determines the sensitivity of the probability calculations to small amounts of pheromone, $\alpha \geq 0$ and the real value of α is zero. Similarly, $0 \leq \beta \leq 2$ is used to modulate the differences between pheromone amounts, and the real value of β is two. But for each of the *N* entries in the node *k* routing table, it will be n_k values of $P_{s,d}$ subject to the condition:

$$\sum_{s \in N_k} P_{s,d} = 1; \;\; d = 1, \dots, N \tag{7}$$

3.3 Termite-hill Agent Model

Termite-hill works with three types of agents: reproductive, soldiers and workers.

Reproductive*:* In termite colonies, the male reproductive "*king*" and the female reproductive "*queen*" are the primary source of pheromones useful in colony integration, and these are thought to be spread through shared feeding. Analogous to that, the *queen* receives data packets from an application layer and locates an appropriate *worker* for them at the source node. Once a *worker* is found, a packet is encapsulated in its payload and the *queen* starts waiting for the next packet. Failure to locate an appropriate *worker* is an indication to the *queen* that no route exists for the sink. At the sink node, the *king* recovers data from the payload of workers and provides it to the application layer.

Soldiers: Soldiers in Termite-hills are classified as forward soldiers and backward soldiers depending upon the direction in which they travel. A source node that detects an event launches a forward soldier when it does not have a route to a sink node. A forward soldier is propagated using the broadcasting principle to all neighbors of a node. Soldiers have a fixed size that is independent of the path length (number of hops) between the source and a sink node. As adopted in [8], the memory M_k of each soldier is reduced to just two records; the last two visited nodes.

Workers: In Termite-hills, workers undertake the labors of foraging. Analogous to the workers behavior in real termite organization whereby the workers feed the other members of the colony with substances derived from the digestion of plant material, either from the mouth or anus, they transport data packets from a source node to the sink node. They receive data packets from queen at a source node and deliver them to the king at the sink node.

3.4 The Termite-hill Modules Design

The algorithm is designed to function as three main modules**:** *route discovery, seed, and data*. The first two modules are control messages. The data packets are used for sending data or events to the other nodes, and the control packets are mainly used for the maintenance of the route as well as increasing the pheromone concentration of the link. Each packet type contains at least six fields including message *identification, source address*, *destination address*, *previous hop address*, *next hop address*, and *Time-To-Live (TTL)*. The previous hop address and next hop address fields may be removed from the packet and the information instead extracted from the MAC header which encapsulates the routing data. The message identification field allows each packet in the network to be uniquely identifiable to enable loop detection as well as allowing the nodes to operate in a limited promiscuous mode. Due to page limitation, we are not able to explain in detail each of the modules and their operations.

4 Experimental and Simulation Results

We use the Routing Modeling Application Simulation Environment (RMASE) which is a framework implemented as an application in the Probabilistic Wireless Network Simulator (PROWLER) [9]. We evaluated all the protocols using the metrics defined below. In our experiment, the network consists of nine sensor nodes with small random offsets. We use the default settings of prowler, and Ant ratio is set to 2, source rate set to 4, c1=0.7, z=1, data gain=1.2, reward scale=0.3, ant table size=400, energy level of nodes = 30 Joules each, BSoldier_Delay=20000, FSoldier_Timeout=28000, FSoldier_Delay=4000, Termite_RTable_Size=10, Termite_Ftable_Size=10, BSoldier_Retries=3. Each experiment was performed for duration of 100 seconds. The experiment was conducted for three scenarios; static, dynamic, and sink mobility.

From several results obtained from our simulation results, we report the following performance metrics for clarity purpose.

Throughput: It is the average rate of successful packets delivered over the network. It is measured in data packets per second.

The Average Energy: It represents the average of energy of all nodes at the end of the experiment. We reported it in percentage (%).

Energy Utilization Efficiency: It is a measure of the ratio of total packet delivered at the sink node to the total energy consumed by the network's sensor nodes (Kbits/Joules).

Standard Deviation*:* This gives the average variation between energy levels of all nodes in the network (Joules).

Lifetime Prediction: It is the difference of total energy of the network and the summation of average used energy of nodes and their energy deviation

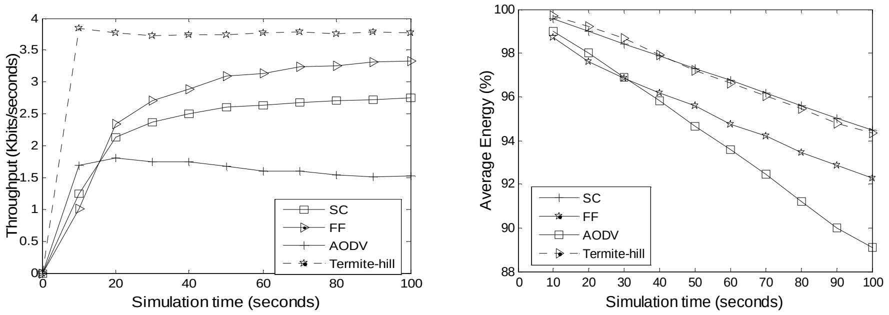
The main aim of this paper is to analyze the differences in performance of the state of the art swarm intelligence based routing protocols and compare with a conventional routing protocol in terms of sink mobility and static scenario in WSNs.

As can be seen in Table 1, the network lifetime of both protocols was improved during sink mobility. The increase in performance is due to the fact that, nodes near the sinks were now rotated to balance the energy consumption in the network. It will be notice in Fig. 4(b) for average remaining energy of the network nodes that, while the speed of mobility increases, the average remaining energy of Termite-hill remains almost constant, but the success rate increases with speed. The increase in success rate tends to increase the energy efficiency in mobility. In other word, the energy efficiency of all the algorithms decreases with time in static scenario due to decrease in average remaining energy of the network nodes and success rate. To further verify performance of the algorithm in mobility scenarios, we compared each of the protocol with itself for the static and mobility scenario to test the reliability of the network with mobile sink as seen in Fig. 5. The performance of the entire algorithms in terms of number of packets delivered to the sink with time dropped drastically. Though, our proposed algorithm that was able to delivered packets as high as in static scenario.

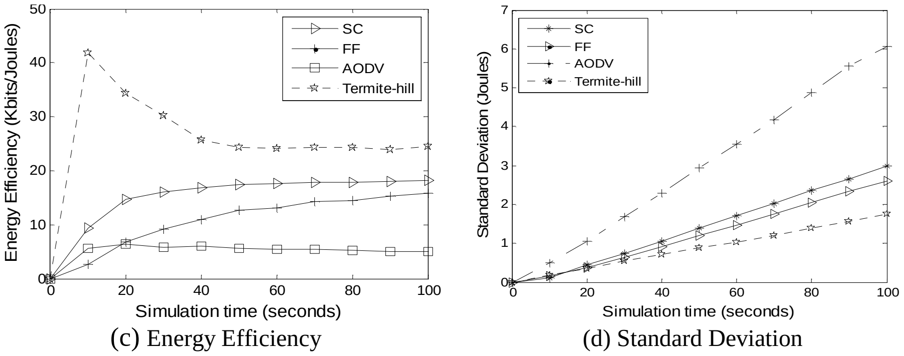
Termite-hill achieves both high packet delivery ratio, and energy efficiency as compared to SC, FF, and AODV due to some of its important features as, first, the launch of its soldier carrying the first generated event in which most cases it is able to find routes to the destination in the first attempt; second, it makes use of restrictive flooding which results in quick convergence of the algorithm; third, it maintains a small event cache to queue events while route discovery is in progress; fourth, it utilize a simple packet switching model in which intermediate nodes do not perform complex routing table lookup as in others, rather packets are switched using a simple forwarding table at a faster rate; and lastly, the updating rule takes into consideration the paths energy, hence the probability of route selection is also a function of paths remaining energy. The instability of AODV was due to pure flooding of RREQ packets, and therefore, it could not quickly discover new routes resulting in its bad performance.

Table 1 Impact of sink mobility on network lifetime among different routing protocols

Protocols	Static Lifetime (%)	Mobile Lifetime (%)	Difference (%)
Termite-hill	98.4648	98.8747	0.4099
AODV	96.5408	98.1824	1.6416
SC	98.2818	98.8741	0.5923
FF	98.1738	98.2185	0.0447

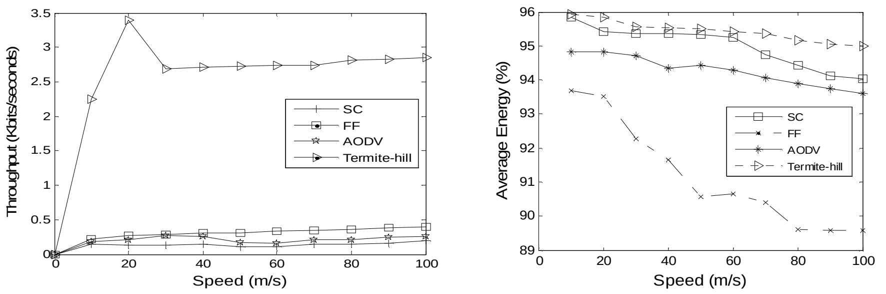


(a) Throughput (b) Average Energy

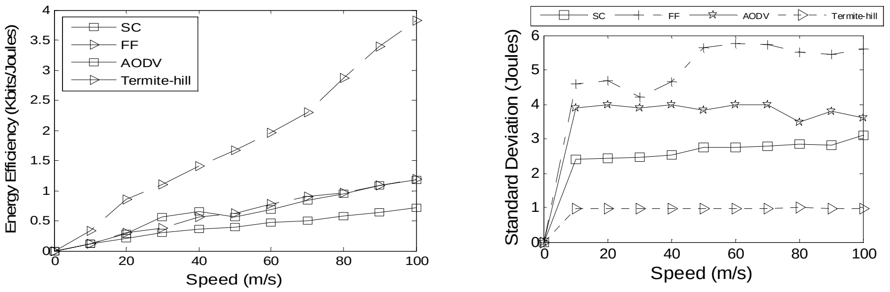


(c) Energy Efficiency (d) Standard Deviation

Fig. 3. Performance evaluation in static scenario among routing protocols

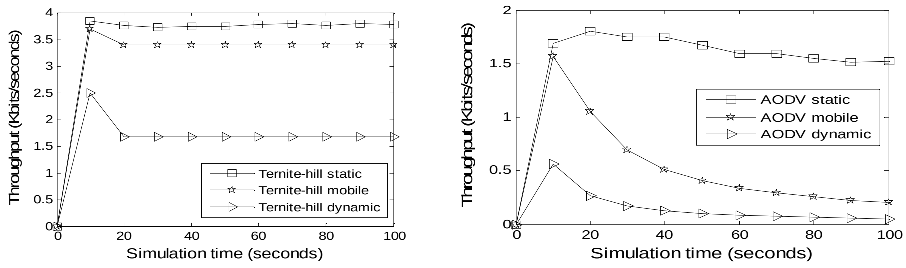


(a) Throughput (b) Average Energy

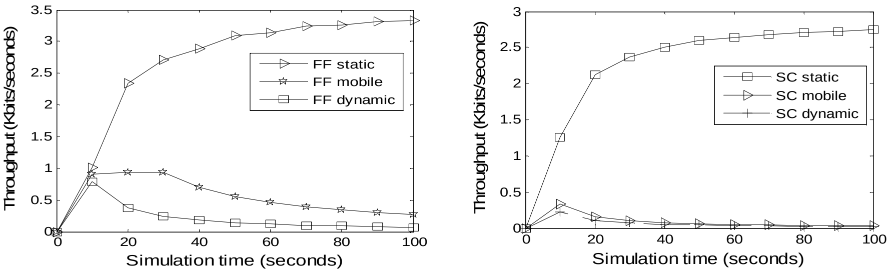


(c) Energy Efficiency (d) Standard Deviation

Fig. 4. Performance evaluation in mobile sink scenario with varying speed



(a) Termite-hill (b) AODV



(c) FF (d) SC

Fig. 5. Evaluation of impact of sink mobility on network reliability

5 Conclusions

In this paper, we studied the application of the Termite Colony Optimization metaheuristic to solve the routing problem in wireless sensor networks. A basic Termite based routing protocol was proposed. Several factors and improvements inspired by the features of wireless sensor networks (low energy level, low memory and processing capabilities) were considered and implemented. We also investigated the impact of sink mobility on network performance in WSN. Through the analysis, it was seen that the performance of the routing protocols in terms of energy efficiency, network reliability, and network lifetime had a strong correlation between sink mobility and simulation time. In fact, a possible side effect brought by sink mobility could be an increase in packet loss rate due to occasional topology changes. The lifetime elongation resulting from sink mobility is justifiable if the increase in packet loss is tolerable. From the results, the network lifetime was improved in all the algorithms, but many tend to sacrifice network reliability as against network lifetime. The proposed algorithm termed Termite-hill was able to balance the improvement of the network lifetime with the reliability of the network. We are in the process of testing the performance of the proposed algorithm on WSN hardware. We will also improve on the Termite-hill routing algorithm based on the experience obtained from the real-time implementation and testing.

References

1. Saleem, M., Di Caro, G., Farooq, M.: Swarm intelligence based routing protocol for wireless sensor networks: Survey and future directions. Information Sciences, vol. 181(20), pp. 4597-4624 (2011)
2. Zungeru, A.M., Ang, L.-M., Seng, K. P.: Classical and swarm intelligence based routing protocols for wireless sensor networks: A survey and comparison. Journal of Network and Computer Applications, (2012), http://dx.doi.org/10.1016/j.jnca.2012.03.004
3. Dorigo, M., Di Caro, G.: AntNet: Distributed Stigmergetic Control for Communications Networks. Journal of Artificial Intelligence Research, vol. 9, pp. 317-365 (1998)
4. Saleem, M., Farooq, M.: Beesensor: A bee-inspired power aware routing algorithms. In: Proceedings of EvoWorkshops (EvoCOMNET), LNCS 3449, pp. 136-146 (2005)
5. Roth, M., Wicker, S.: Termite: ad-hoc networking with stigmergy. In: GLOBECOM ’03, *IEEE Global Telecommunications Conference,* vol.5, pp. 2937-2941 (2003)
6. Zhang, Y., Kuhn, L.D., Fromherz, M.P.J.: Improvements on Ant Routing for Sensor Networks. In: Ant Colony Optimization and Swarm Intelligence, LNCS, 3172, pp. 289-313 (2004)
7. Perkins, C., Royer, E.: Ad-hoc on-demand distance vector routing. In: *Proceedings of 2nd IEEE Workshop on Mobile Comp’t. Systems and Applications*, pp. 90-100 (1999)
8. Zungeru, A.M., Ang, L.-M., Prabaharan, S.R.S., Seng, K. P.: Ant Based Routing Protocol for Visual Sensors, In: A. Abd Manaf et al. (Eds.), *ICIEIS 2011, CCIS 252* pp. 250-264 (2011)
9. Sztipanovits, J.: Probabilistic wireless network simulator (Prowler), http://www.isis.vanderbilt.edu/Projects/nest/prowler/