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Effects of Mica2-based discrete energy levels on the lifetime of cooperation neighbor sensor networks

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Abstract: We investigated the impact of transmission power control using Mica2 mote discrete power levels on neighbor sensor network lifetime. We built a linear programming framework to qualify the cooperation of sensor networks using a discrete energy model in comparison to noncooperating networks. Our results showed that a wireless sensor neighbor network that uses a discrete radio model can be more energy efficient than a network that uses a nondiscrete energy model.

Key words: Wireless sensor neighbor networks, linear programming, network lifetime, cooperation, discrete radio model

1. Introduction

Most studies carried out in the area of wireless sensor networks (WSNs) are heavily dependent on increasing network lifetime and decreasing energy consumption. The most important energy resource constraint is the irreplaceable batteries of sensor networks. Transmission range distance between sensor nodes is the key factor for energy consumption.

A linear programming model with the optimization objective of maximizing the lifetime of neighbor sensor networks with cooperation has been proposed in early work [1], which can also be used in the analysis of the Mica2 mote discrete radio model.

In this paper we investigate the impact of transmission power control using Mica2 mote discrete power levels on neighbor sensor network lifetime. The paper makes two contributions, which are summarized as follows:

Firstly, we considered the fact that sensor nodes are restricted to a few discrete power levels. Mica2 mote radio is limited only to 26 discrete transmit power levels [2]. Secondly, in this paper we used a linear programming (LP) framework, which gives us opportunity to come up with a simple playground avoiding all sorts of protocol and allows sensor nodes to adapt to correct output power level based on a predefined distance from the transmitter.

Section 2 deals with a brief overview of the literature on the lifetime maximization in WSNs, cooperation in WSNs, and discrete energy model. Section 3 briefly outlines the mathematical background to develop a system model. In section 4, the Mica2 mote discrete energy model and assumptions are discussed. Section 5 presents the result of numerical analysis performed using the LP framework. Finally, the conclusion is given in Section 6.

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2. Related work

In this section, we briefly summarize related research efforts on maximizing the lifetime of neighbor sensor networks, especially from the discrete radio model perspective, which involves observing the maximum lifetime routing of the LP.

Most of the studied research topics on WSN focus on reducing energy consumption to prolong lifetime [3–5]. In [6], the sensor network lifetimes for different network sizes with various data compression and flow balancing strategies were investigated. In [7], the routing problem using an LP model that aims to maximize the network lifetime was investigated. In [8], three novel routing algorithms using a discrete transmission energy model that facilitates energy aware routing and provides reliable packet transfer to the base station in a WSN were proposed.

In the same physical area, cooperation between neighbor sensor networks was previously studied and it was clearly seen that multidomain cooperation can extend network lifetime more than an order of magnitude when compared to noncooperating domains of WSNs [9].

Transmission power control in WSNs has already been studied extensively in the literature [2–4,10]. In [3], all transmission power assignment strategies studied so far can be classified as a network-wide, a node level, and a link level solution. The effects of the granularity of power levels on energy dissipation characteristics were investigated through a linear programming framework by modifying a well-known and heavily utilized continuous transmission power model. The results showed that the granularity of discrete energy consumption has a profound impact on WSN lifetime.

In this study, the problem has been investigated from yet another dimension using a LP- framework.

3. System model

Two neighbor sensor networks that both have disc shape and equal area were used for this research. Each base station with R_N radius was located in the center of its associated network. All sensor nodes in the network were randomly placed. The base station of network-n was shown as BN_n. The distance between two base stations was shown as D_{BS}. The value of this distance specifies whether these two networks will collaborate. We also analyzed whether a network has an effect on energy consumption and lifetime.

We constructed an LP model to investigate the impact of the Mica2-based energy model on lifetime of cooperation between neighbor sensor networks. In our model, each node-i sensor produces S_i much data in unit of time. Our main goal here is to keep the networks lifetime L, which represents the time when the first sensor consumed all of its energy, as long as possible [11].

The total energy that was spent for data communication for every node in the network is limited to its own battery energy (e_i). Network topology with maximum transmit power is denoted as an undirected graph G = (U, A), where U represents the nodes, including the base station. A contains radio links and $A = \{(i, j): d(i, j) \geq R_{max}, i \in U, j \in U\}$ is the set of edges. R_{max} is the maximum transmission range that a node can reach by using its maximum transmits power level. N is the set of network-n. All nodes that belong to network-n constitute the U_n set. The union of all sets of U_n's constitute the U set and all nodes of network-n except the base station of network-n (BN_n) constitute set Q_n. The union of all sets of Q_n's set constitutes the set Q. Furthermore, the union of all the base stations constitutes the set X. Data of the network-n flowing from node-i to node-j are represented as f_{ij}^n. All system variables with their acronyms and descriptions are presented in Table 1.

Table 1. Terminology for linear programming formulations.

Parameter	Description
G = (U, A)	Undirected graph of network topology
A	Set of arcs
Un	Set of all nodes that belong to network-n
U	The union of all set Un
N	Set of networks
Qn	All nodes of network-n, except the base station of network-n (BNn)
Q	The union of all set Qk
X	The union of all set base stations
f_{ij}^{n}	Data belong to network-k flowing from node-i to node-j
RN	Radius of the base station of each network
BNn	The base station of network-n
DBS	Distance between the base station
$\mathrm{R}_{\mathrm{max}}^{l}$	The maximum transmission ranges possible of level l
S_i	Each sensor node creates unit of data per unit time
L	Network lifetime
$\overset{Drx}{P}$	Energy consumption in discrete model for receiving one bit of data (0.923 μJ/bit)
$\overset{ltx,ij}{P}$	Energy consumption in discrete model for transmitting data from node-i to node-j of level l
D_{ij}^{l}	Distance between node-i and node-j
Bw	Channel bandwidth of Mica2 (38.4 Kb/s)
SN	Single network for discrete model
N C	Only node cooperation for discrete model
BSC	Only base station cooperation for discrete model
F C	Full cooperation (NC+BSC) for discrete model

The proposed system framework for discrete energy model, depicted in Figure 1, can be used for different network analysis, such as single network (SN), only node cooperation (NC), only base cooperation (BSC), and full cooperation (FC) models.

As the baseline to evaluate the lifetime improvement is attainable with different cooperation strategies, we used the SN discrete model. The LP model for SN is presented in Figure 1 as Eqs. (1)–(4), respectively. Eq. (1) shows that every flow in the network is positive. Eq. (2) is used to limit the maximum transmission range of each node, where R_{max}^{l} is the maximum transmission range possible. Eq. (3) is the flow balancing constraint. Data flowing out of node-i are equal to the amount of data flowing into node-i and data generated by node-i. As we constructed a model for a single network in this section, the set of networks has only one element and we set n as 1. Eq. (4) states that the discrete energy dissipation on node-i is limited by the battery power of node-i. All flows terminate at the base station, which is not energy-limited.

Nodes from different neighbor networks with the NC model collaborate while transmitting data. However, expanding the collaboration is only limited to the sensor nodes. Base stations cannot collaborate in such a model. Sensor nodes of network-n1 can carry data of network-n2. The base station of network-n2 is the stop point. In a similar way, data produced in network-n2 can be carried by nodes of network-n1. This data cannot be divided between network-n1 and network-n2.

The LP discrete model for NC is presented in Figure 1 as Eqs. (1), (2), (5), (6), and (12). Eq. (5) is the flow balancing constraint for sensor nodes, which transport their own network's data. Eq. (6) is the flow balancing constraint for sensor nodes relaying the data of networks that are not a member. Eq. (12) is the energy balancing constraint for the NC model.

Maximize L

Subject to:

$$f_{ij}^{n} \geq 0 \ \forall (n,i,j) \in A \tag{1}$$

$$f_{ij}^{n} = 0, if \ \ d_{ij} \geq R_{max}^{l} \ \forall (n,i,j) \in A \tag{2}$$

$$\sum_{j \in U_n} f_{ij}^{n} = \sum_{j \in Q_n} f_{ji}^{n} + s_i L \ \ n = 1, \ \forall i \in Q_n \tag{3}$$

$$P_{rx}^{D} \sum_{n \in N} \sum_{j \in Q_n} f_{ji}^{n} + \sum_{n \in N} \sum_{j \in U_n} P_{tx,ij}^{D} f_{ij}^{n} \leq e_i \ \ n = 1, \forall i \in Q_n \tag{4}$$

$$\sum_{j \in (Q \cup BN_n)} f_{ij}^{n} = \sum_{j \in Q} f_{ji}^{n} + s_i L \ \forall n \in N, \ \forall i \in Q_n \tag{5}$$

$$\sum_{j \in (Q \cup BN_n)} f_{ij}^{n} = \sum_{j \in Q} f_{ji}^{n} \ \forall n \in N, \ \forall i \notin Q_n \tag{6}$$

$$\sum_{j \in (Q_n \cup X)} f_{ij}^{n} = \sum_{j \in Q_n} f_{ji}^{n} + s_i L \ \forall n \in N, \ \forall i \in Q_n \tag{7}$$

$$f_{iv}^{n} = \sum_{j \in Q_n} f_{ji}^{n} \ \forall n \in N, \ \forall i \in X, \ v = BN_n \tag{8}$$

$$\sum_{j \in U} f_{ij}^{n} = \sum_{j \in Q} f_{ji}^{n} + s_i L \ \forall n \in N, \ \forall i \in Q_n \tag{9}$$

$$\sum_{j \in U} f_{ij}^{n} = \sum_{j \in Q} f_{ji}^{n} \ \forall n \in N, \ \forall i \notin Q_n \tag{10}$$

$$f_{iv}^{n} = \sum_{j \in Q} f_{ji}^{n} \ \forall n \in N, \ \forall i \in X, \ v = BN_n \tag{11}$$

$$P_{rx}^{D} \sum_{n \in N} \sum_{j \in Q_n} f_{ji}^{n} + \sum_{n \in N} \sum_{j \in U_n} P_{tx,ij}^{D} f_{ij}^{n} \leq e_i \ \forall n \in N, \ \forall i \in Q_n \tag{12}$$

Figure 1. LP framework for discrete lifetime maximization problem.

Collaboration in neighbor networks with the BSC discrete model is only limited to base stations of neighbor networks. In this model, neighbor networks' nodes do not collaborate. More precisely, nodes of network-n1 can send data to both network-n1's base station and network-n2's base station. The same is valid for network-2's nodes. The LP discrete model for BSC is presented in Figure 1 as Eqs. (1), (2), (7), (8), and (12). Eq. (7) is the flow balancing constraint for sensor nodes. Eq. (8) is the flow balancing constraint for base stations relaying the data of networks of which they are not a member to the networks' base stations. The BSC model can be interpreted as all networks have multiple base stations. In this model, each sensor node can use any base station as its own base station.

Each node from different neighbor networks with its base stations can collaborate in neighbor networks with the FC discrete model. There is full collaboration in this model. For example, any node in network-n1 can send data to nodes in its own network, its base station, and also neighbor base stations on neighbor nodes. The LP model for FC is presented in Figure 1 as Eqs. (1), (2), (9), (10), (11), and (12). The FC model consists of NC and BCS models.

While using Eq. (9) for transferring its own network's data, Eqs. (10) and (11) are relaying other networks' data, and base stations are relaying other networks' data to the corresponding base stations, respectively.

4. Discrete energy model and assumptions

In this study we used Mica2 platform energy consumption characteristics to determine the energy dissipation model. The Mica2 motes are equipped with 433 Mhz RF, CC1000 radios, 38.4 Kbit/s data rate, and operate on two 1.5-V AA batteries as presented in [10]. Whenever a Mica2 node is deployed, its battery voltage decreases linearly. Mica2 based transmission ranges and corresponding energy dissipations for this model are presented in Table 2. At any time, energy dissipation for transmitting one bit of data at power level l is denoted as P^{l}_{tx} and the maximum transmission range at power level l is indicated as R^{l}_{max}. If the distance between node-i and node-j is longer than R^{l}_{max} (i.e. $\mathrm{d}_{ij} > \mathrm{R}^{l}_{max}$), then they cannot communicate using power level l. Energy dissipation for receiving one bit of data is constant denoted as P^{D}_{rx} (0.923 μJ).

Table 2. Transmission energies (μj/bit) and corresponding maximum transmission ranges (m) in different power levels (P^{l}) of Mica2 mote (computed using the data [2]). Reception energy is fixed ($\mathrm{P}^{M}_{rx} = 0.923$ μj per bit). Mica2 mote bandwidth is 38.4 Kbit/s.

Power level(l)	P^{l}_{tx}	R^{l}_{max} (m)	Power level(l)	P^{l}_{tx}	R^{l}_{max} (m)
1	0.672	19.30	14	0.844	41.19
2	0.688	20.46	15	0.867	43.67
3	0.703	21.69	16	1.078	46.29
4	0.706	22.69	17	1.133	49.07
5	0.711	24.38	18	1.135	52.01
6	0.724	25.84	19	1.180	55.13
7	0.727	27.39	20	1.234	58.44
8	0.724	29.3	21	1.344	65.67
9	0.758	30.78	22	1.344	65.67
10	0.773	32.62	23	1.445	69.61
11	0.789	34.58	24	1.500	73.79
12	0.813	36.66	25	1.664	78.22
13	0.828	38.86	26	1.984	82.92

The optimal power level to transmit over a distance d_{ij} is given in Table 2. For example, for $\mathrm{d}_{ij} = 25$ m, since 24.38 m $< \mathrm{d}_{ij}$, 25 m uses power level 6 (l_6) to transmit data on its link node-i (i.e. $\mathrm{P}^{l}_{tx}(\mathrm{l}_6) = 0.724 \mu\mathrm{J}$).

For the proposed model, energy consumption of sensor nodes is dominated by communication energy dissipation rather than sensing and processing energy dissipation. Energy factors such as sleep-mode energy are also ignored for the sake of simplicity. This assumption is supported by the results of experiments in actual WSN testbeds [3].

We neglected dissipation energy for idle listening or overhearing in promiscuous mode. In these modes to avoid wasting energy there are many intelligently designed MAC protocols for wireless networks [4]. We assume such a MAC layer is used in our discrete framework.

Energy dissipation of a Mica2 mote for transmission is constant for a particular power level, whereas energy required to receive data is the same for all 26 power levels. The nodes of each network are scattered randomly following a uniform distribution in a disk-shaped topology. The locations of the two neighbor networks are known by all sensors. After node deployment, all nodes remain stationary, and they are homogeneous in terms of energy, communication, computation, and processing capabilities.

As shown in Figure 2, in the analysis we simplify neighbor networks with two disk-shaped networks that have equal areas. Each network's base station is centered in the network. For each analysis, 100 sensor nodes were randomly deployed and each node generates data at a constant rate (S_i).

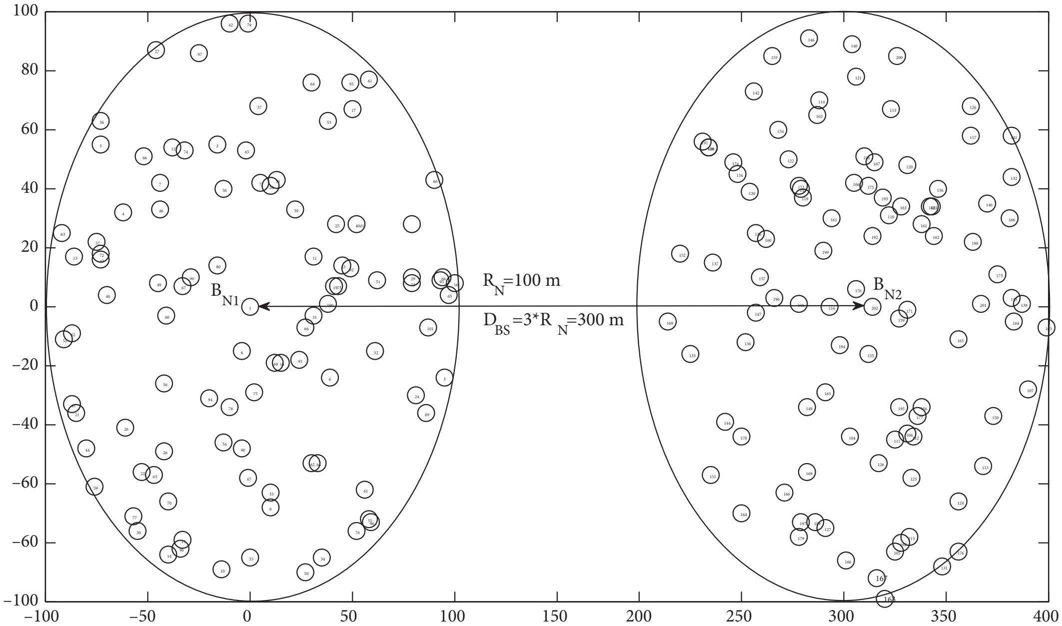

Figure 2. Neighbor sensor networks with two disk-shaped networks.

5. Analysis

For each numerical analysis of LP models, we used the general algebraic modeling system (GAMS) as a model development environment, which is a high-level modeling system for mathematical programming and optimization [12]. To obtain results of the analyses, we used many x86-based server computers with 2.4 GHz multicore CPU and 12 GB RAM. The analyses were performed for two different network areas (10^4 m^2 and 10^5 m^2). Each data point presented in the graphics was the average of 300 different random topologies. All LP models were solved using the same node distributions. Figures 3–5 present normalized lifetimes for cooperation strategies as functions of D_{BS}. Normalization was achieved by dividing absolute lifetime values by the corresponding absolute lifetime value of the SN model.

The results of our analysis are itemized as follows:

1) When the area is 10^4 m^2, 10^5 m^2, and $D_{BS} = 0$ (the centers of base stations are overlapped), the FC or BSC model in two neighbor networks collaborates as if they were one centered network. In this model, sensors, which belong to two neighbor networks, choose only one of the base stations for data delivering.

2) When the area is 10^4 m^2, 10^5 m^2, there is full cooperation with $D_{BS} <= 2.4$ R_N range, $D_{BS} <= 2.3$ R_N range, respectively.

3) When the area is 10^4 m^2, 10^5 m^2, there is base cooperation with $D_{BS} <= 2$ R_N range, DBS $<= 1.4$ R_N range, respectively.

4) When the area is 10^4 m^2, 10^4 m^2, and $D_{BS} = 0$ (the centers of base stations are overlapped), there is cooperation between these two neighbor networks using the NC model.

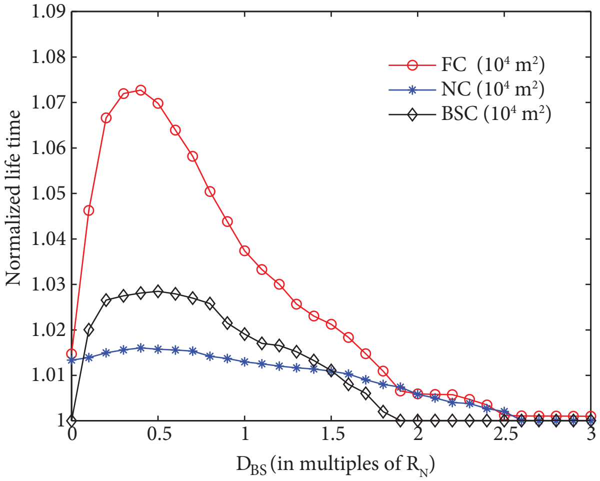

Figure 3. Normalized lifetimes for cooperation strategies as a function of D $_{BS}$ for 104 m^2.

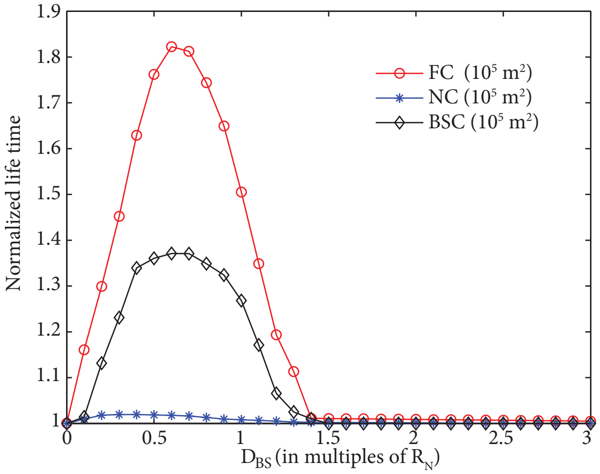

Figure 4. Normalized lifetimes for cooperation strategies as a function of D $_{BS}$ for 105 m^2.

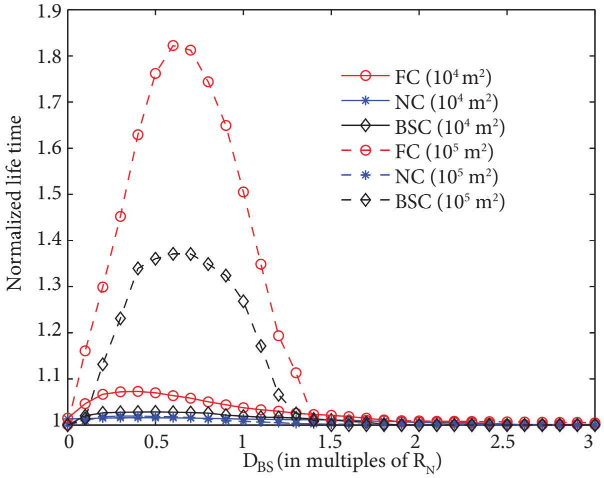

Figure 5. Normalized lifetimes for cooperation strategies as a function of D $_{BS}$ for 104 m^2 and 105 m^2.

5) As shown in Figures 3–5, when the area is 10^4 m^2 and 10^5 m^2, there is NC cooperation between nodes with $D_{BS} <= 2.7\ R_N$ range, $R_{BS} <= 2.25\ R_N$ range, respectively. Even though areas get larger and lifetime values of individual networks decrease, these values increase with cooperation.

6) As shown in Figure 4, the lifetime of BSC based on closeness is affected positively in the big areas. Because of BSC, when network individuals get further from each other, their lifetime gets closer to 1.

7) As shown in Figures 3 and 4, when the area is 10^4 m^2 and 10^5 m^2, the lifetime for both conditions ranging from the biggest to the smallest is ordered as FC, BSC, and NC.

8) When the area is 10^4 m^2 in the discrete model, the lifetime order is the same as in the nondiscrete model.

9) When the area is 10^4 m^2 in the discrete model, the lifetime order is FC, BSC, and NC, while it is FC, NC, and BSC in the nondiscrete model [1].

10) Network lifetime increases with the number of nodes and base station cooperation. Greater impact is observed when R_{BS} is increased from 0 to $D_{BS} <= 0.5\ R_N$. After that point the network lifetime begins to decrease.

6. Conclusion

In this study, we revised the LP model discussed in [1], and we investigated the impact of transmission power control using Mica2 mote discrete power levels on neighbor sensor network lifetime. Our results showed that a wireless sensor neighbor network that uses a discrete radio model can be more energy efficient than a network that uses a nondiscrete energy model.

References

[1] Tavli B, Bicakci K, Bagci İE, Pala Z. Neighbor sensor networks: Increasing lifetime and eliminating partitioning through cooperation. Computer Standards & Interfaces 2013; 35: 396-402.

[2] Vales-Alonso J, Egea-Lopez E, Martnez-Sala A, Pavon-Marino P, Bueno-Delgado MV, Garca-Haro J. Performance evaluation of mac transmission power control in wireless sensor networks. Comput Netw 2007; 51: 1483-1498.

[3] Cotuk H, Bicakci K, Tavli B, Uzun E. The impact of transmission power control strategies on lifetime of wireless sensor networks. IEEE Transactions on Computers 2014; 63: 2866-2879.

[4] Cayirpunar O, Kadioglu Urtis E, Tavli B. The impact of base station mobility patterns on wireless sensor network lifetime. In: Personal Indoor and Mobile Radio Communications (PIMRC) IEEE 24th International Symposium; 8–11 September 2013; London, United Kingdom: IEEE. pp. 2701-2706.

[5] Pala Z, Bicakci K, Turk M. Effects of node mobility on energy balancing in wireless networks. Computers & Electrical Engineering 2015; 41: 314-324.

[6] Tavli B, Bagci İE, Ceylan O. Optimal data compression and forwarding in wireless sensor networks. IEEE Communications Letters 2010; 14: 408-410.

[7] Chang JH, Tassiulas L. Maximum lifetime routing in wireless sensor networks. IEEE/ACM Transactions on Networking 2004; 12: 609-619.

[8] Balazs K, Andras B, Janos L. Energy aware routing protocols for wireless sensor networks using discrete transmission energies. In: Trust, Security and Privacy in Computing and Communications (TrustCom) IEEE 10th International Conference; 16–18 November 2011; Changsha: IEEE. pp. 1704-1707.

[9] Bicakci K, Tavli B. Prolonging network lifetime with multi-domain cooperation strategies in wireless sensor networks. Ad Hoc Networks 2010; 8: 582-596.

[10] Gurbuz AC, Karakus C, Tavli B. Analysis of energy efficiency of compressive sensing in wireless sensor networks. IEEE Sensors Journal 2008; 13: 1999-2008.

[11] Heinzelman WB, Chandrakasan A, Balakrishnan H. Application specific protocol architecture for wireless microsensor networks. IEEE Transactions on Wireless Comm. 2002; 1: 660-670.

[12] Rosenthal RE. GAMS - A User Guide. Washington, USA: GAMS Development Corporation, 2015.