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Maximizing the Life Time of Wireless Sensor Networks: A Survey with a possible solution to further enhance the life time of WSNs

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Abstract: *Maximizing the life time of wireless sensor networks through various techniques has been the focus of the number of researchers for almost a decade. The techniques so far used have focused on various power aware algorithms and encryption techniques used for the communication between the nodes. Numerous studies earlier have resulted in various mathematical models for deriving bounds on the operating lifetimes of the sensor nodes. However most of the earlier work did not consider the role of the battery dynamics in determining the life time of the sensor nodes. And in most of the cases from the published results from actual deployment indicate that in practice , sensor node lifetimes are far lower than expected due to premature drain of batteries. This reveals an important fact that even the battery itself has an important role to play in determining the life time of the sensor node. It is important to discharge the battery in a systamatic way that maximizes the amount of charge extracted from it. In this paper a survey of all the models presented by the researchers is presented and concludes with suggesting a possible method by which the life time of the sensor node can be further extended.*

Keywords: *Battery life, Sensor node, Power consumption, Target coverage*

I. Introduction

In remote or hostile sensor fields, randomly scattering sensor nodes might be the only way to deploy sensor networks. If only one sensor is air-dropped at the proximity of a target, it is possible that this target is not within the sensing range of this sensor due to the randomness around each target. In such a randomly deployed sensor network, a target may be covered by more than one sensor, and a sensor may also cover more than one target. WSNs are formed by a large number of energy-constrained and inexpensive nodes. Energy is a primary concern, because nodes usually run on non-rechargeable batteries. Thus, the improvement of network lifetime is a fundamental research issue. All sensor nodes are assumed to be equipped with only limited energy supply and hence the network operational time is not unlimited. Batteries do not supply current linearly, which affects sensitivity and transmission power. It is not wise to switch on all sensors as this consumes the sensor energy fast and results in a short-lived network.

II. Different techniques used to maximize the life time of the sensors networks

Recent research showed that significant energy savings can be achieved by scheduling node duty cycles in high density sensor networks. Specifically, some nodes are scheduled to sleep while the remaining ones provide continuous monitoring. The main issue here is how to minimize the number of active nodes in order to maximize the network lifetime. In this direction research is on where Sensors can be partitioned different ***covers***- a subset of sensors that can satisfy the coverage requirement and activate these covers in a round-robin fashion. The network operating time for target coverage is then the total time span of these sensor covers runtime.

Wireless Sensor Node consists of three basic functional units: communication unit, computation unit and sensing unit. Of the three units, communication unit consumes major part of the energy budget. Recent research work is also focusing on reducing the energy consumption on communication and computation unit.

Consider a simple case of target coverage. As shown in Fig. 1, there are six sensors and four targets in a randomly deployed network. Considering a disk coverage model, the targets $z2$ and $z4$ are each covered by two sensors; and the targets $z1$ and $z3$ are each covered by three sensors. Coverage mapping is used to refer the coverage relations among all sensors and all targets that can be represented by a sensor-target bipartite graph. The vertices are the sensors and targets, and an edge exists between a sensor and a target if the sensor covers the target. Fig. 2 shows the plots of the sensor-target bipartite graph of the sensor network.

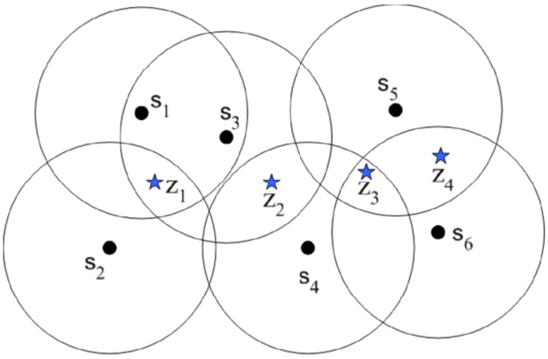

Fig. 1 A randomly deployed sensor network for covering the targets

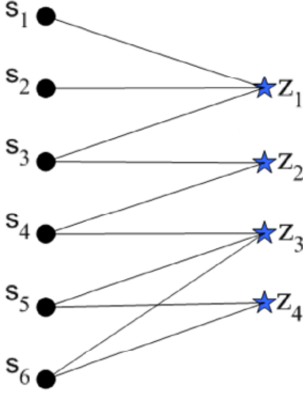

Fig. 2 sensor-target bipartite graph

In the context of target coverage, it is a common prerequisite that all targets can be covered if all sensors are activated for sensing. However, activating all the sensors at the same time is not energy efficient. If every sensor can only operate for one time unit in a continuously active state, then activating all sensors all the time results in a total network lifetime of also one time unit. Instead, sensors can be alternatively activated. For example, in the network shown in Fig.1, activate *C*1 = {s1, s3, s6} for one time unit and *C*2 = {s2, s4, s5} for another time unit. Since all targets are still covered by either *C*1 or *C*2, the coverage requirements are not sacrificed. Furthermore, the target coverage lifetime can be extended to two time units. Obviously, other choices of partitioning the sensors into different subsets is also possible, such as *C*3 = {s1, s2, s5} and *C*4 = {s3, s6}. The objective of the target coverage problem is to find the optimal subsets and their active intervals such that the coverage requirements can be satisfied and the total target coverage lifetime can be maximized.

An irreducible set cover containing a dead sensor cannot satisfy the coverage requirement and is no longer used for target coverage. The *target coverage lifetime* is defined as the duration from the time that the network starts operation till the time that the coverage requirement cannot be satisfied even if all sensors are activated. Since all sensor nodes have only limited initial energy, the network lifetime for target coverage hence is also limited. The objective of the coverage lifetime maximization problem is to find an optimal schedule (C_k, t_k), k = 1, 2, . . . , consisting of the set covers *Ck* and their corresponding active intervals t_k , such that the coverage requirement can be satisfied by each set cover during its operating interval, and the coverage lifetime can be maximized.

Where C_k is the k^{th} set cover (indexed by subscript *k*, *k* = 1. . . K) and t_k is the active time interval for set cover C_k.

$\Psi(Z, C_k)$ as an indicator function to denote whether the network-wide target coverage requirement can be satisfied by a set cover C_k . That is, if coverage requirement is satisfied, then $\Psi(Z, C_k) = 1$, and otherwise, $\Psi(Z, C_k) = 0$.

Where Z = = $\{z_1, \ldots, z_M\}$ the set of all targets, $|Z| = M$.

The coverage lifetime maximization problem can be formulated as the following optimization problem. The lifetime *T* is defined as the sum of all the active intervals. The number of set covers is denoted by *K*. Since all nodes have limited energy, both t_k and *K* are finite but unknown. Two basic constraints are the energy constraint and the coverage requirement.

Network lifetime can be extended by alternatively activating sensors. This corresponds to construct a series of sensor covers, C_k , and allocate each operating time interval t_k, $t_k > 0$, k = 1, 2, ... All the sensors in C_k are activated for covering targets in the allocated interval t_k , and the sensors not in C_k deactivate their sensing unit to save their energy. Let $e_k(s_i, Ck) \geq 0$ denote the energy consumption of a sensor s_i when only the set cover C_k is selected to be active for t_k time units. $e_k(si, C_k) = 0$ indicates that s_i consumes no energy, which implies that $si \notin C_k$. $e_k(si,Ck)$ does depend on the role of the sensor in the interval t_k and the detailed energy consumption model in different application scenarios. Furthermore, every sensor in C_k cannot consume the energy more than its residual energy in a time interval t_k , which implicitly restricts the length of an active interval. Each sensor is assumed to have limited initial energy supply E_i, $i = 1, 2, \ldots, N$. A sensor is dead if its residual energy becomes zero. An irreducible set cover containing a dead sensor cannot satisfy the coverage requirement and is no longer used for target coverage.

2.1 Coverage Lifetime Maximization Model

K
Maximize: $T \equiv \sum t_k$ k=1

Subject to: $\sum e_k(s_i, C_k) \leq E_i$ for all s_i (energy constraint)

$\Psi(Z, C_k) = 1$ for all C_k (coverage constraint)
. . . (Other constraints)

Subscript i and j are used to index sensors and targets, respectively.

2.2 Disjoint Set Cover Model

In *disjoint set cover* (DSC) Model the available sensors are partitioned into *disjoint* subsets to be activated consecutively. Two sets are called disjoint if their intersection is an empty set, that is, $C_k \cap C_{k'} = \emptyset$ for $k \neq k'$. All sensors are assumed to have the same amount of initial energy and have the same energy consumption rate in the active state. If a set cover is scheduled to be continuously active, then all sensors in the set cover will die at the same time. Each disjoint set cover is activated till its death, and all the disjoint set covers are activated one by one. With such an arrangement, the target coverage lifetime equals to the number of these set covers times the runtime of a single set cover. The objective of the lifetime maximization problem then can be converted to the problem of finding the maximal number of disjoint set covers that satisfy the coverage requirements.

2.3 Maximal Disjoint Set Cover for Complete Target Coverage

A straightforward coverage requirement is the complete target coverage. All targets should be covered all the time. The complete coverage requirement indicates that $\Psi(Z, C_k) = 1$ if $\{C_k\} = Z$ and $\Psi(Z, C_k) = 0$ otherwise. The objective is to find the maximal number of disjoint set covers, each covering all targets. The maximal disjoint set cover model is defined as follows:

Given a collection 'C' of subsets of a finite set 'Z', find the maximum number of disjoint set covers, C_k, $k = 1, 2, \ldots, K$, such that each set cover can cover all targets, $\{Ck\} = Z$ for all Ck , and for any two covers C_k and $C_{k'}$, $C_k \cap C_{k'} = \emptyset$. Where $\{Ck\}$ indicates the set of targets covered by the set cover C_k.

The decision version of the MDSC mathematical model is as follows: Given a collection C of subsets of a finite set Z and a positive integer K, can we find K disjoint set covers, each covering all targets. As a variant of the coverage lifetime maximization problem, the optimization version of the MDSC model can also be formulated as the following maximization mathematical model:

Maximize: $T \equiv K$
Subject to: $\sum_{k=1}^{K} \delta(si, Ck) \leq 1$ for all si (energy constraint)
$\{Ck\} = Z$ for all C_k (coverage constraint
$C_k \cap C_{k'} \_ = \emptyset$ for all $k = k'$ (disjoint constraint)
$\delta(s_i, C_k) \in \{0, 1\}$ for all s_i, C_k (inclusion constraint)

The network lifetime is defined by the number of disjoint set covers. This is because each set cover is active for one time unit. The energy constraint states that a sensor can be in at most one of the set covers. The coverage constraint requires complete target coverage. The inclusion indicator function $\delta(s_i, C_k)$ indicates whether the sensor s_i is included in the set cover C_k , that is, $\delta(s_i, C_k) = 1$ if $s_i \in Ck$ and $\delta(s_i, C_k) = 0$ otherwise. An intuitive upper bound of K is determined by the minimal number of sensors covering a target, that is, $K \leq \min zj \in Z(|S(z_j)|)$. This is because each sensor can only be in one of the set cover (disjoint constraint), and all targets should be covered by each set cover (coverage constraint). Recall that we use $S(z_j)$ to denote the set of the sensors covering the target z_j.

2.4 Disjoint Set *K*-Cover for Minimum Coverage Breach

Covering all the targets all the time is a strict coverage requirement. Sometimes, this can be relaxed by allowing some *coverage breach*. If a target is not covered by any active sensor, then it is said to be *breached.* In other words, the coverage requirement becomes a *partial target coverage* requirement, and a set cover is allowed to cover only a fraction of targets. Instead of running till its death, a set cover can only be activated for short time duration, and all set covers are alternatively activated. With such rotative activations of set covers, a target that is not covered in this round may be covered in the next round.

2.5 Non-disjoint Set Cover

In this a *non-disjoint set cover* is considered where the constructed set covers need not be disjoint. Again, all sensor nodes with the same amount of initial energy and with the same energy consumption rate in the active state are considered. The lifetime of a single sensor is assumed as one time unit if it is activated all the time. In the context of disjoint set cover problem, each sensor can only be included into one set cover, and all sensors have the same length of the active interval. Therefore, the network lifetime depends on the number of constructed disjoint sensor set covers. However, if the disjoint constraint is relaxed such that a sensor can be included in more than one set cover and each set cover can be activated for less than one time unit, then the network lifetime may be extended.

2.6 Maximum Set Cover (MSC) for Complete Target Coverage

The complete target coverage requires that all targets should be covered all the time. This indicates that $\{C_k\} = Z$ for all set cover C_k. ek(si,Ck)is used, where $e_k(s_i,C_k) \geq 0$, to denote the energy consumption of sensor s_i when the set cover C_k operates for t_k time units. Note that $e_k(s_i,C_k) = 0$ implies $s_i \notin C_k$. The energy constraint indicates that $\sum_{k=1;k=K} e_k(s_i,C_k) \leq E_i$, where E_i is the initial energy of sensor s_i . The objective is to find a *schedule* (C_k, t_k), $k = 1, 2, \ldots ,$ of a series of set covers C_k and their active intervals t_k such that the sum of all active intervals $\sum_k t_k$ is maximized.

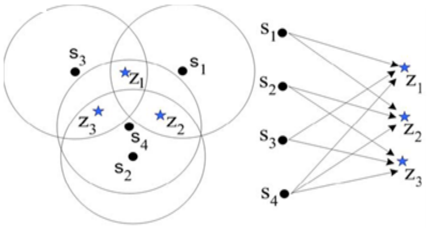

Fig.3 A sensor network consisting of four sensors {s1, s2, s3, s4} and three targets {z1, z2, z3} and the corresponding sensor-target bipartite graph

The optimization version of this MSC problem can be formulated as follows:

$$\text{Maximize: } T \equiv \sum_{k=1}^{K} t_k$$

Subject to:

$$\sum_{k=1}^{K} \delta(s_i, C_k) t_k \leq 1 \text{ for all } s_i \text{ (energy constraint)}$$

$$\{Ck\} = Z \text{ for all } Ck \text{ (coverage constraint)}$$

$$\delta(si,Ck) \in \{0, 1\} \text{ for all } s_i,C_k \text{ (inclusion constraint)}$$

The energy constraint states that each sensor cannot be activated for more than one time unit. The coverage constraint requires that each target should be covered by at least one sensor in a set cover. The inclusion indicator function $\delta(s_i,C_k)$ indicates whether the sensor s_i is included in the set cover C_k . That is, $\delta(s_i,C_k) = 1$ if $s_i \in C_k$ and $\delta(s_i,C_k) = 0$ otherwise.

2.7 Set *K*-Cover for Minimum Coverage Breach

Similar to the Disjoint Set KCover problem, the Set K-Cover problem is to construct K set covers, yet without the constraint that these K set covers should be disjoint. Suppose that each sensor has a lifetime of one time unit and consumes the same amount of energy in the active state. In the Disjoint Set K-Cover problem, each sensor can only be included in one set cover, and each set cover is active for one time unit. Hence, in the Disjoint Set K-Cover problem, the network lifetime equals to K. In the non-disjoint Set K Cover problem, a sensor can be included in more than one set cover, and the active intervals can be different for different set covers. In the non-disjoint Set K-Cover problem, the network lifetime is the sum of these active intervals.

In both the Disjoint Set K-Cover problem and the non-disjoint Set K-Cover problem, a target is allowed to be not covered by any active sensor. Recall that a target is called *breached* if it is not covered by any active sensor. The objectives of the Set K-Cover are to minimize the coverage breach while maximizing the network lifetime. However, they are two conflicting objectives in most cases. These two objectives need to be balanced. For example, a threshold may be set as the acceptable minimum network lifetime and then minimize the coverage breach. On the other hand, a threshold may be set as the acceptable maximum allowable coverage breach and then maximize the network lifetime.

The solution to the Set K-Cover problem is a schedule (C_k, t_k), $k = 1, 2, \ldots, K$, and the network lifetime is given by $T \equiv \sum_{k=1} tk$. Again, we use {Ck} to denote the set of targets covered by the set cover C_k. The *total coverage breach* is defined as $\sum^{K}_{k=1} t_k \times (|Z| - |\{Ck\}|)$, and the *average coverage breach rate* is defined as $\sum^{K}_{k=1} tk \times (|Z| - |\{Ck\}|) / \sum^{K}_{k=1} t_k$.

III. Proposed ideas to further enhance the life time of WSNs

No work has been done to mathematically construct an energy model that takes all the energy consumptions into account. Since the sensor nodes are often inaccessible, the lifetime of a sensor network depends on the lifetime of the power resources of the nodes. Power is also a scarce resource due to the size limitations. For instance, the total stored energy in a smart dust mote is on the order of 1 J. For wireless integrated network sensors (WINS), the total average system supply currents is less than 30 µA to provide long operating life. WINS nodes are powered from typical lithium (Li) coin cells of size 2.5 cm in diameter and 1 cm in thickness. The transceiver unit of sensor nodes in general is a radio frequency (RF) device. RF communications require modulation, band pass, filtering, demodulation and multiplexing circuitry, which make them more complex and expensive. Also, the path loss of the transmitted signal between two sensor nodes may be as high as the fourth order exponent of the distance between them, because the antennas of the sensor nodes are close to the ground.

RF communication is preferred in most of the ongoing sensor network research projects, because the packets conveyed in sensor networks are small, data rates are low and the frequency re-use is high due to short communication distances. These characteristics also make it possible to use low duty cycle radio electronics for sensor networks. However, designing energy efficient and low duty cycle radio circuits is still technically challenging, and current commercial radio technologies such as those used in Bluetooth is not efficient enough for sensor networks because turning them on and off consumes much energy.

3.1 Power consumption

The wireless sensor node, being a portable-electronic device, can only be equipped with a limited power source (<0.5 Ah, 1.2 V). In some application scenarios, replacement of power resources might be impossible. Sensor node lifetime shows a strong dependence on battery lifetime. In a multi-hop adhoc sensor network, each node plays the dual role of data originator and data router. The dis-functioning of few nodes can cause significant topological changes and might require re-routing of packets and re-organization of the network. Hence, power conservation and power management becomes very important.

Power consumption can hence be divided into three domains: sensing, communication, and data processing. Sensing power varies with the nature of applications. Sporadic sensing might consume lesser power than constant event monitoring. The complexity of event detection also plays a crucial role in determining energy expenditure. Higher ambient noise levels might cause significant corruption and increase detection complexity. Power consumption in data communication and processing are discussed in detail in the following subsections.

3.2 Communication

Of the three domains, a sensor node expends maximum energy in data communication. This involves both data transmission and reception. It can be shown that for short-distance communication with low radiation power, transmission and reception energy costs are nearly the same. Mixers, frequency synthesizers, voltage control oscillators, phase locked loops (PLL) and power amplifiers; all consume valuable power in the transceiver circuitry. It is important that in this computation we not only consider the active power but also the start-up power consumption in the transceiver circuitry. The start-up time, being of the order of hundreds of micro-seconds, makes the start-up power non-negligible. This high value for the start-up time can be attributed to the lock time of the PLL. As the transmission packet size is reduced, the start-up power consumption starts to dominate the active power consumption. As a result, it is inefficient in turning the transceiver ON and OFF, because a large amount of power is spent in turning the transceiver back ON each time.

Normally, a sensor node has three major units that consume energy: the micro-controller unit (MCU) which is capable of computation, communication subsystem which is responsible for transmitting/receiving messages and the sensing unit that collects data. Each subsystem can be turned on or off depending on the current status of the sensor which is summarized in Table I.

Table I. ENERGY CONSUMPTION

Sensor mode	MCU	Radio	Sensor	*P ower (mW)*
Listening	On	On	On	20.05 + f(ri)
Active	On	Off	On	9.72 + f(ri)
Sleep	Off			0.02
Energy needed to send a 2-bit-content message:				0.515

In Table I, the function *f*(*ri*) is the spent energy related to the sensing range *ri* of sensor *si*. two kinds of function *f* are considered:

Linear function: $f(r_i) = (1/K) \times r_s$

Quadratic function: $f(r_i) = (1/K) \times r_s^2$; where K is an energy co-efficient.

For the sake of simplicity, the energy needed to receive a message, to turn on the radio, to start up the sensor node, etc is avoided. However these energies must be taken into account which also contributes to the lifetime of the battery. Table I are taken from the statistical data of MEDUSA-II node - a sensor node developed at the University of California, Los Angeles.

IV. Conclusions

Work done so far has concentrated on maximizing the life time of the sensor nodes by designing power aware algorithms without involving the energy source. In the proposed work a different approach would be taken up where the focal point will be the battery of the sensor node itself. If only a quantitative analysis is taken up as how the energy of the battery is consumed during the various modes of the sensor node like active, listening and sleeping modes along with the energy consumed as a function of number of bits used while messaging, energy consumed while making the radio of the sensor node on from off state and energy that is consumed as a function of the distance and most importantly life of the battery as a function of ambience conditions of the surroundings in which the node is placed, then it would be possible to visualize the new strategies to use the energy very economically. Thus the face of all the power aware algorithms designed earlier could undergo phenomenal changes which would definitely further improve the life time of the sensor networks.

References

[1] Abrams, Z., Goel, A., Plotkin, S.: Set *k*-cover algorithms for energy efficient monitoring in wireless sensor networks. In: ACM International Symposium on Information Processing in Sensor Networks (IPSN), pp. 424–432 (2004).

[2] Ahuja, S.K., Kini, S., Ramasubramanian, S.: Bounds on coverage time and node density for multi- modality sensing. Ad Hoc Networks (Elsevier) (2009).

[3] Ai, J., Abouzeid, A.A.: Coverage by directional sensors in randomly deployed wireless sensor networks, Journal of Combinatorial Optimization **11**(1), 21–41 (2006).

[4] Aly, M., Pruhs, K., Znati, T., Hunsaker, B.: The coverage problem for myopic sensors, In IEEE International Conference on Wireless Networks, Communications and Mobile Computing, pp. 964–968, (2005).

[5] Berman, P., Calinescu, G., Shah, C., Zelikovsky, A.: Power efficient monitoring management in sensor networks. In: IEEE Wireless Communications and Networking Conference (WCNC), pp. 2329–2334 (2004).

[6] Berman, P., Calinescu, G., Shah, C., Zelikovsky, A. "Efficient energy management in sensor networks", In: Pan, Y., Xiao, Y. (eds.) Ad Hoc and Sensor Networks: Wireless Networks and Mobile Computing, Nova Science, New York (2006).

[7] Brinza, D., Zelikovsky, A.: Deeps: Deterministic energy-efficient protocol for sensor networks. In: IEEE the 7th ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing (SNPD), pp. 261–266 (2006).

[8] Cai, Y., Lou, W., Li, M., Li, X.Y.: Target-oriented scheduling in directional sensor networks. In: IEEE Infocom, pp. 1–9, (2007).

[9] Cardei, M., Du, D.Z., "Improving wireless sensor network lifetime through power aware organization", Wireless Networks, **11**(3), 333–340 (2005).

[10] Cardei, M., Thai, M.T., Li, Y., Wu, W.: Energy-efficient target coverage in wireless sensor networks. In: IEEE Infocom, pp. 1976–1984 (2005).

[11] Cardei, M., Wu, J., Lu, M., Pervaiz, M.O.: Maximum network lifetime in wireless sensor networks with adjustable sensing ranges. In: IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pp. 438–445 (2005).

[12] Cheng, M.X., Ruan, L., Wu, W.: Coverage breach problems in bandwidth-constrained sensor networks, ACM Transactions on Sensor Network (ToSN) **3**(2), 1–23 (2007).

[13] Deshpande, A., Khuller, S., Malekian, A., Toossi, M.: Energy efficient monitoring in sensor networks, In: The 8th Latin American Symposium on Theoretical Informatics (also in LNCS, vol. 4957), pp. 436- 448 (2008)

[14] 14. Deshpande, A., Khuller, S., Malekian, A., Toossi, M.: Energy efficient monitoring in sensor networks, Technical Report, Computer Science Department, University of Maryland, USA (2009)

[15] Dhawan, A., Prasad, S.K.: Energy efficient distributed algorithm for sensor target coverage based on properties of an optimal schedule. In: The 15th International Conference on High Performance Computing (HiPC), also in LNCS, vol. 5374, pp. 269–281 (2008).
[16] Garey, M., Johnson, D.: Computers and Intractability: A Guide to the Theory of NPCompleteness, Freeman, New York (1979).
[17] Gu, Y., Ji, Y., Li, J., Zhao, B.: Qos-aware target coverage in wireless sensor networks, Wireless Communications and Mobile Computing (Wiley) (2009).
[18] Heinzelman, W.B., Chandrakasan, A.P., Balakrishnan, H.: An application-specific protocol architecture for wireless microsensor networks. IEEE Transactions on Wireless Communications 1(4), 660–670 (2002).
[19] Jaggi, N., Abouzeid, A.A.: Energy-efficient connected coverage in wireless sensor networks. In: The 4th Asian International Mobile Computing Conference (AMOC), pp. 77–86 (2006).
[20] Li, D., Cao, J., Liu, M., Zheng, Y.: K-connected target coverage in wireless sensor networks. In: The 1st International Conference on Combinatorial Optimization and Applications (COCOA), also in LNCS, vol. 4616, pp. 20–31 (2007).
[21] Liu, H., Wan, P., Yi, C.W., Jia, X., Kakki, S., Pissinou, N.: Maximal lifetime scheduling in sensor surveillance networks. In: IEEE Infocom, pp. 2482–2491 (2005).
[22] Liu, H., Wan, P., Jia, X.: Maximal lifetime scheduling for k to 1 sensor-target surveillance networks, Computer Networks (Elsevier) 50(2), 2839–2854 (2006).
[23] Liu, H., Wan, P., Jia, X.: Maximal lifetime scheduling for sensor surveillance systems with k sensors to one target. IEEE Transactions on Parallel and Distributed Systems 17(12), 1–11(2006).
[24] Liu, H., Jia, X., Wan, P.J., Yi, C.W., Makki, S.K., Pissinou, N.: Maximizing lifetime of sensor surveillance systems. IEEE/ACM Transactions on Networking 15(2), 334–345 (2007).
[25] Lu, M., Wu, J., Cardei, M., Li, M.: Energy-efficient connected coverage of discrete targets in wireless sensor networks. International Journal of Ad Hoc and Ubiquitous Computing (Interscience) 4(3–4), 137–147 (2009).
[26] Motwani, R., Raghavan, P.: Randomized Algorithms. Cambridge University Press, Cambridge (1995).
[27] Prasad, S.K., Dhawan, A.: Distributed algorithms for lifetime of wireless sensor networks based on dependencies among cover sets. In: The 14th International Conference on High Performance Computing (HiPC), also in LNCS, vol. 4973, pp. 381–392 (2007).
[28] Pyun, S.Y., Cho, D.H.: Power-saving scheduling for multiple-target coverage in wireless sensor networks. IEEE Communications Letters 13(2), 130–132 (2009).
[29] Rolf, H.L.: Finite Mathematics, 7th Edition. Engage Learning (2007).
[30] Shih, K.P., Chen, H.C., Chou, C.M., Liu, B.J.: On target coverage in wireless heterogeneous sensor networks with multiple sensing units, Journal of Network and Computer Applications (2009).
[31] Slijepcevic, S., Potkonjak, M.: Power efficient organization of wireless sensor networks. In: IEEE International Conference on Communications (ICC), vol. 2, pp. 472–476 (2001).
[32] Vashistha, S., Azad, A.P., Chockalingam, A.: Efficient scheduling of sensor activity for information coverage in wireless sensor networks. In: IEEE the 2nd International Conference on Communication System Software and Middleware (COMSWARE) (2007).
[33] Wang, B., Wang, W., Srinivasan, V., Chua, K.C.: Information coverage for wireless sensor networks, IEEE Communications Letters 9(11), 967–969 (2005).
[34] Wang, B., Chua, K.C., Srinivasan, V., Wang, W.: Scheduling sensor activity for point information coverage in wireless sensor networks. In: International Symposium on Modelling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt) (2006).
[35] Wang, B., Vikram, S., Chua, K.C., Wang, W.: Information coverage and network lifetime in energy constrained wireless sensor networks. In: IEEE the 32rd Conference on Local Computer Networks (LCN), pp. 512–519 (2007).
[36] Wang, C., Thai, M.T., Li, Y.,Wang, F.,Wu,W.:Minimum coverage breach and maximum networklifetime in wireless sensor networks. In: IEEE Global Telecommunications Conference (Globecom), pp. 1–6 (2007).
[37] Wang, C., Thai, M.T., Li, Y., Wang, F., Wu, W.: Optimization scheme for sensor coverage scheduling with bandwidth constraints. Optimization Letters 3(1), 63–75 (2009).
[38] Wang, J., Niu, C., Shen, R.: Randomized approach for target coverage scheduling in directional sensor network. In: International Conference on Embedded Software and Systems, (ICESS), also in LNCS, vol. 4527, pp. 379–390 (2007).
[39] Yang, S., Dai, F., Cardei, M., Wu, J.: On multiple point coverage in wireless sensor networks. In: IEEE International Conference on Mobile Ad-hoc and Sensor Systems (MASS), pp. 757–764 (2005).
[40] Yang, S., Dai, F., Cardei, M., Wu, J., Patterson, F.: On connected multiple point coverage in wireless sensor networks. International Journal of Wireless Information Networks (Springer) 13(4), 289–301, (2006).
[41] Zhao, Q., Gurusamy, M.: Lifetime maximization using observation time scheduling in multihop sensor networks. In: IEEE/CreateNet International Workshop on Broadband Advanced Sensor Networks (BroadNets) (2005).
[42] Zhao, Q., Gurusamy, M.: Maximizing network lifetime for connected target coverage in wireless sensor networks. In: IEEE International Conference onWireless and Mobile, Networking and Communications (WiMob), pp. 94–101 (2006).
[43] Zhao, Q., Gurusamy, M.: Optimal observation scheduling for connected target coverage problem in wireless sensor networks. In: IEEE International Conference on Communications (ICC), pp. 3728–3733, (2007).
[44] Zhao, Q., Gurusamy, M.: Connected k-target coverage problem in wireless sensor networks with different observation scenarios. Computer Networks (Elsevier) 52(11), 2205–2220 (2008).
[45] Zhao, Q., Gurusamy, M.: Lifetime maximization for connected target coverage in wireless sensor networks. IEEE/ACM Transactions on Networking 16(6), 1378–1391 (2008).