International Journal of Business and Technology

Volume 2
Issue 1 *Fall 2013*

Article 2

November 2013

Estimation and Improvements of the Fundamental QoS in Networks with Random Topologies

Zhilbert Tafa
University for Business and Technology, tafaul@t-com.me

Estimation and Improvements of the Fundamental QoS in Networks with Random Topologies

Zhilbert Tafa

Faculty of Computer Science and Information Systems
University of Business and Technology Prishtina, Kosovo
tafaul@t-com.me

Abstract: The computer communication paradigm is moving towards the ubiquitous computing and Internet of Things (IoT). Small autonomous wirelessly networked devices are becoming more and more present in monitoring and automation of every human interaction with the environment, as well as in collecting various other information from the physical world. Applications, such as remote health monitoring, intelligent homes, early fire, volcano, and earthquake detection, traffic congestion prevention etc., are already present and all share the similar networking philosophy. An additional challenging for the scientific and engineering world is the appropriateness of the alike networks which are to be deployed in the inaccessible regions. These scenarios are typical in environmental and habitat monitoring and in military surveillance. Due to the environmental conditions, these networks can often only be deployed in some quasi-random way. This makes the application design challenging in the sense of coverage, connectivity, network lifetime and data dissemination. For the densely deployed networks, the random geometric graphs are often used to model the networking topology. This paper surveys some of the most important approaches and possibilities in modeling and improvement of coverage and connectivity in randomly deployed networks, with an accent on using the mobility in improving the network functionality.

Keywords: QoS, random topologies, autonomous, wirelessly networked

1 Introduction

Starting from e-mail communications and static web page applications, computer networking and Internet technologies have extended their services through the social networking and multimedia applications to the actual third step of their evolution: ubiquitous computing and IoT. While the Internet revolution led to interconnection between people at an unprecedented scale and pace, the next revolution will be the interconnection between objects to create smart environment [1]. Simultaneous development in circuit integration, greater unification in data representation as well as the developments in wireless networking technologies such as 4G-LTE, WiFi, WiMax, wireless sensor networks (WSNs) etc., bring up all the needed infrastructure for moving a step forward towards full integration of the ICT into every domain of the human interaction with the environment.
The IoT trends incorporate context-aware computation aggregated from the network of small unobtrusive devices that integrate sensing, computation, communication. The need for unobtrusiveness makes the devices limited in most of the resources, hence making the whole system design more complicated and challenging. The usual IoT networking infrastructure that interfaces the environment pose a specific philosophy of networking design, starting from the physical layer, through MAC and routing to the data aggregation and knowledge extraction. The challenges become more accentuated when it comes to the applications where the only way to deploy the network is quasi-randomly. In these applications, network have to self-organize, to cope with node failure, with energy-aware routing and MAC issues, to obtain the multi-hop connectivity and the needed redundancy in the environment with obstacles, to achieve the immunity to noise and mechanical influences, etc.
In this paper, an aspect of the ubiquitous computing is covered from the fundamental Quality of Service (QoS) problems' point of view - the coverage and connectivity. The analysis covers the cases when the networks are deployed quasi-randomly and its physical topology is modeled using the concept of random geometric graphs. The rest of the paper is structured as follows. Section 2 presents an overview on the architecture, the critical challenges, and the applicability of the ubiquitous networks. The emphasis is given to the quasi-randomly deployment scenarios. The network modeling and the mathematical description of the deployments are given in Section 3 while the methodologies for evaluation and improving two fundamental QoS issues such as the coverage and connectivity are given in Section 4. Section 5 presents future possible improvements and concludes the paper.

2 The infrastructure of pervasive computing: challenges and random deployments

From the connectivity and data communication point of view, ubiquitous networks are mainly composed of up to three layers (Fig. 1).

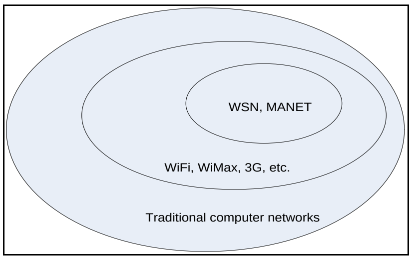

Fig. 1. The communication infrastructure of pervasive computing.

The top layer is consisted of traditional computer networks that enable the data transfer to the point of visualization, storage, and analysis. Alternatively, personal user devices (PDA, mobile phones) can directly communicate with the lower layer, bypassing the middle or the upper layer and directly executing applications that measure and visualize the information of interest. The lowest layer, on the other side, always include sensors or/and actuators equipped with wireless transceivers and usually organized into the ad-hoc wireless networks. These WSNs present the most critical part of the application. The middle layer is consisted of sink nodes and gateway devices that aggregate data and communicate the information between lower and top level networks. This level involves border technologies that interface between wireless and wired networks or between two wireless networks, taking care of transferring the data from the whole region of interest to the largest integration points towards internetworking technologies. Some examples of typical IoT applications are shown in Figure 2.

Fig. 2: An example of IoT environment.

The lowest level of the ubiquitous networks' connectivity differs from traditional computer networking in the sense of the networking architecture, hardware capabilities and protocol design. Actually, the design of the mesh ad-hoc wireless networks inherits the design issues of the traditional wireless networks with the addition of many other issues that need to be addressed.

First, the WSN is made of small devices that are directly embedded into the environment; hence they experience the electro-mechanical influences (e.g. physical movement, the proximity to various electromagnetic sources, increased humidity or temperature, etc.).

Second, these devices are battery supplied. This means that the process of implementation and the design of communication protocols (routing, medium access, and even the top layer protocols) have to be energy aware because some applications are meant to last for months or a year without human intervention. This means that the cross-layer design is the only approach that optimizes the performances.

Finally, because of the physical dimensions and the energy issues, the micro devices are very limited in ICT resources. This additionally limits the range of the available communication mechanisms and the available networking protocols.

On top of the mentioned issues, there is a range of applications that involve a kind of the random deployment. By inserting this sort of physical topology unpredictability in the application design, the design itself becomes more complicated in the sense of coverage, connectivity, data dissemination, and network lifetime.

Obviously, and as noted in [2] as well, the scientific challenges that must be overcome in order to realize the enormous potential of the WSNs are substantial and multidisciplinary in nature. In [3], more than 200 pervasive computing applications are listed. Among those, the greatest interest is shown in medical applications, industry, science, telemetry, intelligent environments, and military applications. The lower layer of the ubiquitous network architecture is used to communicate the information about the presence/intrusion of the objects or humans (e.g.,

DOI: 10.33107/ijbte.2013.2.1.02

based on combination of infrared, photoelectric, laser, acoustic, vibration sensors); presence of the chemical, biological, radio, nuclear and toxic materials; in taking images and in ranging (e.g., RADAR, LIDAR, ultrasonic etc.). Examples of pervasive military applications are given in [4]. Beside the various range of signal types, the major reason that makes military applications specific is related to the deployment area. These networks are often deployed in “unfriendly” environments such as battlefield. In these occasions, the networks have to self-organize, be resistant to jamming, mechanical influences, direction finding, and other electronic warfare threats, and provide end-to-end security at the same time. Moreover, these networks are sometimes deployed by using artillery or aircrafts which means that the nodes will not be placed at the optimal predefined positions and the evaluation and improvement of the Quality of Service (QoS) parameters will be more complicated. In these networks, before dealing with the optimization issues the network functionality need to be achieved. This means that the fundamental QoS parameters such as the network coverage and connectivity should primarily be treated. In context of deploying the network on the inaccessible regions for the purpose of intrusion detection and identification or border surveillance, the coverage is defined either regarding a given region (as the union set of the sensing fields around all the nodes) or as the coverage built of a chain of nodes. On the other hand, the minimum connectivity is defined as the ability of each node to communicate the information to the sink node. Similarly, the k-coverage and k-connectivity are defined as the ability of the network to cover the specific point of the area of interest by k sensing fields of k nodes and the ability of each node to have connectivity with k other nodes, respectively. Because of the similar nature of the sensing and radio-wave propagation, as shown in [5], in a homogenous network, the connectivity is implied by the full coverage if the transmission radius is not less than twice the sensing radius (and when the Boolean sensing/connection model is assumed). This makes the analysis reductive to one of the concept: either coverage or connectivity.

In most of the implementations, the coverage or connectivity measures are related to the context of the area, a specific direction, or a specific line. In the first case, we deal with the area coverage. The second case covers the best-case and worst-case coverage/connectivity, while the last case covers the barrier coverage/connectivity.

The focus of the proceeding material is on modeling and improvement of the coverage and connectivity in the most typical quasi-random implementations.

3 Network modeling and estimation of the fundamental QoS parameters

Fundamental QoS parameters of a network are related to its ability to collect the information of interest from the physical world and to communicate this information to the data center.

Basically, there are two major parameters that influence these QoS measures: a) the sensing and communication model, and b) the deployment manner. Generally, given the exact or approximate positions of the nodes, along with the sensing/communication model, the minimum coverage and connectivity quality, i.e., the application functionality can be estimated.

The most common sensing models are Boolean ([6]-[8]), Elfe’s [9], general model ([10]-[12]), shadow-fading [13] and Neyman – Pearson [14]. Similarly, communication pattern modeling also includes some probabilistic models, i.e., mathematical electromagnetic radiation models where the environmental influences are incorporated. The deployment styles can be deterministic or stochastic. This paper is focused on the mathematical modeling and improvements of the fundamental QoS parameters in the randomly deployed networks. The model involves the approximations that are appropriate for using the probabilistic approach to build simulators for the analysis of the large-scale randomly-deployed surveillance networks. The simulations are based on random geometric graphs. Future work should, however, address and improve the modeling issues that introduce the evaluation errors.

Firstly, even though all the other mentioned models are more accurate in case of isolated systems of small number of nodes where the terrain and object topology is priory known, using the Boolean model is the most common way to modeling the sensing/communication field in the densely deployed networks (that can consist of thousands of nodes), where there is no prior information on terrain-specific electromagnetic obstacles and influences, and where the nodes are placed at random. Boolean model models the sensing and communication area as a disk with a certain sensing or communication range, respectively. In case of area coverage, the union set of the sensing fields represent the area of the covered region. When dealing with line-wise coverage (barrier coverage, best case coverage, etc.), two nodes are considered as connected in a virtual (sensing) way when the distance between them is smaller than twice the sensing radius. On the other hand, when dealing with connectivity, two nodes are considered as connected if the distance between them is smaller than the communication radius. Bearing in mind that the sensing and communication patterns are not of a regular shape, i.e., are not of same intensity in all the directions (especially in the presence of obstacles), it is obvious that using the Boolean model in a homogenous way, inserts some modeling error that should be taken into consideration.

Second error is inserted from the mathematical formulation of the deployment probabilistic nature. Regarding the deployment randomness, there are two common assumptions that are used in literature: a) the assumption of

Poisson distribution to represent the quasi-uniformly scattered network, and b) the assumption of Gaussian distribution (to model the network topology when the network is deployed from the aircrafts).
Finally, the model assumes that there are no node failures immediately after the initial installation which is quite an unrealistic assumption, especially when the nodes are dropped in a way.
Although practically rarely achieved, as shown in [15], when the number of nodes per unit area is increased, Poisson distribution becomes an appropriate way to represent the random uniform distribution of the nodes on the area. Here, each node has an equal likelihood of being at any location within the deployed region. This representation of the position of the nodes is also referred as the location model. Therefore, when the sensors are scattered uniformly and independently across the region, the location of the nodes can be described by Poisson point process with intensity λ:

$$P(N(A)=k)=\frac{e^{-\lambda A}(\lambda A)^k}{k!} \quad (1)$$

On the other hand, the situation when sensors are thrown from the aircraft intuitively would be more accurately modeled if sensor distribution was considered to be nearly uniform or normally distributed along the axis of flight, while it is Gaussian in the orthogonal direction. The probability distribution along the y axis (orthogonal to the flight line-axis) is:

$$f(y)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(y-\mu)^2}{2\sigma^2}} \quad (2)$$

where μ is the mean that represents the line of flight and the σ^2 is the y-axis offset variance which represents the measure the positions of nodes are expected to vary along the y-axis due to the influence of many factors such as: wind, variable flight speed, inertia, terrain characteristics, etc. Although the influence of these factors is not treated separately, a simple model given above can, to some extent, serve as an approximation when a combined influence of all these factors can be estimated and encapsulated into the concept of σ. According to the 68-95-99.7 rule for the Gaussian distribution, 68% of the nodes are likely to be situated in proximity ±σ to the flight line. Similarly, 95% and 99.7% of the number of nodes are expected to fall within the distance ±2σ and ±3σ from the line of flight, respectively.
As shown in [16], when the network is quasi-uniformly distributed over the region, if $S=\{s_i\}, i=1,2,\ldots k$ are the nodes whose sensing/communication ranges cover the point P(x_i,y_i), if Rs and A are the sensing radius and the area of interest, respectively, if the boundary effects are neglected and the Boolean sensing model is used, the probability that the coverage/connectivity will be provided at some point by any arbitrary node would be $p=\frac{\pi Rs^2}{A}$. Consequently, the probability that a point will be covered by at least one of the N nodes is equal to the coverage fraction:

$$Pa=1-(1-p)^N=1-\left(1-\frac{\pi R_S^2}{A}\right)^N\approx 1-e^{-Np} \quad (3)$$

With the assumption given by the relation (1), the connectivity and coverage along a specific path in the region can also be estimated. By using the above given notations, the probability that k nodes will be located in a region A can be described with:

$$P(N(A)=k)=\frac{e^{-\rho A}(\rho A)^k}{k!} \quad (4)$$

Now, the probability that none of the nodes are within a given zone, would be:

$$P(N(Y)=0)=e^{-\rho A} \quad (5)$$

On the other hand, if the trajectory can be interpolated by analytical functions $f_i(x)$, each with starting and ending x coordinate A_i and B_i, respectively, the coverage of the network along a given path can be formulated with:

$$P_{di}=1-e^{-\rho(2r\int_{Ai}^{Bi}\sqrt{1+(f_i'(x))^2}+\pi r^2)} \quad (6)$$

Finally, the weak barrier coverage is a special case of the above relation, if the axes are rotated. In this case, the coverage probability can be expressed with:

$$P(detection)=1-e^{-2\rho rh} \quad (7)$$

where h is the width of the belt-like region. In military most of the applications, the probability higher than 0,95 is considered to be satisfying. However, as shown in [17], in a strip-like region of a finite length, the percolation never occurs.
The strong barrier coverage is mostly treated by simulation tools. Since the purpose of application here is to assure the network coverage across a given line (of border), the relations (1) and (2) are used to represent the space diversity of the nodes in a belt like region, i.e., in a region that is much longer than wide. The topology models the scenario of intrusion detection or border surveillance in military applications. Based on the given formulations, for the purpose of analysis and comparison, a simulation-based approach is used in [18]. Similarly, in [19] the authors develop the algorithms and simulation framework and show that, given the equivalent regions, i.e., the width of the region when the network is uniformly distributed to be of 6σ, the uniform-Gaussian distribution over performs the uniform distribution in 40-50% of savings in the number of nodes for the same probability (higher

https://knowledgecenter.ubt-uni.net/ijbte/vol2/iss1/2
DOI: 10.33107/ijbte.2013.2.1.02

than 0,95). It is also shown that the sensing/communication radius has the greater influence in fundamental network QoS parameters. The second parameter is the deployment preciseness, and the last one the deployment density.

4 Methodologies for improving the fundamental QoS in randomly deployed networks

From the given network deployment inputs, it is obvious that the improvement methodologies should be focused towards increasing the r and ρ, and decreasing the σ parameter. The first solution is sometime unfeasible. The sensitivity and the radiation strength often cannot be changed either due to the physical sensing phenomenon or due to the energy constraints. On the other hand, increasing the network density implies the gain in the overall network cost. In addition, It has been observed in practice that a sensor network cannot be too dense because of spatial reuse; specifically, when a particular node is transmitting, all other nodes within its transmission radius must remain silent to avoid collision and corruption of data [20]. Finally, it is sometime hard for the greater network deployment preciseness to be achieved.
There is, however the fourth alternative to the above mentioned methods. The methodology includes the mobility in the network. In a network, some or all nodes may be able to move at some extent. Usually, either sink nodes, relay nodes, or sensor nodes are used for the network quality improvement. Alternatively, mobile robots can be used to improve the network performances. The mobility can be used to improve the design in all the layers of the protocol stack. For example, Mobile Low Energy Adaptive Clustering Hierarchy (M-LEACH) is an extension of the widely used LEACH data propagation and routing method which adds mobility to the network and reduces the consumption of the network resources [21]. Practically, the sink and relay mobility are used in prolonging the network lifetime while the approach of using robots and mobile nodes is used in fundamental coverage and connectivity improvements.
In uniformly deployed networks, the repulsive and attractive forces, i.e., the vector-based approaches are mostly used to move the nodes at the desired positions. The optimal positions are calculated by using Voronoi diagrams ([22]-[26]), Delaunay triangulation [27], quorum-based approaches ([28], [29]) or the grid structures such as triangular, hexagonal, or squares ([30]-[33]).
In Voronoi diagram Fig. 3, each point in a given polygon is closer to the node in this polygon than to any other node. This maximizes the coverage and minimizes the intersections in coverage fields. If all the Voronoi polygons are covered by at least one node, the minimum area coverage degree can be considered as achieved.

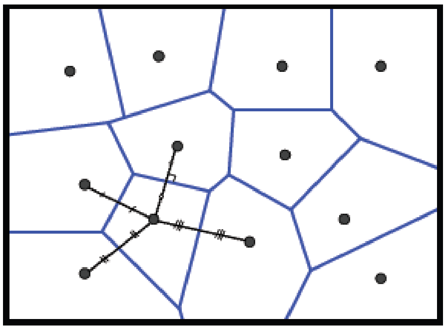

Fig. 3: Voronoi diagram.

The Delaunay triangulation given in Fig. 4 is the geometric dual of the Voronoi diagram.

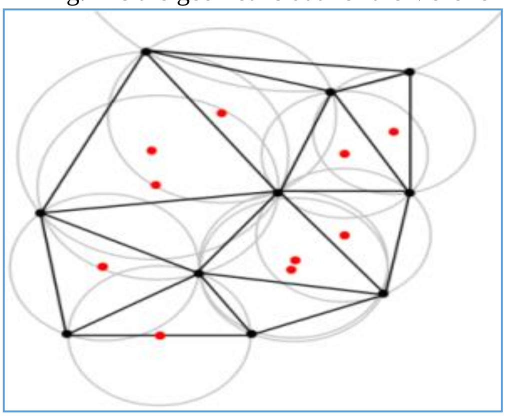

Fig. 4: Delaunay triangulation.

Delaunay triangulation can be defined as the triangulation of the sites with the property that for each triangle, the circum circle of that triangle is empty of all the other sites. This means that the centre of the largest empty circle has the weakest detection probability (and also the weakest radio signal presence, if considered in context of connectivity). In conjunction with the given methods, Potential Field Algorithm (PFA) given in [34] as well as Virtual Force Algorithm (VFA) given in [35] and can be used for the achievement of both coverage and connectivity.
In improving the line-wise coverage and connectivity, e.g., the strong barrier coverage, when there is some sort of the mobility in the network, there are two methodologies: a) when some nodes of the network are mobile, and b) when the robots can help in achieving the needed coverage/connectivity quality. Alternatively, the network can contain only mobile nodes, but this option greatly impacts the overall cost of the network.
An approach for controlling and moving the mobile nodes is shown in Fig. 5.

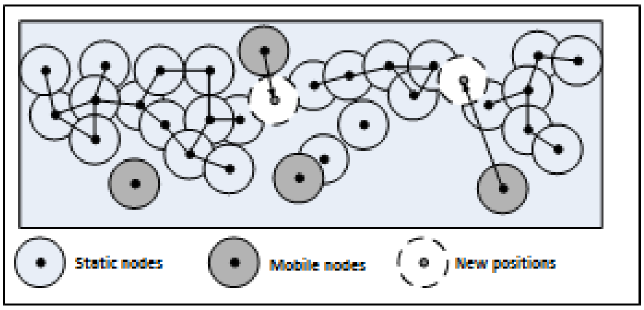

Fig. 5: Movement control in a network with mobile nodes.

The mobile nodes are dispersed along with the fixed nodes. The network is self-organized in ad-hoc manner and creates the connected and trivial graphs both in coverage and in connectivity sense. When a gap towards the destination appears, the nearest mobile node is informed by the largest connected (or even trivial) graph. After this node takes the position in the direction of destination, if the gap still persists, another nearest mobile node is informed about the gap. The algorithm continues in the direction from one site called source (S) to another site called destination (D). The information on the gap positions can be communicated locally to the mobile nodes, but this approach introduces the risk of not having any mobile node into the communication range of the farthest static node towards the destination that is part of the connected graph. Nevertheless, in a uniformly deployed dense network with a relatively high number of mobile nodes and with the communication range much higher than the sensing range, this situation is unlikely to happen.
Alternatively, the information can be communicated to the "secure sites" of the network. In this scenario, the robot(s) can move to the node that is part of the largest connected graph and that is at the same time the farthest one towards the destination D. In this scenario, the robots can inspect the area around those (MAX) nodes, and can calculate the optimal positions where they should place another node in order for the full barrier coverage and network connectivity to be improved. This method however, can be unfeasible when deployed in the terrain with lot of obstacles. In these situations, increasing the network density to some extent could be the only solution.

5 Conclusions and future work

Ubiquitous computing is becoming the next step of the ICT evolution. While cloud computing, as the most recent paradigm to emerge, promises reliable services delivered through next generation data centers that are based on virtualized storage technologies [36], the underlying IoT networking infrastructures that are also the most critical part of the ubiquitous computing, have to cope with all the difficulties of direct interfacing the environment.
Beside the inherited ordinary computer network issues related to the MAC and routing protocols, security issues and all other aspect of the interfacing network, the design should be resource (computational, communication, memory) aware and energy aware.
This paper covers the parameters that directly influence the main functionality of a randomly deployed network, i.e. the network ability to collect and to transmit t data by using multi-hop infrastructure in a network with quasi-random physical topology. By relying on the concept of random geometric graphs, which is mostly used in representation of the random deployment in the large-scale surveillance networks, the paper presents the approaches on estimating and improving the fundamental QoS parameters such as coverage and connectivity. It surveys the most typical scenarios, their modeling (approximation) errors and the most popular improvement approaches in literature.
Still, the feasibility of the mentioned methodologies is highly application specific. Accordingly, the model should incorporate the terrain-specific data and should also include the node failure probability. Therefore, the future

DOI: 10.33107/ijbte.2013.2.1.02

research should include the Digital Terrain Modeling (DTM) techniques to integrate data (regarding the geographic shapes) into the deployment and sensing/communication models, resulting in modification of the disk-based graphs. After defining the shapes and content of the terrain, by using segmentation and the multimedia data extraction as give in [37] for the case of cultural heritage multimedia data retrieval model, conceptual modeling could also be used in presenting the relations between the various environmental and deployment factors as well as their influence to the network modeling and simulation environment. Such an adaptive modeling of the networking topology would consequently lead to the more accurate estimations and improvements.

References

1 J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, “Internet of Things (IoT): A vision, architectural elements, and future directions,” Springer: Future Generation Computer Systems, vol. 29, pp. 1645-1660, 2013.

1. F. Akylidiz, W. Su, Y. Sankarasubramaniam, E. Cayirici, “Wireless sensor networks: a survey, Computer Networks, vol. 38, pp. 393-422, 2002.
2. K. Sohraby, D. Minoli, and T. Znati, “Wireless Sensor Networks: Technology, Protocols, and Applications,” A John Wiley & Sons, 2009.
3. Pejanovic, M., Tafa, Zh., Dimic, G., Milutinovic, V., “A Survey of Military Applications of Wireless Sensor Networks,” Proc. of IEEE Mediterranean Conference on Embedded Computing, Bar, Montenegro, pp. 196-199, 2012.
4. X. Wang, G. Xing, Y. Zhang, C. Lu, R. Pless, and C. Gill,“ Integrated Coverage and Connectivity in Wireless Sensor Networks,” Proceedings of the 1st International Conference on Embedded Sensor Systems, pp. 28-39, 2003.
5. Tian and N. D. Georganas, “A Coverage Preserving Node Scheduling Scheme for Large Wireless Sensor Networks,” in ACM International Workshop on Wireless Sensor Networks and Applications, pp. 32–41, 2012.
6. F. Ye, G. Zhong, S. Lu, and L. Zhang, “Peas: A Robust Energy Conserving Protocol for Long-lived Sensor Networks,” in Proc. ICDCS, 2003.
7. S. Shakkottai, R. Srikant, and N. Shroff, “Unreliable Sensor Grids: Coverage, Connectivity and Diameter,” in Proc. IEEE Infocom, 2003.
8. Elfes, “Occupancy Grids: A Stochastic Spatial Representation for Active Robot Perception,” in Autonomous Mobile Robots: Perception, Mapping, and Navigation, S.S. Iyengar and A. Elfes, Eds. Los Alamitos, CA: IEEE Computer Society Press, pp. 60-70, 1991
9. M. Hata, “Empirical Formula for Propagation Loss in Land Mobile Radio Services,” IEEE Transactions on Vehicular Technology, vol. 29, pp. 317–325, 1980.
10. Li, K. Wong, Y. Hu, and A. Sayeed, “Detection, Classification, Tracking of Targets in Micro-Sensor Networks,” in IEEE Signal Processing Magazine, 2002.
11. M. Chu, H. Haussecker, and F. Zhao, “Scalable Information-Driven Sensor Querying and Routing for Ad Hoc Heterogeneous Sensor Networks,” International Journal on High Performance Computing Applications, vol. 16, no. 3, pp. 293-313, 2002.
12. Y-R. Tsai, “Sensing Coverage For Randomly Distributed Wireless Sensor Networks in Shadowed Environments,” IEEE Transactions on Vehicular Technology, vol. 57, no. 1, pp. 556-564, 2008.
13. Kazakos and P. Papantoni-Kazakos, “Detection and Estimation,” Computer Science Press, 1990.
14. P.Hall, “Introduction to the Theory of Coverage Processes,” John Wiley & Sons, 1998.
15. Hossain, P.K. Biswas, and S. Chakrabarti, “Sensing Models and Its Impact on Network Coverage in Wireless Sensor Network,” ICIIS, Kharagpur, India, 2008.
16. B.Liu & D. Towsley, “A Study of the Coverage of Large-scale Sensor Networks,” IEEE International conference on Mobile Ad-Hoc and Sensor Systems, pp. 475-483, 2004.
17. Saipulla, C. Westphal, B. Liu, J. Wang, “Barrier Coverage of Line-Based Deployed Wireless Sensor Networks,” INFOCOM, pp. 127-135, 2009.
18. Z. Tafa, “Towards Improving Barrier Coverage Using Mobile Robots,” Proc. of IEEE Mediterranean Conference on Embedded Computing, Bar, Montenegro, pp. 166-169, 2012.
19. Ghosh and S. K. Das, Coverage and Connectivity Issues in Wireless Sensor Networks, In Mobile, Wireless and Sensor Networks: Technology, Applications and Future Directions, John Wiley & Sons, 2006.
20. T. Nguyen, X. Defago, R. Beuran, Y. shinoda, “An energy efficient routing scheme for mobile wireless sensor networks,” Proc. of the IEEE International Symposium on wireless Communication Systems, pp. 568-572, 2008.
21. Megerian S., Koushanfar, F., Potkonjak, M., and Srivastava, M. “Worst and Best-Case Coverage in Sensor Networks” IEEE Transactions on Mobile Computing, vol. 4 (1), pp. 84 – 92, 2005.

22. Wang, G. Cao, and T. L. Porta, "Movement-Assisted Sensor Deployment", Proceedings of IEEE INFOCOM, vol. 4, pp. 2469-2479, 2004.
23. J. Jiang, L. Fang, H. Zhang and W. Dou, "An Algorithm for Minimal Connected Cover Set Problem in Wireless Sensor Networks", Journal of Software, vol.17, no.2, pp. 175-184, 2006.
24. M. Viera, L. Viera, L. Ruiz, A. Loureiro, A. Fernandes and J. Nogueira, "Scheduling Nodes in Wireless Sensor Networks: a Voronoi Approach", Proceedings of the 28th Annual IEEE International Conference on Local Computer Networks, pp. 423-429, Bonn, Germany, 2003.
25. Aurenhammer, "Voronoi Diagrams – A Survey Of A Fundamental Geometric Data Structure," ACM Computing Surveys, pp. 345-405, 1991.
26. Ch-H. Wu, K-C Lee, and Y-C. Chung, "A Delaunay Triangulation Based Method for Wireless Sensor Networks," Computer Communications, vol. 30 (14-15), pp. 2744-2752, 2007.
27. X. Li, N. Santoro, "ZONER: a ZONE-based sensor relocation protocol for mobile sensor networks," Proc of the 6th IEEE conference on Mobile Ad-hoc and Sensor Systems, pp. 493-502, 2006.
28. X. Li, N. Santoro, I. Stojmenovic, "Mesh –based sensor relocation for coverage maintenance in mobile sensor networks, "Proc. of the 4th International conference on Ubiquitous Intelligence and Computing, pp. 696-708, 2007.
29. S. Yang, L. Minglu, J. Wu, "Scan-based movement-assisted sensor deployment methods in wireless sensor networks," IEEE trans. in Parallel Distrib. Systems, vol. 18, pp. 1108-1121, 2007.
30. Wang, G. Cao, T. Porta, W. Zhang, "Sensor relocation in mobile sensor networks," Proc of 24th annual joint conference of the IEEE computer and communications societies, pp. 2302-2312, 1005.
31. Mousavi, A. Nayyeri, N. Yazdani, C Lucas, "Energy conserving movement assisted deployment of ad hoc sensor networks, " IEEE Comm. Lett., vol. 10, pp. 269-271, 2006.
32. X. Li, H. Frey, N. Santoro, I. Stojmenovic, "Localized sensor self-deployment with coverage guarantee," ACM SIGMOBILE Mobile Computing Commun Rev, vol. 12, pp. 50-52, 2008.
33. Howard and S. Ponduri, "Potential Field Methods for Mobile-Sensor-Network Deployment" in N. Bulusu, S Jha "Wireless Sensor Networks A System Prespective", Artech House, London, 2005.
34. Y. Zou and Krishnedu Chakrabarty, "Sensor deployment and target localization based on virtual forces," Twenty-Second Annual Joint Conference of the IEEE Computer and Communcations Societies, vol. 2, pp. 1293-1303, 2003.
35. R. Caceres, A. Friday, "Ubicomp systems at 20: progress, opportunities, and challenges," IEEE Pervasive Computing, vol. 11, pp. 14-21, 2012.
36. S. Vrochidis, C. Doulaverakis, A. Gounaris, E. Nidelkou, and Y. Kompatsiaris, "A Hybrid Ontology and Visual-Based Retrieval Model for Cultural Heritage Multimedia Collections," International Journal on Metadata Semantics and Ontologies, vol.3, no.3, pp. 167-182, 2008.

https://knowledgecenter.ubt-uni.net/ijbte/vol2/iss1/2
DOI: 10.33107/ijbte.2013.2.1.02