M-073

ワイヤレスアドホックセンサネットワークにおいてのセンサ配置評価
Evaluation of Sensor Disposition in Wireless Ad-Hoc Sensor Networks

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1. Introduction

Wireless ad-hoc sensor networks have recently been emerging as a topic of conversation. Advancements in micro-sensor and communication technologies has made sensor networks applicable to environmental monitoring (such as stationary watch towers) or battlefield surveillance. The final research aim of the networks is to give the networks great long-term, economic, and potential benefits.

Though we can consider a variety of network scenarios [1], [2], [3], [4], [5], [6], [7], in this work, we consider the circumstance where networks hold their long-term life by remaining in stand-by mode of redundant monitors at a little sacrifice of detectability. In other words, in order to maintain long-term workdays we aim at a self-management service [8] for wireless sensor networks that, for the power saving, automatically controls the network redundancy in holding to an adequate certain level of higher value of detectability when the coverage is not perfect. Coverage represents the quality of service that it can provide and how well a region of interest is monitored by the network. However the life time of the network also represents the quality of service. The coverage approaches 0 as the network nears the end of life. This means that there is a trade-off in relationship between the coverage and the life time. In this work, we will investigate the detectability in each case of several different sensor placements where coverage is not enough and discuss an optimum sensor placement.

In order to find the optimum solution for sensor deployment, we will discuss the following items (1) ~ (4);

(1) In the binary sensing model, in order to evaluate the detectability taking the most time and using the most precise measure, we perform simulation experiments.

In order to evaluate the environment where many sensors are deployed in a narrow or vast geographical area,

(2) We will investigate the detectability in two different areas 100×100 m^2 and 1000×1000 m^2 where sensors are deployed.

Several papers use "exposure" as a computational measure [9], [10]. The measure "exposure" presupposes the general sensing model conceptually in terms of the sensing model. It is said that exposure is directly related to coverage where it is a measure of how well an object can be observed by the sensor network over a period of time. We will evaluate "exposure" by comparing it with the other new computational measure "closer".

(3) We will investigate the detectability with two measures "exposure" and "new" defined latter, and verify which is closer to the data which is obtained by the simulation experience, in other words, closer to the real data.

The detectability evaluated by the "exposure" watches only the weakest sensing-route, but not the average sensing-route in the sensor field. This means it is doubted that "exposure" can evaluate the detectability of the sensor disposition exactly. Instead of the evaluation of the weakest sensing-route, we try to consider a new computational tool to evaluate the average sensing-route.

(4) We will directly evaluate "All-Sensor Field Intensity".

This study, which is a combination of theoretical and simulated evaluations, quantifies the trade-off between power conservation and quality of surveillance while presenting guidelines for efficient deployment of sensor for the application to environmental monitoring.

This paper is organized as follows: In section 2, we prepare the technical terms which will be used in the later sections. Sections 3 and 4 present Detectability using binary sensors and Detectability using general sensors, respectively. Section 5 presents evaluation results in the case of "All-Sensor Field Intensity". This paper concludes in section 6 with a comparison of experimental and computational data.

2. Preliminaries

2.1 Coverage

The sensor field is assumed as two-dimensional. For enhanced coverage of the sensor field, a large number of sensors are typically deployed in the sensor field so as to get rid of uncovered point. Even if the coverage areas of multiple sensors overlap, the precise location of the target can be determined by examining the location of these sensors. We will consider the opposite circumstance where the absolute quantity of sensors is insufficient because of a secular change or other reasons. Since we consider in the case of an insufficient number of sensors, we will define the coverage N of sensor field as the ratio of the number of deployed sensors to (the necessary and sufficient number of nodes which leave no uncovered point in the grid distribution, as shown in Fig 1).

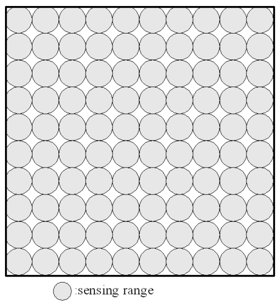

Fig. 1. Case of N=1

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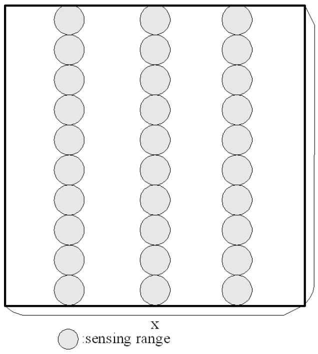

Fig. 2. Case of N=0.3

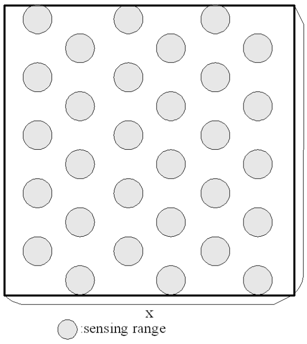

Fig. 3. Case of N=0.3

2.2 Sensor Deployment

We prepare three kinds of sensor deployment; Straight, Zigzag, and Random deployments. For each deployment, we will give formulas to automatically determine the deployment of all sensors with the parameters; coverage N, the sensor field X × Y, and the detection range r.

2.2.1 Straight deployment

We first define the straight deployment of N=1 as shown in Fig 1. This deployment is given by X × Y. The deployment of general N (<1) is given as the deployment whose number of columns is in the ratio of N to the number of columns of N=1. Fig 2 shows a straight deployment in the case of N=0.3.

2.2.2 Zigzag deployment

The zigzag deployment of N is given as the deployment when every even order sensor of each column is shifted to the next new column as shown in Fig 3 where a zigzag deployment in the case of N=0.3 is shown.

2.2.3 Random deployment

The location point (x_i, y_j) of each sensor s_i is given randomly.

2.3 Sensing Model

2.3.1 Binary sensing model

The binary sensor model assumes that sensor readings have no associated uncertainty. Consider an X by Y sensor field grid and assume that there are k sensors deployed in the random deployment stage. Each sensor has a detection range r. Assume sensor s_i is deployed at point (x_i, y_i). For any point p at (x, y), we denote the Euclidean distance between s_i and p as d(s_i, p), i.d. $d(s_i, p) = \sqrt{(x_i - x)^2 + (y_i - y)^2}$. The following equation shows the binary sensor model [7], [11] that expresses the coverage c_{xy} (s_i) of a grid point p by sensor s_i. $c_{xy}(s_i)$= 1or 0 if $d(s_i, p) < r$ or otherwise, respectively.

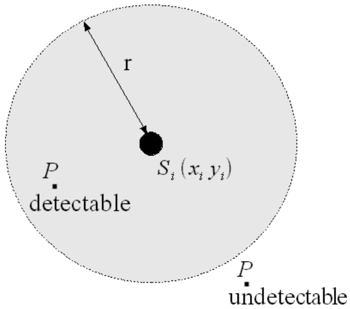

Fig. 4. Binary sensing model

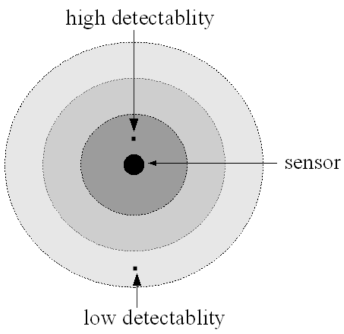

Fig. 5. General sensing model

2.3.2 General sensing model

General sensing model is a model whose sensing ability depends on the distance from the target as shown in Fig 5 [9]. All-Sensor Field Intensity is defined as $I_A(F,p) = \sum S(s_i,p)$, for a point p in the field F, that is, as the effective sensing measures at point p from all sensors in F, where sensor $S(s_i,p)$ is the general sensing model S at an arbitrary point p for a sensor s and defined as follows: $S(s,p)=\lambda / [d(s,p)]^{\kappa}$. The positive constants λ and κ are sensor technology-dependent parameters. In this work, we assume λ and κ are 1 and 2, respectively. The exposure path is defined as a route whose total value on the path is the smallest between source S and destination D. If we assume the value of each sensor as shown in Fig 6, then the exposure path takes a dashed line. Finally, in order to introduce a new measure, we define new Field Intensity as $I_A'(F,p) = \sum S'(s_i,p)$ where $S'(s,p) = [d(s,p)]^2$.

We refer to this identity as “closer”. A closer path is also defined as a route whose total value on the path is the smallest between source S and destination D. Though $S(s_i,p)$ and $S'(s_i,p)$ have the same sense that their paths trace so as to taking the smallest total value, the new measure “closer” expresses the larger difference in the domain where the target leaves from each sensor. “Exposure” does not express the larger difference in such a domain. Fig 7 shows the closer of each sensor and the path in this measurement. The divisional sizes in Figs 6 and 7 are determined at will.

2.4 Measure of Detectability

In binary sensing models, the detectability is measured as the ratio of the times that the target passes through the detection range of a sensor, to the total number of trials. On the other hand,

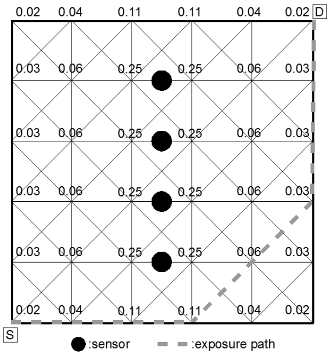

Fig. 6. Exposure path

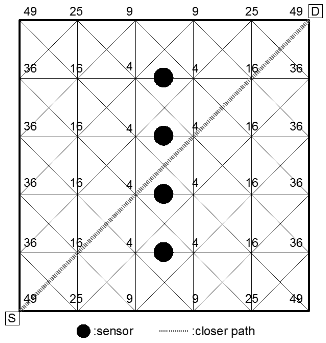

Fig. 7. Closer path

in general sensing models the detectability is measured as the exposure of the exposure path between the start and destination nodes [1]. In general sensing models, the detectability ismeasured also with the new measure "closer" of the closer path between the start and destination nodes.

2.5 Measure of "All-Sensor Field Intensity"

As defined in 2.3, the intensity by "exposure" of the sensor deployment shown in Fig 6 can be calculated as 0.02+0.04+0.11+…+0.04+0.02 by adding from left to right and from top to bottom. The intensity by "closer" of the sensor deployment shown in Fig 7, 49+26+9+…+25+49.

2.6 Simulation Method

Finally we describe the input parameters and output measures for the evaluation of the detectability in different sensor deployments. For the purpose of our simulation, we consider two square domains; 100×100 m and 1000×1000 m where sensors required for coverage between 90% ~ 10% are distributed in a variety of sensor deployments. In binary sensing models, the target is given randomly start and destination positions and moves in a straight line between the two positions at speed 1(m/s) where the average distances are taken as 50, 40, 30, 20, 10m in domain 100×100, and 500, 400, 300, 200, 100m in domain 1000×1000, respectively. The detectable rage of each sensor is a radius 5m. The detectability of a given sensor deployment is evaluated as the average by generating 100 different pairs of start and destination positions.

3. Detectability using binary sensor model

In this section, we present the results of simulations that is in the case of using binary sensors model. Figs 8~11 in Section 3, a plot the detectability and the average time interval required to detect with parameters of coverage N, average traversing distance of target, and sensor deployment, in the case of 100×100 m field. Figs 12~15 show the results in the case of 1000×1000 m field.

3.1 100×100 m field

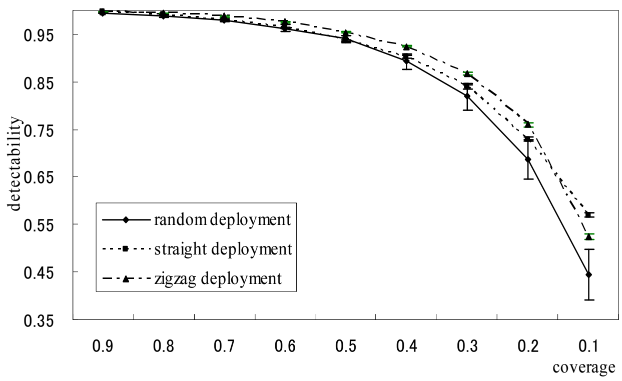

Fig. 8. Detectability
(average traversing distance 50m)

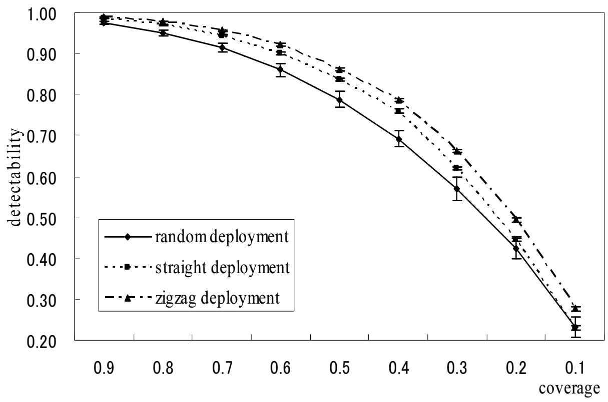

Fig. 9. Detectability
(average traversing distance 20m)

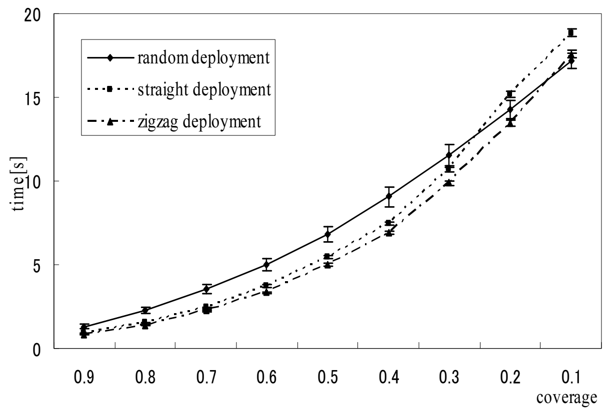

Fig. 10. Average time interval required to detect
(average traversing distance 40m)

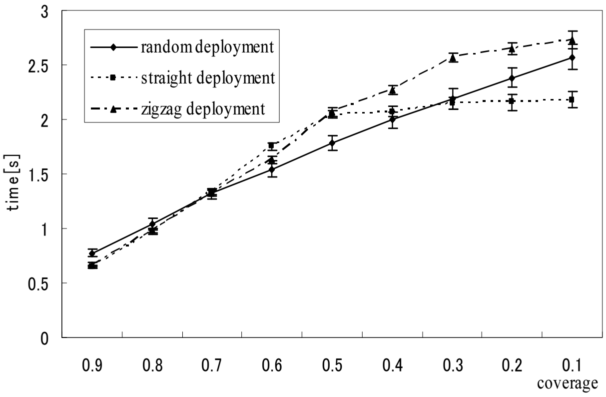

Fig. 11. Average time interval required to detect (average traversing distance 20m)

3.2 1000×1000 m field

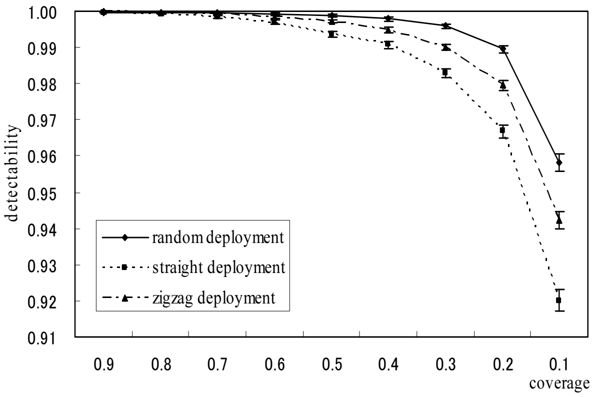

Fig. 12. Detectability (average traversing distance 500m)

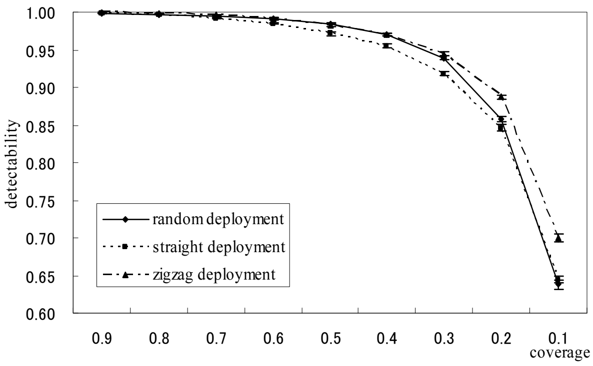

Fig. 13. Detectability (average traversing distance 100m)

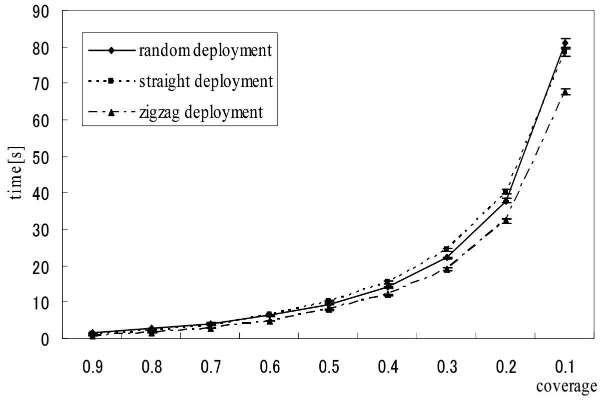

Fig. 14. Average time interval required to detect (average traversing distance 500m)

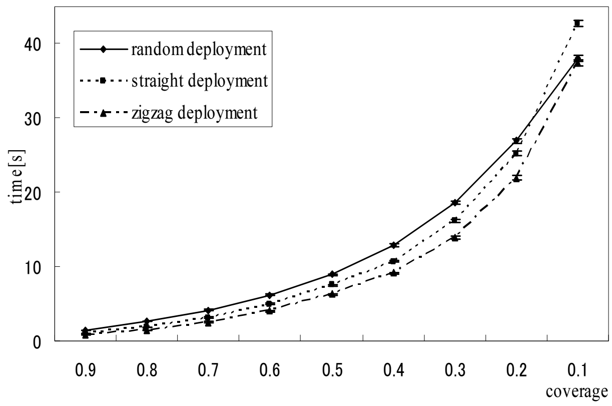

Fig. 15. Average time interval required to detect (average traversing distance 100m)

4. Detectability using general sensor model

In this section, in the case of using a general sensor as a computational model, the detectability is plotted as “exposure” in 4.1 and “closer” in 4.2 with the parameters: coverage N, average traversing distance of target, and sensor deployment.

4.1 Exposure

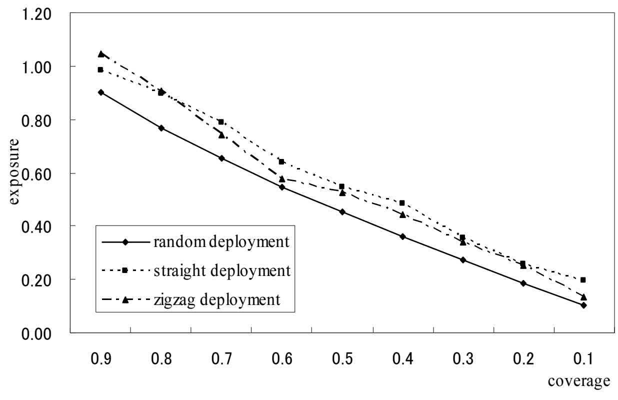

Fig. 16. Comparison in the case of “exposure” in 100×100 m field

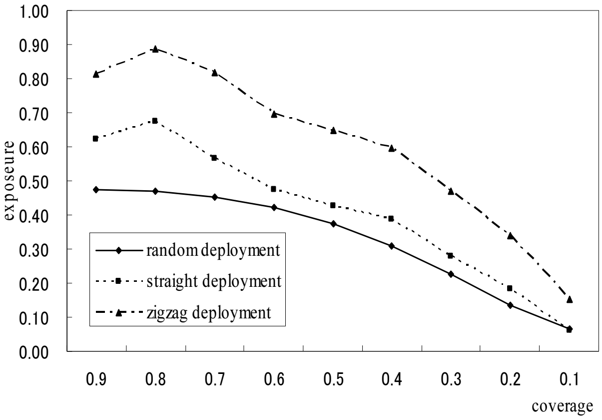

Fig. 17. Comparison in the case of “exposure” in 1000×1000 m field

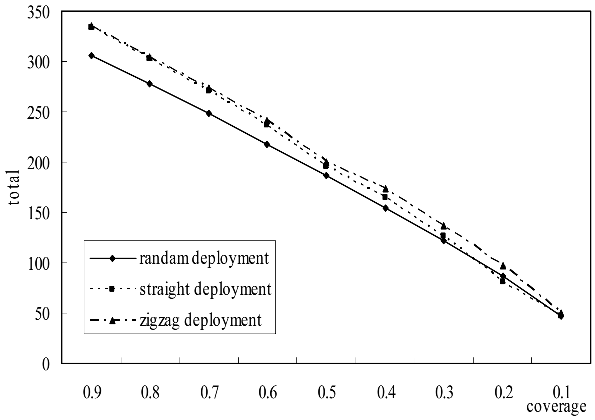

Fig. 20. Intensity by "exposure" in 100×100m field

4.2 Closer

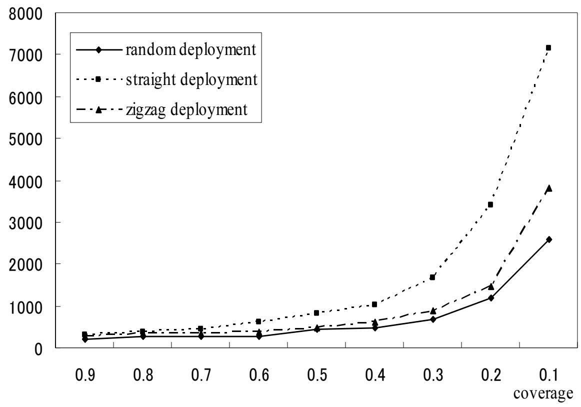

Fig. 18. Comparison in the case of “closer” in 100×100 m field

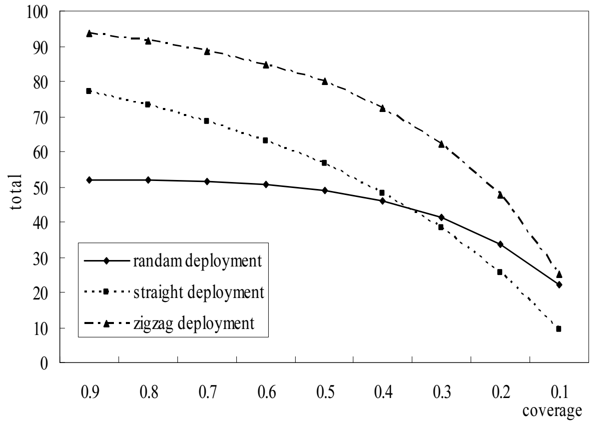

Fig. 21. Intensity by "exposure" in 1000×1000m field

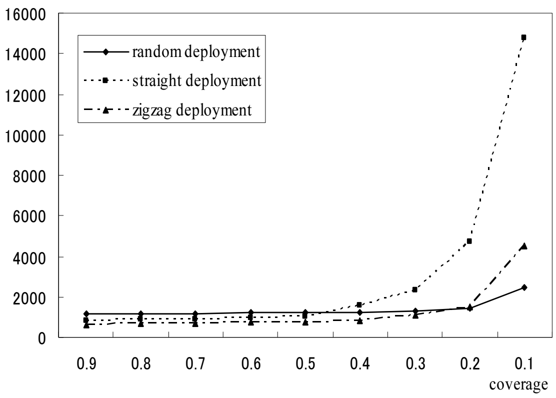

Fig. 19. Comparison in the case of “closer” in 1000×1000 m field

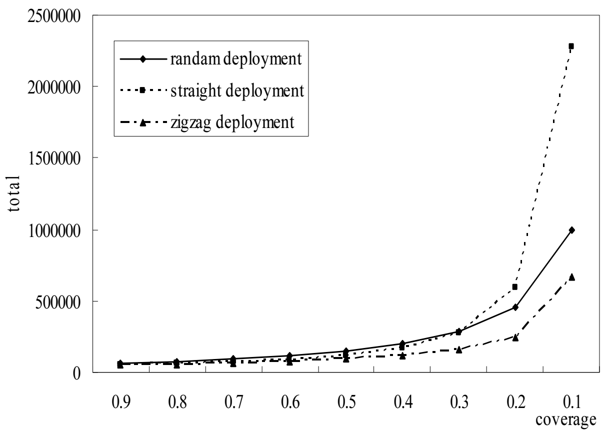

Fig. 22. Intensity by "closer" in 100×100m field

5. Detected-ability using “all-sensor field intensity”

In this section, we present the results in the case of using “All-Sensor Field Intensity”. Figs 20 and 21 show the intensity by “exposure”. Figs 22 and 23 show the intensity by “closer”. The divisional size is 50×50 in every case.

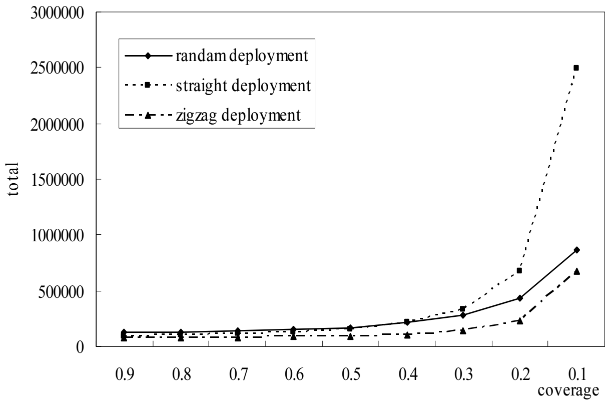

Fig. 23. Intensity by "closer" in 1000×1000m field

6. Conclusion

In this work, we prepared three kinds of sensor deployments; Straight, Zigzag, and Random deployments and evaluated each detectabilities. The experimental evaluation was performed with using several different measures. The results show little discrepancy among them in the easy discoverable circumstance (smaller domain, many sensors, and large average traffic traversal distance), but show the explicit superiority or inferiority in the opposite circumstance. In non-easy discoverable circumstance, though Binary sensing model (that is, simulation results) and the exposure of general sensing models show considerably the same experimental results, "All-Sensor Field Intensity" by "closer" is more close to the simulation results. Zigzag is indeed the best as the sensor deployment. The new closer path shows the different results from the simulation result. These experimental evaluations lead to the following conclusion: judging from the simulation result, the best deployment is Zigzag. In the circumstance where every deployed sensor operates as a binary model, the best computing evaluation in place of the simulation experience is "All-Sensor Field Intensity" by "closer". The discussion on the circumstance where every sensor operates as a general model is left to the future work.

References

[1] B.Liu and D.Towsly, "A study of the coverage of large-scale sensor networks," First IEEE Intrernational Conference on Mobile Ad-Hoc and Sensor Systems, pp.475–483 (2004).

[2] G.Wang, G.Cao, T.LaPorta, and W.Zhang, "Sensor relocation in mobile sensor networks," IEEE INFOCOM, vol.4, pp.2302–2312 (2005).

[3] S.Meguerdichian, F.Koushanfar, M.Potkonjak, and M.B.Srivastava, "Coverage problems in wireless ad-hoc sensor networks," IEEE INFOCOM, vol.3, pp.1380–1387 (2001).

[4] F.Xing, C.Lu, Y.Zhang, Q.Huang, and R.Pless, "Minimum power configuration for wireless communication in sensor networks," ACM Trans. on Sensor Networks, vol.3, pp.200–233 (2007).

[5] S.Balasubramanian and D.Aksoy, "Adaptive energy-efficient registration and online scheduling for asymmetric wireless sensor networks," Computer Networks, vol.51, pp.3427–3447 (2007).

[6] G.Wang, G.Cao, and T.L.Porta, "Movement-assisted sensor deployment," IEEE INFOCOM, vol.4, pp.2469-2479 (2004).

[7] K.Chakrabarty, S.S. Iyegar, H..Qi, and E.Cho, "Grid coverage for surveillance and target location in distributed sensor networks", IEEE Trans. on Computers, vol.51, pp.1448–1453 (2002).

[8] I.G.Siqueira, L.B.Ruiz, A.A.F.Loureiro, and J.M.Nogueira, "Coverage area management for wireless sensor networks," Int. J. Network Mgmt, vol.17, pp.17–31 (2007).

[9] S.Meguerdician, F.Koushanfar, G.Qu, and M.Potkonjak, "Exposure in wireless ad-hoc sensor networks," MOBICOM, pp.139–150 (2001).

[10] T.Clouqueur, V.Phipatanasuphorn, P.Ramanathan, and K.K.Saluja, "Sensor deployment strategy for target detection," First ACM International Workshop on Wireless Sensor Networks and Application, pp.42–48 (2002).

[11] Y.Zou and K.Chakrabarty, "Sensor deployment and target localization based on virtual forces," IEEE INFOCOM, vol.2, pp.1293–1303 (2003).