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High Perfomance Communication Protocol for Wireless Ad-Hoc Sensor Networks

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Abstract**—**In order to monitor for traffic traversal, sensors can be deployed to perform collaborative target detection. Such a sensor network achieves a certain level of detection performance with the associated costs of deployment and routing protocol. This paper addresses these two points of sensor deployment and routing algorithm in the situation where the absolute quantity of sensors or total energy becomes insufficient. This discussion on the best deployment system concluded that two kinds of deployments; Normal and Power law distributions, show 6 and 3 times longer than Random distribution in the duration of coverage, respectively. The other discussion on routing algorithm to achieve good performance in each deployment system was also addressed. This discussion concluded that, in place of the traditional algorithm, a new algorithm can extend the time of coverage duration by 4 times in a Normal distribution, and in the circumstance where every deployed sensor operates as a binary model.

Keywords**—**binary sensor, coverage rate, power energy consumption, routing algorithm, sensor deployment

I. Introduction

WIRELESS sensor networks place sensors into an area to collect data and send them back to a base station. These wireless ad-hoc sensor networks have recently been emerging as a popular topic of conversation [1], [2]. Advancements in micro-sensor and communication technologies have 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.

We can consider a variety of network scenarios [3]-[6] and many works has been considered when the coverage is almost perfect [7]-[11].

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 detection-ability. In other words, in order to maintain long-term workdays when the coverage is not perfect, we aim at a self-management service [12] for wireless sensor networks that, for the purpose of saving power, automatically controls the network redundancy in holding to an adequate certain level of higher value of detection-ability. 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 its 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 detection-ability in each case of several different sensor placements where coverage undergoes changes to insufficient levels. Since the coverage rate also depends on the routing protocol, we must discuss an optimum routing protocol associated with sensor placement.

In order to find the optimum solution for sensor deployment and the associative routing protocol, we must investigate what is the pair of sensor deployment and routing protocol which holds the highest coverage rate for a long time. We will mainly discuss the following 2 items:

1) In the binary sensing model, we will evaluate coverage by performing simulated experiment with sensor networks provided for Random, Normal, and Power law distributions of monitors.
2) We will evaluate the coverage rate by performing simulated experiments in sensor networks provided by traditional (AODV) protocol and 2 new protocols defined in this paper.

These above studies, which were performed by simulated evaluations, quantify the trade-off between power conservation and quality of surveillance while presenting guidelines for efficient deployment of sensors in the application of environmental monitoring.

Several papers use "exposure" as a computational measure of the detection-ability [13], [14]. The measure of "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 during a period of time. This "exposure" by comparing it with the other new computational measure of "closer" is evaluated in [3]. Though several other techniques such as data fusion [15] are also important, we will focus on the two above items.

This paper is organized as follows: In section II, we prepare the technical terms which will be used in the later sections. Section III presents the evaluation results. This paper concludes in section Ⅳ with the analysis of the experimental data.

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II. Preliminary

A sensor network is shown in Fig. 1 as an example. Communication between two sensors, or a sensor and a base station is performed by a multi-hop connection which is shown by the solid lines. Sensors without a stretched solid line are isolated sensors which cannot communicate with the base station. One of problems on a sensor network is how to connect the area covered by isolated sensors. Communication radius R_c and sensing radius R_s of each sensor have the following relation: $R_c > R_s$.

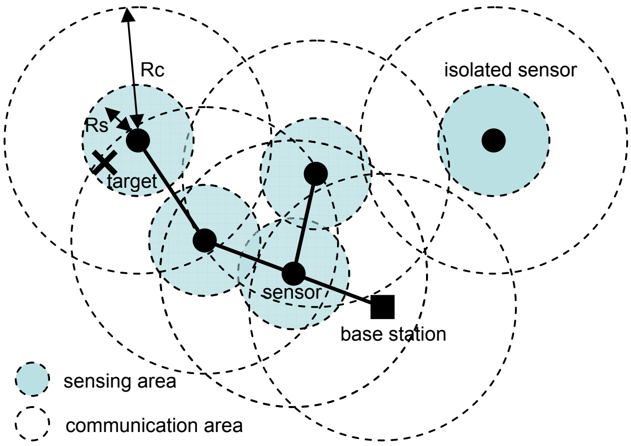

Fig. 1 A sensor network

2.1 Coveragee

The sensor field is assumed to be 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 points. 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 the case of an insufficient number of sensors, we will define the coverage rate of the sensor field as the ratio of covered area to overall area.

2.2 Sensor deployment

We prepared three kinds of sensor deployments: Random, Normal, and Power law distributions.

2.2.1 Random distribution

We first prepared the Random distribution. The location point (x_i, y_j) of each sensor s_i is given randomly.

2.2.2 Normal distribution

Sensor deployment was given in a Normal distribution whose function of probability density is given by (1),

$$f(r)=(1/2\pi\sigma^2)\, exp(-r^2/2\sigma^2) \quad (1)$$

where r is the distance from the base station, and σ^2 is variance, which can be determined actually by the shape, weight, and scattering height of sensors. Fig. 2 shows an example of this distribution.

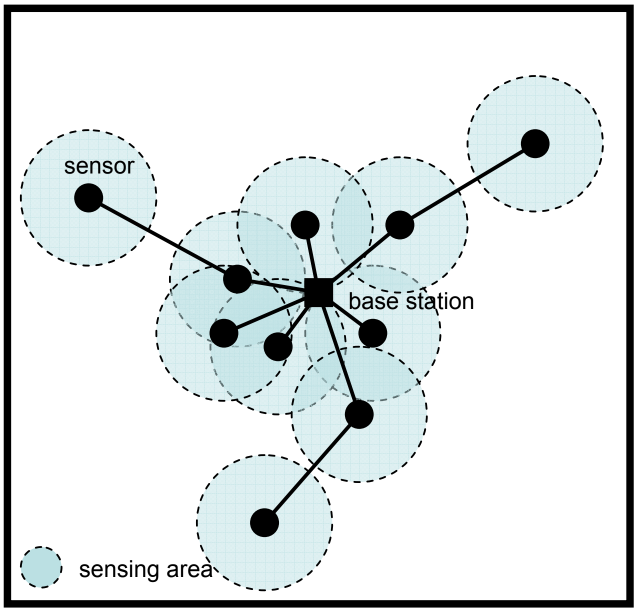

Fig. 2 Normal distribution

2.2.3 Power law distribution

Sensor deployment was given in a Power law distribution whose function of probability density is given by (2),

$$f(r)=1/2\pi rR \quad (2)$$

where R is the distance from the base station to the edge of the sensor field. Fig. 3 shows an example of this distribution.

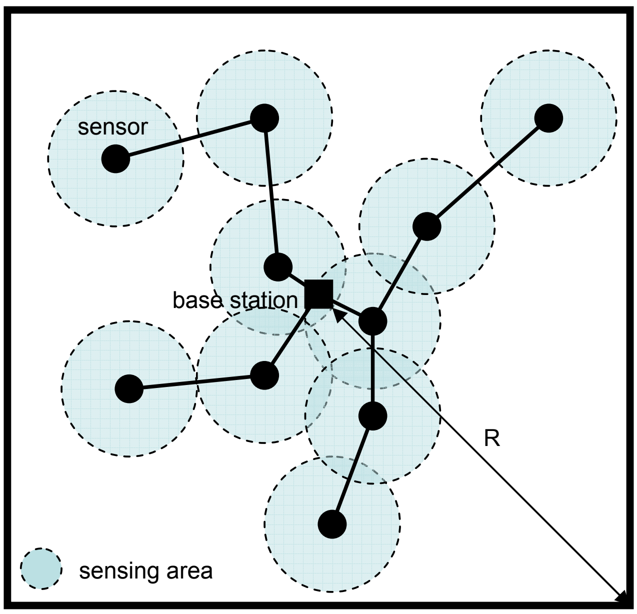

Fig. 3 Power law distribution

2.3 Sensing model

Sensing models are divided into two classes; Binary sensing model and General sensing model. The former is used in many application fields, so we use it in this paper.

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 [6], [16] that expresses the coverage $c_{xy}(s_i)$ of a grid point p by sensor s_i :

$c_{xy}(s_i)$= 1 or 0 if $d(s_i, p)<r$ or otherwise, respectively.

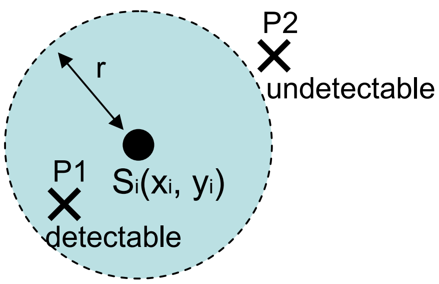

Fig. 4 Binary sensing model

General sensing model: The general sensing model is a model whose sensing ability depends on the distance from the target [13].

2.4 Routing protocol

There are many algorithms to find the data relaying path for each sensor. For saving calculating resources, one of traditional algorithms; AODV (Ad hoc One Distance Vector) [17] is effective, so we considered this traditional algorithm as one of examine algorithms.

2.4.1 The Traditional Algorithm

At the time of route searching; sender sensor broadcasts RREQ(Route REQuest) packets to the network. After a RREQ packet arrives at base station, the base station unicasts a RREP (Route REPly) packet to the sender sensor. In this process, the sender sensor and the intermediate sensors can obtain the necessary routing information from RREQ. If the intermediate sensors have the necessary routing information, then they return RREP packets, so the number of times required for packet sending is saved.

During an ordinary state; developed routes can be utilized until any one of the sensors on the route uses up its battery.

At the time when the route is destroyed because of battery becoming depleted, the sensors using the route destroys the routing information and send RERR(Route ERRor) packet, then again broadcasts RREQ packets to search for a substitute route. When sensors have the wrong route and receive the RERR, they destroy the wrong route information and also send RERR. In this process senders meet with an intermediate sensor which knows the route to the base station, this information can be utilized for the rebuilding of a route.

The above algorithm contains dangers of concentrating large loads on a small number of sensors and of small coverage rate. Fig. 5 and Fig .6 show the initial state of a route search and the final state of a route construction. Fig. 7 shows rebuilt route by taking off sensor 3 which still maintains sensing function, though it has no relay function. The following algorithm 1 is considered to utilize the sensing function of sensor 3 as shown in Fig. 8.

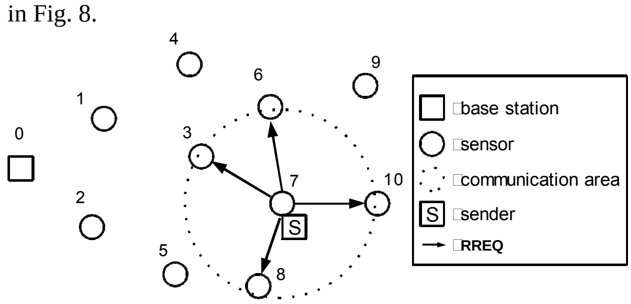

Fig. 5 Route search by broadcast

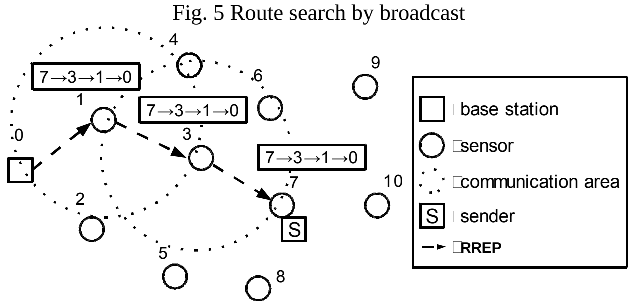

Fig. 6 Final state of route construction

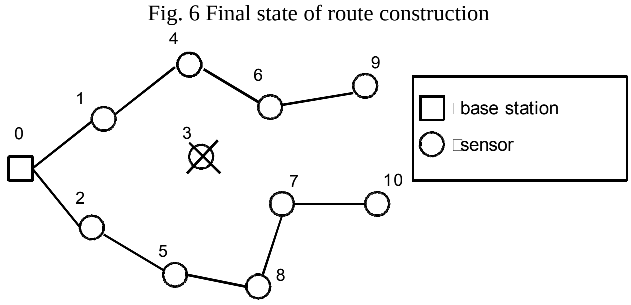

Fig. 7 Rebuilt route

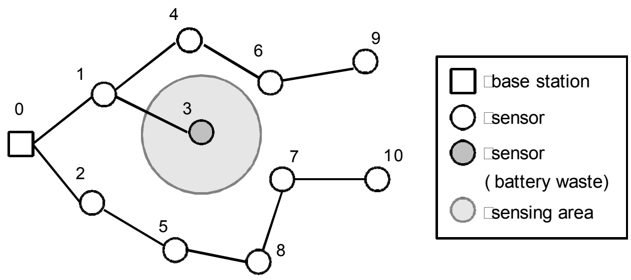

Fig. 8 An example of using a sensor without relay function

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2.4.2 New Algorithm 1

This algorithm introduces an idea that a sensor is still used for the use of its sensing function when the relay function can no longer be used. That is, the developed route is dumped when the power of any one of the relay sensors on the route comes down under a certain threshold value.

Relay sensor (R) sends RERR packets when the power comes down under a certain threshold value. Sensors which receive the RERR packet dump the relay information if R is included in its own relay information, and then sends the same RERR packet. Also, the relay sensor sends RREQ packets to search for a bypass route. Every sensor which holds the bypass information in itself hands the received RREQ packet to the succeeding sensor after it waits for the time in inverse proportion to its remainder power energy of battery. In this and the former traditional algorithms, the base station obtains the same duplicate information many times over. The following algorithm 2 is considered to avoid generating these duplicate extra packets.

2.4.3 New Algorithm 2

In order to avoid generating duplicate packets, when a sensor detects an intrusion, the sensor waits until a time depending on the sensor ID passes and then it sends STOP packets. The other nodes which receive the STOP packet do not send the information of the intrusion even if they detect the intrusion. By this algorithm, the network can avoid generating duplicate packets for detecting the same instruction.

2.5 Simulation method

Finally we describe the input parameters and output measures for the evaluation of (the coverage, the number of live sensors, the number of isolated sensors, and the number of required hops) for different sensor deployments and for different routing algorithms. For the purpose of our simulation, we considered one square domain; 100×100(m) where 6 numbers (10, 30, 50, 100, 200, 500) of sensors were distributed in a variety of sensor deployments. In binary sensing models, a target (intrusion) is set in random position where the target is sensing. The appearance term of a target follows the exponential distribution of average 72 (minutes). The detectable rage of each sensor was a radius 10m. Each sensor had 20J (Joule) initially as its battery power, and requires 0.396J and 0.228J for broadcasting and receiving, respectively. Our simulations were performed for different sensors whose communication radiuses are 5, 10, 20, 30, and 100m. In this paper, data in radiuses of 20 and 100m will be shown.

III. Simulation Results

In this section, we present the results of the simulations, that is, in the case of using a binary sensor model. Each figure shows the data in the case of broadcasting radius of 20m except Fig. 16 and Fig. 17.

3.1 Coverage Rate

Fig. 9 plots the coverage rate with the lapse of time for each different routing protocol and each different sensor deployment. New Algorithm 2 highly sustained the coverage rate for a longer time, but not New Algorithm 1. Algorithm 2 yielded a larger area of duplicate sensing (but not sending redundant data), so this seems to be effective for sustaining coverage rate (because of small battery consumption).

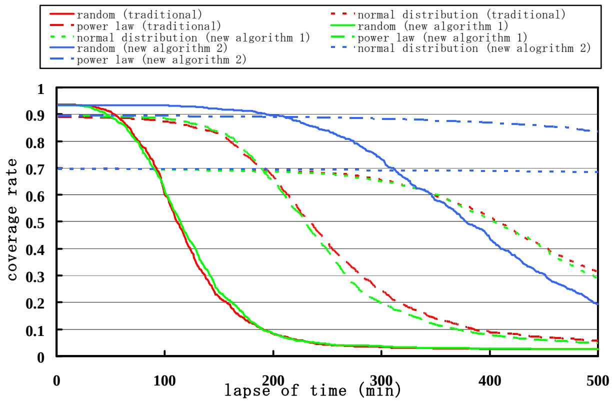

Fig. 9 Coverage rate in each sensor deployment for different protocols

3.2 Number of active sensors

Fig. 10 plots the number of active sensors with the time for each different routing protocol and each different sensor deployment. New Algorithm 1 has the characteristic that more sensors extend their life time.

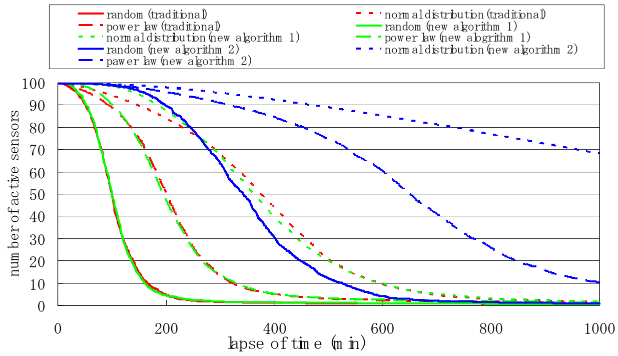

Fig. 10 Number of active sensors in each sensor deployment for different protocols

3.3 Number of isolated sensors

Fig. 11 plots the number of isolated sensors with the time for each different routing protocol and each different sensor deployment. This result shows that the traditional algorithm cannot reduce the number of isolated sensors with any routing protocol, but new algorithms can reduce it in Normal or Power law distributions.

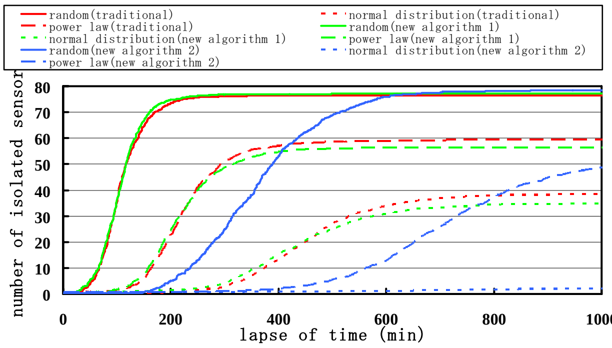

Fig. 11 Number of isolated sensors in each sensor deployment for different protocols

3.4 *Number of required hops*

Fig. 12 plots the number of hops required to arrive at the base station in routing. In Random deployment, sensors under 5, which require over 5 hops in the initial state, increase the number up to 20. New Algorithm 1 can prevent the number of sensors which requires over 5 hops from increasing.

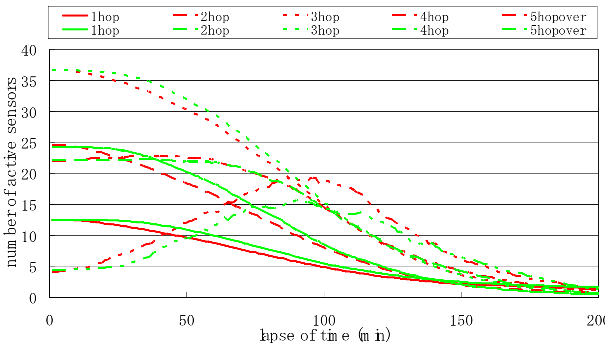

Fig. 12 Number of required hops in each sensor deployment for different protocols

3.5 *Number of sensors by which events can be discovered*

Fig. 13 plots, in the case of New Algorithm1, the number of sensors which can succeed in the discovery of intrusions with time for each different sensor deployment. In the case of New Algorithm 2, the number of sensors is a constant, 1.

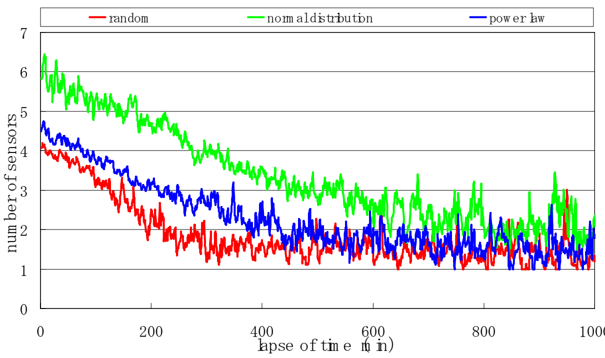

Fig. 13 Number of sensors which can succeed in the discovery of intrusions

3.6 *Coverage rate versus the number of deployed sensors*

Fig. 14 plots coverage rate versus the number of deployed sensors at the initial state.

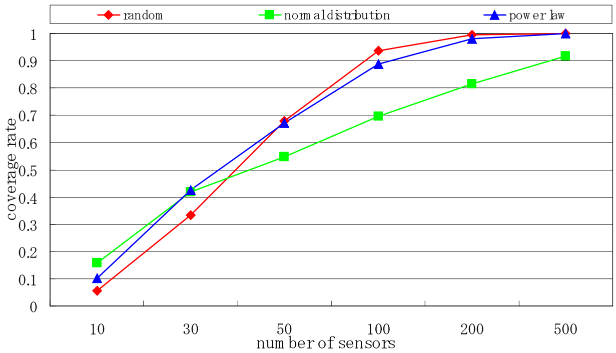

Fig. 14 Coverage rate versus the number of deployed sensors

Since Fig. 9 showed the advantage of a Normal distribution for a long battery life span and the disadvantage of a small coverage rate, Normal distribution proved to be an able property in the place of few deployed sensors where coverage rates do not differ much in different distributions.

3.7 *Other results*

Fig. 15 shows the initial effective sensor rate and effective sensor rate for different numbers of sensors used with the parameter of sensor deployments. The former is defined as the rate of sensors able to communicate with the base station in the initial deployment, and the latter is defined as the rate of full used sensors at the final stage (when the base station becomes isolated).

In the initial deployment when the number of deployed sensors was up to 50 and also at the final stage, many sensors were effective in the Normal distribution more than the others. Fig. 16 shows coverage rate versus broadcast radius. In this figure, a broadcast radius of less than 20m means ineffective. Finally, Fig. 17 shows how coverage rate changes with the lapse of time in the case of the different communication radius of 100m. In this case, where every sensor can communicate directly with the basic station, Random distribution maintains a relatively high coverage rate.

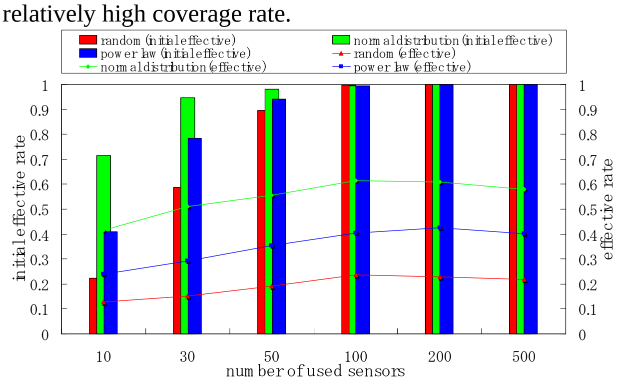

Fig. 15 Initial effective rate and effective rate for a different number of used sensors in each sensor deployment

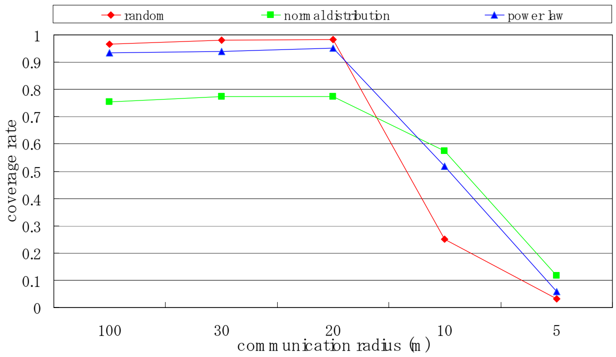

Fig. 16 Coverage rate versus communication radius

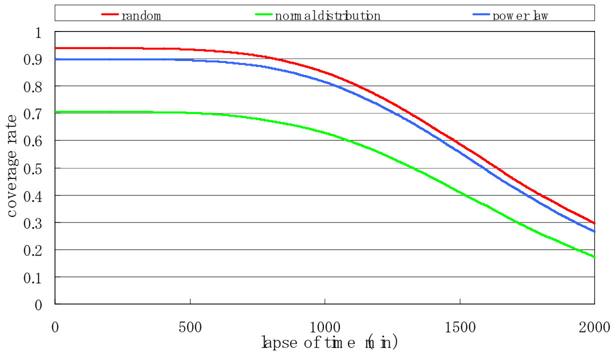

Fig. 17 Coverage rate for another radius (100m) of communication

IV. Conclusion

In this work, we discussed three kinds of sensor deployments; Random, Normal, and Power law distributions and evaluated each record of coverage rates with the lapse of time. The experimental evaluation was performed using 3 different routing algorithms; a newly presented algorithm planned to avoid the dangers of concentrating large loads on a small number of sensors and of the resultant small coverage. The other new one is planned to avoid the danger that the base station obtains the same information duplicated many times over.

The results show a Normal distribution can maintain coverage rate six times longer than Random distribution, and Power distribution can maintain three times longer than Random distribution. The occurrence of isolated sensors in Normal distribution can be saved 50% that of Random distribution. Power law distribution can save up to 75% that of Random distribution. The experimental evaluation also lead to the following result that 2 new routing algorithms presented in this paper can maintain a high coverage rate for a longer time. When algorithm 2 was applied in a Normal distribution, the coverage rate was able to be extended to 4 times longer than the traditional algorithms.

The discussion on the circumstance where every sensor operates as a general model is left to the next work.

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