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# 무선 센서 네트워크에서 지역밀집도를 고려한 활성노드 선택기법

# ( An Active Node Selection Scheme based on Local Density in Wireless Sensor Networks )

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( Jeong-sahm Kim, Jeong-pil Ryu, and Ki-jun Han )

## 요 약

무선 센서네트워크에서 프로토콜을 설계하는데 가장 중요한 목표는 네트워크의 수명을 연장하는 것이다. 많은 수의 노드들을 임의로 살포하기 때문에 노드는 주변의 많은 노드들과 센싱영역과 통신영역에 있어 중첩되는 부분이 많다. 이렇게 심한 중첩으로 인한 부하는 네트워크 수명에 심각한 영향을 미친다. 따라서 일반적으로 모든 노드들이 항상 센싱과 통신을 위해 활성화될 필요는 없다. 네트워크 수명을 연장시키는 최적의 방법 중의 하나가 네트워크 커버리지와 연결성 보장을 유지하기위해 필요한 주변노드의 수를 구하는 것이다. 최근까지 무선 네트워크 분야에서 이를 위한 연구들이 활발히 진행되고 있다. 만일 네트워크 커버리지와 연결성을 만족시키는데 필수적으로 필요한 이웃노드들을 확보할 수 있다면, 노드들의 상태를 스케줄 하는 것이 아주 유용하다. 본 논문에서는 각 노드들이 자신만의 확률 값을 가지고 자신을 활성화 할지를 판단하는 새로운 활성노드선택기법을 제안한다. 이 확률 값은 네트워크 커버리지와 연결성을 보장하기 위해 필수적으로 필요한 이웃노드의 개수와 확보된 이웃 노드의 수를 이용하여 구할 수 있다. 본 논문에서는 F. Xue et al 과 S. Song et al 의 연구결과를 이용하였으며, 필수적으로 필요한 노드수의 검증을 위해 컴퓨터 시뮬레이션을 실시하였으며, 일정한 확률 값을 가지는 기법과 비교하여 시뮬레이션 한 결과를 제시하였다.

## Abstract

In wireless sensor networks, one of the most important goals of designing protocols is to extend the network lifetime. A node has lots of duplication in sensing and communication range with surrounding nodes after many of nodes are randomly scattered. Such a heavy duplication overhead affects on the network lifetime seriously so usually all nodes need not activated constantly to carry out sensing and communication operation. One of the optimal methods of prolonging the network lifetime is finding the number of surrounding nodes necessary to maintain the network coverage and connectivity. It has been studied till the current date in wireless networks. If the neighbor necessary can be acquired to satisfy the network coverage and connectivity, it is very useful to schedule the state of nodes. In this paper, we propose an active node selection scheme that each node determines whether it is activated with its own probability. We can calculate the probability using the ideal number of neighbors necessary and the acquired number of neighbors necessary to guarantee network coverage and connectivity. We use the result that F. Xue et al and S. Song et al derive previously in finding the neighbor necessary to guarantee the network connectivity and carry out the computer simulation to verify the necessary number. We present that our scheme satisfy the network coverage and connectivity. We present the simulation results compared with constant probability scheme through computer simulation.

**Keywords :** wireless sensor network, network lifetime, local density, network coverage, network connectivity

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## Ⅰ. Introduction

Due to the outstanding advance in electronics technologies and wireless network, very small sensor nodes which have multi-function and can communicate with each other in short range have been rapidly developed in recent days. A wireless sensor network consisted of a large number of sensor nodes and a sink node. Sensor nodes are densely deployed in the sensing field with random distribution. These sensor nodes can monitor the physical environments, process sensing data and communicate with each other[1~4]. Due to the constrained physical resources of sensor nodes, the fundamental and ultimate issue of wireless sensor networks is to provide a long span of network lifetime as long as possible. To solve this problem, generally a large number of sensor nodes are deployed in high density with random distribution to the target place. Also, network topology is formed by active nodes subset and the rest of them make transition to sleep state which turned their sensor and radio off.

In the most of approaches, activating the necessary nodes up to the acceptable degree is adapted until now. In high densely sensor networks, all nodes need not turn the radio part on at the same time for basic operations (e.g., sensing or forwarding). We select the node which is turned radio part on impartially extending the network lifetime and reducing the number of nodes necessary. These selected nodes (called "active mode") should provide the global network connectivity. Topology management is an important issue since energy saving is acquired by turning the radio off (called "sleep mode") while the others active nodes give the global network connectivity. This problem has been studied in many other previous works[5~9, 14~16].

In this paper, we propose an active node selection scheme which selects active nodes dynamically based on the local information while guaranteeing the network connectivity as well as network coverage by the selected active node. In our scheme, each node probabilistically decides whether to activate or not, based on the neighbor distribution around it. In other words, each node determines whether it should participate in sensing and routing procedures in a probabilistic manner based on the distribution density of neighbor nodes around itself. If we know the number of necessary nodes to give a network connectivity and coverage perfectly, each node more easily determined whether to make transit to sleep mode or not. It is not easy problem that how many surrounding nodes are necessary to guarantee the network connectivity. But recently that is a hot issue in wireless sensor networks[11~12].

The rest of this paper is organized as follows. Literature reviews are presented in the section Ⅱ. Our proposed dynamic probabilistic active node selection scheme is introduced in the section Ⅲ. Performance evaluation of the proposed scheme and comparison with the constant probabilistic scheme are presented in the section Ⅳ. Finally, conclusion remarks are presented in the section Ⅴ.

## Ⅱ. Related Works

We have reviewed the recent studies about topology management scheme and working node selection algorithms. Also, analyses about the lower bounds of the number of neighbor nodes necessary for network connectivity have been investigated.

In [6], Tian et al proposes a distributed and localized scheme. Energy conservations are gained from the scheduling of state of the node among the sponsor node of it. Firstly each node gathers the neighbor information and then performs the eligibility rule for turning the radio part off. Each node determines whether its coverage is covered by its sponsor nodes. If its sensing coverage is covered by its sponsor nodes, it needs not participates in the sensing and communication operation. But all nodes determine simultaneously, sensing holes may be originated. In order to avoid thus problem, Tian et al suggests back-off based self scheduling algorithm.

In [7], Zhang and Hou proved that if the communication range Rc is at least twice the sensing range Rs, a complete coverage is satisfied maintaining the connectivity of the working nodes. If two node's sensing area is overlapped, two nodes become neighbors. At that time two neighbors are within their communication range by Rc ≥ Rs. Because of the interference the communication range should be adjusted and they address to satisfy the connectivity is to set communication range as twice the sensing range. Furthermore based on the optimality conditions they suggest decentralized and localized density control algorithm, called OGDC (Optimal Geographical Density Control) for density control in the large sensor network.

In [10], Cerpa and Estrin introduce a topology management scheme can be able to self configure according to the application only using local information in high density sensor network called ASCENT. In ASCENT, each node decides its state (Sleep or Active) based on the number of neighbor nodes and data loss rate. The solution of communication hole between two nodes is using the HELP message. The intermediate node becomes to the active and interconnects the disconnected two nodes.

The analysis about the asymptotic connectivity of ad hoc networks has been given by F. Xue et al. They proved that if each node has $\Theta \log n$ neighbors, the network connectivity can be asymptotically guaranteed, where n is the number of nodes in the network. If each node connects with less than $0.074 \log n$ to the nearest neighbors, then the network is asymptotically disconnected. As each node connected more than $5.1774 \log n$ to the nearest neighbors, then the network is asymptotically connected.

S. Song et al. have improved the lower bound that the number of neighbors required for connectivity of wireless ad hoc networks[12] using different model. E. M. Royer et al. mentioned that each node must have more than six neighbors[13]. There were some studies in the 1970s and 1980s which recommended various "magic numbers" for the nearest neighbors (i.e. three, six, seven and eight). In Chapter 4, we show the result of experiments to investigate the number of neighbors necessary for network coverage and connectivity.

## Ⅲ. Working Node Selection Scheme

We describe the working node selection procedure using the state transition diagram. Let us define $MN_{COV}$ as to the necessary number of neighbor nodes around a node for network coverage and $MN_{CON}$ as to the necessary number of neighbor nodes around a node for network connectivity. We quote this value from [12, 13]. Finally, every node (ni) has the transition probability to the ACTIVE state $P_r^{n_i}$ and the transition probability to the SENSE/ROUTE state $P_{sr}^{n_i}$ as shown in Eq. (1).

$$P_r^{n_i} = MN_{CON} / S(n_i)$$
$$P_{sr}^{n_i} = MN_{COV} / S(n_i) \qquad (1)$$

Where S(ni) denotes the acquired number of neighbors at a node (ni) by exchanging HELLO message the nodes located in its communication range.

Each node can be one of three states; LISTEN, ACTIVE, SENSE/ROUTE and SLEEP, as shown in Fig. 1.

A node in the SLEEP state turns its sensor and radio part off. In the SENSE/ROUTE states, the radio and the sensor part are turned on. The nodes in

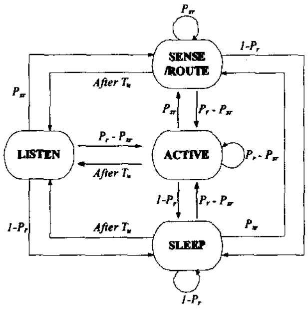


그림 1. 각 노드의 상태전이 다이어그램
Fig. 1. State transition diagram at each node.

the SENSE/ROUTE state, participate in the sensing operation and generate sensed data. Also, the nodes play a part in the delivery of data to the sink node. In the LISTEN and ACTIVE states, every node turns the radio part on. In the LISTEN state, as an initial state, all of nodes turn their radio part on and exchange HELLO messages with each other. The nodes in the ACTIVE state simply participate in the routing procedure to the sink node.

After the nodes are deployed in the sensing field, each node exchanges HELLO messagesin order to construct a local topology in the LISTEN state as an initial state. Then, it waits for a query message from the sink node. Query messages include the network parameters ($MN_{COV}$, $MN_{CON}$, $T_u$). Each node calculates state transition probabilities using the network parameters. Based upon these probabilities, each node determines the next state for the next round. A round is defined as the period whereby the sink receives sensed data from the sensor nodes in response to its query. After a few round intervals, all nodes are transited to the LISTEN state regardless of its previous state. We have defined this update interval as $T_u$.

After each round, each node can transit to the ACTIVE, SENSE/ROUTE or SLEEP state. It transits to the SENSE/ROUTE state with a probability of $P_{sr}$ and it can transit to the ACTIVE state with a probability of $P_r - P_{sr}$, or it can transit to the SLEEP state with a probability of $(1- P_r)$. Each node dynamically computes $P_r$ and $P_{sr}$ based upon the number of neighbor nodes around itself. As probability increases, the node is more likely to be activated. If there are more neighbors around a node than needed in order to satisfy minimum requirements for network connectivity and coverage, the node does not need to be activated. In this case, probability should be assigned a small value. On the other hands, if there are too few neighbors around a node to satisfy minimum requirements for network connectivity and coverage, $P_r$ and $P_{sr}$ should be assigned a large value so that the node can become easily activated.

In the ACTIVE state, each node receives a query from the sink, as shown in Fig. 2. In this figure, $T_q$ represents the maximum allowable duration until every node hears the query message. This means that every node is expected to hear the query message within $T_q$. $T_q$ should be given a sufficiently large value considering the potential transmission delay from the sink to the farthest node. In most cases, every node can hear the query message within $T_q$ since it has transited in the ACTIVE state.

Once a node enters the ACTIVE state, it remains in the ACTIVE state with a probability of $P_r - P_{sr}$ and it transits to the SENSE/ROUTE state with a probability of $P_{sr}$. It transits to the SLEEP state with a probability of $(1- P_{sr})$. Since a node can transit to the SENSE/ROUTE state from the ACTIVE state, the remaining probability of the ACTIVE state is $P_r - P_{sr}$.

A node in the SENSE/ROUTE state transits to the ACTIVE state with a probability of $P_r - P_{sr}$ in the next round. A node remains for one round in the SENSE/ROUTE state with a probability of $P_{sr}$. It transits to the SLEEP state with a probability of $(1- P_{sr})$. After the transition to the ACTIVE and the SENSE/ROUTE state, it remains in the state if it hears the query message within $T_q$. If any node does not receive the query within $T_q$, it immediately transits to the SLEEP state after $T_q$. This is because the node becomes isolated (in other words, it has no path to reach the sink) in this case. Nodes in the ACTIVE or SENSR/ROUTE states exchange HELLO messages in order to acquire local information for routing procedures.

A node in the SLEEP state turns its radio and sensor part off and waits the time of the round has expired. When the time has expired, the node transits to the ACTIVE state with $P_r - P_{sr}$ or transits to the SENSE/ROUTE state with $P_{sr}$, or it can remain in the SLEEP state with a probability of $(1- P_{sr})$.

In our scheme, every node updates its neighbor information periodically. The update period which is denoted by $T_u$, is given by the sink when the query message is flooded. Every node transits to the

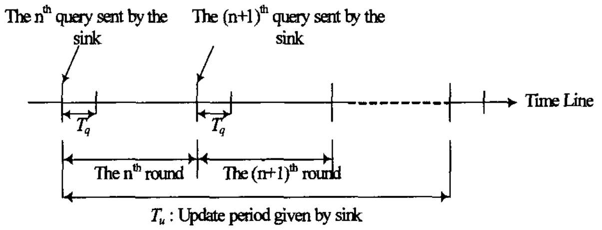


그림 2. 라운드 및 갱신 주기
Fig. 2. Round and update period.

LISTEN state regardless of its current state after the update period. For example, if $T_u$ is assigned 12 by the sink, every node transits to the LISTEN state after 12 rounds from the time it heard the query message.

## Ⅳ. Performance Evaluations

We present a performance evaluation for the constant probabilistic scheme and the dynamic probabilistic scheme. We show the network coverage, connectivity, and the network lifetime. We have some assumptions as follow. The sensing and communication range are the same size. There is only a symmetric link and mobility is not a factor. Nodes are deployed in a 100×100 rectangular region and the radio range radius of each node is as 5, 10 or 15. We have deployed 20 nodes for each instance, up to 1000 nodes, in a random manner.

### 1. Evaluation of the number of neighbor nodes necessary

We have evaluated the number of neighbor necessary for network coverage and connectivity through a simulation. We fix the radio ranges of each node to 10 and the network size changed from 100×100 to 500×500.

In Fig. 3 and 4, if the number of neighbor of each node is between 6 and 8, the network coverage and connectivity is guaranteed sufficiently. When the number of neighbor is about 4 and 5, connectivity is exponentially increased and coverage is nearly satisfied. The several isolated connected areas may be connected to the area at this time, so this area suddenly increases. After connectivity is 0.9, it increased linearly. It is important that the number of neighbor for network connectivity needs 2 or 3 neighbor nodes than that of the number of neighbors for the full coverage.

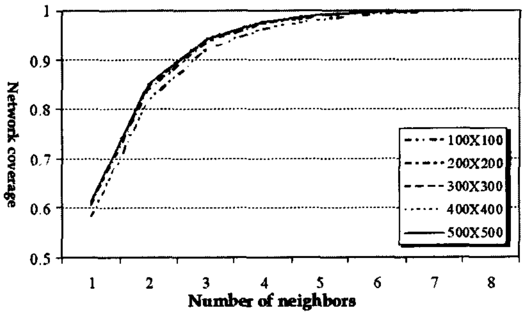


그림 3. 네트워크 커버리지 보장을 위해 필요한 이웃노드
Fig. 3. Number of neighbor nodes necessary for network coverage.

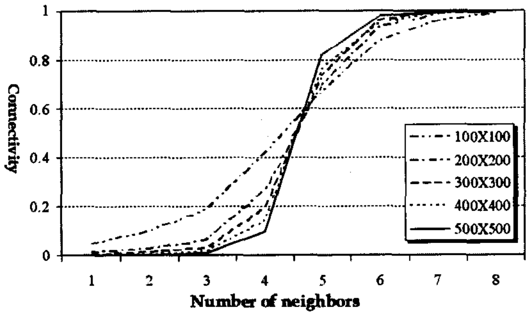
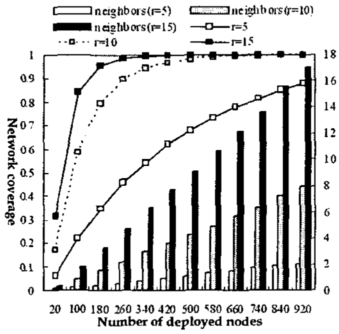


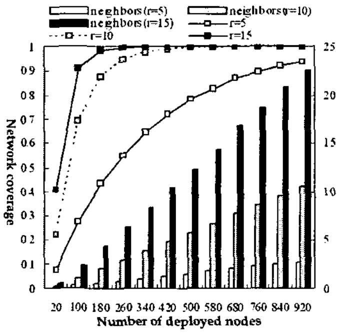
그림 4. 네트워크 연결성 보장을 위해 필요한 이웃노드
Fig. 4. Number of neighbor nodes necessary for network connectivity.

### 2. Simulation Results of the proposed scheme

In this section, we present simulation results of the constant probabilistic scheme and the dynamic probabilistic scheme. There are many studies about network topology management, but there are no other working nodes selection scheme based on probability. So, in this paper, we compare the simulation result while increasing Psr and Pr under constant probability environment and that of dynamic probability environment. In the constant probabilistic scheme, we have set Pr from 0.2 to 1. Psr is set to 0.5Pr. In the dynamic probabilistic scheme, we set $MN_{CON}$ to 6, 7 and $MN_{COV}$ is set to 4, 5.



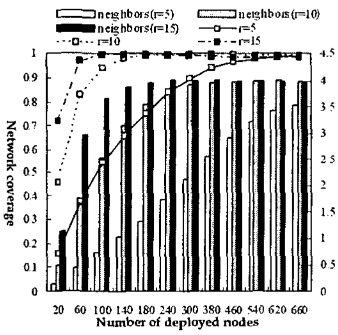
(a) $P_r$ = 0.6 and $P_{sr}$ = 0.5 $P_r$



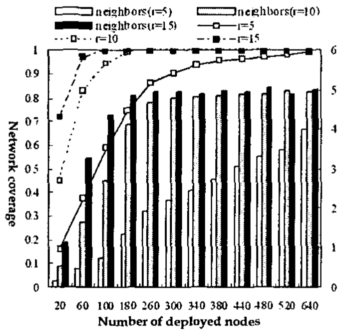
(b) $P_r$ = 0.8 and $P_{sr}$ = 0.5 $P_r$

그림 5. 고정 확률기법에서의 네트워크 커버리지

Fig. 5. Network Coverage of the Constant Probabilistic Scheme.



(a) $MN_{CON}$ = 6 and $MN_{COV}$ = 4



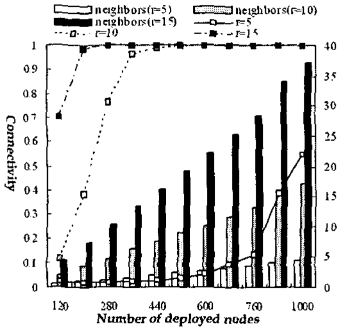
(b) $MN_{CON}$ = 7 and $MN_{COV}$ = 5

그림 6. 동적 확률기법에서의 네트워크 커버리지

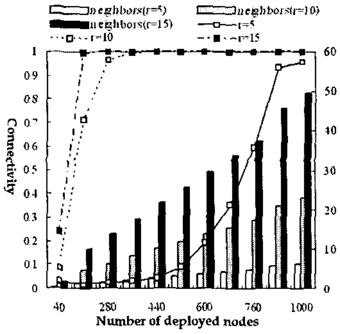
Fig. 6. Network Coverage of the Dynamic Probabilistic Scheme.

Fig. 5 and 6 show the network coverage of the constant probabilistic scheme and the dynamic probabilistic scheme respectively. $P_r$ is set at 0.6 and $P_{sr}$ is set at 0.5 $P_r$ in Fig. 5(a). $P_r$ is set at 0.8 and $P_{sr}$ is set at 0.5 $P_r$ in Fig. 5(b). Naturally, as the sensing range and $P_r$ increased, the number of nodes that participate in the sensing task multiplied. When network coverage is fully covered by the sensing nodes, the number of sensing neighbors of each node is greater than nearly 5. At this time, the number of deployed node number is greater than 250. Especially, when sensing range is 5, the constant probabilistic scheme cannot guarantee the network coverage. It means that sensing nodes cannot be distributed effectively due to the constant probability and sensing holes may be occurred in the networks. The coverage, however, based on the dynamic probabilistic scheme considerably limits the number of sensing nodes (about half of the constant probabilistic scheme) and maintain the number of sensing neighbors to 4 or 5 in case that sensing range is 10 or 15. As illustrated in this figures, it is sufficient to cover the whole sensing field with 4 sensing neighbor nodes at least.

Fig. 7 and 8 present the network connectivity of the constant and the dynamic probabilistic scheme respectively. In Fig. 7 and 8, neighbor nodes are the sum of neighbors which are in the SENSE/ROUTE and ACTIVE state. Fig. 7(a, b) shows the number of working neighbors which is in the SENSE/ROUTE or ROUTE state and the network connectivity when the constant probability $P_r$ is set at 0.6 and 0.8 respectively. In Fig. 7(a), in case that the communication range is 15, the network connectivity is satisfied when the number of working neighbors is nearly 10 or 11. When the communication range is 10 in Fig 7(a), the number of working neighbors almost shows the same result when the communication range is 15.The result whose communication range is 5, however, shows a poor connectivity. Although the deployed node number is 1000, the network connectivity cannot be guaranteed perfectly. In case that the constant probability is 0.6, there are many of



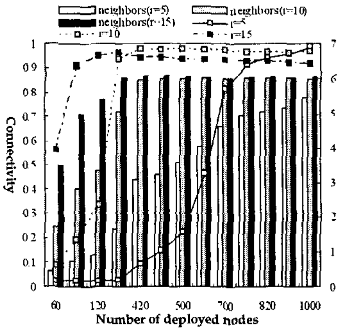
(a) $P_r$ = 0.6



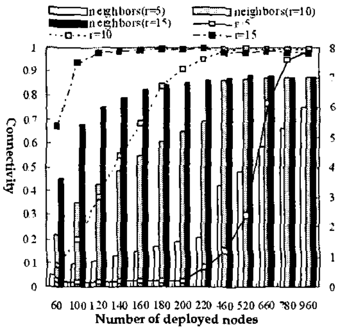
(b) $P_r$ = 0.8

그림 7. 정적 확률기법에서의 네트워크 연결도

Fig. 7. Network Connectivity of the Constant Probabilistic Scheme.



(a) $MN_{CON}$ = 6



(b) $MN_{CON}$ = 7

그림 8. 동적 확률기법에서의 네트워크 연결도

Fig. 8. Network Connectivity of the Dynamic Probabilistic Scheme.

communication holes. When the constant probability is 0.8, it shows better results than that of the prior. About 96% of the activated nodes are connected to the sink node with direct or multi-hop manner. The difference in the number of working neighbors between the two constant probabilities is one or two working neighbors. It makes the difference of network connectivity larger.

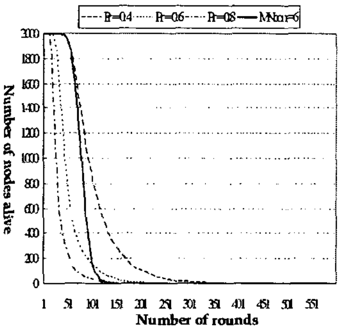
Fig. 8 presents the network connectivity of the dynamic probabilistic scheme. In Fig. 8(a, b), $MN_{CON}$ is set at 6 and 7 respectively. In Fig. 7(a), all activated nodes are connected to the sink node with direct or multi-hop manner. The number of working neighbors is about 5 or 6 and this number is an intended parameter ($MN_{CON}$). Compared with the constant probabilistic scheme, the number of working neighbors can be reduced to the half value of the constant probabilistic scheme in case that the communication range is 15. The number of working neighbors is nearly 6, when the network connectivity is preserved more than 95%. However, the more the network connectivity falls down a little the more deployed nodes increase. Since the number of neighbor nodes increases a lot (nearly 60 when 1000 nodes are deployed), the dynamic probability drop down by slow degrees. Therefore the network connectivity goes down in some degree. All of activated nodes are mostly connected to the sink node when the communication range is 10. At this time, the number of working neighbors is about 6. It is similar with the result of the range of 15. The number of working neighbors is twice of that of the constant scheme whose probability is 0.6. The network connectivity cannot be satisfied when the communication range is 5 in the constant scheme, but it is perfectly guaranteed in the dynamic scheme with smaller number of working neighbors. It means that activated nodes are well distributed geographically in the dynamic probabilistic scheme. So, the network connectivity can be preserved with smaller number of working neighbors than the constant probabilistic scheme. When $MN_{CON}$ is set at 7, the results are similar with the results of Fig. 8(a). Since the $MN_{CON}$

parameter is given to 7, the number of working neighbors of each node approaches to 7. All nodes are connected completely to the sink node when each node has more than 6 activated nodes.

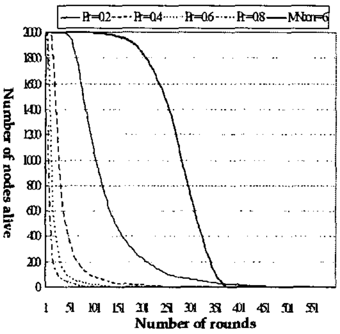
In this section, we presented the comparison of the network coverage and connectivity of the two schemes. In those figures, we can know that the dynamic probabilistic scheme completely preserves the sensing field without any sensing holes and give the perfect network connectivity. In addition, the number of neighbors necessary for the network connectivity requires nearly 2 or 3 neighbor nodes than that of the number of neighbors necessary for the network coverage. It implies that if the network connectivity is guaranteed, the sensing field can be completely covered.

### 3. Network Lifetime

Fig. 9 shows the system lifetime of the constant probabilistic and the dynamic probabilistic scheme. We use the energy consumption model in the LEACH protocol[10]. Three types (80-bits HELLO, 288-bits QUERY, 512-bits DATA) of message are used.



(a) Radio range is 5



(b) Radio range is 10

그림 9. 라운드 동안 살아남은 노드 수

Fig. 9. Number of nodes alive over rounds.

In this result, the time of the first node to die of the dynamic probabilistic scheme is similar when Pr is set at 0.4. After 300 nodes are died, the system lifetime of the dynamic probabilistic scheme is dropped more quickly. At this time the network connectivity of the constant probabilistic scheme can't be satisfied. In Fig. 8(b), it takes approximately 100 rounds for the last node to die in the dynamic probabilistic scheme, while 50 rounds in the constant probabilistic scheme. Since there are more activated nodes in the constant scheme than that of the dynamic scheme, the network lifetime of the constant scheme is dropped more shortly.

## V. Conclusions

In this paper, we proposed the active node selection scheme that each node probabilistically determines its state using the local density. Probabilities are derived based on the number of neighbor nodes and changed dynamically according to local density. We have experimented to obtain the optimal number of neighbor necessary for the network coverage and connectivity. If each node has about 4 neighbor nodes, the network coverage is satisfied and it has about 6~8 neighbor nodes, the network connectivity is guaranteed. Performance evaluations of our scheme present the satisfaction of the coverage and connectivity using the dynamic probability. The advantage of our scheme is that it does not require the additional control overhead and it is a simple approach. Also, in wireless sensor network with very high density, we can expect the extension of network lifetime through simulation results of our works.

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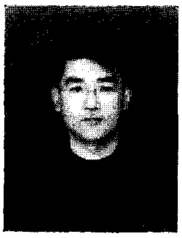

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