Energy Aware Routing Protocol in Wireless Sensor Networks

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Summary
Mobile node should be fully connected with the other nodes to communicate to each others in wireless networks. Data can be propagated to the destination with various delivery methods: one-hop model, multi-hop planer model and cluster-based hierarchical model. One-hop model is the simplest delivery method and makes the link by directly communicating any two nodes. Multi-hop model with store-and-forward method delivers data by forwarding to one of its adjacent nodes that are closer to the destination. In cluster model, mobile nodes have been grouped into a cluster. It has benefits of delivery latency and route management. In this paper, we propose energy-aware routing protocol to reduce the energy consumption of wireless sensor networks using the combination of tree-based minimum transmission energy routing and cluster-based hierarchical routing. In our technique, the highest energy node within h hops becomes a cluster-head. Therefore the size of every cluster is less than and/or equal to h hops. Every node can have different energy level the same as real environment and transmits its data to its cluster-head with short distance tree algorithm. Cluster-head sends data to the other cluster-head or the sink with tree-based minimum transmission energy algorithm due to the limit of nodes' transmission range. We perform simulations to compare its performance with that of conventional routing protocol such as direct and minimum transmission energy, and various energy levels. From simulation results, we confirm that the proposed routing strategy offers better performance.

Key words:
Routing, cluster, energy-aware, connectivity, wireless sensor networks.

1. Introduction

The advance of microsensor technology is easy to develop sensor devices of low cost and small size. These devices are consisted of wireless sensor networks (WSN) to monitor previously specified phenomenon and may be deployed in numerous numbers depending on the acceptable accuracy and/or fault-tolerant. Since WSN has an unattended nature, sensor node is energy-constrained and needs lower processing power in order to live longer [1-2],[15].

In WSN, every sensed data propagates to the sink node (SN) with various delivery methods: one-hop model, multi-hop planer model and cluster-based hierarchical model [7]. One-hop model is the simplest delivery method and tries to communicate directly with SN. But sensor nodes far away from SN cannot connect it due to the limited transmission range and suffer from severe energy dissipation. Because the bandwidth of wireless network is lower than that of wired network, the more the number of nodes transmitting data, the higher the probability of collision.

Multi-hop planer model transmits sensed data by forwarding to one of its neighbors which are closer to the sink node [5-6],[9],[11],[14]. These data propagate from source to the sink by hop from one node to another until they arrive at the sink. The collision probability of this model is lower than that of one-hop model because shorter transmission range makes data collision occur locally. Most nodes therefore can connect to WSN and transmit their sensed data to the sink. This approach uses data aggregation technique that enhances the efficiency of network by reducing the number of transmitting data. Because nodes closer to the sink must forward data received from others nodes though they have no sensed data, the batteries of these nodes will quickly drain more than the others. In this method, all nodes stay alive as long as possible, since network quality decrease considerably as soon as one node dies. Also, the more the number of sensor nodes within WSN increases, the longer the data dissemination latency.

In cluster-based hierarchical model [3-4],[8],[10],[16], sensor nodes have been grouped into a cluster. One node of a cluster becomes a cluster-head (CH) and the others become non-head members. Cluster members should deliver their data not to the sink node but to their CH. Then CH aggregates received data and transmits them to either the sink or a higher-level CH. Since this method can reduce the number of hops between the sink and the sender, the latency is less than that of multi-hop planer model. Only CH performs data aggregation whereas every intermediate node performs data aggregation in multi-hop model. This model therefore is more suitable for time-critical applications than multi-hop model. If the distance between CH and the sink increases, the energy consumption is proportional to the square of the distance.

In this paper, we propose wireless sensor networks that adopt the cluster-based routing protocol to reduce energy consumption needed to transmit data from the sender to the sink. For this, we have developed MTECH (Minimum Transmission Energy with Clustering Hierarchy), a cluster-based routing protocol that uses multi-hop planer model with tree-based minimum transmission energy scheme among cluster-heads and non-head members. CH

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is selected by the predefined probability p and sends data to the sink through the nearest another CH with minimum transmission energy scheme. We assume that all nodes are homogenous and energy-constrained and can reach to the sink one-hop directly. But at the beginning the energy quantity of the battery of each node may be different. CH will be elected a node which has the most energy level within a cluster.

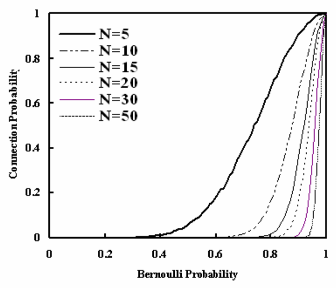
The remainder of the paper is organized as follows: In the next section we describe the connectivity in mobile wireless networks. In section 3, we describe cluster-based routing mechanism with minimum transmission energy. Performance analysis is introduced in section 4. In section 5, we present the simulations and analysis of the results. Finally, we give out conclusion in section 6.

2. Connectivity in Mobile Wireless Networks

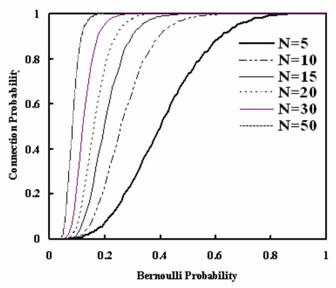
Mobile nodes (MNs) can communicate with the desired destination node whenever they want to delivery data with either one-hop model or multi-hop planer model. One-hop model is the simplest delivery method and tries to communicate directly with the destination node. In multi-hop model, the connection between two nodes can be manifested with graph. A random graph G can be described as a graph that is generated by some random experiment called *random graph model*. Fixed edge number model is denoted $G = G(n, e)$, given n and e, choose G uniformly at random from all graphs consisting of n vertices and e edges.

Each MN can whether connect to the other nodes or not. It can be represented as successive-connection and failure-connection, respectively. Because this random experiment has two possible outcomes, it become *Bernoulli* trials of which the probabilities of two outcomes are p and q, respectively, $p + q = 1$. Binomial distribution of Bernoulli trials is dented $B(n, p)$, where n and p are the number of trials and the probability of succession, respectively. If one-hop model is applied to binomial distribution, random graph model is denoted $G = G(n, p)$, given n and p, construct n vertices and edge between pairs of nodes with connection probability p. Fig. 1 shows the connection probability p with binomial probability $0 \leq p \leq 1$. In one-hop model, if there are n nodes in the networks, a node is able to connect n-1 nodes. As shown in Fig. 1(a), the more the number of nodes n, the less the connection probability p_b significantly.

As the transmission range of MN is limited due to the energy consumption, one-hop model is not a proper method. From Fig. 1(b), if multi-hop model is used in Binomial trials, the connection probability is higher than that of one-hop model due to the existence of multiple paths toward a desired destination.



(a) One-hop model



(b) Multi-hop model

Fig. 1 Connection probability of the various numbers of mobile nodes N in Bernoulli trials with probability $0 \leq p \leq 1$

In multi-hop model, the transmission range is fixed as R. Thus this can be expressed as $G = G(n, R)$, where nodes are placed randomly according to Poisson random distribution in the Euclidean plane. There is an edge between two vertices if and only if the corresponding nodes are within a distance R of each other.

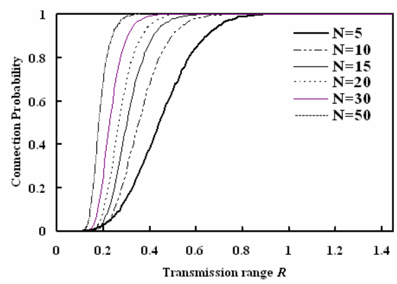
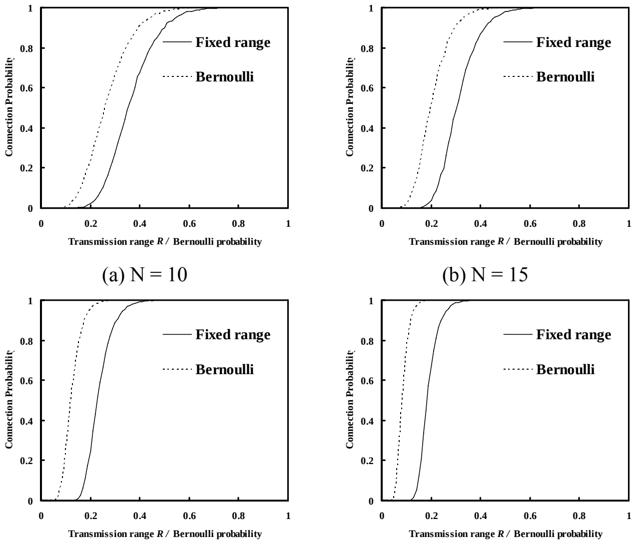


Fig. 2 Connection probability of the various numbers of mobile nodes N in fixed transmission range $0 \leq R \leq \sqrt{2}D$

To estimate connectivity in multi-hop model with fixed transmission range R, we use following assumptions: 1) Nodes in the networks are placed in a disc of unit area. 2) The location of each node can be modeled as Poisson random process. 3) Each node can communicate with transmission range R at a power level so as to cover a unit area as a rectangular planer of which both height and width are D, i.e, its dimension is D^2. Fig. 2 shows the connection probability p with fixed transmission range $0 \leq R \leq \sqrt{2}D$. As shown in Fig. 2, the more the number of nodes, the higher the connection probability. Furthermore, the variation which is represented by a slope is narrower. This implies that the critical transmission range is needed to transmit in order to ensure that all nodes are connected with probability one when the number of nodes in the given network goes to infinity. Gupta and Kumar [12] have proven that if n nodes are placed in a unit area in R^2, and each node transmits at a power level so as to cover an area of $\pi r^2 = (\log n + c(n))/n$, the connection probability is one if and only if $c(n) \to \infty$.



(a) N = 10 (b) N = 15

(c) N = 30 (d) N = 50

Fig. 3 Comparison of Bernoulli model and fixed transmission range model where N = 10, 15, 30, and 50

We assume that binomial probability p and fixed transmission range R can be used the same factor $0 \leq R$, ($R = p) \leq 1$. From the previous assumption, as shown in Fig. 3, there are some differences between Bernoulli trials model and fixed range model as the function of the number of nodes in the network N = 10, 15, 20, 30, and 50. The probability that there are no mobile nodes within range R is $e^{-\pi R^2 \lambda}$, where λ is the density of nodes in the plane [13]. The interval separating two consecutive nodes has an exponential distributed length, whose distributed function is

$$F(x) = \begin{cases} 1 - e^{-\lambda x}, & \text{if } 0 \leq \text{x} < \infty \\ 0, & \text{otherwise} \end{cases} \qquad (1)$$

and the pdf of x is given by

$$f(x) = \begin{cases} \lambda e^{-\lambda x}, & \text{if x} > 0 \\ 0, & \text{otherwise} \end{cases} \qquad (2)$$

The distance between sender and receiver should be below or equal $R/2$. Let I_i dente the event that node i is isolated, i.e., has no links to any other node. The probability that at least one node is isolated is $P(\bigcup_{i=1}^{n} I_i)$, where I_i is mutually exclusive, $I_j \cap I_k = ø$, and $j \neq k$. Since the area within the range of a node is at least $(\pi R^2)/4$, for all i, $1 \leq i \leq n$,

$$\begin{aligned} P(I_i) &\leq (1 - \frac{1}{4}\pi R^2)^{(n-1)} \\ &= e^{\ln n + (n-1)\ln(1 - \frac{1}{4}\pi R^2)} \end{aligned} \qquad (3)$$

Because R decreases to zero as $n \to \infty$, R must decreases more slowly than $\sqrt{\ln n / n}$. In the topology graph, there is a link (i, j), from node i to j, if node i can send to node j. But if two nodes are not connected in this graph, then they cannot be connected when arbitrary sets of nodes are allowed to transmit.

3. Minimum Transmission Energy with Clustering Hierarchy

Tree-based clustering structure to reduce latency and energy consumption is shown in Fig. 4. Every cluster consists of one cluster-head and non-head cluster members that are no more than h hops away from their CH. A delivery route construction mechanism both within a cluster and among cluster-heads is done by tree algorithm with minimum transmission energy. For wireless sensor networks we make the following assumptions:

-. The sink node (SN) is located away from the sensors.
-. SN is immobile basically but can be mobile.
-. All nodes in the network are homogeneous and energy constrained.
-. Initially, charged energy levels of the battery of each node may be different.
-. All nodes can travel to SN one hop directly, and identify by a variable length of addresses.
-. Transmitting/receiving propagation channel is symmetric.

The operation of MTECH consists of advertisement phase, cluster-head election phase, cluster-head tree construction phase and steady-state phase. Since all nodes can be a cluster-head, in order to select cluster-heads, we use a stochastic process that the percentage of cluster-heads is p_t. Each node *n* generates a random number *r(n)* between 0 and 1. If $r(n) < p_t$, the node *n* initiates advertisement phase. Advertisement is represented by $AD_n(E, A_n, h)$, where *E* is the node which has the highest energy level, A_n is an address of forwarding node to reach the cluster-head and is identical with its own address, and *h* is the number of hop counted from the node whose energy level is *E*, respectively.

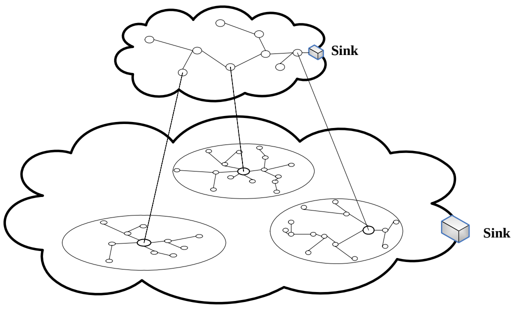


Fig. 4 Topology of Minimum Transmission Energy with Clustering Hierarchy (MTECH)

In Fig. 5, node *i* broadcasts $AD_i(E_i, A_i, 0)$ contained its energy level E_i to neighbor nodes one-hop away. In our technique, because each node identifies its energy level as address of itself, A_i is identical with E_i. Node *i+1* that receives this advertisement stores and then compares its energy level E_{i+1} with E_i. If E_{i+1} is less than E_i, node *i+1* broadcasts $AD_{i+1}(E_i, A_{i+1}, 1)$. If not, it broadcasts $AD_{i+1}(E_{i+1}, A_{i+1}, 0)$ and become a candidate for a cluster-head as it has the highest energy level. Node *i* therefore sets its advertisement to $AD_i(E_{i+1}, A_i, 1)$ and rebroadcasts it. This process will be continued until all nodes $n \neq i$ within *h* hop away from the node $AD_i(E_i)$ has the same value $AD_{n \neq i}(E_i)$. Let the maximum hop count be 2. From Fig. 5, if advertisement phase is initiated by node *i*, cluster-head becomes node *i* and the list of a cluster members is <i, i+1, i+2>. Node i+3 and i+4 do not process advertisement phase because they are in out of bound, $h > 2$. If node i+4 initiates this phase, cluster-head is i+4 and cluster is <i+4, i+3, i+2>. After finishing advertisement phase, there is two clusters <i, i+1> and <i+2, i+3, i+4>. As node i+2 has received two advertisements from node i and i+4, it can join either of them. In this case, since node i+4 has higher energy level than that of node i, it joins the member of the cluster whose CH is node i+4 as non-head cluster member.

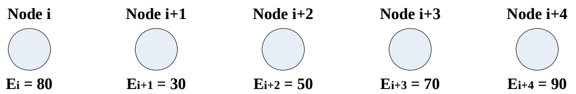


Fig. 5 Example of initial energy level in advertisement phase

When a node transmits data to its cluster-head, MTECH delivers these data with tree-based multi-hop minimum distance algorithm. When node *i* initiates advertisement phase, nodes are grouped into <i, i+1, i+2>. Thus, advertisements of each node i, i+1 and i+2 are $AD_i(E_i, A_i, 0)$, $AD_{i+1}(E_i, A_{i+1}, 1)$ and $AD_{i+2}(E_i, A_{i+2}, 2)$, respectively. If node i+2 wants to send data to a cluster-head, it gets the address of forwarding node, A_{i+1}, from the received advertisement $AD_{i+1}(E_i, A_{i+1}, 1)$, and then transmits data to node i+1. This process is executed repeatedly until it reaches a cluster-head.

Routing protocol between cluster-heads is done by tree-based minimum transmission energy scheme. In cluster-head tree construction phase, cluster-head first creates its address in random fashion. Thus, each cluster-head *CH* has a previously generated random number $r(CH)$ as its address. Let A_{sink} be the address of the sink node and a fixed value. If a cluster-head wants to send data, it tries to connect to either another cluster-head or the sink. For this, *CH* increases its radio transmission power until it reaches to one of them. When cluster-head CH_j reaches to the sink by one hop, its address is $(A_{sink}+CH_j)$ with a cascade addressing algorithm which makes new address as a received address followed by its own address. When CH_k is located at 1-hop away from CH_j and has been connected to the sink, the address of CH_k is $((A_{sink}+CH_j)+CH_k)$. Thus, each cluster-head can be connected to only one cluster-head with its own address after finishing cluster-head tree construction phase. Furthermore, this method requires less amount of network bandwidth than cluster model with one hop propagation because it prevent data from flooding overall network and can be possible to send along the specified route.

4 Performance Analysis

In the above discussion, each cluster is consisted of a cluster-head and non-head cluster members. Cluster-head aggregates data in its cluster and sends them to the sink directly or through other cluster-heads with multi-hop propagation fashion. Hence the total amount of transmission data of cluster-head *CH* can be computed as D_{CH}. D_{CH} is equal to the sum total of all data generated in its cluster members.

Let *N(n)* be the total number of nodes in wireless network. Node can join a member of the nearest cluster at most *h* hops away. We assume a square grid consisting of $m_x * m_y$ clusters, where m_x and m_y are the number of clusters in x axis and y axis, respectively. Each cluster-head can communicate with four neighboring cluster-heads on the grid. The number of nodes in each cluster is $N(CH) \approx N(n)/m^2$ if $m=m_x=m_y$. Because cluster-head sends data with a tree-based minimum transmission energy method, cluster-heads can be connected to each other via either vertical link or horizontal link. Thus, transmission route of 4-ways square grid becomes a tree form of which the maximum number of branch is two.

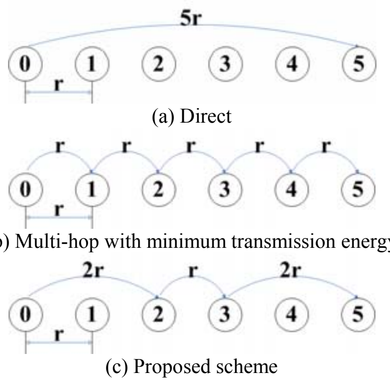


Fig. 6 Examples of delivery model where the distance between adjacent two nodes is r, and the distance between sink node and sensor node is $5r$.

Fig. 6 shows the delivery examples of direct, multi-hop with minimum transmission energy and proposed scheme. If node 0 wants to send data to the sink node 0, the transmission range of the node 0 should be $5r$ at least in direct model and it should be more than r in multi-hop model. If cluster-heads are node 2 and node 3, each node can deliver data over a distance of $2r$. To calculate the energy dissipation, we use the same radio model as stated in [16] with E_{elec} = 50 nJ/bit as the energy being dissipated to run the transmitter or receiver. The energy dissipation of the transmission amplifier is ε_{amp} = 100 pJ/bit/m^2 and the pass-loss exponent is 2. The costs of transmitting a k-bit message a distance d are calculated as follows:

Let each node send b bits during a time unit t and the distance between any two nodes be r in the linear network. If node i located a distance nr away from the sink node, the energy dissipation E_{Direct} is

$$E_{Direct} = E_{Tx}(k, d = nr) = E_{elec}k + \varepsilon_{amp}kn^2r^2 = k(E_{elec} + \varepsilon_{amp}n^2r^2) \quad (4)$$

In minimum transmission energy (MTE) as multi-hop propagation, if node i located a distance nr from the sink node, there are n transmissions and n–1 receptions. Thus the energy dissipation of E_{MTE} is

$$E_{MTE} = k((2n-1)E_{elec} + \varepsilon_{amp}nr^2) \quad (5)$$

In MTECH, we assume that the distance d between two cluster-heads is lr. If node i is located at a distance of hr from a cluster-head which is md away from the sink, there are h transmissions and h-1 receptions heading for cluster-heads, and m transmissions and m-1 receptions toward the sink. So the energy dissipation E_{MTECH} is

$$\begin{aligned} E_{MTECH} &= E_{MTE\_for\_CH} + E_{MTE\_for\_Sink} \\ &= k((2h-1)E_{elec} + \varepsilon_{amp}hr^2) + k((2m-1)E_{elec} + \varepsilon_{amp}ml^2r^2) \\ &= k(2(h+m-1)E_{elec} + \varepsilon_{amp}r^2(h+ml^2)) \end{aligned} \quad (6)$$

If the distances r and d are variable at every node, from equation (5) and (6) the energy dissipations of MTE and MTECH are

$$E_{MTE} = k((2n-1)E_{elec} + \varepsilon_{amp}\sum_{i=1}^{n} r_{i-1,i}^2) \quad (7)$$

$$E_{MTECH} = k(2(h+m-1)E_{elec} + \varepsilon_{amp}(\sum_{i=1}^{h} r_{i-1,i}^2 + \sum_{j=1}^{m} d_{j-1,j}^2)) \quad (8)$$

where $r_{i-1,i}$ is the distance between node i-1 and node i, $d_{j-1,j}$ the distance between cluster-heads, respectively. The distances from its cluster-head and from the sink node are defined by $r_{0,(n\ or\ h)}$ and $d_{0,m}$, respectively.

5 Simulations and Analysis of the Results

In this section, we show simulation results to demonstrate the benefit of proposed wireless sensor networks with minimum transmission energy strategy based on clustering hierarchy mechanism and analyze on the results of performance using it. We assume that simulation network is created within a 100m x 100m space with 100 nodes that are homogeneous and energy-constrained, but their energy levels are different initially. The transmission range of node is selected from uniform distribution from 1m to 5m. Basically, the proportion of cluster-heads to the other nodes is 5%. The maximum energy charged level of each node is 0.5J. We use a simple first order radio model in [16], where the amount of consumed energy in transmitter or receiver is E_{elec} = 50 nJ/bit and in the transmit amplifier ε_{amp} = 100pJ/bit/m^2.

Fig. 7 shows the mean number of nodes still alive at each round. The X-axis shows the simulation rounds while the left Y-axis shows the number of nodes still alive. In this case, the number of nodes is 100, the ratio of cluster-heads to the other nodes is 5% and every node' energy level is equal to 0.5 nJ. The simulation results show the proposed technique is better than direct transmission and minimum transmission energy methods. Direct transmission mechanism dissipates less energy than MTE where the range between a sink node and a sensor node is at a short distance. Therefore, in the proposed technique, nodes closed to the sink node can live longer as the number of data message must go through a long distance is fewer than that of MTE.

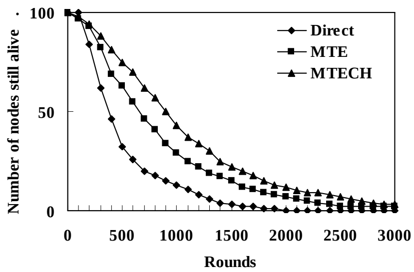


Fig.7 The mean number of live nodes using various routing with 0.5 J/node and the ratio of cluster-heads 5%

Fig. 8 shows the results where the ratios of cluster-heads are 5%, 10%, 20% and 40%. The X-axis shows the simulation rounds while the left Y-axis shows the ratio of the number of nodes still alive. The number of nodes is 100 and energy level is 0.5 J/node. In our technique, cluster-head collects data from adjacent nodes and then sends them to another cluster-head or the sink node. The simulation result shows that the ratio of cluster-head 5% is the best performance than the others. As the increase of cluster-heads has a result in the reduction of the number of hops toward cluster-head and the sink node, energy dissipation in each node decreases linearly.

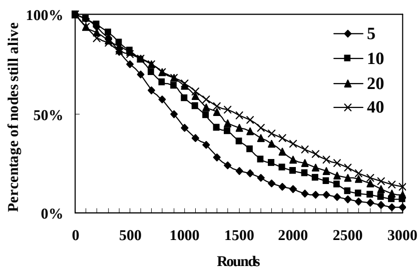


Fig.8 The mean number of live nodes where the ratios of cluster-heads are 5%, 10%, 20% and 40%, respectively.

Fig. 9 and Fig. 10 show simulation results of proposed routing technique that the proportion of nodes still alive at every round as the function of various difference of charged energy level of each node's battery 10%, 20%, 30%, 40%, 50% and 100%, and the others parameters were used the same ones in above simulations, the ratio of cluster-heads 5%, the number of nodes 100 and maximum charged energy level 0.5 J/node. The difference 10% means that every node has an energy level varied with 10% of the maximum energy level. For example, the maximum charged energy level is 0.5 J/node and the minimum is 0.45 J/node. It shows that the proposed technique can achieve about the same performance with 5% of the variation when the difference is below 20%.

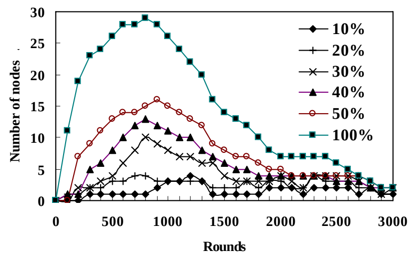


Fig. 9 The difference of live nodes between equally charged energy level 0.5 J/node and various charged energy levels

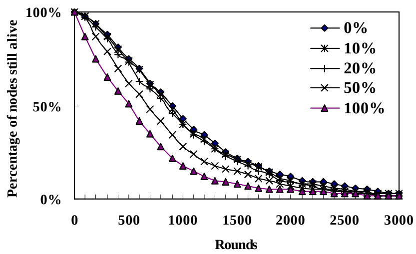


Fig. 10 The mean number of live nodes when the ratio of cluster-heads is 5% and the maximum energy level is 0.5 J/node

6. Conclusion

This paper presents energy-efficient routing protocol in wireless sensor networks using the combination of tree-based minimum transmission energy routing scheme and cluster-based hierarchical routing scheme. In the proposed technique, wireless networks are consisted of clusters that have cluster-head and non-head members. Cluster-head is elected among the nodes that have the highest energy levels to keep the lifetime of wireless networks longer. Every node transmits its data to its cluster-head with minimum distance tree algorithm. Then cluster-head sends data to the other cluster-heads or the sink node with tree-based minimum transmission energy algorithm due to the limit of nodes' transmission range. Since the node address represents its energy level, it is easy to reconstruct routing tree when wireless nodes or cluster-heads die. Also, this mechanism can be possible to make new route before any node along the path toward the sink die. From the simulation results, when the difference of charged energy level is below 20%, the same performance of wireless networks can be accomplished.

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