Increasing the Lifetime of Ad Hoc Networks Using Hierarchical Cluster-based Power Management

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Abstract

One inevitable problem in Ad Hoc networks is the limited battery capacity, which explains why portable devices might shut down suddenly when the power of hardware is depleted. Hence, how to decrease the power consumption is an important issue in ad hoc networks. With the development of wireless technology, mobile devices can transmit voices, surf the Internet, download entertaining stuffs, and even support some P2P applications, like sharing real-time streaming. In order to keep the quality stable, the transmission must be continuous and it is thus necessary to select some managers to coordinate all nodes in a P2P community. In addition to assigning jobs to the staffs (children) when needed, these managers (ancestors) are able to reappoint jobs in advance when employees retire. This paper proposed a mechanism called Cluster-based Power Management (CPM) to stabilize the transmissions and increase Time to Live (TTL) of mobile hosts. In our new proposed method, we establish the clusters according to every node's joining order and capability, and adjust their sleep time dynamically through three different mathematical models. Our simulation results reveal that this proposed scheme not only reduces the power consumption efficiently, but also increases the total TTLs evidently.

Keywords: Ad Hoc networks, cluster, power management, P2P, real-time streaming

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1. Introduction

In recent years, wireless communications have been developed rapidly due to users' requirements, and wireless technologies nowadays allow users to exchange information or communicate with one another at any locations you can image. Telecommunication and computer networks are the two most important alliances to promote the 4G networks, in which the maximum transmission rate achieves at least 100M bits per second [1]. These facts reveal that people can transmit voices via mobile devices, download movies and music, and even watch real-time programs at anytime and anywhere. Nevertheless, without the Systems on a Chip (SOC) technology, mobile devices cannot acquire the above-mentioned value-added services. Generally speaking, only when the performance and the power consumption [2][3][4][5][6][7][8][9] are balanced, can the mobile devices work functionally. To this day, lithium cell remains the only type that supports all kinds of mobile devices. The concept of solar cells has been promoted recently, but its realistic applications to mobile phones are still full of uncertainties.

In this paper, we bring up a method called Cluster-based [10][11][12][13][14][15][16][17][18][19][20][21][22][23][24] Power Management (CPM) to decrease the power consumption of mobile phones. A necessity of IEEE 802.11 power management protocol for ad hoc networks is that each mobile host must get timing synchronization in one hop distance. However, in multi-hop environments, it is never easy for mobile hosts to achieve timing synchronization, which reduces the performance of IEEE 802.11 protocol also. For these reasons, we select a mobile host with the highest capability (C) to be the cluster header (CH) to manage its hierarchical structure and adjust the sleep time of its children dynamically. The simulation results show that by selecting the binary tree as the management model, our method can really increase the Time to Live (TTL) of mobile hosts.

The rest of this paper is organized as followed. Section 2 displays how to calculate the capability (C) of each node while Section 3 presents the procedure for building up the clusters. The Cluster-based Power Management (CPM) is elaborated in Section 4. The simulation results and analysis are manifested in Section 5 and the conclusion is given in Section 6.

2. The Value of Capability (C)

The purpose of this section is to introduce how to figure out the C for each node while the C is founded by four basic elements as listed in the following. Note that with the attempt to balance the values and the importance, we normalize the four important parameters before calculating the C.

The Similarity (S): The S, called Resemblance Coefficient [2], helps to distinguish the importance of similarity between different nodes. There are three basic forms of coefficients for demonstrating the S as the following:

- JACCARD Coefficient:

$$S(a,b)=n(1,1)/[n(1,1)+n(1,0)+n(0,1)] \quad (1)$$

- SORENSON Coefficient:

$$S(a,b)=2*n(1,1)/[2*n(1,1)+n(1,0)+n(0,1)] \quad (2)$$

- SIMPLE MATCHING Coefficient:

$$S(a,b)=[n(1,1)+n(1,0)]/[n(1,1)+n(1,0)+n(0,1)+n(0,0)] \qquad (3)$$

The symbol $S(n_i,n_j)$ shows the similarity between node i and node j, and n(1,1), n(1,0), n(0,1), and n(0,0) refer to the totally different attributes between them. For further explanations, **Fig. 1** displays an 8-node network.

Next, we calculate S(1,2) and list the neighbors of node 1 and 2 in **Table 1**. Node 1's neighbor list [2] is (1, 1, 0, 0, 1, 0, 0, 1) and node 2's neighbor list [2] is (1, 1, 1, 0, 0, 1, 0, 0). The number 1 and 0 represents connection and disconnection respectively. Therefore, the S can be calculated by the foregoing two lists. By (2), the S(1,2) undoubtedly equals 0.5.

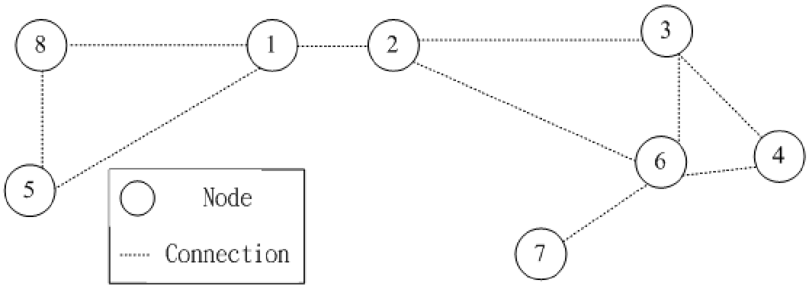


Fig. 1. 8-node network in a wireless environment.

Example:

$$S(1,2)=\frac{2\times n(1,1)}{2\times n(1,1)+n(1,0)+n(0,1)}=0.5$$

where n(1,0) = 2, n(0,1) = 2 and n(0,0) = 2.

Through the above-mentioned method, we can conclude that the S ranges between 0 and 1, and a higher S means the higher similarity between each pair.

Table 1. The neighbor list [2] of **Fig. 1**.

Node	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	1	1	0	0	1	0	0	1
2	1	1	1	0	0	1	0	0
3	0	1	1	1	0	1	0	0
4	0	0	1	1	0	1	0	0
5	1	0	0	0	1	0	0	1
6	0	1	1	1	0	1	1	0
7	0	0	0	0	0	1	1	0
8	1	0	0	0	1	0	0	1

The Number of neighbors (N): To normalize the linked numbers, we use a logarithm function to represent the number of nodes within every node's transmission range. One main reason why the logarithm function is adopted as our normalized function is displayed below. At the beginning, the tendency of the logarithm function keeps increasing faster and faster because in a wireless environment, adding a new neighbor is much more important to a node with only 1 neighbor than a node with 50 neighbors. In addition, the normalized linked number must range between 0 and 1. Note that the maximum number of neighbors of each node is assumed to be N_{MAX} and X is the present number of neighbors. The normalized function can be given by:

$$N(node_i) = \log X / \log N_{MAX} = \log(X - N_{MAX}) \tag{4}$$

By (4), we can get the N that ranges between 0 and 1.

The Power (P): This element represents the surplus power of hardware in mobile hosts. It is assumed that the maximum power is P_{MAX} and the X is the surplus power of each node at certain moments. So, we use the following formula to normalize the surplus power of each node.

$$P(node_i) = X / P_{MAX} \tag{5}$$

The P calculated by (5) also ranges between 0 and 1.

The Quality of connection (Q): We use a reasonable and applicable equation called Cumulative Distribution Function (CDF) to completely imitate TI/Chipcon CC2420 SNR/PRR curve in [5]. By (6), it is possible to formularize the relationship of RSSI between any pairs of nodes. As shown in **Fig. 2**, each node can get the corresponding packet receive rate according to their relative distances. Note that the Q is set to 0.5 when the node compares with itself.

$$Q(node_i) = e^{-\lambda} \times \sum_{i=1}^{X} (\lambda^i / i!),\ \lambda = 10 \tag{6}$$

As mentioned at the beginning, the C can be composed by four basic elements, and four undetermined weights are further adopted for users to adjust based on different network environments. Moreover, users choose different weights dynamically to fit their needs. Note that the prerequisite is that $W_S+W_N+W_P+W_Q$ must equal 1.

$$C(n_i) = W_S \times S(n_i, n_j) + W_N \times N(n_i) + W_{P\times} P(n_i) + W_Q \times Q(n_i) \tag{7}$$

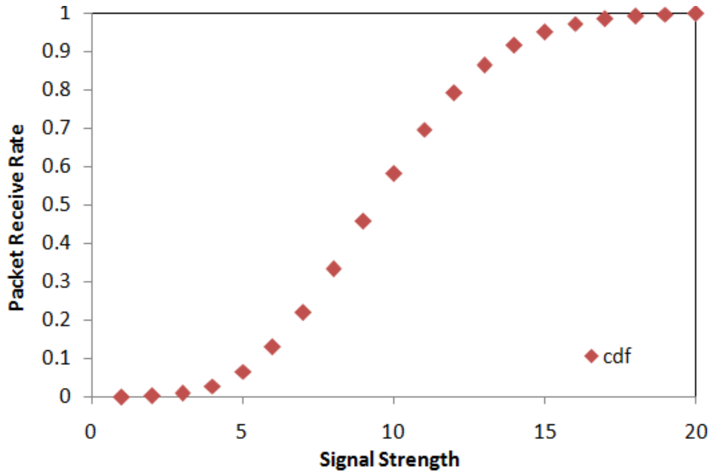


Fig. 2. The values of CDF when λ=10.

3. The Procedure for Constructing the Clusters

This section will introduce the procedure for establishing the clusters. At present, wireless devices (e.g., notebooks, mobile phones) do not have constant and stable power supply and we therefore have to decrease the message exchanges in the procedure. Thus, a specific mechanism is necessary for new members to join in a cluster immediately without wasting power. In order to attain these goals, we adopt the hierarchical mechanism called Bottom-Up, in which each new member sends a “RREQ” message to inform its neighbors of the “joining event”, and the neighbors reply with the “RREP” message that includes the information about the S, N and P. For example, there are three nodes in **Fig. 3**: as a new member, node A sends the RREQ to its neighbors, including node B and C. Before this joining event, node B and C were not interrelated. After receiving the RREQ message that comes from node A, node B and C reply to node A with the RREP message that includes the information about the S, N, and P.

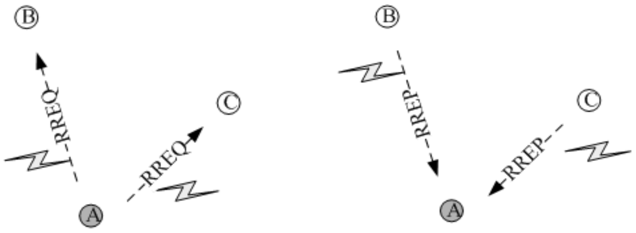
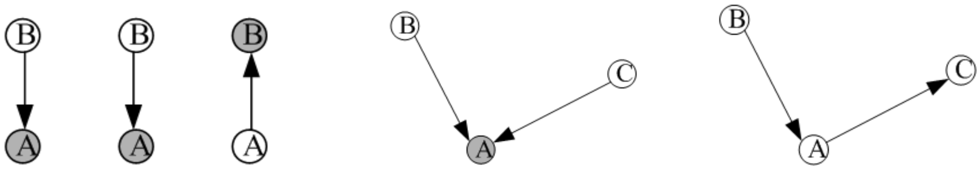


Fig. 3. The standard steps for a “joining event”.

In a while, the new member A collects the information about its neighbors and calculates the C of the neighbors, including itself. After obtaining the C of other neighbors, node A broadcasts the calculated result to its neighbors. The relationship diagram as shown in **Fig. 4-(a)** displays three kinds of situations. Note that it is assumed that in this scenario, node A and B are interrelated in advance.

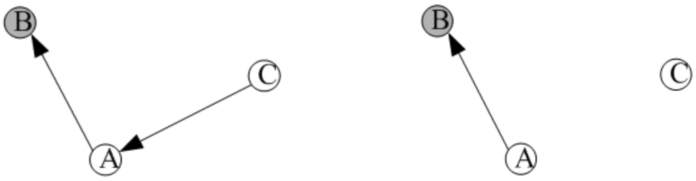


(a) **(b)** **(c)**

Fig. 4. **(a)** Different situations of management and **(b)** C(A)□C(B) □C(C), (c) C(C)□C(A) □C(B).

Three situations in **Fig. 4-(a)** respectively denote that C(A)>C(B), C(A)=C(B) and C(A)<C(B). The C(A) means the capability value of node A. While taking part in the community, the new member owns the right to manage itself at the beginning. Next, the new member compares its neighbors’ capability value with itself for selecting a better candidate to be its manager. If the condition is C(A)>C(B) or C(A)=C(B), node A will be the manager. On the contrary, if the condition is C(A)<C (B), node B will be the manager. However, when node C participates in the community, many circumstances may happen. In **Fig. 4-(b)**, for node C to transfer its management right to node A, the C(A) must be bigger than the C(C) or equal to the C(C), and node C is not others’ employee. Next, in **Fig. 4-(c)**, for node A to transfer its management right to node C, the C(C) must be bigger than the C(A) or equal to the C(A), and node A is not others’ employee.

In **Fig. 5-(a)**, since the C(B) is bigger than C(A) and C(C), node C gives its power of management to node A. Nevertheless, if the C(C) is bigger than C(A), there is no relationship of management between node A and C, as displayed in **Fig. 5-(b)**. At that time, node C manages itself and node A will not be confused by the duplicate management transference. Through this process, we can get a tree-like cluster as our expectation. In **Fig. 6**, the degree of tree is set to 2, and each member in the cluster has a neighbor list to record the replaceable neighbors of each node. Furthermore, a manager only has two employees that are selected from the neighbor list by the above-mentioned cluster-building process. In this way, the manager can reappoint the job for its employees when unexpected massive data comes.



(a) **(b)**

Fig. 5. **(a)** C(B)□C(A)□C(C), **(b)** C(B)□C(A) and C(C)>C(A).

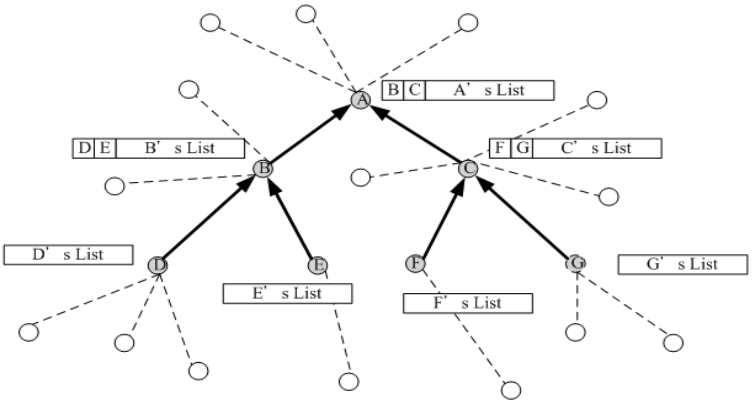


Fig. 6. The logical topology of tree-like cluster.

To sum up, by the cluster-building procedure as shown in **Fig. 7**, every node will be managed by its ancestor, or become the CH in the environment.

4. The Cluster-based Power Management (CPM)

After constructing the clusters, we furthermore introduce the Cluster-based Power Management (CPM) in this section. Generally speaking, the power saving mode in IEEE 802.11 is based on timing synchronization to reduce the power consumption. In this paper, we adopt and adjust a power management protocol called "Periodically-Fully-Awake-Interval" [3]. In **Fig. 8**, for example, there will be a fully-awake beacon every four beacons intervals (N=4), which means that station A receives the beacon signal from station B during station A's fully-awake beacon to locate other neighbors' locations and to receive the information about the existence of all nodes in the environment. As given in [3], there are two types of beacon intervals: low-power intervals, in which the active time is reduced to the minimum, and fully-awake intervals, in which the active time is extended to the maximum. As shown in **Fig. 8**, each low-power interval initiates with an active window that contains a beacon window followed by a MTIM window and the STA can turn to the power saving mode. Although each fully-awake interval initiates with an active window that contains a beacon window followed by a MTIM window also, the STA must stay awake and keep active for the rest of the time. For this reason, compared with low-power beacons, fully-awake beacons consume more power and can only appear in every N interval. Based on the "Periodically-Fully-Awake-Interval" power management protocol, our proposed mechanism modifies the parameter N to control the sleep time of all members in the tree-like clusters. Note that the function of the MTIM frame is the same as ATIM frame in IEEE 802.11, and the MTIM just emphasizes that the network is a multi-hop ad hoc network.

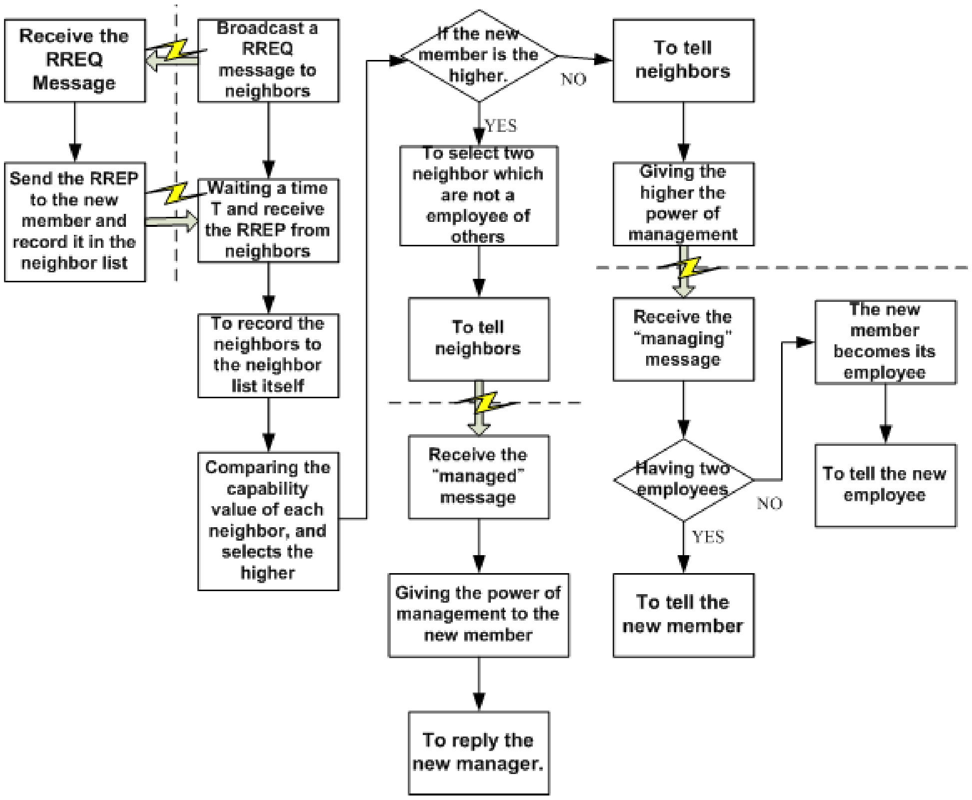


Fig. 7. The cluster-building flowchart.

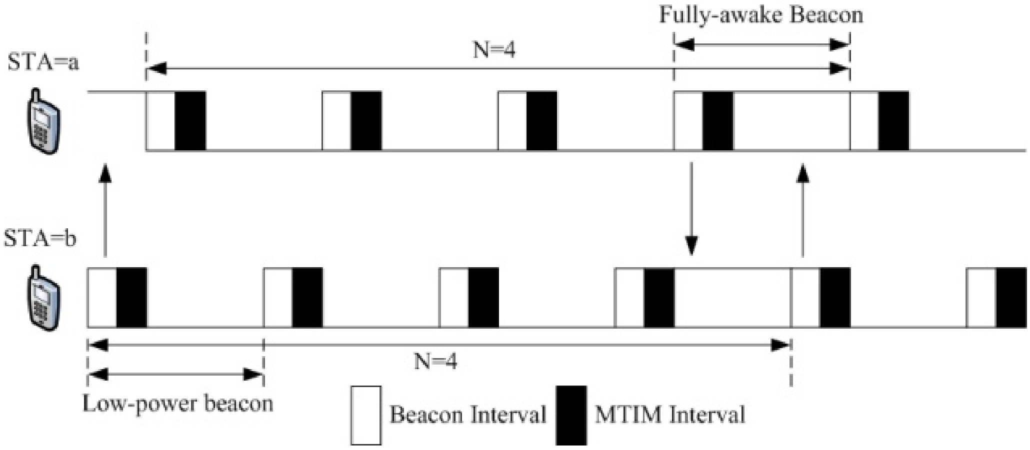


Fig. 8. An example for Periodically-fully-awake-interval protocol.

In CPM, different locations and depths lead to different N of the members and different sleep time. A node near the root is awake very often while a node near the leaves sleeps longer than the first one. In **Fig. 9**, we use three different mathematical models to describe the relationship between the sleep time and the depth of a node. One hypothesis is that every member in the cluster obtains its N value based on its own level. Further, the following three mathematical models just provide the simple ways for a cluster member to find its sleep time. For example, in linear model, the N value of the root node is 4*1=4, and the N value of the second-level node is 4*2=8, and so on. Note that the first parameter is the initial setting of the N value, which varies to satisfy the environmental demands.

The equations of the proposed linear model, 2^X model, and e^X model are given in the final subsection of Section 5. To demonstrate the relationship between the levels of the hierarchical structure and the value N in the Periodically-Fully-Awake-Interval, **Fig. 9** reveals not only the sleep time of each member, but also the limited scale of clusters. Usually, a member that wants to transmit data to others has to wait until the destination node wakes up. This means that when the sleep time of the destination node is too long, the delay time of data will be problematic in the network environment. Therefore, our paper defines one possible solution that the level of the hierarchical architecture must range between 2 and 4.

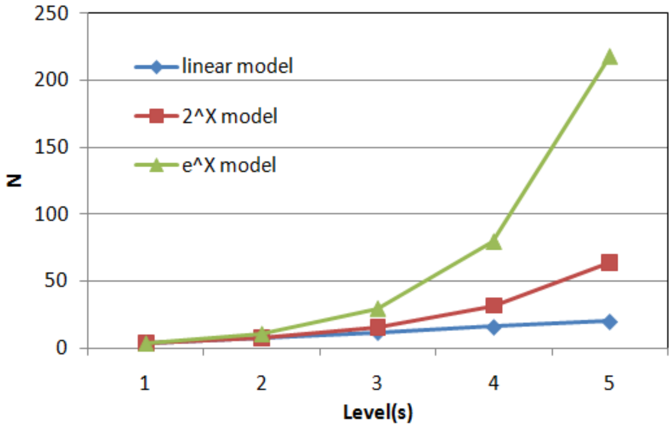


Fig. 9. Three different mathematical models.

5. Simulation and Analysis

Owing to the operation of our CPM mechanism, the environment is divided by several clusters. Thus, we have to define the number of members in each cluster and the structures of the clusters in advance. The following subsections further discuss our designed experiments under different Heights (H) and the number of degrees. **Fig. 10** displays the definition for different Heights (H) and **Fig. 11-(a)** and **(b)** moreover explain the definition for different number of degrees under H = 2.

5.1 The Selecting Principle for Cluster Model while H=3

The CPM basically chooses the binary tree as its model of logical management, but it is important to prove that the binary tree is a reasonable choice for our research. Note that as the logically managed model, the binary tree model does not mean that data must be transmitted through the hierarchical architecture. Besides, the binary tree is not the physical topology in the environment.

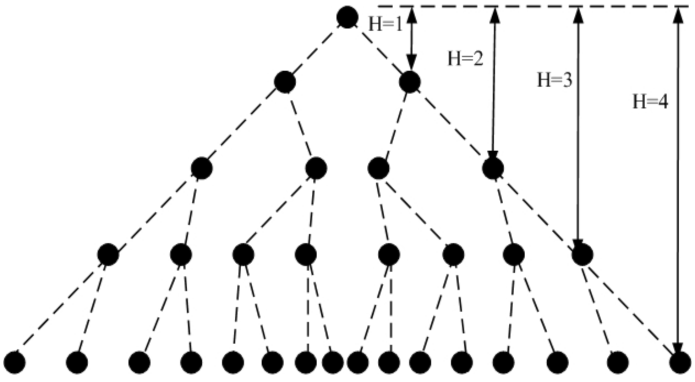
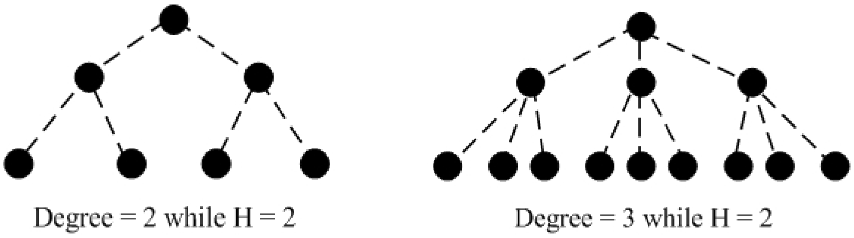


Fig. 10. The definition for different Heights (H).



(a) **(b)**

Fig. 11. **(a)** Degree = 2 while H = 2. ; **(b)** Degree = 3 while H = 2.

First, in the simulation environment, 50 mobile nodes are distributed randomly to construct the clusters according to the joining orders and capabilities (C). After the constructing procedures, we combine three differently mathematical models with the clusters based on ad hoc networks, and keep transmitting beacons and MTIM signals [3] within 1,000ms. In **Fig. 12**, we can confirm that selecting degree 7 or 8 as our logically managed model is the best choice because the power consumption is the lowest.

Next, the CH adjusts the sleep time to prolong the TTL of its children, but the delay time will magnify when the sleep time is too long. For this reason, we design an experiment that allows a “Hello” message to pass through the 50 nodes, and display a comparative diagram to demonstrate the effect on the delay time of the three models.

Fig. 13 reveals that the minimum delay time locates at degrees 1 to 2 and 27 to 50. By taking the power consumption as shown in **Fig. 12** into consideration, we recommend degree 2 or 3 as the optimal choices. **Fig. 12** and **13** both display that degree 1 leads to the shorter delay time but the higher power consumption. Although degrees 27 to 50 cause the shorter delay time, these degrees are not suggested because a mobile host cannot support and manage too many children, or the host will die out soon. Degrees 7 and 8 are good at maintaining battery capacity, but the delay time is too much longer than others. Finally, degree 2 is chosen as our logically managed model because it does not complicate our management but maintains the shorter delay time and the lower power consumption.

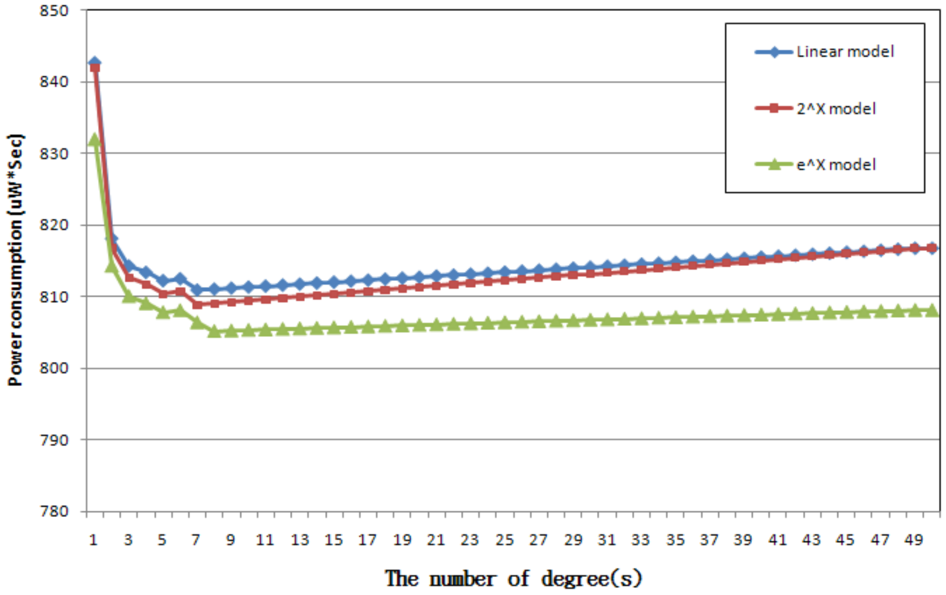


Fig. 12. The number of degree(s) vs. the power consumption while H=3.

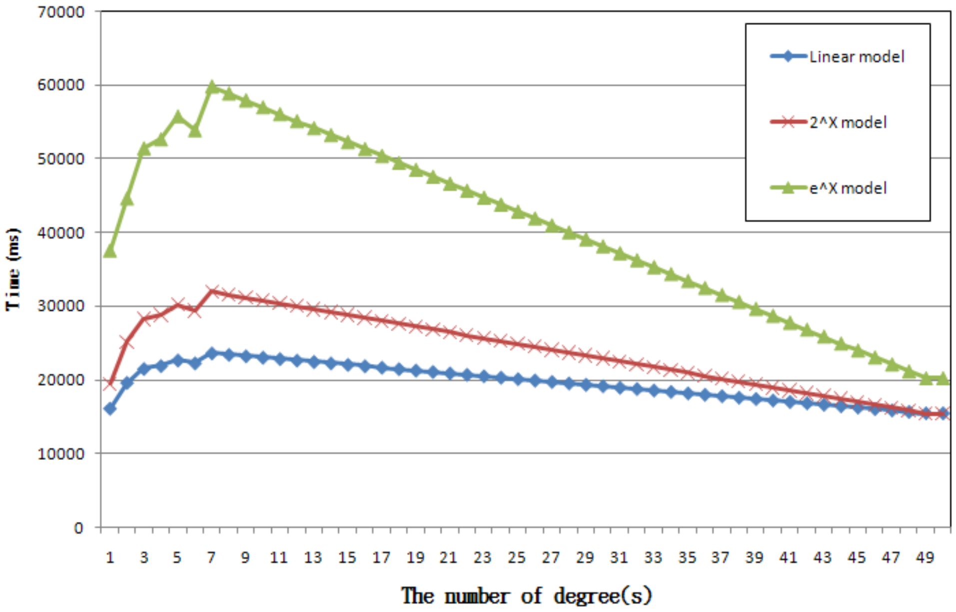


Fig. 13. The number of degree(s) vs. the delay time while H=3.

5.2 The Selecting Principle for Cluster Model while H=4

When H=4, the selecting principle for cluster model differs. The experimental conditions in **Fig. 14** and **15** are the same as those in **Fig. 12** and **13**, respectively. **Fig. 14** shows that selecting degree 2 to 11 as our logically managed model is the best choice for its lower power consumption while comparing with other degrees of clusters.

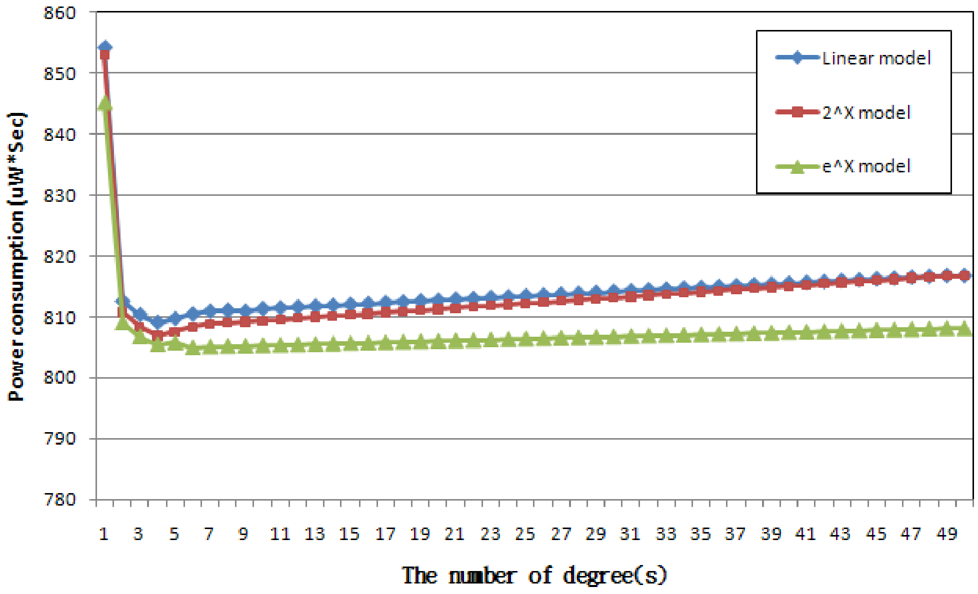


Fig. 14. The number of degree(s) vs. the power consumption while H=4.

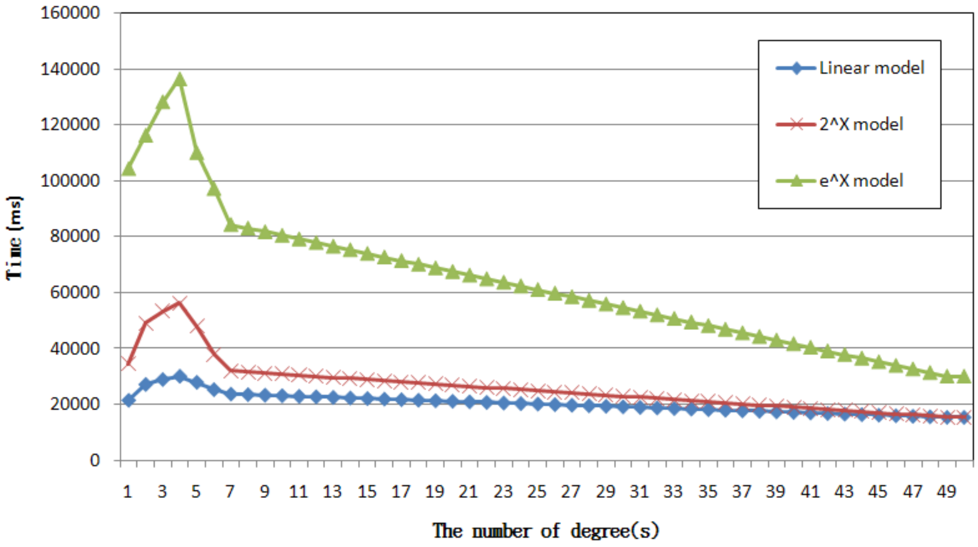


Fig. 15. The number of degree(s) vs. the delay time while H=4.

Fig. 15 reveals that the minimum delay time locates at degrees 7 to 50. By taking the power consumption as shown in **Fig. 14** into account, we recommend degrees 7 to 9 as the optimal choices. **Fig. 14** and **15** display that degree 1 brings about the highest power consumption and is thus excluded. Though degrees 10 to 50 result to the shorter delay time, these degrees are not suggested because a mobile host cannot support and manage too many children, or it will die out soon. Degrees 2 to 6 are good at maintaining battery capacity, but the delay time is too much longer than others.

5.3 The Selecting Principle for Cluster Model while H=5

To make it clearer, we further introduce the selecting principle for cluster model while H=5. Also, the experimental conditions in **Fig. 16** and **17** are the same as those in **Fig. 12** and **13**, respectively. As shown in **Fig. 16**, selecting degrees 2 to 6 as our logically managed model is the best because the power consumption is obviously lower than other degrees of clusters.

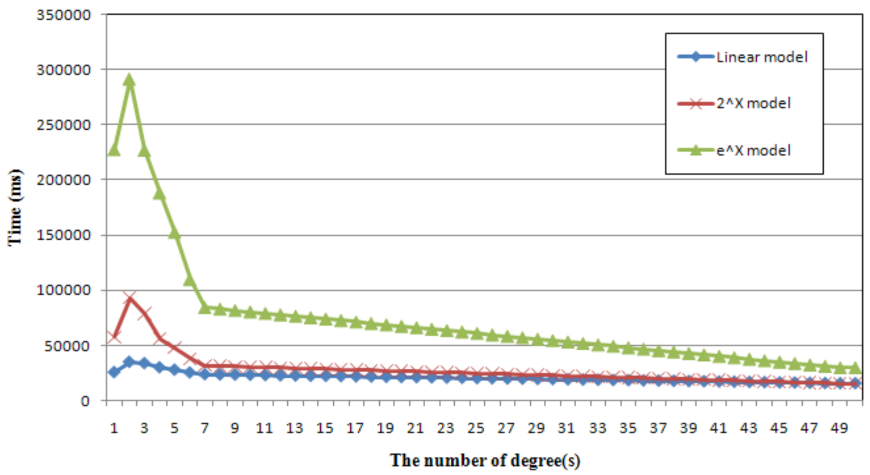


Fig. 16. The number of degree(s) vs. the power consumption while H=5.

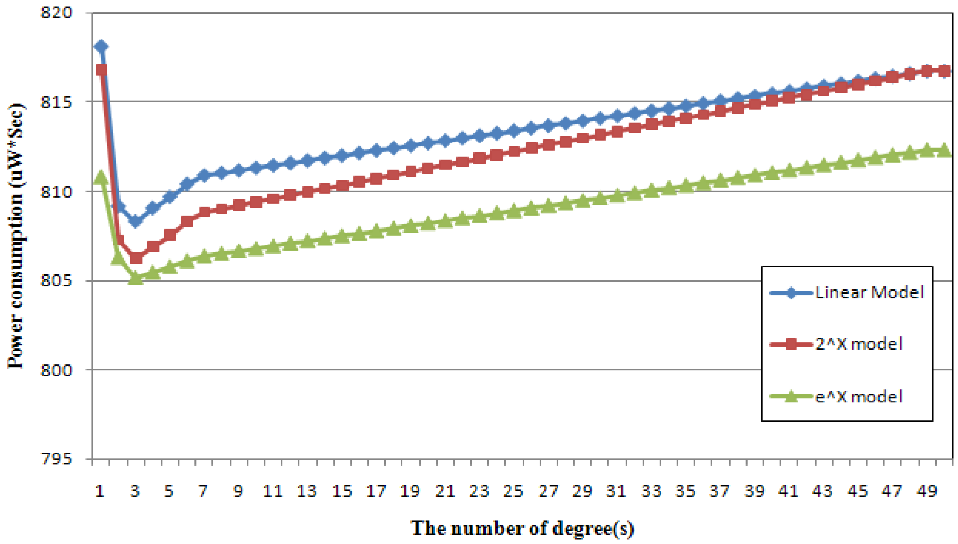


Fig. 17. The number of degree(s) vs. the delay time while H=5.

Fig. 17 displays that the minimum delay time locates at degrees 7 to 50. However, we cannot recommend what kinds of clusters to use by considering the power consumption as illustrated in **Fig. 16** because **Fig. 16** and **17** are not interrelated. When H=5, a CH probably manages 16 to 32 nodes, which is a heavy burden to a simple mobile device. Therefore, the scale of clusters must be restricted in some circumstances. The following **Table 2** summarizes the above-mentioned selecting principles for cluster model while H=3, H=4 and H=5.

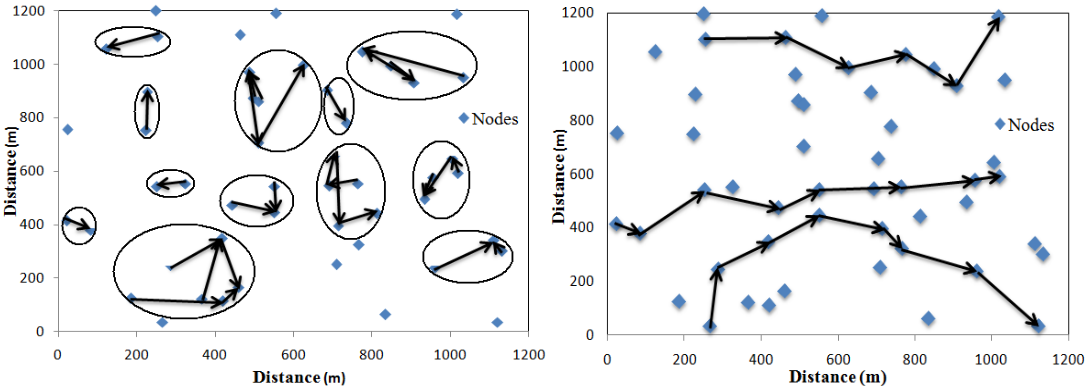
After the previous discussions, we have to announce some conditions and restrictions in the following. While the scale of the clusters keeps increasing, more and more members will aggravate the workload of the CH. Consequently, the battery capacity becomes a controversial issue when the mobile devices are smart phones or PDAs without plug-in power. To enlarge clusters to H=4 is already the limitation of a cluster's scale because a CH cannot manage too many members. To completely apply the three mathematical models to the clusters, the performance changes with different models. Though maintaining better battery capacity, the e^X model is not quite recommended because its transmission delay time does not conform to real-time applications. As for the linear and 2^X models, the selecting principles differ according to the application types. The linear model is a good choice when the application type is real-time service. Otherwise, the 2^X model is already a suitable one. To conclude, with appropriate restrictions on the clusters and right models at right time, our CPM method truly provides more elastic choices for ad hoc networks in power-saving issues.

Table 2. The summary for the selecting principles for cluster model while H=3, H=4 and H=5.

	Considering Power	**Considering Delay**	**In Summary**
H=3	D = 7~8	D = 1~2, and 27~50	D = 2 or 3
H=4	D = 2~11	D = 7~50	D = 7~9
H=5	D = 2~6	D = 7~50	Not recommend to use

5.4 Design of the Experiment

Our simulator is organized by C language. The range of the simulation environment is 1200m * 1200m, and 50 mobile nodes that have 200 m transmission range are distributed randomly in the scope. Note that each mobile node joins in the environment through the methods mentioned in Section 2 and 3, and the relationship of management has been completed according to their joining orders. Next, we will put our simulation into practice in the physical topology. The arrows in **Fig. 18-(a)** reveal that every mobile node renders its power of logical management to the most appropriate node. No arrows around the mobile node represents that its power of logical management does not belong to any other nodes. In addition, every ellipse means a cluster constructed by the nodes (H=3, Degree=2).



(a) **(b)**

Fig. 18. **(a)** the relationship of management.; **(b)** three different routes to transmit streaming data.

To testify the performance, we select three different routes to transmit streaming data [25][26][27][28][29][30] in **Fig. 18-(b)**. The detail values of power consumption for maintaining the transmission routes have been proposed by [4], and the method to manage the clusters has been demonstrated in Section 5. When a node cannot maintain the transmission route, its ancestor assigns another node to take over the position according to the member list given in **Fig. 6**.

5.5 Comparisons of the Performance

It is assumed that the three transmissions continue for 25 minutes and each node can reserve the battery power for 30-sec full power transmission. **Fig. 19** shows that there is no difference between IEEE 802.11 and our proposed methods (Linear, 2^X, and e^X model). However, at the 17th minute, the nodes based on ad hoc mode suddenly pass away massively because the battery capacity will be depleted soon. Moreover, **Fig. 19** is used to observe the performance of four mechanisms. Before the 17th minute of the transmission, the number of live nodes supported by the four mechanisms shows no difference. But, after the 17th minute, the number of live nodes supported by IEEE 802.11 suddenly dies out massively for the depletion of the batteries. Back to our CPM, the three mechanisms (Linear, 2^X, e^X model) outperforms IEEE 802.11 during the entire simulation. Formally, our methods allow the mobile hosts to reappoint the job to its employees before retiring. Note that users should choose which models to use very carefully based on the application types. For example, when users are using portable devices to watch real-time programs, the most suitable method will be the linear method because the delay time of the 2^X and e^X methods is problematic. However, if the users' battery power is low, the suitable methods will be the 2^X and e^X methods. That is to say that the battery power is the most critical issue to consider.

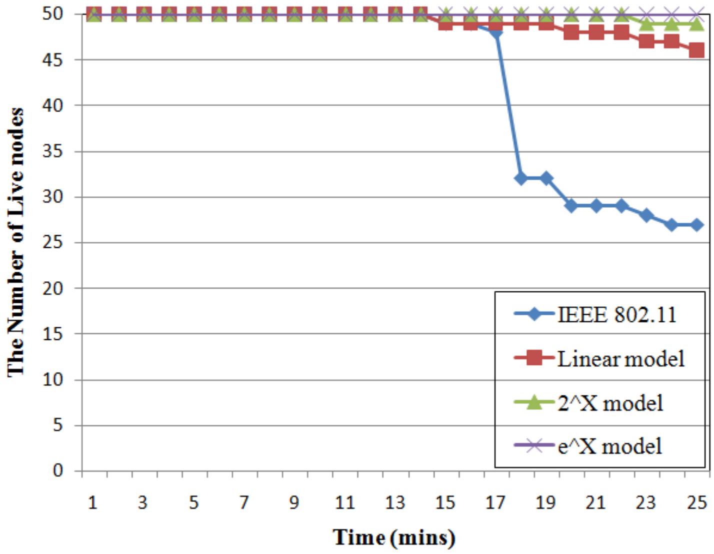


Fig. 19. The number of live nodes in the simulation environment.

5.6 Recommended Simulation Parameters

Supposing the number of nodes is M, we first calculate the needed degree under different heights. First, when H=2, the needed degree will be D_2, in which $D_2^0 + D_2^1 + D_2^2 \leq M$ and $D_2 \geq 2$.

$$(D_2^3 - 1)/(D_2 - 1) = D_2^2 + D_2 + 1 <= M \qquad (8)$$

We get that $D_2 = (-1 \pm \sqrt{4M-3})/2$. Since D_2 must be bigger or equal to 0, $D_2 = (-1 + \sqrt{4M-3})/2$. Next, the above (8) is further extended to the general form. While considering H=h, the possible degree is D_h, in which $D_h^0 + D_h^1 + D_h^2 + \cdots + D_h^{h-1} + D_h^h \leq M$.

Assuming that $D_h \geq 2$, we can get the following equation.

$$(D_h^{h+1} - 1)/(D_h - 1) = D_h^h + D_h^{h-1} + \cdots + D_h^2 + D_h + 1 <= M \quad (9)$$

After figuring out the optimal solution to (9), D_h, by numerical analysis, we can make out the better degree of the tree-like cluster in the same way. **Table 3** lists the recommended simulation parameters for the tree-like cluster while H=3 and 4. Before getting into **Table 3**, several parameters are defined: BI_{base} ,which is formulated as 4, is the initial setting mentioned in Section 5; the minimum of Level (L) is 1 and increases one unit every time; and the power consumption of the low-power beacon is 16.07 uW*Sec.

Table 3. Recommended simulation parameters for the tree-like cluster while H=3 and H=4.

Height	Degree	Model	Power Consumption (uW*Sec)	Sleep Time (ms)
H=3	2	$N = BI_{BASE} * L$	The root: 17.07 The 2nd Level: 16.32 The 3rd Level: 16.18	125 312.5 508.33
		$N = BI_{BASE} * 2^{L-1}$	The root: 17.07 The 2nd Level: 16.32 The 3rd Level: 16.13	125 312.5 706.25
		$N = BI_{BASE} * e^{L-1}$ (Note: round off to the decimal point.)	The root: 17.07 The 2nd Level: 16.23 The 3rd Level: 16.09	125 410 1353.45
H=4	2, 3	$N = BI_{BASE} * L$	The root: 17.07 The 2nd Level: 16.32 The 3rd Level: 16.18 The 4th Level: 16.13	125 312.5 508.33 706.25
		$N = BI_{BASE} * 2^{L-1}$	The root: 17.07 The 2nd Level: 16.32 The 3rd Level: 16.13 The 4th Level: 16.08	125 312.5 706.25 1503.13
		$N = BI_{BASE} * e^{L-1}$ (Note: round off to the decimal point.)	The root: 17.04 The 2nd Level: 16.23 The 3rd Level: 16.09 The 4th Level: 16.08	125 410 1353.45 3901.25

Table 3 lists the recommended degree while H=3 and H=4, the power consumption of different levels, and the expected sleep time. When H=4, the power consumption of members on the leaves almost achieves the minimum, 16.07 uW*Sec, and the sleep time is close to 4 seconds. Thus, for the timely multimedia transmissions, H=5 or above are not suited and the recommended parameters for H=5 are not included. In addition, the purpose of 2^X and e^X is to allow the three mathematical models to have the same N value of the root node. Take **Fig. 9**

as an example. When L=1, the N value of the linear model is 4*1=4, the N value of the 2^X model is 4*21-1=4, and the N value of the e^X model is 4*e1-1=4. Up to now, we have appropriately adjusted the parameters of the tree-like cluster. Another important parameter in establishing the clusters is "the Capacity (C)," four arguments of which are set to 0.25. Here, we do not discuss the weight variation of different parameters for they shall be determined by different environments.

6. Conclusions

In this paper, we propose a new cluster-constructing method that allows the nodes in the environment to form several clusters in single hop distance. According to the nodes' Capability (C) that contains the Similarity (S), the Number of neighbors (N), the batter Power (P) and the Quality of connection (Q), each cluster chooses a CH, whose job is to reappoint its members' jobs to others when the battery is depleted, and to adjust its members' sleep time according to the proposed three mathematical models. The analyses in Section 5 show that the magnitude of clusters must be restricted within H=2 to H=4 and three mathematical models must be used appropriately for different application types. The comparison between our method and IEEE 802.11 ad hoc mode further reveals that, even though the physical environment of networks is not considered, the addition of the cluster-based management (CPM) not only decreases the power consumption efficiently, but also prolongs the total TTLs obviously.

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