The Cluster-based Power Management for Promoting Time to Live in Ad Hoc Networks

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Abstract—**In ad hoc networks, one inevitably serious problem is that the power of battery is not permanent which explains that portable devices perhaps shut down suddenly if the power of hardware is die out. Hence, how to decrease the power consumption is an important issue in ad hoc networks. With the development of wireless technology, mobile devices are not only permitted of transmitting voice, but also allowed to surf the Internet or download entertaining stuffs. Furthermore, it also can support some P2P applications such as sharing real-time streaming. In order to keep a stable quality, the transmission cannot break off unexpectedly which illustrates that it is necessary to select some managers to coordinate each node in a P2P community. Those managers can assign jobs to their staffs if needed. When employees retire, the managers can reappoint jobs in advance. In this paper, we proposed a mechanism called Cluster-based Power Management (CPM). The CPM could keep transmissions stable and increase Time to Live (TTL) of mobile hosts. In our new proposed method, we build the clusters according to the joined order and capability of each node, and adjust sleep time of each node dynamically though three differently mathematical models. By this way, the actual advantages of reducing the power consumption and increasing the total TTLs are presented in our simulation results.**

Keywords- ad hoc networks, cluster, power management, P2P, power consumptions, real-time streaming, Time to Live (TTL).

I. INTRODUCTION

In recent years, wireless communications is developed very quickly due to the requirements from users, and wireless technologies allowing users to exchange information or communicate with each other at any locations as you can image. Telecommunication and computer networks are the two most important alliances to promote the 4G networks allowing maximum speed 100M bits per second for transmission. Those facts mean that people not only can transmit voice by mobile devices but also download movies and music or watch real-time programs at anytime and anywhere. Without the Systems on a Chip (SOC) technology, mobile devices are not permitted of those mentioned value-added services.

However, only the power consumption [2], [5], [6], [8] can keep the functional works of mobile devices which means that how to get balance between performance and power consumptions is very important. To this day, the lithium cells remain the only type to support all kinds of mobile devices. Although many people promote the concept of solar cells, its realistic applications to mobile phones are full of uncertainties.

In this paper, we bring up a method called Cluster-based [1], [3], [4], [7] Power Management (CPM) to decrease the power consumptions of mobile phones. In IEEE 802.11 standard, its power management protocol for ad hoc networks requires that each mobile host must get timing synchronization in one hop distance. However, in multi-hop environment, mobile hosts are not easy to achieve timing synchronization, and it also reduces the performance of IEEE 802.11 protocol. Under above reasons, we pick up a mobile host which has the highest capability (C) to be the cluster header (CH) to manage its binary tree, and it also can adjust the sleep time of its children dynamically. Simulation results show that our method can really increase the Time to Live (TTL) of mobile hosts and selecting binary tree as its management model is the most appropriate one.

The rest of this paper is organized as followed. Section 2 displays how to calculate the capability (C) of each node. The procedures of building the clusters are presented in Section 3. Section 4 shows the Cluster-based Power Management (CPM), Section 5 manifests the simulation results and analysis. Section 6 gives the conclusions of this paper.

II. THE VALUE OF CAPABILITY (C)

In this section, we introduce how to come up the C for each node, and the C is founded by four basic elements as following. Note that the following contain not only shows important parameters but also normalizes them, because we must equal significance with magnitude before calculating the C.

- The Similarity (S): calculating this element can achieve an objective that distinguishes the importance of similarity between different nodes, and the S also has been called Resemblance Coefficient [2]. There are three basic forms of coefficients for demonstrating the S as following:
  - *JACCARD Coefficient:*
    S(a,b)=n(1,1)/[n(1,1)+n(1,0)+n(0,1)] (1)
  - *SORENSON Coefficient:*
    S(a,b)=2*n(1,1)/[2*n(1,1)+n(1,0)+n(0,1)] (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)] (3)

This symbol S(a,b) shows the similarity between node a and node b, and n(1,1), n(1,0), n(0,1), and n(0,0) mean the totally different attributes between them. For further explanations, there is an 8-nodes network as shown in Fig. 1.

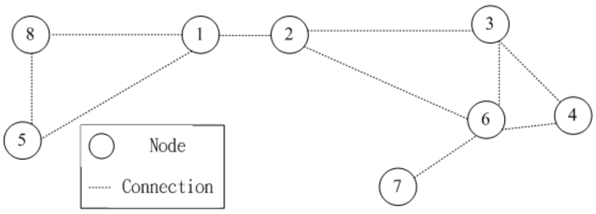

Fig. 1. 8-nodes network in wireless environment.

Next, we calculate S(1, 2) and list the neighbors' list of node 1 and node 2. The neighbors' list [2] of node 1 is (1, 1, 0, 0, 1, 0, 0, 1) and the neighbors' list [2] of node 2 is (1, 1, 1, 0, 0, 1, 0, 0). Note that the number 1 and 0 represents connection and disconnection respectively. Therefore, the S can be calculated by those above two lists. By (2), the S(1,2) equals 0.5 is undoubted result.

Ex:

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

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

Though the mentioned method, we can conclude that the S is ranged between 0 and 1, and a higher S means higher similarity between each pair.

- The Number of neighbors (N): in this paper, we use a logarithm function to normalize the linked numbers which represent that the number of nodes within its transmission ranges of each node.

  One main reason of why we use logarithm function to be our normalized function is displayed below. At beginning, the tendency of logarithm function is increasing faster, because adding a new neighbor to a node only owning 1 neighbor is truly important than adding a new neighbor to a node owing 50 neighbors in wireless environment, and we do have to normalize the linked numbers to ranges between 0 and 1. Note that we assume the maximum number of neighbors of each node is N_{MAX} and X is the present number of neighbors. Next, we give the normalized function as following:

$$N(node_i) = \frac{\log X}{\log N_{MAX}} = \log(X - N_{MAX}) \quad (4)$$

  Though (4), the N will be within 0 and 1.

- The Power (P): this element represents the remained power of hardware in mobile hosts. We assume that the maximum power is P_{MAX}, and the X is the remained power of each node at certain moment. So, we use the following formula to normalize the remained power of each node.

$$P(node_i) = \frac{X}{P_{MAX}} \quad (5)$$

  Thought (5), the P will also be within 0 and 1.

- The Quality of connection (Q): we survey a reasonable and applicable equation called Cumulative Distribution Function (cdf) to completely imitate TI/Chipcon CC2420 SNR/PRR curve in [8]. By (6), formularizing the relationship of RSSI between any pairs of nodes is possible which means that each node can get corresponding packet received rate according to their relative distances as shown in Fig. 2. Note that the Q is set to 0.5, when the node compares with itself.

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

The C can be composed by the four basic elements that we mentioned above, and we further select four undetermined parameters for users adjusting them based on different network environment. On the other hand, users determine those different weights dynamically to fit their demands. There is one prerequisite that W+X+Y+Z must equal 1.

$$C(node_i)=W*S(node_i)+X*N(node_i)+Y*P(node_i)+Z*Q(node_i) \quad (7)$$

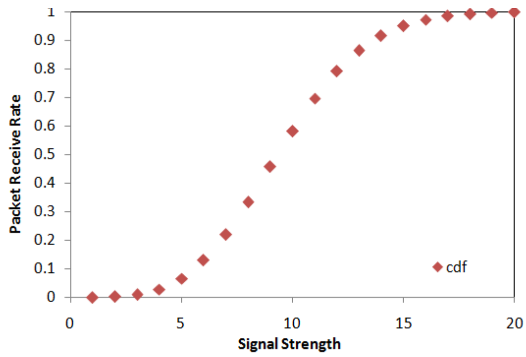

Fig. 2. The values of cdf, when λ =10.

III. THE PROCEDURES FOR CONSTRUCTING THE CLUSTERS

In this section, we introduce the procedures of cluster building. In our environment, each wireless device (e.g., notebook, mobile phone) has no constantly stable power supply. Hence, the procedures of cluster building have to decrease the message exchanging. So we have to design a mechanism for that the new member can join in a cluster immediately without wasting the unnecessary power consumption. In order to attain these goals, we choose the hierarchical mechanism called Bottom-Up. In this mechanism, each new member sends a "RREQ" message to convey a "joined event" to its neighbors, and the neighbors reply a "RREP" message to the new member. The RREP message includes the information about the S, N and P. For example, there are three nodes as shown in Fig. 3, the node A is a new member and it sends the RREQ to its neighbors (including node B and C), and the node B and C had no connection before this jointed event. While node B and C receive the RREQ message that comes from node A, the node B and C send the RREP message that includes the information about the S, N, and P to the node A.

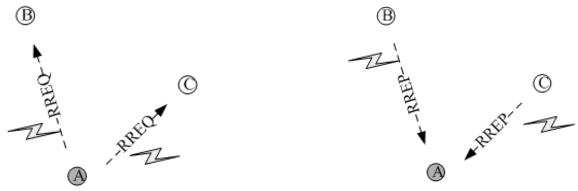

Fig. 3. The standard steps for a "joined event".

After a moment, the new member A collects all information of its neighbors, and then it calculates the C of each neighbor including itself. When the member A obtains the C of other neighbor, it broadcasts the calculated results about the C to its neighbors. There are three different situations of relationship as shown in Fig. 4 (a). Note that we assume that the member A and B establish the connection first in this scenario.

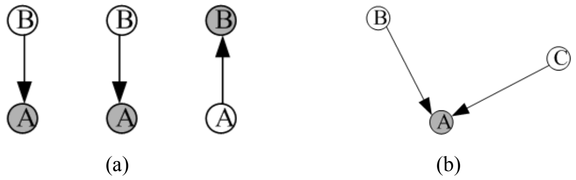

Fig. 4. (a) the different situations of management, (b) C(A)≧C(B) ≧C(C).

There are three situations that are C(A)>C(B), C(A)=C(B) and C(A)<C(B) in Fig. 4.(a) respectively. The C(A) is the capability value of member A. While a new member takes part in this community, it owns the right to manage itself at beginning, and then the new member compares other neighbor's capability value with itself for selecting a better candidate to be its manager. If the condition are C(A)>C(B) or C(A)=C(B), the manager will be the member A. On the contrary, if the condition is C(A)<C(B), the manager will be the member B. Then, there will many circumstances happen while a new member C is coming in this community.

In the Fig. 4.(b), the C(A) is bigger than C(C) or equal to C(C) in keeping with the prerequisite that the member C is not a employee of others. So the member C gives the power of management to node A to establish the management transfer.

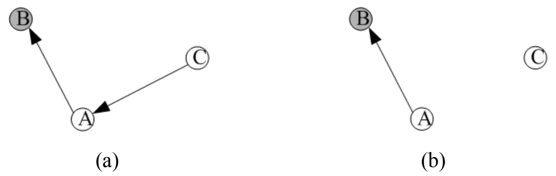

Fig. 5.(a) C(B) ≧C(A) ≧C(C), (b) C(B) ≧C(A) and C(C) > C(A).

The C(B) is bigger than C(A) and C(C) in Fig. 5.(a). Of course the member C gives its power of management to member A. Then in Fig. 5.(b), there is no relationship of management between the member A and C if the C(C) is bigger than C(A). By this process, we can get a tree-like cluster as our expectation. In Fig.6, we set the degree of tree equals 2, and each member in cluster has a neighbor list that uses to record the replaceable neighbors of each node. For further explanation, a manger has two employees only and the employee is selected from the neighbor list by the process of cluster building as mentioned in this section above, so the manager can reappoint the job to its employees when the unexpectedly massive data comes.

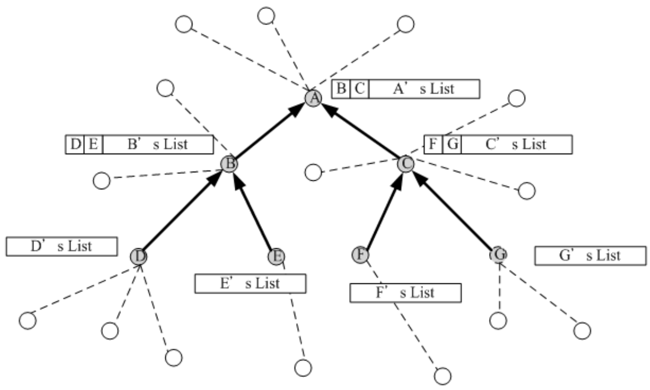

Fig. 6. The logical topology of tree-like cluster.

In summary, we conclude the flowchart for constructing the clusters being used in our simulator. By the procedures in Fig. 7, each node will be managed by its ancestor or be the Cluster header (CH) in environment.

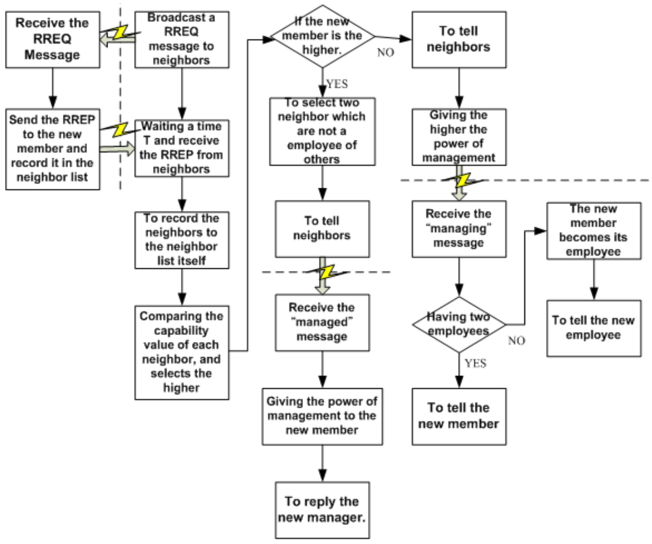

Fig. 7. The flowchart of cluster building.

IV. THE CLUSTER-BASED POWER MANAGEMENT (CPM)

After constructing the clusters, we 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 a power management protocol called "Periodically-Fully-Awake-Interval" being described in [5]. In Fig. 8, for example , there will be a fully-awake beacon in every four beacons intervals (N=4) which means that the station A can receive the beacon signal from station B in the fully-Awake beacon of A, and the beacon signal is used to locate other neighbor's location. On the other hand, the fully-awake beacon is used to receive the information about the existence of each node in environment. In our mechanism, we can modify the parameter N to control the sleep time of each member in the tree-like clusters based on the "Periodically-Fully-Awake-Interval" power management protocol.

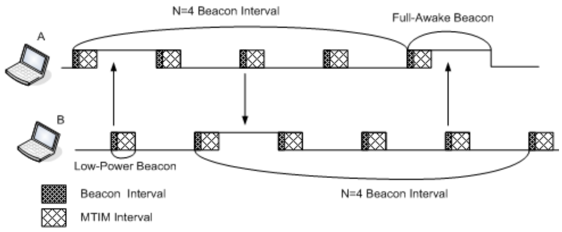

Fig. 8. The example for Periodically-fully-awake-interval protocol.

In CPM, each member's N is different because the value N is based on the location and depth of a member, so different depth of each member has different sleep time. If a node is near the root, it will be conscious very often. On the contrary, if a node is near the leaves, it will sleep longer than we mentioned above. We use three different mathematical models to describe the relationship between the sleep time and the depth of a node as shown in Fig. 9.

For example, we demonstrate the relationship between the levels of binary tree and the value N, and each member can find out the sleep time by Fig. 9. The other important issue is that the scale of clusters should be limited. If a member wants to transmit data to others, it has to wait until the intended node waking up which means that if the node's sleep time is too long, the delay time of data will be problematic in network environment. One possible way for solutions is defined the scale of binary tree. In our paper, the level of binary tree will be ranged between 1 and 4.

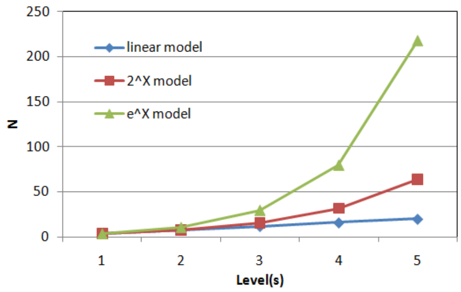

Fig. 9. The three different mathematical models.

V. The Simulation and Analysis

A. The Cluster Model of Binary Tree

The CPM chooses the binary tree as its model of logical management, but there is an important theme for discussion before we enter this subsection. The question is how we can prove that the binary tree is the best choice for our research. Note that the binary tree model is only the logically managed model and it does not mean that data must transmit though the hierarchical architecture. On the other hand, it is not the physical topology in environment.

First, we drop 50 random mobile nodes in our simulation environment, and construct the clusters according to their joined orders and capabilities (C). After the constructing procedures, we combine three differently mathematical models with our cluster being based on ad hoc networks and keep transmitting beacon and MTIM signals [5] within 1,000ms.

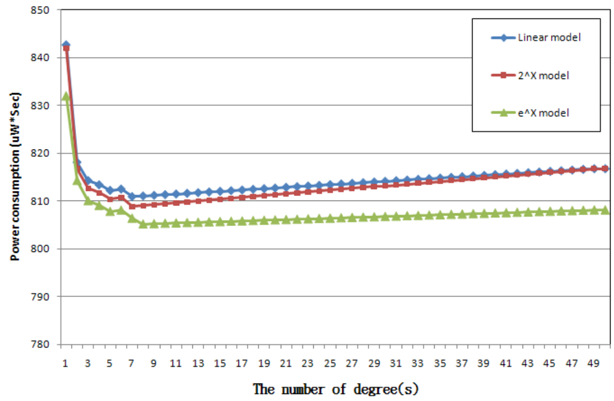

Fig. 10. The number of degree(s) vs. the power consumption.

In Fig. 10, it is clear for observation that selecting degree 7 or 8 as our logically managed model confirms the best choice, because its power consumption is the lowest one when we compare with any other degrees of the clusters.

Second, CH adjusts the sleep time for prolonging the TTL of its children, but one disadvantage accompanies with the longer sleep time. If the sleep time is too longer, the delay time must magnify. Under this reason, we design an experiment which allows a "Hello" message to pass though those 50 nodes, and display a comparable diagram to demonstrate the effect on the delay time between three models.

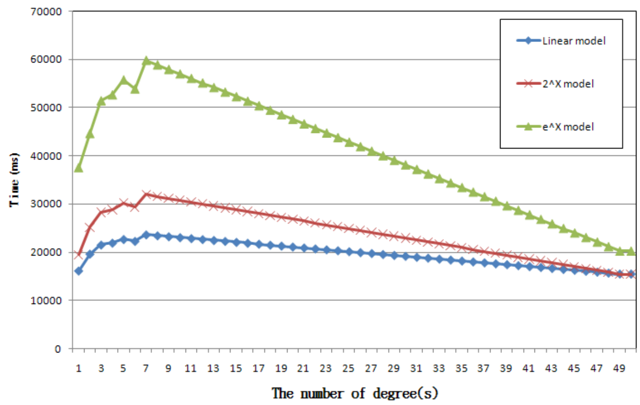

Fig. 11. The number of degree(s) vs. the delay time.

In summary, in Fig. 11, the minimum delay time locates within 1 to 2 and 27 to 50. When further considering the power consumption as shown in Fig. 10, we recommend that selecting degree 2 or 3 are the considerable chooses. In Fig. 10 and 11, the degree 1 has the lower delay time but higher power consumption. Further, the degree 27 to 50 also has the lower delay time, but we do not suggest using those degrees because mobile host cannot support and manage too many children--otherwise it dies out very fast. Although the degree 7 or 8 is good at maintaining batter power, its delay time is too much longer than others. Finally, we select degree 2 to be our logically managed model because it does not complicate our management and maintain the lower delay time and lower power consumption.

B. Design of experiment

Our simulator is organized by C language. The range of the simulation environment is 1200m * 1200m, and we random drop 50 mobile nodes which have transmitted range of 200m into the physical range. Note that each mobile node joins the environment though the mentioned methods as introducing in section 2 and 3, so the relationship of management is completed by their joined orders. After those procedures, we will come true the physical topology in our simulation. In Fig. 12, the arrows identify one fact that mobile node renders its power of logical management to the most proper node. If there are no such arrows around the mobile node, it represents that its power of logical management does not belong to any other nodes as shown in Fig. 12. Note that each ellipse in Fig. 12 means that those nodes become a cluster.

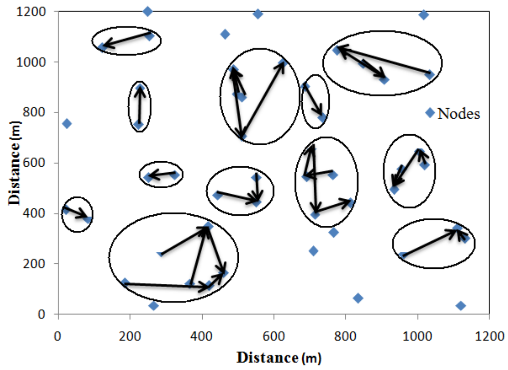

Fig. 12. The relationship of management.

For testing the performance, we select three different routes to transmit streaming data in Fig. 13. The detail values of power consumption for maintaining the transmitting route have been proposed by the authors in [6], and the method to manage the clusters is demonstrated in section 4. Besides, if the node could not maintain the transmitting route, its ancestor assigns which node to replace its positions according to the member list as shown in Fig. 6.

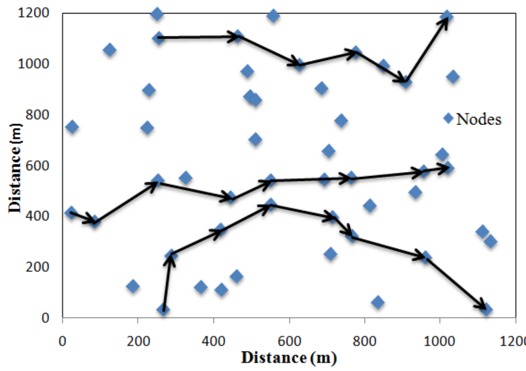

Fig. 13. Three different routes to transmit streaming data.

C. Comparisons of performance

We assume that the three transmissions continue 25 minutes and each node could reserve its own battery for full power transmission within 30 seconds. As we can see in Fig. 14, there are no differences between normal ad hoc networks and our method, but things change when the transmissions continue 18 minutes. The nodes based on ad hoc mode are sudden death massively because they will consume the battery until dying out, but out method can reappoint the job to its employees before die out. Note that we do not consider the other two models due to the too long delay time, and the linear model fit our demands already.

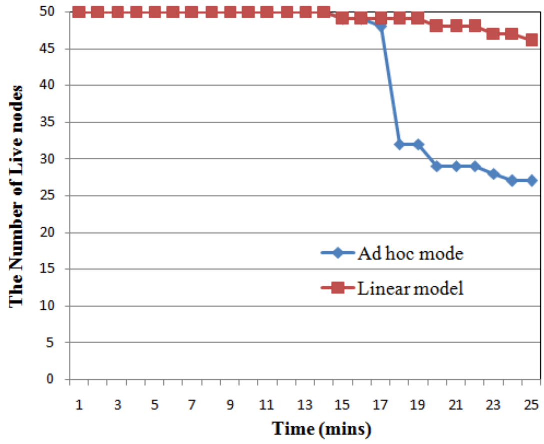

Fig. 14. The number of live nodes in simulation environment.

VI. Conclusions

First, this paper implements our simulations through C language. Although the physical environment of networks is not considered, the addition of the cluster-based management obviously brings great advantages to the ad hoc networks. Second, we encounter many problems while arguing about the procedures for CPM, for example, how to combine the CPM with routing protocols (e.g., DSDV, AODV, ZRP). So the works will be strengthened our method in the future.

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