A Power Efficient Routing Algorithm Based on Betweenness

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***Abstract*—In recent years, routing and efficient energy are important topics in mobile ad hoc networks (MANET). According to the resources of MANET are limited, such that, advance routing strategies have to be considered the issues of resources consumption and transmission effect. Complex network has non-trivial topological features. A network can be measured by multiple properties and be presented network behavior, such as betweenness. We propose a new routing algorithm with betweenness analysis. The results show that our algorithm is used to increase network lifetime.**

Keywords-betweenness; routing algorithm; power saving; wireless networks

mobile ad hoc networks (MANET)[1]. Two types of wireless networks are commonly used to access the Internet services. One is mobile node connecting to wired networks with base station. The base station is acting as a bridge between mobile nodes and wired networks. The other is a network without infrastructure. The MANET is formed by mobile nodes without the fixed infrastructures and has a logic network topology induced by self-organization. In early, most of routing literatures of MANET focus on QoS, delay, bandwidth, power saving and other costs. According to the resources of MANET are limited. Routing strategies have to consider the issues of saving resources and efficient transmission.

Complex network has non-trivial topological features. That is complex networks do not occur in simple network architectures. Complex network properties include average path length, clustering coefficient, node degree distribution, betweenness and etc. A network can be understood by measuring these network propertie.

Small-world network[2] and scale-free network[3] are two typically complex networks. The concept of small-worlds was originally used in describing human social interconnections. Watts and Strogatz [2] formally proposed two characteristics of small-world networks, one is low average network path length and another is high clustering coefficient value. A network with a power law distributed degree distribution is called sale-free network [3]. The probability of a node with k edges is defined as $P(k)$. The relationship describing power-law distribution of $P(k)$ can be written as $P(k) \sim k^{-\gamma}$ where γ is the tail index of the power-law distribution.

In a simple graph, the "betweenness centrality" of node i is the number of shortest paths between two nodes that pass through node i. In a connected network, at least one shortest path exists between each pair of nodes [4]. There may more than one shortest path exists between two nodes in complex networks[2]. Betweenness centrality can be regarded as a measure of the network to which a node has control over packet forwarding between other nodes Betweenness of node i can be formulated as

$$B(i) = \sum \frac{\sigma(s,i,d)}{\sigma(s,d)} \qquad (1)$$

node s and d. $\sigma(s,i,d)$ be the number of shortest path from node s to node d passed by node i. A node i with high betweenness means i is in central of network. Because of high betweenness, node i has high probability to be chosen in shortest path of routing algorithm. Therefore, node i consumes its energy very fast. Node i will be creased if battery exhausted.

Wireless networks have limited energy supply and low-power operation, an efficient routing algorithm is need. It may employ some methods such as clustering transmission or power saving and etc [5-7]. The energy efficient routing protocols consider residual battery capacity and find a routing path for transmission [8-13]. Multipath is However, before discussing our algorithm, we focus on the betweenness property and how to increase lifetime of a network.

II. Notations and Definitations

The notations in this paper are shown in Table 1. A network $G=\{V,E\}$ consists of two sets, $V=\{1, 2,\ldots,N\}$ is the set of vertices and $E=\{e_{ij} \mid i,j \in V\}$ is the set of edges. We use $e_{ij}=1$ to denote the existence of edge e_{ij} in network G. The number of elements in set V is represented by its absolute value $N=|V|$.

We introduce the concepts regarding to relationship between two nodes in a network and we study an efficient routing algorithm on network $G(V,E)$. Most of routing

TABLE I. NOTATION DEFINITIONS

Notation	Description
s:	Source node.
d:	Destination node.
$G(V,E)$	A network graph G. V is a set of all nodes, E is a set of all edges.
$g_{s,d}(V',E')$:	A directed graph of all possible shortest paths from s to d. $V' \subseteq V$ and $E' \subseteq E$. The compact form denote $g_{s,d}$
$a^i_{s,d}$:	Number of shortest paths from s to node a in $g_{s,d}$.
$a^o_{s,d}$:	Number of shortest paths from a to node d in $g_{s,d}$.
$r_{s,d}(a)$:	Number of shortest paths from s to d via node a.

builds up a spanning tree for a source node to all destination nodes. The spanning algorithm decided next node on the spanning tree considers bandwidth, hop count or ther costs. We employ betweenness and battery capacity to be our cost to select next node. The $a_{s,d}$ denotes as number of shortest path from s to d. Four definitions as following:

Definition 1: Upstream paths
Number of shortest path from node s to node a in $g_{s,d}$, denote as.

$$a^i_{s,d} = \sum_{k \in B_p(a)} k^i_{s,d} \tag{2}$$

where $B_p(a)$ is a set of parent nodes of node a in $g_{s,d}$.

Definition 2: Downstream paths
Number of shortest path is from node a to node d in $g_{s,d}$, denote as

$$a^o_{s,d} = \sum_{k \in B_c(a)} k^o_{s,d} \tag{3}$$

where $B_c(a)$ is a set of child nodes of node a in $g_{s,d}$.

Definition 3: Node Betweenness
According the definitions 1 and 2, the betweenness of node a in $g_{s,d}$ can be calculated as

$$r_{s,d}(a) = a^i_{s,d} \times a^o_{s,d} \tag{4}$$

From (4), node a knows its weight in $g_{s,d}$.

Definition 4: Link Betweenness
Numbers of shortest path pass through a link. The Link paths of E_{ab} defined as

$$\lambda_{s,d}(a,b) = a^i_{s,d} b^o_{s,d} \tag{5}$$

where $e_{ab} \in E$ and node b is a child node of node a in $g_{s,d}$. Following sections, we study node betweenness and link betweenness for routing strategies.

III. POWER EFFICIENT ROUTING ALGORITHM

The shortest path is finding a path from one node to another node, such that the number of edges is minimized over all possible paths. A shortest path minimizes a pre-defined metric such as hop counts, delay, distance or other costs. Determination of shortest paths is often described as shortest path algorithm. AODV [14] is an on-demand shortest path on wireless networks. We proposed a Power Efficient Routing (PER) algorithm to find a shortest path between two wireless nodes. In PER algorithm, the cost of choosing a child node in routing path depends on the node/link betweeness. Based on betweenness, PER algorithm considers path fault tolerance and power saving.

A node with highest/lowest metric value will easily to be selected in the shortest path algorithm. In this case, the node is fast approaching to low battery. Because of the node have more chances to responsible for transmitting data packets. For example, four nodes form a grid network; there are two paths for each pair of opposite nodes in the network. That is, a source node has two options to forward packets to destination node. If source node always sends its packet via same route, then the nodes on the path consume larger amount of energy for transmissions. Thus, residual battery capacity should be considered in path selection function.

To maximize the lifetime of wireless network, our algorithm selects the efficient energy path for packet transmission. We present a new betweenness-based power efficient algorithm called the Power Efficient Routing algorithm. This algorithm can be easily integrated into ad-hoc routing protocols such as AODV. The PER algorithm tries to select the route path, which maximizes the lifetime of wireless nodes. PER algorithm calculates node betweenness metric, residual battery capacity and optimal route path. We simulated and studied how PER algorithm acquires longer network lifetimes than alternative distance vector routing algorithms.

A. Node betweenness

A shortest path from source node to destination node is a directed path. There is a node a on the shortest path of node s and d. Upstream path defines all the paths from node s to node a. The a^i is sum of all shortest paths from its parent nodes. An example shows in Figure 1. As Figure 1 shows three shortest paths from s to a; and $a^i_{s,d}$=3. Downstream paths is all the paths from node a to node d. The $a^o_{s,d}$ represents that number of path from a to d is counting on number of path of its child nodes. Thus, $a^o_{s,d}$ is 3. The $a^i_{s,d} / a^o_{s,d}$ shows on node a. Then, we know the number of shortest path from node s to d via node a is $r_{s,d}(a)$. Another example is the 3/1 of node b represents $b^i_{s,d}$=3, $b^o_{s,d}$=1 and $r_{s,d}(b)$=3.

According definition 3, each node knows its node betweenness for node s and d. Our shortest path routing algorithm employs node betweenness as routing metric. As Figure 1, both node a and c will be selected by our algorithm. First, the node s selects one of parent nodes of node a with power efficient strategy, because node betweenness of parent nodes of node a are equal. Then,

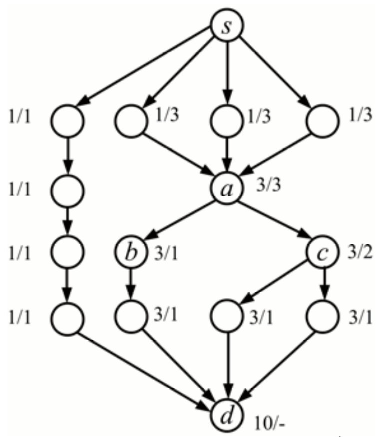


Figure 1. an example of notations. $c^{i}_{s,d}$=3, $c^{o}_{s,d}$=2, $r_{s,d}(c)$=6. All shortest paths from s to d is 10.

node a join the route path. Because $r_{sd}(c)$ is higher than node $r_{sd}(b)$; node c will be chosen by routing algorithm. Following this strategy, a route path is created from node s to d. According to $r_{sd}(c)$, upstream and downstream of node c represent that it easy to find second path if link is creased.

A spanning tree routing algorithm such as AODV adopts node betweenness as metric to find a shortest path to all nodes in the network. The definition 3 considers one pair of source and destination nodes. In spanning tree algorithm, we have to consider all nodes in the network. The node betweenness of node a should be $r'(\mathrm{a})=\Sigma r_{sd}(a)$ for all possible source node s and destination node d pairs. Routing algorithm selects the node with high r' to join the spanning tree. After spanning tree is created, the nodes on the tree have high r'. Because the nodes in route path or spanning tree have high node betweenness. It is easy to find a second path for recovery, if a node or link failure.

B. *Link betweenness*

A node a is on the shortest path of node s and d. Figure 2 shows the betweenness of node a between node s and d. $B_p(a)$ is a set of parent nodes of node a from source node. $B_c(a)$ is a set of child nodes of node a to destination node. In node a, there are $|B_c(a)|$ paths from node b to destination. For example if the routing algorithm then selects a shortest path from s to d that includes the node b, then the node a

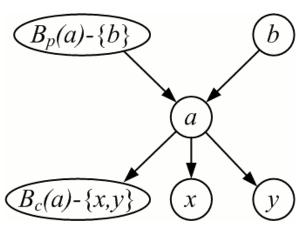


Figure 2 betweenness of node a.

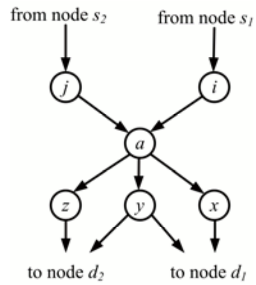


Figure 3 an example of multicast routing. Source node s_1 creates a multicast tree to node d_1 and d_2. The metric of e_{ax}, e_{ay} and e_{az} are $\lambda(a,x)=\lambda_{s_1d_1}(a,x)$, $\lambda(a,z)=\lambda_{s_1d_2}(a,z)$ and $\lambda(a,y)=\lambda_{s_1d_1}(a,y)+\lambda_{s_1d_2}(a,y)$.

selects next node by definition 4. Thus, $\lambda_{s,d}(a,x)$ and $\lambda_{s,d}(a,y)$ decide which node x or y join the shortest path.

In multicast communication, one source node send messages to a group of destination nodes, link betweenness can be used to select next node in multicast routing algorithm. Figure 3 shows an example of multicast routing. Assume that multicast routing algorithm has been reached node a. And then, node a selects one of three child nodes to join the multicast tree. Because the value of $\lambda(a,y)$ is larger than $\lambda(a,x)$ and $\lambda(a,z)$, the node y will be selected to join the multicast tree. It decreases number of transmission in the network.

C. *Network lifetime*

An important issue on wireless network is power saving. When a wireless node exhausted its power energy, it will become useless in the network. Perhaps, the network may become unconnected. A wireless network decomposes with the increase of useless nodes. Battery capacity is a limited resource on wireless networks, how to lengthen the lifetime of batteries is an important issue. Hence, network throughput will be increased, when the network lengthen the lifetime of network.

A node with high betweenness consumes its battery power fast. Distance vector routing algorithms optimal a shortest path from s to d. If a node has high betweenness means it has high probability to be part of route path. Therefore routing algorithm considers not only betweenness but also the residual battery capacity of node.

The betweenness $B(i)$ may be normalized by dividing through the number of pairs of nodes not including i, which is $(N\text{-}1)(N\text{-}2)$. The normalized betweenness B' defined as

$$B'(i)=\frac{B(i)}{(N-1)(N-2)} \qquad (6)$$

Suppose that, there are m messages will be transmitted and P_E battery capacity for each node. For each transmission, the $P_E = P_E$ -1. The node becomes useless when P_E is equal to zero. In this scenario, there may m $B'(i)$ times forward messages via node i. From Equation (7), we know the lifetime of node *i*. That is $m \le P_E / B'(i)$. The *m* is the maximum number of packets that node *i* can send.

$$B'(i) \times m \le P_E \tag{7}$$

High value of $B'(i)$ has high probability to be selected as the node which forward packets. Thus, the node with high $B'(i)$ has less lifetime than low $B'(i)$. To prevent this situation, an α is proposed to lengthen the lifetime of the node with high $B'(i)$. And let network keeps working for packet transmission.

IV. EXPERIMENTAL RESULTS

Our experiments are simulated PER algorithm on random networks. There are *N* nodes randomly distributed on a plane in the network and each nodes recorded its location *x* and *y*. Each wireless node connects other nodes which are in its transmission range.

First, we analyze betweenness distribution of random networks. As Figure 4, our results show that most of nodes have low betweenness and a few nodes are high betweenness. The second step, we studied residual battery capacity between AODV and PER algorithm. In this session, 100 nodes are distributed on a plane. At beginning, the battery capacity of a node is 100 units. Every packet pass the node will be consumed battery power. Each transmission is randomly chosen source and destination nodes from set *V*. Figure 5 represent the results of simulation after 200 times transmissions. Figure 5(a) represents results of AODV routing algorithm in our network. The figure shows some battery capacities of nodes are quickly consumed. By this trend, the alive of network will be shorter. Figure 5(b) illustrates the result used our new routing algorithm. By our rules, the data is transferred by second path if residual battery capacity is low.

Comparing Figure 5(a) and (b), the PER routing is batter than AODV algorithm. The Figure 6 shows how many nodes are over of the power after difference times of transmission. By the 8th, 14th and 20th node clearly show the advantage.

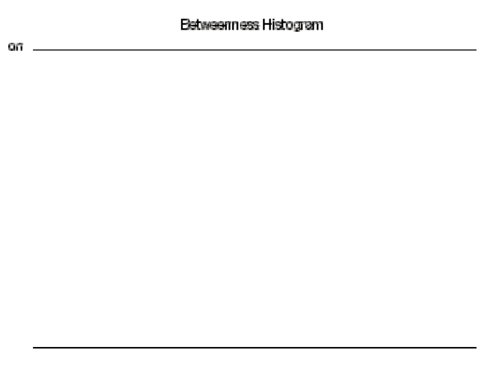
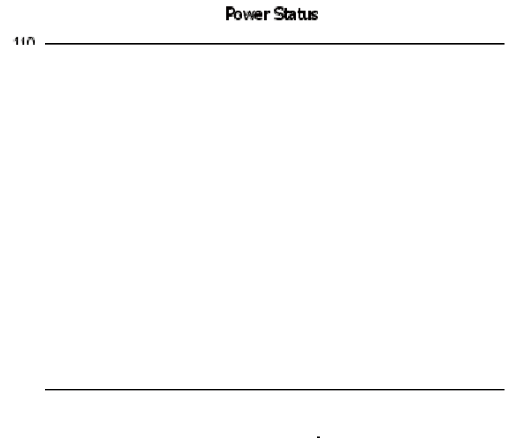
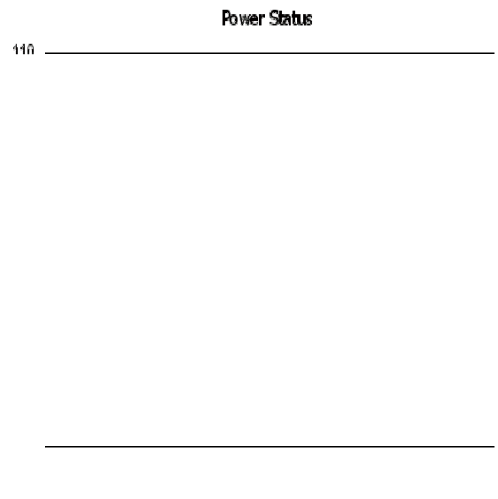


Figure 4 Betweenness distribution. N=500. X-axis is node betweenness.



(a) AODV routing



(b) PER routing

Figure 5 residual battery capacity ,*N*=100, battery capacity=100,

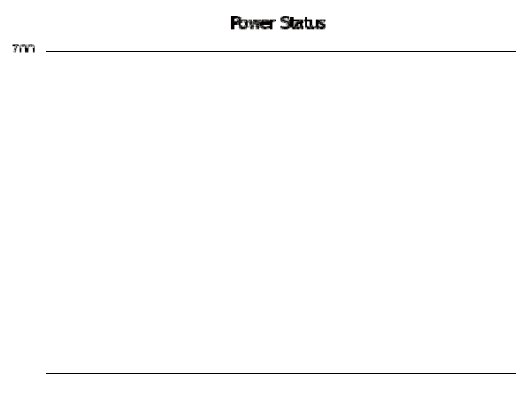


Figure 6 X-axis shows number of node which power exhausted. Y-axis illustrates number of packet transmission.

V. CONCLUSIONS

In this paper, we studied betweenness in wireless networks and proposed a power efficient routing algorithm for lengthen the lifetime of networks. Node betweenness and link betweenness are proposed to calculate routing path in wireless networks. Minimum spanning tree protocols built routing path with some weights, such as bandwidth. Node betweenness can represent the important fact of a node in the network. Link betweenness use to be metrics for unicast or group communications. Thus, both node and link betweenness can be used to wireless routing protocols.

Based on properties of complex networks, there exists difference in betweenness value of nodes. The nodes with high value of betweenness use more energy for packet transmission, where they have high probability to be chosen by routing protocols. In this paper, we aimed at more efficient throughput in network communications. So we select the next node depend on betweenness at routing. At figure 6, we showed that our routing strategy work well as other routing algorithm. The important contribution of our paper is our routing algorithm improves power consumed on multipath and increases the lifetime in wireless network.

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