Constructing Longest Lifetime Route in Mobile Ad-hoc Networks

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Abstract: A mobile ad hoc network (MANET) is an autonomous system consisting of mobile hosts connected by wireless links. Every host can move in any direction at any speed and time. This leads to a dynamic topology as hosts move constantly. MANET broadcast messages to each host, the transmission of one host can be heard by all hosts in its communication range. If two hosts are not located in each other’s transmission range, intermediate relay hosts must be employed as bridges to build communication paths. This is the multihop characteristic of the mobile ad hoc network, for which routing decisions must be made for far-away hosts to communicate. Node mobility causes links between nodes to break frequently, thus terminating the lifetime of the routes containing those links. An alternative route has to be discovered once a link is detected as broken, incurring extra route discovery overhead and packet latency. Traditionally route discovery has been done using flooding based approaches, which sometimes leads to broadcast storm problem. In this paper, we study the problem of how to construct a route with the longest lifetime for any given one-to-one communication request as a solution to link breakage in MANET. An algorithm is proposed with time complexity of $O(m + n \log n)$, where $n$ is the number of the nodes and $m$ is the number of the links. The proposed algorithm complexity is similar to that of the Dijkstra algorithm implemented using Fibonacci heap.

Key words: MANET, links, longest lifetime routing

INTRODUCTION

A mobile ad hoc network (MANET) is an autonomous system consisting of mobile hosts connected by wireless links. It can be flexibly, quickly deployed and dismantled easily for many practical applications such as battlefield operations, festival grounds, search and rescue and disaster relief emergency. Unlike wired networks or cellular networks, there is no physical infrastructure and central administration in mobile ad hoc networks. Every host can move in any direction at any speed and any time. These factors among others introduce a dynamic topology. Due to the broadcast advantage of wireless communication, the transmission of one host can be heard by all hosts in its communication range. If two hosts are not located in each other’s transmission range, intermediate relay hosts must be employed as bridges to build communication paths. This is the multihop characteristic of the mobile ad hoc network, for which routing decisions must be made for far-away hosts to communicate. When choosing a routing path among several hosts, there are usually many factors to be considered, such as route length, route quality, signal strength, path bandwidth and route lifetime. Mobile ad hoc network hosts are usually light-weight and battery-powered. Compared to wired lines, wireless links have much less available bandwidth.

Routing protocols used in mobile ad hoc networks can be divided into two categories: table-driven (proactive) and on-demand (reactive). Examples of table-driven protocols include optimized link state routing (OLSR)\cite{1} and destination-sequenced distance vector (DSDV)\cite{2}. These protocols require nodes to maintain a route table for all other nodes so that a route is always available when a packet is ready to be transmitted. However, on-demand protocols attract more interest than table-driven protocols because they only initiate a route discovery process when a packet is ready to be transmitted. Without the necessity of persistent maintenance of a routing table, where shortest path algorithms are usually applied, on-demand protocols typically have lower routing overhead than table-driven protocols. Examples of on-demand protocols include dynamic source routing (DSR)\cite{3} and ad-hoc on-demand distance vector (AODV)\cite{4}.

Node mobility is one of the most important characteristics that affect the performance of mobile ad hoc networks. When a link breaks due to node mobility, the routes containing this link also become invalid. Therefore, an alternative route has to be discovered. For example, in on-demand routing protocols, a route discovery process will be invoked to search for a new route, which is intrinsically flooding. Flooding suffers from the notorious broadcast storm problem\cite{5} and may result in excessive redundancy,
contention and collision, which will cause high protocol overload and interference to ongoing traffic. This issue becomes more serious when the mobility of the network is high. Several schemes such as probabilistic, counter-based, distance-based, location-based and cluster-based have been proposed to alleviate this problem\cite{6,7}. These schemes even the adaptive approaches help in relieving the broadcast storm problem in MANET, they do not eliminate it completely\cite{6,7}.

In order to minimize the adverse impact of link breakage and corresponding route discoveries from node mobility, an intuitive approach is to find routes with longest lifetime. So if a route with long lifetime is selected, the frequency of route discovery process being invoked will be reduced and the protocol overload will also be reduced. This is so because most of existing protocols attempt to find a route with shortest distance (such as DSR\cite{3}) or one with minimum energy consumption\cite{5,6}. Few considers the lifetime of the route\cite{5,6}: we define lifetime of a route as the time duration starting from beginning of broadcast service until the first node in the route fails due to energy exhaustion or link breakage.

**LONGEST LIFETIME CONSTRUCTION**

We assume that at the beginning, a snapshot of the network is given. From the snapshot we know which links exist and the lifetime of each, which means how long the link can be maintained before it is disconnected. The lifetime of links can be obtained by a prediction of each node signal strength and its movement\cite{5,6}. Thus the network can be modeled as a graph $G=(V,E)$ with a weight function $l: E \rightarrow \mathbb{R}^+$, where $E$ is the set of links, $l(e)$ is the lifetime of link $e\in E$. An example is shown in Fig. 1, where in (a) the arrow beside each node indicates the movement of the node and in (b) the number beside each link represents the lifetime of the link.

**Definition 1: Longest lifetime routing I (LLR-I):**

*Given a graph $G = (V, E, l)$ and a communication request $(s,t)$, the problem is to find a path $p$ from $s$ to $t$ such that the lifetime of $p$ is the longest. The lifetime of $p$ is defined as $l_p = \min_{e\in p} (l(e))$. Let $P$ be the set of all paths from $s$ to $t$, the objective of LLR-I is to find $\max_{p\in P} \min_{e\in p} (l(e))$, which is in fact the same as the traditional bottleneck path problem. The problem can be solved by Dijkstra algorithm with minor modification.*

**Definition 2: Longest Lifetime Routing II (LLR-II):**

*Given a graph $G = (V, E, l)$ and a communication request $(s,t)$, let $\Delta$ be the delay on each node.*

![Fig. 1: Model mobile ad hoc networks as a weighted graph](image)

the problem is to find a path $p$ from $s$ to $t$ such that the lifetime of $p$ is the longest. The lifetime of $p$ is defined as $l_p = \min_{e\in p} (l(e) - d_p(e)\Delta)$, where $d_p(e)$ is the sequence number of $e$ in $p$ in the order from $s$ to $t$. For those problems which can be solved by Dijkstra-like algorithm, they must satisfy the following optimal substructure property: there exists an optimal path $SP(s,t)$, if $k$ is an intermediate node in $SP(s,t)$, then the $SP'(s,k)$ is an optimal path from $s$ to $k$, where $SP'(s,k)$ is the subpath from $s$ to $k$ in $SP(s,t)$. Unfortunately, for LLR-II, this property doesn’t hold. For example, in Fig. 1(b) let $\Delta=1$, then the longest lifetime path from $a$ to $c$ is $a\rightarrow b\rightarrow c$, the lifetime is $\min\{5\rightarrow 1,6\rightarrow 2\}=4$, while the longest lifetime path from $a$ to $d$ is $a\rightarrow c\rightarrow d$, the lifetime is $\min\{4\rightarrow 1,3\rightarrow 2\}=1$.

We find that LLR-II has the following property, which is similar to the optimal substructure property of Dijkstra algorithm.

**Theorem 1:** For any $u,v\in V$, let $P(u,v)$ denote a longest lifetime path from $u$ to $v$. If $k$ is an intermediate node in $P(s,t)$, then the path $s\rightarrow P(s,k)\rightarrow k\rightarrow P(k,t)\rightarrow t$ is also a longest lifetime path from $s$ to $t$.

**Proof:** Let $P'(s,k)$ and $P'(k,t)$ denote $s\rightarrow P'(s,k)\rightarrow k$ and $k\rightarrow P'(k,t)\rightarrow t$ respectively. And let $P'(s,t)$ denote the path $s\rightarrow P'(s,k)\rightarrow k\rightarrow P'(k,t)\rightarrow t$, which is concatenated by $P'(s,k)$ and $P(k,t)$. Let $h$ be the length of $P'(s,k)$.

Then $l_{P'(s,t)} \leq l_{P(s,t)}$ and

$$I_{P'(s,t)} = \min_{e\in P'(s,t)} (l(e) - d_{P'(s,t)}(e)\Delta)$$

$$= \min_{e\in P'(s,t)} \{ l(e) - d_{P'(s,t)}(e)\Delta \}$$

$$= \min_{e\in P'(s,t)} \{ l(e) - d_{P'(s,t)}(e)\Delta / h \Delta \}$$

$$\leq \min\{ l_{P'(s,k)}, l_{P'(k,t)} - h\Delta \}$$
energy being consumed for delivering the same number of packets as there are more hops along the route and self interference by successive nodes in a route which may make them not as attractive as shorter routes.

We currently working on the design of a distributed algorithm and expect to evaluate its performance experimental. Further, we expect to consider a number of other factors at the same time, such as the energy consumption and signal strength.

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