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A mobile ad hoc network (MANET) consists of a collection of wireless mobile nodes that are capable of communicating with each other. There is no use of a static network infrastructure such as base station or any centralized administration in MANET. Due to the limited transmission range of wireless network interfaces, multiple hops (intermediate hosts) may be needed for one host to transfer data to another across the network. In MANET, each mobile host may operate not only as a terminal but also as a router, forwarding packets from other mobile hosts. The mobile hosts are free to move around, thus changing the network topology dynamically. Thus routing protocols for MANET should be adaptive and able to maintain routes in spite of changing the network connectivity. Such networks are very useful in military and other tactical applications such as emergency rescue or exploration missions, where static cellular phone infrastructure is unavailable or unreliable. Commercial applications are also likely where there is a need for ubiquitous communication services without the present or use of a fixed network infrastructure.

Design and analysis of routing protocols are the key issues in MANET. The primary goal of a MANET routing protocol is to establish a correct and efficient route between a pair of two hosts for delivering message in a timely manner. Many different routing protocols [2, 3] have been proposed for MANETs. They can be classified into two categories: *table-driven* and *on-demand*.

The table-driven routing protocols are similar to and come as a natural extension of those for the wired networks including Internet. They essentially use proactive schemes, which attempt to maintain consistent up-to-date routing information from each host to every other node in the MANET. These protocols require each host to maintain one or more tables to contain latest routing information, and any change in network topology needs to be reflected by broadcasting updates information throughout the network in order to maintain a consistent network view.

On the other hand, the on-demand routing protocols take a lazy approach to routing. The motivation behind the on-demand protocols is to reduce large amount of overhead for maintaining the routing table in the table-driven protocols in the dynamic MANET. They are source-initiated schemes which do not maintain or constantly update their route tables with the latest route topology. This type of routing creates routes only when desired by the source node. When a node requires a route to a destination, it initiates a route discovery process within the network. This process is completed once one or more routes are found or all possible route permutations have been examined. However, routing overhead for on-demand protocols may be still large mainly because the flooding process used in discovering routes, where the source (i.e., the host seeking a route) floods the entire network with a query packet in searching a route to the destination.

The Dynamic Source Routing (DSR) protocol (e.g., [1, 4]) is one of the more generally accepted on-demand routing protocols. It is natural to consider the DSR protocol with multple routes since they may be built during the route discovery by flooding. The Dynamic Source Routing (DSR) protocol proposed in [1] also has an option of maintaining multiple routes, so that an alternate route can be used upon failure of the primary one. But in DSR [1], too many routes are maintained in a trivial manner, without any regard to their ultimate usefulness. The performance study of DSR protocols has not been conducted in [1].

The concept of multipath routing has been used for circuit switched and packet switched networks, as it provides an easy mechanism to distribute traffic and balance the network load, as well as provide fault tolerance. For MANET, the Temporally Ordered Routing Algorithm (TORA) [5, 6] provides multiple alternate paths by maintaining a "destination-oriented" directed acyclic graph from the source. However, TORA does not have any easy mechanism to evaluate the performance of these multiple routes.

Two interesting DSR protocols which use disjoint multipath routes were proposed in [4]. In the first DSR protocol proposed in [4] , the source host will select the shortest route to the destination at first and will cache all the alternate routs. If the first route breaks, the shortest remaining alternate route is selected. The process continues until all routes break, then a new route discovery is initiated. In the second DSR protocol, all intermediate nodes are now equipped with a disjoint, alternate route. If a data packet is sent into an intermediate host and the link connecting to the next host is broken, the alternate route from the intermediate node will be used for sending the all the later data packets. Since some data packets may be lost due to a link break and the message about the data loss may not be sent back to the source host, the losing data packets may not be resent and be lost permanently in the second DSR protocol in [4]. Because of the possibility of lossing data packets, we consider that the second DSR protocol cannot be used as a practical one.

We note that an interesting analytic model is developed for analyzing the performance of DSR protocols. The performance used in the analysis is the time interval between route discoveries for a data transmission in an on-demand DSR protocol. This time interval between route discoveries is also the lifetime of the multiple routes used for the data transmission. Note that the lifetime for a data transmission changes dynamically. If the lifetime for a data transmission is shorter than the lifetime of multiple routes, it is not necessary to have long lifetime of multiple routes since the data transmission will finish before the start of the next route discovery. On the other hand, the lifetime of a data transmission may be longer enough which may need more than two route discoveries. The performance metric used in [4] does not reflect the performance of the DSR protocols well.

In this paper, we develop a comprehensive analytic model for the performance study of the multiple route DSR protocol for MANET. At first, we introduce two performance metrics. The first metric is the probability that the lifetime of multiple routes is larger than the lifetime of a data transmission. It is easy to see that the larger the probability is, the better the performance of a multiple route DSR protocol is. We call the probability *probability of a successful data transmission*. The second metric is the *probability that the multiple routes can be used for the next data transmission*. Note that in the multiple route DSR protocol, the lifetime of multiple routes for a source S to destination D may be longer than the time interval between two data transmission. It means that some routes used for a data transmission may also be available for the next data transmission. The second metric is used to study the possibility of using multiple routes for the next data transmission, while the first metric shows the probability of using multiple routes for one data transmission. We derive both the probability of a successful data transmission and the probability that the multiple routes can be used for the next data transmission for the general case over n multiple routes. These analytic results provide insights into mechanics of the multiple DSR routing protocol. It is also useful for the design and implementation of the on-demand routing for MANET.

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