



**IN THE NAME OF ALLAH,
MOST GRACIOUS, MOST MERCIFUL**

Analytical Study of MFR Routing Algorithm for Mobile Ad Hoc Networks

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(Received 20/12/2008; accepted for publication 31/5/2009)

Keywords: Ad hoc networks, MFR routing algorithm, Analytic model, Message delivery.

Abstract. In mobile ad hoc network (MANET), efficient routing algorithm must deal with the changing network topology created by the mobility of nodes. Therefore, the aim of a MANET routing protocol is to establish a correct and efficient route between a source node and a destination node for delivering a message in a timely manner. In this paper, we analyze the performance of Most Forward within Radius (MFR) routing algorithm for mobile ad hoc networks. We use an analytic model to evaluate the performance of MFR algorithm. The results show that successful message delivery decreases with the increase in the number of links or with the increase in the number of nodes in the network. Also, successful message delivery increases as the lifetime of message delivery decreases.

1. Introduction

A mobile ad hoc network (MANET) consists of a collection of wireless nodes that can communicate with each other. This network provides connectivity in areas where there is no other networking infrastructure available. A routing protocol for ad hoc networks must be distributed, since in view of the dynamic topology no centralized point of control is possible. It should generate routes quickly so that they can be used before topology changes (Abolhasan, Wysocki and Dutkiewicz, 2003). The routing algorithms that use the position of nodes (that is their coordinates in two dimensional space) in routing a message from source to destination are called position based routing. The position of nodes may be available directly by communicating with a satellite, using GPS (Global Positioning System) (NAVSTAR GPS Operations), if nodes are equipped with a small low power GPS receiver (Stojmenovic, 2002a).

In MANETs, node mobility causes frequent unpredictable topological changes. Hence, this mobility makes communication links break and these breaks may occur at a rapid rate. This dynamic change of network topology is the key challenge that MANET routing protocols must overcome. Several

position based routing protocols have been proposed that deal with this mobility problem. Therefore, any attempt to provide efficient routing protocol in MANETs must deal with the changing network topology created by the mobility of nodes. Mobile ad hoc networks are useful for many applications where fixed network infrastructure is not available such as disaster recovery, law enforcement activities, automated battlefields, rescue/emergency operations, crowd control, conferences, and educational classrooms (Abolhasan, Wysocki and Dutkiewicz, 2003; Chlamtac, Conti and Liu, 2003).

In this paper, we present an analytic model to study the performance of MFR routing protocol. In the next section, we discuss the related work. In Section 3, we present the analytic model to study the MFR routing algorithm. We discuss the results in Section 4. Finally, we conclude the findings of this work in Section 5.

2. Related Work

Position based routing algorithms use information about the geographical location of the participating nodes in the networks (Stojmenovic, 2002a; Chlamtac, Conti and Liu, 2003; Frey, 2004;

Giordano, Stojmenovic and Blazevic, 2001; Stojmenovic, 2002b; Mauve, Widmer and Hartenstein, 2001).

There are three main strategies used in position based routing algorithms: greedy routing, directed flooding, and hierarchical routing. The basic idea behind these algorithms is to forward a packet or message towards node(s) that are closer to the destination than itself. Greedy routing algorithms forward the packet to one of its neighbors, whereas the directed flooding forwards the packet to more nodes in the direction of the destination. Hierarchical routing algorithms are a combination of position based and topology based (non-position based) routing algorithms. Position based routing is typically used for long distances (i.e., when the forwarding node and destination are far away), while a non-position based routing is used at local level (i.e., the packet is closer to the destination).

In greedy routing, a node tries to forward the packet to one of its neighbors that are closer to the destination than the node itself. If more than one neighboring node exists, then different choices are possible to select the best neighboring node. Examples of greedy routing algorithms are: Most Forward progress within Radius (MFR) (Takagi and Klienrock, 1984; Woo and Singh, 2001), Compass Routing (referred as DIR) (Kranakis, Singh and Urrutia, 1999), Geographic Distance Routing (GEDIR) (Lin and Stojmenovic, 1998).

Most Forward within Radius algorithm (MFR) is a greedy routing algorithm that tries to minimize the number of hops a message has to travel to reach the destination D . The distance between a source node S and the projection A' of a neighbor node A onto the line connecting the source S and destination

D is defined as *progress* shown in Fig. 1. MFR routing algorithm forwards the message to a neighbor node that makes the most progress towards the destination D , while neighbors with negative progress are ignored. In Fig. 1, node A is considered as the best neighbor for node S to further forward the message to destination D in MFR algorithm.

3. Analytical Model

In this section, we present an analytic model of MFR routing algorithm. This model is used to evaluate the performance of MFR routing algorithm (Li, Pan and Xiao, 2005; Corson and Macker, n.d.; Ross, 2003; Papoulis, 1990; Trivedi, 2003). Lifetime of a wireless link is defined as the amount of time (time interval) the link is available for transmission, and its unit is seconds. We consider the lifetime of a wireless link between two nodes in the network as a continuous random variable. Further, we consider a route from a source node S to a destination node D that contains a sequence of m wireless links for $m-1$ intermediate nodes. Let x_{l_i} be the lifetime of the i^{th} link in the route. We assume that the lifetimes x_{l_i} , $i=1, 2, \dots, m-1$ are exponentially, independently and identically distributed (iid) random variables, each with rate μ (Ross, 2003; Papoulis, 1990). When any link of the route breaks, then the route fails between the source S and destination D . Therefore, the lifetime of this route r that consists of m links is a random variable expressed as follows:

$$X_r = \min(X_{l_1}, X_{l_2}, \dots, X_{l_m}) \quad (1)$$

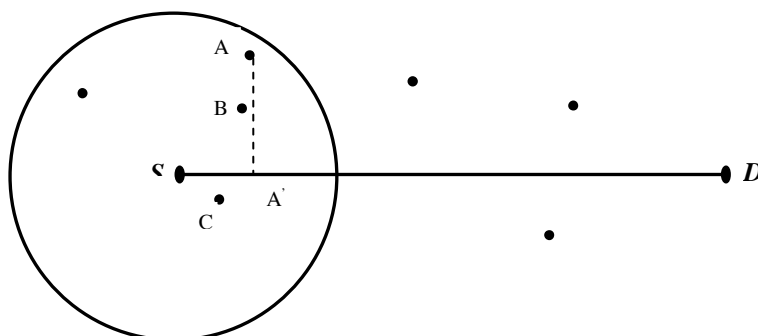


Fig. 1. The message is routed from source S to destination D .

where X_r is also exponentially distributed random variable with rate $m\mu$. The lifetime of using a single route r is a random variable R with rate $m\mu$, where $R = X_r$.

To analyze this MFR routing algorithm, we consider the probability of successful message delivery as a performance metrics. This metric signifies the probability that the lifetime of a route is larger than the lifetime of a message delivery.

It is clear that successful message delivery may finish during a lifetime R . We derive the probability Q that message delivery or transmission finishes within R . Further, assume the lifetime of a message delivery is an exponentially distributed random variable Y with rate λ . It is clear that Y and R are independently continuous random variables. The probability density function (pdf) of R is $f_R(t)$. The probability of a successful message delivery is expressed as:

$$\begin{aligned}
 Q &= p(Y < R) \\
 Q &= \int_{t=0}^{\infty} p(Y < R | R=t) f_R(t) dt \\
 Q &= \int_{t=0}^{\infty} p(Y < R | R=t) m\mu e^{-m\mu t} dt \\
 Q &= \int_{t=0}^{\infty} \int_{y=0}^{y=t} \lambda e^{-\lambda y} dy m\mu e^{-m\mu t} dt \\
 Q &= \int_{t=0}^{\infty} (1 - e^{-\lambda t}) m\mu e^{-m\mu t} dt \\
 Q &= \int_{t=0}^{\infty} m\mu e^{-m\mu t} dt - \int_{t=0}^{\infty} m\mu e^{-(\lambda+m\mu)t} dt \\
 Q &= \lambda / (\lambda + m\mu) \tag{2}
 \end{aligned}$$

The mean wireless links is the average distance between any pair of nodes or the average path length (Albert and Barabasi, 2002) is given by the formula $m \approx \frac{\ln(n)}{\ln(k)}$ where m is the distance between two nodes in terms of wireless links or hop counts, n is the number of the nodes in the network, and k is the connectivity of the network (i.e., the average number of neighbors of a node in the network). Therefore, the probability of successful message delivery is given by:

$$Q = \lambda / (\lambda + \mu \ln(n) / \ln(k)) \tag{3}$$

4. Numerical Results

In this section, we present and discuss numerical results that show the performance of MFR routing algorithm. We choose the lifetime of a wireless link to be 1.0 unit of time interval in seconds, i.e. $\mu=1$.

First we study the effect of varying the number of wireless links on the probability of successful message delivery. We select three cases for the lifetimes of message delivery (1, 0.5 and 0.1) seconds such that $\lambda=1, 2$ and 10. Figure 2 shows the probability of successful message delivery vs. number of links. The figure shows that the probability of successful message delivery decreases as the number of links increases. This is because the probability of the route to break increases as the number of links of that route increases. It is clear that the probability increases as the lifetimes of the message delivery decreases.

Next, we study the impact of varying the lifetimes of message delivery on the probability of successful message delivery. We select three cases for the number of wireless links (1, 5 and 10). Figure 3 shows the probability of successful message delivery vs. lifetimes of message delivery. The figure shows that the probability of successful message delivery decreases as the lifetime of message delivery increases.

Also, we study the impact of varying the connectivity of the network on the probability of successful message delivery as shown in Fig. 4. The figure shows that as the connectivity of the network increases, the probability of successful message delivery increases. Further, it is clear that the probability increases as the lifetimes of the message delivery decreases.

Also, we study the impact of varying the number of nodes in the network on the probability of successful message delivery as shown in Fig. 5. In this case, we select the connectivity of the network $k = 8$. The figure shows that as the number of nodes of the network increases, the probability of successful message delivery increases. Further, it is clear that the probability increases as the lifetimes of the message delivery decreases.

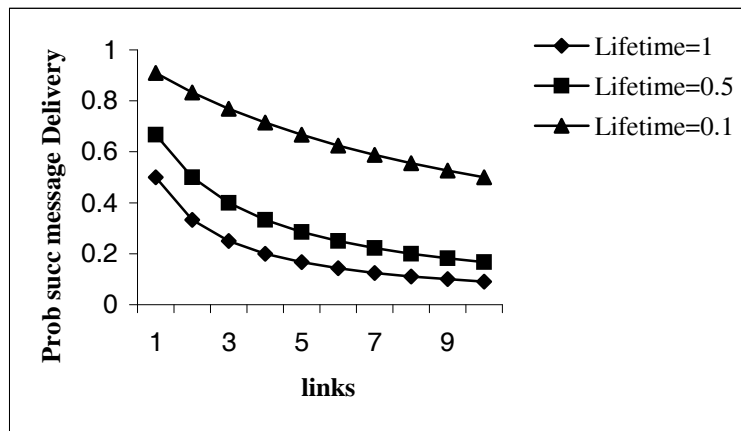


Fig. 2. Probability of successful message delivery vs. number of links.

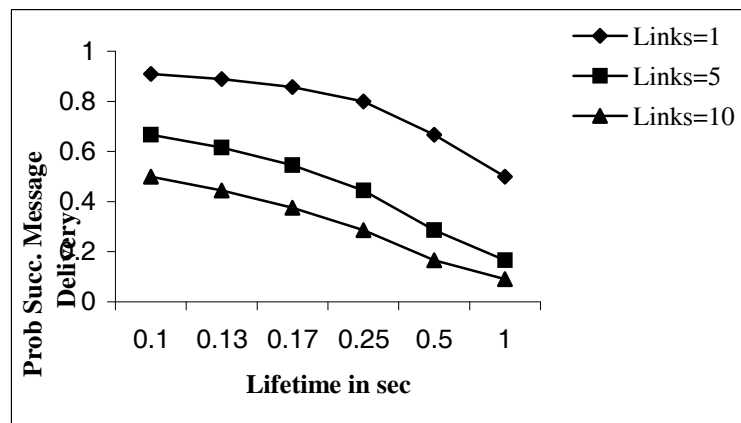


Fig. 3. Probability of successful message delivery vs. lifetime of message delivery.

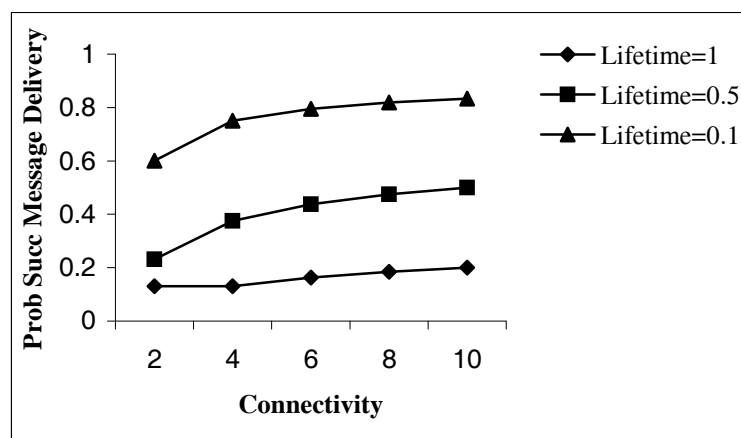


Fig. 4. Probability of successful delivery vs. connectivity of the network.

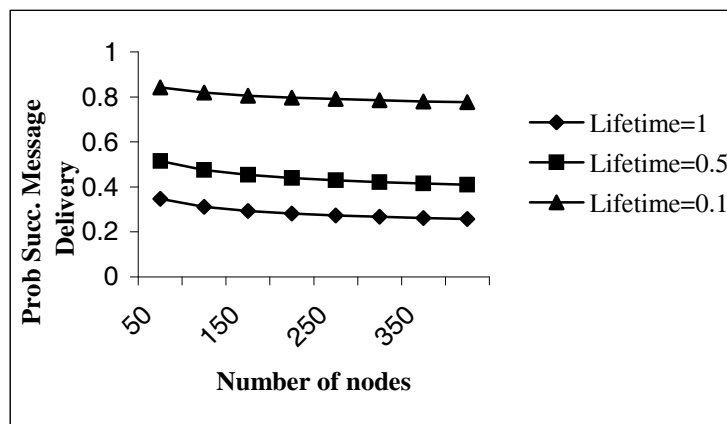


Fig. 5. Probability of successful delivery vs. number of nodes in the network.

5. Conclusion

In this paper, we analyze the performance of Most Forward within Radius (MFR) routing algorithm for mobile ad hoc networks. We present the analytic model based on the lifetimes of the wireless links and the successful message delivery. We use the probability of successful message delivery as performance metrics. The results show that the probability of successful message delivery decreases with the increase in the number of links. Also, this probability decreases as the number of nodes in the network increases, and the probability of successful message delivery decreases as the lifetime of message delivery increases. Finally, the probability of successful message delivery increases as the lifetime of message delivery decreases.

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دراسة تحليلية لخوارزمية التوجيه في شبكات الحاسوب الجوال MFR

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(قدم للنشر في ٢٠/١٢/٢٠٠٨م؛ وقيل للنشر في ٣١/٥/٢٠٠٩م)

ملخص البحث. تعتبر خوارزمية التوجيه فعالة في شبكات الحاسوب النقال (الجوال) عندما تتعامل بفعالية مع الشبكة التي تتسم بالتغير المستمر نتيجة لحركة النقاط (أجهزة الحاسوب في الشبكة). لهذا فإن هدف خوارزمية التوجيه في شبكات الحاسوب النقال هو إيجاد المسار الصحيح والفاعل بين الحاسوب المصدر والهدف لتسليم الرسائل أو البيانات في الزمن المناسب. في هذا البحث يتم تحليل أداء خوارزمية التوجيه MFR المستخدمة في شبكات الحاسوب النقال. وقد استخدم نموذج تحليلي لتقييم أداء خوارزمية التوجيه MFR. ولقد أظهرت النتائج أن الرسائل الواصلة بنجاح إلى الهدف تتناقص مع ازدياد أعداد مراحل الربط (links) أو ازدياد عدد الأجهزة المتنقلة (النقاط) في الشبكة. أيضاً أظهرت النتائج أن الرسائل الواصلة بنجاح تتزايد مع تناقص زمن الرسائل الواصلة.