# Message Delay in MANET

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## ABSTRACT

A generic stochastic model with only two input parameters is introduced to evaluate the message delay in mobile ad hoc networks (MANETs) where nodes may relay messages. The Laplace-Stieltjes transform (LST) of the message delay is obtained for two protocols: the two-hop and the unrestricted multicopy protocol. From these results we deduce the expected message delays. It is shown that, despite its simplicity, the model accurately predicts the message delay under both relay strategies for a number of mobility models (the random waypoint, random direction and the random walker mobility models).

**Categories and Subject Descriptors:** C.2.2 [Network protocols]: Routing protocols; C.4 [Performance of systems]: Modeling techniques; G.3 [Probability and statistics]: Stochastic processes
**General Terms:** Performance
**Keywords:** Mobile ad hoc, delay, performance prediction, networks, statistics, estimation, modeling

## 1. INTRODUCTION

In mobile ad hoc networks, a mobile (or simply a node) can only send data to another node if both nodes are within transmission range of one another or *in contact*. Message relaying is a technique that reduces message latency by using intermediary nodes to forward the message. We study two relay protocols: *two-hop multicopy* and the *unrestricted multicopy* protocol. In the two-hop multicopy protocol the source node copies the message to all the nodes it meets along its route, including of course the destination node. Any node which has received a duplicate copy of the message from the source node may only forward it to the destination node. Note that this is different from the two-hop *relay* protocol proposed in [3] (see also [4]): there a packet is relayed (instead of being copied) to another node. In the unrestricted multicopy protocol the source node copies the message to all the nodes it meets, but in addition, any node that carries the message may in turn copy the message to all the nodes *it* encounters, along *its* trajectory. A full version of this paper is available as a technical report [1].

## 2. THE MODEL

We consider a network with $N+1$ identical mobile nodes. There is a single message to be delivered by a source node to a destination node. Intermediary nodes can be used as relay nodes.

Let $0 \leq t_{i,j}(1) < t_{i,j}(2) < \cdots$ be the successive *meeting times* between nodes $i$ and $j$ ($i \neq j$). Define $\tau_{i,j}(n) := t_{i,j}(n+1) - t_{i,j}(n)$, as the $n$-th *inter-meeting time* between nodes $i$ and $j$.

Transmissions between two nodes only take place at meeting times and are assumed to be instantaneous and always successful. The former assumption corresponds to the situation where the transfer time of a message between two nodes is negligible with respect to the time it takes the two nodes to meet one another (this is the case when the transmission radius is small with respect to the size of the area). We assume that the rvs $\{\tau_{i,j}(n)\}_{i,j,n}$ are mutually independent and exponentially distributed with mean $1/\lambda$.

Let $T_2$ (resp. $T_U$) be the message delay under the two-hop (resp. unrestricted) multicopy protocol, defined as the time needed to send the message (or a copy of the message) from a source node to the destination node. For $\theta \geq 0$, let $T_2^\star(\theta) := E[e^{-\theta T_2}]$ and $T_U^\star(\theta) := E[e^{-\theta T_U}]$ be the LST of $T_2$ and $T_U$, respectively.

Our main result is the LST of the message delay, given in Proposition 1. From this the expected message delay is easily derived (Proposition 2). The proofs can be found in [1].

PROPOSITION 1 (LST OF MESSAGE DELAY). *Under the two-hop multicopy protocol*

$$T_2^\star(\theta) = \sum_{i=1}^{N} i \frac{(N-1)!}{(N-i)!} \left(\frac{\lambda}{\lambda N + \theta}\right)^i,$$

*and under the unrestricted multicopy protocol*

$$T_U^\star(\theta) = \frac{1}{N} \sum_{i=1}^{N} \prod_{j=1}^{i} \frac{\lambda j (N+1-j)}{\lambda j (N+1-j) + \theta}. \qquad \diamond$$

PROPOSITION 2 (EXPECTED MESSAGE DELAY). *Under the two-hop multicopy protocol, the expected message delay is given by*

$$\mathbb{E}[T_2] = \frac{1}{\lambda N} \sum_{i=1}^{N} \frac{i^2 (N-1)!}{(N-i)!\, N^i} = \frac{1}{\lambda}\left(\sqrt{\frac{\pi}{2N}} + \mathcal{O}\left(\frac{1}{N}\right)\right),$$

*and under the unrestricted multicopy protocol we have*

$$\mathbb{E}[T_U] = \frac{1}{\lambda N} \sum_{i=1}^{N} \frac{1}{i} = \frac{1}{\lambda N}\left(\log(N) + \gamma + \mathcal{O}\left(\frac{1}{N}\right)\right),$$

*where $\gamma \approx 0.57721$ is Euler's constant.* $\diamond$


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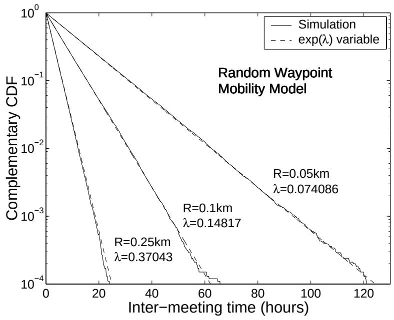


**Figure 1: Inter-meeting time between two nodes is (approx.) exponentially distributed.**

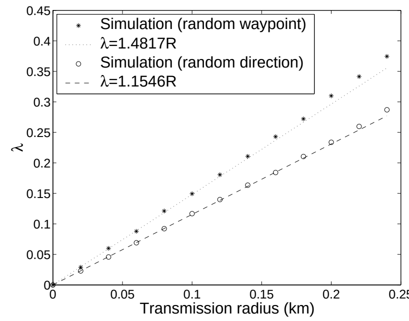


**Figure 2: Relationship between inter-meeting time intensity $\lambda$ and transmission radius $r$.**

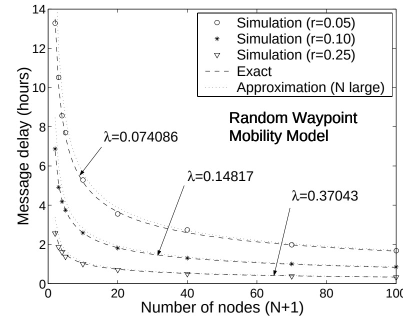


**Figure 3: Expected message delay as a function of the number of nodes: the two-hop multicopy protocol.**

# 3. APPLICATIONS

The accuracy of our model is demonstrated by applying it to three different mobility models: the random waypoint, the random direction, and the random walker mobility models. For each model the nodes move on a $L \times L$ square and the fixed disk model is used (nodes can transit to each other only when the distance between them is not greater than some fixed $r$).

In the random direction mobility model, a node moves in a direction that is uniformly distributed in $[0, 2\pi)$, for an exponential amount of time with mean $1/4$ (in hours), before the node chooses a new direction, travel time and speed.

For the random waypoint and the random direction mobility models, there are no pause times and a new speed is chosen each time uniformly in $[v_{min}, v_{max}] = [4, 10]$ km/h. The random walkers move one block per minute, where the blocks are 80 meters apart.

In order to apply our model we need to check the validity of assumption (A) and to identify the parameter $\lambda$ of the exponential inter-meeting time distribution.

Figure 1 shows that, on a log-scale for the $y$ axis and for the random waypoint model, the complementary cumulative distribution function (cdf) of the inter-meeting time resembles an exponential $\lambda$ distribution. We observe an excellent agreement between the estimated cdf (solid line) and the exponential cdf (dashed line), for three different transmission radii. The independence of consecutive inter-meeting times is shown in [1], as well as the presence of the exponential distribution for the random direction and the random walker mobility models. Estimates for $\lambda$ have been derived in [2, Chapter 4] and are displayed in Figure 2 and the following lemma.

LEMMA 1 (ESTIMATES FOR $\lambda$).
*The parameter $\lambda$ for the random direction (RD) and the random waypoint (RWP) mobility models are given by*

$$\lambda_{RD} \approx \frac{2r\mathbb{E}[V^*]}{L^2} \qquad \text{and} \qquad \lambda_{RWP} \approx \frac{2\omega r\mathbb{E}[V^*]}{L^2}$$

*respectively. Here $\omega \approx 1.3683$ is a constant specific to the RWP model, and $\mathbb{E}[V^*]$ is the average relative speed between two nodes. If $v = v_{min} = v_{max}$, we have $\lambda_{RD} \approx \frac{8rv}{\pi L^2}$ and $\lambda_{RW} \approx \frac{8\omega rv}{\pi L^2}$.* $\diamond$

The average speed $\mathbb{E}[V^*]$ can be calculated numerically [2, Proposition 4.2.2]. For example, if $[v_{min}, v_{max}] = [4, 10]$ km/hour, then $\mathbb{E}[V_*] \approx 9.2$ km/hour for the random direction and $\mathbb{E}[V_*] \approx 8.7$ km/hour for the random waypoint mobility model.

An estimate for $\lambda$ for the random walker model has yet to be found.

Figures 3 and 4 display the expected message delays, obtained both through simulations and by our model, as a function of the number of nodes. Other combinations of mobility models and relay protocol produce similar figures [1].

These results demonstrate the ability of this simple analytical model to capture the main features of the interaction of the mobility models and the relay protocols, across any number of nodes and transmission radii.

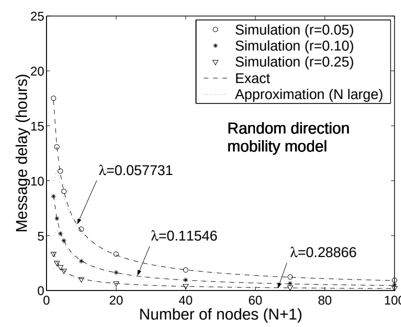


**Figure 4: Expected message delay as a function of number of nodes: unrestricted multicopy protocol.**

# 4. REFERENCES


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