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Overhead Analysis of Reactive Shortest Single and Multi-path Routing Mechanism with Load Balance in MANET

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***Abstract*:**

MOBILE *ad hoc* network (MANET)] is a self-organizing and self-configuring multi hop wireless network, which is composed of a set of mobile hosts (MHs) that can move around freely and cooperate in relaying packets on behalf of one another. MANET supports robust and efficient operations by incorporating the routing functionality into MHs. In MANETs, the unicast routing establishes a multi hop forwarding path for two nodes beyond the direct wireless communication range. Routing protocols also maintain connectivity when links on these paths break due to effects such as node movement, battery drainage, radio propagation, and wireless interference .In this paper, we analyze and compare reactive single-path and multi-path routing with load balance mechanisms in ad hoc networks, in terms of overhead. The results reveals that in comparison with general single-path routing protocol, multi-path routing mechanism creates more overheads but provides better performance in congestion and capacity provided that the route length is within a certain upper bound which is derivable. The analytical results are further confirmed by simulation.

Keywords: *Ad-hoc networks, Load balancing, Multi-path routing, Overheads*.

1. INTRODUCTION

MOBILE Ad Hoc Networks (MANETs) are collections of wireless mobile nodes, constructed dynamically without the use of any existing network infrastructure or centralized administration. Due to the limited transmission range of wireless network interfaces, multiple hops may be needed for one node to exchange data with another one across the network. MANETs are characterized by limited power resource, high mobility and limited bandwidth. Routing in MANETs can be accomplished through either single path or multiple paths. When using single-path routing protocols, the traffic is distributed through one route and is therefore less flexible than in multi-path routing protocols. Although research on multi-path routing protocols has been covered quite thoroughly in wired networks, similar research for wireless networks is still in its infancy. Some multi-path routing protocols for MANETs have been proposed in [1], [2], [3], [4].However, the performance of these protocols are only assessed by simulations in certain limited scenario. Although some recent papers provide analytical models for multi-path routing [5], [6], they are limited on a single aspect of multi-path routing such as route discovery frequency or error recovery. In this paper, we propose models to analyze and compare reactive single-path and multi-path routing protocols in terms of overheads. Thereafter, the terms “single-path routing” and “multi-path routing” are equivalent to “shortest single-path routing" and "multi-path routing with load balance" respectively.

In addition, we focus our analysis only on reactive routing mechanism. The overhead analysis in this paper is only applicable for reactive routing mechanism. The outcome from analytical models is further validated by simulation. The remaining of this paper is organized as follows. Section two provides general information on reactive routing mechanism. Section three gives a detailed analysis of overhead for both single-path and multi-path routing techniques. We finally conclude this study discuss future research directions in section four

2. REACTIVE ROUTING MECHANISM

Reactive routing protocols in MANETs consist of the following dominant candidates Dynamic Source Routing (DSR) [4], Ad-hoc On-demand Distance Vector Routing (AODV) [3] and Temporally Ordered Routing Algorithm (TORA) [2]. They all have two main phases in common: Route Discovery and Route Maintenance.

2.1 Route Discovery

In this phase, the source node S broadcasts a route request packet (RRQ) to locate the destination node D in the network. The first node receiving the RRQ that has a valid route for node D initiates a route reply packet (RRP) back to node S containing a list of nodes along the path from node S to node D

2.2 Route Maintenance

The Route Maintenance phase ensures that the paths stored in the Route Cache are valid. If the data link layer of a node detects a transmission error, the node creates a route error packet (ERR) and transmits it to the source. For error detection, several acknowledgement mechanisms may be used such as ACK packet for each successfully-transmitted packet, link detection mechanism in 802.11. When receiving ERRs, the sources check their route caches and delete the routes containing the failed links. They can either attempt to use other alternate routes in their caches when using multi-path routing mechanism or invoke another route discovery when using single-path routing mechanism.

3. OVERHEADS ANALYSIS

3.1 Route Creation Frequency

Let us firstly review the results of [5]. This significant result indicates that the route creation rate for multi-path routing strategy is lower than it is for single-path routing. The link's lifetime is assumed to be independent and identically distributed exponential random variables with mean *l*. Since a route fails when any links in its path breaks, the lifetime of a route with *L* links is also an exponentially distributed random variable with a mean of *l/L*. Denoting by $\mu i = l/Li$, The probability density function (pdf) of *T*, the time between successive route discoveries, is given by:

$$f_T(t)=\prod_{i=1}^{N}(1-\exp(-\mu i\ t))\ \sum_{i=1}^{N}\ \mu i\ \ \exp(-\mu i\ t))\ /\ 1-\exp(-\mu i\ t))$$

Comment: The expected value of T can be derived by knowing the hop-wise lengths of all the routes ,*i* = 1, . . . , *N*. It was also shown in [5] that using multi-path routing can achieve25% reduction in route discoveries rate for 3-4 hops routes as compared with single-path routing. This reduction is because in multi-path routing, route discovery is only initiated when all the routes to the destination are broken whereas in single-path routing, it is done when one single route is broken.

3.2 Overheads Analysis by Intuition

Overheads in reactive routing protocols are caused in the following phases: Route Discovery, Route Maintenance, and Data Transmission. The overheads for single-path and multi-path routing mechanisms are analyzed according to these phases.

1) Route Discovery*:* Route Discoveries for single-path and multi-path routing mechanisms are shown in Fig 1 and Fig 2 respectively. Clearly shown, the number of broadcasted RRQs is the same for both single-path and multi-path routing. However, when the destination sends the RRPs back to the source, because it has to send Nu (Nu is the number of multiple paths created in the Route Discovery phase) RRQs to correspond to Nu RRQs, the overheads of multi-path routing in Route Discovery phase is higher than that of single-path routing. The extra overhead is proportional the number of paths Nu

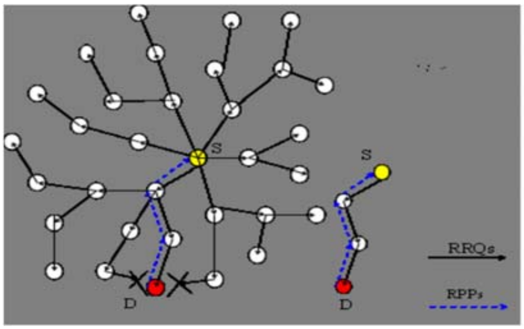

Fig. 1 ROUTE DISCOVERY IN SINGLE-PATH ROUTING

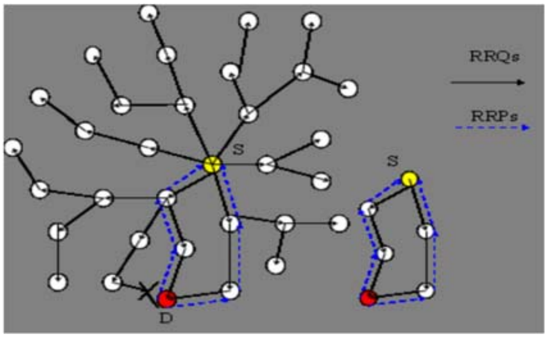

Fig. 2 ROUTE DISCOVERY IN MULTI-PATH ROUTING

2) Route Maintenance: In this phase, when a link is broken, an Error Packet (ERR) is sent back to the source to indicate the route breakage. In multi-path routing, since there are multiple paths for each source-destination pair, assuming the probability of link breakage and the route length for all the routes are the same, the number of route breakages is proportional to the number of paths. Therefore, it can be deduced that in multipath routing, the number of ERRs is higher than in single-path routing, i.e. more overheads.

3) Data Transmission: During this stage, overhead is mainly due to the overhead portion of the data packets which is dependent on the routing protocols themselves. For some protocols such as DSR, the complete route from the source to the destination is stored inside the overhead portion of the data packets. However, in other ones such as AODV, only next node is stored in the data packet which results in less overhead as compared with DSR.

4) Comment: In summary, we can clearly see that there is a trade-off between single-path and multi-path routing mechanisms. In multi-path routing, overheads in multi-path routing are high due to extra RRPs and ERRs. However, the frequency of route discoveries in multi-path routing is lower than in single-path routing as claimed in [5]. Hence, an analytical model is established in the following section to get a better understanding of the trade-off.

3.3 Overhead Analysis Using Analytical Model

1) Network Model: We assume that mobile nodes are distributed uniformly with node density δ inside a disk of radius R. We also assume that there are N nodes in the network. N is related to the node density and the disk radius by the following expression $N = \pi R^2 \delta$. Each link has a link breakage rate of μ, i.e. a link has an average lifetime of 1/μ seconds on average. Furthermore, we assume that the average route length (in terms of number of hops) for single-path routing is Ls and for multipath routing is Lm. Since single-path routing mechanism uses shortest routes, we obviously have $Lm > Ls$. In addition, Le is assumed to be the average length of the route from the source to the node where a link breakage occurs. For multi-path routing, Nu represents the number of paths for each source-destination pair. In addition, the number of active connections per node is denoted by Ac for both routing mechanisms. Furthermore, the size of RRQ, RRP and ERR are respectively denoted as Mrq, Mrp, Me respectively. Finally, a route discovery takes T seconds to find the routes to the destination. All the parameters are summarized in Table I:

Table:1 Summary of parameters

N	Number of nodes
Nu	Number of routes per source-destination pair in multipath
Le	Average length of error route
μ	Link breakage rate
Ls	Average length of a route for single-path routing (no of hope)
Lm	Average length of a route for multi-path routing (no of hope)
Ac	Number of active routes per node
Mrq	Size of the request packet
Me	Size of error request packet
Mrp	Size of reply packet
ε	Inter-arrival rate
p	Overhead portion of a data packet
M_d	Size of the data packet
T	Average delay for route creation
λ_s	Route discovery frequency for single-path routing
λm	Route discovery frequency for multi-path routing

2) Overhead due to RRQs

Single-path Routing Mechanism: Assuming that N nodes each broadcast a RRQ λs times per second, the total overhead created by RRQs is obviously $Mrq\lambda sN^2$. λs (i.e. the route discovery frequency) is related to link breakage as $\lambda s = \mu Ls$. Hence, the amount of overheads due to the RRQs is $Mrq\ \mu\ LsN^2$.

Multi-path Routing Mechanism: Using a similar argument as above, the amount of overheads due to RRQs is $Mrq\lambda mN^2$ where λm is the frequency of route discovery for multi-path routing algorithm.

3) Overhead due to RRPs*:*

Single-path Routing Mechanism: Reply packets follow *Ls* hops to return back to the source. Since the rate of sending the RRPs is the same as the rate of sending RRQs, the overhead created by the RRPs, is $Mrp\ \mu\ L_s^2 N$.

- Multi-path Routing Mechanism: Since the destination node replies to *Nu* RRQs, the overhead due to RRPs is $Mrp\lambda mLmNNu$. Note that the fact that λm is smaller than λs balances the fact that the number of RRPs are increased by a factor of Nu compared to single-path routing.

4) Overheads due to ERRs*:* When a link is broken, an Error Packet is sent back to the source to signal the link breakage. Recall that Le is the average length of the path from the broken link to the source ($Le < Ls < Lm$). Since the error packet has to travel Le links to the source, this effectively produces *Le* error packets per route broken.

- Single-path Routing Mechanism: Since the link breakage rate is μ, the route breakage rate for a route with Ls links is μLs. For each node, the average number of active routes is *Ac*. Therefore, for a node, the route breakage rate is μLsAc. Therefore, in a *N*-node network, the average number of overheads due to error packets is $\mu L sAcNLeMe$.
- Multi-path Routing Mechanism: In multi-path routing, since each source-destination pair

maintains *Nu* routes, the overheads due to error packets is $Nu\mu LmLeAcNMe$.

5) Overheads Due to Data Transmission: The overhead created during data transmission is due to the overhead portion of data packets. We assume that the each route discovery is accomplished in T second on average .Furthermore each mobile node is a simple source with data transmission rate of ε once the route discovery is completed

• Single-path Routing Mechanism: Since the route discovery rate is λs, the interval between each route discoveries is on average 1/λs. Each route discovery takes on average T seconds. Therefore, the actual time for data transmission is $(1/\lambda s - T)$ seconds. The number of data packets sent during that interval is $(1/\lambda s - T)\ \varepsilon$ Thus, data packets are sent with an average rate of $\lambda s\ \varepsilon\ (1/\lambda s - T)$ packets/sec. Since each data packet has to travel Ls hops to the destination, the total amount of overhead is $\lambda s\ \varepsilon\ (1/\lambda s - T)PLs = \mu\ Ls.\ \varepsilon\ (1/(\mu Ls) - T)PLs$.

Multi-path Routing Mechanism: Using a similar derivation as above, the total amount of overheads for multi-path routing is $\lambda m\ \varepsilon\ (1/\lambda m - T)PLm$.

6) Summary: The total amount of overheads due to RRQs, RRPs, ERRs and data packets for single-path and multi-path respectively denoted by Ovs and Ovm can be expressed as:

$Ovs = Mrq\lambda sN^2 + Mrp\lambda sLsN + \mu LeLsAcNMe + \mu Ls\ \varepsilon\ (1/(\lambda s - T)PLs$

$Ovm = Mrq\lambda mN^2 + Mrp\lambda mNLmNu + \mu LeLmAcNMeNu + \varepsilon\ \mu(1/\lambda m - T)PLm$

In Fig 3, we have plotted Ovs and Ovm as functions of the number of paths *Nu*. One can see that there is no significant increase in overheads for Nu up to 3. This confirms the fact that in the literature, authors often mentioned that Nu = 3 provides an optimum trade off [5]. This claim is usually based on simulation results and the study provided in this paper confirms this observation. In Fig 4, Nu = 3 and Ovs and Ovm are compared as the link breakage is varied. It is interesting to note that the maximum increase in overhead ia approximately 20% (for a link breakage rate of 50%). Otherwise, for link breakages less than 10%, the increase in overhead is approximately 10%. One might argue that the figure is not insignificant. In fact, assessing whether this increase in overhead is acceptable or not really depends on the advantages brought out by multi-path routing. This is why a theoretical study such as the one proposed in the following is necessary.

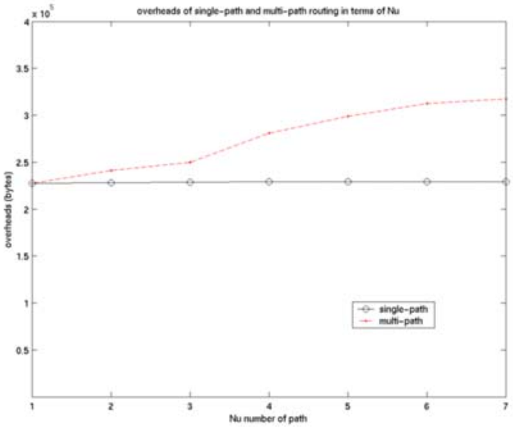

Fig. 3 OVERHEAD COMPARISON WHEN *Nu* INCREASES

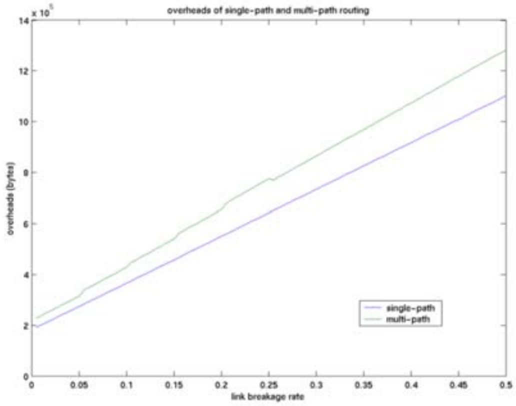

Fig. 4 OVERHEAD COMPARISON AS THE LINK BREAKAGE RATE INCREASES

7. Simulation Results

In the simulation, we choose Dynamic Source Routing (DSR) [4] and Multi-path Routing Protocol with Load Balance (MRP-LB) [1] as typical candidates for shortest path and multi-path routing protocols respectively. The choice of these routing protocols does not limit the applicability of this result into the others. In other words, the result which is derived above is applicable to other reactive routing algorithms such as AODV, TORA. However, the result is not suitable for proactive and hybrid routing protocols. Clearly seen from Fig 5, MRP-LB exhibits higher overhead than DSR which once again confirms the correctness of our analytical model.

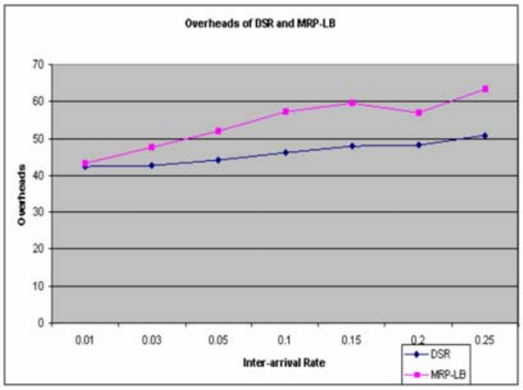

Fig. 5 OVERHEAD OF DSR AND MRP-LP

IV. CONCLUSION

Ad-hoc networks, also known as short-lived networks, are autonomous systems of mobile nodes forming network in the absence of any centralized support. This is a new form of network and might be able to provide services at places where it is not possible otherwise. Absence of fixed infrastructure poses several types of challenges for this type of networking. Among these challenges routing is one of them. In this paper, we have analyzed and compared overheads of a single-path and multi-path routing algorithms. We have shown how the amount of overheads increases with the number of multiple paths and we have seen that when this number exceeds three, the overheads increase significantly. This has confirmed many simulations results presented in the literature which state without any clear explanation that using three paths provides the best trade off.

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