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A low-overhead fault-tolerant routing algorithm for mobile ad hoc networks: A scheme and its simulation analysis

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ABSTRACT

The fault-prone nodes in a mobile ad hoc network (MANET) degrade the performance of any routing protocol. Using greedy routing mechanisms that tend to choose a single path every time, may cause major data losses, if there is a breakdown of such a path in a fault-prone environment. On the other hand, using all the available paths causes an undesirable amount of overhead on the system. Designing an effective and efficient fault-tolerant routing protocol is inherently hard, since the problem is NP-complete because of the unavailability of precise path information in adversarial environments [1].

To address the above mentioned problem, we present a fault-tolerant routing algorithm (FTAR), which bases on the ideas of foraging in natural ants [2]. The algorithm is divided into six stages, namely, initialization, path selection, pheromone deposition, confidence calculation, evaporation and negative reinforcement. Simulation results show that FTAR achieves high packet delivery ratio and throughput as compared to some of the key protocols which do not address fault-tolerance at all. Most importantly, FTAR is established to supersede the performance of one of the best fault-tolerant MANET routing schemes [1] known currently, with respect to the amount of routing overhead incurred – it is an important achievement for ad hoc networks.

1. Introduction

MANETs are self-organizing and self-configuring networks having nodes connected by wireless links. They are infrastructure-less and nodes in them can join or leave at any point of time. There is no centralized control in MANETs, all nodes behave as routers for each other, and data packets are transferred for node to node in a multi-hop fashion.

The mobile nodes, which are inherently resource constrained, exhibit various kinds of faulty behavior. Faulty behavior may be transient or permanent and may be due to hardware or software problems. In such a scenario, a faulty node may not forward packets. Absence of any underlying infrastructure makes it difficult to keep these devices monitored. Moreover, the adversarial environment in MANETs makes the situation worse. Making routing decisions oblivious of these nodes will significantly degrade the performance of any routing protocol and can also threaten its prime objectives. Fault-tolerant routing protocols address this problem by exploring the network redundancy through multipath routing techniques.

The problem of fault-tolerant routing was first identified and addressed by Xue and Nahrstedt [1]. They developed the end-to-end estimation based fault-tolerant routing algorithm (E^2FT). E^2FT uses two complementary processes: *route estimation* and

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route selection. The former estimates the quality of a certain route through end-to-end performance measurement, while the latter uses the information provided by the former to decide a multipath route for packet delivery. Route selection is refined progressively with the increasingly accurate estimation result using *confirmation* and *dropping* procedures, which are elaborated further in Section 2.2.

The work by Xue and Nahrstedt acts as a direct motivation for this work, as it addresses the challenges faced by the E^2FT algorithm. When the mobility of the nodes is taken into account, E^2FT can be less efficient. The optimization of the algorithm to address the mobility of the nodes is a weak one and does not exploit the information gathered by the nodes to its full extent. E^2FT can also incur large packet overhead due to its conservative estimation method. Clearly, there is a need for an algorithm that can address these challenges more effectively, and this can be achieved using *stigmergic* [3] communication among the nodes of a MANET by situating it within the ACO [2] framework.

In this paper, we describe the fault-tolerant ant-based routing (FTAR) algorithm for MANETs. The design of FTAR is based on the self-organizing behavior observed in ant colonies. We use the structure of ACO to develop an effective fault-tolerant routing scheme. It has been observed that ants converge to the shortest path among the various routes found out by independent ants from the nest to the source of food.

As ants travel, they leave out a biochemical substrate, called as the *pheromone*. The shorter paths tend to have a higher concentration of *pheromone* and the ants preferentially move in a direction of higher pheromone content and, thus, further reinforce those paths. These paths will, therefore, attract more ants and, thus, lead to the convergence of the majority of the ants to the shortest path. The local intensity of the pheromone field, which is the overall result of the repeated and concurrent path sampling experiences of the ants, encodes a spatially distributed measure of goodness associated with each possible move. This form of distributed control based on the indirect communication among agents, which locally modify the environment and react to these modifications leading to a phase of global coordination of the agent actions, is called *stigmergy* [3].

The FTAR algorithm provides a confidence value to each path based on the network information collected by the artificial ant agents. The confidence in a particular path shows its degree of fault-tolerance. Instead of blindly routing through all the paths, data can be routed through these fault-tolerant paths, neglecting the highly faulty or the fault-prone ones. Using control packets to select routes on the basis of *a priori* information decreases the overhead further, as equal number of control packets need not be sent on faulty paths, as is done in E^2FT.

The paper is organized as follows. We first discuss the works related to FTAR, which encompasses other significant fault-tolerant routing techniques and the discussion of ant colony optimization (ACO) framework and other ACO routing algorithms. This is followed by a detailed discussion of the FTAR algorithm. We then discuss the simulation scenario and explain the results. Then we provide the conclusion to our work.

2. Related work

Unfortunately, works directly addressing the fault-tolerant routing problem in MANETs are very few in number, despite the importance of this problem. Xue and Nahrstedt [1] proposed the popular end-to-end estimation based fault-tolerant routing algorithm E^2FT. Oommen and Misra [4] also proposed a weak-estimation based learning approach for assessing better routing paths. Additionally, the foraging behavior of swarms of naturally occurring ants has inspired researchers to solve different complex engineering problems. It has given rise to the theory of ant colony optimization [2]. ACO has been used in the past to solve different network routing problems e.g., AntNet [5], AntHocNet [6], ARA [7] and ANSI [8]. However, none of the previously known solutions addressed the fault-tolerant routing problem in MANETs. In this section, we describe the related literature.

We start by giving a short introduction to MANET routing algorithms. Then we discuss the fault-tolerant routing scheme provided by Xue and Nahrstedt [1] and Oommen and Misra [4]. Finally, we discuss the ACO routing algorithm for MANETs.

2.1. Routing in MANETs

Different existing routing algorithms (e.g., [9–20]) for MANETs deal with dynamic aspects in their own way depending upon the requirements of the system and the performance objectives. Broadly, a routing algorithm can behave in a *reactive, proactive,* or a combination of both, that is, *hybrid* manner. Reactive algorithms are those that behave in an on-demand manner, which means that these algorithms gather routing information in response to some event, viz., start of a data session, route request messages and link failure messages. Proactive algorithms are those which gather essential information before hand, so that information is readily available when an event occurs. Hybrid algorithms use both proactive and reactive components in order to try to combine the best of both schemes.

In this paper, we compare the results of the conventional *reactive* routing protocol, dynamic source routing (DSR) [21], among other protocols, with FTAR. DSR is a reactive routing protocol which forms a route on-demand in reply to route request packets by some other node. It uses a source routing algorithm, which encompasses accumulating the address of each node between the source and the destination during route discovery. All the routing information is maintained at mobile nodes. It has two major phases: route discovery and route maintenance.