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A mobile ad-hoc network multi-path routing protocol based on biological attractor selection for disaster recovery communication

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Abstract

The performance of traditional routing protocols for mesh networks can decrease significantly in disaster recovery situations due to dynamic changes to the network environment. A number of multi-path routing protocols have been proposed to address such issues. MMQR is a multi-path routing protocol for OFDM–TDMA mesh networks which use multiple paths that can be replaced immediately by one another in case of link failures. In this paper we extend the MMQR such that the alternative paths are reordered adaptively as the communication environment changes based on the heuristic model of attractor selection mechanism by which biological entities are known to adapt to dynamically changing environment. Simulation results show that the multi-path routing protocol with attractor selection mechanism outperforms existing multi-path routing protocols in terms of packet delivery ratio, throughput and QoS.

Keywords: Disaster recovery; Mobile Ad-hoc Network; Multi-path routing; Bio-inspired networking; Attractor selection

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1. Introduction

In large scale disaster circumstances such as earthquakes, tsunami, floods, tornados, etc., destruction of the existing communication infrastructures can severely interrupt time-critical rescue missions and recovery operations. Thanks to their infrastructure-less nature, Mobile Ad hoc Networks (MANETs) have long been anticipated to play an important role as an alternative networking technology in such scenarios [1–3]. Despite their high expectations, the performance of these networks can degrade significantly in the situations where end-to-end paths become stale easily and spontaneous network partition occurs frequently due to low SNRs and high node mobility. The design of multi-path routing protocols has attracted a considerable amount of attention as an important method of enhancing the reliability of communication under such operating conditions [4–6]. One of the new issues arising from dealing with multi-path routing is how to take advantage of multiple paths adaptively in accordance with the changing communication environment. Re-computing the best paths when an existing path fails is not an efficient approach since it would incur additional routing overhead that is already one of the main problems associated with multi-path routing protocols in general.

The problem of multi-path selection in MANETs under disaster recovery circumstances can be modeled as a complex dynamic system of many parameters. Performance metrics such as reliability, delay, throughput, power consumption, etc. can be taken into account. Furthermore, there exist many operational considerations that require careful investigations such as the dynamic environmental changes, heterogeneity, lack of centralized control, survivability, and autonomous failure recovery. Thus, developing a computationally efficient algorithm is known to be extremely difficult. Heuristic methods such as evolutionary computing and bio-inspired schemes have been brought into attention due to their intrinsic adaptability to varying environmental conditions, robustness to failures and damages, collaborative operation based on simple rules, self-organization, survivability, and evolvability [7].

In this paper, a new approach to enhance the robustness of MANETs by combining a multi-path routing protocol and the attractor selection model such that the proposed scheme displays improved performance in terms of adaptation to a

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dynamically changing environment that is common in disaster recovery operations.

2. Background

2.1. Mesh multi-path QoS routing (MMQR) protocol

MMQR protocol has been developed in order to provide fault-tolerant QoS routing for OFDM–TDMA mobile mesh (ad hoc) networks based on AODV [8]. It finds multiple paths of a specified number by allowing multiple copies of a Route Request (RREQ) message to be forwarded by each node such that one or more paths can be found for each destination. If a packet loss due to a routing failure occurs, the packet is retransmitted along an alternative path stored in a routing table without issuing a Route Error message (RERR) which triggers a new path discovery operation.

MMQR is designed to work on top of the OFDM–TDMA MAC which allows each node to send various management messages to join a network, configure topology, and schedule packet transmissions. By using these management messages, each node can construct a neighbor node table which includes the bandwidth, delay and reliability of the link to each neighbor node up to two hops away. This information is also used to pre-populate the routing table with the entries of neighboring nodes. The paths to the nodes more than two hops away are discovered by an on-demand routing protocol that operates in a similar way as the Ad-hoc On-demand Multipath Distance Vector (AOMDV) routing protocol except that the multiple paths to the same destination are kept in the order of reliability and QoS metrics [9]. Several additional control data fields are added to the original AODV RREQ and RREP format in order to allow the nodes to select the paths with higher reliability and QoS metrics as follows:

- *MIN_Bandwidth*: the minimum bandwidth required by an application, 16 bits
- *Delay bound*: the maximum delay required by an application in milliseconds, 32 bits
- *Accumulated delay*: the accumulated sum of delay of packet transmission from the source node to the current node in milliseconds, 32 bits
- *REQ_Bandwidth*: the minimum bandwidth required by an application, 16 bits
- *Reliability*: the reliability value over the path from the current node to the destination node, 16 bits.

Duplicate RREQ messages are forwarded if they arrive from different previous hop nodes in order to form several different paths. The RREQs whose accumulated delay is larger than the delay bounds are not forwarded to ensure only the paths satisfying the QoS requirements are stored in the routing tables. The detailed description of the MMQR protocol can be found in [9].

2.2. Attractor selection model

In [10], Kashiwagi et al., proposes a mathematical model of Adaptive Response by Attractor Selection (ARAS) by which the biological mechanism of E. coli cells adapting to changing environment in terms of nutrient availability can be described. In this model, the cell activity value decreases when there is a change in external nutrient supply level such that attractors become unstable and the concentration of mRNA changes as the random noise term of the following differential equations dominates:

$$\begin{aligned}\frac{dm_1}{dt} &= \frac{syn(\alpha)}{1+m_2^2} - deg\,(\alpha)\,m_1 + \eta_1\\ \frac{dm_2}{dt} &= \frac{syn(\alpha)}{1+m_1^2} - deg\,(\alpha)\,m_2 + \eta_2\end{aligned} \tag{1}$$

where m_i is the concentration of the mRNA, $syn(\alpha)$ and $deg(\alpha)$ are the rates of mRNA synthesis and degradation in terms of cell activity α, respectively, and η_i are white noise terms. $syn(\alpha)$ and $deg(\alpha)$ are defined by:

$$syn\,(\alpha) = \frac{6\alpha}{2+\alpha} \quad \text{and} \quad deg\,(\alpha) = \alpha, \tag{2}$$

respectively. The value of cell activity is dynamically changed according to:

$$\frac{d\alpha}{dt} = \frac{prod}{\prod_{i=1}^{M}\left[\left(\frac{nutr\_thread_i}{m_i+nutrient_i}\right)^{n_i}+1\right]} - cons\,\alpha, \tag{3}$$

where *prod* and *cons* are the rate coefficients of the production and consumption of α, $nutrient_i$ represents the external supplement of nutrient i, and $nutr\_thread_i$ is the threshold of the nutrient to the production of α, and n_i is the sensitivity of nutrient i.

Leibnitz et al. transformed it into M dimension model with some adjustment to handle the problem of primary path selection as follows:

$$\frac{dm_i}{dt} = \frac{syn(\alpha)}{1+\hat{m}^2-m_i^2} - deg\,(\alpha)\,m_i + \eta_i \quad i = 1, \ldots, M \tag{4}$$

where $\hat{m} = \max_j m_j$.

$$syn\,(\alpha) = \alpha\left[(\alpha-1)^2+\varphi^*\right] \quad \text{and} \quad deg\,(\alpha) = \alpha, \tag{5}$$

where $\varphi^* = 1/\sqrt{2}$ and

$$\frac{d\alpha}{dt} = \delta\left(\left[\prod_{i=1}^{M}\left(\left(\frac{m_i}{\hat{m}}\frac{\check{l}}{l_i+\Delta}\right)^n+1\right)\right]^\beta - \alpha\right) \tag{6}$$

where l_i is the transmission delay on path i and $\check{l} = \min_j l_j$, δ and β are the rate coefficients of production and consumption of α, and Δ is the hysteresis threshold to prevent oscillation between paths.

Using Eqs. (1)–(6) a single path can be selected out of M multiple candidate paths under a given network condition. If the transmission delay of the current primary path becomes larger than that of the other candidate paths, the system autonomously adapts to the new condition and a new primary path is selected with the largest value of m_i.