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FRP: A novel fast rerouting protocol with multi-link-failure recovery for mission-critical WSN

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HIGHLIGHTS

- FRP is lightweight—computes backup paths on each node with least control overhead.
- End-to-end delay is minum with FRP because primary and backup paths are shortest.
- FRP rerouting is fast—a packet is shifted immediately to a pre-computed backup path.

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ABSTRACT

Fast rerouting requires that a backup route is already available at each node so that traffic can immediately be shifted on it without new path discovery and convergence time delay. Handling multiple failures with least possible delay, high throughput and least overhead with regard to memory and battery is a real challenge in Wireless Sensor Networks (WSN). Current fast rerouting techniques that handle multiple failures do not specifically target mission-critical WSN applications. Fast Rerouting techniques use spanning trees, backup topologies or configurations to shift traffic immediately as and when error is detected. These techniques do not focus on finding least hop count on the backup path and therefore, end-to-end delay on the backup paths is higher than on the primary path. The proposed Fast Rerouting Protocol (FRP) establishes primary and backup routes before the start of data transfer. It creates at least one backup path towards destination from every node on the primary path. FRP therefore has the ability to handle multiple failures in mission-critical WSN environment. NS-2 simulation results of FRP against the competitor reveal that, FRP takes least time and control messages to establish shorter fast rerouting paths, produces minimum end-to-end delay, least energy consumption and higher network life time.

1. Introduction

MISSION-CRITICAL applications are classified as *delay and loss intolerant* [1]. An example of such applications is transmission pipeline monitoring in an oil refinery [2]. Such types of mission-critical Wireless Sensor Network (WSN) applications require that content update be made in an interval of 10 ms to 250 ms [3] and, less than 1% failure of data should occur over the unreliable wireless link [4]. Due to these stringent requirements of delay and reliability, fast rerouting can be one of the feasible solutions.

Fast rerouting is different from multipath routing. However, both fall under the general category of convergence-free routing where traffic is immediately shifted to an already discovered alternate path when errors are detected [5]. The route error procedures are not performed because they lead to the delay and loss of data packets. In convergence-free fast rerouting, a protocol establishes alternate or backup paths from each node on the primary path, and therefore, when failure is detected, traffic is immediately shifted to an alternate next-hop from the point-of-failure [6]. On the contrary, in convergence-free multi-path routing, a protocol creates backup paths along with primary path, between source and destination or between specific intermediate node and destination. If

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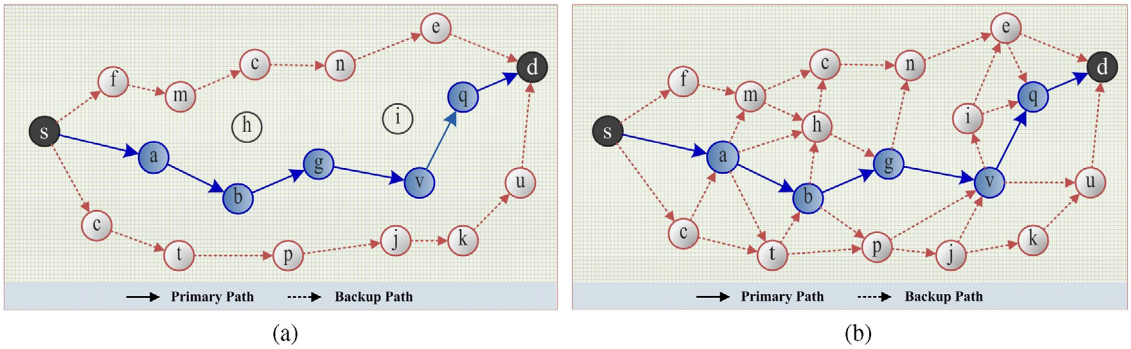

Fig. 1. (a) Multi-path routing (fully-disjoint backup paths from source), (b) Fast rerouting (partially-disjoint backup paths from each node).

failure is detected by a node, the source or the specific intermediate node is first informed which then shifts traffic to the most suitable backup path [7].

Generally, routing protocols work in a partially-disjoint or fully disjoint manner [8]. If they work in a partially-disjoint manner, then only failed nodes are bypassed while rest of the nodes or links of the primary path are used. If they work in a fully-disjoint manner, then backup paths and primary path have different nodes and links. Both of the convergence free techniques, fast reroute and multi-path, can operate either as partially-disjoint or as fully disjoint. In case of fast reroute, the partially or fully disjoint backup path is between the point-of-failure and the destination while in case of multi-path, the partially or fully disjoint backup path is between the source and the destination.

Both convergence-free fully disjoint and convergence-free partially-disjoint mechanisms need elaboration along with trade-offs. If the primary and backup paths are fully disjoint and failure occurs on the primary path at any position, the node detecting failure ahead of it cannot reroute the traffic from this point. This is the case of *multi-path convergence-free routing*. In such a situation, the identifying node informs the source about link or node failure. There are few problems in this technique. First, packet delay (and jitter) increases because source is first informed and then the pending packets are retransmitted from the source to destination. Second, this procedure is repeated for all such packets whose sources are different. Third, informing a source requires control packets. This routing strategy also has some advantages. Total control packets during routing are less as compared to partially-disjoint technique and the routing entries on the intermediate nodes are small. Example of fully disjoint backup path is given in Fig. 1(a).

If the primary and backup paths are partially-disjoint and failure occurs on the primary path at any position, the node which detects failure ahead shifts the traffic to an alternate node. Thus, the problems of packet drop, informing the source node to choose an alternate path and retransmission of inflight packets by the source node do not exist in this technique. This is the case of *fast reroute convergence-free routing*. This technique has drawback of producing higher routing packets and may suffer from higher delay if backup path longer than the primary path. Example of partially-disjoint backup path is given in Fig. 1(b).

Error recovery protocols are classified as single-link failure recovery [9] or multi-link failure recovery [10]. In the case of single-link failure recovery, if traffic has once been shifted to a backup path and another failure has occurred, the recovery is not possible and packets shall be dropped. In the case of multi-link failure recovery, the traffic is shifted to an alternate path every time when a failure occurs. Number of recoveries in multi-link failure protocols depends on the number of backup paths. For example, if a multi-link failure handling technique creates only three backup paths, it can handle at least three link failures.

The proposed Fast Rerouting Protocol (FRP) is reactive, partially-disjoint, designed for mission-critical WSN and has the ability to recover from multi-link failures. During the establishment of primary path, FRP establishes at least one backup path towards destination from each node on the primary path. If a link or node failure is detected at any point on the primary path, an alternate next hop is picked from the point-of-failure. The proposed FRP contributes in the following ways:

- FRP is lightweight—computes backup paths on each node with least control overhead.
- End-to-end delay is minum with FRP because primary and backup paths are shortest.
- FRP rerouting is fast—a packet is shifted immediately to a pre-computed backup path.

The rest of the paper is organized as follows. Section 2 discusses existing failure recovery mechanisms along with their strengths and weaknesses. This section ends with problem statement. Section 3 explains the path setup, data flow and fast rerouting mechanism of the proposed Fast Rerouting Protocol. Section 4 explains in detail the performance evaluation of the proposed FRP and the competitor IRFMP protocols. The last Section 5 presents paper conclusion with some future directions of this work.

2. Related work

This section discusses prominent emergency routing techniques for handling failure recovery. These techniques have been divided into fully disjoint backup path algorithms and partially-disjoint backup path algorithms. The protocols in partially-disjoint backup path algorithms are further divided on the bases of single link failure and multi-link failure.

2.1. Fully disjoint backup path algorithms

These are in fact convergence-free multi-path recovery protocols. Authors in [11] presented a proactive mathematical model to reduce the complexity of recalculation of routes as compared to Dijkstra's algorithm. This technique divides the whole network into subnets and solves the link failure problem for each subnet. When a link breaks the data send to a predefined backup path from the starting point of the subnet. When failure occurs, the technique divides the network into two subsets (portions) with respect to the point-of-failure—one before failure point and the other after failure