Computer Networks 82 (2015) 34–49

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

A Geographic Multi-Topology Routing approach and its benefits during large-scale geographically correlated failures

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ARTICLE INFO

Article history:
Received 16 June 2014
Received in revised form 4 February 2015
Accepted 4 February 2015
Available online 9 March 2015

Keywords:
Geographically correlated failures
Multi-Topology Routing
Architecture
Network virtualization
OSPF

ABSTRACT

Large-scale geographical events can significantly disrupt network services. In particular, the routing *churn* that occurs during such large-scale events has been shown to cause significant impact in route stability and transient behavior. We take a Geographic Multi-Topology Routing (gMTR) approach for pre-planning of geographically correlated failures. Thus, in the event of a failure, the gMTR approach switches to a virtual topology that reduces the impact of routing changes that can result in dropped connections until new paths can be established. Two algorithms are proposed to generate virtual topologies, Geographic Coverage MTR (gcMTR) and Geographic Targeted MTR (gtMTR). The first method, gcMTR, is to create virtual topologies taking a network wide coverage approach for which we consider taking both a circular coverage approach and a hexagonal coverage approach. gtMTR, on the other hand, is a targeted approach that can be used in anticipation of a specific event where the knowledge of the impending event is available. We propose another algorithm that specifies a way to detect a geographic event and select a topology to use. We evaluated our approach on two network topologies and observed that the number of connections that are dropped during a geographic event can be reduced significantly using our gMTR approach, thereby reducing the impact to the non-affected part of the network. We performed an analysis of the topology size versus the disaster size, topology location versus disaster location, and general density of the topology. Finally, a simulation model of the larger topology is used to study the effects of geographically correlated failures both with gcMTR and using default topologies. This provides a way to assess the *gains* from using gMTR to mitigate the impact of large scale geographic impacts.

1. Introduction

Large scale geographical events such as natural disasters, major weather events, and geo-political events can significantly disrupt network services. Thus, efforts to reduce or minimize disruptions is desirable since such events are also when disaster response data is needed and when users want to inform their friends and families about their whereabouts. Therefore, it is imperative to create robust network functionalities.

From a network perspective, when geographically-correlated events occur, several problems surface. These problems range from slow convergence of the routing protocols due to congestion on overloaded links caused from rerouting traffic affected by the event. Furthermore, such events cause stability issues during the transient period. An important issue is how basic link-state interior gateway protocols

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http://dx.doi.org/10.1016/j.comnet.2015.02.024
1389-1286/

(IGP) such as OSPF and IS–IS, that are commonly deployed in large networks, are affected and what can be done to increase throughput during a major event. In [5,1], the authors explore the tradeoff between routing stability and convergence speed in link state protocols. Disruptive outages in networks tend to cause multiple link state advertisements (LSA) to be flooded across the routing area and the routers to perform multiple shortest path calculations and therefore have long convergence times. *Flapping* can occur if link information is propagated through the network too quickly. To prevent flapping, hold down timers are used, but they slow down the convergence time [5]. This highlights the tradeoff between convergence speed and routing stability. In addition, major disruptions can cause large numbers of traffic flows to be interrupted or rerouted to other links causing congestion [1].

Another concern during geographical events is that the failures may not occur at one instance. The outages may *cascade*, moving through the geographic area with the event or subsequent outages are caused by side effects of the initial outage, like congestion. In [24], Sterbenz et al. discussed several examples of major events where cascading outages were an issue. Earthquakes can have aftershocks that cause cascading outages. Floods can cause cascading outages as floodwaters penetrate different geographic areas. Even political situations can escalate and spread across a geographic region. Frequently, routing protocols will attempt to reroute with little knowledge that the paths that are selected are also vulnerable [24] or that the paths go around the edges of the disaster area.

In this work, we propose a preemptive Geographic Multi-Topology Routing (gMTR) approach based on Multi-Topology Routing (MTR) [18,17] to improve network performance during a major geographically correlated event. Basic OSPF and IS–IS protocols have now been extended with MTR functionality. Thus, our gMTR-based approach is intended to improve network throughput compared to basic link-state protocols in order to isolate parts of the network affected by a large-scale geographic event. Using our mechanism, there is less disruption to existing traffic, and the routing convergence time delay due to the basic link-state protocol can be avoided. Specifically, we use gMTR to protect against the problems associated with geographically correlated failures. Briefly, in the gMTR framework, we create a series of topologies that can be useful to mitigate potentially disruptive events in the network.

The general effect is that once the geographic event is detected, the *trunk* of the shortest path tree (SPT) is rapidly moved away from the affected area in the topology. This *isolates* the affected region from the rest of the network and limits the impact of the disruption on the whole network.

To understand why gMTR is needed for geographic failures in networks, an understanding of what happens during link or node failures in link-state routing protocols is necessary. First, detection of a link or node state change (like an outage) occurs. Next, routers affected by the change will create LSAs and send them to their neighbors. This information will be flooded across the routing area till all routers have the same link state database. If database changes occurred, each router independently calculates the shortest path tree to all nodes based on the new database.

If multiple outages occur, like a geographic event, several things can happen that negatively impact the above restoration process. First, where multiple links are involved, links may exhibit repeated and intermittent failures causing link flapping behavior [1]. This behavior typically causes frequent routing changes that lead to routing instability. If the outages are significant, multiple rounds of LSAs will be flooded across the network causing shortest path first (SPF) calculations to run repeatedly at each node. This is commonly referred to as SPF Throttling and can lead to longer convergence times. A significant impact of route instability is that traffic paths may also become unstable and impacted severely [1]. Long `RouterDeadInterval` settings in routers also impact convergence times during major outages.

In this work, we show through simulation that `RouterDeadInterval` directly impacts the time required to re-establish traffic across a network during a large geographic failure. Given that the reduction of this timer setting increases routing instability, a method to switch to a *stable* routing tree quickly is desirable to avoid significant traffic disruption during these events. We show that this can be achieved using gMTR.

In our gMTR approach, we create multiple alternate topologies starting from the default topology where link weights are pre-determined in such a way that in the event of a geographic failure, the routing paths created move away from a vulnerable geographic region. In particular, we propose a method to compute the link weights so that the path selection attempts to avoid an affected region. While the MTR-based approach has been used for network resilience [3,2,9], our approach considers a geographic vulnerability as the driver for how to determine links weights that can be used in MTR. This paper extends our earlier conference paper [6] in a number of ways: (1) we present two different ways to generate alternate topologies, one based on a circular coverage and the other based on a hexagonal coverage; (2) we include additional analysis on assessing improvements based on our approach; and (3) we also include simulation results using the OPNET [15] simulation tool to show gains with gMTR during the transient period.

The primary reason to extend the coverage model to include hexagonal coverage is related to the well known efficiency of the hexagon coverage pattern making them useful for sensor coverage and cellular networks. Hexagon coverage patterns have two important properties. Hexagonal tiling patterns have 100% coverage of a physical space as opposed to circular patterns. The other important property is that all locations in hexagonal coverage patterns are nearest to the center of the covering hexagon.

The rest of the paper is organized as follows. Section 2 covers related work, including a brief overview of MTR and its proposed use by different researchers. We present the two algorithms, gcMTR and gtMTR, for our geographic MTR approach in Section 3. An illustrative example using a 5×5 grid topology is presented in Section 4. Two real-world topologies, one moderate-size and the other large,