

DISASTER RESILIENCE IN COMMUNICATION NETWORKS



Michele Nogueira



Piotr Cholda



Deep Medhi



Robert Doverspike

We experience society's growing dependence on electronic communication networks in every aspect of our lives. With this comes the expectation that communication networks are readily available all the time. Networking protocols are designed to address some simple failures, such as when a packet is dropped, a retransmission occurs, or the size of the transmission window is adjusted to accommodate congestion. Similarly, routing protocols have the functionality to route around a failure. That is, communications networks have certain built-in resilience for certain specific types of failure situations. Furthermore, networks can be designed with backup paths and capacity to protect against a failure as part of critical infrastructure protection.

A disaster in a communication network is generally understood as a massive set of failures that can affect performance to the point where the degradation appreciably affects our lives. It should be noted that not all disasters are visible to end users. A disaster such as a hurricane that encompasses a geographic area can severely affect the communication network in the geographic area and beyond; in such a case, the end users may be aware of the disaster through news reports. On the other hand, if a major disaster occurs at a large-scale data center, users from a very wide geographical region may notice degraded performance, but may not be aware of the actual event that occurred. Examples are over-the-top video provided by data centers that experience failures or with the peering locations that interface these data centers with the Internet. Millions of video customers have been affected over large areas of a country in such cases, but no environmental disaster is present. As another example, a software attack that cripples the network is a virtual disaster that is not directly visible to end users.

It is infeasible and impractical to design and deploy hardened structures, equipment, and transmission facilities that never fail and can withstand any disaster. Therefore, the approach is to design and provide mechanisms that can recover and react to disasters. Thus, the scope of disaster resilience is that a network recovers from a disaster with an acceptable level of performance by a set of mechanisms. Such mechanisms can be either proactive, reactive, or a combination thereof. Usually, proactive approaches include redundancy in a cost-effective manner; hence, the network is sufficiently reli-

able to address a failure or an attack. In the case of reactive approaches, the network may react by rerouting through backup capacity, or, in some cases, by rapidly deploying ad hoc networking capability. Thus, reactive approaches may include emergency communication mechanisms during and after a disaster. The latter are an emerging and exciting approach that we have highlighted in this Feature Topic.

While much research in the past few decades focused on network resiliency, most of this work limited itself to isolated or very localized failures. When a disaster occurs, the ability of the network to recover to a reasonably acceptable performance level is a challenging problem. Thus, this Feature Topic sought submissions that covered the topic of disaster resilience from a broader perspective than had ever been attempted in the past.

For this Feature Topic on disaster resilience in communication networks, we received a surprising 72 submissions! The papers were initially triaged into three categories: 1) appropriate fit for the Feature Topic; 2) appropriate for consideration in a general issue of the magazine; and 3) not as suitable or redundant on this issue. The review process resulted in identifying nine papers for publication. Four papers appear in this first part, and five papers are scheduled to appear in a second part of this Feature Topic in December 2014.

We briefly summarize below the articles included in this issue.

The first article, "All Quiet in the Internet Front?" by Christian Doerr and Fernando Kuipers, looks at Internet failures over the past six years and makes recommendations on Internet resilience research. Different from the traditional classification of those failures as intentional and unintentional, the authors present an interesting perspective, categorizing failures as related to 1) the network infrastructure; 2) the Border Gateway Protocol (BGP); and 3) the services. Furthermore, the authors analyze failures considering their frequency and root cause. Among the authors' findings, they emphasize that almost no major incidents are caused by fiber cuts, a surprising aspect as many of the network resilience schemes in the literature focus on providing alternative routes with low computational or financial costs. However, the authors stress the widespread codependency on multiple systems and the increasing complexity of Internet services, since malicious or

accidental failures of core routers and switches can result in major outages even for geographically distributed services, such as those offered by cloud providers. Finally, the authors reinforce the need for more attention to resilience engineering and the challenges faced in addressing them.

The second article, “Network Design Requirements for Disaster Resilience in IaaS Clouds” by Rodrigo de Souza Couto, Stefano Secci, Miguel Elias Mitre Campista, and Luis Henrique Maciel Kosmowski Costa, addresses a hot topic of resilience provisioning in cloud environments considering infrastructure as a service (IaaS). They focus on geo-distribution of redundancy by providing the general context, guidelines, and fundamental steps to be taken. Among the guidelines to design a data center network infrastructure to support a disaster-resilient IaaS cloud, the authors reinforce the need for carefully choosing data center site locations and disaster-resilient virtual machine placement.

The third article, “On-the-Fly Establishment of Multihop Wireless Access Networks for Disaster Recovery” by Quang Tran Minh, Kien Nguyen, Cristian Borcea, and Shigeki Yamada, elaborates a method to provide connectivity on the site of a disaster area by establishing, on the fly, a multihop wireless access network through users’ mobile devices. This is one of the emerging and exciting technologies mentioned in the introduction. The goal is to offer the opportunity to quickly react in emergency cases, setting up virtual access points to easily extend Internet connectivity. This is not a purely conceptual work, as the authors deployed a testbed during the Japan 2011 earthquake. They present practical results indicating the viability, efficiency, and low cost of the solution.

The fourth article, “Enabling Emergency Communication through Cognitive Radio Vehicular Network” by Yifan Sun and Kaushik R. Chowdhury, proposes an innovative emergency communication network architecture composed of cognitive radios embedded in vehicles, which take advantage of the unused licensed radio bands to provide wireless connectivity under disaster conditions. The authors promote the use of cognitive radio technology for disaster resilience scenarios, describe the state of the art, and point out open issues. Finally, they propose a new approach to spectrum sensing, a challenging phase of the cognitive radio cycle, in order to reduce errors.

Assembling this Feature Topic on this challenging and important topic was truly a rewarding experience. We thank all authors for their contributions and all the reviewers for volunteering their valuable time.

BIOGRAPHIES

MICHELE NOGUEIRA is a professor of computer science at the Federal University of Paraná, where she has been since 2010. She received her doctorate in computer science from the Université Pierre et Marie Curie — Sorbonne Universités, Laboratoire d’Informatique de Paris VI (LIP6), in 2009. She was a visiting professor at Université Paul Sabatier and a visiting researcher at Georgia Institute of Technology in 2013 and 2009, respectively. Her

research interests include wireless networks, security, and dependability. She has worked on providing resilience to self-organized and wireless networks by adaptive and opportunistic technologies such as cognitive radio. She was one of the pioneers in addressing survivability issues in self-organized wireless networks, the article “A Survey of Survivability in Mobile Ad Hoc Networks” being one of her prominent scientific contributions. She was a recipient of Academic Scholarships from the Brazilian Government during her undergraduate and graduate years, and of international grants such as from the ACM SIGCOMM Geodiversity program. She is also an Associate Technical Editor for *IEEE Communications Magazine* and the *Journal of Network and Systems Management*.

PIOTR CHOLDA obtained a doctorate in telecommunications in 2006 from AGH University of Science and Technology. He then joined the Department of Telecommunications there, and now works as an assistant professor. He specializes in design of computer and communications networks. Recently, he has focused on risk-based communications networking. He is the co-author of 16 refereed journal papers and three conference tutorials. He was a Technical Program Committee (TPC) Co-Chair of Communications QoS, Reliability and Modelling Symposium at ICC 2011 and a TPC Co-Chair of NOMS 2014. He is a member of the Editorial Board for *IEEE Communications Surveys and Tutorials* and Editor the Book Reviews Column in *IEEE Communications Magazine*.

DEEP MEDHI is a curators’ professor in the Department of Computer Science and Electrical Engineering at the University of Missouri-Kansas City (UMKC). He received his B.Sc. in mathematics from Cotton College, Gauhati University, India; his M.Sc. in mathematics from the University of Delhi, India; and his Ph.D. in computer sciences from the University of Wisconsin-Madison. Prior to joining UMKC in 1989, he was a member of technical staff at AT&T Bell Laboratories. He was an invited visiting professor at the Technical University of Denmark, a visiting research fellow at Lund Institute of Technology, Sweden, a research visitor at the University of Campinas, Brazil, under the Brazilian Science Mobility Program, and served as a Fulbright Senior Specialist. He is currently the Editor-in-Chief of Springer’s *Journal of Network and Systems Management*, and is on the Editorial Boards of *IEEE/ACM Transactions on Networking*, *IEEE Transactions on Network and Service Management*, and *IEEE Communications Surveys & Tutorials*. He was an Associate Technical Editor of *IEEE Communications Magazine* from 2006 to 2010. His recent IEEE activities include serving as a TPC Co-chair of IEEE NOMS 2010, General Chair of IEEE CloudNet 2013, and Vice-Chair of the Committee on Network Operations and Management (CNOM). He is co-author of the books *Routing, Flow, and Capacity Design in Communication and Computer Networks* (Morgan Kaufmann/Elsevier, 2004) and *Network Routing: Algorithms, Protocols, and Architectures* (Morgan Kaufmann/Elsevier, 2007).

ROBERT DOVERSPIKE [F] received his undergraduate degree from the University of Colorado, and his Master’s and Ph.D. degrees from Rensselaer Polytechnic Institute (RPI). He began his career with Bell Labs and, upon divestiture of the Bell System, went to Bellcore (later called Telcordia). He returned to AT&T Labs (Research), where he is now executive director of network evolution research. He has made extensive contributions to the field of optimization of multi-layered transmission and switching networks, and pioneered the concept of packet transport in metro and long distance networks. He also pioneered work in spearheading the deployment of new architectures for transport and IP networks, network restoration, and integrated network management of IP-over-optical-layer networks and software defined networking. He has over 1500 citations of his books and articles over diverse areas/publications such as telecommunications, optical networking, mathematical programming, *IEEE Magazine*, IEEE Communications Society, operations research, applied probability, and network management. He holds many professional leadership positions and awards, such as INFORMS Fellow, member of the Optical Society of America, co-founder of the INFORMS Technical Section on Telecommunications, OFC Steering Committee, DRCN Steering Committee, and Associate Editor for the *Journal of Optical Communications and Networking*.