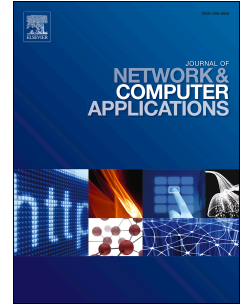


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Giuseppe Aceto, Alessio Botta, Pietro Marchetta, Valerio Persico, Antonio Pescapé



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# A Comprehensive Survey on Internet Outages

Giuseppe Aceto<sup>a,b</sup>, Alessio Botta<sup>a,b</sup>, Pietro Marchetta<sup>a</sup>, Valerio Persico<sup>a,b</sup>, Antonio Pescapé<sup>a,b</sup>

<sup>a</sup>University of Napoli "Federico II" (Italy)

<sup>b</sup>NM2 s.r.l. (Italy)

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## Abstract

Internet outages are inevitable, frequent, opaque, and expensive. To make things worse, they are poorly understood, while a deep understanding of them is essential for strengthening the role of the Internet as the world's communication substrate. The importance of research on Internet outages is demonstrated by the large body of literature focusing on this topic. Unfortunately, we have found this literature rather scattered, since many different and equally important aspects can be investigated, and researchers typically focused only on a subset of them. And, to the best of our knowledge, no paper in literature provides an extensive view on this important research topic. To fill this gap, we analyze all the relevant facets of this important research topic, stepping from the critical review of the available literature. Our work sheds light on several obscure aspects such as, for example, the different challenges considered in the literature, the techniques, tools, and methodologies used, the contributions provided towards different goals (e.g., outage analysis and detection, impact evaluation, risk assessment, countermeasures, etc.), the issues that are still open, etc.. Moreover, it provides several innovative contributions achieved analyzing the wide and scattered literature on Internet outages (e.g., characterization of the main causes of outages, general approach for implementing outages detection systems, systematic classification of definitions and metrics for network resilience, etc.). We believe that this work represents an important and missing starting point for academy and industry to understand and contribute to this wide and articulate research area.

*Keywords:* Outage, Large-scale Outages, Internet Outages, Fault, Detection, Resilience, Earthquake, Tsunami, Hurricane, Cable Cut, DDoS, Network Attack, Security, Outage Impact, Mitigation, Risk Assessment, Survey.

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## 1. Introduction and Motivation

The professional, personal, and political lives of almost two billion users worldwide now critically depend on the Internet. Financial transactions, business operations, and many other applications require high availability and good performance of this critical, highly dynamic, extremely heterogeneous, planetary-scale, and largely opaque ecosystem of networks. However, as any other critical infrastructure, this one trillion-dollar communication system experiences outages.

Internet outages are *inevitable*, *frequent*, *opaque*,

*expensive*, and *poorly understood*. They are *inevitable* because the perfect system is not achievable in practice since issues and threats can not be completely prevented, or their prevention can be economically unfeasible. Outages are *frequent*: in just three weeks of monitoring, Katz-Bassett et al. [132] discovered persistent reachability problems involving about 10,000 distinct prefixes, with one in five of the problems lasting for more than 10 hours. Large-scale Internet outages are also continuously reported in Renesys blog [17] and the outage mailing list [14]. They are also *opaque* since the Internet has good built-in abilities (e.g., IP routing) to limit their impact and thus visibility and traceability. Internet outages are *expensive*: according to Forbes [68], Amazon lost about \$66,240 dollar per minute on 19 August 2013 due to a blackout. More in general, outages preventing users to con-

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*Email addresses:* giuseppe.aceto@unina.it (Giuseppe Aceto), a.botta@unina.it (Alessio Botta), pietro.marchetta@unina.it (Pietro Marchetta), valerio.persico@unina.it (Valerio Persico), pescape@unina.it (Antonio Pescapé)

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