Guest Editors' Introduction: Special Issue on Design and Management of Reliable Communication Networks

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***Abstract*—This Special Issue contains a collection of outstanding papers covering several recent advances regarding the design and management of reliable networks. Papers are organized into seven categories: resilience in NFV-based networks; resilient software defined networks; resiliency of optical networks; Internet of Things and safety of critical services; automation and self-diagnostics for resilient network management, robust network design, and wireless and mobile network resilience. In this editorial, a brief overview of the field is given, followed by a summary of the twenty-six papers, accepted for publication in this special issue.**

***Index Terms*—Resilience, NFV, optical networks, wireless networks, network management, network design, critical services.**

I. Introduction

This Special Issue (SI) features the latest research contributions regarding the design and management of reliable networks. Reliability of communication infrastructure is a top priority for network operators. To ensure reliable network operation, new design and management techniques for reliable communications must be constantly devised to respond to the rapid network and service evolution. As a recent and relevant example, deployments of 5G communication networks will soon enter their second phase, during which the network infrastructure will require upgrades to support new Ultra-Reliable Low-Latency Communication (URLLC) services with availabilities of up to 6 nines to be guaranteed jointly with extremely low latencies. Even in the still preliminary vision of 6G communication networks, reliability is posed as one of the most critical requirements, as 6G networks will represent the communication platform of our future hyper-connected society, supporting essential services as smart mobility, e-health, and immersive environments with application in remote education and working, just to name a few. Similarly, disaster resiliency in communication networks is now attracting the attention of media, government and industry as never before (consider, e.g., the worldwide network traffic deluge to support remote working during the current Coronavirus pandemic). Luckily, several new technical directions can be leveraged to provide new solutions for network reliability as: increased network reconfigurability enabled by Software Defined Networking (SDN); integration/convergence of multiple technologies (optical, wireless satellite, datacenter networks); enhanced forms of data/service replication, supported by, e.g., edge computing; network slicing, used to carve highly-reliable logical partitions of network, computing and storage resources. These, and many others, technological transformations can be leveraged to enable next-generation high-reliability networks.

Hence, we believed it was appropriate to organize an IEEE Transactions on Service and Network Management (TNSM) SI to stimulate a more thorough investigation of new research directions on reliable network design and management.

II. Overview of Special Issue

The Special Issue received sixty-six submissions. After a thorough and timely review process, twenty-six papers were accepted for publication in this Special Issue. The twenty-six accepted papers have been classified into seven categories: (i) resilience in NFV-based networks; (ii) resilient software defined networks; (iii) resiliency of optical networks; (iv) Internet of Things and safety of critical services; (v) automation and self-diagnostics for resilient network management, (vi) robust network design, and (vii) wireless and mobile network resilience.

A. Resilience in NFV-based networks

NFV is a main enabler to achieve resilience in future networks. Several contributions on this topic are covered in this SI. The NFV-MANO (Management and Orchestration) framework currently represents one of the main software platforms to build a NFV-enabled control and management solution. Its robustness and availability are modeled in [1], where the authors propose a model-driven approach for availability performance prediction complemented by realistic recovery parameters obtained through fault-injection simulations. The authors of [2] addressed the problem of Virtual Network

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Function (VNF) placement and considered a general approach where VNFs of a particular service can be executed in parallel, with the objective being maximized revenue. Due to the complexity of the problem, the authors proposed a probability-based approach, in which the placements of the VNFs are determined based on their probabilities of contributing to the profit. In [3] the authors noted that, while 5G technology provides an infrastructure with abundant connectivity and reliability, the network stack of 5G devices continues to be borrowed from legacy operating systems, hence, degrading user experience. To address this, the authors exploit network softwarization technologies to empower 5G devices and have developed 5GSoft, a novel softwarized networking stack on each 5G mobile device. As the failure of a critical network component disrupts services abruptly and leads to users' dissatisfaction, the authors of [4] present a novel approach based on multi-connectivity in 5G networks to tackle this problem and propose an approach that is resilient against i) failure of VNFs, ii) failure of local servers within MEC, iii) failure of communication links, and iv) failure of an entire MEC cloud facility in regional level. The authors present a binary integer program and a polynomial time algorithm to obtain near optimal solutions for the problem. In [5], a self-modeling approach is proposed to address the limitations of network virtualization including the lack of network visibility and dynamic topology changes. The authors introduce an active diagnosis process for virtual networks exploiting both acquired knowledge and learned knowledge provided by fault injection. Paper [6] addresses issues in virtualizing long term evolution (LTE) core with instance-based NFV. Decomposing LTE network functions increases delays in mission-critical network event execution. The authors propose a Fat-proxy that behaves as a stand-alone execution engine of these events while supporting high availability. Finally, paper [7] explores the issue of protection against virtual node failures. A latency-bounded node protection approach is presented, which considers service time for VNFs. Since the problem is NP-hard, the authors proposes a logarithm-approximation algorithm.

B. Resilient Software Defined Networks

Another fundamental technical enabler for high resilience in future networks is SDN. Virtual software defined networks (vSDN), where multiple tenants share the same physical infrastructure, require a survivable control plane so that state inconsistencies are avoided, different tenants are isolated and security can be guaranteed. Paper [8] proposes an approximation algorithm for (hypervisor) placement, which finds the appropriate number and location of hypervisor instances to satisfy the control path length constraints declared in the service level agreements. Moreover, in SDN, to avoid dropped traffic occurring in case of an unreachable next-hop, loop-free alternates (LFA) mechanisms are needed to forward affected traffic over alternate paths, as proposed in paper [9]. The authors propose a solution named RoLPS, which can protect traffic against all single link or node failures, and against most double failures, while inducing only little overhead. Finally, SDN has also stimulated the development of programmable data-plane equipment that can be configured to deploy new monitoring solutions. Paper [10] shows how data plane programmability can be leveraged to develop new in-band network telemetry solutions with low bandwidth overheads in the context of segment routing.

C. Resiliency of optical networks

Optical networks are the backbone of the Internet infrastructure and, as such, their resilience has been traditionally subject of intense investigation. Lately, new technologies, such as the paradigm of elastic optical networks (EON), are emerging to provide new means to achieve high reliability. In [11], the authors explore new design methodologies (as cooperative storage, content replication and multipath routing) to ensure EON survivability in extreme circumstances including disaster events generating multiple and correlated network failures. Specific solutions for protection in EON are investigated also in [12], where the authors investigate the concept of bandwidth squeezing (i.e., providing less data rate to backup paths) together with grooming capability to provide protection under multiple failure events. Finally, in [13], the authors investigate how to perform early soft-failure detection, identification and localization based on the observation of the temporal behavior of Quality of Transmission measures including noise figure in optical amplifiers and reduced signal to noise ratio in wavelength selective switches.

D. Internet of Things and safety of critical services

Edge-assisted intelligence enables and improves the safety of critical IoT applications and services. Paper [14] addresses the problems of privacy preservation, robustness, and communication efficiency in edge-assisted federated learning for IoT applications. To circumvent the limitations of centralized aggregation servers, the authors propose a socially-aware clustering-enabled distributed federated learning framework where each cluster head represents an aggregation point. The proposed framework consists of finding a solution for clustering and allocating resources to devices while striking a balance between model accuracy and deployment cost. The authors in [15] propose a risk-aware cloud edge framework to ensure that delay-sensitive inspection tasks in autonomous warehouses meet their latency requirements. The authors employ a conditional Value-at-Risk strategy to measure the inspection risks, and apply branch-and-check to decide on the optimal placement of inspection tasks to achieve minimal costs and lowest latency guarantees. In [16], authors propose an effective SINR-based model to conduct the QoS analysis of IEEE 802.11p/bd driven VANETs for safety applications. A semi-Markov process (SMP) model is proposed to characterize the channel access behavior of IEEE 802.11 broadcast networks with deterministic message generation rate. Compared with existing analytical SINR-based models for broadcast VANETs, the proposed models are more general, more accurate, and are faster to provide solutions. In [17], the authors focus on mission-critical networks, as those used for autonomous cars and avionics. A novel approach for optimal joint service allocation and routing is introduced, that leverages virtualized embedded devices and shared backup capacity for the fault-tolerant design of these mission-critical networks.

E. Automation and self-diagnostics for resilient network management

Specific network management tasks are being automated, but more automation calls also for more resilient network management solutions. Two important tasks performed in Network Operation Centers (NOC) are failure management and cost-aware traffic engineering, which are nowadays manual processes in most cases. Paper [18] introduces an Action Recommendation Engine (ARE) that can learn implicit NOC action rules with supervised machine learning from historical data. ARE can effectively reproduce implicit action-taking logic of NOC technicians, which supports the transition towards reliable autonomous networks and fully-automated NOCs. In [19], the authors concentrate on the management of edge/cloud computing resources and propose an auto-scaling mechanism relying on multi-agent reinforcement learning, that can reduce network energy consumption while providing an adequate service level, outperforming other benchmark auto-scaling approaches. In [20], the authors noted a dilemma about self-healing in large scale decentralized systems of autonomous agents. That is, fault-detection inherits network uncertainties making a faulty process indistinguishable from a slow process. The paper introduces a novel and general-purpose modeling of these fault scenarios. They demonstrate that their proposed approach can accurately measure and predict inconsistencies generated by fault-correction and fault-tolerance when each node in a network monitors the health status of another node, while both can fail.

F. Robust network design

The following works on robust network design focus specifically on malicious attacks. New probabilistic measures are defined in [21] such that an optimization model can effectively identify the most dangerous sets of attacks that an attacker can plan based on estimated controllers' locations, assuming he/she has full knowledge of the topology of the network. A model for the optimal placement of controllers, to maximize the availability of services against a set of attacks, is also proposed. In [22] three different types of attacks are considered: link-based random attacks, targeted attacks, and random attacks under the protection of critical links. Closed-form analytic approximations for the number of controllable nodes in sparse communication networks, for each of three listed attacks, are proposed and evaluated. Finally, in [23], the authors employ biological robustness to protect against failures in multi-Unmanned Aerial Vehicles (UAVs) networks. The authors prove the NP-Hard nature of the problem and propose a Markov-Chain Monte-Carlo based heuristic. With this approach, the authors were able to improve network efficiency and ground user coverage compared to benchmark algorithms.

G. Wireless and mobile network resilience

Resilience is a key requirement also for wireless access networks. In [24], authors investigate optical attocell networks based on visible light communication (VLC). VLC is vulnerable to shadowing effect as it cannot penetrate opaque objects. A new cross-layer resilience scheme is proposed to address the shadowing effect. Network sharing through multi-operator connectivity is explored as a means to enhance network reliability in [25]. Using a real-world dataset, the result analysis showed that allowing mobiles with weak signal-to-noise (SNR) ratio to multi-connect leads to a reliability increase for mobile operators. This is achieved with only a small reduction of the average capacity. The problem of modeling the repair of cellular networks after base station failures is addressed in [26]. The authors propose to use matrix exponential (ME) distributions to model repair operations and a queuing model framework is employed to study the problem.

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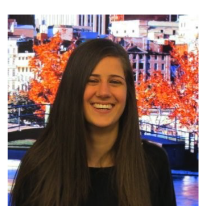

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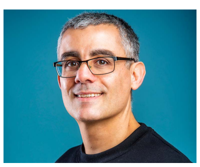

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