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A Review of Telecommunication Network Survivability Models

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Abstract

Telecom networks are employed in numerous critical aspects of our society, such as business, financial services, and life-saving services. Natural disasters, misconfigurations, software upgrades, latent failures, and deliberate attacks can all cause several correlated failures in communication systems' physical infrastructures. These events may result in the long-term deterioration of telecommunications services. For this reason, research has to be carried out to know various methods used in designing survivability models used in resolving failures. A lot of research has been done on the review of telecom network failures, however, not sufficient work has been accomplished on the review of telecommunication network survivability. This paper presents a review and learning structure for telecommunication network survivability models to reveal hidden topics, which are less investigated. The survey comprises 119 accredited journal articles that have been published between 2001 and 2019 in 36 selected journals, which are suitable sources for telecommunication network failure survivability topics. The results reveal that there is a progressive volume of telecommunication network survivability models that have been carried out for various ranges of learning categories. The results reveal hidden telecommunication network survivability topics, which have received lesser attention. The findings can hopefully be used as a learning reference guide to understanding telecommunication network survivability models, as well as a source for researchers interested in telecommunication network survivability research to stimulate their further interests.

Keywords: *Telecommunication, Network, Failure, Quantitative, Qualitative, Survivability model, Trustworthiness, Reliability.*

1.0 Introduction

Telecom networks that span large areas are vulnerable to a variety of failures, including natural tragedies, operational failures, and malevolent assaults. Tragedy failures are those that can cause a wide-area failure and impair network connectivity [1]. A disaster failure on both nodes and links can severely impede network operation. Networks are vulnerable to a wide range of failures, ranging from single-point failures such as fibre cuts and inline equipment breakdown to multiple concurrent failures that can affect a large portion of the network [2].

Many occurrences of system failures have occurred in telecoms and linked devices. These incidents caused significant disruptions, and their slow detection and diagnosis exacerbated their impact in terms of operational service, financial loss, and human factors such as trust in technology [3].

Various techniques for telecommunication network survivability have been suggested in the literature; they differ in the network model used, and there has not been enough work done on a review of telecom network resilience; this inspires the research study.

Telecommunication network failures are of three types [4]:

(i) Single-link failures;
(ii) Multiple-link failures; and
(iii) Tragedy failures that include both single and multiple node failures. The most common types of failures in a telecommunications network are single and multiple failures. As a result, protection against these two types of failures should not be overlooked [5]. A node failure in a disaster failure includes (i) failure of the source or destination node; or (ii) outage of a node in the central portion for a specific connection. A node failure on the transmitter/receiver is typically irreversible [6]. A connection that loses its source/destination node will be terminated. However, an interruption in the system caused by a failed receiving node can be restored by using the reproduction of

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information in a remote area. To resolve these failures, a reliable survivability model has to surface to reroute messages transmitted in the presence of failures. In resolving these failures we need to know which survivability method will be suitable for a particular type of failure. Here comes the quantitative and qualitative method of restoration and the applicability of each method in solving failure problems. An extensive review is done in this work to unveil telecommunication survivability models.

1.1 Main Contributions and Outline

Essential systems in a telecommunications network should be made available to the public even when unfavourable events such as destabilization, natural catastrophes, or service outages occur. This is critical to establish virtual links among peering vertices that meet specific performance requirements, for example, minimal level throughput and peak delay [7]. Such requirements are addressed by the configuration, construction, and maintenance of connectivity, network infrastructures, and networks. A telecommunication network survivability model is designed to resolve network failures without human intervention by assuring the user of the network's trustworthiness. The telecommunication network survivability learning structure because of its relative novelty and explosive growth in network usage is an intriguing area for research. This paper's main contributions are as follows:

- The creation of a learning structure from the literature on telecommunication network survivability research on the extensive survey conducted between 2001 and 2019.
- The structure used reflects our point of view on telecommunication network survivability literature that reveals uncovered or "hidden" research on telecommunication network survivability concepts which have gotten insufficient research attention, generating knowledge and opening up research questions for future researchers.
- To investigate the framework and metrics used to assess network resilience.

It is believed that they will serve as a roadmap for telecommunication network survivability research/teaching for both academics and practitioners in knowledge generation and ensuring quality of service in both voice and data transmission. The learning structure of the network resilience study revealed an exponential increase in the number of published articles, albeit in dense areas. Many people should be interested in the current state and direction of research topics. The rest of this article is organized as follows: Section 2 discusses the need for a more reliable survivability model in the world of telecommunication networks (Reliability) sub-topics. Section 3 presents our proposed learning structure, which includes the major classes of telecommunication network survivability, is presented. A learning structure analysis and comprehensive results are provided in section 4. Open research issues and implications, which provide questions for future academics/researchers, Section 5 presents the results, and Section 6 concludes this paper.

2. Need for a Better Survivability Model in a Telecommunication Network World

This section discusses how trustworthy some of the survivability models are. The following issues were noted: The dependability of the models in terms of reliability, maintainability and safety of the models in resolving network failures without creating other bottlenecks to the network.

Dependability is the assurance that validates the dependence that could be put on a system's service delivery [8], and it is comprised of two major aspects: accessibility and trustworthiness. The outage density's estimated values functions are critical to both of these aspects. The following problems were identified: Fast restoration and quick recovery were found to be more reliable than slow restoration [9]. The analytic research was carried out to determine the dependability and survivability characteristics of the third generation and beyond. To obtain these attributes, the hierarchical architecture of the Universal Mobile Telecommunications Systems (UMTS) network is modelled by stochastic models such as Markov chains, semi-Markov processes, and reliability block diagrams. The model was designed to assess the dependability and survivability of networks outside of 3G, for example, All-IP UMTS and CDMA2000 networks. The computational outcomes demonstrate the utility of the mathematical system suggested. It has been discovered that fault-tolerant boosts system availability and resilience. Furthermore, it can aid in the assurance of network ease of access following any outage, rather than exaggerating the networks. The numerical results revealed that (a) incorporating fault tolerance in UMTS network architecture can result in significant gains in network reliability and (b) Expanding the number of networking devices above a certain limit would not improve system availability. (c) Mobile network developers can use the model to continue providing appropriate guidance on consistency, resilience, and high availability.

Based on empirical data, Andrew P. Snow et. al., [10] provides a dependability and survivability assessment of telecom switches in the United States influenced by the presence of failures. Over 14 years, nearly 13,000 switch outages are investigated, with over 2,500 originating with only 156 switches having 8 or more shutdowns each. For this multiyear period, telecommunication switch outage statistics are examined, allowing investigation into the rate, causes, trends, and consequences of switch malfunction. The reported outage causes codes to generate the classifications of human error, design error, hardware failure, and external factor causality. The main findings are that switches experiencing more frequent outages/failures have significantly different switch and outage characteristics as depicted in Table 1.

Table 1: Distribution and Local Switch Outages (Adapted from [10])

Code	Description	Number	%
1	Planned	3,885	30.2%
2	Errors in the procedure (Telecom installation and maintenance)	446	3.5%
3	Errors in the procedure (Telcom non-installation/maintenance.)	376	2.9%
4	Errors in the procedure (Procedural error by the system vendor)	315	2.4%
5	Errors in the procedure (Other procedural errors by the vendor)	257	2.0%
6	Designing software	1,078	8.4%
7	Designing hardware	136	1.1%
8	Failure of hardware	2,951	22.9%
9	Acts of God	935	7.3%
10	Overcrowding in Traffic	17	0.1%
11	Weather condition	83	0.6%
12	Outer power outage	896	7.0%
13	Major power outages, wire cuts, and other issues	660	5.1%
14	Faraway - loss of infrastructure between the host and the remote	309	2.4%
15	unknown	516	4.0%
	Total	12,860	100%

Figure 1 represents the graphical representation of the percentage of switch outages and the cause is based on empirical data in the United States.

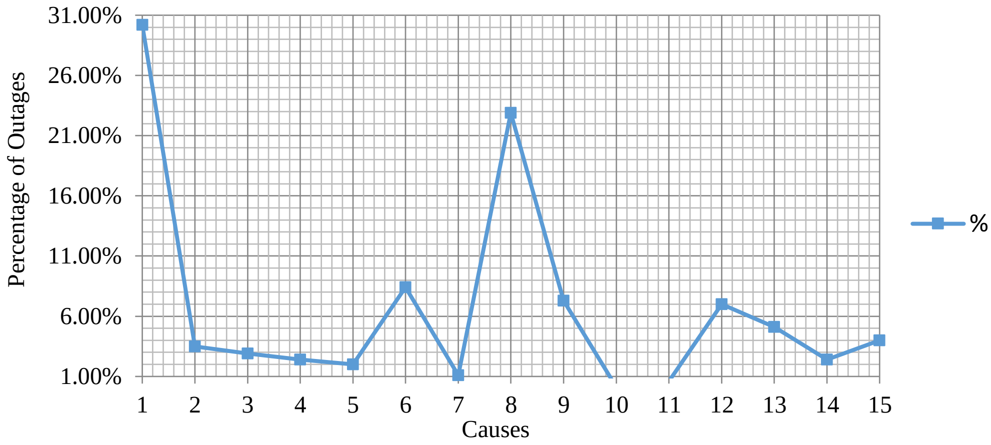

Figure 1: Percentage of Switch Outage against Cause Code (Source [10])

The author's more notable and interesting outcomes for switches that witness quite recurring shutdowns are outlined below:

• Switches that fail more frequently have very severe reliability deterioration, whereas switches that fail less frequently have good reliability growth.

• Switches that fail regularly are much relatively small, more undeveloped, and have far less regular inspection than switches that fail infrequently.

• Human error failures have a much smaller issue when the switches are regularly down switches. This could be due to their remote location, where technicians make fewer visits. Maybe the sparsely populated switches are more regularly featured to bigger switches, necessitating fewer technician visits.

• Routine blackouts are uncommon for switches that are used more frequently, possibly indicating that preventive maintenance is performed less frequently. It might, however, become an artefact of relatively small switches being connected by larger switches.

• For switches that experience frequent outages, attributed to be actions of God, huge line outages, failure to connect to the dedicated server switch, as well as other factors are all significantly problematic. This could point to flaws in host-remote switch frameworks and/or the physical plant's vulnerability to disasters.

3.0 Proposed Learning Structure

119 articles were selected for review from journals, conference proceedings, technical reports, chapters from online books, articles on web pages, and theses. Just publications pertinent to telecommunication network survivability modelling are chosen, resulting in just 36 publications being taken into account for a complete written review. After carefully selecting the article title and abstract, 13 additional articles were chosen from the search. The results reduce the total number of the final selection of 70 publications as the main source with this analysis. The learning structure of telecommunication network survivability is well explained in this review.

Figure 2 shows the various methods used in designing trustworthy telecommunication network survivability models.

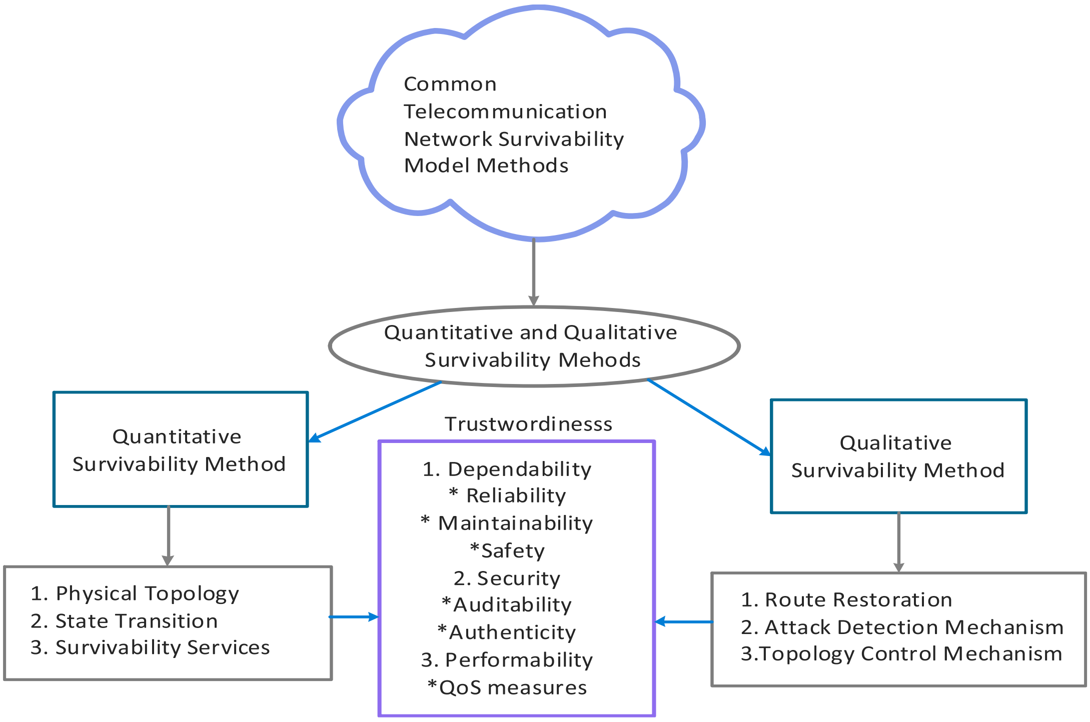

Figure 2: The Proposed Learning Structure of Telecommunication Network Survivability (Adapted from [11])

3.1 Quantitative Survivability Method

Several types of research have been conducted on the quantitative method of analysing and designing telecommunication network survivability and to mention a few of the works done are as follows: To investigate MANETs' worldwide resilience. A.H Azni et. al., [12] proposes a novel framework of survivability focused on associated node actions. For associated node actions in MANETs, the model employs the k-correlated survivability model which is an enhanced version of the node mobility k-connectivity system. The k-correlated resilience design uses a directly linked level to quantify node connection as a new feature of survival rate. The research looks at how interrelated node behaviour, specifically egocentric, harmful, and failing nodes affects restoration and resilience. According to the findings, correlated node behaviours get a greater negative impact on survivability.

Chunlei Wang [13] suggests an extensible and customizable unified framework for connectivity resilience testing and evaluation. The system resilience quantification model's customizability method, as well as the overall validating and assessment of the system survival rate, is thoroughly examined. The network survivability testing is carried out using a particular framework for measuring system survival rate, and a corresponding test mechanism with a collection of testing instances is created. The quantification results of system resilience metrics are used to evaluate the system survival rate, and to assess connection survival rate, a multi-criteria decision-making technique is employed. The experimental results demonstrate the framework's generality and applicability as well as the efficacy of the suggested connection survival rate sample design and evaluation approach.

Lang Xie et. al., [14] introduces a generic state transition model for quantifying a telecommunication network's survivability attributes in terms of failure regeneration. This model offers a basis for characterizing connection speeds following the event of a failure, during successive failure regeneration, and until the system is restored. With both physical and infrequent failures, two distinct models are presented. Survivability quantification analysis for the system's transient behaviours is performed using the models resulting in measures such as infrequent connection. The numeric value outcomes show that the suggested modelling and assessment methods accomplish admirably in both instances. The outcomes are useful not only for assessing the quantifiable resilience of a system but for deciding between different survivable strategies.

Marcelo D. Rodas-Britez and Diego P. Pinto-Roa [15] suggests a new framework of quality of protection (QoP) based on standardized levels of safety, in which the series of setups could be outlined according to the network official's needs, i.e., an adjustable QoP method for which the specific situation is the conventional technique. The suggested generic status is premised on the restoration likelihood hood principle that determines the degree of discord among main light paths which communicate recovery light paths for outage healing. A Genetic Algorithm (GA) is proposed to investigate how this strategy affects network cost. It computes the main and alternative light paths using an enhancement with different goals and methods regarding lexicographical ordering. The Optimizer reduces the number of stuck demands, the number of unprotected solutions, the overall disparity between demanded and allotted QoP, and the network cost, all while accounting for the optical fibres in use and the spectral utilization restriction. The investigational findings indicate that the suggested adaptable QoP method is a viable technique in surroundings with both heterogeneous and uniform QoP prerequisites, in which system cost, amount of requests, and QoP stages are conflicting goal functions.

3.1.1 Physical Topology

A network topology is categorized into two ways: directed and undirected. The term "directed topology" is described [16] by:

- A network is represented by $G = (N, L)$ in which N is a collection of nodes and L is a collection of directed links;
- A collection of capacities $C = \{c_{ij}\}$ in which c_{ij} is the link(i, j) capacity;
- Functional data transfer constraints.

The *undirected topology* is described as a graph $G = (N, L)$ such that L is the collection of undirected links. Every one of the components c_{ij} in C depicts the entire available capacity on the (i, j)link. In other words, c_{ij} should be equal to or greater than the amount of traffic conveyed over the link (i, j) between i and j plus the traffic transmitted on the link (i, j)between i and j. As a result, undirected networks have increased route discovery options and last longer. Many authors work on the physical topology of telecommunication networks. For example, Hanh V. Ngu Yen and D ieu Linh Truong [17] suggests a method for developing the physical topology of optical metro infrastructures with the goals of (i) making sure traffic demands between access points, (ii) reducing costs of fibre, and (iii) ensuring network survivability. The author designed the solution with a high level of fibre redundancy, but the computational outcomes indicate that the suggested solution achieves those goals while saving so much more fibre than current systems.

3.1.2 State Transition

It describes the possible behaviour of discrete systems. It consists of states and transitions respectively that may be labelled with labels from a collection; the same label could arise on various transitions. Mathematically, transition systems are equivalent to abstract rewriting systems and directed graphs. State transition connections are a broad concept that has several subsets, including enlarged transition systems, iterative transition connections, and enhanced iterative systems. The technique for survival rate is proposed by Lang Xie et. al., [18]. A survivable connection is made up of connectivity management and design techniques that in the past reduced the consequences of system outages on communication networks.

3.1.3 Survivability Services

The system's ability to offer services continuously following the existence of outages, in given requirements and other undesirable occurrences is referred to as its survivability service [19]. Although when unfavourable occurrences like sabotage, natural catastrophes, or service outages happen, essential systems in a telecommunication system must be made available to the public. Remote links between peering nodes must satisfy specific quality standards, such as minimal level throughput, optimum delay, or loss. Muhammad Waqar Ashraf et. al., [19] worked on the system survival rate to ensure that the network operator could keep providing solutions in the event of a disaster. According to media reports, physical attacks and natural catastrophes have a serious influence on optical systems. Such system outages can end up causing a portion of a system to fail, as a result of the inability to provide services and increasing congestion throughout the network.

3.2 Qualitative Survivability Method

Qualitative modelling entails determining the critical system elements required to deliver benefits or satisfy qualities which must be sustained in the face of threats or outages. It is linked to insecurity measurement and can be validated using quantitative techniques. There are fewer research works on qualitative methods of designing good telecommunication network survivability models, as opposed to quantitative models, which have a larger number of articles on telecommunication network survivability models.

3.2.1 Route Restoration

Route restoration is the discipline that explains the design and implementation of efficient strategies and/or designs for attaining desired system stability by developing effective system alternative plans for networks in the occurrence of anticipated or unanticipated outages [20]. The primary objective of system recovery is to attempt to provide alternative paths whenever one or more system elements fail so that data transmission is not disrupted. The alternative paths are typically computed either directly at the time of failure or before the failure occurs. Khalid Mahmood et. al., [21] worked on On-demand communications recovery for WSNs in the occurrence of a single or multiple-node failure. Since energy is a limited resource in sensor networks, all suggested measures for connectivity restoration must be energy efficient. This study suggests a smart on-demand interconnection recovery method for wireless sensor networks (WSNs) to resolve the interconnection recovery difficulties, whereby vertices make use of their transmitting distance to guarantee accessibility and the substitution of node failures because of their redundant nodes. The suggested method aids in maintaining device architectures and responses to outages successfully Thus, the system can handle node failure better by trying to introduce less overhead on sensor nodes, more reliable power consumption, wider connectivity, and communication without moving the sensor nodes.

In Muhammad Waqar Ashraf et. al., work [22], the review specifically discusses by studying previous research studies on safety, recovery, cascading failures, accidental failures, and traffic delays routing. The research also concentrated on the issue of concurrent cascading failures (which could also obstruct transmitted data within a layer or services at higher layers) and trying to mitigate methods as well as tragedy connectivity resilience. Since transmission congestion is a serious issue, finally, the work highlighted and discussed some unresolved problems in the tragedy-resilient network in resilience research, as well as potential solutions. Bao Ju Liu et. al., [23] is developing a survivability-aware routing restoration framework for connectivity with intelligent grid networks in the event of a widespread outage. Natural disasters, such as earthquakes, have long-term consequences for the smart grid because of aftershock activity.

3.2.2 Attack Detection Mechanism

The term attack detection relates to the critical issue of detecting and refusing to conform trends or behavioural patterns in real-time traffic information. Data collected from a network or a host (typically, incoming and outgoing transmission) can be used to identify threats [24]. Jordi Cucurull et. al., [25] suggests a comprehensive security structure for tracking and responding to destructive attacks. It has a set of features for detecting, diagnosing, and mitigating anomalies. The initiatives are spread in each node but their combined effect is significant attack resistance allowing players to spread the message even when conditions are adverse. The method was tested in the context of a disaster area network using the Random Walk Gossip protocol with a store-and-forward method.

Yuanjiang Huang et. al., [26] thought about a particular kind of danger in which the harm is malevolent battery exhaustion of sensor batteries. Unlike a traditional denial-of-service attack, the quality of service is not necessarily compromised under the considered attack. Furthermore, the service quality can improve until the sensor set fails. He asserts that this is a unique type of attack. As a result, using a traditional defence mechanism to combat this threat is not always feasible. As a result, effective methods for mitigating the threat must be developed. He begins by explaining the feasibility of rapid battery depletion. The author then proposed a model for calculating energy usage during such an attack. Finally, a strategy for counter-attack is addressed.

3.2.3 Topology Control Mechanism

Topology control from the standpoint of network topology is a popular method of preserving or improving wireless network connectivity by controlling network topology [26]. It should be noted that accessibility is one of the primary considerations in wireless network design but it is not always the only one. When optimising other features Scope, power and the number of nodes should be considered. In most cases, network coverage and connectivity must be recognized.

3.3 Trustworthiness

This guarantees that a process will function properly in terms of measurable properties which are defined as trustworthiness [27]. The trustworthiness disciplines, which include (1) overall reliability, (2) safety, and (3) effectiveness, thus measure network service delivery.

4.0 The Learning Structure Analysis and Results

According to our scheme, 119 articles were classified. We looked at the articles identified by the year of publication, the total number of articles published in the selected journal, and articles by topic.

4.1 Pattern of Publication by Year

A literature search was conducted in the databases Science Direct, ACM Digital Library, and IEEE Digital Library using keywords such as "survivability, trustworthiness in mobile and wireless telecommunication networks." The analyses have been restricted to quantitative English studies using survey data and statistical analysis techniques with the quality of service concept described from the customers' point of view. This analysis is not restricted to one article per research instrument; for example, when more than one article was ascertained utilizing the same research instruments (for example, model reliability), all of the articles found, such as [3-18] were included for assessment. Moreover, the assessment is not restricted to one article per country; when numerous articles from the same country [18, 21] were established and reported, they were all included in the analysis.

Table 2 summarizes some related articles reviewed to support our claims. Some of these articles were about the survivability and reliability of telecommunication networks. The papers are displayed in tabular form in five categories of information: author(s) and year, the task performed, the field of study, the method used, and model trustworthiness. They are subjected to extensive and close examination to determine the trend of these fields of study.

Table 2: Summary of Selected Past Related Work on Telecommunications Network Survivability Models

Reference	Task Completed	Field	Technique	Model Trustworthiness
[28] Jose Yallouz and Ariel Orda (2017)	He utilized switchable survivability, which offers a quantitative estimate for stating the optimal state of survival rate (0%-100%) and allows for routing path adaptability.	Telecommu-nications	The author developed effective algorithmic schemes for improving resilience within the additive end-to-end quality of service constraints.	Reliability: Exhaustive simulation results showed that at the cost of a minimal decrease in survival rate, a substantial change in end-to-end QoS performance (up to a factor of 2) is achieved.
[29] P. Papanikolaou, K. Christodoulopoulos, and E. Varvarigos (2017)	The author formulates the multi-layer resilience issue for an IP-over-elastic-optical-network and presents ILP formulations for solving it with two levels of survivability in thought: Failure of a single optical link and failure of an optical and IP node.	Telecommu-nications	The author used joint multi-layer techniques	Reliability: (The suggested multi-layer techniques improve efficiency by leveraging IP grooming functionality allowing for the taking the time to share recovery reserves for a specific failure state, as well as primary backup resource sharing).
[30] Ning-Hai Bao, Guo-Qing Su, Ya-Kun Wu, Ming Kuang, Da-Yong Luo (2020)	The suggested work investigates survivability techniques for telecom networks such as Wavelength-Division-Multiplexing (WDM) and optical networks.	Telecommun ications	To recover the impacted failures, the author used a reliability sustainable survivability (RSS) scheme.	Reliability: (RSS routes principal pathways and/or adds peripheral pathways first to ensure connection consistency, then allocates connection bandwidth to enhance system throughput based on provider consistency and bandwidth baselines. According to simulation results, RSS can maintain required connection

				reliability, adjust to post-disaster traffic fluctuations and achieve good results in terms of networking and traffic failure percentages.)
[31]Elaine Wong, Elena Grigoreva, Lena Wosinska, and Carmen Mas Machuca (2017)	The goal of this study is to provide solutions to improve the survivability and power savings of mobile transport networks in 5G transport networks that use sleep mode operation.	Mobile Communicat-ions	The authors formulate strategies based DWDM optical ring transport network, which has previously been shown to be energy efficient as a 5G transport network.	Reliability :(The suggested mechanism allows for network energy savings through sleep mode operation without sacrificing failure detection time. In comparison to conventional ring architecture, the proposed survivable schemes provide improved connection availability and power savings while incurring less than a 0.2% incremental network cost.)
[32] Li Jin, Guoan Zhang, Jue Wang (2018)	The researchers create a complete Markov chain (CTMC) model for the proposed V2V network and then use the PRISM language to describe the CTMC model and continuous-time stochastic logic to describe the objective survivability properties. In the analysis, two common failures are considered: node failure and link failure, which are caused by external malicious attacks on a target V2V node and an interruption in a communication link respectively.	Communicat-ions	The authors successfully used the suggested probabilistic model checking-based survivability analytical method for V2V networks.	Reliability (It is expected that the technique can be appropriately applied to other networks).
[33] Zhu Weiwei, Zhang Xu, Jin Xin, Li Xing, Chen Yitong, Sun Yi, and Li Bin (2017)	The authors propose a power communication network with multi-layer survivability and inter-level coordination planning.	Power Communicat-ion network	This article suggests a two-layer network system that maintains an interlayer coordination mechanism to improve the resilience of the optical fibre transmission network.	Reliability: (After the fibre failure, the information exchange service improves.)
[34] Ying Xu and Baihan Zou (2020)	To assess the overall resilience of totally reliant networks based on their inherent interconnection, the principle of node distribution was suggested.	Telecommu-nication network	Node dispersion was suggested as a fundamental idea.	The reliant network was discovered as the most resilient once one-to-many relatively uniform coupling was used.
[35]Anuj Agrawal, Purva Sharmay, Vimal Bhatia and Shashi Prakashy (2020)	To improve the survivability of the Indian RailTel disaster multiple link outages in an optical connection.	Telecommu-nication	This paper proposes a seismic zone-aware node resettlement (SZANR) scheme to improve optical network resilience in the face of multiple link failures caused by natural disasters.	Experiments on the real-world Indian RailTel optical network show that the proposed SZANR can achieve up to 98:25% earthquake survivability. Furthermore, combining the suggested SZANR with traditional devoted route safety can improve

				network survivability by 88:2%. (DPP).
[36] Elham Moridi, Majid Haghparast, Mehdi Hosseinzadeh and Somaye Jafarali Jassbi (2020)	In this article, paradigms for fault management in wireless sensor networks were developed.	Sensor Network	The researchers proposed a new model that focuses on the management performance of each framework and the number of involved nodes. Following that, frameworks were analyzed and evaluated based on their major challenges.	The findings have allowed us to provide more precise paradigms for efficient network monitoring with lower power consumption, delay, and operating costs.
[37] Chunlei Wang, Liang Ming, Jinjing Zhao and Dongxia Wang (2011)	Current network survivability research is primarily concerned with the classifications and estimations of particular network resilience features or benchmarks.	Telecommu-nication networks	This article suggests an expandable and customized cohesive blueprint for examining and assessing system survivability.	The experiment's findings show the framework's generality and applicability, as well as the efficacy of the suggested network resilience check design and method of assessment.
[38] Huaiyuan Wang, Xu Ding, Cheng Huang and Xiaobei Wu (2016)	This paper suggests a comprehensive workable alternative to node failure problems (single and multiple).	Sensors Network	The authors propose The Collaborative Single Node Failure Restoration Algorithm (CSFR) developed to address the issue of single-node failure through data transmission. To reestablish collaborative connectivity, the Collaborative Connectivity Restoration Algorithm (CCRA) is also suggested after multiple nodes failure using cooperative communication and node manoeuvrability.	Besides this, by choosing the most proximity viable candidate, an individual node's distance travelled during recovery is reduced. Simulation experiments eventually affirm the progress of CSFR, CSFR-M, and CCRA.
[39] John Doucette, Wayne D. Grover (2002)	This article investigates the potential impacts of span maintenance tasks on network restorability and, thus, accessibility. The authors suggest this issue in the context of span-restorable networks.	Telecommu-nication	The authors examine two major advances: The first is a bi-criteria optimal solution approach that allows for a controlled trade-off between the cost of spare capacity and the reduction of restorability risk by improving the ability to roll to protection on the same span without exporting any working flow onto other spare channels throughout the network. The second approach directly designs the spare capacity of a span-restorable network so that it is	The concept of maintenance immunity design is easily adaptable to limit servicing protection to prioritized delivery routes.

			completely immune to the risk of restorability loss due to maintenance actions.	
[40] Lang Xie, Poul E. Heegaard, and Yuming Jiang (2012)	This article employs survivability modelling to classify the dynamic response of an infrastructure-based wireless connection in the existence of catastrophic outages and maintenance.	Telecommu-nication	Different designing methods are presented: a precise design and a rough product-form design.	Computational modelling with the two models shows that the approximate solution product-form technique produces results that are close to precise while requiring significantly less computational complexity.
[41]Rudy Deca, Omar Cherkaoui and Yvon Savaria (2012)	This study's goal is to show a rule-based solution for automated network service provisioning. The suggested technique showcases configuration data dependence using high-level, provider-specific, and consumer-specific rules.	Telecommu-nication network	To overcome this limitation, regulation techniques can provide enough power and influence to automate a variety of network administrative functions.	This article demonstrated how to rule efficiency can be improved while preserving regulations simple and the rule set minimal.
[42] Marcelo D. Rodas-Britez and Diego P. Pinto-Roa (2015)	This study suggests a new Quality of Protection (QoP) paradigm premised on generic levels of safety in which the series of protection levels could be identified as required by the network engineer, i.e., an adaptable QoP technique whose particular instance is the conventional or rigid QoP technique.	Telecommu-nication network	It is suggested that a Genetic Algorithm be used. It computes the main and secondary light paths to use a lexicographical sorting-based multi-objective optimization technique.	The suggested scheme reduces the number of blocked requirements, unprotected systems, and the overall discrepancy between the demanded and allotted QoP and network cost all while accounting for the optical fibres used and susceptible to the wavelength utilization restriction.
[43] Brody Todd, Abiose Ibigbami, and John Doucette (2014)	This article investigates how the network family concept can be used to provide a solid unbiased foundation for comparing different network protection models.	Communicat-ion network	1+1 APS, span restoration, path restoration, SBPP, and P-cycles are the survivability models used in this study.	Since the network group examines a protection scheme across a range of average nodal connectivity, a more complete picture of the scheme's performance is obtained than if the simulation were only run on a single network or a subset of networks.
[44] Manijeh Keshtgary, Fahad A. Al-Zahrani, Anura P. Jayasumana and A.H. Jahangir (2004)	The article suggests a survivability composite model based on performance and availability analysis.	Telecommu-nication	An algorithm is suggested for performing network availability analysis even when the available paths between nodes are non-disjoint. These two models are combined to form a hierarchical model that is used to assess network survivability performance.	When the system is operating in gracefully degraded states, an analytical technique is presented to determine the excess loss due to failure (ELF).

Figure 3 depicts the number of studies conducted each year to assess telecommunications survivability from 2001 to 2019. It is clear that the number of studies conducted during the first five years between 2001 and 2005 is (5); this increases to (10) during the next five years; and then decreases to (4) between 2011 and 2015. From 2016 to 2017, researchers in the field of telecommunication network survivability increased their work attitude until 2018 to 2019, when work in this field gradually decreased. This means that the emphasis on measuring survivability and trustworthiness is waning, and the debate over which dimensions should be used is still ongoing. As telecommunication network survivability improves, so will service quality in handheld devices such as personal digital assistants, tablets and smartphones, and wireless and mobile technologies, which are essential for daily life.

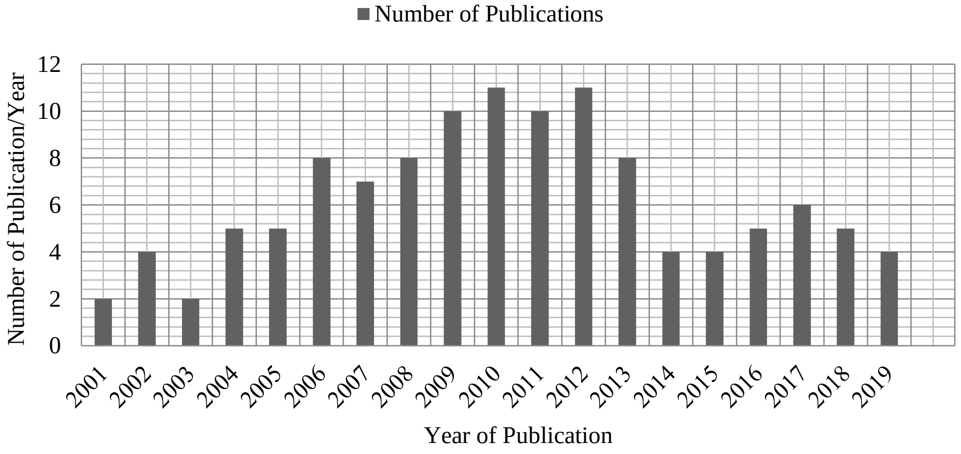

Figure 3: Reviewed Studies that Measured Telecommunications Network Survivability

4.2 Pattern of total articles in selected journals

The review includes 72 articles from 36 journals drawn from three different literature databases: "ScienceDirect," "IEEE," and "Springer Link," as depicted in Table 3. Table 3 summarizes the dimensions of the top standard of telecommunications systems as perceived by subscribers as a result of an integration of search queries restricted to publications written in English.

Table 3: Journals Reviewed

Journal name	**Total**
Optical Switching and Networking	3
World Conference on Technology, Innovation and Entrepreneurship	1
Journal of Networks 2012	4
Procedia Engineering	3
IFIP International Federation for Information Processing	2
Discrete Applied Mathematics	1
Sensors (MDPI) 2016	3
COMNET: Resilient and Survivable Networks	2
Design of Reliable Communication Networks	1
Computer Networks(ScienceDirect)	4
National Fiber Optic Engineers Conference 2001	1
Telecommunications Infrastructure in Disasters: *Preparing Cities for Crisis Communications*	1
CLEI Electronic Journal	2

IEEE Networks	3
Photonics Network Communication, 2003, 2018	4
Procedia - Social and Behavioral Sciences, 2015	2
IEEE Communications Surveys & Tutorials	1
Ministry of Information and Communications: Journal on Information Technologies and Communications	1
Springer Telecommunication Systems Journal	3
Journal of Computer Networks and Communications (Hindawi Publishing Corporation)	3
IEEE Xplore	6
Int. Journal of Engineering Research and Applications	2
Journal of Communications and Network 2015	1
IEEE/ACM Transactions on Networking 2005	2
Open Access at Springerlink.com	2
Computer Communications, 2020	1
Procedia Computer Science, Available online at www.sciencedirect.com	1
IEEE Transactions on Network and Service Management	2
Wireless Communications and Mobile Computing (Hindawi)	1
Journal on Wireless Communications and Networking	1
International Journal of Distributed Sensor Networks	1
Journal of Optical. Communication. Networks (IEEE Xplore).	2
Journal of Networks & Security (IEEE Xplore)	1
Journal of Network Technologies & Applications (IEEE Xplore)	1
IEEE Access	2
IEEE International Conference on Artificial Intelligence and Computer Applications	1

Figure 4 shows that the IEEE journals have the most articles on telecommunication network survivability. It publishes journals on network survivability, with a focus on the network's ability to withstand major and minor failures in network infrastructure and service platforms caused by unwanted external or internal events. The second highest percentage is in computer networks (Science Direct) and photonics network communication. Procedia Engineering, IEEE Networks, Optical Switching and Networking, Sensors (MDPI), Journal of Computer Networks and Communications (Hindawi Publishing Corporation), and Springer Telecommunication Systems Journal have the third highest percentage of telecommunication network survivability articles. Discrete Applied Mathematics, IEEE Communications Surveys & Tutorials, Journal on Wireless Communications and Networking, International Journal of Distributed Sensor Networks, Journal of Networks & Security (IEEE Xplore), and Wireless Communications and Mobile Computing have the lowest percentage of publications (Hindawi). Elsevier's Telecommunication Network Survivability publication is dedicated to the network survivability model, which states that critical services in a telecommunication network should be continuously provided even when unfavourable events such as sabotage, natural disasters, or network failures occur [18]. It is also possible to recover virtual connections between peering nodes with specific performance guarantees such as minimum throughput, maximum delay, or loss. Such requirements are addressed by the design, construction, and management of virtual connections, network infrastructures, and service platforms.

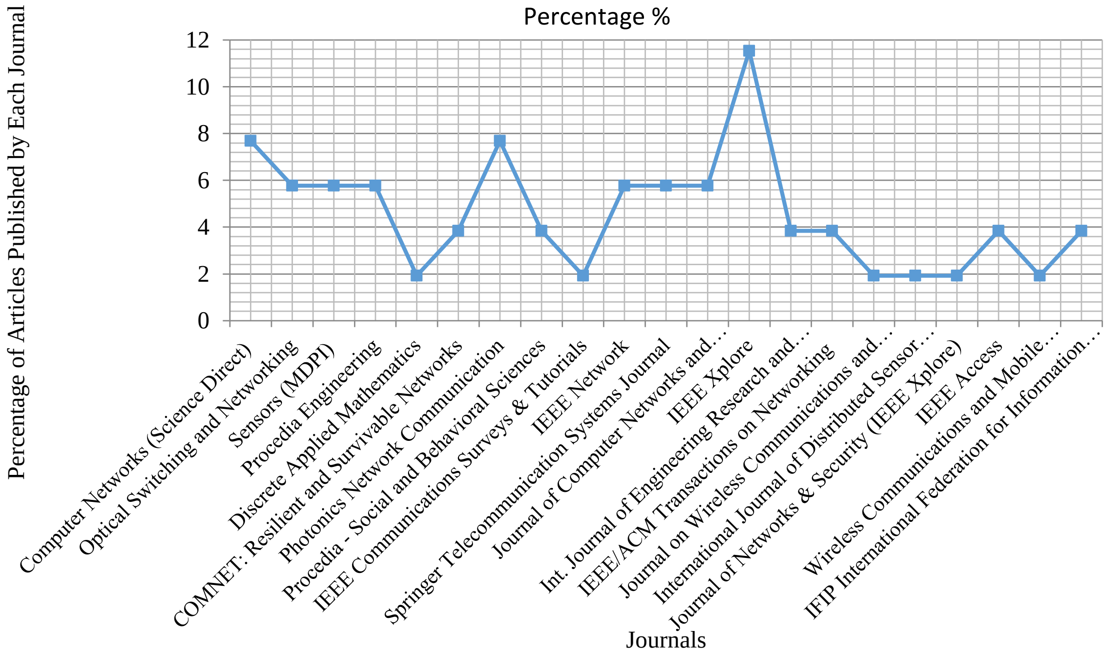

Figure 4: Pattern of Survivability Articles by Journals

4.3 Pattern of Publication by Method

The studies by James P.G. Sterbenz et. al., [11] show that survivability is modelled both qualitatively and quantitatively. Figure 5 depicts the model distribution used in the primary study. According to figure 5, 73% use quantitative modelling, 19% use qualitative modelling, and 8% use both methods. This demonstrates that quantitative modelling has established a solid theoretical foundation in terms of a mathematical model, whereas qualitative modelling still has room for improvement. The qualitative model entails studying network survivability using conclusion, deduction, and synthetically analysis methods based on the analyst's knowledge and experience. [45].

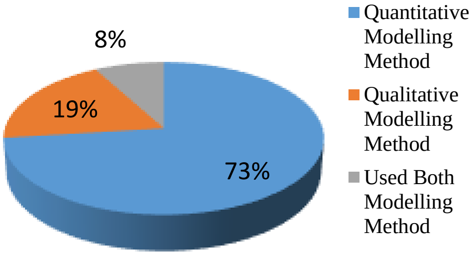

Figure 5 Telecommunication Networks Survivability Modelling Methods

Limitations and Future Scope of Research

From 2001 to 2019, this paper only examines empirical studies based on survey data and statistical methods of analysis. It may not have been possible to cover all existing articles in the field of telecommunications survivability completely. Nonetheless, the review process covered a large proportion of the available studies. It would be extremely difficult, if not impossible, to cover all existing articles in the field of telecommunications survivability. The paper once again focuses on analyzing the dimensions of telecommunications survivability models to determine the direction of research in this field.

• Future research should look into quality factors for novice and long-term customer cohorts so that the factors can be identified, resulting in an improvement in overall telecommunications quality.

• Future research should concentrate on developing service quality models for new services delivered via wireless network

technology (e.g. mobile education, mobile health services, mobile commerce, and mobile banking).
• More research on service quality assessment from the management perspective would aid in understanding and improving the concept and implementation of service quality.

6. Conclusions

Since telecom network survivability research is difficult to confine to a specific area, the important materials are dispersed across many journals. An in-depth literature survey was conducted to identify network survivability-related articles from the 36 selected journals that are relevant outlets for network survivability research. As a result, 191 accredited journal articles published between 2001 and 2019 were identified. This paper offers useful insights into the understanding of survivability learning structure, but it does not purport to be exhaustive.

The majority of the implications that have received little research attention consistently placed resilience at the top of the categories considered. These survivability models are one of the major pillars that support the trustworthiness of telecom networks. It is, however, difficult to find articles on computational techniques for evaluating telecom network survivability. Computational techniques, which are also a major pillar, are very useful in rating telecom network survivability.

This paper presents a review and learning structure for telecommunication network survivability models to reveal hidden topics, which are less investigated. The survey comprises 191 accredited journal articles that have been published between 2001 and 2019 in 36 selected journals, which are suitable sources for telecommunication network failure survivability topics. The results reveal hidden telecommunication network survivability topics, which have received lesser attention. The findings can hopefully be used as a learning reference guide to understanding telecommunication network survivability models, as well as a source for researchers interested in telecommunication network survivability research to stimulate their further interests.

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