

Classification of Anomalies in Telecommunication Network KPI Time Series

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Abstract—The increasing complexity and scale of telecommunication networks have led to a growing interest in automated anomaly detection systems. However, the classification of anomalies detected on network Key Performance Indicators (KPI) has received less attention, resulting in a lack of information about anomaly characteristics and classification processes. To address this gap, this paper proposes a modular anomaly classification framework. The framework assumes separate entities for the anomaly classifier and the detector, allowing for a distinct treatment of anomaly detection and classification tasks on time series. The objectives of this study are (1) to develop a time series simulator that generates synthetic time series resembling real-world network KPI behavior, (2) to build a detection model to identify anomalies in the time series, (3) to build classification models that accurately categorize detected anomalies into predefined classes (4) to evaluate the classification framework performance on simulated and real-world network KPI time series. This study has demonstrated the good performance of the anomaly classification models trained on simulated anomalies when applied to real-world network time series data.

I. INTRODUCTION

ANOMALY detection in network KPI time series has gained significant attention in recent years due to the increasing complexity and scale of the systems. Communication networks generate massive amounts of time series data capturing various activities and behaviors. The detection of anomalies in time series data is crucial in traffic analysis and performance monitoring or Key Performance Indicators (KPI). Compared to anomaly detection, classification of anomalies detected on network KPI has received relatively less attention in research, giving less information on the anomalies characteristics and classification processes. Exploiting classification techniques to identify and categorize anomalies within network KPI time series data remains an open area for exploration. Further research is needed to find new approaches and methodologies to accurately detect and classify anomalies, enhancing network KPI monitoring capabilities.

This article addresses the problem of effectively simulating anomalies on KPI and assessing anomaly classification models on both simulated and real-world time series datasets. In this paper, we separate the detector and classifiers as two parts within the anomaly classification framework. The detector identifies the anomalies in the time series while the classifiers categorize the time series into their corresponding classes or types. This separation allows for a modular approach between the detection and the classification.

This paper introduces an anomaly classification framework. This framework includes a network KPI time series simulator,

a detection model, classification models. The detection and classification models are evaluated on both simulated and real-world time series datasets. The simulator generates simulated time series with anomalies to mimic real-world network KPI systems. This simulator provides time series to train and test the detection and classification models. The detection model is built to identify the anomalies within the simulated and real-world time series. Additionally, we aim to build classification models to accurately classify the anomalies in their respective classes. Finally, we evaluate the performance and generalization capabilities of these classification models by testing them on both simulated datasets, generated by our time series simulator, and real datasets, obtained from network KPI.

The paper is organized as follows. Section II provides a comprehensive review of existing literature on network KPI anomaly definition, anomaly classification models, and evaluation methodologies. Section III presents our method for the anomaly classification framework, detailing the simulation, the detection and classification models. Finally, Section IV presents the experimental setup, including the datasets used and the performance of the models on both simulated and real-world time series datasets, followed by concluding remarks in Section V.

II. BACKGROUND

This background section aims to provide an overview of the key concepts, methodologies, and advancements in the field of network anomaly definition, simulation, detection, and classification.

Defining anomalies is the first step in the creation of a simulator and classification model. Network KPI anomalies encompasses a wide range of definitions and interpretations, reflecting the diverse nature of anomalies that can occur in network systems. Choi *et al.* [1] identified 3 major anomaly types in time series: point, contextual, and collective anomalies. Point anomalies refer to a data point or sequence that exhibits a sudden and significant deviation from the normal range. These anomalies are typically caused by sensor errors or abnormal system operations and are detected by comparing values against predefined upper and lower control limits. Contextual anomalies present a challenge for detection as they do not deviate from the normal range based on predefined limits. This type of anomaly is characterized by a group of points that do not contains extreme values and modify the

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Understanding Telecommunications Networks Andy Valdar, 2006-11-15 This book provides a broad introduction to all aspects of modern telecommunications networks covering the principles of operation of the technology and the way that networks using this technology are structured The main focus is on those technologies in use today and the next generation networks NGN and how they will be implemented *Optical Code Division Multiple Access Communication Networks* Hongxi Yin, David J. Richardson, 2009-03-15 Optical code division multiple access OCDMA communication network technology will play an important role in future optical networks such as optical access and metropolitan area networks OCDMA technology can also be applied to implement optical signal multiplexing and label switching on backbone networks Optical Code Division Multiple Access Communication Networks Theory and Applications introduces the code theory of OCDMA the methods and technologies of OCDMA encoding and decoding the theory and methods of analyzing OCDMA systems with various receiver models and realizing multiple class services with different bit rates and QoS In addition OCDMA network architectures protocols and applications are discussed in detail The up to date theoretical and experimental results on OCDMA systems and networks are also reported A large number of encoding decoding examples and many analysis and simulation results of code and system performances are given It is a valuable text and or reference book for postgraduates majoring in telecommunication and photonics to obtain a well knit theoretical foundation and for engineers in R D and management of optical communications Dr Yin is an Associate Professor of the School of Electronics Engineering and Computer Science at Peking University China and was a Visiting Research Fellow of Optoelectronics Research Centre ORC at University of Southampton UK Dr Richardson is a Professor for optical communications and Deputy Director of ORC at University of Southampton UK and is responsible for much of the ORC s fiber related activities **Wireless-Powered Communication Networks** Dusit Niyato, Ekram Hossain, Vijay Bhargava, Lotfollah Shafai, 2017 A comprehensive introduction to architecture design protocol optimization and application development **Space-time Array Communications** Jason Wee Peng Ng, 2007 Space time array communications have gained a great deal of interest in recent years Its superior performance in practical multipath propagation environments has established it as a core aspect in next generation mobile networks as well as several portable wireless communication systems In fact the employment of the sensor array component has already been provided for in the current UMTS standard and there is presently a major thrust to make space time processing an important part of 3G 4G networks This book hence attempts to bridge the knowledge gap looking at the integration of two emerging technologies from an array manifold perspective space time array processing and spread spectrum multiple access communications It covers a range of novel multiuser channel estimation and reception techniques which is designed to provide mitigations of the various associated channel impairments in accordance to its environmental context For convenience of the readers the book is written in a self contained modular format with its mathematical

frameworks and tools readily extendable to other research domains Software Agents for Future Communication Systems
Alex Hayzelden, John Bigham, 2012-12-06 Agent technology has recently become one of the most vibrant and fastest growing areas in information technology And advanced digital communication is a central enabling technology for the coming information society So software agents and their exploitation for future communication systems are attracting particular attention from the research and development community as well as from economic and user communities interested in everyday private and professional digital communication applications This monograph like anthology is the first systematic introduction to software agents and future communication systems Fifteen coherently written chapters by leading software agent researchers provide complementary coverage of the relevant issues Multi agent systems and mobile agent approaches are presented in a well balanced way and applied to most important topics in future communication systems In addition the volume editors have provided a detailed introductory survey chapters **5G Multimedia Communication** Zoran S. Bojkovic, Dragorad A. Milovanovic, Tulsi Pawan Fowdur, 2020-10-27 In bringing to the readers the book 5G Multimedia Communication Technology Multiservices and Deployment the aim is to present current work and direction on the challenging subject of multimedia communications with theoretical and practical roots The past two decades have witnessed an extremely fast evolution of mobile cellular network technology The fifth generation of mobile wireless systems has achieved the first milestone toward finalization and deployment by 2020 This is vital to the development of future multimedia communications Also it is necessary to consider 5G technology from the performance point of view by analyzing network capabilities to the operator and to the end user in terms of data rate capacity coverage energy efficiency connectivity and latency The book is divided into three major parts with each part containing four to seven chapters Critical enabling technology Multiservices network Deployment scenarios The first part discusses enabling technologies such as green communication channel modeling massive and distributed MIMO and ML based networks In the second part different methodologies and standards for multiservices have been discussed Exclusive chapters have been dedicated to each of the open research challenges such as multimedia operating in 5G environment network slicing optimization mobile edge computing mobile video multicast broadcast integrated satellite and drone communication The third part paved the way to deployment scenarios for different innovative services including integration of a multienergy system in smart cities intelligent transportation systems 5G connectivity in the transport sector healthcare services 5G edge based video surveillance and challenges of connectivity for massive IoT in 5G and beyond systems The book is written by experts in the field who introduced scientific and engineering concepts covering the 5G multimedia communication areas The book can be read cover to cover or selectively in the areas of interest for the readers Generally the book is intended for novel readers who could benefit from understanding general concepts practitioners who seek guidance into the field and senior level as well as graduate level engineering students in understanding the process of today s wireless multimedia communications

Molecular Communication Tadashi Nakano, Andrew W. Eckford, Tokuko Haraguchi, 2013-09-12 This comprehensive guide by pioneers in the field brings together for the first time everything a new researcher graduate student or industry practitioner needs to get started in molecular communication Written with accessibility in mind it requires little background knowledge and provides a detailed introduction to the relevant aspects of biology and information theory as well as coverage of practical systems The authors start by describing biological nanomachines the basics of biological molecular communication and the microorganisms that use it They then proceed to engineered molecular communication and the molecular communication paradigm with mathematical models of various types of molecular communication and a description of the information and communication theory of molecular communication Finally the practical aspects of designing molecular communication systems are presented including a review of the key applications Ideal for engineers and biologists looking to get up to speed on the current practice in this growing field

Optical WDM Networks Jun Zheng, Hussein T. Mouftah, 2004-08-04 The essential guide to the state of the art in WDM and its vast networking potential As a result of its huge transmission capacity and countless other advantages fiber optics has fostered a bandwidth revolution addressing the constantly growing demand for increased bandwidth Within this burgeoning area Wavelength Division Multiplexing WDM has emerged as a breakthrough technology for exploiting the capacity of optical fibers Today WDM is deployed by many network providers for point to point transmission but there is strong momentum to develop it as a full fledged networking technology in its own right The telecommunications industry network service providers and research communities worldwide are paying close attention Optical WDM Networks presents an easy to follow introduction to basic concepts key issues effective solutions and state of the art technologies for wavelength routed WDM networks Responding to the need for resources focused on the networking potential of WDM the book is organized in terms of the most important networking aspects such as Network control architecture Routing and wavelength assignment Virtual topology design and reconfiguration Distributed lightpath control and management Optical layer protection and restoration IP over WDM Trends for the future in optical networks Each chapter includes examples and problems that illustrate and offer practical application of concepts as well as extensive references for further reading This is an essential resource for professionals and students in electrical engineering computer engineering and computer science as well as network engineers designers planners operators and managers who seek a backbone of knowledge in optical networks

Information Technology Network and Internet C. T. Bhunia, 2005-12 This Book Is Specially Designed To Improve The Problem Solving Ability And The Imaginative Power Of Students Over The Subjects Of Information Technology Network And Internet The Conventional Text And Reference Books Ignore That Fact Young Minds Need To Be Properly Trained And Nurtured To Achieve Excellency In The Book Lots Of Research Issues Are Discussed Pertaining The Current Issues Of Networking The Book Covers General Topics Of Information Technology Including The Future Trends Of Computing And Networking Networks In General Starting With

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Wireless Communications Z. Ghassemlooy, W. Popoola, S. Rajbhandari, 2019-04-30 The 2nd Edition of Optical Wireless Communications System and Channel Modelling with MATLAB with additional new materials is a self contained volume that provides a concise and comprehensive coverage of the theory and technology of optical wireless communication systems OWC The delivery method makes the book appropriate for students studying at undergraduate and graduate levels as well as researchers and professional engineers working in the field of OWC The book gives a detailed description of OWC focusing mainly on the infrared and visible bands for indoor and outdoor applications A major attraction of the book is the inclusion of Matlab codes and simulations results as well as experimental test beds for free space optics and visible light communication systems This valuable resource will aid the readers in understanding the concept carrying out extensive analysis simulations implementation and evaluation of OWC links This 2nd edition is structured into nine compact chapters that cover the main aspects of OWC systems History current state of the art and challenges Fundamental principles Optical source and detector and noise sources Modulation equalization diversity techniques Channel models and system performance analysis Visible light communications Terrestrial free space optics communications Relay based free space optics communications Matlab codes A number of Matlab based simulation codes are included in this 2nd edition to assist the readers in mastering the subject and most importantly to encourage them to write their own simulation codes and enhance their knowledge

Driving 5G Mobile Communications with Artificial Intelligence towards 6G Dragorad A. Milovanovic, Zoran S. Bojkovic, Tulsi Pawan Fowdur, 2023-04-06 Driving 5G Mobile Communications with Artificial Intelligence towards 6G presents current work and directions of continuous innovation and development in multimedia communications with a focus on

services and users The fifth generation of mobile wireless networks achieved the first deployment by 2020 completed the first phase of evolution in 2022 and started transition phase of 5G Advanced toward the sixth generation Perhaps one of the most important innovations brought by 5G is the platform approach to connectivity i e a single standard that can adapt to the heterogeneous connectivity requirements of vastly different use cases 5G networks contain a list of different requirements standardized technical specifications and a range of implementation options with spectral efficiency latency and reliability as primary performance metrics Towards 6G machine learning ML and artificial intelligence AI methods have recently proposed new approaches to modeling designing optimizing and implementing systems They are now matured technologies that improve many research fields significantly The area of wireless multimedia communications has developed immensely generating a large number of concepts ideas technical specifications mobile standards patents and articles Identifying the basic ideas and their complex interconnections becomes increasingly important The book is divided into three major parts with each part containing four or five chapters Advanced 5G communication Machine learning based communication and network automation Artificial Intelligence towards 6G The first part discusses three main scenarios and standard specification of 5G use cases eMBB URLLC mMTC vehicular systems beyond 5G and efficient edge architecture on NFV infrastructure In the second part different AI ML based methodologies and open research challenges are presented in introducing 5G AIoT artificial intelligence of things scheduling in 5G 6G communication systems application of DL techniques to modulation detection and channel coding as well as 5G Open Source tools for experimentations and testing The third part paved the way to deployment scenarios for different innovative services including technologies and applications of 5G 6G intelligent connectivity AI assisted eXtended Reality integrated 5G IoT architecture in next generation Smart Grid privacy requirements in a hyper connected world and evaluation of representative 6G use cases and technology trends The book is written by field experts from Europe and Mauritius who introduce a blend of scientific and engineering concepts covering this emerging wireless communication era It is a very good reference book for telecom professionals engineers and practitioner in various 5G vertical domains and finally a basis for student courses in 5G 6G wireless systems Integrated Sensing and Communications Fan Liu,Christos Masouros,Yonina C. Eldar,2023-07-18 The coming generations of wireless network technologies will serve not only as a means of connecting physical and digital environments but also to set the foundation for an intelligent world in which all aspects are interconnected sensed and endowed with intelligence Beyond merely providing communication capabilities future networks will have the capacity to see and interpret the physical world This development compels us to re imagine the design of current communication infrastructures and terminals taking into account crucial aspects such as fundamental constraints and tradeoffs information extraction and processing technologies issues of public security and privacy as well as the emergence of numerous new applications This field of research is known as Integrated Sensing and Communications ISAC and it has ushered in a paradigm shift towards the omnipresence of radio

devices This book provides the first comprehensive introduction to the ISAC theoretical and practical framework Each chapter is authored by a group of world leading experts including over 10 IEEE Fellows Readers can expect to gain both a broad overview and detailed technical insights into the latest ISAC innovations *Ultra-Wideband Wireless Communications and Networks* Xuemin Shen,Mohsen Guizani,Robert Caiming Qiu,Tho Le-Ngoc,2007-01-11 Learn about Ultra wideband UWB transmission the most talked about application in wireless communications UWB wireless communication is a revolutionary technology for transmitting large amounts of digital data over a wide spectrum of frequency bands with very low power for a short distance This exciting new text covers the fundamental aspects of UWB wireless communications systems for short range communications It also focuses on more advanced information about networks and applications Chapters include Radio Propagation and Large Scale Variations Pulse Propagation and Channel Modelling MIMO Multiple Input Multiple Output RF Subsystems and Ad Hoc Networks Focuses on UWB wireless communications rather than UWB radar which has been covered before Provides long and short term academic and technological value Teaches readers the fundamentals challenges and up to date technical processes in this field *Full-Duplex Communications for Future Wireless Networks* Hirley Alves,Taneli Riihonen,Himal A. Suraweera,2020-04-21 This book focuses on the multidisciplinary state of the art of full duplex wireless communications and applications Moreover this book contributes with an overview of the fundamentals of full duplex communications and introduces the most recent advances in self interference cancellation from antenna design to digital domain Moreover the reader will discover analytical and empirical models to deal with residual self interference and to assess its effects in various scenarios and applications Therefore this is a highly informative and carefully presented book by the leading scientists in the area providing a comprehensive overview of full duplex technology from the perspective of various researchers and research groups worldwide This book is designed for researchers and professionals working in wireless communications and engineers willing to understand the challenges and solutions full duplex communication so to implement a full duplex system High-performance Communication Networks Jean Walrand,Pravin Pratap Varaiya,2000 Retaining the first edition s technology centred perspective this book gives readers a sound understanding of packed switched circuit switched and ATM networks and techniques for controlling them **Green Radio Communication Networks** Ekram Hossain,Vijay K. Bhargava,Gerhard P. Fettweis,2012-07-05 Presents state of the art research on green radio communications and networking technology to researchers and professionals working in wireless communication Papers on optical access networks ,1993 **Deep Learning and Its Applications for Vehicle Networks** Fei Hu,Iftikhar Rasheed,2023-05-12 Deep Learning DL is an effective approach for AI based vehicular networks and can deliver a powerful set of tools for such vehicular network dynamics In various domains of vehicular networks DL can be used for learning based channel estimation traffic flow prediction vehicle trajectory prediction location prediction based scheduling and routing intelligent network congestion control mechanism smart load balancing and vertical handoff control intelligent

network security strategies virtual smart and efficient resource allocation and intelligent distributed resource allocation methods This book is based on the work from world famous experts on the application of DL for vehicle networks It consists of the following five parts I DL for vehicle safety and security This part covers the use of DL algorithms for vehicle safety or security II DL for effective vehicle communications Vehicle networks consist of vehicle to vehicle and vehicle to roadside communications This part covers how Intelligent vehicle networks require a flexible selection of the best path across all vehicles adaptive sending rate control based on bandwidth availability and timely data downloads from a roadside base station III DL for vehicle control The myriad operations that require intelligent control for each individual vehicle are discussed in this part This also includes emission control which is based on the road traffic situation the charging pile load is predicted through DL and vehicle speed adjustments based on the camera captured image analysis IV DL for information management This part covers some intelligent information collection and understanding We can use DL for energy saving vehicle trajectory control based on the road traffic situation and given destination information we can also natural language processing based on DL algorithm for automatic internet of things IoT search during driving V Other applications This part introduces the use of DL models for other vehicle controls Autonomous vehicles are becoming more and more popular in society The DL and its variants will play greater roles in cognitive vehicle communications and control Other machine learning models such as deep reinforcement learning will also facilitate intelligent vehicle behavior understanding and adjustment This book will become a valuable reference to your understanding of this critical field

International Reference Guide to Space Launch Systems Steven J. Isakowitz, Joseph P. Hopkins, Joshua B. Hopkins, 1999 This best selling reference guide contains the most reliable and up to date material on launch programs in Brazil China Europe India Israel Japan Russia Ukraine and the United States Packed with illustrations and figures the third edition has been extensively updated and expanded and offers a quick and easy data retrieval source for policymakers planners engineers launch buyers and students

European Optical Communications and Networks: Papers on networks Conference on European Fibre Optic Communications and Networks (11, 1993, 's-Gravenhage), 1993

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