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Path Problems in Networks

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Path Problems In Networks George Theodorakopoulos

Randal Berry,Eytan Modiano,Murtaza Zafer

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Path Problems in Networks John Baras,George Theodorakopoulos,2022-06-01 The algebraic path problem is a generalization of the shortest path problem in graphs Various instances of this abstract problem have appeared in the literature and similar solutions have been independently discovered and rediscovered The repeated appearance of a problem is evidence of its relevance This book aims to help current and future researchers add this powerful tool to their arsenal so that they can easily identify and use it in their own work Path problems in networks can be conceptually divided into two parts A distillation of the extensive theory behind the algebraic path problem and an exposition of a broad range of applications First of all the shortest path problem is presented so as to fix terminology and concepts existence and uniqueness of solutions robustness to parameter changes and centralized and distributed computation algorithms Then these concepts are generalized to the algebraic context of semirings Methods for creating new semirings useful for modeling new problems are provided A large part of the book is then devoted to numerous applications of the algebraic path problem ranging from mobile network routing to BGP routing to social networks These applications show what kind of problems can be modeled as algebraic path problems they also serve as examples on how to go about modeling new problems This monograph will be useful to network researchers engineers and graduate students It can be used either as an introduction to the topic or as a quick reference to the theoretical facts algorithms and application examples The theoretical background assumed for the reader is that of a graduate or advanced undergraduate student in computer science or engineering Some familiarity with algebra and algorithms is helpful but not necessary Algebra in particular is used as a convenient and concise language to describe problems that are essentially combinatorial Table of Contents Classical Shortest Path The Algebraic Path Problem Properties and Computation of Solutions Applications Related Areas List of Semirings and Applications

Path Problems in Networks John S. Baras,George Theodorakopoulos,2009-10-15 The algebraic path problem is a generalization of the shortest path problem in graphs Various instances of this abstract problem have appeared in the literature and similar solutions have been independently discovered and rediscovered The repeated appearance of a problem is evidence of its relevance This book aims to help current and future researchers add this powerful tool to their arsenal so that they can easily identify and use it in their own work Path problems in networks can be conceptually divided into two parts A distillation of the extensive theory behind the algebraic path problem and an exposition of a broad range of applications First of all the shortest path problem is presented so as to fix terminology and concepts existence and uniqueness of solutions robustness to parameter changes and centralized and distributed computation algorithms Then these concepts are generalized to the algebraic context of semirings Methods for creating new semirings useful for modeling new problems are provided A large part of the book is then devoted to numerous applications of the algebraic path problem ranging from mobile network routing to BGP routing to social networks These applications show what kind of problems can

be modeled as algebraic path problems they also serve as examples on how to go about modeling new problems This monograph will be useful to network researchers engineers and graduate students It can be used either as an introduction to the topic or as a quick reference to the theoretical facts algorithms and application examples The theoretical background assumed for the reader is that of a graduate or advanced undergraduate student in computer science or engineering Some familiarity with algebra and algorithms is helpful but not necessary Algebra in particular is used as a convenient and concise language to describe problems that are essentially combinatorial Table of Contents Classical Shortest Path The Algebraic Path Problem Properties and Computation of Solutions Applications Related Areas List of Semirings and Applications

Scheduling and Congestion Control for Wireless and Processing Networks Libin Jiang,Jean Walrand,2022-06-01 In this book we consider the problem of achieving the maximum throughput and utility in a class of networks with resource sharing constraints This is a classical problem of great importance In the context of wireless networks we first propose a fully distributed scheduling algorithm that achieves the maximum throughput Inspired by CSMA Carrier Sense Multiple Access which is widely deployed in today s wireless networks our algorithm is simple asynchronous and easy to implement Second using a novel maximal entropy technique we combine the CSMA scheduling algorithm with congestion control to approach the maximum utility Also we further show that CSMA scheduling is a modular MAC layer algorithm that can work with other protocols in the transport layer and network layer Third for wireless networks where packet collisions are unavoidable we establish a general analytical model and extend the above algorithms to that case Stochastic Processing Networks SPNs model manufacturing communication and service systems In manufacturing networks for example tasks require parts and resources to produce other parts SPNs are more general than queueing networks and pose novel challenges to throughput optimum scheduling We proposes a deficit maximum weight DMW algorithm to achieve throughput optimality and maximize the net utility of the production in SPNs Table of Contents Introduction Overview Scheduling in Wireless Networks Utility Maximization in Wireless Networks Distributed CSMA Scheduling with Collisions Stochastic Processing networks

Performance Modeling of Communication Networks with Markov Chains Jeonghoon Mo,2022-05-31 This book is an introduction to Markov chain modeling with applications to communication networks It begins with a general introduction to performance modeling in Chapter 1 where we introduce different performance models We then introduce basic ideas of Markov chain modeling Markov property discrete time Markov chain DTMC and continuous time Markov chain CTMC We also discuss how to find the steady state distributions from these Markov chains and how they can be used to compute the system performance metric The solution methodologies include a balance equation technique limiting probability technique and the uniformization We try to minimize the theoretical aspects of the Markov chain so that the book is easily accessible to readers without deep mathematical backgrounds We then introduce how to develop a Markov chain model with simple applications a forwarding system a cellular system blocking slotted ALOHA Wi Fi model and multichannel based LAN model

The examples cover CTMC DTMC birth death process and non birth death process We then introduce more difficult examples in Chapter 4 which are related to wireless LAN networks the Bianchi model and Multi Channel MAC model with fixed duration These models are more advanced than those introduced in Chapter 3 because they require more advanced concepts such as renewal reward theorem and the queueing network model We introduce these concepts in the appendix as needed so that readers can follow them without difficulty We hope that this textbook will be helpful to students researchers and network practitioners who want to understand and use mathematical modeling techniques Table of Contents Performance Modeling Markov Chain Modeling Developing Markov Chain Performance Models Advanced Markov Chain Models

Network Connectivity Chen Chen,Hanghang Tong,2022-01-26 Networks naturally appear in many high impact domains ranging from social network analysis to disease dissemination studies to infrastructure system design Within network studies network connectivity plays an important role in a myriad of applications The diversity of application areas has spurred numerous connectivity measures each designed for some specific tasks Depending on the complexity of connectivity measures the computational cost of calculating the connectivity score can vary significantly Moreover the complexity of the connectivity would predominantly affect the hardness of connectivity optimization which is a fundamental problem for network connectivity studies This book presents a thorough study in network connectivity including its concepts computation and optimization Specifically a unified connectivity measure model will be introduced to unveil the commonality among existing connectivity measures For the connectivity computation aspect the authors introduce the connectivity tracking problems and present several effective connectivity inference frameworks under different network settings Taking the connectivity optimization perspective the book analyzes the problem theoretically and introduces an approximation framework to effectively optimize the network connectivity Lastly the book discusses the new research frontiers and directions to explore for network connectivity studies This book is an accessible introduction to the study of connectivity in complex networks It is essential reading for advanced undergraduates Ph D students as well as researchers and practitioners who are interested in graph mining data mining and machine learning Modeling and Optimization in Software-Defined Networks Konstantinos Poularakis,Leandros Tassiulas,T.V. Lakshman,2022-06-01 This book provides a quick reference and insights into modeling and optimization of software defined networks SDNs It covers various algorithms and approaches that have been developed for optimizations related to the control plane the considerable research related to data plane optimization and topics that have significant potential for research and advances to the state of the art in SDN Over the past ten years network programmability has transitioned from research concepts to more mainstream technology through the advent of technologies amenable to programmability such as service chaining virtual network functions and programmability of the data plane However the rapid development in SDN technologies has been the key driver behind its evolution The logically centralized abstraction of network states enabled by SDN facilitates programmability and use of sophisticated

optimization and control algorithms for enhancing network performance policy management and security Furthermore the centralized aggregation of network telemetry facilitates use of data driven machine learning based methods To fully unleash the power of this new SDN paradigm though various architectural design deployment and operations questions need to be addressed Associated with these are various modeling resource allocation and optimization opportunities The book covers these opportunities and associated challenges which represent a call to arms for the SDN community to develop new modeling and optimization methods that will complement or improve on the current norms *Sharing Network Resources* Abhey Parekh,Jean Walrand,2022-06-01 Resource Allocation lies at the heart of network control In the early days of the Internet the scarcest resource was bandwidth but as the network has evolved to become an essential utility in the lives of billions the nature of the resource allocation problem has changed This book attempts to describe the facets of resource allocation that are most relevant to modern networks It is targeted at graduate students and researchers who have an introductory background in networking and who desire to internalize core concepts before designing new protocols and applications We start from the fundamental question what problem does network resource allocation solve This leads us in Chapter 1 to examine what it means to satisfy a set of user applications that have different requirements of the network and to problems in Social Choice Theory We find that while capturing these preferences in terms of utility is clean and rigorous there are significant limitations to this choice Chapter 2 focuses on sharing divisible resources such as links and spectrum Both of these resources are somewhat atypical a link is most accurately modeled as a queue in our context but this leads to the analytical intractability of queueing theory and spectrum allocation methods involve dealing with interference a poorly understood phenomenon Chapters 3 and 4 are introductions to two allocation workhorses auctions and matching In these chapters we allow the users to game the system i e to be strategic but don t allow them to collude In Chapter 5 we relax this restriction and focus on collaboration Finally in Chapter 6 we discuss the theoretical yet fundamental issue of stability Here our contribution is mostly on making a mathematically abstruse subdiscipline more accessible without losing too much generality Wireless Network Pricing Jianwei Huang,Lin Gao,2022-06-01 Today s wireless communications and networking practices are tightly coupled with economic considerations to the extent that it is almost impossible to make a sound technology choice without understanding the corresponding economic implications This book aims at providing a foundational introduction on how microeconomics and pricing theory in particular can help us to understand and build better wireless networks The book can be used as lecture notes for a course in the field of network economics or a reference book for wireless engineers and applied economists to understand how pricing mechanisms influence the fast growing modern wireless industry This book first covers the basics of wireless communication technologies and microeconomics before going in depth about several pricing models and their wireless applications The pricing models include social optimal pricing monopoly pricing price differentiation oligopoly pricing and network externalities supported by introductory discussions of

convex optimization and game theory The wireless applications include wireless video streaming service provider competitions cellular usage based pricing network partial price differentiation wireless spectrum leasing distributed power control and cellular technology upgrade More information related to the book including references slides and videos can be found at ncel ie cuhk edu hk content wireless network pricing **A Primer on Physical-Layer Network Coding** Soung Chang Liew,Lu Lu,Shengli Zhang,2022-05-31 The concept of physical layer network coding PNC was proposed in 2006 for application in wireless networks Since then it has developed into a subfield of communications and networking with a wide following This book is a primer on PNC It is the outcome of a set of lecture notes for a course for beginning graduate students at The Chinese University of Hong Kong The target audience is expected to have some prior background knowledge in communication theory and wireless communications but not working knowledge at the research level Indeed a goal of this book course is to allow the reader to gain a deeper appreciation of the various nuances of wireless communications and networking by focusing on problems arising from the study of PNC Specifically we introduce the tools and techniques needed to solve problems in PNC and many of these tools and techniques are drawn from the more general disciplines of signal processing communications and networking PNC is used as a pivot to learn about the fundamentals of signal processing techniques and wireless communications in general We feel that such a problem centric approach will give the reader a more in depth understanding of these disciplines and allow him her to see first hand how the techniques of these disciplines can be applied to solve real research problems As a primer this book does not cover many advanced materials related to PNC PNC is an active research field and many new results will no doubt be forthcoming in the near future We believe that this book will provide a good contextual framework for the interpretation of these advanced results should the reader decide to probe further into the field of PNC **An Introduction to Models of Online Peer-to-Peer Social Networking** George Kesidis,2022-06-01 This book concerns peer to peer applications and mechanisms operating on the Internet particularly those that are not fully automated and involve significant human interaction So the realm of interest is the intersection of distributed systems and online social networking Generally simple models are described to clarify the ideas Beginning with short overviews of caching graph theory and game theory we cover the basic ideas of structured and unstructured search We then describe a simple framework for reputations and for iterated referrals and consensus This framework is applied to a problem of sybil identity management The fundamental result for iterated Byzantine consensus for a relatively important issue is also given Finally a straight forward epidemic model is used to describe the propagation of malware on line and for BitTorrent style file sharing This short book can be used as a preliminary orientation to this subject matter References are given for the interested student to papers with good survey and tutorial content and to those with more advanced treatments of specific topics For an instructor this book is suitable for a one semester seminar course Alternatively it could be the framework for a semester s worth of lectures where the instructor would supplement each chapter with additional lectures

on related or more advanced subject matter A basic background is required in the areas of computer networking probability theory stochastic processes and queueing Table of Contents Networking overview Graphs Games Search in structured networks Search in unstructured networks Transactions reputations and referrals False Referrals Peer to peer file sharing Consensus in dynamical belief systems Byzantine consensus Epidemics **Communication Networks** Jean Walrand,Shyam Parekh,2022-05-31 This book results from many years of teaching an upper division course on communication networks in the EECS department at the University of California Berkeley It is motivated by the perceived need for an easily accessible textbook that puts emphasis on the core concepts behind current and next generation networks After an overview of how today s Internet works and a discussion of the main principles behind its architecture we discuss the key ideas behind Ethernet WiFi networks routing internetworking and TCP To make the book as self contained as possible brief discussions of probability and Markov chain concepts are included in the appendices This is followed by a brief discussion of mathematical models that provide insight into the operations of network protocols Next the main ideas behind the new generation of wireless networks based on LTE and the notion of QoS are presented A concise discussion of the physical layer technologies underlying various networks is alsoincluded Finally a sampling of topics is presented that may have significant influence on the future evolution of networks including overlay networks like content delivery and peer to peer networks sensor networks distributed algorithms Byzantine agreement source compression SDN and NFV and Internet of Things *Analytical Methods for Network Congestion Control* Steven H. Low,2022-05-31 The congestion control mechanism has been responsible for maintaining stability as the Internet scaled up by many orders of magnitude in size speed traffic volume coverage and complexity over the last three decades In this book we develop a coherent theory of congestion control from the ground up to help understand and design these algorithms We model network traffic as fluids that flow from sources to destinations and model congestion control algorithms as feedback dynamical systems We show that the model is well defined We characterize its equilibrium points and prove their stability We will use several real protocols for illustration but the emphasis will be on various mathematical techniques for algorithm analysis Specifically we are interested in four questions 1 How are congestion control algorithms modelled 2 Are the models well defined 3 How are the equilibrium points of a congestion control model characterized 4 How are the stability of these equilibrium points analyzed For each topic we first present analytical tools from convex optimization to control and dynamical systems Lyapunov and Nyquist stability theorems and to projection and contraction theorems We then apply these basic tools to congestion control algorithms and rigorously prove their equilibrium and stability properties A notable feature of this book is the careful treatment of projected dynamics that introduces discontinuity in our differential equations Even though our development is carried out in the context of congestion control the set of system theoretic tools employed and the process of understanding a physical system building mathematical models and analyzing these models for insights have a much wider applicability than to congestion control Stochastic Network

Optimization with Application to Communication and Queueing Systems Michael Neely,2022-05-31 This text presents a modern theory of analysis control and optimization for dynamic networks Mathematical techniques of Lyapunov drift and Lyapunov optimization are developed and shown to enable constrained optimization of time averages in general stochastic systems The focus is on communication and queueing systems including wireless networks with time varying channels mobility and randomly arriving traffic A simple drift plus penalty framework is used to optimize time averages such as throughput throughput utility power and distortion Explicit performance delay tradeoffs are provided to illustrate the cost of approaching optimality This theory is also applicable to problems in operations research and economics where energy efficient and profit maximizing decisions must be made without knowing the future Topics in the text include the following Queue stability theory Backpressure max weight and virtual queue methods Primal dual methods for non convex stochastic utility maximization Universal scheduling theory for arbitrary sample paths Approximate and randomized scheduling theory Optimization of renewal systems and Markov decision systems Detailed examples and numerous problem set questions are provided to reinforce the main concepts Table of Contents Introduction Introduction to Queues Dynamic Scheduling Example Optimizing Time Averages Optimizing Functions of Time Averages Approximate Scheduling Optimization of Renewal Systems Conclusions Performance Modeling, Stochastic Networks, and Statistical Multiplexing, Second Edition Ravi R. Mazumdar,2022-05-31 This monograph presents a concise mathematical approach for modeling and analyzing the performance of communication networks with the aim of introducing an appropriate mathematical framework for modeling and analysis as well as understanding the phenomenon of statistical multiplexing The models techniques and results presented form the core of traffic engineering methods used to design control and allocate resources in communication networks The novelty of the monograph is the fresh approach and insights provided by a sample path methodology for queueing models that highlights the important ideas of Palm distributions associated with traffic models and their role in computing performance measures The monograph also covers stochastic network theory including Markovian networks Recent results on network utility optimization and connections to stochastic insensitivity are discussed Also presented are ideas of large buffer and many sources asymptotics that play an important role in understanding statistical multiplexing In particular the important concept of effective bandwidths as mappings from queueing level phenomena to loss network models is clearly presented along with a detailed discussion of accurate approximations for large networks

Energy-Efficient Scheduling under Delay Constraints for Wireless Networks Randal Berry,Eytan Modiano,Murtaza Zafer,2022-05-31 Packet delay and energy consumption are important considerations in wireless and sensor networks as these metrics directly affect the quality of service of the application and the resource consumption of the network especially for a rapidly growing class of real time applications that impose strict restrictions on packet delays Dynamic rate control is a novel technique for adapting the transmission rate of wireless devices almost in real time to

opportunistically exploit time varying channel conditions as well as changing traffic patterns Since power consumption is not a linear function of the rate and varies significantly with the channel conditions adapting the rate has significant benefits in minimizing energy consumption These benefits have prompted significant research in developing algorithms for achieving optimal rate adaptation while satisfying quality of service requirements In this book we provide a comprehensive study of dynamic rate control for energy minimization under packet delay constraints We present several formulations and approaches adopted in the literature ranging from discrete time formulations and dynamic programming based solutions to continuous time approaches utilizing ideas from network calculus and stochastic optimal control theory The goal of this book is to expose the reader to the important problem of wireless data transmission with delay constraints and to the rich set of tools developed in recent years to address it Table of Contents Introduction Transmission Rate Adaptation under Deadline Constraints Average Delay Constraints **Diffusion Source Localization in Large Networks** Lei Ying,Kai Zhu,2022-05-31 Diffusion processes in large networks have been used to model many real world phenomena including how rumors spread on the Internet epidemics among human beings emotional contagion through social networks and even gene regulatory processes Fundamental estimation principles and efficient algorithms for locating diffusion sources can answer a wide range of important questions such as identifying the source of a widely spread rumor on online social networks This book provides an overview of recent progress on source localization in large networks focusing on theoretical principles and fundamental limits The book covers both discrete time diffusion models and continuous time diffusion models For discrete time diffusion models the book focuses on the Jordan infection center for continuous time diffusion models it focuses on the rumor center Most theoretical results on source localization are based on these two types of estimators or their variants This book also includes algorithms that leverage partial time information for source localization and a brief discussion of interesting unresolved problems in this area **Network Games** Asu Ozdaglar,Ishai Menache,2022-05-31 Traditional network optimization focuses on a single control objective in a network populated by obedient users and limited dispersion of information However most of today s networks are large scale with lack of access to centralized information consist of users with diverse requirements and are subject to dynamic changes These factors naturally motivate a new distributed control paradigm where the network infrastructure is kept simple and the network control functions are delegated to individual agents which make their decisions independently selfishly The interaction of multiple independent decision makers necessitates the use of game theory including economic notions related to markets and incentives This monograph studies game theoretic models of resource allocation among selfish agents in networks The first part of the monograph introduces fundamental game theoretic topics Emphasis is given to the analysis of dynamics in game theoretic situations which is crucial for design and control of networked systems The second part of the monograph applies the game theoretic tools for the analysis of resource allocation in communication networks We set up a general model of routing in wireline networks

emphasizing the congestion problems caused by delay and packet loss In particular we develop a systematic approach to characterizing the inefficiencies of network equilibria and highlight the effect of autonomous service providers on network performance We then turn to examining distributed power control in wireless networks We show that the resulting Nash equilibria can be efficient if the degree of freedom given to end users is properly designed Table of Contents Static Games and Solution Concepts Game Theory Dynamics Wireline Network Games Wireless Network Games Future Perspectives

Advances in Multi-Channel Resource Allocation Bo Ji,Xiaojun Lin,Ness B. Shroff,2022-05-31 The last decade has seen an unprecedented growth in the demand for wireless services These services are fueled by applications that often require not only high data rates but also very low latency to function as desired However as wireless networks grow and support increasingly large numbers of users these control algorithms must also incur only low complexity in order to be implemented in practice Therefore there is a pressing need to develop wireless control algorithms that can achieve both high throughput and low delay but with low complexity operations While these three performance metrics i e throughput delay and complexity are widely acknowledged as being among the most important for modern wireless networks existing approaches often have had to sacrifice a subset of them in order to optimize the others leading to wireless resource allocation algorithms that either suffer poor performance or are difficult to implement In contrast the recent results presented in this book demonstrate that by cleverly taking advantage of multiple physical or virtual channels one can develop new low complexity algorithms that attain both provably high throughput and provably low delay The book covers both the intra cell and network wide settings In each case after the pitfalls of existing approaches are examined new systematic methodologies are provided to develop algorithms that perform provably well in all three dimensions **Edge Intelligence in the Making** Sen Lin,Zhi Zhou,Zhaofeng Zhang,Xu Chen,Junshan Zhang,2022-06-01 With the explosive growth of mobile computing and Internet of Things IoT applications as exemplified by AR VR smart city and video audio surveillance billions of mobile and IoT devices are being connected to the Internet generating zillions of bytes of data at the network edge Driven by this trend there is an urgent need to push the frontiers of artificial intelligence AI to the network edge to fully unleash the potential of IoT big data Indeed the marriage of edge computing and AI has resulted in innovative solutions namely edge intelligence or edge AI Nevertheless research and practice on this emerging inter disciplinary field is still in its infancy stage To facilitate the dissemination of the recent advances in edge intelligence in both academia and industry this book conducts a comprehensive and detailed survey of the recent research efforts and also showcases the authors own research progress on edge intelligence Specifically the book first reviews the background and present motivation for AI running at the network edge Next it provides an overview of the overarching architectures frameworks and emerging key technologies for deep learning models toward training inference at the network edge To illustrate the research problems for edge intelligence the book also showcases four of the authors own research projects on edge intelligence ranging from rigorous theoretical analysis to

studies based on realistic implementation Finally it discusses the applications marketplace and future research opportunities of edge intelligence This emerging interdisciplinary field offers many open problems and yet also tremendous opportunities and this book only touches the tip of iceberg Hopefully this book will elicit escalating attention stimulate fruitful discussions and open new directions on edge intelligence Poisson Line Cox Process Harpreet S. Dhillon,Vishnu Vardhan Chetlur,2022-06-01 This book provides a comprehensive treatment of the Poisson line Cox process PLCP and its applications to vehicular networks The PLCP is constructed by placing points on each line of a Poisson line process PLP as per an independent Poisson point process PPP For vehicular applications one can imagine the layout of the road network as a PLP and the vehicles on the roads as the points of the PLCP First a brief historical account of the evolution of the theory of PLP is provided to familiarize readers with the seminal contributions in this area In order to provide a self contained treatment of this topic the construction and key fundamental properties of both PLP and PLCP are discussed in detail The rest of the book is devoted to the applications of these models to a variety of wireless networks including vehicular communication networks and localization networks Specifically modeling the locations of vehicular nodes and roadside units RSUs using PLCP the signal to interference plus noise ratio SINR based coverage analysis is presented for both ad hoc and cellular network models For a similar setting the load on the cellular macro base stations MBSs and RSUs in a vehicular network is also characterized analytically For the localization networks PLP is used to model blockages which is shown to facilitate the characterization of asymptotic blind spot probability in a localization application Finally the path distance characteristics for a special case of PLCP are analyzed which can be leveraged to answer critical questions in the areas of transportation networks and urban planning The book is concluded with concrete suggestions on future directions of research Based largely on the original research of the authors this is the first book that specifically focuses on the self contained mathematical treatment of the PLCP The ideal audience of this book is graduate students as well as researchers in academia and industry who are familiar with probability theory have some exposure to point processes and are interested in the field of stochastic geometry and vehicular networks Given the diverse backgrounds of the potential readers the focus has been on providing an accessible and pedagogical treatment of this topic by consciously avoiding the measure theoretic details without compromising mathematical rigor

Decoding **Path Problems In Networks George Theodorakopoulos**: Revealing the Captivating Potential of Verbal Expression

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Table of Contents Path Problems In Networks George Theodorakopoulos

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