Software defined Network Inference with Passive/active Evolutionary-optimal pRobing (SNIPER)

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ABSTRACT

A key requirement for network management is accurate and reliable network monitoring where critical information about internal characteristics or states of the network(s) must be obtained. In today's large-scale networks, this is a challenging task due to the hard constraints of network measurement resources. In this paper, a new framework (called SNIPER) is proposed where we use the flexibility provided by Software-Defined Networking (SDN) to design the optimal observation or measurement matrix which leads to the best achievable estimation accuracy using Matrix Completion (MC) techniques. Here, to cope with the inherent complexity of the process of designing large-scale optimal observation matrices, we use the well known Evolutionary Optimization Algorithms (EOA) which directly target the ultimate estimation accuracy as the optimization objective function. We evaluate the performance of SNIPER using both synthetic and real network measurement traces from different network topologies and by considering two main applications including network traffic and delay estimations. Our results show that this framework is generic and efficient that can be used for a variety of network performance measurements under hard constraints of network measurement resources. Also, to demonstrate the feasibility of our framework, we have also implemented a prototype of SNIPER in Mininet environment.

1. INTRODUCTION

In computer networks, network management refers to the activities, methods, procedures, and tools that pertain to the operation, administration, maintenance, provisioning and security of networked systems [1]. A key requirement for network management is accurate and reliable network monitoring where critical information about internal characteristics or states of the network(s) must be directly measured or indirectly inferred. In addition, accurate network monitoring is essential for network management in order to reach QoS agreements.

In today's complex networks, the direct measurement of network's Internal Attributes of Interest (IAI) can be challenging or even inefficient and infeasible due to the hard constraints of network measurement resources including the limited number of Ternary Content Addressable Memory (TCAM) entries at switches, the limited processing power and storage capacity and limited available bandwidth in active network performance measurement.

Network Inference (NI) techniques are powerful network monitoring tools that can help estimate the IAI based on a limited set of measurements and, accordingly, mitigate the limitations and constraints of direct network measurement techniques. NI techniques are usually formulated as under-determined inverse problems which are naturally ill-posed problems, that is, the number of measurements are not sufficient to uniquely and accurately determine the solution. Hence, side information from different perspectives and sources must be incorporated into the problem formulation to improve the estimation precision [2] [3] [4].

Recently, Matrix Completion (MC) techniques have been used as network inference tools where the problem is the completion of a matrix of IAI from the direct measurement of a sub-set of its entries [5][6][7]. The main assumption in MC techniques is that the matrix of IAI is a low-rank matrix which contains redundancies and thus not all of its entries are needed to represent it. In the theory of matrix completion, the matrix of IAI can be completely reconstructed from a sub-set of observed entries (i.e. measurements) if the number of *randomly* chosen observations are *high* enough [8][9]. Accordingly, in [5] and [6] the MC methods are used for network Traffic Matrix (TM) completion to estimate the missed entries of the TMs. Also, in [7], a new MC technique has been used for active network performance measurements where the status of path delays or available bandwidths are predicted from a set of active measurements and using a new MC technique. Since in communication networks a variety of resources of the communication infrastructure at different layers are shared, the MC methods rely on the fact that the matrices of IAI in network monitoring applications contain spatio-temporal redundancies (i.e. correlations or structures) that can be used to estimate missed or non-observed entries from a sub-set of randomly measured entries.

Software-Defined Networking (SDN), along with its OpenFlow enabler, is an emerging technology that nicely separates the measurement data plane and control plane functions, and provides a capability to control/re-program the internal configurations of switches in dynamic environments. Consequently, SDN allows to adaptively and efficiently implement more complex network monitoring applications, including both passive and active network measurements, without the need of customization [7] [10] [11] [12]. For passive network measurement, the most SDN based works related to traffic engineering and network security applications where the main goal is focused on network traffic measurement or identifying aspects of the network traffic such the presence of Heavy Hitters (HH) and Hierarchical Heavy Hitters (HHH). In [11], the authors propose a reconfigurable measurement architecture for hierarchical heavy hitter detection, and then in [12], they propose a re-programmable structure (called OpenSketch) where a variety of sketches for different measurement tasks can be defined and installed by the operator. In [13], OpenTM estimates a traffic matrix by keeping track of statistics for each flow. Recently, in [10], we have proposed an intelligent SDN based traffic measurement framework (called iSTAMP) with the ability of adaptive and accurate fine-grained flow estimation. In addition, for active network measurement under SDN paradigm, the very recent work [14] establishes a general framework where accurate measurements of flow throughput, packet loss and delay can be obtained.

Accordingly, in network monitoring applications, the flexibility provided by the SDN can be used to intelligently and adaptively measure the entries of the matrix of IAI. Hence, an interesting question that can be asked is as follows:

Under hard resource constraints of network measurement resources, how can we optimally measure or sample the entries of the matrix of IAI and design the optimal observation matrix which leads to the best possible estimation accuracy via using matrix completion techniques?

However, the *direct* design of observation matrices for maximizing the performance of NI methods is prohibitive due to the complexity of the process [10][15]. To simplify the process of designing the optimal observation matrix other objective functions (e.g. coherency [15] or condition number [3]) are considered in the optimization process, while accepting the unavoidable sacrifice in performance [15]. The underlying difficulty in this direct optimal observation matrix design is that formulating the network inference process or algorithm into a closed-form and well-defined mathematical objective function that can be efficiently optimized is extremely complicated and computationally complex, if it is not impossible or intractable.

Therefore, in this paper, we change the main approach in designing the optimal observation matrix for network inference problems where we *directly* target the ultimate estimation accuracy in network monitoring applications in our optimization framework. However, to cope with the inherent complexity of the process of designing large-scale optimal observation matrices, we use the well known Evolutionary Optimization Algorithms (EOA) that are suitable for the optimization problems where the main objective function is a procedure or an algorithm that can not be formulated as a well-defined mathematical function. In this framework, under the very hard constraints of measurement resources in network monitoring applications, the evolutionary optimization algorithm acts as a SNIPER which precisely captures or measures the best entries of the matrix of IAI which leads to best estimation accuracy via matrix completion techniques.

Under hard resource constraints of network measurement resources, SNIPER is simple, generic, and efficient with the ability to optimally measure the most informative IAI which lead to the best achievable estimation accuracy via matrix completion methods. In fact, SNIPER can be easily deployed on commodity OpenFlow-enabled routers/switches to enhance the performance of various passive or active network monitoring applications with low computation and communication overhead between control and data planes. Here, we build upon the recent achievements in the theory of matrix completion to develop a practical foundation for guiding the design of optimal measurement or observation matrices under hard resource constraints of network measurement resources.

Our main contributions are summarized as follow:

- To the best of our knowledge for the first time, we use the EOAs to design the optimal observation matrix where ultimate network inference performance is the main objective function to be optimized.
- We evaluate the performance of SNIPER using both synthetic and real network measurement traces from different network topologies by considering two main applications including network traffic and delay estimation. Furthermore, we implement a prototype of SNIPER and demonstrate its feasibility and effectiveness in Mininet environment.

The rest of this paper is organized as follows.

2. REFERENCES

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