Guest Editorial Deep Packet Inspection: Algorithms, Hardware, and Applications

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DEEP packet inspection (DPI) examines the content in packet payloads to search for signatures of network applications, signs of malicious activities, and leaks of sensitive information, rather than just examine packet headers for information such as IP addresses and port numbers. The inspection provides network devices with rich information of application protocol messages in packet payloads, and enables them to make intelligent decisions in packet processing based on the information. Therefore, the network devices equipped with the capability of DPI can provide numerous functions, such as network intrusion detection, traffic classification and content-aware policy control of network traffic, which will be otherwise much restricted if only packet headers are known.

DPI is inherently challenging due to the need to handle ever-increasing number of signatures and the diversity of application protocol messages. The signatures to be inspected must be also flexible and robust enough to resist possible evasion when facing the adversary of network attacks. Furthermore, the solutions usually should operate in real time in a high-speed network, while dealing with the above complexity. As a result, we believe that DPI still deserves careful study in depth, even though it has been studied for longer than a decade [1] and simultaneously searching a byte stream for thousands of patterns or even more at multi-giga bits per second is feasible in many state-of-the-art designs.

We received a total of 39 submissions, and selected 13 quality papers for publication after two rounds of reviews. The papers are organized into the following four sections: (1) Scalable Algorithms and Architectures for DPI, (2) Network Traffic Analysis with DPI, (3) Network Protocol Identification with DPI, and (4) Network Security Analysis with DPI.

It is essential that the algorithms for DPI should be scalable to accommodate a large number of signatures in limited memory space, and the architectures should be also scalable to operate in a high-speed network. The first section covers five papers to address the scalability issue.

Reading multiple bytes per memory access can potentially achieve high speed in DPI, but is also likely to suffer from the memory explosion problem. The paper "Kangaroo: Accelerating String Matching by Running Multiple Collaborative Finite State Machines" by Xiaofei Wang, Bin Liu, Junchen Jiang, Yang Xu, Yi Wang, and Xiaojun Wang presents a matching scheme that splits the original rule set into multiple sub-rule sets and partitions the input stream with a window of fixed size. The scheme scans multiple bytes in parallel using a compact state machine, while keeping the memory usage down at the same magnitude as a conventional single-byte scheme.

The size of deterministic finite automata (DFA) is usually exponential in the number of regular expressions (RegExes). The paper "Towards Fast and Optimal Grouping of Regular Expressions via DFA Size Estimation" by Tingwen Liu, Alex X. Liu, Jinqiao Shi, Yong Sun, and Li Guo presents an algorithm to estimate the DFA size for a given RegEx set without constructing the DFA, and a grouping algorithm which is much faster and memory efficient than conventional DFA construction.

The paper "TFA: A Tunable Finite Automaton for Pattern Matching in Network Intrusion Detection Systems" by Yang Xu, Junchen Jiang, Rihua Wei, Yang Song, and H. Jonathan Chao introduce an automaton representation of regular expressions to resolve the problems of state explosion and unpredictable performance in deterministic and non-deterministic finite automata (i.e., DFA and NFA) representation. This representation allows a limited number of concurrent active states, and the required memory space is significantly reduced.

The paper "Revisiting State Blow-up: Automatically Building Augmented-FA while Preserving Functional Equivalence" by Xiaodong Yu, Bill Lin and Michela Becchi is also intended to avoid state explosion in conventional DFA construction. The proposed method features several advantages, such as limited worst-case processing time and coverage of arbitrary regular expressions.

Deploying DPI systems in an ISP backbone network is challenging because of the high data rate. The paper "A Scalable Carrier-Grade DPI System Architecture using Synchronization of Flow Information" by NamUk Kim, GanHo Choi, and JaeHyeong Choi introduces a highly scalable DPI architecture based on the concepts of flow information synchronization and

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adaptive traffic control. The system is manufactured to operate at 40 Gbps with four 10 Gbps DPI modules.

Network analysis with DPI usually requires various underlying supports to isolate low-level functions from application developers. The second section covers two papers which present the frameworks for flow tracking, packet reassembly and application protocol parsing. Existing network traffic capture frameworks provide applications with raw packets and do not deal with complex operations such as flow tracking and TCP stream reassembly. The paper "Stream-Oriented Network Traffic Capture and Analysis for High-Speed Networks" by Antonis Papadogiannakis, Michalis Polychronakis and Evangelos P. Markatos presents the stream capture library, called scap, which can deliver flow-level statistics and reassembled streams to user applications. This design will facilitate obtaining application protocol messages for developers.

Application protocol parsing and field extraction is essential to understand the semantics of packet payloads, and is also an indispensable part in network traffic analysis. The paper "High-Speed Application Protocol Parsing and Extraction for Deep Flow Inspection" by Alex X. Liu, Chad Meiners, Eric Norige and Eric Torng presents an automated online method based on two models: counting regular grammars and counting automata. The models have the ability to facilitate parsing and extracting fields from context sensitive application protocols.

Traffic classification or network protocol identification is an essential part for content-aware network management. The third section covers three papers about protocol identification. Fine-grained traffic identification tells not only what network application generates a certain packet, but also what application function or user behavior generate the packet. The paper "MP-ROOM: Optimal Matching On Multiple PDUs for Fine-Grained Traffic Identification" by Hao Li and Chengchen Hu presents a method to split the identification rules into fields in a matching order, and construct a hierarchical layered matching tree, which reduces the space complexity and increases throughput for matching over multiple packet payloads.

The paper "Toward Unsupervised Protocol Feature Word Extraction" by Zhuo Zhang, Zhibin Zhang, Patrick P. C. Lee, Yunjie Liu, and Gaogang Xie designs an unsupervised method to systematically and efficiently extract protocol feature words. The feature words can be used to distinguish application protocols and are building blocks of payload analysis.

The paper "Efficient Methods for Early Protocol Identification" by Béla Hullár, Sándor Laki, and András Gyärgy presents a protocol identification method which inspects only the first few bytes of the first (or first few) packet(s) of each flow. The piece of information is analyzed by machine-learning-based methods with very low computational complexity, and high early classification accuracy is demonstrated on traffic traces from a diverse set of applications.

Network security analysis is traditionally an important application of DPI. The fourth section covers three papers in this respect. The paper "A Reconfigurable Platform and Programming Tools for High-Level Network Applications demonstrated as a Hardware Honeypot" by Sascha Mühlbach and Andreas Koch presents the NetStage platform, which allows rapid deployment of FPGA-accelerated attack-resilient interactive communication applications. This platform does not have software-programmable processors, and the FPGA configuration port is completely isolated from network traffic. The authors demonstrated the usage of the platform with a hardware honeypot.

It is important to detect infected hosts from the overwhelming alerts of intrusion detection systems. The paper "IDS Alert Correlation in the Wild with EDGe" by Elias Raftopoulos and Xenofontas Dimitropoulos presents an information theoretic measure to identify statistically significant temporal associations between the alerts, and detects infected hosts that exhibit recurring multi-stage behavior.

A fast-flux service network is widely adopted by attackers to hide hosts behind flux bots. The paper "Detect Fast-Flux Domains through Response Time Differences" by Fu-Hau Hsu, Chuan-Sheng Wang, Chi-Hsien Hsu, Chang-Kuo Tso, Li-Han Chen, and Song-Hui Lin presents a lightweight fast-flux domain detector based on fluctuation of the response time of a sequence of DNS requests with low false positive and false negative rates.

We would like to thank all the authors, who contribute their excellent work to this special issue, and the reviewers for their invaluable review comments. We also appreciate Prof. Muriel Medard, the Editor-in-Chief, Prof. Alberto Leon-Garcia, Laurel Greenridge, and Lauren Briede for their assistance during the entire process of the special issue, as well as the support from the other members in the JSAC Editorial Board. Finally, we thank the Editorial Staff at IEEE for the efforts in the production of the issue.

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