Chapter 9
Hybrid Intelligence for Smarter Networking Operations

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ABSTRACT

The ever-growing and ever-evolved Internet targets supporting billions of networked entities to provide a wide variety of services and resources. Such complexity results in network-data from different sources with special characteristics, such as widely diverse users, multiple media, high-dimensionality and various dynamic concerns. With huge amounts of network-data with such characteristics, there are significant challenges to a) recognize emergent and anomalous behavior in network-traffic and b) make intelligent decisions for efficient network operations. Endowing the semantically-oblivious Internet with Intelligence would advance the Internet capability to learn traffic behavior and to predict future events. In this chapter, the authors discuss and evaluate the hybridization of monolithic intelligence techniques in order to achieve smarter and enhanced networking operations. Additionally, the authors provide systematic application-agnostic semantics management methodology with efficient processes for extracting and classifying high-level features and reasoning about rich semantics.

1. INTRODUCTION

Due to semantically-oblivious networking operations, the current Internet cannot effectively or efficiently cope with the explosion in services with different requirements, number of users, resource heterogeneity, and widely varied user, application and system dynamics (Feldmann, 2007). This leads to increasing complexity in Internet management and operations, thus multiplying challenges to achieve better security, performance and Quality of Service (QoS) satisfaction. The current Internet largely lacks capabilities to extract network-semantics to efficiently build behavioral models of Internet elements at different levels of granularity and to pervasively observe and inspect network dynamics. For example, a network host might know the role of TCP; however, it might not know the behavior of TCP in a mobile *ad hoc* network.

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We refer to the limited utilization of Internet traffic semantics in networking operations as the Internet semantic gap. Additionally, many evolutionary cross-layer networking enhancements and clean-slate architectures, see for example (Bouabene et al., 2010; Day, Matta, & Mattar, 2008; Hassan, Eltoweissy, & Youssef, 2009; Zafeiropoulos, Liakopoulos, Davy, & Chaparadza, 2010), did not consider capabilities for representing, managing, and utilizing the inherent multi-dimensional networking data patterns. Also, these architectures lack facilities to learn network-semantics and utilize them to dynamically allocate and predict "right-sized" services/resources on demand for example.

The current and future internetworks (for example, Internet of things (IoT) (Khan, Khan, Zaheer, & Khan, 2012; Zhiming, Qi, & Hong, 2011)) support a massive number of Internet elements with extensive amounts of data. Fortunately, these data generally exhibit multi-dimensional patterns (for example, patterns with dimensions such as time, space, and users) that can be learned in order to extract network-semantics (Srivastava, Cooley, Deshpande, & Tan, 2000). These semantics can help in learning normal and anomalous behavior of the different networking elements (for example, services, protocols, etc.) in the Internet, and in building behavior models for those elements accordingly. Recognizing and maintaining semantics as accessible concepts and behavior models related to various Internet elements will aid in possessing intelligence thus helping elements in predicting future events (for example, QoS degradation and attacks) that might occur and affect performance of networking operations. Furthermore, learning behavior of those elements will better support self-* properties such as awareness with unfamiliar services and also advance reasoning about their behavior. For instance, a router can classify a new running service in a network as a specific type of TCP-based file transfer service when it finds similarity between behavior of the new service and that of an already known service.

The lack of efficient methodology and capabilities for analyzing and learning patterns of high- and multi-dimensional big network-data and reasoning about network-semantics presents challenges including but not limited to the following:

- Recognizing emergent and abnormal behavior of various Internet elements;
- Making effective decisions for efficient network operations;
- Ensuring availability of resources on-demand; and
- Efficient utilization of networked entities' capabilities to store, access and process data and extract valuable network-semantics.

Many research works targeted intelligence-based solutions to enhance operation performance in different fields (e.g., networks, speech and image recognition). Those works present solutions either using monolithic or hybrid intelligence techniques for achieving intelligence in different areas, such as speech recognition, language modeling and networking. In this chapter, we discuss the hybridization of monolithic intelligence techniques in order to achieve smarter and enhanced operations, especially in the networking field. Endowing the semantically-oblivious Internet with Intelligence would advance the Internet capability to learn traffic behavior and to predict future events. Additionally, we present our proposed network-semantics reasoner which is designed via hybridizing hidden Markov models (HMM) and latent Dirichlet allocation (LDA) for enabling latent features extraction with semantics dependencies.

In literature, some works have targeted intelligence-based solutions to enhance operation performance in different fields (e.g., speech and image recognition). In (Willett & Rigoll, 1998), authors integrated HMM and Neural Networks (NN) to form a hybrid speech recognition system. They employed NN to extract discriminative speech features by processing multiple instances of the same feature vector.