Automatic protocol reverse-engineering: Message format extraction and field semantics inference

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A B S T R A C T

Understanding the command-and-control (C&C) protocol used by a botnet is crucial for anticipating its repertoire of nefarious activity. However, the C&C protocols of botnets, similar to many other application layer protocols, are undocumented. Automatic protocol reverse-engineering techniques enable understanding undocumented protocols and are important for many security applications, including the analysis and defense against botnets. For example, they enable active botnet infiltration, where a security analyst rewrites messages sent and received by a bot in order to contain malicious activity and to provide the botmaster with an illusion of successful and unhampered operation.

In this work, we propose a novel approach to automatic protocol reverse engineering based on dynamic program binary analysis. Compared to previous work that examines the network traffic, we leverage the availability of a program that implements the protocol. Our approach extracts more accurate and complete protocol information and enables the analysis of encrypted protocols. Our automatic protocol reverse-engineering techniques extract the message format and field semantics of protocol messages sent and received by an application that implements an unknown protocol specification. We implement our techniques into a tool called Dispatcher and use it to analyze the previously undocumented C&C protocol of MegaD, a spam botnet that at its peak produced one third of the spam on the Internet.

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1. Introduction

Protocol reverse-engineering techniques extract the specification of unknown or undocumented network protocols and file formats. Protocol reverse-engineering techniques are needed because many protocols and file formats, especially at the application layer, are closed (i.e., have no publicly available specification). For example, malware often uses undocumented network protocols such as the command-and-control (C&C) protocols used by botnets to synchronize their actions and report back on the nefarious activities. Commercial off-the-shelf applications also use a myriad of undocumented protocols and file formats. Closed network protocols include Skype’s protocol [1]; protocols used by instant messaging clients such as AOL’s ICQ [2], Yahoo!’s Messenger [3], and Microsoft’s MSN Messenger [4]; and update protocols used by antivirus tools and browsers. Closed file formats include the DWG format used by Autodesk’s AutoCAD software [5] and the PSD format used by Adobe’s Photoshop software [6].

A detailed protocol specification can enable or enhance many security applications. For example, in this work we enable active botnet infiltration by extracting the specification of the C&C protocol used by the MegaD spam botnet and use it for deep packet inspection and rewriting of the C&C communication. Protocol specifications are also the input for generic protocol parsers used in network
monitoring [7,8] and can be used to build protocol-aware fuzzers that explore deeper execution paths than random fuzzers can [9], as well as to generate accurate fingerprints required by fingerprinting tools that remotely distinguish among implementations of the same specification [10].

Currently, protocol reverse-engineering is mostly a time-consuming and error-prone manual task. Protocol reverse-engineering projects such as the ones targeting the MSN Messenger and SMB protocols from Microsoft [11,12],1 the Yahoo! Messenger protocol [14], or the OSCAR and ICQ protocols from AOL [15,16], have all been long term efforts lasting years. In addition, protocol reverse-engineering is not a once-and-done effort, since existing protocols are often extended to support new functionality. Thus, to successfully reverse engineer a protocol in a timely manner and keep up the effort through time, automatic protocol reverse-engineering techniques are needed.

Previous work on automatic protocol reverse-engineering proposes techniques that take as input network data [17–19]. Those techniques face the issue of limited protocol information available in network traces and cannot address encrypted protocols. To address those limitations, we present a new approach for automatic protocol reverse-engineering, which leverages the availability of a program that implements the protocol. Our approach uses dynamic program binary analysis techniques and is based on the intuition that monitoring the execution of a program that implements the protocol reveals a wealth of information about the protocol. Polyglot extracts the protocol grammar [23–25] and the protocol state-machine [26]. The works that focus on protocol grammar extraction use the approach we introduced in Polyglot of monitoring the execution of a program that implements the protocol. Their techniques target two issues: (1) they consider the message format to be hierarchical [23–25], rather than flat as considered in Polyglot and (2) they extend the problem scope from extracting the message format as done in Polyglot, to extracting the protocol grammar by combining information from multiple messages [23,25]. In Dispatcher we still focus only on message format extraction because it is a pre-requisite for both protocol grammar and state-machine extraction, but we consider the hierarchical structure of the protocol messages. In this work, we present a unified view of the techniques introduced in Polyglot and Dispatcher that considers the hierarchical structure of protocol messages. We also unify the protocol nomenclature used across the different protocol reverse-engineering works.

2. Overview and problem definition

In this section we introduce automatic protocol reverse-engineering and its goals, describe the scope of the problem we address, introduce common protocol elements and terminology, formally define the problem, and provide an overview of our approach.

2.1. Automatic protocol reverse-engineering

The goal of automatic protocol reverse-engineering is given an undocumented protocol or file format to extract

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1 Microsoft has since publicly released the specification of both protocols as part of their Open Specification initiative [13].
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