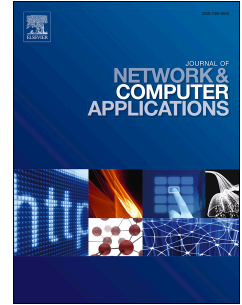


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Saad Saleh, Junaid Qadir, Muhammad U. Ilyas



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Shedding Light on the Dark Corners of the Internet: A Survey of Tor Research

Saad Saleh^{a,*}, Junaid Qadir^b, Muhammad U. Ilyas^{a,c}

^a*School of Electrical Engineering and Computer Science (SEECS),
National University of Sciences and Technology (NUST), Islamabad-44000, Pakistan*

^b*Information Technology University, Lahore, Pakistan*

^c*Department of Computer Science, Faculty of Computing and Information Technology,
University of Jeddah, Jeddah, Mecca Province 21589, Saudi Arabia*

Abstract

Anonymity services have seen high growth rates with increased usage in the past few years. Among various services, Tor is one of the most popular peer-to-peer anonymizing service. In this survey paper, we summarize, analyze, classify and quantify 26 years of research on the Tor network. Our research shows that ‘security’ and ‘anonymity’ are the most frequent keywords associated with Tor research studies. Quantitative analysis shows that the majority of research studies on Tor focus on ‘deanonymization’ the design of a breaching strategy. The second most frequent topic is analysis of path selection algorithms to select more resilient paths. Analysis shows that the majority of experimental studies derived their results by deploying private testbeds while others performed simulations by developing custom simulators. No consistent parameters have been used for Tor performance analysis. The majority of authors performed throughput and latency analysis.

Keywords: Tor; Security; Anonymity; Survey; Analysis; Deanonymization; Breaching; Path selection; Performance analysis.

1. Introduction

The Internet has revolutionized the world by transforming it into a global entity. Widespread advantages of Internet have spawned new industries and services. However, this connectivity comes at the cost of privacy. Every Internet client has a unique identity in the form of an Internet protocol (IP) address which can be translated to its location by the local Internet service provider (ISP). This lack of privacy has serious implications, particularly for journalists, freedom fighters and ordinary citizens.

Lack of privacy has led to the use of anonymous communication networks (ACN). ACNs hide client IP addresses through various techniques. There are a number of ACNs including Tor, Java anonymous proxy (JAP), Hotspot Shield and UltraSurf etc. Among various ACNs, Tor is the one of the most popular network, owing to its distributed nature which makes it difficult to connect the two end points of a session. Recently, Tor has been used for bomb hoax at Harvard [1]. Similarly, it has been used by the Russians to bypass online censorship [2]. A number of attempts are being made by FBI and other organizations to breach Tor network [3][4][5].

In this paper, we survey various studies conducted on the Tor network covering the scope of these studies. We quantify the studies into three broad but distinct groups, including (1) deanonymization, (2) path selection, (3) analysis and performance improvements, and several sub-categories. To the authors’ best knowledge, this is the most comprehensive attempt at analyzing Tor network research with a focus over its anonymity mechanism. Table 1 presents a comparison of this survey with previous surveys covering the scope of researches and implementation (experiments), verification (simulations) and analysis of various research works. Categorization of first column is made by listing all Tor areas considered in our study. AlSabah and Goldberg [6] presented the most comprehensive study covering complete Tor network and our paper is complementary to their survey paper. However, our paper pays more focus to the anonymity and breaching aspects of Tor than their paper. Their research paper presents only twenty references related to anonymity while we present more than 120¹ references.

Analysis of keywords used in various studies shows that anonymity, security and privacy have been used the most. Our study shows that majority of the research works have been made in the field of “deanonymization”

*Corresponding author

Email addresses: saad.saleh@seecs.edu.pk (Saad Saleh), junaid.qadir@itu.edu.pk (Junaid Qadir), usman.ilyas@seecs.edu.pk, milyas@uj.edu.sa, usman@ieee.org (Muhammad U. Ilyas)

¹This paper has 146 references, some of the references are to tools rather than research works; in all, we are considering a research corpus of 120 references.

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