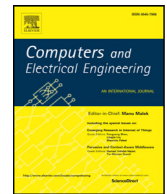




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journal homepage: www.elsevier.com/locate/compelecengSystematic literature review on the state of the art and future research work in anonymous communications systems[☆]Mehran Alidoost Nia^a, A. Ruiz-Martínez^{b,*}^aSchool of Electrical and Computer Engineering, University of Tehran, Tehran, Iran^bDepartment of Information and Communications Engineering, Faculty of Computer Science, Campus of Espinardo, Murcia, 30100, SPAIN

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ABSTRACT

Privacy is an important research topic due to its implications in society. Among the topics covered by privacy, we can highlight how to establish anonymous communications. During the latest years we have seen an important research in this field. In order to know what the state of the art in the research in anonymous communication systems (ACS) is, we have developed a systematic literature review (SLR). Namely, our SLR analyzes several issues: activity performed in the field, major research purposes, findings, what the most ACS study, the limitations of current research, how is leading the research in this field and the most highly-cited articles. Our SLR provides an analysis on 203 papers found in conferences and journals focused on anonymous communications systems between 2011 and 2016. Thus, our SLR provides an updated view on the status of the research in the field and the different future topics to be addressed.

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1. Introduction

Progressively, citizens perform more activities on the Internet such as surfing on the Web, establishing Voice over IP communications, sending and receiving instant messages (e.g. through WhatsApp Messenger), which facilitates that different entities such as Internet Service Providers, websites, advertisers, and governments can obtain more information on their activities and can create users' profiles [1–6] or surveillance them.

At the same time, in order to prevent this gathering of information as well as personally identifiable information (PII) can be obtained and managed without users' consent, both technical solutions and regulations (mainly in Europe) are being developed to protect our privacy and anonymity [7–12].

There are different technologies to protect privacy on the Internet, named Privacy Enhancing Technologies (PETs) [13], from these technologies, we can point out anonymous communication systems (ACS).

This kind of systems are fundamental to preserve freedom of speech and avoid censorship [2,14,15]. Indeed, they are the cornerstone to define and develop different kind of systems that need to preserve privacy and anonymity such as electronic voting system, anonymous payment systems, anonymous Voice Over IP (VoIP) communications based on SIP [16–18], and electronic auctions [5,11,19].

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ACS aim is to protect communications between entities from traffic analysis by providing unidentifiability and unlinkability [20]. Depending on the system, sender identity, receiver identity or sender and receiver identity will be preserved. A formal definition of these concepts can be found in [14,21].

For this purpose, these ACS define different architectures, types of networks (wired, wireless or hybrid), algorithms to establish a path between the sender and the receiver (establishing the length of the path and selecting the nodes), and cryptographic techniques.

In a general way, ACS can be classified into high-latency systems and low-latency systems [14,22,23] depending on whether it is important or not the delay in the communication.

High-latency systems (e.g. Mixminion or Mixmaster) are suitable for non-interactive applications and often provide stronger anonymity than low-latency systems (e.g. Tor, I2P or Crowds), which aim to support real-time communications such as web browsing or instant messaging. In order to deanonymize them there are two general kinds of attacks [22]: application based attacks (try to obtain user's IP by means of applications that do not consider privacy) and network level attacks (trying exploiting ACS limitations or trade off made in its design).

Due to the importance of ACS, a significant research work is being made in the latest years on the existing ACS, its features, possible improvements, its attacks and possible countermeasures as well as the proposal of new systems considering different approaches or scenarios.

In this paper we aim to provide an analysis of the state of the art in ACS and open challenges. Namely, we have managed to focus on any research work which its main goal is to provide an application for new trends of anonymous systems. Any researcher who wants to start a research work in this area should know about recent trends and current research directions in ACS.

To perform the review of the state of the art we have made a systematic literature review (SLR). This SLR responds to the growing body of knowledge in accordance with various categorization of studies such as new problems, novel applications, future issues, and security analysis of the current ACSs. To the best of our knowledge this is the first SLR that is developed in the field of anonymous communication systems.

We have tried our best to review recent studies in two main directions. The first direction is research works which their goal is related to new applications for ACSs. The second one is new applications or new versions of current applications that some security and performance issues have been solved. A lot of quality and quantity factors are included in this SLR. We have classified research papers by their types (either journal or conference paper), number of citations, number of references, year of publication, their main goal, researchers countries, type of ACS, and etc.

We have analysed the most cited papers, distribution of researchers by countries, current trends and studies, future directions, limitations of the proposals, and the source of publications.

This literature review attempts to sum up recent publications from popular academic databases like IEEE Xplore, Scopus, and ACM Digital Library. We discovered some useful information from these papers that is very applicable for young researchers or beginners in the research field who are going to work on the related subjects. This paper systematically reviews the papers and extract their strong features. Also, some research questions are answered during this work and hot topics are explored.

It must be taken into account that the selection process of the papers is systematically organized by the predefined criteria and it does not depend on our personal view.

The rest of this paper is organized as follows. Section 2 is a background section that presents previous research made in anonymous communications systems and introduces SLR. Section 3 presents the different research questions that our SLR aims to answer. Next, in Section 4 we present how we have developed the SLR. Section 5 presents the results of the SLR we have conducted. Based on the results obtained, we made a discussion on Section 6. Finally, Section 7 presents the main conclusions of our work and introduces future work.

2. Background

This background section provides a literature review on previous surveys on ACS, present systematic literature reviews and point out the main feature about this SLR.

To the best of our knowledge, this is the first SLR on anonymous communication systems. Although there are no previous SLR, in this section, we comment the main surveys on ACS that have been performed so far. We also present SLR and point out its main advantages in comparison to the other surveys.

2.1. Previous surveys on ACS

Recent surveys focusing on ACS are organized according to two popular approaches. The first approach is to select the main topic, collect all the related papers via undefined academic databases, summarize issues and trends, and compare original researches together. The output of such papers will be presented as tables/graphics with quality measurements. They may discuss on the issues and give some recommendations on how to continue the work for future researches. We have classified three review papers with this manner in the current SLR.

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