Privacy and Anonymity

Adrian Yanes
Aalto University - School of Electrical Engineering
Department of Communications and Networking (ComNet)
Challenged Networks S-38.3455 P
adrian.yanes@aalto.fi

Abstract—Since the beginning of the digital area, privacy and anonymity have been impacted drastically (both, positively and negatively), by the different technologies developed for communications purposes. The broad possibilities that the Internet offers since its conception, makes it a mandatory target for those entities that are aiming to know and control the different channels of communication and the information that flows through. In this paper, we address the current threats against privacy and anonymity on the Internet, together with the methods applied against them. In addition, we enumerate the publicly known entities behind those threats and their motivations. Finally, we analyze the state of the art concerning the protection of the privacy and anonymity on the Internet; introducing future lines of research.

I. INTRODUCTION

Despite the familiarity of the concepts, privacy and anonymity are commonly misunderstood within the digital context. In this paper, we refer to these concepts as foundations of the Common Criteria for Information Technology Security Evaluation (CC) standard [13]. Therefore, we strictly refer to the implications of these concepts within the technological jargon, with a deep emphasis on the Internet. We make the following contributions:

1) We provide a precise definition of the research terms, privacy and anonymity, and their implications.
2) We analyze the main threats against privacy and anonymity and their originators.
3) We share a resume of the state of art in terms of the protection of the privacy and anonymity on the Internet.

The remainder of the paper is organized as follows. In Section 2 we analyse the main threats against privacy and anonymity and their originators. In Section 3, we show the current methodologies applied to gain control over the privacy and anonymity of the users. We enumerate the current technologies available to protect privacy and anonymity on the Internet in Section 4. In Section 5 we introduce the proposed improvements over the state of the art. We present our conclusions in Section 6.

A. Privacy

In the past few decades there have been several debates about the precise definition of privacy. The Universal Declaration of Human Rights [12] in both article 12 and 19, references the concept as a human right:

Article 12: No one shall be subjected to arbitrary interference with his privacy, family, home or correspondence, nor to attacks upon his honour and reputation [...]  
Article 19: Everyone has the right to freedom of opinion and expression: this right includes freedom to hold opinions without interference and to seek, receive and impart information and ideas through any media and regardless of frontiers.

Other authors refer to privacy as “the claim of individuals, groups, or institutions to determine for themselves when, how, and to what extent information about them is communicated to others.”[25]

According with the CC standard [13], privacy involves “user protection against discovery and misuse of identity by other users”. In addition, the CC standard [13] defines the following requirements in order to guarantee privacy:

- Anonymity
- Pseudonymity
- Unlinkability
- Unobservability

Thus, we consider the definition of privacy as a framework of requirements that prevents the discovery and identity of the user.

B. Anonymity

As stated before, anonymity is intrinsically present in the concept of privacy. Nevertheless, anonymity refers exclusively to the matters related to the identity. The CC standard [13] defines “[anonymity] ensures that a user may use a resource or service without disclosing the users identity. The requirements for anonymity provide protection of the user identity. Anonymity is not intended to protect the subject identity. [...] Anonymity requires that other users or subjects are unable to determine the identity of a user bound to a subject or operation.”[13][21]

Accordingly, we consider the definition of anonymity as the property that guarantees user’s identity from being disclosed without consent.

C. Other concepts involved in privacy & anonymity

1) Pseudonymity: Notwithstanding, the use of anonymity techniques can protect the user from revealing their real identity. Most of the time there is a technological requirement necessary to interact with an entity, thus, such entity requires to have some kind of identity. The CC [13] claims [pseudonymity] ensures that a user may use a resource or
service without disclosing its user identity, but can still be accountable for that use.

2) Unlinkability: In order to guarantee a protection of the user’s identity, there is a need for unlinkability of the user’s activities within a particular context. This involves the lack of information to distinguish if the activities performed by the user are related or not.

3) Unobservability: The CC standard [13] refers to this concept as “[unobservability], requires that users and/or subjects cannot determine whether an operation is being performed.”. Other authors claim that unobservability should be differentiated from the undetectability [21]. The reasoning behind this, claims that something can be unobservable, but can still be detected. In this paper we refer to unobservability as the property that guarantees the impossibility to distinguish if something exists or not.

II. BACKGROUND

Historically, the control of the communications and the flow of information, are mandatory for any entity that aims to gain certain control over the society. There are multiple entities with such interests: governments, companies, independent individuals, etc. Most of the research available on the topic claims that the main originators of the threats against privacy and anonymity are governmental institutions and big corporations [16]. The motivations behind these threats are varied. Nevertheless, they can be classified under four categories: social, political, technological and economical. Despite the relation between them, the four categories have different backgrounds.

A. Social & political motivations

The core of human interaction is communication in any form. The Internet has deeply impacted in how social interaction is conducted these days. The popularity and facilities that the Internet offers, makes it a fundamental asset for the society. Currently, it is estimated that there are more than 2.7 billion individuals users of the Internet in the world [24].

![Fig. 1: 460 Million IPv4 addresses on world map (2012)](image)

Any entity that gains any level of control over this massive exchange of information, implicitly obtains two main advantages: the capability to observe the social interaction without being noticed (hence, being able to act with certain prediction), and the possibility to influence it. Privacy and anonymity are the core values against these actions. Nevertheless, several authoritarian regimes implemented diverse mechanisms for the dismissal of both, privacy and anonymity.

Many of the authors highlight that the foundations of these threats are most often motivated for ideological reasons [16], thus, in countries in which free of speech or political freedom are limited, privacy and anonymity are considered an enemy of the state. In addition, national defense and social “morality” are also some of the main arguments utilized when justifying actions against privacy and anonymity [8].

According to the OpenNet Initiative [11], there are at least 61 countries that have implemented some kind of mechanism that negatively affects privacy and anonymity. Examples of these countries are well-known worldwide: China [26], Iran [2], North Korea and Syria, among others. In addition, recent media revelations [4] shown that several mechanisms that are negatively affecting privacy and anonymity have been implemented in regions such as the U.S. and Europe.

B. Technological issues

There are some cases in which the threats against privacy and anonymity occur due to the lack of proper technology. Sometimes these threats can occur unintentionally. An example of this are bugs in software that are not discovered and somehow reveal information about the identity or data of the users. Also, misconfigured Internet services that do not use proper encryption and identity mechanisms when offering interaction with their users. Certain techniques utilized by the ISPs can lead to situations in which the user’s data and identity gets compromised even if the ISPs’ intentions are focused on bandwidth optimization. Finally, non-technological educated users can be a threat to themselves by unaware leaking their identity and data voluntarily but unaware of the repercussions (e.g. usage of social networks, forums, chats, etc).

C. Economical motivations

As stated previously, the impact and penetration of the Internet in modern society affects almost every aspect of it, with a primary use of it for commercial/industrial purposes. There are multiple economical interests that are related directly to the privacy and anonymity of the users. Several companies with Internet presence take advantage of user’s identity in order to build more successful products or to target a more receptive audience. Lately, the commercialization of user’s data has proven to be a profitable business for those entities that have the capability of collecting more information about user’s behavior. In addition, due to the popularity of Internet for banking purposes, the privacy and anonymity of the users are a common target for malicious attackers seeking to gain control over user’s economical assets.

1Global surveillance programs: PRISM(UK), Tempora(NSA), Muscular (NSA)
III. MECHANISMS USED TO INTERFERE PRIVACY AND ANONYMITY

In the past few decades, a big technological and economical investment has been made by some entities seeking to gain some control over the privacy and anonymity on the Internet. Nevertheless, there are not too many commercial technologies developed with this particular purpose [16]; forcing the development of custom solutions adapted to the particular use case/target. Depending of the originator, the technology utilized can have different types of targets, the most common being nodes and individual users on the Internet. The categorization of the technology falls in two areas: hardware and software solutions. The devices utilized for these targets are commonly denominated Deep Packet Inspection (DPI) devices. Their main use is the classification of the network traffic, together with the inspection of packet headers and payloads. Note that most of these devices are not manufactured to directly target the privacy and anonymity of the users. Instead, they have a generalist purpose (commonly associated to routing and QoS purposes). Nevertheless, these devices can be configured in ways that the privacy and anonymity get affected.

We will analyze the different threats using the OSI model [7] as reference, highlighting the most common compromises on terms of privacy and anonymity across the different layers.

A. Physical Layer

Any possible threat on the physical layer implies direct access to the hardware involved in the network. Most common artifacts utilized are known as network taps: devices that provide access to the data flow of the network once they are attached to it. These devices can be used either to monitor the network silently (sniffing) or to redirect the full traffic of the network to a different node. Implicitly, any observation of the network traffic involves the possibility of affecting the privacy and anonymity of the traffic.

B. Data link layer

Most of the hardware solutions targeting the data link layer focus on the media access control (MAC) sublayer. It is in the MAC sublayer that certain filters can be implemented. The addressing of the destinations occurs in this layer, which are unique. This is the first control point for those entities that are aiming to obtain some information concerning user’s identity, data flows and destinations. Note, the property of uniqueness of the MAC address and the current standard [2] allows the categorization of the devices present in the network. This can lead to a premature identification of the user (by manufacturer/model).

C. Network layer

Due to the nature of the Internet protocol suite, and the use of Internet Protocol (IP) as its core; the network layer plays a crucial role while interfering with the privacy and anonymity of the network traffic. Most of the DPI hardware focused on the network layer targets the inspection of the IP packets. The IP packets contain all of the relevant information required for routing purposes. Therefore, it is a mandatory target when aiming to reveal the identities of the users. The analysis is performed mainly on the IP header; more specifically, on the source address, destination address and protocol type. This data can be utilized with different malicious purposes; the analysis and processing of IP headers can lead to the direct identification of the user involved in the communication.

![IPv4 header fields commonly targeted (red)](image)

Furthermore, statistical analysis can be performed to determine the population of users even if they are using encrypted protocols over the IP [6]. Finally, the identification of the protocol utilized, provides enough information to perform further analysis of the data that the IP packet is transporting. This makes the network layer a critical asset for inspecting the network traffic. It is in this layer where some of the entities previously mentioned implement heavy traffic analysis and/or filtering.

D. Transport layer

The Transport Control Protocol (TCP) is the most popular protocol on the transport layer on the Internet protocol suite. There is an agreed assumption that TCP remains to be the main transport protocol on the Internet, thus it is the most targeted when interfering with the privacy and anonymity of the users. A TCP header contains (among other data) the source port and destination port. This information makes it possible to identify (in most cases) what type of application is being used over TCP; therefore allowing it to determine the kind of inspection required to capture the data transmitted in the TCP segment.

Despite, the fact that some applications can use TCP ports out of range of well-known ports, most of the Internet traffic is based on protocols such as HTTP, SMTP, POP3, IMAP, etc; for which TCP ports and protocol states are easily recognized while using DPI techniques/solutions. Therefore, this facilitates the task of targeting a particular network traffic and its processing for further analysis. The biggest concerns, in terms of privacy and anonymity, is that the current technology allows inspection of every single TCP segment and its
content. Despite encryption gaining in popularity, in both the implementation of application protocols and as user practice, most of the Internet traffic is still unencrypted. Hence, any traffic analysis that is performed over the transport layer on unencrypted data reveals the content of the transmission, thus, eliminating any kind of privacy.

In addition, due to TCP’s architecture, the inspection realized over the data flows is granular and accurate, mainly due to the possibility to identify sources and destinations, together with the content of the payload. There is still a possibility in which the transport layer gets compromised but not the identity of the source and destination. Nevertheless, an observer can gather enough information to conclude over time, the final identity of the parties involved, in the case that the payload contains sensitive data about their identity.

E. Application Layer

The DPI solutions utilized over the application layer are varied, and sometimes protocol specific [16]. DPI techniques/technologies focused on the application layer provide the possibility to capture and recompose the data of the transmission. This generates high-risk threats of the privacy and anonymity of the users exposing the data of a particular application that the user is using. Examples include the indiscriminate analysis of the web traffic that some entities are performing [16]; resulting in the compilation of user profiles, type of content visiting, frequency, location, etc. The possibility to cross-reference the analysis of different application protocols utilized for the same user; building user profiles that contain all kinds of personal and behavioral information that gets stored and categorized without the user’s consent.

Due to the fact that it is in this layer where the data gets originated, other techniques get in place that can affect the privacy and anonymity. Other popular protocols such as those dedicated to e-mail, are common targets due to the sensibility of information that they usually transmit. In this case, the threats against privacy and anonymity does not necessarily happen in the transmission, but in the software itself. Certain entities have implemented control mechanisms over the software utilized to handle e-mail, such as desktop clients and webmails.

Several applications make heavy use of encryption techniques in order to secure the communication on the layers below. Nevertheless, there is a possibility that the methods utilized by the application protocol to encrypt the communication are being compromised even before the transmission begins. Examples of this include possible backdoors recently claimed [23] on some of the cryptographically secure pseudo-random number generators (CSPRNG) utilized to generate encryption keys. If this is the case, certain entities could decrypt traffic that is thought to be secure by the users, leading again to an attack of their privacy and anonymity, even when the users think they are using proper mechanisms to protect themselves. These recent events open several questions about how reliable a protocol can be if the cryptographic assumptions utilized are somewhat misleading.

IV. MECHANISM TO ENFORCE BETTER PRIVACY AND ANONYMITY

In the previous section we enumerate the different technologies utilized in order to establish certain controls over the privacy and anonymity of the users. As it is common when any mechanism of oppression is enforced, several alternatives are created in order to avoid those mechanisms. Privacy and anonymity have been a big concern since the beginning of the Internet. In addition to those entities that are aiming to establish the above mentioned controls, there are also several companies, organizations and individuals, that are spending time and resources developing mechanisms of defense against the mentioned threats.

We introduce the state of art concerning the enforcement of privacy and anonymity on the Internet.

A. Technological principles behind the privacy and anonymity

The majority of the techniques utilized to guarantee privacy are related to a combination of encryption and anonymity techniques. The vast majority of anonymity techniques rely on protecting the real identity through a combination of methods that are difficult to trace the origin and destination of the communication channel. Despite the complexity that encryption mechanisms can involve, most of the modern and popular application protocols provide the possibility to establish the connection through secure channels; either through the use of the Transport Secure Layer (TLS), or through the configuration of proxies or socket secure (SOCKS) mechanisms.

There are certain methods to measure the grade of privacy and anonymity. The degree of privacy is mostly linked to the type of encryption utilized and computational capacity available. Different encryption algorithms are currently available, offering certain guarantees for the users. Several protocols in the application layer rely on these algorithms as the core of privacy enforcement. Some examples of this is the use of public-key cryptography [14] and the use of algorithms such as RSA [14] and DSA [20]. In addition, and due to recent media revelations, some applications are moving to new cryptography schemes based on the use of elliptic curve cryptography such as Elliptic Curve Diffie-Hellman (ECDH), Integrated Encryption Scheme (IES) or Elliptic Curve Digital Signature Algorithm (ECDSA). The main argument behind the use of new cryptography schemes, is the suspected evidences concerning the pseudo-random number generators utilized for them, and the possibility of broken cryptography [23]. Furthermore, the possibility to encapsulate the connections through a SOCKS interface allows the use of routing techniques through anonymous networks, that are difficult to trace.

B. Proxy server

One of the oldest technologies used to enforce privacy and anonymity has been the use of proxy servers. Perhaps due to the simplicity in their functioning, together with their popularity in the early days of the Internet, proxy servers still are one of the main technologies in use when enforcing privacy and anonymity. The function of a proxy server consists mainly in masking the client requests, providing a new identity, i.e. a
different IP address possibly located in a different geographical location. There is a vast number of proxy servers publicly and privately currently available such as www.anonymizer.ru, provides integrated proxy solutions within the web browser. In addition, several lists of free proxies are published daily across the Internet[7] offering all kind of proxies located in different countries, with different levels of anonymity. Notwithstanding, proxys servers cannot be considered a reliable method to guarantee privacy and anonymity by definition. The main reason being that the proxy server knows the origin and destination of the requests, therefore, if it is compromised, it can expose the identity of the users behind its use[17]. Also, although the proxy server can keep the identity secret, there is no guarantee that the content of the requests is not being monitored. Therefore, proxy servers cannot guarantee any property related to plausible deniability and true anonymity/privacy, thus they should be avoided as method to guarantee privacy and anonymity as defined in this paper.

C. Onion routing

Onion Routing is a general purpose infrastructure for private communication over a public network[10]. The core architecture of onion routing is the implementation of mixed networks, i.e. nodes that are accepting messages from different sources and routing them randomly to other nodes within the network. The messages transmitted between them are encrypted, and different layers of encryption get removed in the process of routing while traveling across the nodes[10]. This increases the difficulty of monitoring the traffic (thus revealing the identity). In addition, onion routing is not node-dependent, therefore, the compromising of a router does not compromise the network itself (although can facilitate the traffic analysis). Nevertheless, onion routing has some weaknesses while protecting the privacy and anonymity of its users.

Recent research[6] shows that even if the traffic is encrypted and hard-traceable, there are still possibilities to conclude the population of users and their geographical location. Furthermore, intersection attacks and timing analysis[22], can reveal user’s behavior within the onion routing network, leading to further identification of the sources or destinations. Despite these issues, onion routing is still considered one of the best alternatives when aiming to guarantee privacy and anonymity.

D. TOR

TOR, previously known as The Onion Router[9], is among the most popular solutions used these days to protect privacy and anonymity on the Internet. The main goal of TOR it is to provide a circuit-based low-latency anonymous communication service[9]. TOR’s core architecture is based on the same principles as onion routing. TOR contains several improvements over traditional onion routing, including: “perfect forward secrecy, congestion control, directory servers, integrity checking, configurable exit policies, and a practical design for location-hidden services via rendezvous points”[9].

Some nodes within the TOR network act as discovery servers, providing “trusted” known routers, that are available for the end users. TOR routers have different roles and they can be classified as:

- **Middle-relay**: receive traffic and passes it to another relay
- **Bridges**: publicly listed and their main goal is to provide an entry point on networks under heavy surveillance and censorship
- **Exit-relay**: the final relay before reaching the destination and are publicly advertised

TOR has won popularity across the most common Internet users. The main reason (in addition to its enforcement of privacy and anonymity) is due to the fact that the it is free-software and there are multiple cross-platform clients available. In addition, several extensions/add-ons are available for the most popular web-browsers, making TOR a very suitable solution. In addition, because TOR is configurable in most of the applications through a SOCK interface, TOR can be used for a broad number of protocols, facilitating anonymity in different type of services[9].

The success of TOR does not rely only on its core technology and principles, but on the network of volunteers that maintain the nodes. Due to TOR’s design, anyone with enough bandwidth can provide a new router, allowing this to expand TOR worldwide. Nowadays, TOR network is composed of more than 5000 routers.

Furthermore, TOR user’s population has been fluctuating over time. Recent media revelations concerning global surveillance programs, allowing TOR to win even more popularity across common users, making the network grow considerable, both on relays and users, in the past months, reaching peaks of more than **5 million** daily connections to the network.

Despite its popularity, TOR is subjected to a certain degree of the techniques mentioned in Section 3. TOR architecture does not prevent statistical analysis over its traffic. Some authors highlight the possibility to interfere in nodes with high traffic, being able to perform traffic analysis with enough accuracy that can affect the anonymity of the network[19]. In addition, and due to the publicity of the exit-relays, these particular nodes can be targeted either for traffic interception
or Denial of Service attacks (DoS), affecting the functionality of the network. Finally, TOR relay advertisement leads to the generation of blacklists by ISPs and governmental organizations that are aiming to control mechanisms enforcing privacy and anonymity, making it difficult for the end users to use TOR. In Section 5 we introduce the possible improvements to do in order to comply with the definitions stated in this paper.

V. RELATED WORK AND FUTURE IMPROVEMENTS

In the previous sections, we have analyzed the different motivations, technologies and state of the art concerning the threats and enforcement of privacy and anonymity on the Internet. All of the research available these days focuses mainly on two aspects related to privacy and anonymity: how to obtain secure and trustable encryption methods, and how to guarantee, real anonymous communications.

As of today, there is still no single solution available that is complaint with the definitions of privacy and anonymity introduced in Section 1. Nowadays, every communication done through the Internet that aims to be private and anonymous requires the use of cryptography and hard-trace routing techniques. Proxies and TOR are among the most used anonymity technologies[17] and public-key cryptography is the most popular method aiming for privacy. Nevertheless, it is still possible to perform different attacks over these techniques, leading always to some result that invalidate the required properties for privacy and anonymity mentioned in Section 1. We introduce some of the possible improvements that current lines of research are proposing in order to enforce better privacy and anonymity.

A. Possible solutions for traffic analysis

Traffic analysis (both active and passive), is one of the primary techniques when targeting networks such as TOR. Recent research suggests that one way to achieve better privacy and anonymity over this kind of networks, will be the generation of random connections to achieve better plausible deniability[6]. In addition, there are some proposals to obfuscate TOR’s traffic, adding delays or artificial traffic, together with package batching techniques[15]. Theoretically, these two improvements, will guarantee true anonymity by making the traffic analysis hard-computable. Nevertheless, there is no empirical evidence yet, mainly because they have not been implemented within the production network (i.e. with a real population of users).

B. Blacklisting techniques

Both proxy servers and TOR routers are suffering blacklisting techniques. Because the implicit principles of both technologies (available public nodes), it will require a modification of how they are used and discovered, in order to avoid blacklisting. The main proposals aim for using a rendezvous protocol as the only way to distribute the address of the nodes[18].

C. Better encryption methods

There is a common effort within the cryptography community, to provide more robust and reliable encryption schemes. In the last year, there has been new contributions related to Elliptic curve cryptography, specially those not linked to any corporation or standardization organization such as the Curve25519[3]. It is expected that several well known protocols will start using these new cryptography schemes, thus avoiding the possible backdoors established in the current/popular schemes utilized.

D. ISP cooperation

It has been highlighted by some authors[11], that ISPs are playing a crucial role in privacy and anonymity matters. They are the main entities responsible for implanting mechanisms that can affect the privacy and anonymity of the users. Nevertheless, there are not too many “friendly” ISPs in these matters. Some proposals involve the commitment of the ISP to provide better quality relay-bridges for TOR[11]. Also, there have been official requests to get more neutrality and protection from the ISPs. Nevertheless, all of them are still subjected to the laws that sometimes conflict with the mechanisms for guaranteeing privacy and anonymity.
VI. CONCLUSION

In this paper we introduced the definitions of privacy and anonymity according to the latest related standards of the field. We analyzed the main originators behind the threats against the privacy and anonymity on the Internet; we enumerate their motivations, together with the techniques and technologies utilized to control the privacy and anonymity on the Internet. In addition, we gave an overview of the state of the art concerning the enforcement of privacy and anonymity on the Internet, enumerating the most common technologies by the users, together with their shortcomings. Finally, we introduced the new lines of research together with their proposals. We conclude that there is not yet available any method that guarantees real privacy and true anonymity.

The author considers that despite the reasons given by governments and corporations, privacy and anonymity are a human right that must be preserved no matter the channel of communication used. It is a moral responsibility for the scientific community to research, develop and implement better technologies to guarantee our fundamental rights.

REFERENCES

[1] Opennet initiative. 2013.

[2] Simurgh Aryan, Homa Aryan, and J. Alex Halderman. Internet Censorship in Iran: A First Look. In Free and Open Communications on the Internet, Washington, DC, USA, 2013. USENIX Association.

[3] Daniel J. Bernstein. Curve25519: New diffie-hellman speed records. In Public Key Cryptography - PKC 2006, 9th International Conference on Theory and Practice of Public-Key Cryptography, volume 3958 of Lecture Notes in Computer Science, pages 207–228. Springer, 2006.

[4] J. Callas, L. Donnerhacke, H. Finney, D. Shaw, and R. Thayer. OpenPGP Message Format. RFC 4880 (Proposed Standard), November 2007. Updated by RFC 5581.

[5] Carne Botnet. Internet census 2012 — port scanning /0 using insecure embedded devices, March 2013.

[6] D. Choffnes, J. Duch, D. Malmgren, R. Guiermá, F. E. Bustamante, and L. Amaral. Swarmscreen: Privacy through plausible deniability in p2p systems. Technical report, Northwestern University, March 2009.

[7] J. D. Day and H. Zimmermann. The OSI reference model. Proceedings of the IEEE, 71(12):1334–1340, December 1983.

[8] Ronald J. Deibert, John G. Palfrey, Rafal Rohozinski, and Jonathan Zittrain. Access denied: The practice and policy of global internet filtering. 2008.

[9] Roger Dingledine, Nick Mathewson, and Paul Syverson. Tor: The second-generation onion router. In In Proceedings of the 13th USENIX Security Symposium, pages 303–320, 2004.

[10] David Goldschlag, Michael Reed, and Paul Syverson. Onion routing for anonymous and private internet connections. Communications of the ACM, 42:39–41, 1999.

[11] Amir Houmansadr, Giang T.K. Nguyen, Matthew Caesar, and Nikita Borisov. Cirripede: Circumvention infrastructure using router redirection with plausible deniability. In Proceedings of the 18th ACM Conference on Computer and Communications Security, CCS ’11, pages 187–200, New York, NY, USA, 2011. ACM.

[12] United Nations international community. The universal declaration of human rights. 1948.

[13] Information technology Security techniques Evaluation criteria for IT security, 2005.

[14] J. Jonsson and B. Kaliski. Public-Key Cryptography Standards (PKCS) #1: RSA Cryptography Specifications Version 2.1. RFC 3447 (Informational), February 2003.

[15] Stevens Le-Blond, David R. Choffnes, Wenxuan Zhou, Peter Druschel, Hitesh Ballani, and Paul Francis. Towards efficient traffic-analysis resistant anonymity networks. In SIGCOMM, pages 303–314, 2013.

[16] Christopher S. Leberknight, Mung Chiang, and Felix Ming Fai Wong. A taxonomy of censors and anti-censors: Part i-impacts of internet censorship. IJEP, 3(2):52–64, 2012.

[17] Bingdong Li, Esra Erdin, Mehmet H. Gunes, George Bebis, and Todd Shipley. An overview of anonymity technology usage. Computer Communications, 36(12):1269–1283, July 2013.

[18] Patrick Lincoln, Ian Mason, Phillip Porras, Vinod Yegneswaran, Zachary Weinberg, Jeroen Massar, William Simpson, Paul Vixie, and Dan Boneh. Bootstrapping Communications into an Anti-Censorship System. In Free and Open Communications on the Internet, Bellevue, WA, USA, 2012. USENIX Association.

[19] Steven J. Murdoch and George Danezis. Low-cost traffic analysis of tor. In Proceedings of the 2005 IEEE Symposium on Security and Privacy, SP ’05, pages 183–195, Washington, DC, USA, 2005. IEEE Computer Society.

[20] National Institute of Standards and Technology. FIPS PUB 180-1: Secure Hash Standard. April 1995. Supersedes FIPS PUB 193 1995 May 11.

[21] Andreas Pfitzmann and Marit Hansen. A terminology for talking about privacy by data minimization: Anonymity, unlinkability, undetectability, unobservability, pseudonymity, and identity management. http://dud.inf.tu-dresden.de/literatur/Anon_Terminology_v0.34.pdf, August 2010. v0.34.

[22] Vitaly Shmatikov and Ming-Hsiao Wang. Timing analysis in low-latency mix networks: attacks and defenses. In IN: PROCEEDINGS OF ESORICS, pages 18–33, 2006.

[23] D. Shumow and N. Ferguson. On the possibility of a back door in the NIST SP800-90 dual Ec prng. 2007.

[24] International Telecommunication Union. World telecommunication/ict indicators database, dec 2013.

[25] A.F. Westin. Privacy and Freedom. Bodley Head, 1970.

[26] Philipp Winter and Jedidiah R. Crandal. The great firewall of china: How it blocks tor and why it is hard to pinpoint. :login:, 37(6):42–50, 2012.