

# Research Statement - Privacy Preserving Decentralized Systems

Gonalo Pestana (gpestana@protonmail.com)

Dec 2018

This document motivates and summarizes my research goals for the short and long term. In addition, it outlines initial ideas for potential research topics, leaving a thorough literature review and further details for a later document.

## Research goals

As a researcher and engineer, my long term goals are to study and build privacy preserving technologies that are secure and private by design. Given how pervasive the Internet has become, I believe that a free and ethical Internet is synonym with a free and ethical society. Thus, I am committed to help building an Internet that respects our fundamental rights to privacy and freedom.

Decentralized and peer-to-peer (P2P) systems have demonstrated their potential as the underlying paradigm for building online systems that respect it users' privacy (Dingledine, Mathewson, and Syverson 2004). Recent episodes such as the Snowden leaks have clearly reaffirmed the urgency to replace, complement or fix current online systems with respect to protecting users against private data and metadata leaks, pervasive online surveillance and also online censorship. While decentralized and P2P systems may be part of the solution, it has been discussed and demonstrated that naive implementation of decentralized systems may harm privacy more than centralized systems (Troncoso et al. 2017), (Wolchok and Halderman 2010), (Jia et al. 2016). I am highly motivated to investigate how current decentralized systems may harm user privacy and to design and develop privacy enhancing mechanisms to address those problems. Moreover, I am interested in designing and developing privacy

preserving and decentralized alternatives to current systems deployed at large scale, such as communication systems, authentication infrastructure, search engines and service discovery.

As P2P networks and decentralized systems (re)gain popularity among researchers and industry alike, I believe that it is important to design and implement decentralized systems that not only preserve users' privacy but also deliver on scalability, performance and usability. Failing to deliver on those properties will render decentralized systems unusable and unattractive for mass adoption or as a viable alternative to centralized systems.

The short term goals of my research are to study, design and help to implement privacy enhancing mechanisms and protocols for decentralized systems. The focus would be on studying and implementing privacy in the building blocks of P2P systems, while considering their security, scalability, performance and usability. From this starting point, I would expect the research to cover topics such as distributed systems, applied advanced cryptography (e.g. zero knowledge proofs, multi-party computation, threshold crypto, homomorphic encryption) and incentive design for agent collaboration in P2P networks.

## Initial research directions

This section outlines ideas and initial thoughts for research directions. There may be overlapping between topics.

**Privacy preserving and censorship resistant search engines:** Search engines have been (literally) the engine of the Internet and are the backbone

of online services. Due to their importance, there has been interest in designing privacy preserving and censorship resistant web search engines (Lai et al. 2018) and to study current implementations regarding their security and privacy (Herrmann et al. 2014). There are, though, many challenges ahead to fulfill the vision of decentralized, private and censorship resistant search engines. Open challenges remain in terms of storage and communication constraints (Li et al. 2003), indexing and ranking mechanisms that suit the decentralized context and scalability (Herrmann et al. 2014).

This research topic would consist of 1) investigating the challenges of indexing, discovering and distributing content in decentralized networks; 2) study and design mechanisms for privacy preserving and censorship resistant search engines; 3) build primitives for indexing and querying data in a decentralized system at scale. I expect this topic to require research on anonymous computation techniques (e.g. homomorphic computation), privacy preserving content discovery and routing, anonymous communication systems and incentive design in P2P networks.

**Practical privacy preserving DHTs:** (Wang and Borisov 2012), (Mittal and Borisov 2009), studied protocols and mechanisms to achieve secure and anonymous low latency communication systems. Many other research studies focus on the the same topic (Shirazi et al. 2018). However, real-world implementation of DHTs such as, for example, IPFS (Benet 2014) and Hyperswarm do not seem to adopt any of the privacy preserving mechanism studied in recent literature. My hypotheses are the following: 1) the penalty to paid for the added complexity and decreased performance is seen as too large for the system designers; 2) current secure and private protocols assume centralized infrastructure (e.g PKI infrastructure); 3) it is not clear how to define and quantify privacy in P2P networks and 4) there are no incentive and trust models to make sure peers collaborate to improve peer and network privacy as a whole. I propose to study and measure privacy of deployed systems using DHTs. Based on the results and previous research, investigate novel privacy enhancing mechanisms, protocols and primitives that could improve privacy of DHTs,

taking into consideration scalability, performance and security. As a byproduct, I expect to compile an authoritative framework for defining and measuring privacy in P2P networks.

**From centralized to privacy preserving decentralized systems:** Decentralized networks are becoming sound alternatives to centralized systems due to advances in P2P protocols and incentive mechanisms, the constant increase of computation power and storage in edge devices and recent public cases disclosing how current centralized systems are harming user privacy and security. Ledgers (Nakamoto, n.d.), shared contracts (Buterin 2013) file systems (Benet 2014), file sharing (“Bittorrent,” n.d.), in-band PGP key distribution (Kulynych et al. 2018) are examples of decentralized systems which aim to replace and improve analogous centralized services. However, while decentralization can potentially improve privacy, scalability and integrity, it has been shown that naive protocol design and implementations may be counterproductive in regards to those properties (Troncoso et al. 2017). ClaimChain (Kulynych et al. 2018) is a sound example of how to replace centralized, brittle infrastructure and processes with advanced cryptographic primitives, while adding interesting security and privacy properties which can be used in a decentralized context.

This research topic would focus on answering the question of “which centralized infrastructure can be replaced by privacy preserving decentralized systems and how?”. PKI infrastructure, certificate authorities (Jayaraman, Li, and Evans 2017), search engines (Lai et al. 2018), DNS infrastructure are examples of infrastructure that have the potential for improvement in terms of privacy, availability and censorship resistance with a decentralized design.

**Systematization and privacy vulnerability research:** It has been discussed that lack of systematization when defining and measuring privacy in decentralized systems makes it hard to design and implement such systems (Troncoso et al. 2017). In addition, research work analyzing privacy vulnerabilities in decentralized systems are vital for improving protocols and develop privacy enhancing technologies

(PETs) that help mitigating privacy vulnerabilities (Jia et al. 2016), (Kwon et al. 2015), (Evans, GauthierDickey, and Grothoff 2007). Similarly, I propose to investigate how data and metadata are leaked in decentralized systems. The main goals are 1) define a framework to study privacy in decentralized networks 2) to investigate and enumerate privacy vulnerabilities in current systems; 3) propose, design and implement protocols and/or primitives to address the privacy vulnerabilities found.

**Incentives in privacy preserving decentralized systems:** Cryptocurrencies and smart contracts have - at least theoretically - shown the potential of game theory and incentive design for aligning interests of participants in P2P networks (Buragohain, Agrawal, and Suri, n.d.), (Park and Schaar 2010), (Ciccarelli and Cigno 2011), (Nakamoto, n.d.). Instead of focusing exclusively on incentives in decentralized networks as research topic, I believe it to be transversal to all the research directions mentioned previously.

**Open research topics:** I am open to relevant topics focusing on privacy preserving networks, PETs and applied cryptography in the context of PETs.

## References

- 
- Benet, Juan. 2014. “IPFS - Content Addressed, Versioned, P2p File System.”
- “Bittorrent.” n.d. <https://bittorrent.com>.
- Buragohain, C., D. Agrawal, and S. Suri. n.d. “A Game Theoretic Framework for Incentives in P2p Systems.” *Proceedings Third International Conference on Peer-to-Peer Computing (P2P2003)*. IEEE Comput. Soc. <https://doi.org/10.1109/ptp.2003.1231503>.
- Buterin, Vitalik. 2013. “Ethereum: A Next-Generation Smart Contract and Decentralized Application Platform.” <https://github.com/ethereum/wiki/wiki/White-Paper>.
- Ciccarelli, Gianluca, and Renato Lo Cigno. 2011. “Collusion in Peer-to-Peer Systems.” *Computer Networks* 55: 3517–32.
- Dingledine, Roger, Nick Mathewson, and Paul Syverson. 2004. “Tor: The Second-Generation Onion Router.” In *Proceedings of the 13th Conference on Usenix Security Symposium - Volume 13*, 21–21. SSYM’04. Berkeley, CA, USA: USENIX Association. <http://dl.acm.org/citation.cfm?id=1251375.1251396>.
- Evans, N. S., C. GauthierDickey, and C. Grothoff. 2007. “Routing in the Dark: Pitch Black.” In *Twenty-Third Annual Computer Security Applications Conference (Acsac 2007)*, 305–14. <https://doi.org/10.1109/ACSAC.2007.7>.
- Herrmann, Michael, Ren Zhang, Kai-Chun Ning, Claudia Díaz, and Bart Preneel. 2014. “Censorship-Resistant and Privacy-Preserving Distributed Web Search.” *14-Th IEEE International Conference on Peer-to-Peer Computing*, 1–10.
- Jayaraman, Bargav, Hannah Li, and David Evans. 2017. “Decentralized Certificate Authorities.”
- Jia, Yaoqi, Guangdong Bai, Prateek Saxena, and Zhenkai Liang. 2016. “Anonymity in Peer-Assisted Cdns: Inference Attacks and Mitigation.” *Proceedings on Privacy Enhancing Technologies* 2016 (4): 294–314. <https://content.sciendo.com/view/journals/popets/2016/4/article-p294.xml>.
- Kulynych, Bogdan, Wouter Lueks, Marios Isaakidis, George Danezis, and Carmela Troncoso. 2018. “ClaimChain.” *Proceedings of the 2018 Workshop on Privacy in the Electronic Society - WPES’18*. ACM Press. <https://doi.org/10.1145/3267323.3268947>.
- Kwon, Albert, Mashael AlSabah, David Lazar, Marc Dacier, and Srinivas Devadas. 2015. “Circuit Fingerprinting Attacks: Passive Deanonimization of Tor Hidden Services.” In *24th USENIX Security Symposium (USENIX Security 15)*, 287–302. Washington, D.C.: USENIX Association. <https://www.usenix.org/conference/usenixsecurity15/technical-sessions/presentation/kwon>.
- Lai, Ziliang, Chris Liu, Eric Lo, Ben Kao, and Siu-Ming Yiu. 2018. “Decentralized Search on Decentral-

ized Web.”

Li, Jinyang, Boon Thau Loo, Joseph M. Hellerstein, M. Frans Kaashoek, David R. Karger, and Robert Morris. 2003. “On the Feasibility of Peer-to-Peer Web Indexing and Search.” In *Peer-to-Peer Systems II*, edited by M. Frans Kaashoek and Ion Stoica, 207–15. Berlin, Heidelberg: Springer Berlin Heidelberg.

Mittal, Prateek, and Nikita Borisov. 2009. “ShadowWalker: Peer-to-Peer Anonymous Communication Using Redundant Structured Topologies.” In *Proceedings of the 16th Acm Conference on Computer and Communications Security*, 161–72. CCS ’09. New York, NY, USA: ACM. <https://doi.org/10.1145/1653662.1653683>.

Nakamoto, Satoshi. n.d. “Bitcoin: A Peer-to-Peer Electronic Cash System.”

Park, Jaeok, and Mihaela van der Schaar. 2010. “A Game Theoretic Analysis of Incentives in Content Production and Sharing over Peer-to-Peer Networks.” *IEEE Journal of Selected Topics in Signal Processing* 4: 704–17.

Shirazi, Fatemeh, Milivoj Simeonovski, Muhammad Rizwan Asghar, Michael Backes, and Claudia Díaz. 2018. “A Survey on Routing in Anonymous Communication Protocols.” *ACM Comput. Surv.* 51: 51:1–51:39.

Troncoso, Carmela, George Danezis, Marios Isaakidis, and Harry Halpin. 2017. “Systematizing Decentralization and Privacy: Lessons from 15 Years of Research and Deployments.” *CoRR* abs/1704.08065. <http://arxiv.org/abs/1704.08065>.

Wang, Qiyan, and Nikita Borisov. 2012. “Octopus: A Secure and Anonymous DHT Lookup.” *CoRR* abs/1203.2668. <http://arxiv.org/abs/1203.2668>.

Wolchok, Scott, and J. Alex Halderman. 2010. “Crawling Bittorrent Dhts for Fun and Profit.” In *Proceedings of the 4th Usenix Conference on Offensive Technologies*, 1–8. WOOT’10. Berkeley, CA, USA: USENIX Association. <http://dl.acm.org/citation.cfm?id=1925004.1925007>.