

Institution: Royal Holloway, University of London		
Unit of Assessment: 11 Computer Science and Informatics		
Title of case study: Enhancing the Security and Scalability of IBM's Blockchain and Cloud Computing Technology		
Period when the underpinning research was undertaken: 2012-2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Gregory Chockler	Professor	2012 – 2020
Peter Robinson	Lecturer	2016 – 2018
Period when the claimed impact occurred: 1 st August 2013-2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact Research at Royal Holloway supported the development of <i>WebSphere Liberty</i> and <i>HyperLedger</i>, two of IBM's flagship enterprise products, vital to the <i>IBM Cloud Computing</i> and <i>Blockchain Platform</i>. These developments consolidated IBM as the market leader in blockchain, securing 32% of a global market worth approximately USD700,000,000 (01-2018) in 2018. IBM's blockchain platform has been used to track conflict minerals, providing an immutable record of the resources throughout the supply chain, and to reduce ocean plastic waste through monetizing recycling in economically disadvantaged parts of the world.		
2. Underpinning research This case study highlights the impact of the RHUL team's research into the theory and practice of large-scale distributed computing systems conducted over the past seven years. Such systems occupy a major part of today's computing technology landscape ranging from Internet-of-Things devices to data-intensive platforms operated by big Internet companies (such as IBM, Google, and Amazon). Specifically, the research of the case study team provides algorithmic foundations for new distributed system technology that IBM has been and is currently building in two key areas of its business: <i>Cloud Computing</i> and <i>Blockchain</i>. In cloud computing, the main contribution has been made to <i>WebSphere Liberty</i>, a distributed application server for the IBM cloud. The key challenge was to implement a repository for storing critical configuration data (such as information about server capacity and the registry of deployed applications) that guarantees continuous data availability despite high update rates, machine failure and intermittent network connectivity. The RHUL team's solution arose from its research into the foundations of data replication in transactional data stores. This research produced a new theoretical framework, called a <i>Transaction Certification Service</i>, TCS (R1). TCS extends and adapts the decades old Atomic Commitment Problem by Gray to modern transactional data stores (such as Google Spanner), facilitating their formal analysis and uncovering their core algorithmic insights. The RHUL team's research in scalable data replication protocols, consensus, and distributed transactions (R1, R2), as exemplified by the TCS framework, resulted in a new reconfigurable replication protocol (patents in references R5 and R6) that was incorporated into <i>WebSphere Liberty</i> in 2014. The protocol guarantees that in most situations, the configuration repository can continue serving update transactions even when its underlying physical composition is changing. In the Blockchain area, the team's research has resulted in several contributions critical to IBM's open-source <i>Hyperledger Fabric</i> project (HLF). HLF implements a general purpose		

permissioned blockchain infrastructure for secure management of critical assets (such as cryptocurrency, customer and product registries, etc.) within a network of businesses. Typically, each business will maintain its own instances of a ledger and an asset database to protect privacy and security of its sensitive business data. HLF consists of an ordering service that maintains a replicated ledger of transactions, and a collection of peers that store replicas of the asset database. The primary challenge was to develop a data diffusion protocol to guarantee that data reaches all peers quickly even if some of the peers behave unreliably. An additional challenge was to devise a cross-organisation transaction protocol that could withstand malicious attacks without leaking sensitive information.

The RHUL team's solution to the first challenge leveraged their previous research into large-scale data diffusion in adversarial settings (R4), which proposed a number of randomized protocols with well-defined message reliability and performance properties. These laid the foundation for a scalable and robust data propagation technology that was adopted by IBM in 2017 in the context of the HLF project.

For the second challenge, the RHUL team developed a new cross-chain transaction scheme to guarantee the required levels of fault tolerance and security, based on their recent research into cross-shard transaction commit protocols as part of the TCS framework (R1). Finally, in ongoing work the team is incorporating techniques from their research on secure hardware for cloud computing (e.g. Intel SGX) into transaction processing protocols of Hyperledger. This will enhance the HLF protocols' failure-tolerance while reducing the costs of data replication and software complexity.

3. References to the research

The research has been published in peer reviewed proceedings of the most important international conferences in the fields of the theory of distributed computing, theoretical computer science and security research in distributed systems and networks. Patents are held with co-inventors at IBM and Technion - Israel Institute of Technology. (Royal Holloway researchers are shown in **bold**)

- R1: **Gregory Chockler** and Alexey Gotsman. *Multi-Shot Distributed Transaction Commit*. Received Best Paper Award in the Proceedings of 32nd International Symposium on Distributed Computing (2018) DOI: <https://arxiv.org/abs/1808.00688>.
- R2: Alexey Gotsman, Anatole Lefort, and **Gregory Chockler**. *White-Box Atomic Multicast*. In Proceedings of the 49th IEEE/IFIP International Conference on Dependable Systems and Networks (2019) <https://arxiv.org/abs/1904.07171>.
- R3: Artem Barger, **Gregory Chockler et al.** *Scalable Communication Middleware for Permissioned Distributed Ledgers*. In Proceedings of the 10th ACM Systems and Storage Conference (2017) <https://doi.org/10.1145/3078468.3078492>.
- R4: John Augustine, Gopal Pandurangan, **Peter Robinson**, Scott Roche, Eli Upfal. *Enabling Efficient and Robust Distributed Computation in Highly Dynamic Networks*. In Proceedings of the 56th Annual IEEE Symposium on Foundations of Computer Science (2015) DOI: [10.1109/FOCS.2015.29](https://doi.org/10.1109/FOCS.2015.29).
- R5: *Efficient Fail-Over in Replicated Systems*, Vita Bortnikov, Shlomit Shachor, Ilya Shnayderman, and **Gregory Chockler**, US Patent 9,329,950, (2016). Available from HEI on Request.
- R6: *Continuous Operation During Reconfiguration Periods*, Vita Bortnikov, **Gregory Chockler**, Dmitri Perelman, Shlomit Shachor, Ilya Shnayderman, and Alexey Roytman, US Patent 8,943,178, (2015), (filled in 2012 and issued in 2015). Available from HEI on Request.

Grants:

IBM Shared University Research Award for GBP22,482.86 (2017). PI: **Gregory Chockler**. The award "recognizes the quality of Prof Chockler program - Scalable and Resilient Data Replication for Distributed Ledgers and Blockchains - and its importance to IBM industry."

4. Details of the impact

Context

Prior to the research of the case-study team (2014 to 2020), IBM was struggling with the problem of how to scale and secure their distributed computing products for the cloud computing and Blockchain industries. Solutions founded on Royal Holloway's research helped to consolidate IBM as a market leader in these industries. This case study describes the economic benefits to IBM and its customers, as well as how the research led to environmental and societal benefits through IBM's Blockchain platform.

Scaling IBM Cloud Computing to serve large enterprise customers

In the cloud computing sphere, the main beneficiaries were **IBM** and **large enterprise customers using WebSphere Liberty (WL)**, IBM's market-leading application server platform.

In 2014, the scalability of large enterprise customer deployments of WL was increasingly bottlenecked by the inability of WL's replicated configuration store, Liberty Collectives, to handle the corresponding load increase from configuration and critical metadata updates. These enterprise customers were particularly important to IBM, since access to the Liberty Collectives feature is only available as part of the lucrative WL 'Network Deployment' premium enterprise license.

As a result of Royal Holloway's research, **IBM was able to meet these customers' scalability requirements**. According to [text removed for publication] IBM Research, Haifa, the research "[text removed for publication]." (Source S1). The **financial and economic impact of the research on IBM** was recognised by an outstanding recognition award from IBM research, which according to [text removed for publication]." (S1)

As an indication of **the total economic impact (TEI) and return on investment (ROI) of WL for IBM's customers**, IBM commissioned an independent study in 2018 by Forrester (S2). The study surveys 30 US-based IT decision makers in large multinational companies (approximately 14,000 employees and USD4,000,000,000 revenue for a typical company). The overall benefit of WebSphere Liberty to these organisations is estimated at approximately USD150,000,000 (09-2018) over 3 years (USD5,000,000 per org).

Meeting commercial demands of IBM's Blockchain Platform for security and scalability

Direct beneficiaries of the team's work in the Blockchain space are **IBM** and **IBM customers and industry consortia using HyperLedger Fabric (HLF)**. HLF provides the foundation for IBM's market leading Blockchain platform, in combination with associated cloud computing technology such as IBM Cloud Pak for Applications, of which WL is a key component.

Prior to 2017, the market for so-called 'permissioned' enterprise blockchains was in its infancy, but its potential to transform whole industries through increased collaboration between industry competitors was clear. In conversations with market leaders from several industries (e.g. food and shipping/logistics), IBM identified several key technical shortcomings of existing permissioned Blockchains, which according to IBM's [text removed for publication]." (S1).

To address these issues, in 2017 IBM incorporated Royal Holloway's research into a new gossip-based dissemination framework for HLF. According to [text removed for publication]" (S1). Prominent examples of these consortia include FoodTrust and TradeLens, which according to IBM's [text removed for publication]." (S1). Founding members of FoodTrust include household names such as Walmart and Nestle (S3), while TradeLens (S4) involves 175 unique organizations as of 2019, including 5 of the world's 6 largest ocean carriers (e.g. Maersk) (S5). In addition to benefiting its customers, **the economic and financial impacts on IBM** were recognised through IBM outstanding awards at both research and corporate level (S1).

To illustrate the total **economic impact on IBM's customers** of IBM DLT (Blockchain), in 2018 IBM commissioned an independent survey by Forrester (S6). Forrester interviewed six

organisations with experience using IBM's Blockchain, including three Canadian companies in the utilities, financial services and IT industries, a global transport and logistics company, and a joint venture of nine global banks. The survey estimated a net benefit from IBM's Blockchain for a typical organisation over 5 years of between USD2,700,000 (low) - USD36,000,000 (high). For IBM, the revenue from HLF was estimated at approximately USD220,000 (07-2018) per customer per year in licensing and ongoing development fees after an initial pilot phase. Furthermore, in 2018 IBM's share of the overall blockchain market of approximately USD700,000,000 (01-2018) was estimated at 32% (S10).

Improving the Environment and benefitting Human Rights

Finally, through the IBM Blockchain platform the team's research has contributed to substantial environmental and societal impacts. For example, a company called PlasticBank are using IBM Blockchain to reduce ocean plastic waste through monetizing recycling in economically disadvantaged parts of the world (S7). As of 2020, PlasticBank have recovered **over 14,000 tonnes of ocean-bound plastic**, with collectors active in countries such as Haiti, the Philippines and Indonesia (S8).

As another example, iPoint, a market leader in the field of conflict minerals reporting software, used IBM Blockchain in 2018 to 2019 to launch SustainBlock, a platform to track conflict minerals from areas such as the Democratic Republic of Congo and Rwanda, providing an immutable record of the resources throughout the supply chain (S9). SustainBlock gives mines an incentive to comply with sustainability and conflict-free mining requirements, and helps downstream companies ensure their products aren't used to finance conflicts and are free of slavery and child labour. A pilot study of SustainBlock was conducted in 2019, focused on two tungsten mining sites in the African Great Lakes region. To participate in the network, the companies needed to prove they are following responsible business practices.

5. Sources to corroborate the impact

S1: Letter of support written by [text removed for publication], IBM Research

S2: A Forrester Total Economic Impact (TEI) Study on WebSphere Liberty commissioned by IBM, (2018), (https://hosteddocs.ittoolbox.com/tei_websphere_liberty.pdf)

S3: Coin Telegraph article (2018): Walmart, IBM Blockchain Initiative Aims to Track Global Food Supply Chain, (<https://cointelegraph.com/news/walmart-ibm-blockchain-initiative-aims-to-track-global-food-supply-chain>)

S4: IBM Blog post, (2018) TradeLens: How IBM and Maersk Are Sharing Blockchain to Build a Global Trade Platform, (<https://www.ibm.com/blogs/think/2018/11/tradelens-how-ibm-and-maersk-are-sharing-blockchain-to-build-a-global-trade-platform/>)

S5: Unblocked article, (2019), Blockchain supply chain: Interview with Richard Stockley, IBM, (<https://un-blocked.co.uk/2019/10/02/blockchain-supply-chain-interview-richard-stockley-ibm/>)

S6: A Forrester Total Economic Impact (TEI) Study on IBM Blockchain commissioned by IBM, (2018), (<https://www.ibm.com/downloads/cas/QJ4XA0MD>)

S7: IBM Client Stories article (2020), Revolutionizing recycling by creating an ecosystem for plastic, (<https://www.ibm.com/blockchain/use-cases/success-stories/#section-5>)

S8: Impact of the Plastic Bank (2020), (<https://plasticbank.com/our-impact/>)

S9: IBM Block chain User Cases Showcase (2020), (<https://www.ibm.com/blockchain/use-cases/success-stories/#section-10>)

S10: IBM Share of Blockchain market news item (2018), (<https://uk.news.yahoo.com/walmart-embraces-ibm-apos-blockchain-200500127.html>)