BLOCKCHAIN™ IN HEALTHCARE TODAY

Applications of Blockchain Within Healthcare

Liam Bell,[1] William J Buchanan,[1] Jonathan Cameron,[2] Owen Lo[1]

Authors
[1]The Cyber Academy, Edinburgh Napier University, Edinburgh, UK, [2]NHS NSS, Edinburgh, UK.

Corresponding Author
Prof. William (Bill) Buchanan, OBE, PhD, FBCS, FIET, CEng, BSc (Hons), Cisco Regional Instructor, Professor of Computing, Edinburgh Napier University, 10 Colinton Road, Edinburgh. EH10 5DT. B.Buchanan@napier.ac.uk.

Keywords: Asset Tracking, Blockchain, Drug tracking, Ethereum, Healthcare, Internet of Things, IoT

Section: Opinion/Perspective/Point of View

There are several areas of healthcare and well-being that could be enhanced using blockchain technologies. These include device tracking, clinical trials, pharmaceutical tracing, and health insurance. Within device tracking, hospitals can trace their asset within a blockchain infrastructure, including through the complete lifecycle of a device. The information gathered can then be used to improve patient safety and provide after-market analysis to improve efficiency savings. This paper outlines recent work within the areas of pharmaceutical traceability, data sharing, clinical trials, and device tracking.

Blockchain is a distributed ledger technology, with the potential to disrupt many industries. Indeed, with $1.4 billion invested in blockchain related startups in 2016;[1] and with this projected to grow further in 2017 the hype cycle shows no sign of slowing. At the time of writing, a lot of the attention around blockchain has centered on cryptocurrency, predominantly Bitcoin[2] and the effect that blockchain is predicted to have on the financial sector. This effect led to the established consultancy Accenture labeling it as one of three technologies that will change the financial services world.[3] Despite this focus on financial services, there are many other areas prime for disruption including voting,[4] real estate,[5] supply chain management,[6] and of course, healthcare.[7] Healthcare is prime for disruption as it has a variety of problems in the industry that blockchain can solve through its immutability, fraud prevention and capability to share data between organizations without requiring trust. Current issues within modern healthcare industry are listed in Table 1.

A key challenge, as identified by Frost & Sullivan,[8] is to tag medical equipment with a usable ID and in integrating trust in device identification and tracking. When a device, such as an infusion pump is shown to have malfunctioned, the tracking of the device can reveal the source of the problem and prevent unnecessary repurchasing in the case of lost devices. A strong trust infrastructure based around the identification of medical devices is likely to reduce these threats. The report estimates that only 20% to 30% of medical devices are connected within hospitals due to security and privacy issues.

Within the pharmaceutical industry, blockchain can help overcome the increasing risks around counterfeit and unapproved drugs. As with device tracking, it is possible to define smart contracts for drugs and then identify pill containers, with integrated GPS and chain-of-custody logging.

Table 1. Current issues within the modern healthcare industry

Issue	Activity
Healthcare Data Interchange	Data must pass between healthcare providers to necessary third parties, insurers, and patients while meeting data protection regulation in the healthcare sector.
Nationwide Interoperability	Having a single standard for patient data exchange allows for ease of passing data between healthcare providers, which legacy systems often do not provide.
Medical Device Tracking	Medical device tracking from supply chain to decommissioning allows for swift retrieval of devices, prevention of unnecessary repurchasing, and fraud analytics.
Drug Tracking	As with medical devices, blockchain offers the capability to track the chain of custody from supply chain to patients, allowing for frictionless recalls and prevention of counterfeit drugs.

Within clinical trials, blockchain can be used to overcome the problems of fraudulent results and removal of data, which do not support the researcher's bias or funding source's intention. This will enforce integrity in clinical trials. In addition, it allows an immutable log to be kept of trial subject consent. It is thought that the pharmaceutical industry could benefit with savings of $200 billion in defining a chain-of-custody in the supply chain.[8]

With health insurance, many areas could benefit from a trusted record of events around the patient pathway, including improved reporting around incidents and automating underwriting activities. Contracts could also be clearly defined and then enacted, such as automated payments for parts of the patient pathway.

CURRENT IMPLEMENTATIONS

Blockchain Implementation

A blockchain is ostensibly a chain of blocks secured by cryptographic techniques. One of the features most appealing about this to many industries is its immutability. Data added to the blockchain cannot be modified; and therefore, a consensus-based, verifiable and correct ledger of data can be created. This makes blockchain particularly suited to tasks where data integrity is of utmost importance, a practical example of this immutability is ProvChain,[9] an architecture built on the blockchain for providing chain-of-custody for data objects on the cloud.

There are multiple implementations of the blockchain, these include Bitcoin,[2] the cryptocurrency token implemented on the Blockchain; Ethereum,[10] the blockchain-based ledger that features a Turing-complete virtual machine allowing execution of code on the blockchain using smart contracts; and JP Morgan's Juno,[11] an Ethereum fork using a different consensus method known as Quorum as well as many other blockchain implementations.

Consensus methods is one of the ways in which blockchain implementations differ. Bitcoin, for example, uses a Proof-Of-Work algorithm known as HashCash,[12] and is an intentionally expensive algorithm originally designed prevent denial-of-service attacks. All Bitcoin miners validate the blockchain by performing this proof-of-work algorithm as a vote towards the consensus on the blockchain. Ethereum also uses a Proof-of-Work algorithm, Ethash,[13] as addressed in the Ethereum Yellow Paper,[10] based on the Dagger-Hashimoto algorithm.[14] Ethereum will, however, move to a Proof-Of-Stake Algorithm, Casper, in the future. This is to address the extreme energy requirements of Proof-Of-Work, made clear by both Ethereum and Bitcoin using similar amounts of electricity to all of Ireland.[15]

Ethereum also differs from Bitcoin due to its implementation of smart contracts. Smart contracts are pieces of code executed on every node on the blockchain. They are self-executing contracts in which the agreement is enforced on all members of the blockchain. They set out the benefits, obligations and penalties associated with behavior related to the contract like the way a traditional contract works. As they mimic traditional paper contracts and laws, they can be used, for example, to model the HIPAA healthcare personal health information (PHI) workflow to meet regulatory and audit requirements, such as is implemented within Patientory.[16]

A different type of blockchain trust model is also emerging, that of trust in the consortium. Microsoft has recently developed a framework named Coco which allows for blockchain agnostic consortiums to be created.[17] These consortium models rely on a pre-defined group of trusted parties. In healthcare this may be multiple hospitals or in the UK, NHS Trusts, as well as medical device manufacturers and third parties.

By executing smart-contracts solely on these trusted partner's hardware, consensus is generated without the need for miners. This has resulted in a significantly greater performance with a Coco-optimized blockchain instance able to process 1600 transactions per second, a performance improvement bringing blockchain much closer to the big payment processors.[18] Coco is also agnostic of trusted execution environments allowing the use of Intel Software Guard Extensions, Windows Virtual Secure Mode and Arm TrustZone among others.

Clinical Trials

Clinical trials and the management of trial subject consent are an area where blockchain has the potential to increase transparency, auditability and accountability of medical practitioners and researchers.[19]

By maintaining an immutable log of patient consent, regulators can easily monitor clinical trial standards, ensuring that the trial meets the country's informed consent regulations. This is particularly important as fabricated informed consent forms have been among the most common type of clinical fraud.[20] this includes editing records and falsifying patient consent, which indicates that a level of trial subject authentication would be required to prevent this. This system could be further augmented; as proposed by Benchoufi, Porcher and Ravaud,[21] implementing a smart contract system that prevents clinicians from using patient data until a key has been released at the end of an auditable smart contract process requiring consent at each stage of the trial. This process should also allow for the revocation of patient consent. Implementing a blockchain clinical trial consent log gives clinical trial subjects ownership of their own data while providing an audit trail for clinical staff, researchers, and regulators.

Data Sharing

Data sharing represents one of the greatest opportunities for improvements in healthcare but also one of the largest privacy challenges. Indeed, Powles and Hodson[22] address the need to provide transparency on how patient data are shared with 3rd parties using the case study of the DeepMind collaboration with Royal Free London NHS Foundation Trust. The lack of patient consent in the previous case study is addressed as one of the most significant issues, despite the positive effect Google's product suite had on patient diagnosis and treatment. On the opposite end of the spectrum, IBM and the American Sleep Apnea Association[23] are using IBM's Watson supercomputer to study sleep apnea in thousands of Americans at home, with clear and informed consent from patients to solve major challenges in healthcare.

It is important to have a nationwide standard for interoperability in IT services in healthcare. This has been underlined in a UK NHS white paper written by Wachter and Hafter[24] in a comparison with the U.S. healthcare system, which underlined the importance of interoperability in allowing access to patient Electronic Health Records (EHRs) across multiple hospitals, as many trusts have different systems built by different vendors for accessing these records. And as shown in the U.S., this creates issues for doctors and nurses. Social care and mental health are reported as having suffered as in both the U.S. and UK it is still mostly paper-based.

Medical device asset tracking is a current problem within the healthcare sector. A report by Harland Simon[25] on a project justifying RFID tagging in NHS Cambridgeshire asserted that 15% of a hospital's assets are lost every year, representing a significant cost in repurchasing items the hospital already has. Additionally, according to a report published by GE Healthcare [26] nurses spend an average of 21 minutes per shift searching for devices and beds that have been misplaced with many hospitals, according to the study, defining any device below $5000 consumable and to be repurchased if they can't be found representing significant cost in the sector. By adopting radio-frequency identification (RFID) standards for medical device tracking, NHS Forth Valley in Scotland, according to another study published by Harland Simon[27] were able to save almost £400,000 in cost avoidance due to not having to purchase significant medical devices that would have otherwise been lost to the system.

Drug tracking is a different problem entirely to medical device tracking, as the main concern is counterfeit drugs. A study by the WHO[28] identified that as many as 10% of the pharmaceutical supply in the U.S. is counterfeit. The Food and Drug Administration (FDA) in the US recently endorsed the use of RFID to track pharmaceuticals from the supply chain to the patient. This allows the complete chain of custody to be monitored, ensuring that the hospitals have bought the pharmaceuticals from a legitimate source. Pfizer[29] was the first pharmaceutical company to adopt RFID "e-pedigree" where patients and doctors could trust the source and capabilities of their flagship medicine, Viagra, as they identified that it was among their most counterfeited drugs. This system has allowed wholesalers and pharmacists to verify the authenticity of their Viagra using a simple RFID scanner with the cost to Pfizer being low due to the use of low-cost passive RFID tags & barcodes.

Patient Records

Blockchain has significant power to disrupt healthcare and put data in the hands of patients. One particularly interesting move towards this is MedRec,[30] which gives patients and doctors an immutable log of healthcare records. It takes a different approach to incentivization for miners by giving access to anonymized healthcare data in exchange for sustaining the network. MedRec uses Smart Contracts to map Patient-Provider Relationships (PPRs) where the contract shows a list of references detailing the relationships between nodes on the Blockchain. It also puts PPRs in the hands of the patient, giving them the ability to accept, reject, or modify relationships with healthcare providers such as hospitals, insurers, and clinics.

Blockchain offers an opportunity for interoperability in healthcare systems as having a decentralized ledger of accepted fact in medical records where all healthcare providers have access to this ledger. This means that though the user-interfaces may be different, their central ledger will be identical across all providers. A challenge that exists relates to the current state of health records across providers, which contain significant amounts of the same information under different identifiers that may not be linked. This creates duplication and as the blockchain grows, the performance degrades and this level of replication of data across records would require deduplication to maintain a reasonably performant system with unique, anonymized identifiers to identify patients across all services. This is a business challenge in and of itself of adopting a blockchain health record, it is important to note that health records would not start from zero as they would have to replace the existing system which creates challenges.

Additionally, the sheer volume of data generated in healthcare environments, which is only set to increase further, with Kaiser Permanente believed to have between 26 and 44 petabytes of data on its 9 million members from EHRs and other medical data in 2014.[31] The volume of data logged and referenced to will only add to this scalability problem.

Drug Tracking

Drug tracking on the blockchain is another opportunity as it leverages the immutability of the blockchain to develop tracking and chain of custody from manufacturer to patient. Chronicled is a technology start-up company developing their product, Discover,[32] which creates a chain of custody model showing where the drug was manufactured, where it has been since, and when it has been disbursed to patients, leveraging the immutability of the blockchain to prevent fraud and theft of pharmaceuticals. This allows healthcare providers to meet current healthcare standards regarding pharmaceutical supply security, again with an emphasis on interoperability between healthcare providers. Hyperledger,[33] the Open-Source Blockchain Working Group, recently launched the Counterfeit Medicines Project[34] focusing on the problem of counterfeit pharmaceuticals. Using Blockchain, the origins of counterfeit medicines can be traced and removed from the supply chain.

The advantage of blockchain in drug tracking over traditional means is the decentralization of trust and authority inherent in the principles behind the technology, where central authorities can be bribed or faked it is much harder to bribe a consensus of those on the blockchain. For this reason, the current industry standard in pharmaceutical tracking, ePedigree,[29] which currently uses RFID and a traditional database is moving towards their own blockchain solution. If pharmaceuticals can be modified and tracked using blockchain's inherent anti-tampering capabilities at the point of manufacture, counterfeit pharmaceuticals can be completely removed from participating supply chains.

Device Tracking

Medical device tracking is another opportunity for the blockchain in disrupting healthcare from manufacturer to decommissioning. The monetary savings created by asset tracking are clear, NHS East Kent Hospital found that as a result of a case study by Harland Simon[35] in which they implemented active RFID trackers on their high waste equipment they found 98 infusion pumps they had no idea they still owned across three sites. At a cost of $1,500 each they saved $147,000 due to this single case study. The use of the blockchain along with this technology offers the opportunity for an immutable ledger, which shows not only where the device is but where it has been in its lifecycle, as well as which manufacturer, reseller, and the serial number are associated with the device, aiding regulatory compliance. This capability was addressed by Deloitte[7] in a white paper as one of the potential game-changers for blockchain in the healthcare sector. Indeed, an IBM study[36] showed that 60% of government stakeholders in healthcare believe that medical device integration and asset management are the greatest areas for disruption in the sector.

A blockchain approach offers several benefits over traditional location tracking products. The most obvious of which is the immutability and tamper-proof qualities of the Blockchain. This prevents a malicious user from changing the location history of a device or deleting it from record. This is particularly important factor considering that medical device theft and shrinkage has become a multi-million-dollar problem both in the US and the UK.[37,38]

As well as traditional theft, this immutability also prevents devices being lost and reordered, which incurs a significant cost both in terms of the care provided and in actual equipment costs. This system should not add significant additional workload to a nurse, porter or support worker, as it would only require a tap on the device with the mobile phone or scanner and then entering of the current location of the device.

While the application of blockchain within the Internet of Things (IoT) is fast developing, Huh[39] defines a way for devices to intercommunicate through an Ethereum blockchain and use an RSA public key system. In this way, a device stores their public key on the blockchain and the associated private key is stored on the device.

CONCLUSIONS

Proofs of concept have been developed which bring blockchain technologies into the healthcare industry however there are still many barriers to adoption. One of the most significant barriers will be the inherent resistance of the healthcare industry to change its current practices,[40] especially relating to organizational, structural, technological, and human factors.

Funding Statement [change if needed]

There was no public or private funding provided in the creation of this work.

Conflict of Interest: None

References

1. Courbe J. Financial services technology 2020 and beyond: embracing disruption. PWC. 2016. p. 48.
2. Nakamoto S. Bitcoin: A peer-to-peer electronic cash system. *www.bitcoin.org*, 2008. p. 9.
3. Accenture. Three technologies that are changing the financial services game. How visionaries are exploiting digital technology to reshape the future of financial services. 2016.
4. Boucher P. What if blockchain technology

revolutionised voting? European Parliament. 2016.
5. Deloitte. Blockchain in commercial real estate. The future is here! 2017.
6. Korpela K, Hallikas J, Dahlberg T. Digital supply chain transformation toward blockchain integration. *Proc. 50th Hawaii Int. Conf. Syst. Sci.* 2017. p. 4182–91.
7. Krawiec R, Barr D, J. Killmeyer J, et al. Blockchain: opportunities for healthcare. *NIST Work. Blockchain Healthc.*, August, pp. 1–12, 2016.
8. F. & Sullivan, "Why Healthcare Industry Should Care About Blockchain?," 2017. [Online]. Available: https://ww2.frost.com/files/8615/0227/3370/Why_Healthcare_Industry_Should_Care_About_Blockchain_Edited_Version.pdf. [Accessed: 28-May-2018].
9. Liang X, Shetty S, Tosh D, et al. ProvChain: A Blockchain-based data provenance architecture in cloud environment with enhanced privacy and availability. *17th IEEE/ACM Int. Symp. Clust. Cloud Grid Comput. 2017*. pp. 468–77.
10. Wood G, Ethereum: a secure decentralised generalised transaction ledger, *Ethereum Proj. Yellow Pap.* 2014. pp. 1–32.
11. Martino W, Popejoy S, Schroeder B, and Kent L, Juno distributed cryptoledger. CIB New Product Development. 2016.
12. Back A. Hashcash - A denial of service counter-measure. Adam Beck. 2002, *http://Www.Hashcash.Org/Papers/Hashcash.pdf*.
13. Ethereum. Ethash. 2017.
14. Ethereum. Dagger Hashimoto Algorithm. 2015.
15. O'Dwyer KJ, Malone D. Bitcoin mining and its energy footprint. *25th IET Irish Signals Syst. Conf. 2014 2014 China-irel. Int. Conf. Inf. Communities Technol. (ISSC 2014/CIICT 2014)*, 2014. pp. 280–5.
16. McFarlane C, Beer M, Brown J, Prendergas N. Patientory: a healthcare peer-to-peer emr storage network v1.0. 2017.
17. Microsoft. The Coco Framework. 2017.
18. Microsoft. Microsoft announces the Coco Framework to improve performance, confidentiality and governance characteristics of enterprise blockchain networks. 2017.
19. Roma P, Quarre F, Israel A, et al. Blockchain: an enabler for life sciences and healthcare blockchain: an enabler for life sciences healthcare. Delotte. 2016. pp. 1–16.
20. Barrett J. Fraud and Misconduct in Clinical Research. *Princ Pract Pharm Med.* Second Ed. 2007;4(2):631–41.
21. Benchoufi M, Porcher R, Ravaud P. Blockchain protocols in clinical trials: transparency and traceability of consent. *F1000Research*. 2017;6:66.
22. Powles J, Hodson H. Google DeepMind and healthcare in an age of algorithms. *Health Technol (Berl)*. 2017;7(4):351-67.
23. Fraser H, Kwon Y, Neuer M. The future of connected health devices. *Life Sci. 2011*. p. 20.
24. Wachter K. Making IT work: Harnessing the power of health information technology to improve care in England. Report of the National Advisory Group on Health Information Technology in England. 2016.
25. Booth C, Jarritt P, Dawkins S. The Role of RFID in managing mobile medical devices. *Harl. Simon*, 2013. pp. 1–28.
26. Horblyuk R, Kaneta K, Mcmillen GL, et al. White paper: out of control. How clinical asset proliferation and low utilization are draining healthcare budgets. *GE Healthc*. 2012.
27. Hynd B, Physics M, Valley NHSF. Healthcare science final report on test of change passive RFID tracking of mobile medical devices within forth valley royal hospital. 2017;1:1–8.
28. WHO, *International medical products anti-counterfeiting taskforce (IMPACT)*. 2010.
29. Bacheldor B. Pfizer prepares for Viagra E-Pedigree Trial. *RFID J*. 2007.
30. Azaria A, Ekblaw A, Vieira T, Lippman A. MedRec: using blockchain for medical data access and permission management. *Proc. - 2016 2nd Int. Conf. Open Big Data, OBD 2016*. pp. 25–30.
31. Raghupathi, R Raghupathi V. Big data analytics in healthcare: promise and potential. *Heal. Inf. Sci. Syst.* 2014;2(1):3.
32. Chronicled, Chronicled - Supply Chain Compliance. 2017.
33. Hyperledger. Hyperledger. 2017. .
34. Taylor P. Applying Blockchain Technology to Medicine Traceability. 2016.
35. Simon H. Case study tracking medical devices with

RFID. 2014.
36. IBM Institute for Business Value. Healthcare rallies for blockchains. 2016.
37. ADT Services. Preventing shrinkage and equipment losses in hospitals, 2011.
38. Auditor General for Scotland. Equipped to care managing medical equipment in the NHS in Scotland. 2001.
39. Huh S, Cho S, Ki S., Managing IoT devices using blockchain platform. *2017, 19th International Conference on Advanced Communication Technology (ICACT)*, 2017. pp. 464–467.
40. Sligo J, Gauld R, Roberts V, Villa L. A literature review for large-scale health information system project planning, implementation and evaluation. *Int. J. Med. Inform.* 2017;97:86–97.

Supplementary data: None