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Blockchain Technology as a Mechanism for Digital Railway Ticketing

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Abstract—This paper introduces a novel digital ticketing platform using blockchain technology. Taking in a number of considerations by observing legacy ticketing systems and existing attempts at digital ticketing, we make use of IBM's Hyperledger Fabric framework to design an architecture that distributes the tickets across all participating organisations. We note the potential benefits this platform has. Governing organisations maintain their right to set the rules of the platform and access the data to generate statistics. Vending organisations share access to the same underlying tickets whilst preserving competition. The platform offers passengers a variety of ways to pay for and access their tickets, using a combination of legacy and modern methods. Furthermore, we note the platform has the potential to eradicate paper ticketing and surplus voucher cards.

Index Terms—blockchain, ticketing, railway, hyperledger

I. INTRODUCTION

This paper addresses the potential of blockchain technology as a mechanism for digital ticketing. Section I provides a background on the state of railway ticketing and blockchain technology. Section II considers requirements for the new platform, and introduces the new architecture and mechanics of the platform. Section III offers results from stub tests simulating interactions on the platform between governing organisations, vending organisations, and passengers. Section IV discusses the benefits and limitations of the platform. Section V concludes the research and discusses future avenues of work in the field.

A. The State of Railway Ticketing

Railways across the globe are experiencing a modern renaissance. At the forefront of this period of revitalisation is the pursuit of digitalisation, whereby the industry upgrades the numerous legacy systems our railways rely upon to conform to twenty-first century expectations. [1] There are a plethora of fields which digitalisation has benefited the railway industry, and one such topic is railway ticketing. Passengers have seen an increasing number of options to purchase digital tickets in the over the recent decade. National Rail indicate that passengers in the United Kingdom (UK) may download an *m-Ticket*, which is “just like the standard orange rail ticket, but its held on your mobile device”. [2] As of October 2019, a selection of Train Operating Companies (TOCs) and certain vendors will permit the use of a smartcard that utilises Quick

Response Code (QR Code) and Near-Field Communication (NFC) technologies to validate tickets.

1) *The Passenger Experience*: Passengers using the railways in the UK may purchase tickets via two distinct methods: the passenger may purchase a ticket at any station on the network using cash or bank cards, henceforth known as *station purchase*; or the passenger may purchase a ticket via the World Wide Web (WWW), henceforth known as *online purchase*. Station purchase allows passengers to buy from a machine or (where available) at the ticket office from a member of staff, whereas online purchase bypasses the need to use station facilities and allows the passenger to purchase a ticket via a browser or a bespoke phone application.

The passenger then obtains the tickets depending on their method of purchase. If a passenger chooses station purchase, the machine (or member of staff at the ticket office) prints the tickets at the point-of-sale in the form of a paper ticket. Online purchase allows passengers to print tickets using a personal printer at home or at a station machine/staff member, or in particular situations, downloaded as an m-Ticket.

Passengers validate tickets when entering or leaving stations through electronic gates, or via a conductor whilst on board a train. With the former method, it is more common for the barriers to support the physical tickets with magnetic strips, whereby certain criteria of the moment of validation (i.e. correct date and route) test the validity of the ticket. Some gates offer scanners that allow for QR Codes from m-Tickets and home-printed tickets, and NFC for smartcards. Otherwise, interaction with a staff member at the barriers is necessary to gain access.

2) *Existing Digital Tickets: Problem Solved?*: Though m-tickets are a step in the right direction, this approach to digital ticketing is not without limitations. To use m-tickets, it is a prerequisite that a passenger must: own a mobile phone; have access to the WWW; and be willing to pay with an digital method of payment. A report conducted by Grant et al. [3] identified that approximately 20% of residents in the UK do not have access to the WWW. Therefore, this approach to digital excludes a large group of passengers who may not own mobile phones, have no access to the WWW, or those who seek to pay with cash.

Moreover, passengers who opt to use this approach are

subject to specific issues. Should the mobile phone hosting the application become inoperable (due to a flat battery, hardware issue etc.), the passenger has no way of proving their ticket's validity and will be subject to a fine. Furthermore, the organisations selling tickets restrict the digital tickets to their own applications. In the event that this application suffers from any downtime, the ticket is no longer accessible, and the passenger is subject to a fine.

Smartcards offer a viable alternative to those excluded from using m-tickets. However, the smartcards due for release in the UK have a number of restrictions. Each smartcard is only capable of storing five tickets at one time, and a ticket may take up to two hours to deliver to the card. [4] As such, the current approach to digital ticketing is not yet a suitable replacement for legacy ticketing.

3) *Fare Tracking and Statistics*: The privatised nature of the railway industry in the UK requires the ticket vendors to record their ticket transactions, and share them on a large database known as Latest Earnings Network Nationally Over-Night (LENNON), operated by the Rail Delivery Group (RDG). LENNON is the revenue settlement service for the TOCs in the UK, and distributes the income according to the Rail Settlement Plan (RSP) within twenty-four hours of the purchase of the ticket. LENNON consists of data and models that provides a fine level of granularity: franchise competition; franchise management; fare policies; strategic fare modelling; and revenue impact. LENNON is a centralised database that relies upon a cloud solution provided by Google. Data queries and the addition of data must go through the Application Programming Interface (API) provided by the RDG. This API is static, and is subject to modification when the database requires upgrading.

B. Blockchains: A Brief Introduction

1) *Blockchain Mechanics*: A blockchain is a form of distributed ledger that records transactions between users on a network. [5] To become an active user on the network, one must create an identity. The majority of platforms use an Elliptic Curve Cryptography (ECC) keypair; a public key and a private key. An address, where other users may direct transactions to, is a hash digest of the public key. The private key signs transactions in order to verify them, by utilising an appropriate Digital Signature Scheme (DSS).

An amalgamation of peer nodes forms a blockchain network, hosted by the active users and responsible for maintaining the ledger of transactions. To perform a transaction, User A selects User B's address. Using the platform protocol, User A forms a transaction¹, signs the transaction using their private key, and announces the transaction to the network. Other peer nodes listen for new transactions and forms a candidate block; a hash digest of valid transactions that have yet to make the ledger. The node announces the candidate block to the network in order to add it to the ledger. Other nodes check the candidate block is valid to ensure that the block contains

no fraudulent or incorrect transactions included by the block's creator. A consensus mechanism prevents block duplication and a bottleneck of network traffic. As the process continues, the ledger continues to expand as a chain of these blocks of transactions; hence the term blockchain. This version of transaction flow is *order-execute-update*.

Embedded within the mechanics of a blockchain platform is a plethora of cryptographic procedures to provide security. A consensus mechanism ensures all transactions performed on the network are valid via a cryptographic protocol. Furthermore, the blocks on the ledger contain information about the previous block to ensure a tamper-proof ledger. Smart contracts provide controlled access to the ledger, and is a form of distributed computing whereby the ledger stores the variables and results of a program. This allows applications to interact with the ledger and for users to agree on automated tasks that will affect the state of the ledger.

2) *HyperLedger Fabric*: Hyperledger Fabric is an open-source distributed ledger framework designed for enterprise solutions. [6] As a permissioned blockchain, it bypasses the global behaviours of public blockchain platforms (such as Bitcoin and Ethereum), whilst maintaining the core mechanics and securities that blockchain technologies provide. The framework uses a Membership Service Provider (MSP) in the form of X.509 certificates to verify the user permissions on the network. Organisations, who regulate the network policies via hosting peer nodes, use the concept of memberships to determine the rights of individuals within the network and peer nodes alike. Channels regulate whom can access various ledgers hosted on a network. Hyperledger Fabric uses a modified transaction flow to that of a conventional blockchain. The *execute-order-validate-update* flow allows transactions to execute before appearing on the ledger, thereby improving throughput. As such, the throughput of Hyperledger Fabric is approximately 3,500 transactions per seconds [6], though Gorenflo et al. [7] propose an architectural modification to achieve up to 20,000 transactions per second.

3) *Blockchain Ticketing*: Ticketing based on blockchain technology is not a novel concept. However, the platforms that exist focus on the prevention of fraud and distribution of event tickets. BitTicket [8] and DigiTix [9] are two such Distributed Applications (DApps) that make use of smart contracts on the Ethereum blockchain to perform transactions and store tickets in a wallet.

C. Research Intentions

This paper intends to introduce a novel digital ticketing platform based on state-of-the-art blockchain technology to achieve five goals:

- A platform fit for use by all passengers without any exclusions;
- A platform that distributes underlying data amongst the competing organisations to prevent siloation;
- A platform that retains all necessary requirements of current ticketing systems;

¹This may be a reallocation of digital tokens/currency, or a transfer of data

- A platform that retains the capabilities of fare-splitting systems (such as LENNON);
- A platform that eradicates the need for paper tickets and surplus materials.

The paper shall use the current ticketing system within the UK as a reference, though the concepts throughout are transferable across ticketing systems throughout the globe.

II. METHODOLOGY

A. Considerations

The platform takes a number of requirements into consideration, concerning both passengers and ticket vendors alike. This is to retain the advantages of the existing method of railway ticketing offers, and to eradicate any disadvantageous or surplus features.

1) *Passengers*: Section I-A1 describes the experience for passengers purchasing tickets in the UK. However, there are additional considerations regarding the specificity of the tickets. First, a variety of types of ticket must exist: advanced single and return journeys, whereby the tickets restrict passengers to specific trains; open single and return journeys, restricting passengers to a specific route; and seasonal tickets, where the ticket is valid on a particular route for an extended period of time. Within these types, vendors offer various fares: first class and standard to differentiate the class of travel taken; peak off-peak fares, restricting travel during specific times of the day; and discounted tickets due to age or the validity of an accompanying railcard. On top of this, passengers book seat reservations alongside advanced tickets.

With these aspects taken into consideration, we note that the platform must preserve the following aspects:

- Passengers must have the option of station purchase and online purchase, so to not discriminate against non-online users;
- Passengers must have the option to purchase with cash or bank card;
- Passengers must have access to tickets without requiring online access;
- The platform must handle all existing types and fares of tickets as listed above;
- The platform must handle seat reservations;
- The platform must protect passengers against loss or theft of an identity.

2) *Organisations*: On privatised railway networks, it is crucial to maintain competition between organisations acting as ticket vendors. As such, passengers should be able to choose whom they purchase their ticket from (when using online purchase). Vendors should offer identical base tickets and prices, with allowances for sales. Particular organisations refuse to accept the validity of m-tickets from other organisations, making paper tickets necessary. In the UK, LENNON captures data from the vendors and other TOCs on a daily basis. LENNON combines this data with relevant non-Lennon data to calculate passenger usage and split the fares between the TOCs in a fair manner.

As such, the platform should aim to achieve the following:

- Vendors must offer identical base tickets and prices, with allowances for sales;
- Vendors must have access to tickets sold by other companies, without sacrificing security and privacy of their systems;
- The platform must store data in a distributed manner to allow for sharing and to avoid downtime.

3) *External Factors*: A pressing issue of many organisations is the need to be conscious of the environmental impacts. Paper tickets and plastic railcards are still in use in the UK. As such, the platform should aim to achieve the following:

- Organisations must eradicate paper tickets to reduce waste;
- Organisations must eradicate surplus plastic railcards to reduce waste;
- Tickets and railcards must still be accessible to those without access to the WWW.

B. Platform Architecture

The platform makes use of the Hyperledger Fabric framework. Figure 1 illustrates the network architecture of the ticketing platform to achieve decentralised data sharing, whilst maintaining individual rights and security for participating organisations. First, one of the participating organisations initiates the network. The most likely candidate to act as the initiating organisation is the organisation responsible for governance of the railway network.² Within Figure 1, the colour red represents this organisation. Upon initiation, the network (represented by the outer bold line in Figure 1) consists of three artefacts: a network policy, which provides the initiating organisation with administrative rights for the network in the form of a MSP; a certificate authority, which dispenses digital identities to permitted users within the initiating organisation; and an Orderer node³, responsible for ordering future transactions into blocks prior to consensus.

Once the initiating organisation establishes the base network, they create a channel to add additional organisations. (Figure 1 illustrates this channel with a dashed line, and the additional organisations in green and blue.) These organisations do not require network administrative privileges, hence they exist in the channel. Channels are sub-networks that possess self-contained ledgers and smart contracts for members of the channel to share between one another. Upon creation, the initiating organisation establishes a channel policy, granting MSPs to each organisation participating in the channel to allow for shared administrative rights. Furthermore, the initiating organisation forms a unique sub-organisation to maintain the identities of passengers seeking to use the platform. This allows organisations on the channel to share the underlying data, eradicating the need for passengers to create a separate identity for each organisation they interact with.

²In the case of the UK, this is the RDG

³There may be more than a single Orderer node

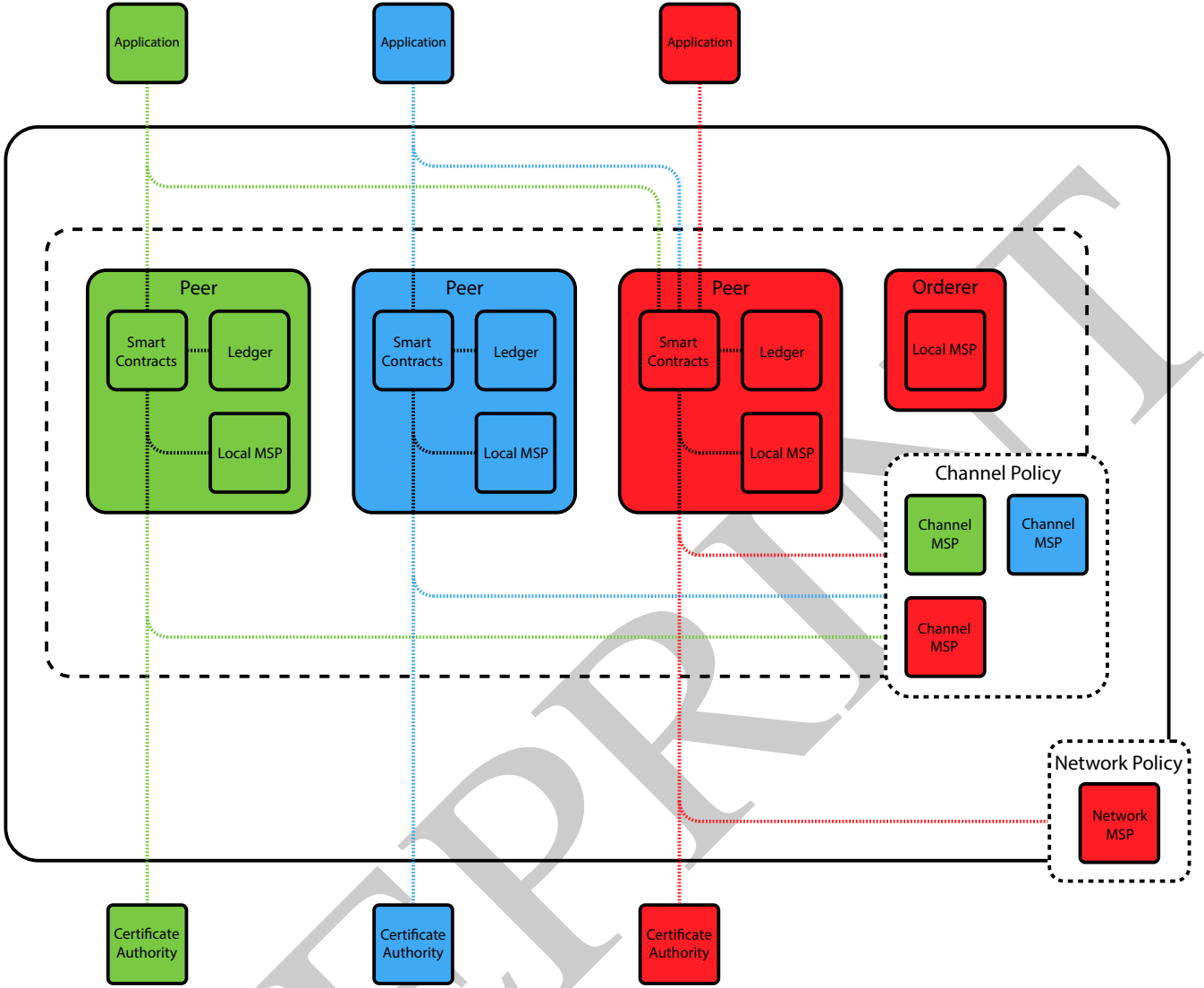


Fig. 1. The digital ticketing platform architecture. The differing colours represent different organisations.

The additional organisations host Peer nodes on the channel to store a copy of the channel ledger, execute smart contracts, and provide consent to transactions initiated by other organisations. Furthermore, the additional organisations provide their own applications to allow passengers to purchase tickets. The organisations construct the applications around the various methods identified in Section I-A1; for example, mobile applications, websites, or fixed station ticket terminals. Applications are responsible for verifying the identity of a passenger prior to requesting a transaction to issue a ticket (as a digital asset on the channel ledger).

C. Platform Mechanics

Figure 2 illustrates the platform mechanics that operate on the architecture of Figure 1. Any passenger who wishes to purchase a ticket must create a platform identity. The platform stores the identity as an X.509 digital certificate

which contains appropriate information about the passenger, such as their age (to determine permissible fares) and any railcards and other discounts the passenger is subject to. The platform restricts the creation of an identity to a smart contract built and stored by the initiating (governing) organisation. Nonetheless, applications from additional organisations (the ticket vendors) have access to this smart contract by invoking the contract via a request to the governing organisation peer node. Figure 1 demonstrates this. The Channel MSP of the governing organisation stores the identity, thus is accessible to all participating organisations within the channel. This results in organisations using the same identity, preventing data duplication and redundancy.

The platform entitles passengers with digital identities to purchase tickets. As the Channel Policy maintains their identity, the passenger may use an application provided by

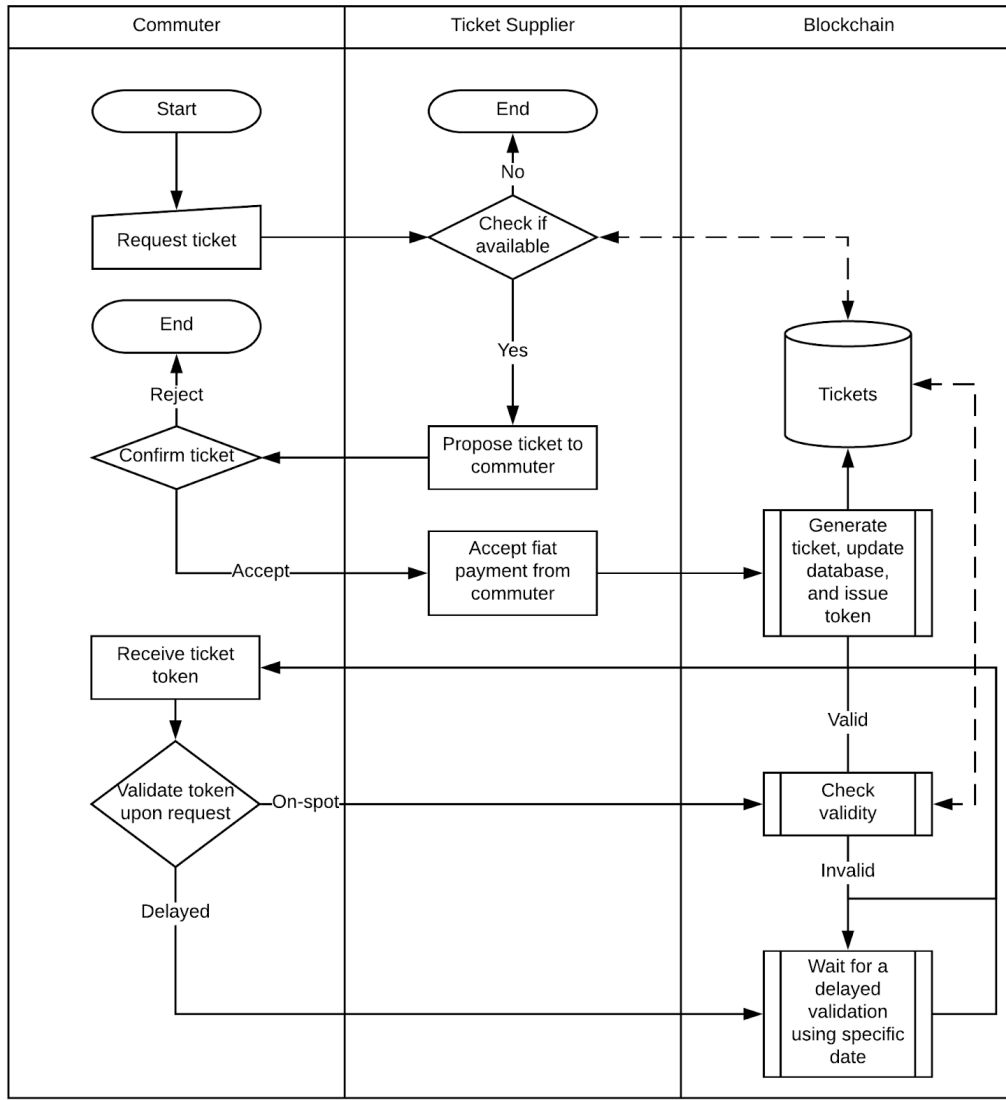


Fig. 2. The process flow of the platform.

any organisation. The passenger submits a request of the tickets they wish to purchase (along with a valid signature corresponding to their digital certificate) to the application, which proceeds to validate this request via a smart contract stored within the Peer node of the dispensing organisation. The Channel's distributed ledger records the ticket as a transaction, whereby the vendor's identity transfers the underlying asset (the ticket) to the passenger's identity. The transaction contains the necessary information about the ticket. Certain organisations within the channel require the ability to validate tickets. An application designed by this organisation obtains passenger credentials upon request and queries the ledger via a smart contract to establish whether a valid ticket exists that meets the criteria provided within the application.

III. RESULTS

In order to test the capabilities of the platform, we performed a series of case studies. The perspectives of the different users of the platform are key to forming these case studies: the passenger seeking to purchase a ticket; the organisations seeking to vend and verify tickets; and the organisation responsible for the governance of platform. To simulate the behaviour of hypothetical applications and technologies, the tests were in the form of stub testing, whereby mock data simulates the inputs and outputs required.

A. Case Study: Administrative Organisations

There are two significant administrative organisations required for the platform; an organisation to initialise the network and provide rules and platform governance, and an organisation to analyse ticketing statistics. The following tests

combine these responsibilities into one organisation. However, this is achievable with two separate organisations.

Organisation R (denoted by red in Figure 1) is responsible for initiating the network and adding organisations to the channel. The first test for Organisation R is as follows:

- 1) Organisation R initiates the network, providing a certificate authority, an Orderer node, and a network MSP.
- 2) Organisation R initiates a channel within the network, providing a Peer node and a channel MSP.
- 3) Organisation R provides smart contracts on their Peer node to allow applications to add passenger identities to the channel.

Further to their initiating responsibilities, Organisation R requires access to the entire database to provide a statistical overview of the ticketing data. Moreover, access allows Organisation R to evaluate the fares of the passengers and distribute the profit between the stakeholders as per the agreement of LENNON. The second test for Organisation R is as follows:

- 1) Organisation R creates an additional smart contract to perform queries on the ledger.
- 2) Organisation R gathers this data in a suitable format for further analysis.

B. Case Study: Ticket Vendors

Two hypothetical ticket vending organisations exist to test the platform against the passenger considerations of Section II-A.

Organisation B's (denoted by blue in Figure 1) sole responsibility is selling tickets for passengers. To achieve this, Organisation B must host one or more peers on the channel for two reasons; to consent to other transactions within the channel, and to issue new tickets to passengers using their application. Thus, the test for Organisation B is as follows:

- 1) Organisation B adds at least one peer node to the channel.
- 2) Organisation B issues an application for passengers to purchase tickets. This application will connect to the channel to identify the passengers from the passenger organisation.
- 3) Organisation B provides consensus for other transactions on the channel.

Organisation G (denoted by green in Figure 1) is a TOC, and is therefore responsible for both issuing and validating tickets. Validation occurs upon request. Aside from this additional responsibility, the test is identical to that of Organisation B's.

- 1) Organisation G adds at least one peer node to the channel.
- 2) Organisation G issues an application for passengers to purchase tickets. This application will connect to the channel to identify the passengers from the passenger organisation.
- 3) Organisation G validates the passenger tickets.
- 4) Organisation G provides consensus for other transactions on the channel.

C. Case Study: Passengers

Three hypothetical passengers (henceforth named Alice, Bob, and Charlie) exist to test the platform against the passenger considerations of Section II-A.

Alice is twenty-four years of age, and thus qualifies for the Young Persons Railcard which offers a discount of 25% on the usual fare. She uses Organisation B's application on her mobile phone to create her identity, procure her railcard, and purchase an open return, standard-class ticket. The test for Alice is as follows:

- 1) Alice creates an identity and purchases a Young Persons Railcard with Organisation B's application.
- 2) Alice purchases an open return ticket from Organisation B's mobile application.
- 3) Alice validates the ticket with Organisation G.

This tests against the feature of built-in railcards, removing the separation between the ticket and the railcard. Furthermore, the test proves the ability for two competing companies to interact with the same underlying ticket.

Bob is under sixteen years-of-age, thus qualifying for a child's fare. Bob sets up his account online at home under the supervision of his parents. Using their own accounts, they send Bob an advance single ticket with corresponding seat reservations via the website provided by Organisation G. The test for Bob is as follows:

- 1) Bob's parents create an account.
- 2) Bob creates an account, providing his age.
- 3) Bob's parents purchase an advance single ticket from Organisation G using their credentials.
- 4) Bob's parents send him the ticket via the application provided by Organisation G.
- 5) Bob validates the ticket with Organisation G.

This test checks the automatic qualification of cheaper fares, and the transfer of tickets between passenger accounts. Once again, the underlying ticket is accessible by competing companies.

Charlie creates an account and purchases a season ticket using station facilities. He loses his card and wishes to cancel the digital identity to prevent anybody who finds his card from using it. The test for Charlie is as follows:

- 1) Charlie creates an account at the station.
- 2) Charlie purchases a season ticket from Organisation G using cash at a station.
- 3) Charlie validates the ticket with Organisation G.
- 4) Charlie loses the physical card provided, and cancels the identity using Organisation B's application.

This tests the ability to create seasonal tickets that require validation between a large range of dates. Moreover, it tests the revocation of identity should that be the passengers desire.

IV. DISCUSSION

The architecture and the mechanics of the platform combine the requirements of railway ticketing with state-of-the-art technologies to provide the platform with the capability to support them. This section discusses how the symbiotic development

of the platform results in a number of beneficial aspects, along with the limitations of such an approach.

A. Technological Benefits

The design of the platform on Hyperledger Fabric - with channels and a separate organisation for handling passenger identities - maintains competition between ticket vending organisations. This grants vending organisations with freedom to design their own applications and offer tickets in a similar fashion to any legacy applications. The applications provided are external to the network, thus can interact with other databases and APIs. For example, timetabling data and vehicle information required for seat reservations is accessible by the application, which can use the data to inform decisions prior to dispensing tickets. Furthermore, the flexibility offered gives rise to the possibility of a number of methods of accessing tickets; for example NFC or QR Code.

The use of blockchain technology provides a secure distributed platform. This results in no centralisation of the data, preventing the possibility of network downtime and the redundancy of duplication. If one vending organisation experiences an issue, a passenger's ticket is accessible through any other participating organisation. The Peer nodes store a local copy of the distributed ledger, allowing for real-time ticket enquires. This reduces the network bandwidth that would otherwise be necessary to transmit the request and response across the network via an API.

B. Additional Benefits

1) *Environmental*: Paper tickets and surplus plastic railcards become redundant with use of the platform. The platform provides organisations with flexibility in designing their own applications. This offers a variety of methods for passengers to access their tickets and digital identities, including mobile phones and reusable multi-purpose smart cards that have access to NFC and QR Code technologies. The identities are X.509 certificates that store personal details and any valid railcards. The distributed ledger records transactions of tickets, whereby the accounts are intrinsic to the passenger identities.

2) *Passenger Experience*: The platform does not require a paradigm shift in ticketing from the perspective of a passenger. Passengers are still offered a variety of methods to purchase tickets, and online access is not a prerequisite for using the platform. This avoids forcing passengers to obtain online access. Once a passenger has created a platform identity, they may reuse this with any vending organisation participating in the platform. Because the platform uses a distributed ledger to store and access tickets, and passengers have multiple avenues of accessing their platform identity, the platform reduces single points-of-failure point of failure for the passenger. For example, should a passenger's phone run out of battery rendering inaccessible phone applications, they may use a smartcard linked with their identity instead to access exactly the same ticket; the ticket is not restricted to one organisation.

C. Limitations

The limitations of the platform pertain to the participating organisations, and the existing infrastructure that must adapt to support the platform.

1) *Organisations*: In order to make use of the platform's mechanics, vending organisations must modify existing applications to interact with the network. Furthermore, organisations must decide upon where they host their own Peer nodes.

2) *Infrastructure*: Infrastructure must adapt to support the platform. To validate any ticket, the organisation queries the latest copy of the ledger. Though possible to perform offline (from a local copy of the ledger at any Peer node) the nodes require internet access to update the ledger to the newest state. Any machine that validates a ticket - whether an electronic gate or a handheld device - must have access to the internet in order to update the ledger.

V. CONCLUSION

A. Summary of Findings

This paper has presented a novel approach to digital ticketing using blockchain technology. We have utilised the security and decentralisation of the technology to provide a distributed system that benefits both passengers and organisations.

The platform utilises the existing technology of IBM's Hyperledger Fabric. Channels separate organisations into relevant groups that control the accessibility to particular tickets. Organisations host peer nodes which hold a local copy of the ledger and the smart contracts designed to issue new tickets and query the ledger. Peer nodes are responsible for endorsing transactions to add to the ledger.

This design gives rise to a platform whereby participating organisations may still compete against one another to issue tickets to passengers, but the underlying ticket data is the same.⁴ We note the platform does not force a paradigm shift in the approach to ticketing, as the platform preserves a range of inclusive methods of ticket purchase for the passengers.

B. Impact of Research

This research will promote interest in the area of digital ticketing using distributed solutions. As of the time of writing this paper, the majority of digital ticketing takes the form of QR Codes on mobile applications and restrictive smartcards, both of which have limitations that might result in loss of proof for the passenger. The platform presented is the first step towards a system inclusive for all passengers, whilst providing numerous other technological and environmental benefits.

C. Future Research

Though we address the throughput of Hyperledger Fabric, the platform must handle the number of ticket transactions and validations that occur on a real-time basis; thus the platform must be stress tested against the demands of the railway networks around the world. Furthermore, the platform

⁴This is analogous to a paper ticket purchased with one vending organisation and verified by another.

requires testing with real applications and integration with real hardware. The stub tests performed as part of this paper simulate application behaviour to evaluate the architecture and mechanics, and does not test the efficiency of real software and hardware used in the industry. Moreover, this paper has laid the groundwork from which to build on, but blockchain technology is evolving, which may result in more elegant solutions to the problem at hand.

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