BaaS Architecture for DApps and Application for Veterinary Medicine Case Study in Ireland

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***Abstract*—Blockchain technology provides promising solutions to problems where trust between participants is a significant concern. Blockchain technology eliminates centralised trusted authorities and provides decentralised trust assessments and improved transparency and immutability for transactions. Blockchain platforms have tightly connected decentralised consensus mechanisms and distributed ledgers. However, within DApps(decentralised applications), blockchain platforms should easily communicate with other systems, including data storage systems and front-end applications. Blockchain is not for storing big data. The transactions cost is a primary concern when developing DApps for commercial use. This paper proposes a BaaS(Blockchain as a Service) architecture enriched with a loosely coupled service API(Application Programming Interface) connecting IPFS(Interplanetary File System) as the information storage and smart contracts to govern the business logic. We realised the proposed architecture for prescriptions management in a veterinary medicine case study in Ireland. The solution DApp continuously monitors the updates of prescriptions, medicine dispenses, and medicine administrations while restricting the overuse of prescription and the use of counterfeit drugs. The traceability improves the transparency of treatment activities and information retrieval for users. Moreover, the proposed architecture is easily adaptable and maintains low-cost transactions with the support of IPFS and smart contract events.**

***Index Terms*—Blockchain, Smart Contract, Interplanetary File System, Blockchain As A Service, Decentralised Applications**

I. Introduction

Blockchain technology eliminates the need for a trusted authority and replaces it with a system of publicly verifiable proofs. The use of blockchain technology for e-Prescriptions is not new. Authors in [1] present a blockchain solution to combat the opioid crisis. However, veterinary medicine in the agriculture sector has its challenges. This research considered a prescriptions management case study in Ireland to identify its known challenges and resolve them using a blockchain-based trusted solution.

Animal medicines, including vaccines, play an essential role in the control and prevention of animal disease. There are strict controls to govern the authorisation, distribution and use of animal medicines in Ireland [2]. Antimicrobial Resistance has emerged in recent years as a significant threat to public health, and several countries have substantially reduced national antimicrobial usage in animal production. A recent study in [3] has five recommendations, including an electronic prescribing system. Irish dairy farmers and veterinary practitioners use a farmer-based tool called dairy antibiotic use calculator to record and monitor the antibiotic use [4]. The prudent use of antibiotics is essential to maintain their efficacy. The medicine should be used appropriately, responsibly and safely. However, trust is still significant concern about these records, and these records are not verified for trust.

Healthy stock is inextricably linked to safe food and healthy consumers. Farm to fork information retrieval is becoming popular. The consumers' trust can be developed by improving transparency and access to information attached to livestock farming, including farming conditions, treatments, and processing of commodities. Moreover, consumers have a right to know accurate information regarding what they consume. However, in the present market, consumers do not have knowledge about medicines used in livestock farming. There are several known issues in the domain of veterinary medicine prescription management and livestock farming:

- Overuse of prescription medication is because there are no control mechanisms to prevent purchasing prescribed medication from multiple sources.
- Counterfeit drugs are increasingly available and difficulty to establish provenance.
- Monitoring constraints, including never sell animals or supply milk before the withdrawal period has elapsed.
- Lack of consumer access to information regarding medicine used at livestock farming.

We use blockchain technology and a decentralised file storage concept to resolve the challenges mentioned above, including challenges in the trusted provision, provenance, and traceability of veterinary prescriptions and related activities. Trusted data management is one of the critical enablers of blockchain technology compared to other system development technologies. On the other hand, veterinary medicine treatments for food-producing animals need transparency, trusted data management, and compliance to reduce consumers' health risks, ultimately enabling sustainable farming. This research presents a BaaS architecture for DApps and realises a veteri-

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nary medicine case study in Ireland. BaaS has decentralised IPFS as the storage and Ethereum blockchain [5] as the public blockchain platform. We evaluated the proposed solution for trusted provision, provenance, and traceability. The BaaS architecture was evaluated for adaptability and cost.

The next section, section II, will explain the literature review. The section III explains a veterinary medicine case study in Ireland. The proposed BaaS architecture is explained in section IV and design, implementation and testing are presented in section V. Finally, results and discussion are presented in section VI.

II. Literature Review

Blockchain provides a shared, immutable and transparent history of transactions enabling the building of applications that incorporate trust, accountability and transparency [6], [7]. However, blockchain is primarily proposed for publicly verifiable transactions and does not provide privacy to individuals. Authors in [8] propose a data-sharing framework to provide the authenticity of the shared data and transactional privacy. Authors in [9] introduce a dynamic consent model for health data sharing using blockchain. The consent and purpose recorded on the blockchain via the smart contract enable data sharing between two peer-to-peer nodes.

Blockchains are optimised for transparency. However, managing public and private information of transactions using semantic triples is discussed in [6]. The Triples for Transactions(T4T) model defines blockchain transactions and enable peer-to-peer sharing of private and sensitive information. Pubic information is recorded on the blockchain, and private information is recorded on private data stores. T4T transactions recorded on the blockchain enables private data sharing, access to public information for traceability, and information access for auditing. Bitcoin enables trusted, auditable, and peer-to-peer transactions using public ledgers [7]. The iShare framework proposed in [10] for privacy-aware multi-agent information sharing uses the decentralised nature of blockchain and digital signatures to ensure that an adversary cannot pose as a legitimate organisation/user or cannot control/hamper the system.

As in [11], a general theory of trust in networks of humans and computers should be build considering both behavioural trust and computational trust. Blockchain systems built on foundations of mutual mistrust can become trustworthy, and blockchain architecture is considered as a new architecture of trust [12]. An adaptable RESTful architecture has been introduced in [13]. However, recording a large amount of information on the blockchain is extremely expensive. On the other hand, IPFS [14] introduces content-based decentralised file addressing than traditional location-based centralised file addressing. Therefore, Blockchain, IPFS, and adaptable architecture together can develop trusted and cost-efficient blockchain solutions.

Symbol	Route of Supply	Associated Meaning
VPO 1	Veterinary Practitioner use only	For use by veterinary practitioners only
VPO	Veterinary Practitioner use only	For use by veterinary practitioners only (render assistance if required)
POM	Prescription only medicine	supplied by a pharmacist or registered veterinary practitioner for use under the prescription of a veterinary practitioner. Certain POM animal remedies may also be supplied by a licensed merchant.
POM(E)	Prescription only medicine exempt. Prescription not required.	For supply by veterinary practitioners or pharmacists (in person) only
PS	Pharmacy only. Prescription not required.	For supply by veterinary practitioners or from pharmacies only
LM	Licensed merchant. Prescription not required.	For supply by a pharmacy, veterinary practitioner, or merchant licensed to sell animal remedies
CAM	Companion animal medicine. Prescription not required.	For supply by a pharmacy, veterinary practitioner, merchant licensed, or retailer registered to sell such medicines

TABLE I: Route of Supply

III. Veterinary Medicine Case Study in Ireland

Here, we describe an Irish case study regarding prescribing and administering animal remedies and related concerns. In Ireland, veterinary medicine importation is regulated by the Department of Agriculture, Food and the Marine (DAFM). The prescribing and dispensing regimes are defined by national legislation (SI no. 786 of 2007) [15], [16]. The symbol, route of supply and associated meaning of remedies are described in table I, and more details can be found on [15], [17]. Medicines authorised by the HPRA [15] for animals should be purchased from suppliers who are specifically licensed by the DAFM. Users should be responsible for ensuring that veterinary medicines are sourced in accordance with the legislation. As in [18], it is the responsibility of farmers to maintain accurate records in relation to the use of veterinary medicines on their farms.

In Ireland, medicine recording is a legal requirement and is an area that frequently challenges farmers to ensure all details are correct for audits and cross compliance [19]. Bord Bia has given a farm book to record medicine [20], and Bord Bia inspections include a list of compliance requirements, including animal remedy prescriptions, animal remedy purchase records, animal remedy usage records, animal health plans, dead animal receipts, and animal mortality and significant health issues record [21].

The case study is illustrated using systems, actors(primary and secondary), use cases, and relationships as in figure 1. Primary actors initiate the use of the system, and secondary actors are reactionary. This case study addresses the followings:

- Create Prescription use case - The prescriptions issued by Veterinary practitioners are recorded on the blockchain. The purchased medicine use case - this will record farm details and drugs purchased on the blockchain. Creating prescriptions and purchasing medicines will automatically verify registered drugs, suppliers, and their validity

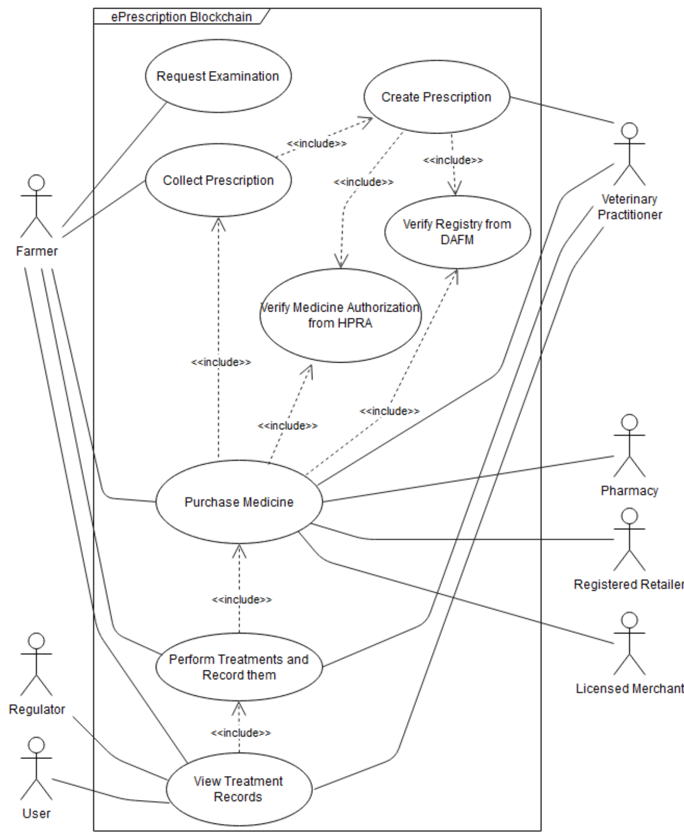


Fig. 1: ePrescription Case Study and Use Cases

to issue the type of medicine. Medicine will be validated for counterfeit drugs.
- Veterinary practitioners and farmers can record treatments on the blockchain.
- Veterinary practitioners can retrieve prescriptions, including their prescriptions and old prescriptions issued for a given farm.
- farmers and regulators can view the history of treatments, medicines used, pending treatments, withdrawal constraints, and corresponding periods.
- users can view farm animal history, including treatments and medications used.

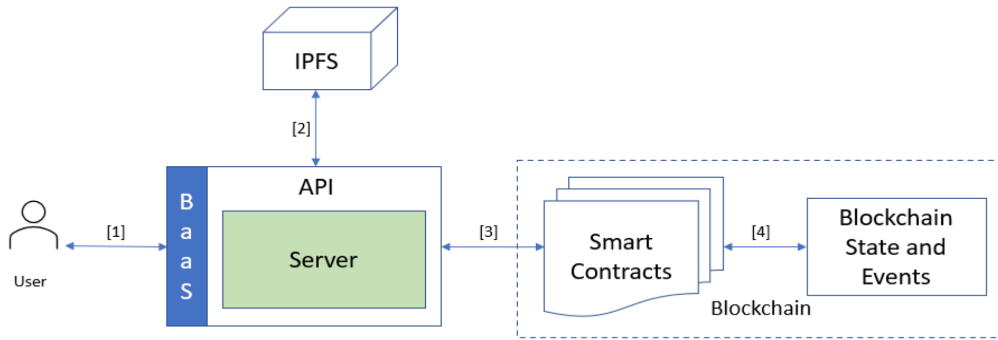
Our future work will extend this case study by applying blockchain and data analytics to analyse records, calculate farmers' trustworthiness, and visualise the evolution of trustworthiness.

IV. BaaS Architecture for DApps

Blockchain architecture enables recording a history of transactions in a shared and immutable ledger. The strength of decentralised governance established through miners maintaining the trust and accountability of transactions. Blockchain architecture comprises decentralised processing and protocols, which should be loosely connected when developing decentralised applications. Here, we present a BaaS architecture where blockchain is connected with external users and systems using a loosely coupled service API(Application Programming Interface). The high-level overview of the BaaS architecture for DApps is illustrated in figure 2a.

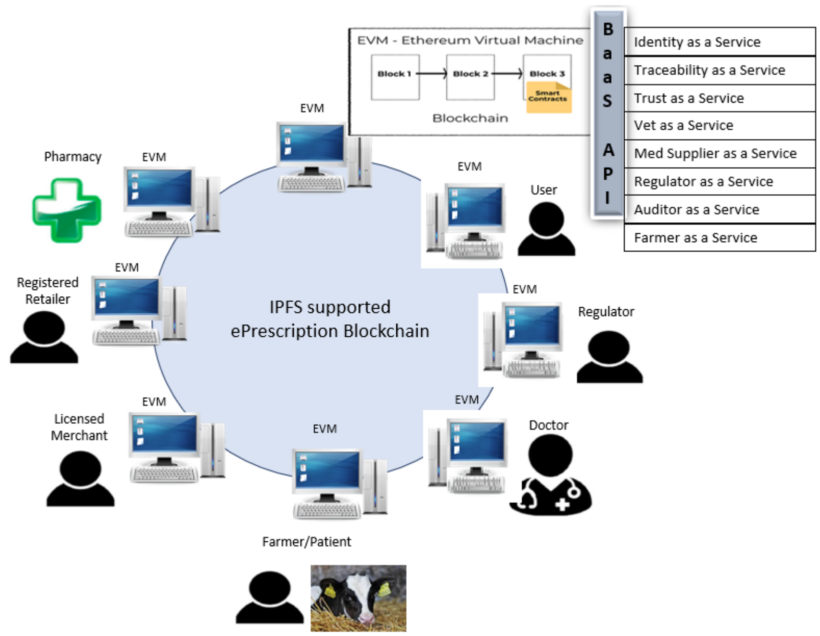
1 Users will use BaaS services. For example, veterinary practitioners will use BaaS to create prescriptions.
2 IPFS provides decentralised content-based addressing than traditional location-based addressing for storing information. A document hash is created for a document stored on IPFS, which can be used to locate the document. API services are used in the proposed architecture for writing documents and reading documents.
3 API services are used in the proposed architecture to call functions defined in smart contracts.
4 Blockchain smart contract will have data structures to maintain the blockchain state. The state and events will govern all the activities happening from users' reactions.

Storing a document on the blockchain is expensive. Therefore, we use IPFS to record information in a document, and the hash of the document will be recorded on the blockchain. Moreover, when the hash does not contribute to the state, we record relevant information in events. Storing information in events is cheaper than storing them on state variables that contribute to the blockchain state. This proposed architecture introduces a loosely coupled service API to communicate with IPFS and smart contracts. The loosely coupled nature of this BaaS architecture can be adapted to the development of DApps in general.



(a)

Fig. 2: Blockchain as a Service Architecture(BaaS) for DApps



(a)

Fig. 3: The High-level Solution Architecture

In this paper, we realise the BaaS architecture to manage prescriptions enriching provenance, provision and traceability of information. Blockchain establishes a history of immutable transactions. A history of transactions regarding animal remedies and treatments recorded on the blockchain can facilitate necessary information provision, provenance and traceability for regulators, uses and customers. The information provision, provenance, and traceability requirements are defined and implemented as services using the proposed BaaS architecture. The high-level design of the solution is illustrated in figure 3a. BaaS provides services for various types of users, including farmer, veterinary practitioners, medicine suppliers, and regulators. The smart contracts governed blockchain solution is proposed to record and manage prescriptions used in veterinary medical services. The smart contract uses state variables and events to update the blockchain regarding the up-to-date veterinary prescription changes, including medicine dispensed and medicine administered.

V. Design, Implementation and Testing

We implemented the proposed BaaS architecture to realise the case study proposed in section III. A service API is introduced and implemented as RESTful Web services [13] so that services can be easily adapted for DApps in general. Create a prescription is one of the essential use cases in this case study. Farmers request veterinary practitioners to examine their farms, and veterinary practitioners will examine and create prescriptions on the blockchain. The practitioner's registration and prescribed medicine are validated based on the records on the blockchain updated by DAFM and HPRA, respectively. Farmers, veterinary practitioners, and suppliers can view prescriptions, and the same prescription is updated when dispensing and administering medicine. The blockchain state and events are updated accordingly. The detailed design of creating a prescription is illustrated in figure 4.

The prescription is saved in IPFS as a JSON object, and content addressed hash value is returned to VaaS. The VaaS saves the hash value and the serial number of the prescription

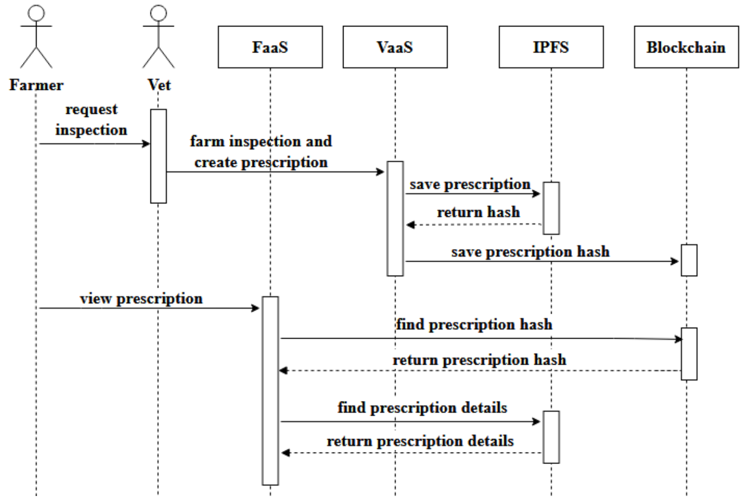


Fig. 4: Use Case - Create/View Prescription

on the blockchain as defined in the mapping. Whenever the prescription is updated, the map is updated with the new hash value. In the meantime, an event is created following "$eventCreatePrescription$" and event details are recorded on the blockchain. This event has detailed information, enabling tracing all the previous events based on the serial number, farmer ID and vet ID. As in figure 4, farmer view prescription will check the prescription map to find the latest prescription issued for the farmer and view its details from IPFS.

A code excerpt of the smart contract is as follows:

```
contract ePrescription {

    //vetID=>IPFS hash of vet details
    mapping(string=>string) public vets;

    //serial no => IPFS hash of prescriptions
    mapping(string=>string) public presDetails;

    ...

    event eventCreatePrescription(
        string serialNo,
        string farmerID,
        string vetID,
        string presHash,
        uint256 timestamp
    );

    event eventRegisterVet(
        string vetID,
        string vetDetailsHash,
        uint256 timestamp
    );
    ...
}
```

We used events to record information because recording events on the blockchain is cheaper than information recording in state variables. We defined events to support traceability services.

We tested our prototype using a dummy dataset. Transaction for creating a prescription will create an event as in figure 5. The hash value recorded on the blockchain is QmUofsJZ2wRUUUQUkGQPCj8xkqGCfaBkSFgkcuUjKtDqci. Tracing events enable extracting information stored on IPFS through the service API. The prescription details can be viewed using the URL https://gateway.ipfs.io/ipfs/QmUofsJZ2wRUUUQUkGQPCj8xkqGCfaBkSFgkcuUjKtDqci. In our DApp, we can retrieve all the events of a particular prescription; hence traceability service can perform continuous monitoring of prescription updates, including medicine dispensed, medicine administered, and imposed constraints. This method can stop the overuse of prescriptions, counterfeit drugs and break compliance imposed by constraints.

▾ returnValues: {…}
0: "00001111"
1: "farmer1111"
2: "v111"
3: "QmUofsJZ2wRUUUQUkGQPCj8xkqGCfaBkSFgkcuUjKtDqci"
4: "1613942694"
farmerID: "farmer1111"
presHash: "QmUofsJZ2wRUUUQUkGQPCj8xkqGCfaBkSFgkcuUjKtDqci"
serialNo: "00001111"
timestamp: "1613942694"
vetID: "v111"

Fig. 5: Create Prescription Event

The cryptocurrency price is going high, and the cost for a transaction is a significant factor when defining smart contracts for DApps. The cost comparisons of storing information in a map (state variable) and events are illustrated in figure 6. Here we used the Ethereum platform. We compared the transaction cost and execution cost of functions defined in a smart contract in Ethereum for a similar input dataset. The cost of computational operations on the Ethereum virtual machine is called execution cost. The costs for sending the contract code(compiled version or byte code) to the Ethereum blockchain and execution cost together is called the transaction cost. Users have to pay the transaction cost that includes the execution cost. The state variables contribute to state changes of the blockchain, and both transaction and execution costs are higher than those of events. Therefore, we tried to minimise defining state variables and used events to record necessary control information. Events are recorded in logs, and we used them to implement traceability services.

VI. Results and Discussion

Trusted data management is one of the critical enablers of blockchain technology compared to other system develop-

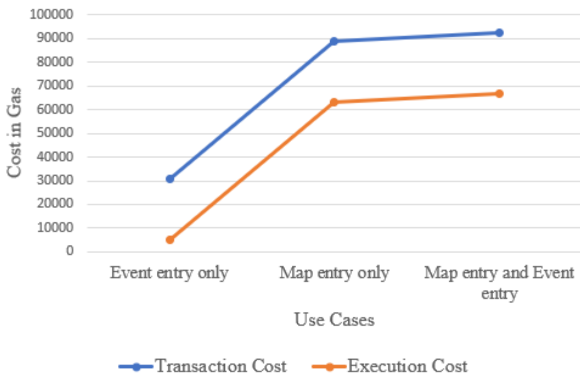


Fig. 6: Cost comparison of state variables and events

ment technologies. On the other hand, veterinary medicine treatments for food-producing animals need transparency and trusted data management to reduce health risks and ultimately enabling sustainable farming. This research presents a decentralised blockchain as a service solution for the veterinary medicine case study explained in section III. The decentralisation is achieved using IPFS and Ethereum blockchain. These proposed methods provide solutions to challenges identified in section I as follows:

- Smart contracts manage prescriptions. All the purchases will be verified and recorded on the blockchain and IPFS. The record-keeping is completely decentralised, immutable and transparent. There is no possibility for the overuse of prescription medications.
- Blockchain and smart contract-based verification of drugs can stop using counterfeit drugs. The provenance and authenticity of drugs are verified every-time they are prescribed and dispensed.
- The transparency, immutability and reliable provision to transactions enable monitoring constraints. The smart contract-based validations can monitor control measures.
- The reliable provision to immutable and transparent transactions enable developing traceability solutions for customers.

Moreover, BaaS architecture is designed and implemented using a loosely coupled service API so that services can be adapted based on the requirements of the application. Moreover, smart contracts are defined in a cost-efficient manner while storing information on IPFS and using events on the blockchain. Our future work will apply data analytics to analyse blockchain records and calculate the trustworthiness of farmers.

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