Data Model, Collection and Evaluation Framework for Local Energy Systems

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ABSTRACT
Distributed ledgers are a new type of database technology that allows open access to data stored across distributed, decentralised, publicly maintained infrastructures. Current implementations of the such ledgers expect competition between participants, are often energy hungry, poor in maintaining the natural structure of data and suffer from scalability constraints. The aim of my research work is to develop a distributed ledger-based middleware for data modelling and collection on household energy generation and use, while addressing scalability and energy inefficiency concerns of the ledger for this particular application domain. The energy data collected and made available through this middleware will be used for digital energy service delivery (e.g., automated peer to peer energy trading, topological estimations, etc.). The middleware also provides a platform for a consumer focused digital energy service delivery, as well as service model evaluation. The model evaluation will enable the prospective service users to evaluate the suitability of the given service for their needs before making a decision of service subscription.

Author Keywords
data models, distributed systems, de-centralized, blockchain, consensus, data stores, data integrity, relations, data access, services

CONTEXT AND MOTIVATION
The term Database has been defined by CJDate [9] as "a collection of related data stored on a computer that can be used for different applications without knowledge of storage details". Modelling data is the central characteristic that any database (DB) should have, such that the management system (MS) around it can free its users from machine representation and organization of data. DBMS implementations based on relational model proposed by EF Codd [6] uses role based management system, controlled centrally by a group of administrators, to make the state changing in data efficient and structured. This leads to an interesting question "are centralized and role based DBMSs efficient in storing data that is immutable in their life cycle?". Pat Helland defined the immutability [12] of data by categorizing data as "Data on the inside" and "Data on the outside". The data sent out from a service and/or web page is in the second category and such data is immutable, semi-structured, has identity and may be versioned. The updates to such data creates a new version data with a new unique identifier. A Dataset is a collection of such data with a unique ID. In other words datasets are immutable collection of data. The data collected and bundled as datasets from local energy systems is either from tailor made services hosted in servers or from internet-of-things (IoT) devices. After defining immutable data, the above question can be modified as "can the datasets that are given by local energy systems be stored efficiently using centralized databases?". Finding an answer to this question is the motivation for my current research work.

The datasets that are emerging from local energy systems contain discrete sets of time-series data values e.g., indicating sensor readings or any other information. The distinctive characteristic of these datasets is that they are cohesive reflecting the natural structure of underlying system. Keeping the cohesion among these discrete datasets is important for service evaluation and modelling tasks.

Traditionally the centralized databases are rather best fit to store the data that belongs to first category, "Data on the inside", because such data lives in transactional world [12]. Another possible way to store the datasets, could be using NoSQL databases, which store data in a schema-less fashion [21]. The popular No-SQL models are: 1) Document databases (e.g., MongoDB) where data stored as free form JSON structure; 2) Key-Value stores (e.g., Redis) values like strings or JSON are accessed using keys; 3) Wide column stores (e.g., Cassandra) where data is stored in columns; 4) Graph database (e.g., Neo4J) in which the data represented as graph of nodes and relationships.

It appears that the Key-Value and Graph databases are not suitable to store the datasets, because of the data model these databases offer. Storing discrete data in the free form or in columns stores may serve as half of a solution. These, however, do not address the second half of the problem, that is preserving natural cohesion among stored datasets. Both types of databases: relational and No-SQL, lack such features (sought
The below research questions (RQ) anchor the various research tasks: from literature review, to feasible solution elaboration:

- **RQ1:** How is blockchain technology adapted in various domains?
  This question aims to elicit how different application areas apply blockchain for data storage tasks, and are used by software applications and as an alternative to traditional databases.

- **RQ2:** What data is stored in a blockchain?
  - Structured or unstructured (e.g., images, documents, logs etc).
  - Discrete or related

- **RQ3:** How are the below data quality features realized?
  - Data integrity: i.e., completeness, accuracy and consistency of data;
  - Data Access: obtaining required data from underlying data store;
  - Data Indexing: optimizing performance of the underlying data store by minimizing the number of disk accesses required;
  - Physical Data Storage: the way that data is physically stored on a disk.

- **RQ4:** How are the below distributed system characteristics of Trusted/un-trusted networks, Synchronized/non-synchronized network (clock synchronization), Data replication strategy used? In short, we view blockchains as a kind of distributed system. Thus we think that mapping the current practice of its use against theoretical concepts will provide relevant insights.

- **RQ5:** How are the (business-related) features of Scalability, Consistency, and Read/Write latency used and modified?

**APPROACH**

To address the above questions, a number of pre-development tasks are identified, such as:

- Conduct Literature review in order to understand the current progress in similar research areas, and to obtain the technical details that drive the existing blockchain solutions like Hyperledger [1], IOTA [13], BigchainDB [10], Tangle [19].

- Review energy sector datasets in order to get a proper insight into datasets from different application domains. It is hoped that a comprehensive knowledge about data life cycle in datasets from different domains will be observed and knowledge about the natural cohesion among such datasets will be gained.

- Gaining perspective on Technical details, given that blockchains are a kind of distributed system, getting theoretical perspective on issues within the existing distributed systems (like network consensus, redundancy, state changing, etc.) will be informative. Similarly, knowledge of existing distributed databases (e.g., Spanner [7], Bigtable [3] ) and file systems (e.g., Google File System [11], IPFS [14]) will be equally relevant.

- Identify viable technical solutions, whereby suitable technical solutions for crucial components of the solution would be identified. The crucial components are
  - Network Creation and participation
  - Consensus among participants
  - State changing
  - Data storage
  - Redundancy of data in network
  - Data indexing and access

Once these tasks are completed, the software development and testing cycle will be iterated. However, the development tasks are presently not detailed upon.

**PROGRESS SO FAR**

Below we briefly outline the work carried out so far.

**Literature Review**

A literature review on use of blockchains as a data storage platform is carried out. For this a systematic literature review protocol (proposed by Kitchenham [15]) is used. The review protocol defines: 1) Search Strategy; 2) Study Selection; 3)
Data Extraction and 4) Data Synthesis tasks. As part of the Search Strategy, relevant search terms (namely: Blockchain, Data Storage, Ledger, Data Integrity) were identified. These terms were formed into search strings: Blockchain AND (Data Store OR Data storage) AND (Transparent OR Open OR Decentralized OR Distributed OR Immutable AND Ledger and Data integrity OR Data quality OR Data consistency OR Related data OR Referential Integrity). The IEEE and Bristol Library Search repositories were used for the document search, from which 185 relevant papers were identified.

The inclusion criteria specifying the publications of type (i.e., peer reviewed conference and workshop papers) and content (papers that cover the architectural details of software that use blockchain to store data and uses distributed system platform features for data management) was used. On basis these criteria, 113 papers were chosen for detailed review from the initial corpus of 185.

For Data Extraction, the search parameters based on features from blockchain and distributed systems along with data characteristics were used. The extraction results are detailed in [18].

The brief summary of the Data Synthesis suggests the below key findings:

- Applicability: The details of application areas that use blockchain to store different kinds of data are extracted and synthesized. The Fig - 1 shows the types of data stored in blockchain by different applications. As shown in the

Figure 1. Usage of blockchain across application areas

Fig-1, majority of applications use blockchain to store metadata that summarizes underlying business data, to ensure the integrity of such data, and to provide trust factor to customers. The Fig - 2 shows those application areas, which use blockchain for storing meta data. However, considerable application areas store data emerging from them in blockchain as shown in Fig - 3.

The key finding from the above data synthesis results is blockchain is used to store datasets. Both metadata and the data emerging from applications are immutable and applications prefer blockchain to store such data to ensure integrity of data and to provide the trust factor to customers.

- Blockchain Variants and networks: The details of blockchain variants used by software designers to store data in blockchain are extracted and analyzed. The Fig - 4 shows the choice of blockchain variants

Ethereum [20] is the most used blockchain variant followed by Hyperledger [1]. Ability to write scripts to customize the state changing in Ethereum blockchain is the main motivation factor. Hyperledger provide more flexibility in terms of customization and getting more prominence.

Another important factor in using blockchain is the type of its network. Three types of Blockchain networks: private, public consortium or permissioned are most used as shown in Fig - 5. Blockchain with private networks is the popular choice for software designers. The motivation is to avoid the GAS charges involved and to reduce the read/write latency. Consortium/permissioned networks are next popular choice, which are created and maintained by group of companies such that network management is controlled and participation is not open.

A key finding from the above analysis is that choice of a blockchain variant and network is dependent on the data to be stored and the data access requirements.

Review energy sector datasets

To gain a better understanding of the blockchain technology, the Ethereum blockchain [20] was used to prototype a solution to to store sample energy datasets. The datasets related to peer-to-peer (P2P) energy trading and occupancy analysis within the university accommodations. The prototyping effort focused on understanding the process of data modelling in Ethereum and maintaining relations between different datasets (using smart contracts). The findings are presented in [5, 4].
To further our perspectives on the nature of the data from different application domains, and to experiment with different implementations with data models, data sets from low voltage distribution stations (OpenLV) and university’s lighting system were studied. The OpenLV [17] data was obtained from sensors deployed at different components of substations. The data was modelled using relational data model and hosted in a relational database. The size and data access times for data hosted in RDBMS were recorded. At the same time, the lighting data was modelled as smart contracts. A middleware prototype was created using private Ethereum blockchain (GETH) such that data can be stores and accessed.

Comparative analysis of these data storage and modelling solution prototypes are presently under our review.

FUTURE WORK
In the first year of PhD the preliminary work was done to understand the landscape of the research by means of experimentation and studying literature.

Next we will focus on technical perspective for middleware along with identifying the efficient technical solutions, as discussed above.

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