Improved trust worthiness in electrical energy management using K-means augmented blockchain technology

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Abstract

The goal of an energy management organization aside from provision of value added services is to generate profit. A widespread perception of unfairness and mistrust regarding electricity distribution and billing method however exist among consumers in several resource-constrained settings like Nigeria. In order to address this perceived notion of unsatisfactory service deliver as well as enhance customer confidence, this study was carried out primarily to create a reliable and efficient smart grid system for energy management using a transparent, secured blockchain technology with K-Means algorithm. The result is a tamper-proof system that ensures accurate storage of record of energy dispensed from the grid and energy used by each consumer before the entire users are then assigned into a four-clustered pattern of electricity usage.

Keywords: Energy management, blockchain technology, K-means algorithm.

1. Introduction

Energy remains one of the top drivers of any growing economy and the impact of energy generation, distribution and utilization transcends all sector of the economy of a nation (Onakoya, Onakoya, Jimi-Salami, & Odedairo, 2013). The benefits it offers the society via direct or indirect utilization includes increased productivity, job creation and enhanced income generation (Rapu et al., 2015). Despite the lofty benefits of energy utilization, electric energy theft and leakages through corrupt activities engaged by the utility company staff and the consumers hamper the successful running and delivery of energy management organizations. In several developing countries, low energy generation with outrageous bills remain a contentious issue. The result is a widespread mistrust among consumers and service providers which further encourages bizarre and dishonest practices in a bid to maximize profit or pay minimal electricity charge. In order to achieve excellence in this sector, a real-time remote monitoring system is required. This can be achieved using the blockchain technology. Blockchain is a special form of a distributed database, which maintains immutability, transparency; security of records stored and does not have a central point of failure. It acts as a protocol enabling parties to transfer value or assets without a trusted third-party (Brilliantova & Thurner, 2018). Blockchain technology has been successfully adapted in management of the Bitcoin crypto currency system (Miraz & Ali, 2018). Although, several existing approaches have been applied to tackle the problems of illegal connections, meter readings and outrageous billing estimated for energy consumers. One of such approach is the introduction of smart meters to ensure that the consumers pay for what they use. However, persistent complaints of outrageous estimated bills by consumers not placed on the pre-paid smart meter scheme and sundry issues related to energy theft are areas where the concept of blockchain technology can offer accurate tracking of energy distributed and consumed at each end point. The incorporation of blockchain technology can provide real-time information to consumers about the origin and cost of their energy supply in a bid to making energy charges more transparent. Thus, in this research, a model was created to re-establish trust in energy management system via the use of concept of blockchain technology and K-Mean algorithm. Blockchain technology can be used to improve any process where the need to access, verify, send or store information securely is critical (Sarah & Cary, 2018).

The remainder of this paper is organized as follows: Section 2 is a discussion of related works in the area of electricity management using blockchain in forecasting customers' usage pattern. Section 3, is a detailed presentation of the developed methodology, while Section 4 discussed the results obtained via the blockchain network that was implemented using the Ethereum framework and the analysis of the clusters generated from the k-means algorithm. Finally, Section 5 provided a summary of this work and the recommendations for its adoption in the electrical energy sector.

2. Literature review

The management of electrical energy remains an essential area in the contemporary business setting. From the point of generation, to transmission and subsequently distribution of power to the various stakeholders, various levels of integrated systems exist between the provider and consumers. Thus, with the growing need of electrical energy, efficient monitoring of generated and supplied electricity to consumers is necessary for proper electricity forecasting and tracking of usage pattern. Additionally, effective and efficient management of energy system also aids decision making, ensures proper accounting of monetary remittances from the consumers, energy generation and usage prediction. Presently, blockchain technology is being deployed in energy management in Europe (Crosby et al. 2015), For instance, Brilliantova and Thurner (2018) presented a review of several instances of usage of blockchain technology and how it could be adapted in the energy sector namely energy grid management, energy metering and billing processes as well as asset management and automation of IoT, with smart devices (Andoni et al. 2018).

Blockchain technology is also applicable for management of energy sector data, consumers identity along with other valuable assets. Gao et al. (2018) noted that electrical data recorded from the smart meters at home onto the grid system can be securely processed and stored in databases for billing and other purposes. Thus, Gao et al., (2018) posited that the concept of a sovereign blockchain model is able to provide transparency to tackle the compromises that exist in meter readings and also allow for consumers to know details of the electricity consumption and other analytics information. The process however lacks the capacity for customer data analytics. Similarly, Konstantinos and Georgios

(2019) presented a novel approach to analyze and identify electricity consumption patterns of consumers based on data mining techniques. His findings showed the possibilities of energy theft within the smart grid system. They constructed a model electricity consumption patterns for commercial and residential consumers and created a power theft scenario using commercial power system analysis software (an interactive power system simulation package). In another study, Amri et al. (2016) employed K means algorithm in the dataset of electricity consumption from 370 clients and were able to obtain interesting seasonal based patterns. The employed method initially involved performing dimension reduction on the dataset by selecting only certain duration of time from the dataset before aggregating the electricity needs for each season within the selected time duration.

3. Methodology

This study adopted a model that can be categorized into two phases:

1. **Data collection/aggregation phase:** This phase entails harnessing customer and electricity record management using blockchain technology
2. **Machine learning:** uses K-means algorithms to process extracted data from the blockchain network in order to generate information on electricity consumer's usage pattern.

The steps are illustrated in Figure 1

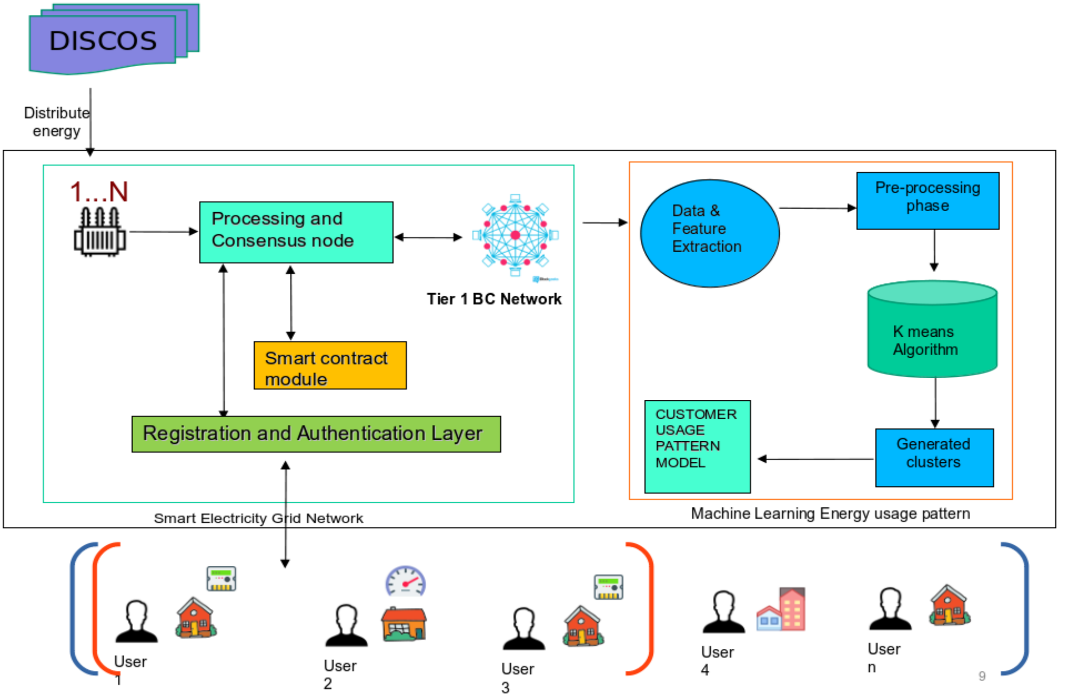


Figure 1: BC-K-means energy grid system

From Figure 1, the registration module entails incorporation of basic user information for identity management. The module also serves as meter reading, authentication and entry point portal into the blockchain network. The data stored here can be collected from a web interface and then stored into the Ethereum blockchain. The Ethereum framework makes it possible for decentralized apps (Dapps) to be created for storing data into the network. After the registration of the user information, the user can register one or more smart meters for home, office or other use by linking the unique identifier number to the meter ID. After this, the meter readings are mapped to the user for appropriate logging of future electrical data.

Sequel to this process, from figure 1, the processing and consensus node module processes the transactions into blocks. It takes the first name, last name; phone number, email, contact address and other data required and creates a block to represent that transaction. It also takes the meter ID, daily meter reading and date when recording customer daily readings. This block is then broadcasted to all the nodes on the network and the validation of the block commences using the proof of stake algorithm embedded in the Ethereum blockchain. Once the nodes in the network validate this block, it gets added into the chain and the transaction gets verified and executed. Every incoming transaction is processed and the smart contract module actively listens to get triggers, which will revoke access to the BC network whenever a user tries a malicious attempt by tampering with the smart meter reading.

The second phase of the model entails learning from the data to obtain clusters of users for various analyses. To enhance model accuracy via learning algorithm, data extraction from the blockchain network database is performed. Data about user and the meter readings stored on the blockchain are downloaded from a designated web interface. Since the electricity data is derived from the blockchain network, the likelihood of having incomplete records, missing values or inconsistent data is minimal. The pre-processing stage involves performing data cleaning by recognizing outliers, smoothening noise data or correcting any inconsistent data. Furthermore, there is allowance for data reduction and transformation provided the dataset extraction is too large for processing at once hence reducing the processing time and works done. Here, K-Means as one of the prevalent classification algorithms is used to cluster users into groups based on their energy consumption. This is further presented in figure two

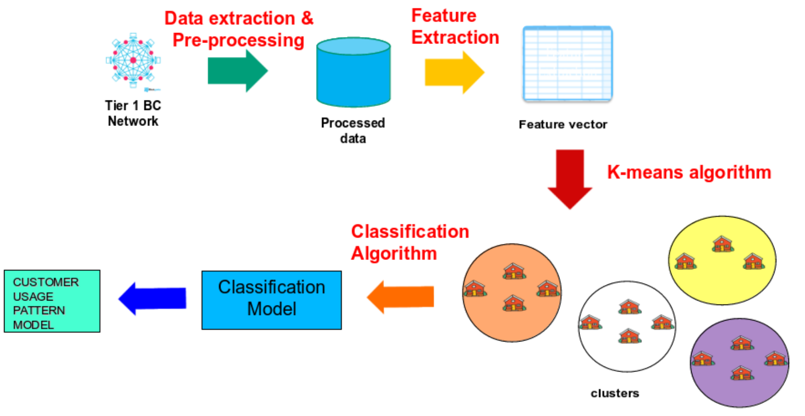


Figure 2: Model for clustering of customers electricity data

The K-means algorithm efficiently cluster the entire users into four groups based on electricity usage while other types of users in each cluster segment are further identified for subsequent analysis over a period to aid decision support. .

4. Result

Towards achieving the research objective, a Decentralized Application was built on the Ethereum framework to store and retrieve information into the blockchain network. 2362 consumers' daily electricity data between July 2009 and April 2010 were observed in the scope of this work for experimentation and evaluation. First, in Figure 3, customers' bio-data information stored into the blockchain at registration point was presented.

```
babafemi@babafemi-pc:~/EthernumBlockchainProjects/smart-grid$ truffle console
truffle(development)> User.deployed().then(function(i){app=i})
undefined
truffle(development)> app.addConsumerRecord("Babafemi","Sorinolu","Male","12, Alagbagba street, ashi road, Bodija");
{ tx: '0x9e35a68c41e4fc4d72b8d78a7ecf1dd8e67b69975b2dac737de7f7746495f9ce',
  receipt:
   { transactionHash: '0x9e35a68c41e4fc4d72b8d78a7ecf1dd8e67b69975b2dac737de7f7746495f9ce',
     transactionIndex: 0,
     blockHash: '0xc19d337d0be5b05fe13072d39e1c464e5a7416ab34011353902da75502505eb7',
     blockNumber: 1,
     from: '0x0fbfb7be0f9fb838ef9f0339882d09eac7dcf912',
     to: '0xdd3367400459be5d50fe3981076e858de5a02d4b',
     gasUsed: 27288,
     cumulativeGasUsed: 27288,
     contractAddress: null,
     logs: [],
     status: true,
     logsBloom: '0x00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000',
     v: '0x1b',
     r: '0x36b9648ec27dfcea056143bb7b0f6ebf1d127340f2e475705ab89ea8d4d0b0',
     s: '0x01d90817904345e1a524a06c2881f83d8eaa347a4d5f93a61d608ea42531c1da',
     rawLogs: [] },
  logs: [] }
truffle(development)>
```

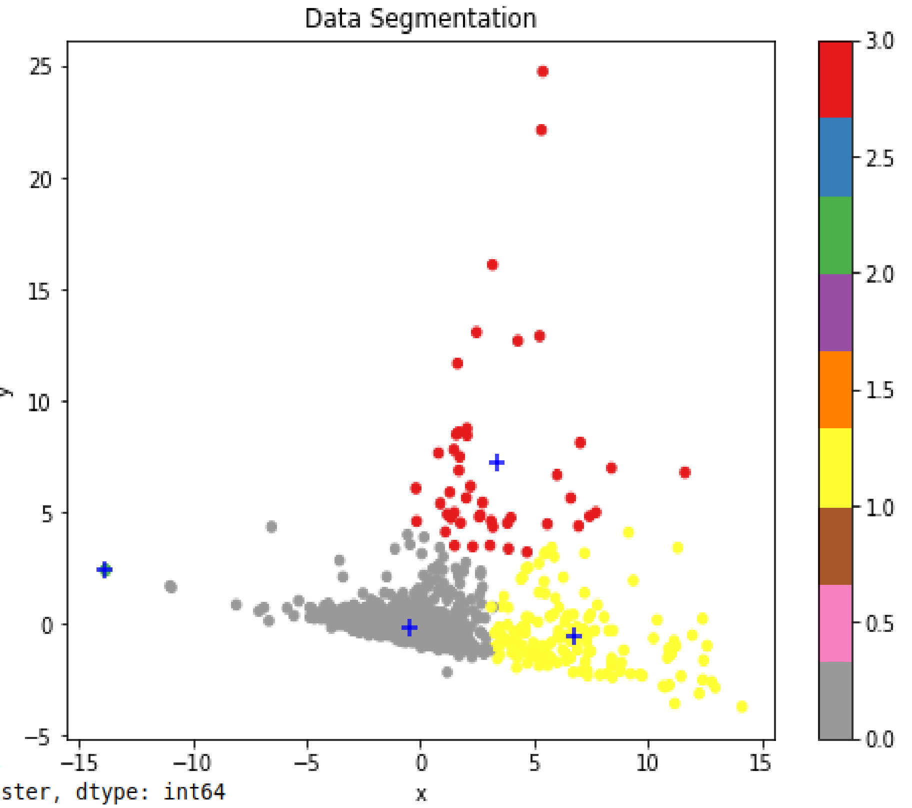
Figure 3: Consumer Record Stored into the Blockchain

Their electricity consumption data were collected via smart meter logging every 60 minute. Some of these data were added into the blockchain network as shown in Figure 4. After the records are added to the chain successfully, it becomes impossible for data to be illegally manipulated and the smart contract is executed in the event of attempts by the parties. Apart from the identity management of the users, meters, transformers and other service equipment's present in the grid, the system also provides management of the assets in the grid.

```
truffle(development)> app.addMeterReading(1000,"11.6","2009-07-20")
{ tx: '0xfe67909431f2383d81ac593b74f85d8801f478cc9a6a227642cc57a579e13ed9',
  receipt:
   { transactionHash: '0xfe67909431f2383d81ac593b74f85d8801f478cc9a6a227642cc57a579e13ed9',
     transactionIndex: 0,
     blockHash: '0x6d9317a425abb42eafb262b08143c31d82dd154ade2ee8938d103a1970f28ba0',
     blockNumber: 14,
     from: '0x0fbfb7be0f9fb838ef9f0339882d09eac7dcf912',
     to: '0xa94be08ac6a7277e0f739d79fc6dccce474a4e15',
     gasUsed: 111362,
     cumulativeGasUsed: 111362,
     contractAddress: null,
     logs: [],
     status: true,
     logsBloom: '0x000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000',
     v: '0x1b',
     r: '0x58ba03db98c99c7a77bc11a6148c25ece9d3185b98f25ffa6534b1c232e76c2c',
     s: '0x69492556721d0ad1d6cc177274b7efa6795bbc667019248c1ce68e0d90d827ac',
     rawLogs: [] },
  logs: [] }
truffle(development)> app.addMeterReading(1000,"4.6099999999999985","2009-07-21")
{ tx: '0xb64af9a258ae0970888be7cb7945929451f2f4fa00eba167eb75235c9b248b5b',
  receipt:
   { transactionHash: '0xb64af9a258ae0970888be7cb7945929451f2f4fa00eba167eb75235c9b248b5b',
     transactionIndex: 0,
     blockHash: '0x834846e4c773b2233749c38f02b715960950c212c81703f4d3782a8a067f5b62',
     blockNumber: 15,
     from: '0x0fbfb7be0f9fb838ef9f0339882d09eac7dcf912',
     to: '0xa94be08ac6a7277e0f739d79fc6dccce474a4e15',
     gasUsed: 112258,
     cumulativeGasUsed: 112258,
     contractAddress: null,
     logs: [],
     status: true,
     logsBloom: '0x000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000',
     v: '0x1c',
                                                                Ln 10, Col 1   Spaces: 4   UTF-8   LF   Plain Text   Formatting: X
```

Figure 4: daily meter readings for a user is stored into the blockchain

Hence, the Customer Data Segmentation and Behavioral Analytics are presented in figure 5




```
0    2162
1     148
3      47
2       4
Name: cluster, dtype: int64
```

cluster	total KW mean	average per day mean	% Monday mean	% Tuesday mean	% Wednesday mean
0	14445.025133	26.949674	14.083309	14.197316	14.092767
1	31757.107918	59.248336	15.775249	17.971579	17.626609
2	0.000000	0.000000	0.000000	0.000000	0.000000
3	167954.714598	313.348348	14.708088	15.289721	15.156290

cluster	% Thursday mean	% Friday mean	% Saturday mean	% Sunday mean	% weekday mean	% weekend mean
0	13.997043	14.082547	14.715718	14.831300	70.452982	29.547018
1	17.305410	16.117066	8.932580	6.271506	84.795914	15.204086
2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
3	15.205475	14.912907	12.716175	12.011345	75.272480	24.727520

Figure 5: Scatter plot showing the segmentation of the users and statistical analysis of electricity usage per cluster

From Figure 5, the table 1, shows the inference from the customer electricity usage after the K-means algorithm was applied on the data

Table 1: Behavioural Analysis of each cluster segment

Cluster	Description	Predicted Customer Category
0	Highest number of users (2162 meter IDs); No significant difference in the percentage of daily usage in weekend or weekdays with an average consumption of 14% approximately	Cluster 0 belongs to homes, shops, sc small scale firms that has same activiti day.
1	Daily electricity usage and the total consumption 59.25 kWh and 31757.11 kWh respectively; high usage during weekdays and a low consumption on weekends.	Cluster 1 comprises of medium size co who only have activities in weekdays.
2	Cluster 2 containing IDs 2083, 2691, 3141, and 3348 were not observed in this work because it has a total electricity usage of 0 kWh.	Outliers
3	Heavy consumers of electricity. Average daily usage and total KW of 313.35 kWh and 167954.71 kWh respectively	Cluster 3 represents large scale indust firms

5. Conclusion

This study showed how blockchain based decentralized application with k-mean algorithm could be deployed for accurate and efficient energy monitoring and data analytics. This model effectively eliminates energy theft, over billing and other fraudulent practices. Consequently, the findings from this study can be applied for efficient and effective management of electricity distribution and delivery with guaranteed assurance of trust between consumers and service providers.

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