Design and Analysis of Incentive Mechanism for Ethereum-based Supply Chain Management Systems

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Abstract— Blockchain is becoming more popular because of its decentralized, secured, and transparent nature. Supply chain and its management is indispensable to improve customer services, reduce operating costs and improve financial position of a firm. Integration of blockchain and supply chain is substantial, but it alone is not enough for the sustainability of supply chain systems. The proposed mechanism speaks about the method of rewarding the supply chain parties with incentives so as to improve the security and make the integration of supply chain with blockchain sustainable. The proposed incentive mechanism employs the co-operative approach of game theory where all the supply chain parties show a co-operative behavior of following the blockchain-based supply chain protocols and also this mechanism makes a fair attempt in rewarding the supply chain parties with incentives.

Keywords—Blockchain, permissionless, reward, ethereum, incentive, game theory, supply chain

I. INTRODUCTION

Blockchain is an immutable record of events and transactions that can be extended to a number of operations and use-cases. Fifty three percent of organizations say that blockchain technology has become a critical priority for them in 2019 which is a ten-point increase over 2018 [1]. Moreover, in India, blockchain related job growth rates are at 2000-6000% and the salary of blockchain developers is 50-100% higher than that of regular developers [2]. The following are the reasons that show blockchain is the future: (1) no more middle men, (2) diverse implementation potential, (3) rapid growth in market value, (4) use in e-governance, (5) confidence of business leaders. Blockchain finds its application in many avenues such as healthcare [3], supply chain systems [4] [5], etc.

Supply chain may be a network of components that deal with producing and moving a product from provisioner to purchaser. There are different parties such as designer, manufacturer, distributor, etc., in the supply chain those are required to coordinate among themselves to ensure on-time delivery without failure. All the supply chain parties are to be integrated to reduce the costs and increase the operational efficiency of enterprises and more importantly to build sustainable supply chain [6].The integration of all the supply chain parties is possible through blockchain. But to make all the supply chain parties follow the protocol, it is necessary to introduce attractive incentive mechanisms that transfer rewards to the supply chain parties. We have developed an AI based incentive mechanism that makes a fair attempt in providing incentives to all the parties in the supply chain. The incentive mechanism was engineered exploiting the co-operative approach of game theory. Game theory explores how rational individuals make strategic selections in numerous eventualities. It is strictly based on mathematical terms and has its application in blockchain networks. Co-operative game theory assumes that a group of players called coalitions, is the primary units of decision making and may enforce co-operative behaviour between coalitions of players striving to achieve a common goal. In the supply chain, all the parties exhibit a co-operative behaviour by following the blockchain based supply chain protocol.

A. Blockchain

Blockchain is the kind of data structure that permits following transactions digitally and sharing information across computers, making an exceeding distributed trust in a network. The distributed ledger technology offered by blockchain provides a clear and secure suggestion for the possession and transfer of assets. Blockchain uses cryptography to form a distributed trust network where every participant on the network is in a position to govern the digital ledger of transactions firmly while not requiring a central authority. Blockchain is a worldwide ledger that anyone on the network will read at any time. All the transactions are verified, and clearly recorded in a block that is encrypted and saved sporadically and is linked to the preceding block, making a series that makes the blockchain. Security, time-stamping and recording all the transactions makes it extraordinarily obedient for a user. Also, a block once mined cannot be modified because of its immutable nature which makes the blockchain more secured.

B. Supply chain

Supply chain management is the phenomenon of managing the flow of products and aids and includes all processes that overhauls raw materials into finished

goods. An offer chain could be a network of shops, distributors, transporters, storage facilities, and suppliers who participate within the production, delivery, and sales of a product that converts and moves products from raw materials to finished goods. It describes the processes and organisations concerned in changing and transferring the products from manufacturers to customers. Through blockchain, corporations gain a time period digital ledger of transactions and movements for all participants in their offer chain network that successively increase the resource utilization and provides additional financial gain. A model supply chain is shown in Fig.1.

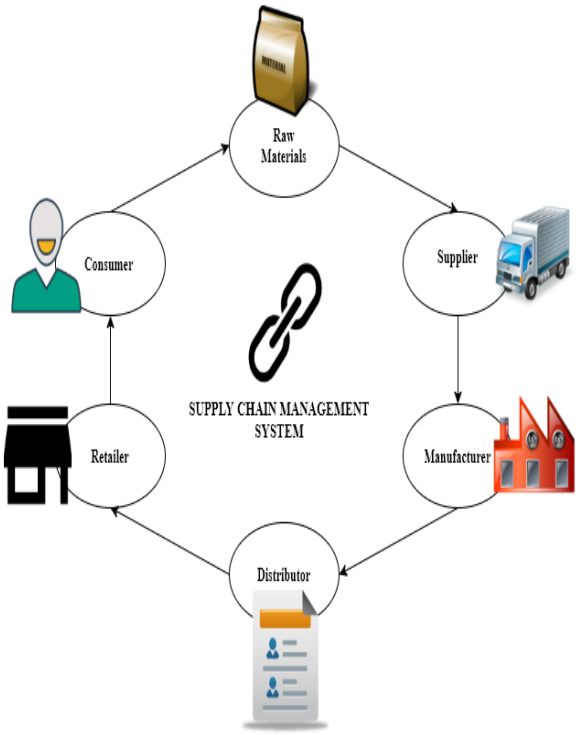

Fig.1. *Supply Chain Management System*

C. Game theory

Game theory is the method of modelling the strategic interaction between two or more players during a scenario containing a set of rules and outcomes. It deals with a scenario containing two or more players that involve better-known payouts or quantitative consequences. We will use the theory of games to assist and confirm the foremost doubtless outcomes like any conception in the economy and there's the idea of rationality. There is conjointly an assumption of maximization and it is assumed that players are rational and can try to maximise their payoffs within the game.

D. Cooperative and Non cooperative game theory

Cooperative game theory assumes that teams of players, referred as coalitions, are the first units of decision-making, and will enforce cooperative behaviour. Consequently, cooperative games are often seen as a contest between coalitions of players, instead of contest between individual players. All the players in a coalition work along for achieving a standard goal. Non-cooperative games are usually analysed through the framework of non-cooperative game theory that tries to predict players' individual methods and payoffs. It is opposite to cooperative theory of games.

E. Incentives

Incentive mechanisms are tools accustomed to encourage, acknowledge and reward exceptional performance. Incentive plans usually are to encourage those who are concerned within the network. There are various benefits related to encouraging business through the employment of incentives, since incentives make sure that the work goes on and each of the users and also the reward payers have been benefited through the inducement of incentive mechanism. Once the individuals concerned, work along the incentive plans, they establish a way of comradeliness and propulsion for the commonweal which can strengthen the business. It also leads to enhanced productivity and makes sure if the cycle goes on with no delays.

F. Contribution

The contribution of this paper is as follows:

- Design of the algorithm to calculate the incentives
- Analysis of the algorithm with respect to the Average transaction fee
- Establish fairness in rewarding the supply chain parties with incentives

The rest of the paper is presented as follows. Section 2 reviews the previously published papers and their pros and cons. Section 3 describes the proposed algorithm for the calculation of incentives. Section 4 analyses the performance of the algorithm with respect to the Average transaction fee. Finally, the conclusions are presented in Section 5.

II. PREVIOUS WORK AND MOTIVATION

There are many supply chain systems that are integrated using blockchain namely, a novel blockchain-based Product Ownership Management System (POMS) and the smart contract- based secured business to consumer (B2C) supply chain system. The Product Ownership Management System (POMS) which is an ethereum-based one, just suggests the fact of providing incentives to the supply chain parties to make them properly follow the protocol, but it doesn't discuss on the mechanism of providing incentives to the supply chain parties [4]. Similarly, the smart contract- based secured business to consumer (B2C) supply chain system focuses on a blockchain-based mechanism for ordering, payment, and shipping of products from the seller to the consumer. It doesn't speak about incentive mechanisms that are required to transfer rewards to the supply chain parties [5]. There are incentive mechanisms that have been designed, to preserve the security of Electronic Health Records (EHR) systems [7], and for mobile health service supply chain [8]. Also, Privacy preserving incentive mechanism has been designed for crowd-sensing applications [9].

Blockchain, being a secured digital ledger of transactions, which will be programmed to record and track not only simple money transactions but it has many other use cases. Blockchain-based cryptocurrency get a lots and a lots of market capitalisation. Therefore, developing a Blockchain based incentive mechanism for distributed peer-to-peer applications to provide incentive to users for better cooperation is indispensable [10]. The blockchain technology is employed to make the primary incentive mechanism of nodes as per knowledge on storage for wireless device networks. During this system process, the nodes storing the information are rewarded with digital cash [11]. Peer-to-Peer (P2P) systems suffer from many sorts of non-contribution that depend upon potential cooperative operations of a peer. Since peers are typically driven by their self-interest at the expense of welfare, incentive mechanisms encourage peers to collaborate, at the same time accomplish self-utility and welfare [12].

Rewarding incentives to users which is indispensable in user-oriented networks will encourage users to share assets and services so as to avoid inconsiderate nodes from hampering the functionality of the entire system. Cryptocurrency and name mechanisms are adopted in on-line communities to spice up participation and trust between the networks [13]. All the above mentioned works talk about incentive mechanisms in their domain except [4, 5]. The POMS [4] speaks that incentives are to be given to the supply chain participants, but the incentive mechanisms have not yet been discussed. The smart contract based secured B2C supply chain system [5] doesn't speak about incentive mechanisms at all. In this paper, we have devised an AI- based incentive mechanism that makes a fare attempt in rewarding incentives to the participants in the supply chain.

III. PROPOSED WORK

The traditional methods of supply chain management have no means to detect the presence of counterfeited products in the supply chain which lowers the influence of the manufacturer in the market. In order to detect and avoid counterfeits in the supply chain, blockchain based supply chain protocols were proposed. But to make all the supply chain parties to follow those protocols, it is necessary for the manufacturers to give them attractive incentives. We have proposed a game theory based incentive mechanism which fairly distributes incentives to all the parties in the supply chain.

A. Blockchain based supply chain transaction

To make all the participants in the supply chain to follow the blockchain-based supply chain protocols, it is necessary for the manufacturer to reward them with attractive incentives. The proposed incentive mechanism makes use of the co-operative game theory and fairly rewards incentives to all the supply chain parties. The figure Fig.2 shows a model supply chain transaction in POMS [4] which interprets the following: (1) Manufacturer issues a transaction for shipment of the product to Party 1. (2) Party 1 issues a transaction for successfully receiving the product from the manufacturer. (3) Manufacturer rewards Party 1 with incentive after the transaction for receiving the product has been successfully issued by Party 1 (4) Party 1 issues a transaction for shipment of product to Party 2. (5) Party 2 issues a transaction for successfully receiving the product from Party 1. (6) Manufacturer rewards Party 2 with incentive after the transaction for receiving the product has been successfully issued by Party 2.

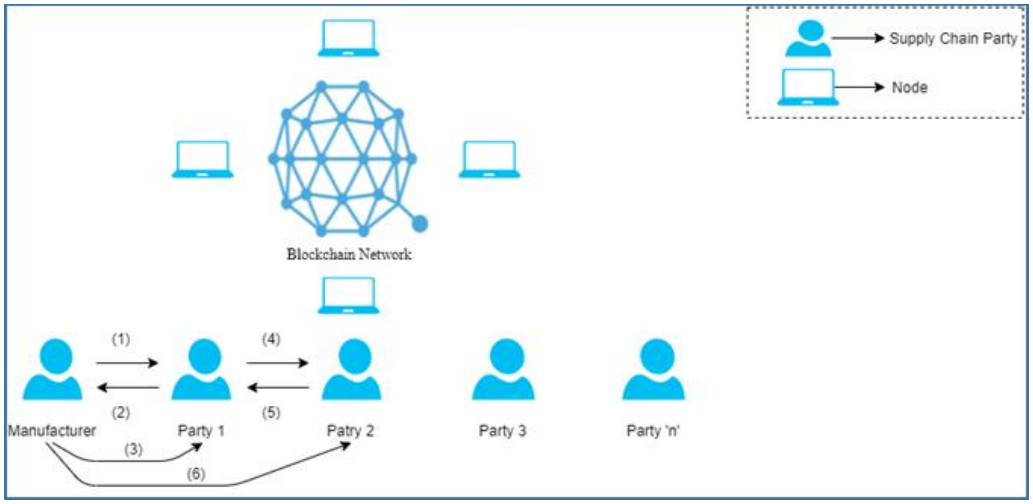

Fig.2. *Blockchain based supply chain transaction model*

B. Incentive calculation mechanism

The manufacturer has the sole responsibility of issuing incentive to the remaining parties in the supply chain because the blockchain based supply chain protocols are mostly benefited to the manufacturers in order to avoid the presence of counterfeited products in the supply chain. But the implementation of these protocols introduces additional overheads to the other supply chain parties in terms of the amount they spend for mining their transactions. So, it is necessary for the manufacturers to provide incentives to the remaining supply chain parties. But a transaction has to be mined by the manufacturers for providing incentives to the remaining supply chain parties which costs the manufacturers some ethers. So, an Ethereum-based fair incentive calculation policy has been devised that satisfies both the manufacturers and the supply chain parties.

The algorithm for the calculation of incentives is presented in Fig.3. To make a fair attempt in the calculation of incentives, a game theory-based approach has been devised. It is to be noted that the goal of all the supply chain parties is the same i.e., to follow the blockchain based supply chain protocol. So, co-operative game theory-based solution has been proposed for the fair calculation of incentives.

Input: Average transaction fee 'A', Transaction fee for issuing a transaction on successfully receiving the product 'R', Transaction fee required to mine the transaction on rewarding incentive 'M'.
Output: Incentive 'I' to be rewarded.
Let 'A' be the Average transaction fee, 'R' be the Transaction fee for issuing a transaction on successfully receiving the product, 'M' be the Transaction fee required to mine the transaction on rewarding incentive, 'I' be the Incentive to be rewarded, 'S' be the list of supply chain parties

1. begin

2. for each member in S:

3. **if** $member \neq Manufacturer$:

4. $Sum = A + R$

5. $Avg = Sum / 2$

6. $I = Avg - M$

7. **end if**

8. end for

9. end

Fig.3. *Algorithm for incentive calculation*

In the algorithm, the Average transaction fee 'A' has been included in place of, the transaction fee required to mine the transaction on shipment of products by the supply chain parties other than the manufacturer, since it is not known at the time of calculation of incentive, thereby providing fairness to the supply chain parties other than the manufacturer. Also, the term 'M' has been introduced to provide fairness to the manufacturer since the manufacturer spends some ethers in mining the transaction for providing incentives. So, the terms 'M' and 'A' in the algorithm play a vital role in establishing fairness to the manufacturer and the other supply chain parties respectively, using the concept of cooperative game theory. Assuming one transaction per block, the incentive mechanism is mathematically represented as follows:

$$I = [(A + R)/2] - M \qquad (1)$$

Where, A refers to Average transaction fee, R refers to the Transaction fee required for mining the transaction on successfully receiving the product, M denotes the Transaction fee required to mine the transaction on rewarding incentive and I refers to the incentive to be rewarded.

IV. RESULTS AND DISCUSSIONS

The factor 'A (Average Transaction Fee)' in equation (*1)* is the varying factor which varies along with time. The variation of Average transaction fee with respect to time is shown in Fig.4 using the data from [14].

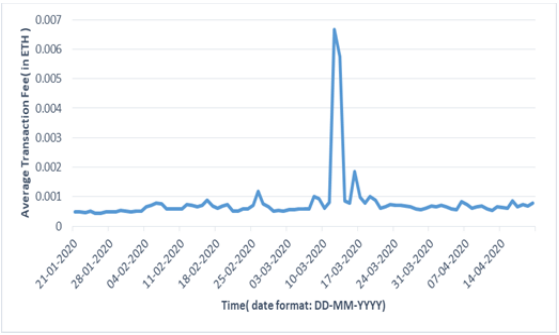

Fig.4. *Average Transaction Fee Vs Time*

The proposed algorithm makes a fair attempt in rewarding incentives, so that both the manufacturers and the other supply chain parties are satisfied. The factors 'R' and 'M' are constants. So, equation (1) is integrated with respect to 'A'.

$$I = \int [(A + R)/2 - M]dA \qquad (2)$$

From (2),

$$I = \int (A/2)dA + \int (R/2)dA - \int MdA \qquad (3)$$

From (3),

$$I = \{[R - (2 * M)/2] + [A/4]\} * A \qquad (4)$$

(Since we know that, $\int xdx = (x^2/2) + C$; $\int dx = x + C$)

From (4),

$$I = [C + (A/4)] * A \qquad (5)$$

(Since $[R - (2 * M)]/2$ is replaced by a constant C)

From (5),

$$I = A + (A^2/4) \qquad (6)$$

(Assuming $C = 1$)

The equation (6) is plotted and shown in Fig.5.

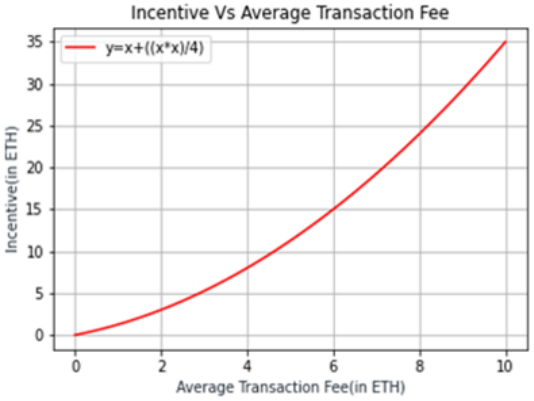

Fig.5. *Incentive Vs Average Transaction Fee*

From the Fig.5, we infer that as 'A' increases, 'I' also increases, because from equation *(6)* it is very clear that 'I' is directly proportional to 'A'; therefore as the Average Transaction Fee increases, the Incentive to be rewarded by the manufacturer also increases. The varying factor 'A' in the equation *(6)* plays a very important role in providing incentives in a fair manner because at the time of calculation of incentives by the manufacturer, the transaction fee required by the supply chain party to mine the transaction for shipping the received products to the next supply chain party is not known. So, here the manufacturer can't say that since he doesn't know that amount, he can't give the share for it. So, to avoid this issue, 'A' has been introduced in the algorithm. Also, manufacturer has to spend a fixed amount of ethers to mine the transaction for rewarding incentives. That is why 'M' has been deducted from average calculated in the algorithm above. Thus the proposed algorithm establishes fairness in rewarding incentives.

V. CONCLUSION

In the recent years, the growth of blockchain technology and the role played by crypto-currency is tremendous. Also, in this day and age, the supply chain and its management is important because it increases competitiveness and customer satisfaction and forms an integral part of a firm's success. In order to make all the participants of the supply chain to accurately follow the blockchain-based supply chain protocols, it is necessary to reward them with incentives. The method of rewarding with incentives will pave the way for a sustainable and secured future. The proposed algorithm of providing incentives to the supply chain parties by the manufacturer has established fairness such that it satisfies both the manufacturers and the other supply chain parties. Our future works will be related to intercepting the repeated cyclic transactions between any two supply chain participants for the sake of receiving rewards, thereby preventing hindrance to the supply chain.

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