Proof-of-QoE NOMA Token: A Crypto Rewarding Concept To Incentivize Local Relay In Non-Orthogonal Multiple Access Wireless Networks

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***Abstract*—In Non-Orthogonal Multiple Access (NOMA) wireless networks, it can be beneficial to allow closer users to relay the cache data to farther users. However, motivating short-distance NOMA users to participate in the relaying requires an appropriate incentive. In this paper, we propose a new crypto token - NOMAToken on the Ethereum blockchain leveraging the Proof of Quality of Experience (QoE) consensus mechanism. NOMAToken serves as a payment token that facilitates all monetary transactions within a NOMA network. As an Ethereum-based token, it can be held or traded against reserve tokens, establishing its own price. The optimal price for retransmission services is determined using the Vickery-Clarke-Groves (VCG) second price auction technique. We discuss the Proof-of-QoE driven consensus model and a Prospect Theory inspired scoring model to regulate the token. The consensus model is designed to ensure that the relay provides the highest possible QoE for its users, while the scoring mechanism serves as a paradigm to allow users to mint new NOMAToken and introduce liquidity.**

***Index Terms*—Non-Orthogonal Multiple Access (NOMA), Proof-of-QoE Consensus, Blockchain.**

I. Introduction

Orthogonal Multiple Access (OMA) protocols are struggling to meet the demands of 5G cellular communications such as high spectral efficiency, low latency and wider bandwidth [1]. Researchers propose Non-Orthogonal Multiple Access (NOMA) for 6G networks to address the current shortcomings. In NOMA downlink, the base station aggregates the content of all users and transmits them simultaneously as one superimposed signal. The user performs Successive Interference Cancellation (SIC) to recovering their data from the aggregated signal [2]. In a NOMA network, users with stronger channel gains can decode and cache signals from weaker users. This cached data can then be forwarded to the intended recipients for a small fee. Additionally, users with weaker channel gains can request copies of data from the caching users to enhance their overall Quality of Experience (QoE). In a NOMA networks with incentivized retransmission, monitoring peer-to-peer monetary transactions can be challenging, and traditional ACH bank transfers can take 3-5 business days to complete after a purchase is initiated. On the other hand, blockchain-enabled transactions offer instant processing while keeping user information private. Therefore, this paper proposes the deployment of a new crypto token called NOMAToken on the Ethereum blockchain. This token is used for making payments to caching relay users and rewarding validating users.

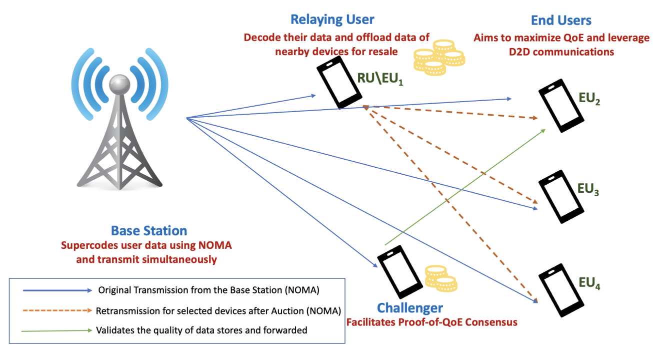

Fig. 1. Transactions Made Simple: Blockchain for D2D enabled NOMA.

The proposed system is depicted in Figure 1 above. As shown in the figure, users who are in closer proximity to the base station can cache data belonging to users farther away and relay it during subsequent time slots. The relaying user can set the price for providing this service, and end users can freely choose among relaying users who have the required cached content. An equilibrium between price and QoE gain achieved through additional transmission is established using the VCG Auction. Additionally, one of the users who is not participating in the interaction can serve as a validator to verify transactions. Validators are rewarded with a small fraction of tokens for their services.

Blockchains are essentially linked data structures that are replicated through a peer-to-peer network where new blocks are created by issuing new transactions [3]. To maintain trust between untrusted nodes in a blockchain and mint new tokens in the network, peers use consensus mechanisms such as Proof-of-Work (PoW), Proof-of-Stake (PoS), Proof-of-Authority (PoA), Practical Byzantine fault-tolerant (PBFT), and Proof-of-Reputation (PoR) [4]. These consensus models were developed for cryptocurrency-based systems and require high computational resources, making them cost-inefficient. Since none of the existing consensus models are specifically designed for NOMA networks, this paper proposes an efficient mechanism called Proof-of-QoE (PoQ) for NOMAToken.

Retransmissions in a NOMA downlink wireless network have been extensively researched due to their potential to improve spectral efficiency and connectivity. Various approaches have been proposed, including deep learning-based cooperative retransmission [5], HARQ-assisted cognitive NOMA [6], and NOMA relay [7]. Economics related, a NOMA pricing scheme (NOMAP) was proposed to improve the utility of the base station and end-user simultaneously [8]. A game-theoretic-based pricing scheme was also developed for a hybrid network with both OMA and NOMA links [9]. In this paper, an auction-based pricing is proposed for NOMA relay, and a new crypto token is introduced to facilitate faster payments.

II. NOMATOKEN: A DECENTRALIZED TOKEN FOR NOMA NETWORKS

Blockchain is a distributed and tamper-proof ledger that enables the recording of transactions and the tracking of assets in a business network. While the terms ”coins” and ”tokens” are often used interchangeably in the cryptocurrency world, they are not the same. Coins are native cryptocurrencies that operate on their own blockchain, such as Bitcoin (BTC), which is used to pay transaction fees on the Bitcoin network [10]. Tokens, on the other hand, are digital units of value that represent an asset or utility and are issued on top of existing blockchain networks. Unlike coins, tokens are not mined during the transaction validation process but are instead minted. An example of a token is Chainlink (LINK), which is built on the Ethereum (ETH-20) blockchain. Similar to Chainlink, the NOMAToken is a digital token that operates on the Ethereum blockchain. Its main function is to serve as a payment method for transactions within a NOMA network. The token architecture is illustrated in Figure 2 below.

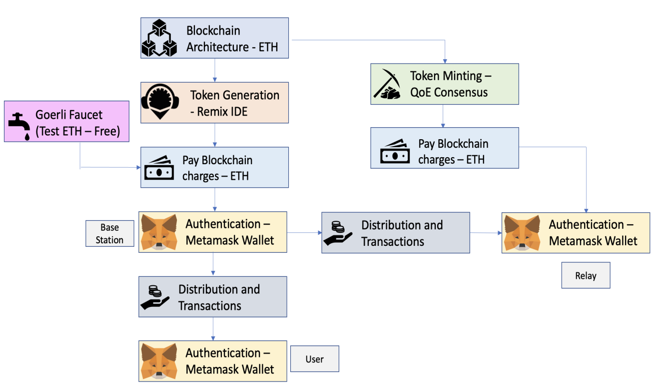

Fig. 2. NOMAToken Architecture

A crypto token is built upon a blockchain platform. In this study, we utilize the Ethereum (ETH) blockchain due to its diverse network resources and tools that expedite the process of token creation. ETH is also one of the few blockchains with a test network that enables us to deploy and test our token without the need for real-world investment. Specifically, we employ the Goerli testnet, a subnetwork of ETH that operates on test ETH for all transactions.

Remix IDE is a user-friendly tool with a graphical interface designed for developing smart contracts without requiring any setup. It enables a quick development cycle and comes equipped with a range of plugins featuring intuitive graphical user interfaces. Remix natively supports Ethereum and was used to write the contract for NOMAToken. The token was initially created with a supply of 10 billion coins, and the necessary functions were written to facilitate the minting of additional coins when required.

The Goerli Faucet is a tool for developers to obtain testnet Ether (ETH) in order to test and troubleshoot decentralized applications or protocols before deploying them on the Ethereum mainnet, where real ETH is required. In our work, we used testnet Ether to pay the blockchain fees for hosting NOMAToken on the Goerli testnet.

MetaMask is a software-based cryptocurrency wallet used to manage and interact with the Ethereum blockchain. After successfully creating NOMAToken, all tokens were transferred to a wallet corresponding to the base station. Transactions within the network were facilitated by the ETH blockchain, which charged a fee called gas fee. The gas price is not fixed, but rather dynamic, and is based on demand: the more individuals attempting to get their transactions processed by the ETH network, the higher the gas fee will be.

III. SYSTEM MODEL AND RELAY SELECTION

In the downlink NOMA communication, the base station (BS) combines all the necessary content for users in the network into a single superimposed signal. Without loss of generality, it can be assumed that the users in a NOMA network are arranged with increasing order of channel gain $|h_1|^2 >= |h_2|^2 >= |h_3|^2 >= |h_4|^2$. Each user device (EU) would then apply Successive Interference Cancellation (SIC) to decode their own signal from the superimposed signal sent by the BS with the SINR as shown below:

$$\mathrm{SINR}_{EU_i} = \frac{P_i\,|h_i|^2}{\sum_{k=1}^{i-1} P_k\,|h_i|^2 + \sigma^2} \tag{1}$$

Users can then decode their own data and also assist in transmitting the data of farther users. The level of interference in the network, due to data of closer users, is a limiting factor for the signal quality or SINR. Consequently, the user with the highest channel gain receives the superimposed signal without any interference. To improve their SINR, other users in the network can use the cached data of the users with higher channel gain. For instance, the user with the second-highest channel gain can obtain a copy of their data from the user with the highest channel gain. If we assume that the user EU, gets a copy of information from all the EUs with higher channel gain, the SINR can then be written in a way similar to [7]:

$$\begin{aligned} SINR_{EU_i} &= \frac{P_i|h_i|^2}{\sum_{k=i+1}^{N} P_k|h_i|^2+\sigma^2} \\ &+ \sum_{k=1}^{N-i-1} \frac{P_{i+k+1,i}|g_{i+k+1,i}|^2}{\sum_{j=i+1}^{N-k} P_{N-k+1,j}|g_{N-k+1,i}|^2+\sigma^2} + \frac{P_{i-1,i}|g_{i-1,i}|^2}{\sigma^2} . \end{aligned} \tag{2}$$

In equation 2, the first part of summation is the SINR gain from the original transmission. The second part of the summation is the SINR gain achieved through retransmission of all data from higher-gain EUs and their respective retransmissions. The last term denotes the SINR gain from the last EU where there is no interference. The QoE experienced by the EU through the wireless channel can be formulated using a two-level logarithmic function of allocated resource [11], as:

$$QoE_{EU_i} = \alpha \log_2 \left(1 + \beta \log_2 \left(1 + SINR_{EU_i}\right)\right) \tag{3}$$

Cached data can be retransmitted to users looking to improve their signal quality for a small fee. A Vickery-Clarke-Groves (VCG) auction is a second price sealed-bid auction type of auction where bidders submit bids that report their valuations, without knowing the bids of the other bidders. The bidder with the highest bid wins the auction, however, pays the second highest bidders bid [12]. In this work, we leverage VCG auction to determine the best price and relay pair for the user to maximize their QoE.

To obtain the services of a relay in the NOMA network, a user first calculates the value (V) of the service that the relay can provide using the backward induction technique. The user then places a bid for the relay based on their actual evaluation. The optimal strategy for the VCG auction is found to be truth-telling. The Groves mechanism is used to determine the efficient outcome of the VCG mechanism for the NOMA relaying service auction. A detailed description of the auction setup and a solved solution can be found in our previous work [14]. We also illustrated the solution using a first price auction and discussed its shortcomings.

After the optimal relay is selected and the service price is determined through the auction, the user pays the relay using NOMAToken. The relay then transmits the data to the user. Additionally, a relay can have multiple users' contents, and the relay can superimpose the signals of the users and send them using NOMA. In this scenario, an auction solution is also presented in our previous work [14].

IV. Proof of QoE Consensus Model

Relays in the NOMA network offer retransmission services to users at preagreed parameters, ensuring user their desired QoE. Users compensate service providers using NOMATokens, and all transactions within the NOMA network are recorded and peer-reviewed. Consensus is the process by which a group of nodes in the network determines which blockchain transactions are valid and which are not. Consensus are the methodologies used to achieve this agreement.

To further elaborate, the *Proof-of-QoE* consensus model involves a challenge-response protocol where the relay must prove that they are delivering the promised QoE. The protocol involves a user (challenger) who compares the delivered QoE gain with the expected QoE gain provided by the relay and obtains cryptographic proof of any dishonest behavior. This proof is then verified by the other nodes on the network through a consensus mechanism. If the proof is valid, the dishonest relay is penalized with a reduction in their stake of NOMATokens. This incentivizes the relays to provide reliable and high-quality QoE.

A. Validator and challenger selection

In the NOMA blockchain network, the base station plays the role of validator for each retransmission. Since the base station initiates the original transmission, it is aware of the nodes/users who have a copy of the data belonging to the target user (EU) who requests the retransmission. The base station then selects non-relay nodes to serve as challengers. The challengers are responsible for retransmitting the cached data of the EU. The EU provides the QoE gain obtained from the retransmission of both the challenger and the relay. Based on this data, the base station validates the relay and awards the challenger with a positive score for their service. The relaying device is then rewarded with a positive score, or penalized based on the validation result. The methodology used for scoring is further discussed in the manuscript.

B. Constructing Proof-of-QoE

In the NOMA blockchain network, the base station broadcasts the NOMA signal to the wireless network. Once the EU receives the original transmission, they search for cached content to improve their QoE gain. The EU obtains a list of users with the required data who are willing to retransmit it. The user then calculates the valuation for each relay, selects the best one, and submits a bid using VCG auction. Other users in need of retransmission also submit their bids to the relays. The relay with the winning bid provides the retransmission service to the user, who pays the winning bid amount in NOMATokens.

The base station serves as the validator in this model and is aware of the data retransmitted and the list of users who received the original transmission. If none of the users are willing to challenge the relay, the *Proof-of-QoE* is deemed complete, and the relay is awarded with a positive score. However, if a user agrees to act as a challenger, the base station requests them to retransmit their cached content to the EU. The EU then computes the QoE gain for the data transmitted by both the relay and the challenger, and sends this information back to the base station.

The base station validates the service and determines whether the relay provided the best service to the user. If the relay provided a higher QoE than the challenger, the relay wins the *Proof-of-QoE* and scores points. If the relay fails the consensus, it is awarded with negative points. In either case, the challenger earns consolidation points for the service provided. If there are multiple users willing to serve as the challenger, the base station selects the one they believe has the best chance to outperform the selected relay. The *Proof-of-QoE* consensus model is detailed in Algorithm 1.

Algorithm 1 Proof-of-QoE Consensus Model

Let u denote the set of NOMA users; Let v denote the user who is willing to purchase additional copy of cached data to improve their QoE. Let w denote the subset of users w ϵ u who have cached content. Let x denote the selected relay x ϵ w to provide retransmission.
The BS polls user set w to challenge the service provided by x to v.
If no users in subset w are interested in challenging the user x.
  Proof-of-QoE is complete. Relay x passes the validation.
  The relay score for transmission is added to the net score.
Let y denote the subset of users y ϵ w who challenge x.
BS chooses z ϵ y as challenger based on the channel information and prior reputation. If no information is available a challenger z is chosen at random from the subset y.
The challenger z transmits the cached content of user v.
The user v computes the valuation for z, then the bid and finally QoE gain based on the received data. Here the user assumed that the bid submitted will the price paid for the service if z was selected as relay.
The user v also computes the QoE gain of the data received from relay x.
The information is sent to validator (BS).
If the base station determines that the relay x provided higher QoE for the user v than the challenger z
  The relay is declared as the winner.
  A positive score is determined for the relay and added to the net score.
  The challenger failed but they are not penalized.
Else If the base station determines that the challenger provided higher QoE for the user.
  The relay receives a negative score as a penalty.
  The negative score is much steeper than the positive score.
  The relay could have achieved if relay won the validation.
  The score is computed using the PT function.
  The challenger receives a positive score for providing high QoE service to the user.
The challenger is compensated for their time and service by awarding an additional fixed positive score.

V. Scoring and Mining

To maintain the stability and integrity of a decentralized blockchain network, it is necessary to introduce a certain degree of inflation. This is typically achieved by creating new tokens or coins that are added to the circulating supply of the network, with miners or validators being responsible for their creation. In our proposed solution for the NOMA blockchain environment, we advocate for a scoring and minting algorithm based on Prospect Theory (PT).

The NOMAToken score assigned to a Miner is a crucial element of the Proof-of-QoE score. Each user joining the NOMA network receives a score ϕ. Any relay with a score higher than ϕ is deemed honest. The score of an honest relay decreases based on the number of validations received and the time elapsed since the last successful verification. A negative score implies that the relay has a poor track record of caching and delivering retransmissions correctly. In order to capture the loss aversion characteristic among relays, we have used the asymmetric value function in a way similar to [15] to model our QoE.

Upon joining the NOMA network, every user is assigned an initial score ϕ=0. For each successful validation, the relay node earns a positive score that is added to the initial score. Users within the network strive to find the relay with the maximum successful validations to achieve the highest score. After a certain period, the relay with the highest score is granted permission to mint new NOMAToken.

Section II discussed the creation of a straightforward API using Remix IDE for the NOMA Token Framework. The API enables the winning user to mint new tokens, which are then deposited into their MetaMask wallet. These tokens can be stacked, used for transactions in the NOMA network, or traded in a cryptocurrency exchange. As an Ethereum-based token, NOMAToken can be traded against reserve tokens, allowing for the establishment of a price. After a period, the scores of all users are reset to zero, and the competition to mint new tokens begins again.

VI. Numerical Study

Simulation were performed using MATLAB to validate the efficiency of the developed NOMA blockchain network and to test the proposed consensus model against existing models. Figure 3 shows a comparison of the QoE achieved by the user versus the distance from the base station. The QoE is calculated using equation 3. As the distance increases, the QoE of the user decreases due to the increase in noise and interference. This issue can be addressed by long distance users by choosing relay transmission. It can be observed that when two levels of retransmission are used, the base station is capable of extending coverage, and the user is able to attain higher levels of QoE. This outcome supports the adoption of relay retransmissions in the NOMA network.

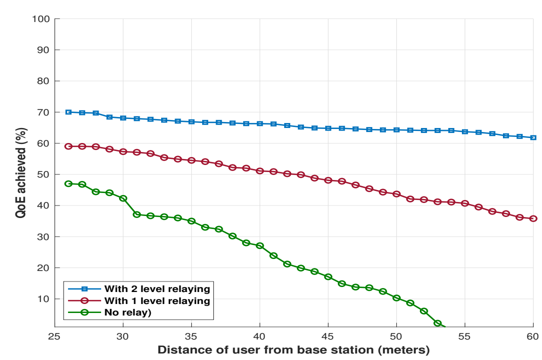

Fig. 3. Scoring Function for *Proof-of-QoE* consensus

In our pursuit of discovering the most pertinent consensus algorithm solution, we explored several widely adopted models such as Proof-of-Work (Bitcoin), Proof-of-Stake, Proof-of-Activity, and more. We identified two models that were pertinent to our objective. Proof-of-service is a validation method based on reputation, ensuring that all users receive service. Proof-of-coverage is a serial validation approach, verifying that the nodes in the network are in a specific geographic location to provide service. Both methods focus on establishing successful connectivity and data delivery, overlooking the quality of the delivered data. In Figure 4, a comparison of the QoE improvement achieved by the three consensus models is presented. It is evident that the proposed proof-of-QoE offers the highest social QoE (cumulative QoE for all users in a network) for the number of coins minted.

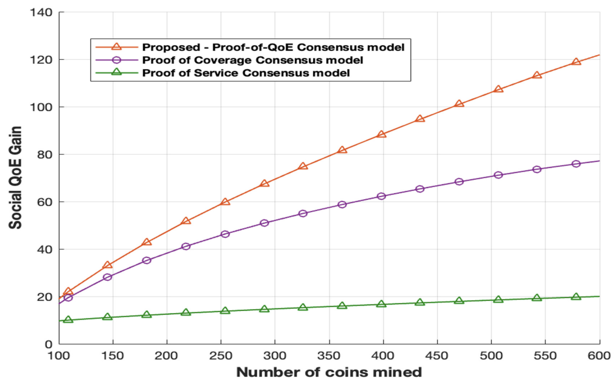

Fig. 4. Scoring Function for *Proof-of-QoE* consensus

Figure 5 presents an analysis of the PT-based scoring algorithm. Whenever a validation is successful, the relaying device receives a positive score, while a failed validation results in a negative score. Since the scoring system is based on PT, the penalty for losses is significantly higher than the reward for gains. Additionally, users who are idle in the network are also penalized as their scores decay over time. The user with the highest score is awarded the opportunity to mint new coins and keeps all the rewards. One the new coins are minted, the scores for all users in the network are reset. This provides a fair chance for all users to participate in relaying and mint coins.

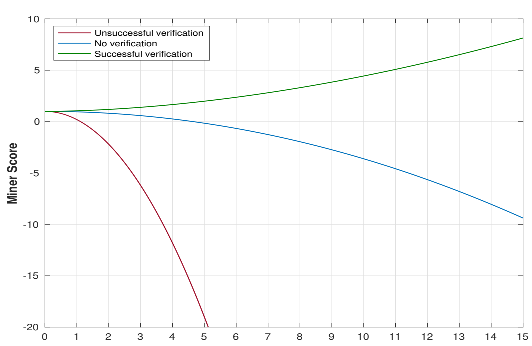

Fig. 5. Scoring Function for *Proof-of-QoE* consensus

VII. Conclusions

Our manuscript presents an innovative blockchain solution for managing and incentivizing retransmissions within a NOMA network. This proposed blockchain model has the potential to significantly enhance the QoE for users and encourage participation from relaying devices. We have introduced a new crypto token, NOMAToken, which facilitates monetization of all network interactions. To govern these interactions, we have proposed a *Proof-of-QoE* consensus model in which the base station serves as a validator and users outside of the interaction act as challengers. The relays are evaluated based on the value function prescribed by PT, and the top-scoring relays are permitted to create new tokens, which are deposited in their wallets. Our simulation tests demonstrate the importance of retransmission in a NOMA network and validate the Proof-of-QoE consensus scheme.

VIII. Acknowledgement

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