Gas Fees and Transaction Fees: Understanding Calculation Methods and Analyzing the Benefits of the Lightning Network and Auction Models

***Abstract*— The recent surge in popularity of cryptocurrencies has sparked heated debates about transaction and gas fees making it a significant concern for users. These fees are necessary for blockchain networks to function, but their calculation methods are not always straightforward. The purpose of this research paper is to provide an overview of the various factors that influence the calculation of gas and transaction fees in various blockchain networks. In addition, the paper will introduce the Lightning Network concept, which promises to reduce fees and increase transaction speeds. The paper will go over the benefits of the Lightning Network in greater detail including its ability to facilitate micropayments, and compare its auction model to the traditional English auction, with its benefits, such as increased transparency, security, and efficiency. The benefits of the Lightning Network, such as lower fees, faster transaction speeds, and increased scalability, will be examined in this paper.**

Overall, the goal of this research paper is to provide a thorough examination of gas fees, transaction fees, the Lightning Network, and auction models. It will assist readers in comprehending the complexities of the blockchain ecosystem and the benefits of newer technologies such as the Lightning Network.

Keywords—gas fees, transaction fees, miners, mining, proof of work, lightning network, lightning auction.

I. Introduction

The transaction related concepts, Gas fees and transaction fees are two distinct blockchain-related concepts. The gas fees are specific to smart contract execution, whereas transaction fees are more general and can be applied to any type of blockchain transaction.

A gas fee is paid by a user to execute a smart contract or a transaction on a blockchain network. The computational effort required to execute a transaction or a smart contract on the blockchain is referred to as gas. The gas fee is paid in the network's cryptocurrency, such as Ether in the case of the Ethereum network. The gas fee is used to compensate network miners for their computational efforts while also preventing spam and denial-of-service attacks.
A transaction fee, on the other hand, is a fee paid by the user to prioritize their transaction on the network. Transaction fees are not limited to smart contract execution and can be applied to any type of blockchain transaction. The transaction fee is also paid in the network's cryptocurrency and is used to incentivize miners to prioritize the transaction during their mining process.

The growing popularity of cryptocurrencies has highlighted the need for more efficient, cost-effective, and scalable transaction processing systems. The decentralized, secure, and transparent nature of blockchain technology, which underpins cryptocurrencies, has garnered widespread attention. However, as blockchain adoption has increased, so have transaction fees and processing times. These difficulties prompted the creation of the Lightning Network, a payment protocol that aims to reduce transaction fees while increasing transaction speed.

The Lightning Network works as a layer on top of existing blockchain networks, allowing peer-to-peer transactions to happen instantly and without the need for a third-party intermediary. It is implemented by establishing payment channels between users that can be used for multiple transactions without requiring each to be recorded on the blockchain. The Lightning Network aims to lower transaction fees and increase the capacity of blockchain networks by reducing the number of on-chain transactions.
In addition to the benefits of the Lightning Network, the Lightning auction model has emerged as a promising application of this technology. Lightning auctions are real-time auctions that use the Lightning Network's capabilities to provide a more efficient and transparent auction experience. Unlike traditional auctions, which can be subject to manipulation and fraud, Lightning auctions provide increased security and transparency through the use of smart contracts and instant payments.

This research paper aims to provide a thorough examination of the Lightning Network and Lightning auctions, examining the benefits and drawbacks of these technologies and comparing them to traditional transaction processing and auction models. This paper will contribute to ongoing discussions about the future of decentralized finance and the broader impact of blockchain technology on financial transactions by examining the use cases, technical design, and economic implications of the Lightning Network and Lightning auctions.
This paper refers to a lot of terminologies related to Blockchains and Auctions and a detailed explanation or definition of these terms are provided towards the end of the paper i.e., in the Glossary section.

II. Literature Review

Laurent et al., 2022 proposes a method for Ethereum users to optimize transaction fees by predicting the minimum fees (gas price) they should pay for their transactions to be mined within a given time limit with a given probability.

The method is based on a deterministic mathematical model for the computation of mining probabilities and an algorithm based on the Monte-Carlo method and a binary search algorithm to solve the gas pricing problem, that considers the pending list state and gas limit to provide an optimal gas price value. The experimental results on real-life data demonstrate the reliability of the method in returning the lowest gas price for a transaction to be processed while ensuring the desired probability. The proposed approach provides an efficient solution for Ethereum users to optimize

transaction fees by configuring the time limit and probability based on their requirements. [7]

Donmez and Karaivanov (2021) This paper studies the economic determinants of transaction fees in the Ethereum blockchain. It estimates an empirical model based on queueing theory and analyze the factors determining the "gas price" (transaction cost per unit of service, "gas").

Using block-and transaction-level data from the Ethereum blockchain, we show that changes in service demand significantly affect the gas price-when there is high block utilization, per-unit fees increase on average, with strong nonlinear effect above 90% utilization. The transaction type is another important factor-larger fraction of regular transactions (direct transfers between users) is associated with higher gas price. [8]

Kim et al., 2022 The importance of transaction fees in the Bitcoin network is increasing due to the continual halving of the block reward. The mining reward must be compensated by an increase in the bitcoin price or a rise in transaction fees to encourage mining activities and maintain the network's security. The research focuses on the relationship between the mining industry and the bitcoin user side, with a particular focus on transaction fees. The history of the average bitcoin transaction fee is highly influenced by changes in the bitcoin price. To filter out the price effect, the values are divided by the bitcoin price.

The observed transaction fee levels before 2016 are unlikely to be the result of user competition because the average block size was considerably below the limit. The competition model only reflects the period in which the average block size is close to 1 MB, so the discussion is limited to the period from 2017 to 2022.

The authors propose a transaction bidding function that increases with the user's aversion to confirmation delay and demonstrate that transaction fees amplify the security and sustainability of the Bitcoin network. The impacts of transaction fees are magnified by their role in the network, and events such as halving events, price decreases, and mining cost increases negatively affect both individual transaction fees and the number of active users. The authors derive each user's equilibrium fee bidding function based on their aversion to confirmation delay using the theory of rank-order allocation game. The study is helpful for those attempting to endogenously determine variables within the cryptocurrency ecosystem or design a new cryptocurrency mechanism. [9]

III. Gas Fee

A. *What is Ethereum gas?*

Ethereum gas is the fee for transactions made on the Ethereum blockchain. You can pay for gas in Ether (ETH) and prices are denoted in gwei (wei being the smallest denomination of ETH).

B. *What are Gas Fees for?*

Transactions on the blockchain are validated by miners and charged a gas fee. This is done to encourage people to become miners and participate in maintaining the integrity of the decentralized ledger.

C. *Gas limit*

The gas limit is the maximum amount of gas that you're willing to pay to run a transaction. If you set the gas limit lower than what is required, the transaction will fail and you'll lose the unused gas.

D. *Gas price*

The gas price is how much you want to pay per unit of gas. The higher the gas price, the faster your transaction will be processed.
To better understand how gas fees work, let's understand with car and gas analogy. The more you're willing to pay per liter of petrol, the faster your car will reach its destination (the blockchain). [1][2]

IV. Transaction Fee

When you perform a transaction on the blockchain, you will pay a fee. These fees are an essential part of the blockchain ecosystem. While high fees can hinder widespread adoption of blockchain technology, very low fees can raise concerns about safety and security.
The amount of the fee depends on the specific cryptocurrency and network being used.

A. *What are Blockchain Transction Fees and Why do they exist?*

1. Transactions on the blockchain require computational power, which is provided by "miners" with sophisticated software that solves complex mathematical problems.

Explanation: Transactions on a blockchain require computational power to be processed and validated by the network. This computational power is provided by "miners," who are nodes in the network that use specialized hardware and software to solve complex mathematical problems in a process called "mining."

When a user submits a transaction on the blockchain, it is broadcasted to the network of nodes, which include miners. Miners compete with each other to add the transaction to the blockchain by solving a complex mathematical problem. This process is known as "proof of work," and the first miner to solve the problem and add the transaction to the blockchain is rewarded with cryptocurrency.

The mathematical problems that miners solve are deliberately difficult and require a significant amount of computational power to complete. This is done to ensure the security of the network and prevent fraudulent transactions from being added to the blockchain.

Miners use specialized hardware, such as application-specific integrated circuits (ASICs), to perform the calculations required to solve the mathematical problems. They also use sophisticated software that is designed to optimize the mining process and increase the chances of solving the problem and earning the reward.

2. Transaction fees are charged when sending, depositing or withdrawing cryptocurrencies and exist for two reasons.
3. While fees are generally cheap, they can become expensive depending on the network's traffic.

B. How do Transaction Fees work?

Fees are tied to the size of the transaction and the throughput of the network. When a blockchain is heavily congested, users can attach a higher transaction fee to entice miners to prioritize their transactions and validate them first.

C. Ethereum Transaction Fees

Ethereum fees are based on the computational power it takes to validate the transaction. Gas fees are made up of two things, the gas limit and the gas price. Recently, Ethereum moved from an auction fee model to a transaction pricing mechanism. This hard fork introduced a fixed-per-block network fee.

Gas prices can rise or fall depending on network traffic, and paying a higher gas price can prioritize your transaction. Total gas fees include payments for computing power and fees for faster transaction processing. The maximum price to pay for a transaction can be determined by the gas limit. ETH is required in your wallet to pay transaction fees, and the network will notify you if you do not have enough. As Ethereum moves towards Proof of Stake, gas fees are expected to drop.

Here's how it works:

A base fee is set per block, but this fee can be increased or decreased depending on how busy the network is.

D. Why Understanding Transaction Fees is Important?

With the rise of decentralized apps and the acceptance of cryptocurrency as legal tender, more businesses are integrating their services with the blockchain. Understanding how blockchain transaction fees work is therefore necessary for predicting expenditure. [3] [4] [5]

V. Top 10 Cryptos with Lowest Transaction Fees

BLOCKCHAIN PROJECT	NATIVE TOKEN	TRANSACTION FEES
Iota	IOTA	0
Nano	XNO	0
Ripple	XRP	~ 0.00001 XRP
Polygon	MATIC	~ 0.044216 MATIC
Litecoin	LTC	~ 0.000090 LTC
Dash	DASH	~ 0.0071 DASH
Stellar	XLM	~ 0.00001 XLM
Monero	XMR	~ 0.0000075 XMR

Fig. 1. Comparision of Cryptos with Low transaction fees

This section discusses the concept of transaction fees in the blockchain ecosystem, which refers to the cost of performing a transaction on the blockchain and is paid out to miners or validators. As the popularity of DeFi grew, transaction fees increased substantially, resulting in the birth of new networks that aim to reduce transaction fees. [6]

VI. Transaction Fees Calculation

A. Ethereum Transaction Calculation

Gas fee is calculated in unit of (gwei)

$$\boldsymbol{Total\ Fee = Gas\ Price * (Gas\ Limit + Tip)}$$

where,

Gas Price → the price in Ethereum which the user is willing to pay for that transaction

Gas Limit → This is the maximum gas amount which can be consumed and is set by the network depending on the traffic

Tip → this is optional. This helps in completing the transaction faster. [22]

If 3 transactions are carried out as following:

$$T1 = 23{,}000\ gwei * (150\ gwei + 20\ gwei)$$
$$\rightarrow 3910000\ gwei\ or\ 0.00391\ eth$$

$$T2 = 27{,}000\ gwei * (150\ gwei + 22\ gwei)$$
$$\rightarrow 4644000\ gwei\ or\ 0.004644\ eth$$

$$T3 = 18{,}000\ gwei * (150\ gwei + 33\ gwei)$$
$$\rightarrow 3294000\ gwei\ or\ 0.003294\ eth$$

$$\boldsymbol{Avg\ Transaction\ cost} = (T1 + T2 + T3) / 3$$
$$= (3910000 + 4644000 + 3294000) / 3$$
$$= 11848000 / 3$$
$$= 3949333\ gwei\ or\ 0.003949333\ eth$$

B. Lightning Network Transaction Fees

There are two types of fees in the Lightning Network.

$$\boldsymbol{Base\ Fee + (payment * Liquidity\ Fee)}$$

Lightning network uses Satoshi (a denomination of Bitcoin) to measure fees, majorly the base fee and the fee based on the liquidity used.

Base fee: The fees set by the node for every transaction that is passed.

Fee-based on liquidity used: This charges fee for every Satoshi that is sent using the channel. This is also set by the node that has set up the channel.

If we set,

$$Base\ fee\ =\ 100\ satoshi$$

$$Liquidity\ Fee\ =\ 0.01\ satoshi\ for\ every\ Satoshi$$

Then if we take the upper 3 transaction and do then through this channel then,

Converting Gas Fee of transactions from gwei to Satoshi,

$$T1\ =\ 23000\ gwei\ =>\ 159\ satoshi$$

$$T2\ =\ 27000\ gwei\ =>\ 186\ satoshi$$

$$T3\ =\ 18000\ gwei\ =>\ 124\ satoshi$$

For each transaction in lightning network

$$Base\ Fee\ +\ (payment\ *\ Liquidity\ Fee)$$

$$T1\ =\ 100\ +\ (159\ *\ 0.01)\ =>\ 101.56\ satoshi$$

$$T2\ =\ 100\ +\ (186\ *\ 0.01)\ =>\ 101.86\ satoshi$$

$$T3\ =\ 100\ +\ (124\ *\ 0.01)\ =>\ 101.24\ satoshi$$

$$Average\ =\ (101.56\ +\ 101.86\ +\ 101.24)/3$$

$$=\ 101.55\ satoshi\ or$$

$$14794\ gwei\ or$$

$$0.000014798436815\ eth$$

From above we can see that using base charges for both the networks we can see the total transaction cost in the lightning network is significantly lower than normal transaction rate. The fee could still be affected by lots of criteria like network traffic, network difficulty, priority fee, base and liquidity fee set by the node. The above calculation was performed with taking minimal charges, however there could be similar or significant changes with actual numbers. [22][23]

VII. The Lightning Network

A. The Lightning Network, Explained

Bitcoin's scalability is a frequently cited problem, as the network can only handle a limited number of transactions at once. This causes delays and high fees. The scalability problem is due to the fact that each transaction must be verified by every node in the network, requiring significant computational power and bandwidth.

The current Bitcoin network is not designed to function as a large-scale payments system, but rather as a decentralized, immutable ledger system. Bitcoin's Proof of Work consensus mechanism is energy-intensive and does not lend itself well to being used as a global medium of exchange.

B. What is the Lightning Network?

The Lightning Network is a Layer 2 protocol designed to improve the efficiency and speed of Bitcoin transactions by allowing users to make transactions off-chain[4] without the need for block confirmation on the blockchain. It was created by Joseph Poon and Thaddeus Dryja in 2016 and uses multi-signature wallets[5] to enable the creation of off-chain payment channels. The Lightning Network runs on top of the Bitcoin blockchain and can help reduce transaction fees and improve scalability.

C. How does the Lightning Network work?

The Lightning Network is a solution to the scalability issues faced by Bitcoin. It allows for the creation of payment channels between users, enabling them to make unlimited transactions off-chain without waiting for block confirmation on the blockchain. This significantly improves the speed and efficiency of the network. Payment channels are created by depositing Bitcoin into a multi-signature wallet on the Lightning Network, and transactions are made by updating the smart contract with the new balance. The only transactions added to the blockchain are the opening and closing transactions. The Lightning Network also allows for the creation of multi-hop payment channels, where users can transact with each other through a series of intermediate channels, further increasing the flexibility and scalability of the network.

D. Is the Lightning Network decentralized?

The Lightning Network is a decentralized protocol that relies on a distributed network of users. This allows users to make transactions directly with each other without the need for custodians like banks or centralized payment processors. As a result, transaction fees can be reduced, and the overall speed and efficiency of the network can be improved.

E. Benefits of the Lightning Network

The Lightning Network can improve the speed, efficiency, and scalability of the Bitcoin network. It is still in the early stages of development but has the potential to become an important part of the Bitcoin ecosystem.

F. Drawbacks the Lightning Network

The Lightning Network is a new technology that may encounter challenges and potential issues. These risks should be taken into account before using the Lightning Network. [10][11]

The hub-and-spoke paradigm that is characteristic of today's financial institutions might be replicated by the Lightning Network, which is supposed to be decentralized. Under the existing system, banks and other financial organizations serve as the main middlemen for all transactions.

By having more open connections with others, companies that invest in Lightning Network nodes may become comparable hubs or centralized nodes in the network. Fraud, fees, hackers, and price fluctuation are further issues. Here's

a list of drawbacks that will be explained in detail in the next section.

1. Closed Channel Fraud
2. Fees
3. Hacks
4. Malicious Attacks

Closed Channel Fraud: One of the risks when using the Lightning Network is closing the channel and going offline. The Lightning Network consists of bidirectional payment channels between two nodes that create smart contracts. If either party drops the channel, it will close and be settled on the blockchain. Let's understand this with an example.
For instance, if Sam and Judy open a channel and Sam purchases goods from Judy, he can take advantage of Judy by broadcasting the initial state after Judy logs off, giving them both their deposits back as if no transactions took place. This means Sam can get the goods without paying for them, which is dishonest.

This makes it necessary for third parties to run on nodes to prevent fraud within the Lightning Network, called a watchtower. The watchtower monitors the transactions and helps prevent fraudulent channel close. A "watchtower" concept has been developed to outsource trust to watchtower nodes to monitor for fraud. A period of 24 hours is given to create a bidirectional channel after receiving a request.

Fees: Using the Lightning Network incurs transaction costs. They are a mix of routing costs for passing payment information between Lightning nodes, creating and shutting channels, and Bitcoin's standard transaction fees. Businesses that use the Lightning Network as a payment and settlement layer may start collecting fees. Furthermore, because the watchtowers are third parties, many collect fees for their services. Once two parties have settled the bill, they must record a closure transaction on the blockchain for the agreed-upon amount, which includes the fee charged for forwarding the transactions. This is either a fixed price or a fee rate (a percentage of the transaction).

Hacks: Because payment channels, wallets, and application programming interfaces (APIs) may all be hacked, the Lightning Network is said to be vulnerable to hacks and thefts.

Malicious Attacks: Congestion induced by a malicious attack is another risk to the network. If the payment channels become congested because of a malicious hack or assault, the participants may not be able to retrieve their money back quickly enough. The attacker might utilize the congestion in these sorts of assaults to steal funds from parties that are unable to withdraw their cash due to the network freeze.

VIII. Comparison: Lightning and English Auction

A. *English Auction*

The English auction is also known as an open ascending price auction. The auctioneer starts with a low price and keeps increasing the bid until no one is willing to bid further. The highest bidder wins the auction and pays the price they bid. The auction can last for a longer period of time, depending on how many bidders are present and how many bids are made.

B. *Lightning Auction*

The Lightning auction is a type of auction that takes place over a short period of time, usually only a few minutes. Bidders have a limited amount of time to place their bids, usually a few seconds or less. The auctioneer sets a high starting price and the price decreases over time until someone makes a bid. The first bidder wins the auction and pays the price they bid.
The below table compares both, the English auction and the Lightning auction based on its features.

TABLE I. Comparision of Auctions

Features	**Auction Types**	
	Lightning Auction	***English Auction***
Purpose	Routing payments through Lightning Network channels	Selling goods or services to the highest bidder
Participants	Lightning Network nodes	Bidders and sellers
Bid structure	Nodes bid on the amount of fees they are willing to charge to route a transaction	Bidders offer increasingly higher bids until no higher bid is offered
Winner determination	Node with the lowest bid that meets the routing requirements	Bidder with the highest bid
Payment	Winning node receives the bid amount as a fee for routing the transaction	Winning bidder pays the bid amount to the seller for the item or service
Timing	Takes place in real-time as Lightning transactions are being routed	Can take place over a period of time, with a fixed deadline for bidding
Incentive	Incentivizes nodes to route transactions more efficiently and earn fees	Incentivizes bidders to offer the highest bid to win the item or service
Application	Designed for routing payments in the Lightning Network	Widely used in traditional auction markets for selling items or services

GLOSSARY

Term	Definition
decentralized ledger	A decentralized ledger is a record of all transactions on a network. This ledger is maintained and updated by many independent nodes, who collaborate based on a ruleset established by the protocol. Bitcoin uses a blockchain and a Proof-of-Work mechanism to organize the network and maintain its decentralized ledger. [14]
deFi	DeFi is a collective term for financial products and services that are accessible to anyone who can use Ethereum – anyone with an internet connection. [15]
gwei	Gwei is a subunit of the cryptocurrency Ethereum and a unit of measurement for the amount of gas required to execute a transaction on the Ethereum blockchain. The word 'gwei' means 'giga-wei', and it is equal to 1,000,000,000 wei. [16]
mempool	In a blockchain transaction, a mempool, or memory pool, is a list of pending transactions waiting for validation from a node before it is committed to a block on the blockchain. [17]
Miners	Miners - computers running software - used their time and computation power to process transactions and produce blocks prior to the transition to proof-of-stake, by solving computationally difficult puzzles to produce blocks, securing the network from attacks. [18]
Mining	Mining is the process of creating a block of transactions to be added to the Ethereum blockchain in Ethereum's now-deprecated proof-of-work architecture. [18]
Proof of work	The Ethereum network began by using a consensus mechanism that involved Proof-of-work (PoW). This allowed the nodes of the Ethereum network to agree on the state of all information recorded on the Ethereum blockchain and prevented certain kinds of economic attacks. [19]
Proof of stake	Ethereum uses proof-of-stake, where validators explicitly stake capital in the form of ETH into a smart contract on Ethereum. [20]
watchtower	A service that surveils a particular Lightning channel to guard against fraud. [21]

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