A Hybrid Architecture for Mitigating Free-Riding in P2P Network: A Comprehensive Review and Strategic Recommendations

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ABSTRACT

Free-riding in the context of a peer-to-peer network has to do with a peer consuming files from the network and not readily contributing in return by uploading files back to the network so they can be beneficial to other peers. As different architectures for peer-to-peer (P2P) networks have been developed, P2P networks have gained popular attention due to their decentralized nature, scalability, and better file sharing and storage capabilities. However, free riding in P2P networks still remains a major problem common to all P2P networks. This work conducted and presented a detailed review on various free-riding mitigation mechanisms, thereby unveiling the drawbacks of existing strategies. The publications were chosen from peer-reviewed papers on Google Scholar, IEEE, ResearchGate, Elsevier, Springer, Science Direct MDPI, arxiv. Discouraging free riding in P2P networks, cooperation in P2P networks, free riding mitigation mechanisms in P2P networks and efficient resource sharing in P2P were some of the terms used in the search. Out of 201 studies, 45 met the criteria for inclusion. 16 of the studies focused on discouraging free riding in P2P network, 3 on cooperation in P2P networks, 20 on free riding mitigation mechanisms and 4 on efficient resource sharing in P2P networks. This study uncovered some research gaps and recommended a dynamic grace period allocation with a content scanning mechanism to mitigate free-riding behaviour among peers in a hybrid peer-to-peer network and stop peers from sharing fake or repeated files in the network.

KEYWORDS

Hybrid
Architecture
Free Riding
P2P Network
Uploading

1. INTRODUCTION

A peer-to-peer (P2P) network is a system in which peers, or nodes, are directly connected and can operate as either clients or servers of different resources. A centralized network, in contrast to the more conventional method, is made up of one or more servers that serve clients. P2P networks have greater scalability and dependability than centralized networks. They are scalable because when a new node joins a P2P network, the system's load grows and its resources expand to handle the additional demand. Since each node only makes up a small fraction of the total, the network has a reduced chance of failing or being penetrated. A centralized network can have its overall performance significantly hampered if a server is the target of an attack (Mane & Ratnaparkhi, 2023).

Since Napster was developed in 1999, the P2P model has become progressively famous in content-sharing cache storage for the web, and storage of contents. Numerous P2P frameworks report tremendous active members, with millions, and billions, of machines that actively participate. Those members encompass home laptops as well as big business PCs. They are called peers or workers, each going about as both a server and a client (Shi et al., 2009). P2P networks have over the years gained popular attention as the need for efficient sharing of files among various users over a network continues to grow. In a P2P network, files are shared among various users known as peers across a particular network. As opposed to a client-server architecture. In P2P networks, files shared are stored in each peer's computer, which brings about a decentralized system and thereby, is not affected by a single point failure.

File exchange between computer users at the edge of the internet is facilitated via P2P file-sharing networks. Users don't need to transfer files using these strategies to know or meet one another. It has been a well-liked topic among individuals who share files because of the dramatic increase in available network bandwidth in recent years, including music and, more recently, movies. P2P applications include Bit-Torrent, which employs a central server known as a tracker to oversee the actions of peers and seeds, who at any given time, have a complete copy of the file to upload, and the file-sharing service Napster. A centralized server manages the peer and seed activities on both of these systems (Mane & Ratnaparkhi, 2023).

Because they use each other's system resources, peers in a P2P system are expected to contribute to the system by sharing their resources. Nonetheless, a sizable portion of peers in many P2P systems are reluctant to share resources. A client that retrieves the record from the system without giving anything back is known as a free-rider in a P2P network. According to the statistics, 7% of peers contributed more files than other peers in file-sharing networks in Gnutella 0.6, and 25% of peers provided roughly 99% of the resources in Gnutella. 25% of peers supplied 99% of all query hits in the network, while the remaining 70% of peers shared no files at all. Free riding weakens the resilience and efficacy of P2P systems and exacerbates network congestion, which causes instability in the system (Biaou et al., 2022).

(Mane & Ratnaparkhi, 2023) introduce solutions for fair P2P content delivery, ensuring that deliverers are rewarded proportionally for their contributions. It uses blockchain to enforce fairness and protect against adversarial peers. The proposed protocols, FairDownload and FairStream, are designed for efficient downloading and streaming in decentralized settings. The practicality of these protocols is demonstrated through experiments on the Ethereum Ropsten network.

According to (Stokkink et al., 2022), there have been advancements in Web3 networks, focusing on a solution to data sharing challenges across partitioned networks through a reputation-based auditing mechanism called the Timely Sharing with Reputation Prototype (TSRP), which ensures efficient and integrity-maintained data distribution by leveraging nodes' reputations. (Pal et al., 2022) address the free rider problem in P2P networks within distributed clouds, proposing a solution called KeyPIn, which is a Key-based, Participation-based, and Incentive-based scheme. Using a game theory approach, KeyPIn encourages resource providers to participate and limits access for

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free riders. Simulation results demonstrate the effectiveness of KeyPIn in reducing the impact of free riders on the network.

(He et al., 2021) introduced solutions for fair P2P content delivery, ensuring that deliverers are rewarded proportionally for their contributions. It uses blockchain to enforce delivery fairness and protect against adversarial peers. (He et al., 2021) proposed an efficient protocol for downloading and streaming, optimizing on-chain costs and communication, and detailing the practical implementation of prototype systems on the Ethereum Ropsten network, demonstrating their practicality.

(Anandaraj et al., 2020) introduced a dynamic smart network coding (DSNC) scheme to cluster content and perform coding operations within each group, reducing duplicate data transmission and improving efficiency. The system enhances P2P content distribution by optimizing resource utilization, reliability, and resilience against peer churn. Simulation results show that DSNC achieves 20–25% higher throughput than existing systems, with better reliability and robustness. Future research is suggested to optimize the system under network congestion and improve group formation and super-peer selection.

(De Lucena et al., 2016) introduced a mechanism for collaborative peers to share resources, ensuring satisfaction and fairness while isolating non-collaborative peers. It enhances the Network of Favors concept to balance resource provision and consumption, promoting cooperation and preventing free riding. A new scheme, Fairness-Driven Network of Favors (FD-NoF), features a feedback control loop to maintain fairness without significantly affecting satisfaction. Simulation results show that FD-NoF achieves desired fairness levels in low resource contention scenarios and performs comparably to Satisfaction-Driven NoF in higher contention scenarios.

Many incentive schemes have been suggested and put in place, such as reputation systems, tit-for-tat, and credit-based strategies. A reputation-based system or scheme can help a user identify problematic peers by monitoring neighbours during data transmissions and spreading the reputation of the uncooperative peer throughout the network. Tit-for-Tat initiatives promote cooperation amongst mobile users by exchanging comparable services based on each person's good behaviour. Every user receives back from its neighbours the same amount of service that it has provided based on its previous behaviour. Credit-based techniques give users who cooperate a fixed amount of virtual currency or credit as a reward. Because these tactics make use of both explicit and flexible incentive systems, they might be the most promising (Khalid et al., 2020).

As P2P architecture has its advantages, one of its persistent challenges is the issue of free riding, where some peers consume resources without contributing adequately to the network. This review studied various approaches used to mitigate free-riding in P2P networks thereby proposing a solution to free-riding in P2P networks by introducing a novel approach of assigning grace periods dynamically to mitigate free-riding behaviours in the network for file uploads based on the popularity of downloads made by peers in the network and a content scanning mechanism to stop peers from uploading repeated files. The second section discusses the various incentive approaches that have been used in mitigating free-riding in P2P networks and various architectures in P2P networks. Section 3 provides a critique of the related research, and Section 4 provides the conclusion.

2. AN OVERVIEW OF APPROACHES TO MITIGATE FREE-RIDING IN A P2P NETWORK

This section provides an overview of various approaches used to mitigate free-riding in P2P Networks. Several research works were compared and evaluated to arrive at the approaches outlined in this review. For each study, we consider several key criteria which are: understanding each study's approach to tackling free-riding, the trustworthiness of each approach in fostering peer trust, the degree of decentralization to distribute decision-making, resistance to various attacks, the effectiveness of incentive mechanisms, scalability, complexity and overhead in implementation, robustness in the face of failures, and transparency in operation. These criteria help in comprehensively assessing the strengths, weaknesses, and innovations of the proposed solutions, offering insights into their applicability and effectiveness in real-world P2P network scenarios.

The reputation-based Approach was chosen due to its effectiveness in fostering trust among peers by relying on peer ratings, promoting decentralized decision-making, and providing incentive mechanisms. However, concerns about centralization and vulnerability to attacks like whitewashing and collusion highlight the need for careful implementation.

The reciprocity-based Approach was also selected for its similarity to a trade-by-barter system, where peers exchange resources based on contribution levels. This approach emphasizes direct and indirect experiences among peers. However, it requires frequent interactions and is susceptible to deception by malicious peers.

The credit/Monetary-Based Approach was also chosen for its effectiveness in incentivizing peer contributions through tangible rewards or virtual currency. This approach relies on a strong central authority for monitoring transactions. However, it necessitates robust accounting systems and carries risks associated with centralization. The game-theory Approach was selected for its ability to model strategic interactions among peers accurately. This approach is suitable for environments requiring strategic decision-making. However, its complexity in implementation and analysis poses challenges. The blockchain-based Approach was chosen for its capability in ensuring security and transparency, particularly in decentralized systems requiring tamper-resistant records. Despite facing scalability challenges, blockchain offers robust protection of privacy and transparent transaction records.

2.1. Reputation–Based Approach

A reputation-based approach judges a peer based on the information provided by other peers to foster trust among the peers in the network. The goal of this approach is to make sure that each peer can trust the system because it completely relies on how peers rate themselves in the system. This approach has been adopted by various researchers with differences in how the trusts are computed in the system, considering the degree of accuracy and complexity. The disadvantages are based on centralization and communication overhead as well as whitewashing and collusion. In addition, this system is implemented based on the assumption that each peer would relate and give honest reports about fellow peers, which is not always the case (Kurdi et al., 2020).

(Ayodeji, 2022) conducted research to deal with the issue of free riding by using a decentralized reputation system to enhance the service capacity of peer-to-peer file-sharing networks. The proposed method used was a decentralized reputation system based on the Ethereum blockchain, where peers are voted on by their fellow peers to identify the most trustworthy peer for downloads. (Goswami et al., 2017) from a game theoretical perspective propose a reputation-based resource allocation in P2P Systems. The study uses game theory to analyze a resource allocation mechanism through two non-cooperative games, which are a demand game and a reputation game. This mechanism makes sure that peers want as a result of their shared capacity. Some known reputation-based mechanisms are shown in Table 1.

2.2. Reciprocity–Based Approach

A reciprocity-based approach can be likened to a trade-by-barter system, which has to do with two peers exchanging resources based on their activities and contribution levels to each other. In this approach, peers either relate with other peers based on their own experience working with that peer, known as a direct experience, or use indirect experience, which has to do with an experience about a peer gathered from other peers (Hazazi et al., 2019). According to (Kurdi et al., 2020), a reciprocity-based system

Table 1. A Summary of Reputation-Based Approach to Mitigate Free-Riding in P2P Network

Author	Algorithm(s) Used	Technique Used	Advantages	Limitations
(Ayodeji, 2022)	▪ Client collection and submission algorithm ▪ Reputation smart contract Algorithm	Decentralized reputation system	There is increased bandwidth when compared to not using reputation system	▪ Some time is required in either number of cycles or number of files transferred to show full potential ▪ Lack of effective file availability technique ▪ Only employed Ethereum block chain and did consider other blockchains like Solana
(Awasthi & Singh, 2019)	▪ Updating the SBCI of peer's algorithm ▪ Simple procedure for peer selection algorithm ▪ College admission and the stability of marriage-based approach for peer selection	Simplified Biased Contribution index (SBCI)	Does not require iterative calculation and can be implemented with lesser message overhead and storage capacity	Was not implemented in an unstructured P2P
(Berenjian et al., 2019)	▪ Symmetric key encryption ▪ RSA methodology	Incentive based security model	Combination of the proposed mechanism with standard methodology in cryptography i.e., RSA helps to secure the channel against line spying and hence providing a fair network	Not recorded
(Goswami et al., 2017)	Nash equilibrium	Demand game and reputation game	Demonstrated game theoretically reputation-based allocation mechanism and demonstrated how Nash equilibrium of two games results in more efficient use of network resources	Not recorded

has to do with the services of peers based on their level of contribution, which can be seen as a barter system. The reciprocity can either be direct or indirect, where peers take into consideration the interactions of all peers collectively. The disadvantage of this system is that it requires frequent interactions between each peer of pairs, while the latter peer can be deceived by malicious peers, and a practical application of this approach can be seen in BitTorrent using the tit-for-tat strategy.

(Adamu, 2021) proposes a Share-Ratio-Based incentive mechanism for file sharing with the BitTorrent Protocol. (Adamu, 2021) in his work, proposes a share-ratio-based incentive mechanism for P2P file-sharing networks, where shared files are done using the BitTorrent protocol. One of the strengths of this study is that it is not susceptible to Sybil attacks and collusion attacks, as it was introduced mainly to foster cooperation among peers, bring about fairness to downloaders, and prevent free riders and whitewashing attacks.

(Kurdi et al., 2020) proposed an Adjusted Free-Market-Inspired Approach (AFMIA) to mitigate free-riding behaviour in peer-to-peer fog computing. In his study, he proposed the AFMIA that takes into consideration resources as goods that have varied prices based on the extent of demand and supply. For example, the Wealth of peers fluctuates based on their activity in the network, in terms of providing and consuming resources. However, the newness of the study is based on the pricing model. I.e., the pricing model is not static as it changes based on the activity of the peers, and a supplying peer gets a higher incentive value if he or she provides a requesting peer with the most requested, least available resources. Some known reciprocity-based mechanisms are shown in Table 2.

2.3. Credit–Based Approach / Monetary-Based Approach

(Kurdi et al., 2020) observed that in a credit-based approach, peers get credit by providing services to other peers and give out credit by receiving services from other peers. As opined by (Hazazi et al., 2019), a monetary–based approach is also sometimes called a micropayment system, where peers are given a mandate to pay for the services they use and, in turn, will be paid for the services they give out to other peers. This system makes use of virtual currency, which is recorded for each peer in an accounting module, and proper exchange of services, a single authority maintains transactions and ensures stability. According to (Alotibi et al., 2019), a monetary incentive mechanism is a system whereby peers are expected to pay for services that come to them while getting paid for services they give out, and this approach involves the use of virtual currency such as PPay.

(Hazazi et al., 2019) proposed a method for overcoming free-riding in peer-to-peer networks using a credit-based incentive mechanism and a grace period. In his study, he uses a credit-based approach with a finite grace period for each peer. However, more focus and attention were on the upload rate of peers and a static grace period, which is a time frame wherein free riders or slow peers must reimburse the system. However, the method for scaling grace periods may have limitations in adapting to the popularity of a file, which can lead to wasting resources due to static grace. It may also be prone to free-riding attacks, which involve a user consuming a file again and again by exiting and joining the network, thus no longer expecting to reciprocate the aspect of fairness. Also, ensuring the legitimacy of uploaded files can also prove difficult, causing difficulty in thwarting duplicate or fake files.

(Alotibi et al., 2019) proposed a point-based system approach to overcome free-riding behaviour in peer-to-peer networks. (Alotibi et al., 2019) in their study developed a point-based algorithm to overcome the effect of free riding. Some known monetary-based mechanisms are shown in Table 3.

2.4. Game–Theory Approach

(Biaou et al., 2022) Game theory has to do with knowing the theory of distinguishing proof and classification of cycles to create togetherness among members. From a different perspective, game theory can be viewed as the study of methods of self-standing and contending members in a strategic solution.

Table 2. A Summary of Reciprocity-Based Approach to Mitigate Free-Riding in P2P Networks

Author	Algorithm(s) Used	Technique Used	Advantages	Limitations
(Adamu, 2021)	Swarm with a single peer set model	Share ratio-based incentive mechanism via BitTorrent protocol	▪ Not prone to Sybil and collusion attacks ▪ Simultaneously foster cooperation, provides fairness to new downloaders and deter free riding while resisting whitewashing attacks ▪ Does not require any central entity to be realised.	▪ The proposed mechanism didn't take into account P2P VoD and live streaming systems. ▪ Problem of finding the optimal values of the protocol's configuration parameters for optical performance was not put into consideration.
(Kurdi et al., 2020)	AFMIA Algorithm	Adjusted free market inspired approach	▪ The proposed algorithm successfully improves fairness for both free and non-free riders' overtime while not compromising on success rate by maintaining similar performance with the baseline case	Network features related to Fog context were not considered; the system algorithm was also studied under a medium sized system of constant number of services and transaction.
(Pal et al., 2022)	Key base, participation based and incentive-based scheme algorithms	A key based, participation based and incentive-based mechanism	▪ Detect free riders using participation scheme ▪ Provides a mechanism that ensures sufficient time for good users to access resources whereas free riders as given limited or no time.	Other game theoretic approach was not explored and compared with the performance of the proposed approach.

Table 3. A Summary of Monetary-Based Approach to Mitigate Free-Riding in P2P Network

Author		Algorithm(s) Used	Technique Used	Advantages	Limitations
(Hazazi et al., 2019)		Credit based approach algorithm	Credit based incentive with grace period	▪ Number of downloads by free riders decreases while downloads by contributing peer increases in comparison with previous systems ▪ Under longer grace period, downloads by fast peers were greater than slow peers	▪ Didn't check the performance of the system under varying grace periods based on the popularity of downloads. ▪ Didn't consider free-riders that might attempt to cheat this approach by repeatedly ▪ consuming one file, leaving the network, and then re-joining the network and consuming again. ▪ Didn't take into account the possibility of uploading repeated files and fake files by the peers ▪ Lack of effective comparatively assessment of the proposed approach against similar algorithm to determine the success rate and performance of the system
(Alotibi et al., 2019)		Point based approach algorithm	Point based approach	Ability to scale with different sizes of networks	Not implemented on large networks with multiple shared files.
(ImaniMehr & DehghanTakht-Fooladi, 2019)		Formalism of repeated game algorithm	Token based incentive mechanism	Showed that repeated game can be converted to one shot game and its Nash equilibrium can be obtained through players dominant strategy coverage	Using same token for all peers was not considered
(Goyal et al., 2019)	▪	▪ Gringotts was proposed to enable secure monetary incentives ▪ Professional surveys were also commissioned	Secure incentivization	results showed that 51% are willing to participate for suitable financial incentive which then motivated the need for alternative payment forms, device security and peer anonymity.	▪ Relies on feedback for the proposed mechanism to be carried out properly in practice ▪ Relies on feed-back from other domain for extension of the proposed mechanism beyond content delivery

The main aspect of game theory is the game. The game is a kind of known occasion among various legitimate members called participants. The importance of game theory about togetherness is that one member's honour is dependent on how the other members behave. The important aspect is that the game brings out the participant's character, front decisions, usable methods, and how these methods determine the result.

The game theory approach was also a technique used to mitigate free-riding in a P2P network. (Biaou et al., 2022) proposed an Ayo game approach to mitigate free riding in peer-to-peer networks. (Biaou et al., 2022) in their study presented a new mechanism of the stochastic model of Ayo game theory to prevent free-riding in a partially centralized P2P in the second generation of unstructured P2P networks. However, the proposed approach was mainly focused on a partially centralized P2P network.

(Zhang & Pei, 2022) provide a review of sustaining cooperation in groups of unrelated individuals from the perspective of game theory. (Heuer & Orland, 2019) conducted a one-shot prisoner's dilemma (PD) game experiment. In his study, he presented a comparison between subjects restricted to playing pure strategies and subjects allowed to play mixed strategies in a one-shot symmetric PD laboratory experiment. (Shareh et al., 2019) implemented a mechanism based on the Evolutionary Game Model to prevent Sybil Attacks in P2P File Sharing Networks. In his study, he uses a centrality relationship incentive mechanism. Some known monetary-based mechanisms are shown in Table 4.

2.5. Blockchain Approach

(Ahmed & Choi, 2023) observed that blockchain is a digital decentralized ledger in a peer-to-peer network that keeps a record of each user's transaction in an encrypted format. This brings about the feature of robust and advanced proof. Therefore, as a result of this, recent studies have adopted this to protect privacy. This protection of privacy merit can serve as a transparent record environment to store people's or users' information. However, scalability can occur in blockchain due to time delays.

According to (Ayodeji, 2022), a blockchain is a ledger system that is distributed and created by Satoshi Nakamoto. It is made up of a series of blocks that are chronologically related to one another, and each block is made up of sets of transactions joined together by a cryptographic chain because the set of transactions consists of block-specific information and a hash of the preceding block, which can be added by special nodes known as miners. Due to this chain structure, it is therefore resistant to alteration.

(He et al., 2021) proposed a fair peer-to-peer content delivery. In his work, two methods were presented to ensure fair P2P content delivery, which are FairDownload and FairStream via blockchain for P2P downloading and P2P streaming cases. The main strength of this paper is not just to ensure contents are delivered fairly and deliverers are paid in proportion to their in-time delivery, but to ensure that the people consuming the content and people delivering the content are treated equally. The two proposed methods were implemented in the Ethereum Ropsten network, and the arbiter contract was implemented in Solidity and divided into Optimistic and Pessimistic modules, where the former are executed when no dispute occurs, and the latter are executed when a dispute occurs.

(He et al., 2018) proposed a blockchain-based truthful incentive mechanism for distributed applications. (He et al., 2018) in their work introduced blockchain technology as an incentive mechanism for distributed P2P, where a cryptocurrency such as Bitcoin was used to incentivize users to cooperate, such that users who help with delivery that results in success get rewarded. A secure validation method and pricing strategy were also proposed and joined with the earlier proposed mechanism to deter miners and users that exhibit selfish actions and collude with each other. For the proposed model, a credit-based incentive mechanism to motivate the intermediate node to cooperate was employed, and questions such as who pays whom, how the bills will be paid, how much is required by the payer to pay, and how to guarantee that the transaction is secure were answered. A summary of blockchain approaches to Mitigate Free-Riding in P2P Network is showed in Table 5.

2.6. Existing Architectures in P2P Networks

In P2P networks, structured architectures use a predefined topology and distributed hash tables for efficient and reliable data retrieval, but are complex to implement. Unstructured architectures randomly connect peers, making them easy to implement and robust, but inefficient and less scalable due to flooding search queries. Hybrid architectures combine centralized components for managing indexing with decentralized peer interactions, balancing efficiency, flexibility, and robustness, making them effective and scalable.

Table 4. A Summary of Game Theory Approach to Mitigate Free-Riding in P2P Network

Author	Algorithm(s) Used	Technique Used	Advantages	Limitations
(Biaou et al., 2022)	Stochastic model based on modified Ayo game model	Stochastic model of Ayo game theoretic – An improved Ayo game model	The modified Ayo game enables more peers to acts as worthy peers and promotes completing of downloads by worthy peers	The presented model was not implemented in an appropriate simulated environment like PeerSim which have a very high scalability (e.g., Can cope with P2P system properties with up to 1 million nodes).
(Heuer & Orland, 2019)	Comparison of treatment means	Comparison between pure and mixed strategies	Subjects in the mixed strategy shows cooperative behaviour which affirms the prediction of the comparison analysis	Questionnaire based on the subject of social value orientation can be adopted for meta value of social value orientation in social dilemmas.
(Shareh et al., 2019)	Server and peer algorithm	Centrality relationship incentive mechanism based on Evolutionary game model	Detected and deter free riders as network life grows Reduced numbers of services delivered to collusive nodes as network life grows	Slow convergence speed and lack of stability factor to the reputation of the mechanism.
(Wu et al., 2014)	Evolutionary game theory model	Novel incentive mechanism (NIM) based on based on social network and game theory	▪ Nim restrains free riders efficiently and is immune to betraying and irrational players. ▪ Social network status used in NIM and the habit of making friends by users contribute to the performance of NIM.	The system was affected greatly by specific parameters
(Hua et al., 2012)	Dynamic and incomplete game theory model	A co-opetition framework with a fairness index monitor	Able to identify peers free riding in the system and limit their downloads.	▪ Does not consider cheating of the proposed system by free riders ▪ Only explored decentralized and unstructured P2P ▪ Results obtained were based on simulation and not a used real case scenario.

Table 5. A Summary of Blockchain Approach to Mitigate Free-Riding in P2P Network

Author	Algorithm(s) Used	Technique Used	Advantages	Limitations
(He et al., 2021)	▪ GenSubKeys algorithm ▪ RevealKeys algorithm ▪ ValidateRKeys algorithm ▪ RecoverKeys Algorithm ▪ ValidatePoM algorithm ▪ RecoverChunkKey algorithm	FairDownload and FairStream via blockchain for P2P downloading and P2P streaming scenarios	▪ Provides strong fairness guarantee for content provider, content consumer and content deliverer and prevent them from been ripped off by other colluding parties	▪ Adaptively choosing deliverers were not explored for each task to be delivered. ▪ Leverage the off-chain payment channels to handle possible micropayments and further reduce the on-chain cost was not explored also ▪ Digital right management (DRM) schemes were not explored also.
(Ma et al., 2023)	▪ Threat intelligence sharing game model ▪ Smart contract algorithm	Block-chain based cyber threat intelligence sharing mechanism (B-CTISM)	▪ In comparison with the existing scheme, the proposed mechanism was vetted and found to effectively promote members active participation in cyber threat intelligence	▪ Evaluation of the value of cyber threat intelligence provided is not enough and accurate scoring reward feedback is not given based on the information provided ▪ proposed mechanism still requires initiators and maintainers ▪ General deployment and operating issue facing smart contracts ▪ General limitation facing sharing of cyber threat intelligence is also a limitation to the system
(Motepalli et al., 2021)	▪ Evolutionary game theory algorithm ▪ Block validation game algorithm	Reward mechanism framework	▪ Proved the importance of penalties in maintaining the integrity of a blockchain leger to avoid free riding	▪ Didn't consider asynchronous environment with the proposed system ▪ Didn't evaluate how the proposed system adapts when delegation of stake is used
(He et al., 2018)	▪ One positive cooperative node algorithm ▪ Multiple positive cooperative nodes algorithm	Blockchain based truthful incentive mechanism	▪ Design a blockchain-based truthful incentive mechanism ▪ Introduction of secure validation ▪ Proposed a pricing strategy mechanism ▪ Used game strategy for evaluation	▪ The possibility of a sender colluding with its receiver were not considered ▪ Contradiction of incentive and privacy in the scheme was also not considered
(Pradhan et al., 2018)	▪ Message Routing ▪ Transaction ▪ Possible Anomaly Attempts in Transactions	Blockchain based security framework	▪ The proposed security framework does not need any central server and it not prone to attacks like RTI and Sybil attacks	Computed file searching time by the proposed mechanism is very small

Table 6 shows a comparative analysis of P2P architectures. Based on the comparison results, it can be seen that the hybrid P2P Architecture is the best overall because it combines the strengths of both structured and unstructured architectures, providing a balanced solution that ensures high efficiency, scalability, robustness, and effective free-riding mitigation. The central indexing server aids in efficient routing and content quality control, while decentralized peer interactions enhance scalability and robustness. This combination makes hybrid architectures the most effective for modern P2P networks.

In summary, the Reputation-Based approach is highly effective in fostering trust within a decentralized community. It performs best in environments with frequent peer interactions and effective mechanisms to prevent collusion and dishonest reporting. However, this approach is vulnerable to centralization and whitewashing.

The Reciprocity-Based Approach is effective in systems with frequent reciprocal interactions, such as BitTorrent with its continuous peer-to-peer exchanges. This approach requires frequent interactions and is susceptible to malicious peers. The Credit/Monetary-Based Approach is highly effective in incentivizing peer contributions with tangible rewards. It is optimal in systems with a strong central authority for monitoring transactions. However, it requires robust accounting and monitoring systems and carries risks associated with centralization.

The Game-Theory Approach is highly effective in strategic interaction environments where peer behaviours can be accurately modelled. It performs best in environments that necessitate strategic decision-making. The main disadvantage of this approach is its complexity in implementation and analysis.

The Blockchain-Based Approach is extremely effective in ensuring security and transparency. It is ideal for decentralized systems that need tamper-resistant records. However, it faces challenges related to scalability and implementation complexity. The Blockchain-Based Approach is extremely effective in ensuring security and transparency. It is ideal for decentralized systems that need tamper-resistant records. However, it faces challenges related to scalability and implementation complexity.

Table 7 shows a comparative analysis of the various approaches considered in this study, while Figure 1 shows a chart that compares the effectiveness of various approaches used in this review. The effectiveness scores for the various approaches were derived based on a qualitative analysis of their strengths, optimal conditions, and disadvantages.

Table 6. Comparative Analysis of P2P Architectures

Feature	Structured P2P	Unstructured P2P	Hybrid P2P
Architecture	Uses a fixed topology with a consistent hashing mechanism.	No fixed topology; peers connect randomly.	Combines centralized servers with decentralized peer interactions.
Efficiency	High efficiency in routing and searching.	Lower efficiency; search queries can flood the network.	Balances efficiency with flexibility; central servers aid routing.
Resource Utilization	Efficient resource usage due to structured routing.	Inefficient; high resource consumption due to flooding.	Efficient balance of centralized and decentralized resource usage.
Free-Riding Mitigation	Challenging to enforce strict policies.	Difficult to track and mitigate free-riding.	Effective due to centralized control over dynamic policies.
Scalability	Can scale efficiently with consistent hashing.	Poor scalability due to network flooding during searches.	Scales well by distributing load between central servers and peers.

Table 7. Comparative Analysis of Strategies to Mitigate Free-Riding in Peer-to-Peer Networks

Approach	Description	Effectiveness	Optimal Conditions	Disadvantages
Reputation-Based	Judging peers based on ratings from other peers to foster trust. Examples include Ethereum blockchain-based decentralized reputation systems and game-theoretic resource allocation mechanisms.	High in decentralized systems with strong community engagement.	Effective in systems where peers frequently interact and where there is a mechanism to prevent collusion and whitewashing.	Vulnerable to centralization, communication overhead, whitewashing, and collusion. Requires honest reporting.
Reciprocity-Based	Peers exchange resources based on their activity and contributions, using either direct or indirect experience. Examples include BitTorrent's tit-for-tat strategy and Share-Ratio-Based incentive mechanisms.	Effective in environments with frequent interactions and established sharing protocols.	Works best in systems with continuous and reciprocal interactions among peers. BitTorrent's tit-for-tat strategy is a prime example.	Requires frequent interactions. Susceptible to deception by malicious peers.
Credit/Monetary-Based	Peers earn credit for providing services and spend credit for receiving services, often using virtual currency. Examples include credit-based mechanisms with grace periods and point-based systems.	High in systems where peers can be incentivized with tangible rewards and where monitoring is feasible.	Best suited for systems with a strong central authority or clear accounting mechanisms. Effective where virtual currency can be efficiently used and tracked.	Centralized nature can lead to single points of failure. Requires robust accounting and monitoring systems.
Game-Theory Approach	Uses game-theoretic models to analyze and incentivize cooperative behaviour among peers. Examples include Ayo game models and evolutionary game models to prevent Sybil attacks.	Highly effective in systems with strategic interactions where peer behaviour can be modelled and predicted.	Optimal in environments where strategic decision-making is critical and where peer behaviours can be accurately modelled and incentivized.	Complexity in implementation and analysis. Requires understanding of game dynamics and participant behaviour.
Blockchain-Based	Utilizes blockchain technology for decentralized, transparent, and tamper-resistant record-keeping. Examples include blockchain-based incentive mechanisms for fair content delivery and truthful incentive mechanisms using cryptocurrencies like Bitcoin.	Extremely effective in decentralized environments requiring high security and transparency.	Ideal for systems needing high transparency, tamper resistance, and decentralized control. Effective in environments where privacy and security are paramount, such as financial transactions.	Scalability issues due to time delays. Complexity in implementation and transaction costs.

Based on the review of different approaches done in Tables 1 - 6, it is obvious that the approaches to mitigate free-riding in P2P networks vary significantly across reputation, reciprocity, monetary, game theory, and blockchain-based methods. Reputation and reciprocity approaches primarily aim to create fairness and incentivize good behaviour, but often suffer from limitations related to scalability and implementation in diverse network structures. Monetary and game theory approaches offer structured incentives and strategic interactions to discourage free-riding, but can be complex and difficult to implement universally. Blockchain approaches provide strong security and fairness guarantees but face challenges related to integration and scalability. Therefore, selecting the most suitable strategy would be based on the specific requirements and constraints of the P2P network in question.

3. REVIEW OF RELATED RESEARCH

The work by Karakaya et al. (2008) offers a distributed solution to free riding in Peer-to-Peer (P2P) networks where each peer monitors its neighbours and imposes actions against them locally without the need for permanent peer identification or a global reputation system. This is mostly achieved by detecting and locating free riders with a message count monitor, then taking counteractions to minimize the effect of free riders (e.g., adjusting TTLs, dropping messages). Its benefits are that it is decentralized, makes very few changes to existing protocols, and lowers network traffic, thereby improving performance. But it is not without its shortcomings: namely, the risk of false positives, in which even cooperative peers might be wrongly identified as free riders.

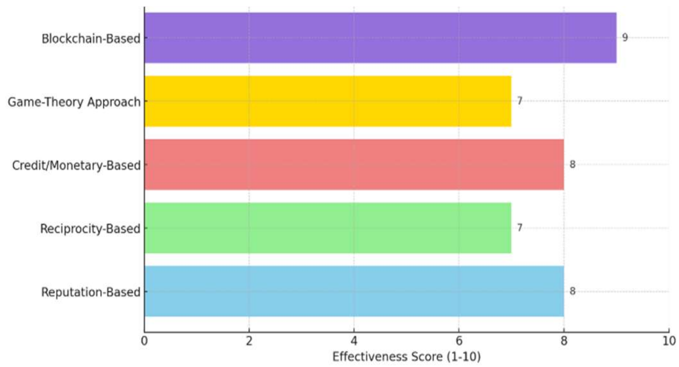

Figure 1: Effectiveness of Approaches to Mitigate Free-Riding in P2P Networks

(Shi et al., 2009) proposed a popular adaptive search in hybrid P2P systems. In their work, they introduced a popularity adaptive search method for the Hybrid (pash) protocol by dynamically estimating the content popularity. The proposed approach was evaluated through synthetic and trace-driven simulations, and the P2P model used consisted of topologies of a hybrid Guntella system from 2004 to 2005. In the simulation, the DHT was formed using the SHA-1 algorithm, and 105 queries were iteratively performed with 30 runs. The proposed approach was then evaluated by the following metrics which are: Estimation error, Traffic overhead, and Response time. And after the simulation to get the right performance evaluation, a smart node assignment scheme was employed based on probability, and the result showed that the proper value of x/n is about 15% when there are about 1000 nodes, but this value is less than 10% when the P2P topology size reaches 104.

An algorithm for reputation evaluation proposed by (Tseng & Chen, 2011) sorts peers into different ranks in terms of past transaction history and contributions, and the update frequency is controlled by group managers. Using a semi-decentralized architecture that splits the network into clusters to alleviate traffic load, with permissions levels preventing access to files by reputation. It also includes time-dependent degradation of the reputation if files are not shared with peers. This system has such advantages in reducing free-riding via incentivizing file sharing, security by identifying and then bypassing the malicious files, and resource utilization efficiency. But it also has drawbacks, including its high complexity (because the reputation is updated and managed continuously), issues related to scalability for large networks, and being fooled positively by dishonest recommendations despite scoring them based on reputation.

Motivated by the prevalent free rider problem in Gnutella-like unstructured P2P networks, (Joung et al., 2012) also provided a solution for policing free riders. The algorithm used alters how the neighbour table is constructed to guarantee that free riders are closely surrounded by non-free riders and vice versa. Bloom filters are used to summarize the files that each peer shares, which helps in faster query processing. By using this method, the problem of free riding in searching can be effectively improved while maintaining high-level search efficiency and reducing the possibility of being a factor for decreased network robustness when facing a high ratio of free riding. Besides, it keeps the overall network, and maybe even because many people have come to appreciate this chain. But the use of bloom filters can lead to false positives, leading to unwanted query retransmission or periodic neighbour table & bloom updates.

The utility exchange incentive mechanism based on a gift-giving game modified in peering is proposed by (Cai et al., 2012), where peers trade resources based on their utilities over the same resource updated after every transaction. This is driven by game theory that models the peer to be interacted with, and a super peer manages utility exchanges and agreements of resource sharing. This approach has the advantage of inducing fairness by incentivizing resource braking, and you can work best to reduce turbulence within your P2P system. The paper, excepting some early discussion (e.g., one tethered-pending-retrieval seed per file), assumes that all peers are honest and good, and does not touch on malevolent or conflicted sharing of resources by other peers.

An introduction of the Dynamic, Incomplete Game Model to analyze peer interactions in P2P networks was provided by (Hua et al., 2012), who used Nash equilibrium in determining optimal strategies for peers. The authors present a co-opetition model with reputation and threshold mechanisms to restrict free riding, and run simulation experiments in different scenarios that ultimately validate the framework. The benefits of this framework include efficiently mitigating free riding, increasing the efficiency of the system, and guaranteeing fairness by forcing all peers to cooperate in file uploading. Then again, the model assumes that there are only altruists and free riders (which might not hold true in reality), and it is also very sensitive to particular parameters, so you really have to be cautious with setting them in a careful manner.

(Amad et al., 2013) also address free riders in P2P networks by proposing a utility function-based approach to detect and isolate them. This algorithm uses the number of positive responses (Serv), detection of free riding attempts (Dect), and a free rider status (FR) as parameters to choose at what rate must be prioritized when requesting dataippets. This solution combines super peers and ordinary peers in a hybrid P2P architecture, letting super peers manage the resources and requests from other commoners, so that more peers are motivated to contribute. It uses priority queuing based on the utility function as an algorithm. This solution leverages the benefits of its scalability and simplicity in implementation by enforcing peering only between contributors, thereby promoting resource sharing and mitigating free riding. But the paper does note that true free riders might be missed and does not consider mobility or dynamic joining/leaving of peers during simulations, indicating that further improvements are needed to address these aspects.

Proposing a game-theoretically inspired utility exchange incentive mechanism, (Yahaya, 2015) provides an adapted gift-giving game to enable peers to exchange resources based on their usefulness, which is updated after each transaction. It uses a super peer to manage utility exchanging among peers, and simulates the interactions between each peer based on mechanism design and game theory, following the natural behaviour of economic exchanges in nature. This solution follows from the principles of fairness, resource contribution, and stability in a peer-to-peer system. All the while, paper assumes all peers to be honest and trustworthy, and hence peer propagating unauthentic or malicious resources is not discussed.

(Azzedin, 2016), in an attempt to minimize free-riding, worked on mitigating the effect of free riders in a distributed system based on a trust-based approach. They proposed an algorithm to mitigate free riding to oppose two attacks, which are dishonesty and collusion. The experiment of the algorithm was conducted in two parts; the first part was done in a real-life environment using two BitTorrent clients, while the second part of the experiment was conducted just like the first but was done in a simulation environment using PeerSim. For the performance metric of the proposed algorithm, download time and detection tolerance were considered and the result based on BitTorrent exploration showed that more than 95% were contributing as compared to the existing scheme while based on detection tolerance in a dishonesty environment, result showed that as the number of dishonest peer goes up, the misdetection rate also rises and based on detection tolerance in colluding environment, result showed that the average contribution factor stays the same and the misdetection rate is also the same. The main strength of this study is the ability to isolate free riders in dishonest and colluding environments. However, the proposed algorithm can be integrated into the WSN environment.

(De Lucena et al., 2016) worked on enhancing fairness in P2P cloud federations. Their study proposed a non-monetary market system for the sharing of resources within the boundary of a decentralized, lightweight P2P federation of private cloud providers. The proposed mechanism aims to make sure that the peers contributing and interacting make the best decisions, ensuring a level of satisfaction and fairness, as well as isolating non-interactive peers. The main strength of this study is that it is an enhancement of the Network of favours and consists of a feedback control loop mechanism that does not encourage free riding and ensures an appropriate degree of fairness. The proposed mechanism was assessed with the assistance of a simplified model of a federated P2P system and also simulated. The result showed that the proposed algorithm accomplished its goals in different scenarios, such as low resource contention and scenarios in which peers are in a consumer state with different frequencies. However, the proposed algorithm was not evaluated within the federated cloud-integrated computing infrastructure.

(Ghaderzadeh et al., 2017) proposed intelligent free rider detection in collaborative distributed systems (InFreD). They provide a more intelligent approach to prevent free-riding completely and bring about better overlay formation to enhance performance metrics. The proposed method was evaluated in a PeerSim simulator with simulation runs with 250, 500, 1000, and 1500 peers compared with a measurement-based approach, and the performance metrics for evaluation are fairness, download time, robustness, scalability, and messaging cost. Results showed that the system enhances performance for regular peers and prevents free riders from exploiting the resources in the system. The major significance of this study is the ability to take into consideration the long-term contribution of peers and select the best neighbour where there are no repeated interactions. However, only free-riding was studied, and other fairness metrics were not considered.

(Singha et al., 2019), in an attempt to stop free-riding by providing an optimal partitioning of link capacity between upload and downloads of peers in the network, developed an adaptive capacity partitioning in cooperative computing to maximize received resources. The work makes use of a resulting algorithm called adaptive step size (ASZ), placed with the task of dynamically changing the splitting of a link to an optimal value. To evaluate the performance of the proposed approach, a metric level optimality was introduced, and results showed that the level of optimality achieved by (ASZ) is closer in comparison to the existing scheme, leading to a better performance of the proposed algorithm. Also, ASZ was integrated with BitTorrent, and the simulation result shows a resource increase for the user. The major strength of this study is the ability to provide optimal partitioning in real-life distributed networks and also to provide an algorithm that is adaptable to network changes.

(Anandaraj et al., 2020) proposed an efficient framework for network code-based multimedia content distribution in a Hybrid P2P network. A random linear combination of coded pieces was used, and a network coding scheme was used such that several contents of the same message are partitioned into different groups with coding operations performed within the same group. The performance is evaluated using two approaches, which are the Traditional non-network coding mechanism (TNNC) and Flat network coding mechanism (FNCM). The proposed system is evaluated against the existing system using the following metrics: Throughput, average finish time, maximum finish time, failure rate, and link state, and the performance is analyzed into two different arrangements: Homogeneous, Heterogeneous, and dynamic arrangement. Results based on homogeneous arrangement showed that the average download time of the proposed mechanism is 20 – 25% shorter than the existing system, while results based on heterogeneous and dynamic arrangements showed that the average download time increases in comparison to the homogeneous arrangement. However, more focus can still be given to the optimization of the system under network congestion and optimization of the process of forming groups and selecting super peers.

(Rahman et al., 2021) proposed a game–theoretic framework to regulate free riding in inter-provider spectrum sharing. The study looked into a subsidy-based spectrum sharing (SBSS) to limit free riding in the SBSS market and also introduced a theoretical model to regulate free riding. A two-provider game NEs with different cases were carefully looked into, and a quantitative analysis was performed on them using simulation. For the SBSS market analysis, consideration was put in place for two providers competing for a single region. NEs and both providers' strategies were observed, and results showed that the proposed game model assisted both providers in keeping mixed strategies to control free riding. NEs with different sizes of providers were also looked into, and it was observed that if there were large size differences between the providers or if the sizes were similar, then free riding wouldn't occur.

However, the NEs algorithm wasn't explored based on repeated games; also, a Mobile Virtual Operator (MVNO) was not put into consideration, as the proposed game-theoretic model stands well and defends against data poisoning attacks and free-riding attacks.

(Stokkink et al., 2022) explored a reputation-based data carrying for Web3 networks. Their study utilizes the Timely sharing with reputation prototype (TSRP). The Reputation mechanism is used for interaction between nodes in different partitions. The TSRP was applied to a real-world trace of Twitter, and for benchmark purposes, two representative solutions were chosen for DHT and data allocation. And at the end of the experiment, based on stored records. Results showed that TSRP achieves the same results successfully as its benchmarks. The main strength of this study is that the proposed mechanism has been able to successfully enable users to uniformly maintain the integrity of records in a Web3 system.

(Sun et al., 2022) proposed a blockchain-based audit approach for encrypted data in federated learning. They used blockchain to keep the gradient that is encrypted from data owners and an audit chain to evaluate the gradient. A privacy-preserving homomorphic noise mechanism, which is a homomorphic BCP algorithm, was used together with an audit algorithm. The algorithm was simulated on datasets CelebA and MNIST. The result showed that the

(Kushwaha et al., 2024) propose a reputation-based incentive approach for P2P live streaming; they use a reputation aggregation formula to monitor peer contributions and manipulate the connections of peers according to their reputation scores in order to keep the network stable. Architecture: Uses something called Distributed Hash Table (DHT) for decentralized reputation management, game-theoretic equilibrium for system stability and request-to-join mechanism to address flash crowds It also allows to reduce the free-riding, encourage active participation and improve scalability while still keeping resilience in addition to enhancing its fault tolerance, reducing latency/buffer (Packet Shuffling), etc. However, it does not grade videos based on their contribution levels and different peer bandwidths.

3.1. Peculiar Challenges in Previous Works on Free Riding in Peer-To-Peer Network

As P2P systems generally become more stable with different architectures being formed for better performance of the distributed system network, the issue of free-riding needs to be properly dealt with to ensure the system attains its full peak and capacity. This, according to previous studies, can be achieved by incorporating various approaches as highlighted above to combat and limit the existence of free riders while significantly promoting fairness in the system. Furthermore, improvements to the existing approaches to limiting free-riding are required to address the issues. Previous works emphasized mitigating free riding via various approaches, but do not emphasize dynamic grace period allocation and the possibility of peers uploading repeated files and fake files either by colluding with other peers in the network or by being intentional in an attempt to circumvent the existing system.

4. METHODOLOGY

In this review, a systematic mapping is used to analyse a total of 43 published research papers, thereby addressing the following research question (RQ):

MAIN RESEARCH QUESTION (RQ):

How effective is dynamic grace period allocation and content scanning in free-riding mitigation in a Hybrid Peer-to-Peer (P2P) architecture as compared to existing strategies?

SUB-RESEARCH QUESTIONS (SUB-RQS):

Sub-RQ1 (Search Strategy):

Which search strategies are the most common and optimal for identifying relevant studies on free-riding mitigation mechanisms in P2P networks?

Answer: We systematically searched Google Scholar for studies related to free-riding mitigation in P2P networks, dynamic grace period, and content scanning mechanisms. Our search resulted in 201 studies, of which 43 were selected due to their specificity in terms of the nature of their freeriding processes and mitigation, particularly those related to structured, unstructured, and hybrid architectures.

Sub-RQ2 (Study Selection):

Selection of the Studies and Categorization into Different Free-Riding Mitigation Approaches. What criteria were applied to include studies, and what are the different free-riding mitigation approaches under which these studies were categorized?

Answer: Studies were then selected on the basis of importance to free-riding, measures for counteracting it, generalizability, decentralization, and applicability to hybrid P2P systems. The selected studies were classified into five categories: reputation-based (8 studies), reciprocity-based (3 studies), credit-based (20 studies), game-theory-based (4 studies), and blockchain-based mechanisms.

Sub-RQ3 (Data Synthesis):

Comparing the free-riding of P2P networks by the different mitigation techniques

The data synthesis process aims to determine the efficiency and reach of different methods used, as well as their limitations.

Reputation-based approaches: They are useful in decentralized environments but lead to dishonest peers and whitewashing (Kurdi et al., 2020). A reputation-based approach judges a peer based on the information provided by other peers to foster trust among the peers in the network. The goal of this approach is to make sure that each peer can trust the system because it completely relies on how peers rate themselves in the system. This approach has been adopted by various researchers with differences in how the trusts are computed in the system, considering the degree of accuracy and complexity. The disadvantages are based on centralization and communication overhead as well as whitewashing and collusion. In addition, this system is implemented based on the assumption that each peer would relate and give honest reports about fellow peers, which is not always the case.

Reciprocity-Based Approaches: It promotes cooperation by tit-for-tat mechanisms but needs ongoing peer interactions, which makes it highly non-scalable. According to (Kurdi et al., 2020), a reciprocity-based system has to do with the services of peers based on their level of contribution, which can be seen as a barter system. The reciprocity can either be direct or indirect, where peers take into consideration the interactions of all peers collectively. The disadvantage of this system is that it requires frequent interactions between each peer of pairs, while the latter peer can be deceived by malicious peers, and a practical application of this approach can be seen in BitTorrent using the tit-for-tat strategy.

Credit/Monetary-Based Approaches: Most successful at stimulating contribution activation; however, alternate approaches demand a fair amount of service coordination and dependability. (Kurdi et al., 2020) in a credit-based approach, peers get credit by providing services to other peers and give out credit by receiving services from other peers (Hazazi et al., 2019). A monetary–based approach is also sometimes called a micropayment system, where peers are given a mandate to pay for the services they use and, in turn, will be paid for the services they give out to other peers.

Further, (Hazazi et al., 2019) proposed a method for overcoming free-riding in peer-to-peer networks using a credit-based incentive mechanism and a grace period. In his study, he uses a credit-based approach with a finite grace period for each peer. However, more focus and attention were on the upload rate of peers and a static grace period, which is a time frame wherein free riders or slow peers must reimburse the system. However, the method for scaling grace periods may have limitations in adapting to the popularity of a file, which can lead to wasting resources due to static grace. It may also be prone to free-riding attacks, which involve a user consuming a file again and again by exiting and joining the network, thus no longer expecting to reciprocate the aspect of fairness. Also, ensuring the legitimacy of uploaded files can also prove difficult, causing difficulty in thwarting duplicates or fake files

Game-Theory Approaches: It models the strategic interactions accurately, but it is complex to put into practice. (Biaou et al., 2022) proposed an Ayo game approach to mitigate free riding in peer-to-peer networks. (Biaou et al., 2022) in their study presented a new mechanism of the stochastic model of Ayo game theory to prevent free-riding in a partially centralized P2P in the second generation of unstructured P2P networks. However, the proposed approach was mainly focused on a partially centralized P2P network

Blockchain-Based Approaches: No doubt, it provides transparency and tamper-resistant records, but it is difficult to scale due to scalability problems (Ahmed and Choi, 2023). Blockchain is a digital, decentralized ledger in a peer-to-peer network that keeps a record of each user's transactions in an encrypted format. This brings about the feature of robust and advanced proof. Therefore, as a result of this, recent studies have adopted this to protect privacy. This protection of privacy merit can serve as a transparent record environment to store people's or users' information. However, scalability can occur in blockchain due to time delays.

Sub-RQ4 (Critique of Related Research):

Where do the current free-riding mitigation strategies fall short, and how does this rationalise the need for a dynamic grace period accompanied by content scanning?

Answer: The reviews listed numerous limitations, one of which was that the existing grace period mechanism is not as flexible, and there is an absence of content scanning for repeated or fake files. A dynamic grace period and content scanning method to dynamically assign peer participation and authenticate files are therefore required.

5. PROPOSED STRATEGY

In this review, various ways and methods to mitigate free riding in P2P systems have been investigated. Certain constraints, such as a lack of effective measures to check and track the quality of uploaded files and varying grace periods based on download popularity, have been identified (Hazazi et al., 2019). These limitations bring about the need to implement an efficient mechanism to mitigate free-riding in a P2P Network.

Dynamic grace period allocation based on download popularity and content scanning mechanisms is required. This study specifically focuses on addressing this limitation in a hybrid P2P Network architecture. Also, based on the comparative analysis of the different P2P architectures in Table 7, it can be seen that hybrid architectures are the most effective for modern P2P networks due to their hybrid nature.

Previous research did not pay enough attention to stopping uploads of repeated files or fake files, and implementing a dynamic grace period in Hybrid P2P architecture and P2P systems generally based on download popularity made by peers, resulting in a significant research gap that must be filled. To address the identified flaws, particularly the issues related to repeated or fake files and the allocation of grace periods, an improved Hybrid Architecture based on Dynamic Grace Period allocation and content scanning mechanism (HADGP) was proposed.

For the implementation of the proposed mechanism HADGP, a hybrid P2P network will be used with a mix of centralized indexing servers and decentralized peer interactions for the Network Setup. The index server will connect uploading peers (UP) and requesting peers (RP), maintain records, and facilitate communication. Also, there will be a Dynamic Grace Period Allocation, which assigns grace periods based on the download popularity score of each peer.

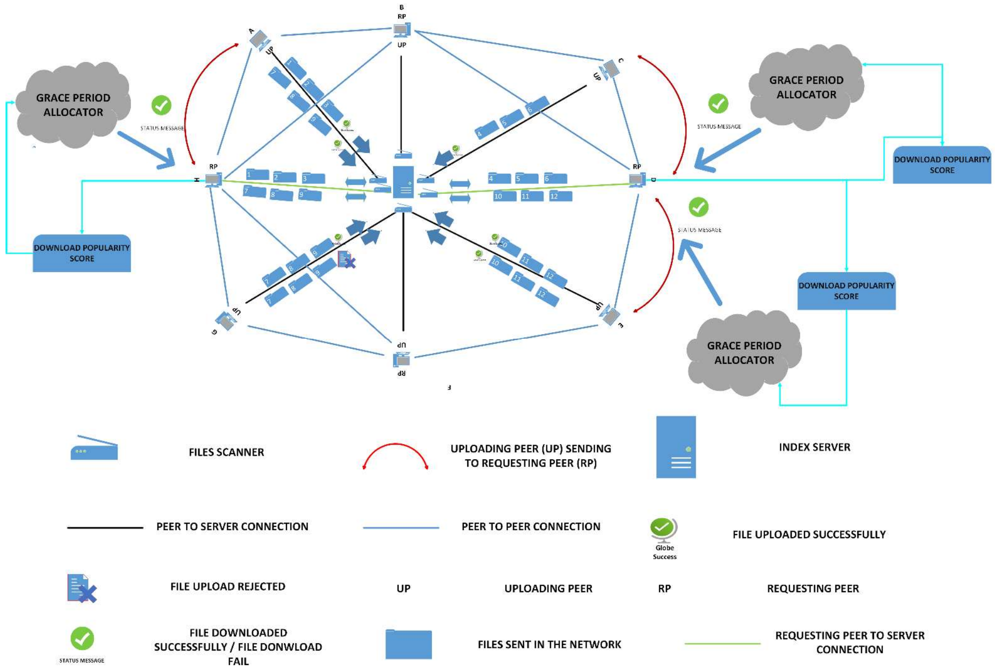

Figure. 2: Proposed Hybrid Architecture based on Dynamic Grace Period

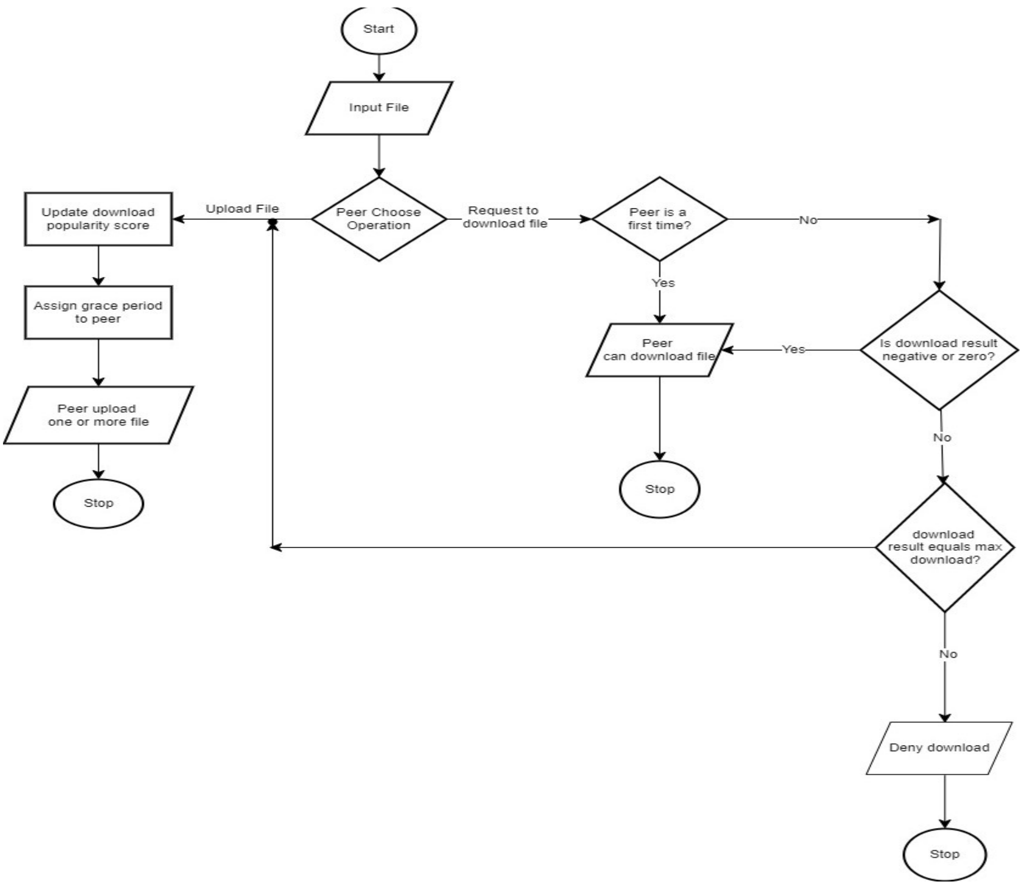

Figure 3: Flowchart for the Proposed Dynamic Grace period allocation

The Improved HADGP architecture can be used to mitigate free riding in a hybrid P2P network system by allocating grace periods to peers dynamically based on their popularity of downloads known as a download popularity score and it also uses a content scanning mechanism to scan the uploaded and downloaded chunks of peers both from the requesting peer (RP) The download popularity score will be dynamically updated based on the number of successful uploads and downloads. Lastly, we have a Content Scanning Mechanism, which will scan all files before and after uploading to prevent the circulation of repeated or fake files. To further strengthen the proposed mechanism, HADGP, an architecture for the proposed mechanism and flowchart are presented in Figures 2 and 3, respectively and the uploading peer (UP) to ensure that repeated or fake files are not promoted by free-riders peers in an attempt to circumvent the system.

The proposed dynamic grace period mechanism consists of a download popularity score that monitors the rate at which peers download files in the network. Also, we have the grace period allocator, the file scanner, the index server, the uploading peer (UP), requesting peer (RP). The grace period allocator assigns a grace period to peers based on their download popularity score. The files scanner servers as a scanning mechanism that ensures that fake files or repeated files are not promoted in the network and it does this by making sure that files sent to the server by an UP are scanned before making it open for all in the network and files sent back by a RP for verification are also scanned. The index server helps in connecting an RP to a UP and vice versa, and the index server also helps in keeping some features extracted from the file's scanner, for verification purposes.

The dynamic grace period allocation framework only takes into consideration the downloads made by peers and allows peers to upload as many unique files as they want. Repeated files will only be uploaded by a UP if the chunks are placed as a rare chunk in the system. For the proposed dynamic grace period based on the popularity of downloads, initially, a maximum download limit is set, let's say ten (10) chunks. Then, once a peer hits the maximum downloads limit, his grace period is calculated and activated during which he must upload at least a single chunk of the file, or else benefits from the network will not be made available to such a peer.

Upon uploading the chunk of the file, a new dynamically assigned grace period is calculated for the peer based on the new download popularity score and this keeps changing as the peer interacts with the system by uploading or downloading of chunk, but the calculated grace period is not assigned until a peer downloads a single chunk from the network. This, in turn, would then activate the grace period calculated and assign it to that particular peer. The peer would then need to repeat the process by uploading at least a chunk of the file to download another file from the network. A peer can upload as many files as possible within the limit of the grace period, provided they are not repeated files.

The download popularity score is calculated based on the (-) symbol assigned after successful uploads and the (+) symbol assigned after successful downloads of chunks, after which the new download popularity score for a peer is computed per activity of the peers through the dynamic grace period calculation formula. If the number of uploads exceeds downloads or the number of uploads and downloads after calculation is at equilibrium, then the peer is allowed to continue interacting freely with the system. If the number of downloads is more than uploads, then the dynamically assigned grace period will come into play.

For the proposed scanning mechanism, firstly, when a peer wants to upload a file, the peer makes it known to the indexing server that a file is available for upload, then the server first scans the file to make sure it has not been previously uploaded. If it has been previously uploaded the upload request is denied else if it hasn't been uploaded, the chunk is scanned by the server and several details like unique value for the full scan, extracted feature, and some details about the peer and the file to be uploaded are kept in the uploading peer's record by the server.

After the record has been kept in the server, if the server finds a requesting peer for the particular saved file, the server will then link up the RP to the UP. Then, direct communication between the peers and file exchange will occur. After this, acknowledgment of the file successfully downloaded by the requesting peer is sent to the server alongside the downloaded chunk for proper verification by the server which will ensure that the kept key features extracted in the uploading peer record can be found in the chunk sent by the requesting peer after this, the server takes note of the record and assigns either a positive upload score to the UP or a no uploading score to the UP and this is also done to the RP in terms of a download score. After this, if the chunk is seen to be successfully uploaded by the UP, the server keeps records for the sending peer and all the files sent and makes sure that the same file is not uploaded again by that particular peer by scanning the content of subsequent files to be sent for uploads by the peer and if not seen to be uploaded by the UP or another file was uploaded the server deletes the record of that particular chunk for the UP. An exception where a particular peer can upload the same file is when the file requested by the requesting peer cannot be found among any peers in the network; then the peer is allowed to upload the same file. If not, the peer is denied.

6. RESULT AND DISCUSSION

The analysis of the 43 studies included identified several key results related to the strengths and weaknesses of the mechanisms for reducing free-riding. The synthesis exposes the deficiencies that support the need for our dynamic grace period assignment and content scanning mechanism in hybrid P2P networks.

(Ayodeji, 2022) announced that trust with peers increases through reputation systems; however, they are manipulated by false reports and formed gangs. The tit-for-tat mechanism in BitTorrent, considered by (Kurdi et al., 2020), encourages resource exchange. Even though it requires more interactions than secure routing, making it not affordable in large P2P networks.

(Hazazi et al., 2019) propose a grace period for peers. However, these grace periods are static and do not take into consideration the dynamic behaviour of peers, making them susceptible to attacks. (Biaou et al., 2022) bring the Ayo game model to reduce free-riding, giving strong theoretical insights. However, deploying game-theoretic solutions at scale is challenging. Blockchain-based solutions, such as those proposed in the work carried out by (He et al., 2021), on the other hand, provide full transparency but have scalability constraints with high transaction costs and time delays. Limitations in reviewed works highlight the need for a more adaptive and robust approach to mitigating free-riding in P2P networks. Specifically, current approaches lack mechanisms for: Dynamically adjusting peer contributions based on behaviour (downloads and uploads) and verifying the authenticity of files to prevent the sharing of repeated or fake files.

The proposed approach introduces a grace period to peers, and the grace period of peers is determined dynamically for their consumption of downloads. By contrast, making grace periods dynamic can better represent peer behaviour compared to static grace periods, which fail to account for individual peer behaviour. In addition, files are scanned before and after upload for authenticity, guaranteeing that nothing is duplicated, nor fake files shared in the network. To avoid abusing the model by repeatedly uploading either the same or fake files.

The above mechanism is designed to tackle these issues by enhancing traditional reputation and credit-based systems with a mechanism that dynamically adjusts the grace period according to the activity of peers. This also adds a content scanning mechanism, which is missing in current approaches, thus increasing the reliability of the network.

7. CONCLUSION

The results of this study imply that, although prior works on countermeasures for free riding provide insightful mechanisms, they are limited in scalability, honesty issues, and static mechanisms for peer contribution. We use a novel hybrid approach based on dynamic grace periods along with content scanning to address these challenges in this paper. The dynamic grace period also allocates download time based on the popularity of downloads, so that every peer gives back relative to its consumption, and implements a content scanning mechanism to protect the integrity of shared files and prevent uploading duplicate or fake content. Our solution combines the best of both centralized and decentralized architecture, providing a more just, scalable, and secure response to free-riding in P2P networks. Work in the future will primarily deal with an executable implementation of this hybrid architecture on simulated or real P2P systems and study of its performance on the network level and peer cooperation.

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