Incentive Mechanisms in Peer-to-Peer Networks — A Systematic Literature Review

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Centralized networks inevitably exhibit single points of failure that malicious actors regularly target. Decentralized networks are more resilient if numerous participants contribute to the network's functionality. Most decentralized networks employ incentive mechanisms to coordinate the participation and cooperation of peers and thereby ensure the functionality and security of the network. This article systematically reviews incentive mechanisms for decentralized networks and networked systems by covering 165 prior literature reviews and 178 primary research papers published between 1993 and October 2022. Of the considered sources, we analyze 11 literature reviews and 105 primary research papers in detail by categorizing and comparing the distinctive properties of the presented incentive mechanisms. The reviewed incentive mechanisms establish fairness and reward participation and cooperative behavior. We review work that substitutes central authority through independent and subjective mechanisms run in isolation at each participating peer and work that applies multiparty computation. We use monetary, reputation, and service rewards as categories to differentiate the implementations and evaluate each incentive mechanism's data management, attack resistance, and contribution model. Further, we highlight research gaps and deficiencies in reproducibility and comparability. Finally, we summarize our assessments and provide recommendations to apply incentive mechanisms to decentralized networks that share computational resources.

CCS Concepts: • **Networks** → **Peer-to-peer networks**; Mobile ad hoc networks; • **Computer systems organization** → Fault-tolerant network topologies; • **Information systems** → *Reputation systems*; *Digital cash*; • **Computing methodologies** → **Self-organization;**

Additional Key Words and Phrases: Peer-to-peer, incentive mechanism, reputation, credit, monetary incentives, service incentives, tit-for-tat, p2p

ACM Reference format:
Cornelius Ihle, Dennis Trautwein, Moritz Schubotz, Norman Meuschke, and Bela Gipp. 2023. Incentive Mechanisms in Peer-to-Peer Networks — A Systematic Literature Review. *ACM Comput. Surv.* 55, 14s, Article 308 (July 2023), 69 pages.
https://doi.org/10.1145/3578581

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0360-0300/2023/07-ART308 $15.00
https://doi.org/10.1145/3578581

1 INTRODUCTION

Today's internet is increasingly centralized, although decentralized systems promise better availability and resiliency at lower costs. Currently, most websites, web services, and applications rely on major service providers like Amazon Web Services, Microsoft Azure, or Google Cloud Platform. Self-hosting becomes progressively infrequent.[1] The flexibility and scalability that cloud hosting offers often comes at the cost of a single point of failure, i.e., the service provider. Disruptions at major service providers have rendered large portions of the internet unavailable in the past.[2,3,4] Moreover, the provision of production-grade cloud services is costly. On average, users pay 0.0000108 USD to store 1 GB for a year on decentralized storage,[5] which is less than 0.01% of Amazon's S3 pricing. Netflix's video streaming service incurs monthly cloud computing costs of approximately ten million dollars.[6] Consequently, Netflix is currently evaluating the **Interplanetary File System (IPFS)** as a decentralized content delivery network.[7]

A computer network's degree of decentralization reflects the share of the network's nodes with redundant capabilities. Peer-to-peer (P2P) communication, i.e., nodes communicating directly instead of via a central server, enables but does not imply decentralization of the network. If all nodes hold different data or provide different functionality—thus do not offer redundant capabilities—the network is *distributed* but not *decentralized* and can exhibit a single point of failure. A distributed system consists of autonomous computing components interacting for a common purpose while residing on various networked computers, but appearing to users as a coherent system [114]. In a decentralized P2P network, nodes communicate directly, can act as service providers and requestors, leave or fail without stopping the service, and have similar privileges [107].

A key challenge in designing and operating decentralized networks is ensuring the cooperation and contribution of peers. Otherwise, the load accumulates in a subset of the nodes, which leads to some degree of centralization and higher costs for high-load nodes. Typically, not all nodes contribute or, worse, attempt to game the system to their advantage. P2P networks are often open for everyone to participate, do not require permissions, and keep the network's data and communication public. Especially, these open, decentralized networks suffer from selfish behavior and denial-of-service attacks by participants trying to game the system.[8] Permissioned or private networks are less prone to suffer from selfish behavior, as they grant access to trustworthy participants, only.

Most public P2P networks implement incentive mechanisms as an integral architectural component to keep the network functional, decentralized, and secure. Incentive mechanisms motivate cooperation and participation, i.e., new participants joining the network, by superseding the participants' intrinsic self-interests via extrinsic pressure, i.e., punitive disincentives or rewards. In this review, we use the term incentive mechanism for both punitive and rewarding mechanisms.

Decentralized P2P systems require all subsystems, i.e., also their incentive mechanisms, to be decentralized. In the past, however, incentive mechanisms required a central authority to oversee participant behavior. Now, decentralized computation allows a P2P network to jointly maintain and use a single source of truth instead of a central authority. Smart contracts [128] combined with distributed ledgers are a recent form of decentralized computation that offers a trustless, more resilient, and transparent alternative to central authorities.

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[1] https://www.canalys.com/newsroom/global-cloud-market-Q121.
[2] https://www.msn.com/en-us/news/technology/cloudflare-service-outage-disrupts-internet-fix-in-place/ar-BB16SQ44.
[3] https://cnn.com/2020/12/14/tech/google-youtube-gmail-down/index.html.
[4] https://tcrn.ch/2V1gvyL.
[5] https://file.app.
[6] https://www.intricately.com/articles/netflix-aws-spend.
[7] https://www.youtube.com/watch?v=wNfk05D887M&t.
[8] https://www.coindesk.com/ethereum-classic-suffers-second-51-attack-in-a-week.

Our literature review supports the research and development of decentralized P2P systems by systematically analyzing the options for devising decentralized incentive mechanisms. To the best of our knowledge, our review is the first to compare incentive mechanisms using a framework that includes incentive type, network type, data management, attack resistance, and contribution model as properties. We analyze three incentive categories (monetary, reputation, and service) for the network types Opportunistic Networks (OppNets), Mobile Ad-Hoc Networks (MANETs), Delay-Tolerant Networks (DTNs), Mobile Social Networks (MSNs), Multi-Cell Cooperation (MCC), Mobile Edge Computing (MEC), and general P2P networks. These network types are not exhaustive, but allow the reader to select incentive mechanisms for their preferred network type. Supplement A.2 explains how the proposed framework, properties, incentive categories, and network types enable readers to retrieve articles relevant to a specific use case from this article.

We conduct an aggregative, structured literature review of 178 primary research publications and 165 prior literature reviews. Paré and Kitsiou characterize a systematic review as an attempt to aggregate, appraise, and synthesize results that meet a set of specified eligibility criteria to answer a clearly formulated and often narrow research question [99]. In our case, we aggregate the primary research on decentralized incentive mechanisms and appraise their design aspects according to their data management, attack resistance, and contribution model. We synthesize a framework that enables comparability of the design aspects to deduce the applicability of selected incentive mechanisms to an example use case. Of the 178 primary research articles, 107 matched our selection criteria (cf. Supplement A.5). We present 105 articles in this review, as we could not retrieve the full text of two articles. Of the 165 prior literature reviews, we select and present 11 representative reviews. Additionally, we give an overview of network types, evaluation and simulation tools, and the features of Distributed Ledger Technology (DLT).

This approach allows us to address the following three research questions:

(1) What are the distinguishing characteristics of decentralized incentive mechanisms regarding network types, data management approach, attack resistance, and contribution model?
(2) What are the research trends and open research questions in the literature?
(3) How to select an incentive mechanism for a specific decentralized use case?

Our review gives a comprehensive overview of decentralized incentive mechanisms and presents a framework that supports researchers and developers in selecting and implementing an incentive mechanism for a specific decentralized use case. We showcase how to apply the framework for an exemplary academic use case. Further, we analyze simulation and evaluation tools to make recommendations for future research on decentralized incentive mechanisms.

Our systematic literature review extends existing reviews (cf. Table 1) by:

— Including significantly more publications than the other reviews.
— Being the first *systematic* review on the topic.
— Introducing a framework to describe and categorize incentive mechanisms.

The article is structured as follows. Section 2 describes our stringent methodology for identifying prior literature reviews and primary research publications, which helps to achieve transparency and reproducibility of the review steps. Moreover, the section summarizes related reviews to highlight the contributions of our article. Section 3 discusses common design aspects and features we derived from prior literature reviews. Section 4 summarizes and classifies primary research publications according to the incentive characteristics we identify. Section 5 showcases the use of the framework we derive for selecting an incentive mechanism for a specific use case. Section 6 discusses simulation tools. Section 7 gives recommendations regarding the applicability of incentive types and outlines promising directions for future research before concluding the review in Section 8.

2 METHODOLOGY

This section presents our three-step process for finding and selecting relevant literature. First, we choose a suitable search engine with a comprehensive underlying literature database. Second, we iteratively define search terms to find previously published literature reviews. Third, we extract topic keywords from taxonomy papers and use them to find the relevant primary sources we review.

2.1 Search Engine Selection

Guidelines for conducting systematic literature reviews recurrently name three quality criteria for the search step: completeness, transparency, and reproducibility [35]. Completeness and reproducibility primarily depend on the search engine used, while the process for compiling the review determines transparency. Consequently, choosing a database that covers most research in the respective field (completeness) and allows repeating the searches undertaken for the review (reproducibility) is of paramount importance. We use a keyword-based automated search [103] to collate the research publications for our review and state the time at which we executed each search to improve the reproducibility of our search process. The natural growth of the database will likely lead to different result sets when repeating our searches. Knowing the search time can help to filter for items added to the database after we conducted our search.

We considered using the Digital Bibliography & Library Project (DBLP), Web of Science (WoS), and Google Scholar for our systematic searches. Contrary to the findings in [35], the DBLP search engine claims to support Boolean operators.[9] However, in our tests, disjunctive queries returned fewer results than the corresponding conjunctive queries. For example, a search for `incentive review` (treated as a conjunctive query) yielded 19 results, while searching for `incentive review | state-of-the-art` returned two results (search performed on Nov. 26, 2020). Adding parentheses around `state-of-the-art` to clarify our intention to the search system did not change the results. Fagan observed similar illogical interpretations of Boolean operators for Google Scholar [28]. Moreover, Google Scholar is frequently criticized for over-emphasizing citation count [28] to rank results and including results from predatory journals [9] and gray literature.

We eventually chose WoS because it was the only search system among the three we considered that yielded reproducible results and sensible outputs when using Boolean search operators. The Core Collection subscription of WoS includes six databases and 1.7 billion bibliographic references.[10] We are confident that a keyword-based automated search in this major literature database yields an accurate approximation of the research undertaken in the relevant field.

2.2 Retrieval of Secondary Literature

This section presents our process for retrieving relevant secondary literature, i.e., publications that summarize and synthesize primary literature, defining search terms, and filtering search results.

Search Term Definition. We initiated our literature search by using the naive query:

```
incentive mechanism
```

As WoS supports stemming,[11] we can use the root of keywords without explicitly stating plurals or derived forms. WoS searches keywords in the title, abstract, author keywords, and "Keywords Plus"[12] of academic literature included in the WoS Core Collection database without restrictions

[9] https://dblp.org/faq/How+to+use+the+dblp+search.html - accessed Nov. 11, 2020.
[10] https://clarivate.com/webofsciencegroup/solutions/webofscience-platform/ - accessed Dec. 11, 2020.
[11] https://images.webofknowledge.com/images/help/WOS/hs_topic.html - accessed Oct. 3, 2022.
[12] KeyWords Plus are unique to WoS and consist of words and phrases harvested from the titles of the cited articles.

regarding the publication date. This initial search retrieved 16, 616 results in 228 WoS categories. This large number of results led us to limit the result set through category selection.

Research Field Selection. To exclude literature insignificant to our research question, we pruned search categories covering non-digital incentives that cannot be adapted to P2P networks, e.g., Human Resource Management literature. We retained the following computer-science-related WoS categories and the 6, 222 results they contained:

```
MULTIDISCIPLINARY SCIENCES,
COMPUTER SCIENCE ARTIFICIAL INTELLIGENCE,
COMPUTER SCIENCE CYBERNETICS,
COMPUTER SCIENCE HARDWARE ARCHITECTURE,
COMPUTER SCIENCE INFORMATION SYSTEMS,
COMPUTER SCIENCE INTERDISCIPLINARY
APPLICATIONS,
COMPUTER SCIENCE SOFTWARE ENGINEERING,
COMPUTER SCIENCE THEORY METHODS,
TELECOMMUNICATIONS,
MEDICAL INFORMATICS,
ECONOMICS,
ENGINEERING ELECTRICAL ELECTRONIC
```

"*ECONOMICS*" (3, 127 results) and "*ENGINEERING ELECTRICAL ELECTRONIC*" (1, 304 results) were the largest categories we excluded. As articles can belong to multiple categories, the reduction of articles in the final corpus can be smaller than the sum of the article counts in each category.

The Web of Science category structure has remained consistent since 2012.[13] Adapting the search query to reproduce our findings can become necessary if fields change in the future. We extended our search query by using WoS search syntax like "Topic Search (TS)" which stands for topic search and analyzes title, abstract, author keywords and "Keywords Plus", as well as "Web of Science Category (WC)" which represents the WoS category to search in.

Search Term Refinement. We read a sample of the retrieved papers and collected the author-assigned keywords of papers we deemed relevant to our research question. We used these keywords to extend the search query with the synonyms "cooperation" for "incentive" and "scheme, protocol" for "mechanism". The extended search query increased the number of retrieved papers to 9, 308.

Identification of Secondary Literature: In this step, we extended our search query to filter for literature reviews and surveys. Furthermore, we dissected the topic selector "TS" into its parts "Abstract (AB)", "Author Keywords (AK)", "KeyWords Plus (KP)", and "Title (TI)" to enable more fine-grained control. The resulting search query was:

```
TI=(survey OR review OR "state-of-the-art")
AND (
  AB=((incentive OR cooperation) AND (scheme OR protocol OR mechanism)) OR
  AK=((incentive OR cooperation) AND (scheme OR protocol OR mechanism)) OR
  KP=((incentive OR cooperation) AND (scheme OR protocol OR mechanism)) OR
  TI=((incentive OR cooperation) AND (scheme OR protocol OR mechanism))
) AND WC=("MULTIDISCIPLINARY SCIENCES"
  OR "COMPUTER SCIENCE ARTIFICIAL INTELLIGENCE" OR "COMPUTER SCIENCE CYBERNETICS"
  OR "COMPUTER SCIENCE HARDWARE ARCHITECTURE" OR "COMPUTER SCIENCE INFORMATION SYSTEMS"
  OR "COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS" OR "COMPUTER SCIENCE SOFTWARE
      ENGINEERING"
  OR "COMPUTER SCIENCE THEORY METHODS" OR "TELECOMMUNICATIONS" OR "MEDICAL INFORMATICS"
)
```

Our search on Oct. 3, 2022, retrieved 165 secondary literature results.

Filtering of Literature Reviews. We pruned the 165 reviews that matched our query as follows. We excluded reviews that either (1) do not discuss incentive mechanisms, (2) do not consider sharing computational resources or bandwidth, or (3) present a centralized system. From the remaining

[13] http://help.prod-incites.com/inCites2Live/filterValuesGroup/researchAreaSchema/oecdCategoryScheme/version/2.

Table 1. Prior Literature Reviews Relevant to our Research Question

Ref.	Authors	Year	Review Type	Papers	Reputation	Monetary	Network
[67]	Li et al.	2022	Aggregative	4	YES	NO	Federated Learning (FL)
[59]	Khan et al.	2021	Aggregative	17	YES	NO	ad-hoc
[124]	Wei and Yu	2021	Aggregative	33	YES	NO	Wireless Sensor Network (WSN)
[108]	Sharghivand et al.	2021	Aggregative	51	NO	YES	Cloud
[78]	Mantas et al.	2017	Aggregative	13	YES	NO	OppNet
[44]	Hua et al.	2017	Aggregative	22	YES	YES	MANET
[110]	Silva et al.	2017	Scoping	24	YES	YES	MANET/DTN
[37]	Haddi and B.	2015	Scoping	18	YES	YES	(mobile) P2P
[105]	Samian et al.	2015	Scoping	32	YES	YES	MANET
[12]	Ben Saied et al.	2014	Scoping	56	YES	YES	DTN
[80]	Marias et al.	2006	Aggregative	9	YES	YES	DTN
	Ihle et al.	2022	Aggregative	116	YES	YES	P2P

reviews, we removed those that examine incentive mechanisms only peripherally or as a secondary contribution. These exclusions reduced the number of reviews to 11.

Identification of Incentive Categories. We created an overview table (A.5) of the properties covered in secondary literature by picking reviews that include a results table and extracting all properties from these tables. We condensed the 286 properties extracted in this manner to 13 design aspects (see Section 3), which we use to characterize incentive mechanisms. We identified the incentive mechanism types “monetary rewards”, “reputation systems”, and “service rewards”. Considering service rewards as a mechanism type is a notable difference between our review compared to previous reviews that predominantly consider only the former two mechanism types.

2.3 Overview of Prior Literature Reviews

Table 1 lists the 11 literature reviews that remained after manually excluding articles as described in Section 2.2. The literature reviews are ordered reverse chronologically and categorized by the incentive and network schemes they cover.

Li et al. [67] reviewed monetary incentives applied to consensus mechanisms for securing a blockchain-based FL network. In federated learning, distributed peers jointly maintain and update a global model, which resides on a central server within the architecture proposed in the article. This design contradicts a pure P2P architecture and makes the use of blockchain questionable, as the central server might also maintain the ledger for monetary incentives. Nonetheless, we include this review, as the monetary incentives could also be applied to a fully decentralized architecture.

Khan et al. [59] surveyed incentive mechanism publications that analyzed selfish nodes in ad-hoc networks. The authors categorized prevention schemes into detection mechanisms, trust-based mechanisms, reputation-based incentive mechanisms, credit-based incentive mechanisms, and evolutionary game-theoretical approaches. Additionally, they provided simulation results that measure the effectiveness of selected incentive mechanisms to prevent selfish node behavior.

Wei and Yu [124] investigated reputation-based incentives for WSN by analyzing which functional components of binominal reputation the incentives apply. The functional components the authors analyzed include direct/indirect reputation, reputation aging, energy reputation, communication reputation, data reputation, reputation redemption, penalty & reward consideration, computational complexity, adaptive reputation threshold, adaptive forgetting factor, and energy consideration. Beyond the detailed analysis of reputation components, the paper gave insight into security issues and attacks in reputation-based incentives.

Sharghivand et al. [108] reviewed auction mechanisms for cloud and edge computing. Auction mechanisms serve to connect users with cloud providers through an auctioneer. Although the paper did not discuss the compatibility of the auctions with decentralized networks, we still analyze this review for its insights into auction-based mechanisms.

Mantas et al. [78] studied 13 representative reputation-based cooperation enforcement schemes in OppNets. The authors dissected the core components of reputation mechanisms and discussed aspects and issues that should be considered when designing such a system. The authors justified what they call a “softer” security approach by stating traditional cryptographic techniques are “complex and resource intensive” [78, p. 9]. The authors focused solely on reputation-based systems and did not discuss studies on other types of cooperation enforcement schemes.

Hua et al. [44] discussed node cooperation and its challenges in Vehicular Ad-Hoc Networks (VANETs) mobile social networking. The article provided a granular categorization and evaluation of incentives for mobile social networking-based cooperation. The intermittent network connectivity makes routing issues the main research focus for VANETs. However, the authors stressed that node cooperation is the foundation for any routing protocol. Hence, addressing cooperation as an independent problem with a balanced and effective incentive mechanism will benefit routing protocols and other cooperation-dependent peer-to-peer use cases.

Silva et al. [110] focused on cooperation approaches in resource-constrained MANETs and DTNs with low node density. The authors reviewed 24 proposals and discussed concomitant challenges while also considering game-theoretical approaches. A table compares the conceptual characteristics, main goals, and key aspects of these approaches.

Haddi and Benchaïba [37] provided a representative overview of peer-to-peer incentive mechanisms to stimulate collaboration. They stated that an incentive mechanism’s goal is to improve the quality and availability of a service. An incentive mechanism can prevent, detect, and punish selfish and malicious behavior or reward positive behavior for achieving this goal. Beyond these two core incentive roles, they proposed a role to compensate for service costs, manage access, reduce the risk of interacting with non-collaborative entities, and enforce sanctions on non-collaborative entities. The review briefly discussed each incentive mechanism to present its specific requirements by distinguishing between static mobile peer-to-peer mechanisms and mechanisms generally applicable to all network types. Static peer-to-peer mechanisms have a stable network topology, bandwidth, and energy supply. In contrast, mobile peer-to-peer mechanisms must consider energy limitations, variable bandwidth, and changing communication routes. The authors further distinguished reciprocity-based and reputation-based incentive schemes. We argue that reciprocity is a kind of reputation value aggregating in the local agent. A more thorough discussion of these differences can be found in Section 3.1.2.

Samian et al. [105] analyzed incentive mechanisms and their behavior monitoring techniques for the use case of motivating full cooperation between nodes in wireless multi-hop networks. They mainly addressed node selfishness and the inability to obtain accurate node behavior data and used credit payment, reputation, and hybrid schemes as incentive categories. The authors differentiated misbehavior observation and detection techniques as passive and active acknowledgment, specification-based monitoring, and game-theoretical approaches.

Ben Saied et al. [12] gave an overview of collaborative services in wireless communication networks. They elaborated on attack vectors against approaches and discussed mitigation tactics. They distinguished between security-by-design and trust-based mechanisms. In the context of this paper, security-by-design complements incentive mechanisms by introducing technical hurdles to prevent misbehavior. In contrast, trust-based mechanisms concern behavior that cannot be controlled technically but is motivated through punishment and rewards instead.

Marias et al. [80, p. 1] discussed the “most important cooperation enforcement methods” in MANETs as of 2006. They listed reported attacks on the network and proposed mitigation measures. Similar to other papers, they discussed and compared cooperation enforcement methods in the two categories of reputation-based and credit-based models. Other articles usually use the term incentive mechanism rather than cooperation enforcement methods. We also prefer the term incentive mechanism to underline that no enforced guarantees exist. Marias et al. emphasized identity spoofing as an important open issue. By now, however, identity spoofing is typically mitigated using public-key encryption or message authentication codes. Regarding the comparability of different schemes, they highlighted the lack of a standard for simulation parameters and configurations. This simulation disparity has led to varying results and differing assumptions. These observations led us to emphasize the implementation and evaluation of an incentive mechanism in our review.

In summary, the presented reviews largely focused on mobile networks that exhibit more restrictive constraints regarding resource availability and network connectivity than static networks. Due to their inherent mobile setup, opportunistic networks like MANETs/VANETs suffer from intermittent connectivity and stark resource constraints. In contrast, blockchain-based peer-to-peer networks are typically sustained by better-connected, more capable peers and are not subject to frequent network topology changes.

2.4 Search Method Anomalies

Ad-hoc networks are overrepresented in the prior literature reviews relevant to our research question (cf. Section 2.3). Surprisingly, none of the reviews has analyzed DLT/blockchain incentives, which has motivated us to contribute a review that includes incentive mechanisms in DLT networks. We attribute the lack of DLT-related reviews to the dominance of gray literature in blockchain research. Fast-moving projects often forgo traditional academic publishing to benefit from their first-mover advantage. This situation is changing, as many established DLT projects become part of the academic community and publish in journals and conferences now.

We complemented our WoS search with a search on Google Scholar to check for blockchain-related gray literature. The lack of fine-grained search parameters in Google Scholar forced us to use the broad search term: `incentive mechanism (survey OR review OR "state-of-the-art")`

Within the first 100 Google Scholar results, we found nine blockchain-related articles our prior WoS search did not retrieve. This finding indicates that not only the field-specific prevalence of gray literature but also the quality-focused curation process of WoS contributes to the underrepresentation of blockchain literature in our results. We decided to favor the quality-focused, curated results of Web of Science and do not include the additional Google Scholar results in our review.

2.5 Retrieval of Primary Literature

Analyzing prior literature reviews on peer-to-peer incentive mechanisms enabled us to formulate a search term for the primary literature search of our review. Hereafter, we explain the chosen search term and present the number of publications retrieved.

Search Term Definition. We required that articles contain the words *incentive* or *cooperation* in their titles. Moreover, the abstracts must contain the words *decentralized*, *peer-to-peer*, or *P2P* in any combination with the words *scheme*, *protocol*, *mechanism*, or *system*. The requirements reflect our findings from analyzing the secondary literature that these terms are often used synonymously. We verified that Web of Science also retrieved papers that use the British English variant *decentralised*. Lastly, an article's Web of Science category had to match one of the categories identified in Section 2.2. The following listing shows the final search term:

```
TI=(incentive or cooperation)
AND (
   AB=((decentralized or peer-to-peer or P2P) and (scheme or protocol or mechanism or system))
) AND WC=("MULTIDISCIPLINARY SCIENCES"
```

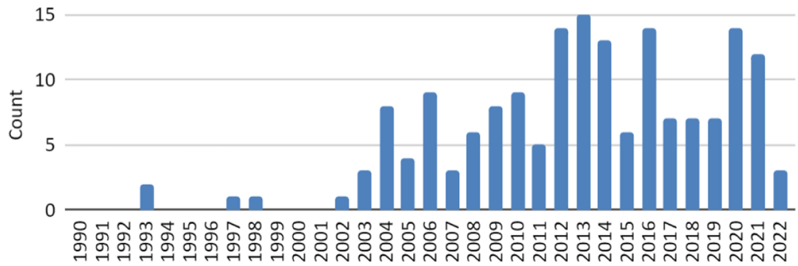

Fig. 1. Histogram showing the number of papers retrieved for our search term grouped by publication year.

```
    OR "COMPUTER SCIENCE ARTIFICIAL INTELLIGENCE" OR "COMPUTER SCIENCE CYBERNETICS"
    OR "COMPUTER SCIENCE HARDWARE ARCHITECTURE" OR "COMPUTER SCIENCE INFORMATION SYSTEMS"
    OR "COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS" OR "COMPUTER SCIENCE SOFTWARE
         ENGINEERING"
    OR "COMPUTER SCIENCE THEORY METHODS" OR "TELECOMMUNICATIONS" OR "MEDICAL INFORMATICS"
)
```

The results comprise 178 publications, mostly from the fields “TELECOMMUNICATIONS”, and “COMPUTER SCIENCE INFORMATION SYSTEMS”. The analysis of prior literature reviews on incentive mechanisms improved the precision of our result set significantly. In Supplement A.5, we list the selection criteria for publications included in the review. We discuss primary research publications that matched all criteria in Section 4 and summarize each of them in Supplement A.4. Figure 1 shows a histogram of the number of papers we found for the search term grouped by the publication year. The rising popularity of peer-to-peer networks and their mainstream adoption since the beginning of the 21st century is visible in the histogram. Famous implementations like the BitTorrent and Napster networks contributed to this trend.

3 REVIEW OF THE SECONDARY LITERATURE

This section presents the findings from analyzing related literature reviews on distributed peer-to-peer incentive mechanisms, whose retrieval we describe in Section 2.2. The key result of this review step is the derivation of a framework consisting of the types of incentive mechanisms and their distinguishing features, which we refer to as design aspects.

The examined literature reviews generally classify cooperation-enforcing incentive mechanisms into trust-establishing reputation systems or monetary schemes. We extend this classification with a third incentive type—service incentives—to cover mechanisms that reward instant privileged access to resources. We found the reward type (Section 3.1), attack resistance (Section 3.2), data management approach (Section 3.3), and contribution model (Section 3.4) to be the most important design aspects of incentive mechanisms. The next sections present the use-case-specific requirements, advantages, and disadvantages that govern the design decisions regarding these aspects.

Our framework enables readers to retrieve relevant publications included in this review by structuring their use case requirements according to the dimensions of the framework. Figure 4 in Section 5 shows a decision tree for picking an incentive type for a specific use case and scoping the research publications relevant to this incentive type and use case from this review.

3.1 Reward Type

Incentive mechanisms can be classified by the type of reward that is distributed to the network participants. Note that we consider punishments, also referred to as de-incentives in the literature, as incentives with a negative reward or payout. We define *payout* in line with game theory research as a quantifiable consequence rather than a monetary unit.

We identified monetary-like credits, reputation value, and access to services as the dominant reward types. They affect the user's ability to transfer, preserve, and accumulate rewards of incentive mechanisms. The three types imply that participants behave rationally, i.e., want to maximize the reward tailored to the network's goals. However, there are also subjective, intrinsic motivators for participation, such as altruism or idealism. Although these intrinsic motivators have positive effects on P2P network participation, they are hard to control as they entail neither an assessable payoff nor controllable metrics. Intrinsic motivators are thus unsuitable for designing an incentive mechanism which is why we exclude them from consideration in this article.

3.1.1 Monetary. A monetary incentive mechanism motivates participants to either participate in the network or behave in the network's best interest by distributing monetary credits, e.g., digital currency, for actions that work towards the network's goals. According to Berentsen and Schär [13], the monetary unit should be durable, transferable, divisible, homogenous, verifiable, stable, and rare to fulfill the functions of being an *exchange medium, an arithmetic unit, and a storage of value.*

These properties cause inherent advantages and disadvantages of monetary rewards. For example, the transferability of the monetary unit enables moving value from one participant to another. This ability makes the reward independent of an identity, which is impossible for a reputation value. On the other hand, a monetary reward poses the challenge of double-spending as a digital token can be copied and distributed to multiple peers simultaneously. Therefore, many monetary incentive mechanisms rely on a central broker to manage the accounting. While a central broker enables a comparably fast transaction time, it constitutes a single point of failure that, when compromised or malfunctioning, can have immensely negative effects on the network.

DLT [91, 128] can solve the centralization and double-spending issues. However, the omnipresence of cryptographic schemes in every interaction entails a resource-intensive overhead that may not be acceptable for certain use cases. Distributed ledgers like blockchains mainly use P2P monetary incentives to achieve participation and cooperation and *consensus mechanisms* to establish a robust trust model by introducing randomness in block creation and maintaining a single source of truth [139]. A new block represents a new computational state that introduces new data and transactions. Therefore, a consensus mechanism is critical for the attack resistance of incentives. A flawed consensus with a predictable outcome could lead to bribes and collusion attacks.

The most prominent consensus mechanism is Proof-of-Work (PoW) [91], in which peers compete to solve a complex mathematical puzzle to gain the right to create a new block. The probability to solve the puzzle is proportional to the utilized computational power (hash rate). If a peer, or group of peers, holds more than 50% of the computational power in the network, the unpredictability of who proposes the next block gets compromised, which weakens attack resistance. As the incentive mechanism rewards block-creating peers (miners), PoW networks tend to spend much computational power and energy to ensure attack resistance. In contrast, Proof-of-Stake (PoS) consensus mechanisms use a distributed randomness source (e.g., Randao[14]) and a deposited value (stake) to select the block-producing peer. Substantial penalties shall prevent 51% attacks (slashing[15]), but colluding peers (>50%) could exploit the reinforcement cycle to inflate their stake inescapably. Many other consensus mechanisms exist to solve the trust problems in DLT, e.g., Delegated Proof-of-Stake (DPoS), Proof of Elapsed Time (PoET), Practical Byzantine Fault Tolerance (PBFT), Proof of Burn (PoB), and others.[16] Consensus mechanisms are not to be confused

[14] https://github.com/randao/randao.
[15] https://ethereum.org/en/staking/.
[16] https://101blockchains.com/consensus-algorithms-blockchain/.

Table 2. Popular Auction Types

Auction Type	Description
English	An auction that maximizes the seller's revenue by increasing the price until no bidder is willing to bid higher.
Dutch	An auction that reduces the price until one or more bidders accept it, typically used for commodities that lose value over time.
Anglo-Dutch	An Anglo-Dutch auction starts as an English auction but switches to a Dutch auction as soon as only two bidders remain. The bidder who drops out last determines the lower price limit.
k-th Sealed-bid	A k-th Sealed-bid allows the highest bidder to pay the price of the k-th highest bidder.
VCG	In a Vickrey–Clarke–Groves auction (VCG) auction, bidders submit sealed bids. The highest bidder receives the item but all other bidders are also charged a payment based on their bid.
Double	A double auction represents a marketplace with multiple sellers and buyers.
Combinatorial	A Combinatorial auction bundles heterogeneous commodities (e.g., CPU cycles, memory, and bandwidth)

with incentive mechanisms, although the two often depend on each other to secure a DLT-based network.

Several schemes for distributing monetary units and determining the pricing of rewards exist. *Auctions* and *deterministic* monetary schemes are widespread variants to calculate the reward.

Auction. An auction is an established process to buy or sell commodities and services; it includes (1) an *asset or service*, (2) a *bidder* with interest in such, (3) a *seller* to provide it, (4) an *auctioneer* who manages the auction, (5) a private or public *valuation* subjective to each buyer or seller, and (6) a *price* proposed by the bidder that has to surpass the seller's ask. To manage an auction, the auctioneer has to choose a suitable auction type [137]. Table 2 describes the prevalent auction types. Auctions resolve discrepancies between prices and the valuation of the provided resources by constantly adjusting the price depending on the asks and bids. Hence, employing auctions increases the likelihood of achieving fair pricing.

Deterministic. Deterministic monetary incentives pay out a fixed reward. Compared to auctions, deterministic schemes guarantee predictable pricing, rewards, and costs. A disadvantage of deterministic monetary rewards is the lack of fair pricing, as overpaying or underpaying is accepted, and efficiency improvements are not automatically priced in. If high demand hits low supply, a *waiting-line* forms, which results in service delays. We consider dynamic pricing schemes part of deterministic pricing as long as the scheme follows a fixed algorithm and participants cannot manipulate pricing. Deterministic pricing solves the problem of variable and unexpected costs for a service with the downside of potential overpaying or underpaying and the risk of service delays.

3.1.2 Reputation. A reputation-based incentive mechanism seeks to establish trust among participants by using direct or indirect (transitive) behavior observations to predict participants' future behavior. Such observations are typically translated into a metric that represents a reputation value. A reputation reward is a digital asset or metric that cannot be used to purchase goods or services but is an indication to predict other network participants' future behavior.

When two peers trust each other, both estimate the probability of benefitting from mutual cooperation high enough to start engaging with each other. As Mantas et al. [78] pointed out, reputation, and the reputation value that reflects it, "is subjective, non-symmetric, dynamic, and context dependent". This means, every participant can judge reputation differently and have different reputation values for other participants, the reputation values change over time, and multiple metrics for different interaction contexts can exist. As an example for the last property, a peer can be assigned a different reputation value for providing media than for sensing data.

Some reputation mechanisms build transitive trust using information from other peers. However, if A trusts B and B trusts C one cannot guarantee that A also trusts C due to the context dependence of reputation. Systems that track reputation using a single source of truth significantly increase the likelihood that reputation-based trust exhibits transitivity. Establishing a single source of truth in a decentralized peer-to-peer network is feasible, e.g., by using a distributed ledger approach, in which participants form a consensus over the validity of every participant's actions and maintain a record of all transactions in the network [10]. However, a distributed ledger as a single source of truth can become a performance bottleneck, as the consensus mechanism demands time for informing participants about new transactions and collecting their validations.

We differentiate reputation incentives by their type of incentive enforcement. The binary *Denylisting* of peers after misconduct is one such type. Denylisting can occur locally, upon decision by an individual peer, or globally as a joint network decision. If incentives are non-binary and consider the past cooperation of individual peers, we subsume them under the type *Individual Reciprocity.* An example of a popular reciprocity-based reputation incentive mechanism is the tit-for-tat reputation strategy first employed on a large scale by the BitTorrent network [75]. In this scheme, two parties replicate the directly observed actions of the other party. If incentives apply to a group or cluster of peers, we consider them to be of the type *Clustered Cooperation.* Further, we distinguish incentive mechanisms that rely on Super Peers (SPs). The advantage of these schemes is that, in many cases, a reputation value can be calculated locally. If transitive information is not incorporated, the reputation value is independent of third parties. Hence, a peer only uses its transaction history with peers to calculate the reputation value. Each peer maintains its source of truth. However, systems in which a single source of truth manages the reputation exist as well. In that case, all peers jointly rely on the same data to track peer reputation, e.g., a single server or a distributed ledger. An inherent problem with reputation systems is the indeterminism of future behavior. A high reputation value does not guarantee beneficial future actions. A reputation value is bound to one identity and cannot be transferred to another participant.

Reputation systems promote cooperation, enforce participation, and thereby increase decentralization. Monetary incentives, on the other hand, often lead to increased centralization when few, efficient peers start selling tokens to other peers. Participants in reputation-based systems cannot benefit from a service without contributing to the network which benefits decentralization.

3.1.3 Service. Monetary rewards *implicitly* capture the interaction history by accumulating value, while reputation rewards *explicitly* express the cooperation history of participants. To cover incentive mechanisms that ignore the interaction history, we consider "service" as a third type of incentive rewards, which include immediate access to computational services, information, or media. Hence, a participant is incentivized with either direct access or exclusion from the service. The advantages of service rewards are less complex cryptographic schemes and no need to deploy or manage monitoring mechanisms. Service incentives are highly effective in preventing identity-based attacks like Sybil attacks.[17]

Given our definition of the service reward type, one could think that the tit-for-tat scheme represents a service reward. To recap: Tit-for-tat is a scheme in which interacting peers mirror

[17] A Sybil attack forges identities on peer-to-peer networks to hide the attacker's history of misbehavior.

observed behavior. If a peer continuously cooperates, the interacting peer reciprocates the cooperation. If a peer stops cooperating, the interacting peer likewise stops cooperating. Hence, a tit-for-tat scheme can be a service reward if it is based on immediate single interactions and does not present a repeated game. If the interaction history is captured over multiple interactions, tit-for-tat constitutes a reputation scheme. Tit-for-tat behavior can also be deployed in a monetary setting, e.g., when a service allows accumulating bilateral monetary debt and settles the debt after a certain time. Hence, tit-for-tat is a reciprocal behavior independent of the deployed incentive type.

In summary, the service incentive type subsumes cooperation schemes that neither use reputation, nor monetary rewards as payoffs. Service incentives limit cooperation complexity by eliminating the need for transaction histories and tracking mechanisms.

3.2 Attack Resistance

Incentive mechanisms rely on rewards and punishment. Attackers can target these rewards to benefit illegitimately. We deviated six subordinate attack categories from the attacks we found in our review of the secondary literature. These categories are false information attacks, identity attacks, sniffing/confidentiality attacks, routing attacks, and collusion attacks. The following paragraphs describe each attack category and explain their relation to the STRIDE [7]— a prominent model for identifying computer security threats developed at Microsoft. The model provides a mnemonic for security threats in the categories of spoofing, tampering, repudiation, information disclosure, denial of service, and elevation of privilege. With STRIDE in mind, we defined specific categories that group threats by their countermeasures.

False Information Attacks describe the tempering of information to harm or illegitimately benefit participants. Possible attacks on incentive mechanisms in this category are false recommendations, misreporting, false accusations, and history modification.

Identity Attacks target the identity of a participant. Spoofing [7] is a prevalent identity attack in which the attacker impersonates another participant to gain personal benefits or falsifies information to misrepresent the origin of data. For example, in an email attack, the attacker may forge the sender's address or spoof an IP address to disguise a host's identity or location and cause non-repudiation [7]. The "Sybil-Attack" is another prominent identity attack, in which a participant creates and uses many pseudonymous identities to gain personal benefits, e.g., increase its own reputation, by discrediting other participants. "White-Washing" is an attack in which an adversary can reset its reputation by rejoining the system under a different identity. Identity attacks also threaten monetary-based incentive mechanisms. Authentication and authorization are common countermeasures to prevent identity attacks.

Sniffing/Confidentiality Attacks cover two of the STRIDE threats: Information disclosure and elevation of privilege [7]. Sniffing attacks allow the extraction and exploitation of data to harm participants. Incentive mechanisms that cannot guarantee the security of personally identifiable information might lose participants as a result.

Routing Attacks correspond to denial of service attacks [7] in the STRIDE model. Denial of service attacks aim to exclude individual participants from the incentive mechanism or entirely disrupt the operation of the incentive mechanism. Routing attacks can deprive participants of opportunities, e.g., by not forwarding bids in an auction mechanism.

Selfish Attacks like free-rolling cause a single user to benefit illegitimately. Incentive mechanisms are the main countermeasure to prevent "Free-Rolling". Selfish attacks are not explicitly reflected in the STRIDE model of threats but negatively impact peer-to-peer networks.

Collusion Attacks describe scenarios in which the majority of participants collaborate to benefit illegitimately. Examples include the Byzantine Generals Problem [64] or Bitcoin's 51%

attack.[18] Collusion attacks in decentralized networks are complex and harder to prevent than selfish attacks.

3.3 Data Management

Incentive mechanisms exhibit characteristic differences in their data management approach, which we discuss by analyzing the properties' (1) access control, (2) anonymity, (3) linkability, and (4) confidentiality as security and privacy are not measurable directly. Table A.1 shows which of these data management aspects are over- or under-represented in certain incentive types by listing the number of papers providing explicit information on these aspects.

We revisit these data management aspects in our discussion of privacy and security in Section (4.1). The significance of privacy and security differs depending on the use-case-specific requirements. An incentive mechanism with insufficient privacy or security might be dismissed, even if it provides outstanding cooperation and participation results. For example, incentives should handle names and other personal information adequately and refrain from sharing personally identifiable information with third parties. Protecting sensitive personal information requires access control anonymization to be General Data Protection Regulation (GDPR) compliant.

Access Control selectively enables participants to access information and perform actions, which can interfere with the openness of a peer-to-peer network. Requiring cryptographic authentication or an identifier to access functionality or data is a basic form of access control. More advanced forms rely on lists to restrict access to different resources. Often, user roles are used to reduce the management overhead of access lists. Decentralized systems can manage access lists on an immutable distributed ledger [45] or let participants manage access to data individually [62]. Access control can harden an incentive mechanism against attacks and protect its data from exploitation.

Anonymity exists if users are non-identifiable, unreachable, or untrackable. Incentive mechanisms use either irreversible anonymity, reversible pseudonymity, or plain identifiable information. Pseudonymity rather than anonymity is often sufficient to be GDPR-compliant as GDPR considers information as identifiable only if it is reasonably likely to be identified [89]. We consider a masked but reversible identifier a pseudonym. By this definition, all encrypted identities are pseudonyms. Hiding the identity and its data from third parties is an obvious benefit of pseudonymized identifiers. Pseudonymization can result in unlinkability which makes the contribution of actions and, hence, the implementation of incentive mechanisms more difficult.

Linkability. This aspect of incentive mechanisms measures if actions are attributable to transacting participants. Weber defines unlinkability as "a property that aims at hiding relationships between items in a system" [122]. Zero-knowledge authentication schemes [1] are a recent innovation to provide linkability and pseudonymity/anonymity by providing encrypted attributes for access control. Linkability is essential to attribute actions and reward or punish users. However, valid reasons for anonymity, like the circumvention of governmental communication restrictions [18], require additional overhead through zero-knowledge proofs to provide linkability and anonymity. One example could be an incentive for user-provided networks like TOR and I2P [88].

Confidentiality can have various benefits and is achievable through access control, encryption, or obfuscation. An auction mechanism might hide bids from other bidders to prevent active competition and generate a fair price. A service-based incentive might hide the services' users to preserve their privacy. Companies might want to hide their engagement with other business partners to strengthen their negotiating position.

[18] https://satoshi.nakamotoinstitute.org/emails/cryptography/11/.

3.4 Contribution Model

In this section, we define the aspects we use in Section 4.1 to specify and compare the contribution models of incentive mechanisms. Contribution models define the demand for tasks. The requirements for the contribution model vary depending on the incentive mechanism's use case. We distinguish whether an incentive mechanism allows participants to process tasks proactively or reactively by assigning the tasks to the participants. Moreover, we analyze whether an incentive mechanism allows claiming rewards for multiple tasks and if it is open for participation. These design decisions affect the efficiency and accessibility of an incentive mechanism.

Proactive Contribution increases the flexibility of participants by allowing them to contribute at any time and freely varying the tasks or resources.

Reactive Contribution assigns specific tasks to contributors, thereby restricting the contributed tasks and resources according to the demand in the system.

Multitasking lets participants choose different homogenous or heterogeneous tasks or resource contribution types. For example, if an incentive mechanism offers an incentive for both bandwidth and uptime, we classify it as offering heterogenous multitasking.

Openness describes whether participation is open to everyone or access to the incentive is permissioned using an onboarding requirement. Such a requirement could be Know Your Customer (KYC) schemes or authorization through a participating institution.

4 REVIEW OF THE PRIMARY LITERATURE

In this section, we present the primary literature, which we retrieved as described in Section 2.5, according to the framework of design aspects derived from the secondary literature on the topic (cf. Section 3). We analyze publications regarding the reward type (Section 4.1), attack resistance (Section 4.2.1), data management approach (Section 4.2.2), and contribution model (Section 4.2.3) to provide insights for specific use cases and network types and highlight research gaps.

Of the 178 primary research publications we retrieved, we selected those that met the following requirements: (1) Contains an incentive mechanism as a core contribution, (2) is a P2P or decentralized network, and (3) focuses on computational resources. We read and analyzed 105 of the remaining 107 papers in detail as we could not retrieve the full texts of two papers. We briefly describe each publication in Supplement A.4.

4.1 Reward Type

In this section, we categorize incentive mechanisms presented in primary research publications by their reward type, i.e., monetary, reputation, and service (cf. Section 3.1). Table 3 for monetary rewards, Table 4 for reputation rewards, and Table 5 for service rewards summarize our findings. Moreover, Table 6 reflects the reward type and network type simultaneously.

4.1.1 Monetary. Monetary incentives can be realized in three ways: (1) blockchain-enabled currencies (cryptocurrency) [91], (2) multiple-currency economy [116], or (3) centrally managed currencies. In Table 3, we summarize decentralized currencies like blockchain-enabled currency and multiple-currency economy as *Unified Virtual Currency* and state centrally managed currencies explicitly. A multiple-currency economy in the design of the Lightweight Currency Protocol [116] does not suffer from blockchain overhead but requires trust in each service provider, as each of them can deploy and operate its own currency. Other monetary incentives compromise decentralization by including a trusted third party or central server to manage the currency. Regardless of the implementation of the specific virtual currency, we observed monetary incentives to represent either an *auction* or *deterministic* scheme.

Table 3. Primary Research Publications that Applied Monetary Incentive Mechanisms

Ref.	Year	Authors	Monetary Type	FS	MS	CP	SD	RR	O	A	Cur
[32]	2012	Gramaglia et al.	*Deterministic*	X							CMC
[41]	2018	He et al.	*Deterministic*	X							CMC
[17]	2013	Centeno et al.	*Deterministic*	X							UVC
[112]	2009	Sirivianos et al.	*Deterministic*	X							CMC
[23]	2014	De Sales et al.	*Deterministic*		X						CMC
[90]	2019	Mousavi and Klein	*Deterministic*		X						UVC
[79]	2008	Manzato and da Fonseca	*Deterministic*		X						CMC
[56]	2017	Kang and Yang	*Deterministic*		X						UVC
[53]	2014	Jin Teng et al.	*Deterministic*					X			CMC
[120]	2014	Wang et al.	*Deterministic*					X			CMC
[138]	2004	Yu and Singh	*Deterministic*							X	UVC
[143]	2021	Zhang et al.	*Deterministic*						X		UVC
[133]	2015	Xin Kang and Yongdong Wu	*Double Auction*	X							UVC
[119]	2003	Wang and Li	*Double Auction*	X							UVC
[48]	2022	Jaiman et al.	*Double Auction*	X							BEC
[147]	2014	Zou and Chen	*Double Auction*		X						UVC
[73]	2019	Lin et al.	*Double Auction*		X						BEC
[70]	2008	Lijuan Xiao et al.	*Double Auction*			X					UVC
[102]	2012	Rius et al.	*Double Auction*			X					CMC
[24]	2013	del Val et al.	*Double Auction*				X				UVC
[25]	2014	del Val et al.	*Double Auction*				X				UVC
[71]	2004	Lin and Lo	*Double Auction*					X			UVC
[96]	2013	Padhariya et al.	*Double Auction*					X			CMC
[95]	2016	Padhariya et al.	*Double Auction*					X			CMC
[135]	2006	Xue et al.	*Double Auction*					X			UVC
[134]	2016	Xu et al.	*Double Auction*					X			UVC
[113]	2020	Sun et al.	*Double Auction*						X		BEC
[74]	2022	Lin et al.	*Double Auction*						X		BEC
[68]	2018	Li et al.	*Double Auction*						X		UVC
[61]	2016	Kim	*Double Auction*						X		BEC
[142]	2012	Zhang et al.	*Double Auction*							X	CMC
[145]	2012	Zhao et al.	*Double Auction*							X	UVC
[66]	2009	Li et al.	*Double Auction*							X	CMC
[138]	2004	Yu and Singh	*Double Auction*							X	UVC
[40]	2020	Haq and Faheem	*Double Auction*	X							UVC
[14]	2020	Bhattacharya and Guo	*Double Auction*	X							CMC
[148]	2014	Zuo and Zhang	*English Auction*	X	X						UVC
[131]	2014	Wu et al.	*English Auction*	X	X						CMC
[21]	2006	Cheng et al.	*English Auction*	X							MCE
[125]	2014	Weijie Wu et al.	*English Auction*	X							UVC
[8]	2018	Aslani et al.	*English Auction (R)*		X						MCE
[123]	2020	Wei et al.	*English Auction (R)*						X		MCE
[29]	2020	Fang et al.	*English Auction*			X					UVC
[85]	2010	Mondal et al.	*English Auction*					X			UVC
[86]	2009	Mondal et al.	*English Auction*					X			UVC
[33]	2008	Guang Tan and Jarvis	*1st Sealed-bid*		X						UVC
[129]	2012	Wu et al.	*2nd Sealed-bid*		X						MCE
[34]	2004	Gupta and Somani	*2nd Sealed-bid*							X	UVC

The table shows the incentive's primary application domain and implementation. Research gaps like underexplored auction types (cf. Table 2) and applications can be identified.
FS: File Sharing; MS: Media Streaming; CP: Computing; SD: Service Discovery;
RR: Routing&Relaying; O: Other; A: Any; Cur: Currency (BEC: Blockchain-Enabled Cur.;
MCE: Multiple-Cur. Economy; CMC: Centrally Managed Cur.; UVC: Unified Virtual Currency);
R: Reverse.

Auction: The *English* auction is the simplest auction type we found in the reviewed P2P systems [21, 29, 33, 85, 86, 123, 129, 131, 147]. This auction type generates high profits for the seller but results in overpaying, especially if bids are private. Gupta et al. [34] used the more complex *k-th Sealed-bid* auction type with $k = 2$ in a private bid lookup protocol to reduce overpay significantly. *Double* auctions that resemble marketplaces because sellers and bidders compete for the ideal bid and ask for prices were used in the publications [14, 24, 25, 40, 48, 56, 61, 66, 68, 70, 71, 73, 74, 79, 95, 96, 102, 113, 119, 125, 133–135, 138, 142, 145]. A marketplace is a fair and decentralized solution. All market participants are equal and can act as buyers and sellers to find a flexible and fair price based on the current demand and supply. However, not all auctions allow flexible pricing to set a fair price. Aslani et al. [8] employed inflexible pricing with only three pricing options and invoked a *Waiting-line* if a providing peer is overloaded. A *Waiting-line* is common in absolute deterministic pricing incentives as we describe in Section 4.1.1.

Table 4. Primary Research Publications that Applied Reputation-based Incentive Mechanisms

Ref.	Year	Authors	Reputation Type	FS	MS	CP	SD	RR	O	A
[63]	2015	Kurve et al.	*Clustered Cooperation SP*	X						
[102]	2012	Rius et al.	*Clustered Cooperation SP*			X				
[115]	2014	Tian et al.	*Clustered Cooperation SP*							X
[43]	2014	Hu et al.	*Clustered Cooperation*	X						
[77]	2006	Ma et al.	*Clustered Cooperation*	X						
[5]	2010	Allen et al.	*Clustered Cooperation*	X						
[109]	2020	Shen et al.	*Clustered Cooperation*	X						
[11]	2013	Belmonte et al.	*Clustered Cooperation*	X	X					
[65]	2012	Li et al.	*Clustered Cooperation*		X					
[76]	2020	Luo et al.	*Clustered Cooperation*			X				
[47]	2016	Ismail et al.	*Clustered Cooperation*						X	
[49]	2016	Jain et al.	*Clustered Cooperation*						X	
[39]	2005	Hales and Edmonds	*Clustered Cooperation*							X
[127]	2019	Wong et al.	*Global Denylisting SP*	X						
[6]	2021	Ansari et al.	*Global Denylisting SP*		X					
[52]	2015	Jin and Kwok	*Global Denylisting*		X					
[55]	2019	Kang et al.	*Global Denylisting*						X	
[97]	2022	Pal et al.	*Global Denylisting*			X				
[62]	2007	Koo and Lee	*Individual Reciprocity*	X						
[16]	2013	Carra et al.	*Individual Reciprocity*	X						
[75]	2010	Liu et al.	*Individual Reciprocity*	X						
[84]	2013	Meulpolder et al.	*Individual Reciprocity*	X						
[58]	2006	Kazatzopoulos et al.	*Individual Reciprocity*	X						
[42]	2013	Hu et al.	*Individual Reciprocity*	X						
[117]	2012	Vakili and Khorsandi	*Individual Reciprocity*	X	X					
[72]	2009	Lin et al.	*Individual Reciprocity*		X					
[118]	2014	Wang et al.	*Individual Reciprocity*		X					
[93]	1396	Nasab and Bidgoli	*Individual Reciprocity*		X					
[79]	2008	Manzato and da Fonseca	*Individual Reciprocity*		X					
[136]	2006	Yang	*Individual Reciprocity*		X					
[42]	2013	Hu et al.	*Individual Reciprocity*		X					
[87]	2012	Montazeri et al.	*Individual Reciprocity*		X					
[101]	2007	Pianese et al.	*Individual Reciprocity*		X					
[132]	2012	Xiao et al.	*Individual Reciprocity*		X					
[130]	2012	Wu et al.	*Individual Reciprocity*					X		
[20]	2020	Chen et al.	*Individual Reciprocity*						X	
[121]	2018	Wang	*Individual Reciprocity*							X
[31]	2018	Goswami et al.	*Individual Reciprocity*							X
[50]	2004	Jiang et al.	*Individual Reciprocity*							X
[54]	2003	Kamvar et al.	*Individual Reciprocity*							X
[94]	2005	Neovius	*Individual Reciprocity*							X
[69]	2019	Li et al.	*Individual Reciprocity*							X
[92]	2005	Nandi et al.	*Local Denylisting*	X						
[30]	2016	Gonçalves et al.	*Local Denylisting*		X					
[36]	2006	Habib and Chuang	*Local Denylisting*		X					
[98]	2006	Papaioannou and Stamoulis	*Local Denylisting*				X			
[24]	2013	del Val et al.	*Local Denylisting*				X			
[111]	2021	Singha and Singh	*Local Denylisting*					X		
[142]	2012	Zhang et al.	*Local Denylisting*							X
[141]	2018	Zhang et al.	*Local Denylisting*							X
[19]	2014	Chang et al.	*Local Denylisting*							X
[140]	2013	Zhang and Antonopoulos	*Local Denylisting*							X
[57]	2008	Karakaya et al.	*Local Denylisting*							X

The table shows the primary application domain and the reputation mechanism type.
FS: File Sharing; MS: Media Streaming; CP: Computing; SD: Service Discovery; RR: Routing&Relaying; O: Other;
A: Any.

Peer-to-peer video streaming [8, 33, 56, 79, 125, 129, 131, 147] and file sharing [14, 21, 40, 48, 119, 131, 133, 148] were the main use cases in which auction mechanisms were deployed. Other auction-incentivized tasks included mobile edge computing [74, 113] and relaying in mobile ad hoc networks [71, 85, 86, 95, 96, 134, 135]. The publications [34, 66, 138, 142, 145] proposed a

Table 5. Primary Research Publications that Applied Service Incentive Mechanisms

Ref.	Year	Authors	Peer Selection Type	FS	MS	CP	SD	RR	O	A
[27]	2017	Esfandiari et al.	*Interest-Based*	X						
[83]	2013	Meng and Li	*Capability-Based*	X						
[3]	2021	Adamu	*Capability-Based*	X						
[60]	2010	Kim	*MTTF-Based*	X						
[100]	2010	Park et al.	*Hop-Counter-Based*		X					
[38]	2016	Hadzibeganovic and Xia	*Tag-Based*					X		

The table shows the primary application domain and the type of peer selection mechanism. Service incentives have not been applied in peer-to-peer computing and service discovery.
FS: File Sharing; MS: Media Streaming; CP: Computing; SD: Service Discovery; RR: Routing&Relaying; O: Other; A: Any.

Table 6. Primary Research Publications Grouped by Reward and Network Types

		P2P	MEC	MANET	DTN	MSN	MCC
Monetary	Auction	[8, 14, 21, 24, 25, 33, 34, 48, 56, 61, 66, 68, 68, 70, 73, 74, 79, 102, 119, 123, 125, 129, 131, 133, 135, 138, 142, 145, 147, 148]	[85, 113]	[29, 71, 86, 95, 96]	[40]	[134]	
	Deterministic	[4, 17, 23, 32, 41, 112, 138, 143]		[90]	[53, 120]		
Reputation		[5, 6, 11, 16, 19, 20, 24, 30, 31, 36, 39, 42, 43, 50, 52, 54, 55, 57, 62, 63, 65, 69, 72, 75, 77, 79, 84, 87, 92–94, 98, 101, 102, 106, 109, 115, 117, 118, 121, 127, 132, 136, 140–142]		[58, 76, 130]			[47, 49, 111]
Service		[3, 27, 38, 60, 81, 83, 100]		[38]			

Less research has addressed resource-constrained networks and networks with a dynamic topology than general peer-to-peer networks.
P2P: Peer-to-Peer; MEC: Mobile Edge Computing; MANET: Mobile Ad Hoc Network; DTN: Delay Tolerant Network; MSN: Mobile Social Network; MCC: Multi-Cell Cooperation.

general auction incentive not restricted to a specific task. The reviewed work on P2P computing [29, 70, 102] and service discovery mechanisms [24, 25] exclusively used *Double* auctions. Wei et al. addressed the crowdsensing task with reverse English auctions, in which the lowest bidder receives a task [123]. A more recent publication by Sun et al. [113] used a smart-contract-capable blockchain to provide a pure decentralized architecture, while the dated publication of Wu et al. [129] deployed a lightweight virtual currency. Some auction mechanisms include centralized components to manage a virtual currency [8, 131], making the incentive mechanism incompatible with pure P2P networks.

Deterministic: File sharing was the prevalent use case for deterministic monetary incentives in the reviewed works [17, 32, 41, 120]. Both file-sharing and media streaming networks rely on routing and relaying data in P2P systems. Teng et al. [53] proposed two variants of a coupon-based incentive mechanism to reach customers. In the first variant, all forwarders benefit equally; in the second a single forwarder benefits randomly. Digital coupons represent a deterministic benefit and have monetary properties. Wang et al. [120] proposed a deterministic reward mechanism for data sharing that considers prior encounters to estimate the closeness of participants and the possible paths to define the expected reward to reach a peer. Although prices differ for each peer, the pricing algorithm follows deterministic rules and is predictable.

De Sales et al. [23] facilitated efficient video streaming in a hybrid Content Delivery Network (CDN)/P2P network. Their deterministic monetary incentive mechanism uses a virtual currency (Tickets of Bits). A relay gains Tickets of Bits (ToB) as it shares its upload bandwidth with other relay nodes that successfully receive media content. The algorithm considers the quality of the stream to calculate the number of ToBs to reward the user. Mousavi et al. [90] also deployed a deterministic monetary incentive for video streaming and combined it with a reputation metric to reflect the quality of service each peer delivers. Al Ridhawi et al. [4] proposed a blockchain-based reward mechanism for peer-to-peer computing. The rewards are generated and paid proportional to a peer's capabilities as a token. Yu and Singh [138] presented a general incentive mechanism using a deterministic and dynamic pricing scheme to mitigate free-riding by agents. In the deterministic pricing scheme, a query issued by a particular peer incurs a cost for said peer if it gets answered by a neighbor. In the dynamic pricing scheme, the authors consider the quality of services provided by neighbors and adjust the payments accordingly. Zhang et al. [143] proposed a blockchain-based deterministic pricing scheme to enable federated learning on a shared AI model.

Summary of Monetary Incentives: Table 3 summarizes the use of monetary incentives in the reviewed works. Each row represents a publication with its monetary incentive and application domains to highlight the prevalence of design decisions and potential research gaps. For instance, the presented auction mechanisms primarily apply English and Double auctions, while other auction types like the *Dutch*, *Combinatorial*, *Anglo-Dutch*, or *VCG* auction types (see Table 2 for details) are rare in P2P incentive research. We expect a *Dutch* auction to provide benefits for time-critical services like video and data streaming, where data becomes less valuable over time. Further, we see *Combinatorial* auctions as a strong candidate for P2P computing as bandwidth, CPU cycles, and memory are interdependent and should be rewarded jointly. The *Anglo-Dutch* could reduce the costs for strictly limited resources for which overpaying is common, like Bitcoin transaction fees. Finally, *VCG* could help in auctions that are majority-dependent, e.g., company shares or stake.[19] The works we reviewed did not incentivize service discovery and peer-to-peer computing with deterministic monetary incentives. We assume that the complexity of services and computing tasks complicates deterministic pricing. Computing use cases require rewarding the CPU cycles, memory, storage, and bandwidth. Not all these tasks are deterministic. Decentralized computing solutions, therefore, include upper limits that abandon tasks.[20] Such limits could be introduced in peer-to-peer computing to deploy a deterministic monetary incentive.

4.1.2 Reputation. In the following, we discuss the application domains and incentive enforcement types, i.e., *Individual Reciprocity*, *Clustered Cooperation*, *Local Denylisting,* and *Global Denylisting*, of reputation mechanisms. Reviewed works predominantly applied reputation-based incentives for file sharing [5, 11, 42, 43, 58, 62, 63, 75, 77, 84, 92, 109, 117, 127] and media streaming [6, 11, 30, 36, 42, 52, 65, 72, 79, 87, 93, 101, 117, 118, 132, 136]. Only two articles covered peer-to-peer computing [76, 97, 102], and service discovery [24, 98], respectively. Other applications included joint radio resource allocation [47, 49], the prevention of fake online media [20], and federated machine learning [55]. Most of the analyzed reputation mechanisms are versatile in use and can be applied in any peer-to-peer application [19, 31, 39, 50, 54, 57, 69, 94, 115, 121, 140–142]. Two publications covered routing and relaying [111, 130]. Reputation mechanisms in the *Any*-category are suitable for incentivizing arbitrary applications. Most reviewed works employed reciprocity (tit-for-tat) supported by calculated individual reputation or trust values that were translated into service quality [20, 31, 42, 51, 54, 58, 62, 69, 72, 75, 79, 84, 87, 93, 94, 101, 111, 117, 118, 132, 136]. The more participants contribute, the more resources of other peers become available to them.

Some reputation mechanisms group participants based on their reputation into clusters, also referred to as coalitions or groups, rather than defining the service quality for individual participants [5, 11, 39, 43, 47, 65, 76, 77, 109]. Super peers that manage peer groups are a semi-centralized approach of grouped reciprocity-based incentives [63, 102, 115, 127]. Peers are assigned to super peers based on their reputation value, physical proximity, thematic similarity, common interest, or

[19] https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/.
[20] https://ethereum.org/en/developers/docs/gas/.

at random. Other approaches put peers on a global, i.e., network-wide, denylist [6, 36, 52, 55, 127], or allow peers to dismiss uncooperative peers locally [19, 24, 30, 57, 92, 98, 111, 121, 140–142]. An approach that allows global peer penalties requires a single source of truth available to all participants. This single source of truth can be a distributed ledger, as Kang et al. have demonstrated [55] or a distributed hash table like Pal et al. [97] have shown.

Summary of Reputation Incentives: Table 4 summarizes the presented works on reputation incentives. Each shows the reputation incentive type and application domain addressed by a publication.

The table shows an even distribution of application domains but a comparably infrequent use of *Global Denylisting*. Only three of 48 primary research publications applied global denylisting. We suspect that reaching a consensus on the network-wide denylist is challenging without a single source of truth. Recent advances in distributed ledger technology allowed Kang et al. [55] to deploy a sophisticated solution to this problem. We see the use of DLT for reputation management as a promising direction for future research. Applying a distributed hash table [97] to achieve similar results with less coordination overhead is particularly promising.

4.1.3 Service. Table 5 shows the application domains and peer selection types of service incentive mechanisms. Other than Tables 3 and 4, Table 5 does not have a column for *Service Type* because service incentives only differ in their peer selection types in case multiple peers compete for the same task but not, e.g., in how the incentive is granted. The peer selection types are *Interest-Based*, *Capability-Based*, *Mean Time To Failure (MTTF)-based*, *Hop-Counter-Based*, and *Tag-Based*.

The main application area for service incentives is file sharing [3, 27, 60, 83]. We also found service incentives applied for media streaming [100] and routing & relaying [38]. Esfandiari et al. [27] connected peers that reported similar interest in files. Hadzibeganovic & Xia had peers report their properties and topic interests as tags [38]. Meng et al. [83] let peers report their maximum capabilities to neighboring peers, which in turn try to connect to highly capable peers. Similarly, Adamu [3] used each peer's share ratio to regulate service access. A peer could only retrieve data if it was simultaneously providing data. Kim [60] used the reported **mean time to failure (MTTF)**. For video streaming, Park et al. [100] relied on peers correctly setting a hop-counter for each package to detect the shortest path and create redundant paths to ensure failure resistance. The common element of all these approaches is their reliance on participants reporting information correctly.

The reviewed works did not apply service incentives for peer-to-peer computing and service discovery (cf. Table 5), which are frequent application areas for other incentive types. For peer-to-peer computing, a binary reward is suboptimal as each computational task has other resource requirements. Service discovery could be a suitable application for service incentives in our view.

4.1.4 Classification by Reward and Network Type. Some use cases impose network-type-specific requirements on incentive mechanisms, such as the ability to handle topological changes and varying paths in the case of MANETs or delay tolerance in the case of DTNs. MEC networks; on the other hand, they strive to provide delay-sensitive computing services so that users can offload expensive computing tasks from their mobile devices to servers nearby. MSNs require the incentive mechanism to respect the limited computing capabilities and energy budget of mobile peers. MCCs relies on stationary cellular uplink infrastructure that leverages clustered cooperation to power mobile device internet connectivity efficiently by avoiding inter-cell interference.

Table 6 allows identifying incentive mechanisms that address the requirements of specific network types using either monetary, reputation, or service incentives. Most incentive mechanisms are designed for general peer-to-peer networks and do not consider network delays, peer mobility, and resource constraints. Less research addressed incentive mechanisms for networks operating under such constraints. While publications in the *peer-to-peer* column may address specific

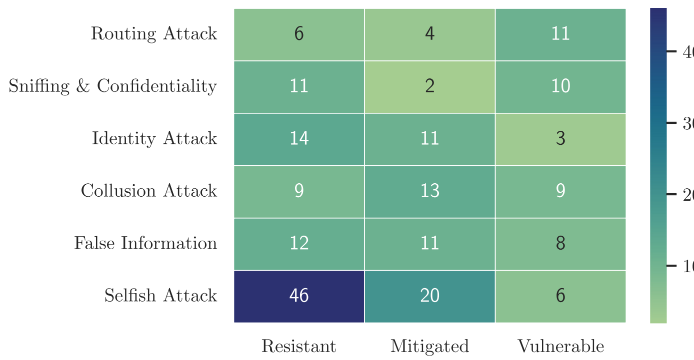

Fig. 2. Categorization of incentive mechanisms regarding their resistance to specific attacks. Selfish attacks received the most attention in the reviewed works; other attacks were rarely addressed.

network types, they do not impose particular constraints. Rewards that use multiple reputation types are categorized by their main incentive in Table 6. For example, an incentive that uses reputation to define the amount of monetary reward [138] is categorized as a monetary reward mechanism.

4.2 Attack Resistance, Data Management, and Contribution Model

In this section, we discuss the attack resistance, data management, and contribution model of incentive mechanisms (cf. Sections 3.2–3.4) presented in primary research publications. Additionally, Table A.1 in Supplement A.3 categorizes publications regarding these design aspects. We exclusively examine these properties for practical projects but not for purely game-theoretical publications that describe abstract peer interactions without providing implementation details.

4.2.1 Attack Resistance. Figure 2 gives an overview of the attack resistance of incentive mechanisms by classifying the publications presenting the incentives. Please note that the figure only considers publications that provide information on resistance to the attacks described in Section 3.2. Many of the analyzed incentive mechanisms lack evaluations of certain attack vectors and none of the analyzed publications provided details on all six attack vectors. This lack of information limits the comparability of the analyzed works. Twenty-three incentive mechanisms implement mitigations for or showed resistance against half or more of the attack vectors, and few incentive mechanisms mitigate five of the six attack vectors [32, 41, 58, 72]. Most of the analyzed incentive mechanisms (66) mitigate network participants' selfish behavior. This prioritization of preventing *Selfish Attacks* is unsurprising, as many incentive mechanisms are designed to promote either participation or cooperation. *Sniffing & Confidentiality Attacks*, on the other hand, seem to be of little relevance in peer-to-peer incentive mechanisms, as only 18 publications allowed for assumptions on the resistance against this attack type. Notably, some mechanisms can resist false information attacks while staying vulnerable to other attacks. An example is the mechanism of Karakaya et al. [57] which is vulnerable to identity attacks. Sybil attacks, for example, flood the system with newly created identities while stating the contribution information correctly. Table A.1 in the supplement facilitates finding related work for use cases that require resistance against specific attack types.

4.2.2 Data Management. Figure 3 summarizes the data management and contribution model properties of the analyzed incentive mechanisms by classifying the research publications that present the mechanisms accordingly. Most incentive mechanisms do not employ *Access Control*.

Fig. 3. Categorization of incentive mechanisms regarding their data management and contribution model properties. Classifications as *Other* in the category *Anonymity* mainly represent pseudonymity.

Such open designs allow for easy onboarding of new peers and, hence, faster growth of the network.

Most peer-to-peer incentive mechanisms employ pseudonymization by assigning masked identifiers to peers. Few mechanisms make peers directly identifiable or use total anonymity. The level of *Anonymity* is relevant for GDPR compliance and security, as malicious actors might bribe or blackmail peers in the network to influence their actions.

However, an identifiable identity only becomes a security concern if *Linkability* is given. Missing *Linkability* masks the relationship between actions and identities in the incentive mechanism to provide privacy. Incentive mechanisms that provide anonymity naturally lack linkability, while linkable incentive mechanisms provide no anonymity or pseudonymity. Most incentive mechanisms we reviewed are linkable according to the definition in Section 3.3. We expected this observation for reputation-based and service incentive mechanisms but not necessarily for monetary incentives. Reputation is identity-dependent and must therefore be linkable. Service incentives provide imminent access to services as a reward for an entity linked to a successful contribution.

Confidentiality describes whether incentive rewards and the action history are visible to other network members. Confidentiality is typically given if each peer calculates the incentive mechanism's payoffs locally and individually.

4.2.3 Contribution Model. The analyzed publication implemented reactive and proactive task management, some both. Most mechanisms are designed for a single task, while the minority allows for heterogeneous actions that simultaneously incentivize multiple tasks (*Multitasking*). Rewarding multiple actions, like storage and bandwidth for file-sharing, is beneficial for some use cases, such as similarity detection. All but one incentive mechanisms are open, i.e., do not enforce preconditions or access control on participating peers. *Openness*, i.e., allowing everyone to participate benefits decentralization, encourages participation, and maximizes contribution rate, which are primary goals for many peer-to-peer networks. However, we found a few exceptions. Gramaglia et al. [32] used banks to manage the monetary rewards of their incentive mechanism. These banks required registration and might deny participants from other jurisdictions. Chen et al. [20] required participants to submit certain data and documents to verify and validate them as news organizations. Kang et al. [55], Lin et al. [73], and Wei et al. [123] managed their incentive mechanisms using a consortium blockchain with predefined members, thereby limiting the incentive mechanisms but keeping the peer-to-peer network open for peers to join. Such closed systems offer a high level of control and are often operated without decentralized incentive mechanisms.

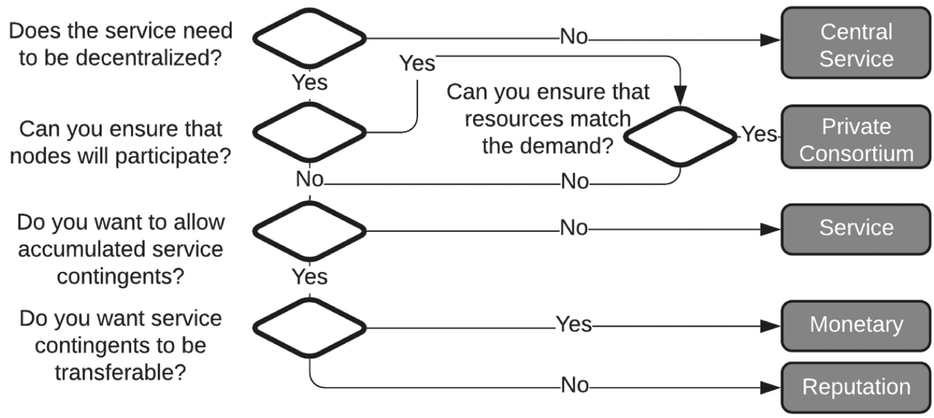

Fig. 4. Decision tree guiding the selection of a suitable incentive type.

5 CASE EXAMPLE

This section applies our framework of design aspects to a specific use case. We wish to find applicable incentive mechanisms for the academic use case of decentralized similarity detection, which we presented in prior work [46]. Decentralized similarity detection would enable literature recommendation or plagiarism checks without disclosing the content of the input document or the collection to which it is compared. Moreover, the system and data would not be controlled by a central provider. This design would eliminate the privacy and legal concerns of current systems.

We use the information provided in the previous section to derive the decision tree depicted in Figure 4 to structure the selection process. In the first step, we decide on the most crucial question: Does the use case require a decentralized service? This question should rule out any service not requiring incentives at all. Academic services like the one we consider here are usually self-hosted or provided by a third party. Often, institutions run similar services but restrict access to their members. For academic institutions, sharing infrastructure and services is still uncommon, which limits the availability and scalability of the services. Cooperatively providing and using incentivized academic services with other institutions could significantly improve this situation. Hence, we aim for a decentralized service provision.

The second question addresses the amount of control we have over participating nodes. In our case, we could set up legally binding contracts to ensure known academic institutions commit to providing defined computational resources and achieving a certain degree of availability. However, this approach would hinder decentralization, as the service would be a closed system lacking the flexibility to onboard unknown nodes to handle heavily fluctuating demand. While we can ensure that a certain number of nodes will participate, we cannot guarantee that they will match our scalability goals if demand rises. Hence, we require a permissionless incentive mechanism.

Having established the need for an open and decentralized incentive mechanism, we decide whether we need accumulated service contingents. Academic services face periodical load shifts, e.g., because students need to submit their papers at the end of a semester. Incentive mechanisms that accumulate rewards (cf. Section 4.1.1) or maintain a transaction history (cf. Section 4.1.2) are advantageous for such use cases, as peers are incentivized to participate outside major load periods. These load periods differ for different institutions.

The last decision addresses the transferability of service contingents. The option to transfer contingents obtained through service contribution opens the service for non-contributing network members. This is a potential security risk, as the service is not guaranteed to remain decentralized

Table 7. Simulation Software used in Multiple Publications

Tool/Platform	References	Note	Tool/Platform	References	Note
SimPy	[102]	Last updated 2020	ONE	[40, 120]	Last updated 2015
PlanetSim	[129]	Released 2004	PeerSim	[83, 127, 148]	Last updated 2015
GNUSim	[57]	Released 2005	OMNeT++	[4, 6, 87, 95, 96]	Actively developed 2022
NetLogo	[27]	Last updated 2020	QTM	[69]	Last updated 2009
p2pstrmsim	[65]	Released 2008	Bharambe	[43]	Released 2006
Query-Cycle	[54]	Released 2003	ProtoPeer	[140]	Last updated 2016
PlanetLab	[36, 106]	Shutdown 2020	NS2	[56]	Actively developed 2022

78 of 105 publications used custom simulation software. PlanetLab was not strictly a simulation software but an experimentation platform.

in that case. Highly efficient nodes could sell their contingents to other nodes and, thus, eliminate the need for other network members to maintain and operate their nodes. These considerations let us choose a reputation-based incentive. Considering the remaining properties of reputation-based incentives lets us choose the mechanism of Chang et al. [19] as the best fit for our use case. Supplement A.2 provides details on our decision process.

6 SIMULATION SOFTWARE

The publications we reviewed evaluated the proposed mechanisms through experiments, simulations, or analytical calculations. To facilitate future simulation studies, we analyzed publications that employed simulations for the software they used. For this purpose, we checked every publication for the keyword `simul*` and extracted the information pertaining to simulation software.

Of the 105 primary research publications we identified as relevant (cf. Section 4), 22 used off-the-shelf software (see Table 7), three did not include an empirical evaluation [20, 30, 94], two conducted applied experiments [58, 112], and 78 simulated their incentive mechanism using custom simulation software. Of the 22 publications that employed off-the-shelf software, two used PlanetLab[21]—a platform that allowed conducting experiments under laboratory conditions on a global research network until its shutdown in 2020.[22] That 3/4 of the reviewed publication developed custom simulation software significantly complicates comparing and reproducing the results of different publications. Moreover, many of the employed off-the-shelf tools are no longer actively maintained. Table 7 shows the dates on which the software was released or last updated, if available.

The tools we found still in active development are NS2, OMNeT++, SimPy, and NetLogo. OMNeT++ and SimPy are discrete event simulators. OMNeT++ and NS2 allow users to specifically build network simulators. NetLogo lets users implement agent-based models to simulate complex systems and their dynamics over time. The sundown of PlanetLab left a gap for large-scale test networks that the peer-to-peer research community should address. Alternatively, future research using network simulators should use NS2, OMNet++, or SimPy to profit from the tools' continuous development.

7 RESEARCH TRENDS AND RECOMMENDATIONS

At the beginning of our systematic review, we expected that we could use established properties to compare incentive mechanisms. However, we had to realize that publications differ drastically in the definition and selection of properties they use to describe, evaluate, and compare incentives. Without generalizing a wide range of related properties, we would not have been able to

[21] https://planetlab.cs.princeton.edu/.
[22] https://www.systemsapproach.org/blog-archive/its-been-a-fun-ride.

present meaningful comparisons. Therefore, we derived a descriptive framework consisting of *Reward Type*, *Attack Resistance*, *Data Management* approach, *Contribution Model*, and subordinate properties. We suggest that future publications consider the framework for describing and evaluating their research contributions to increase the comparability of incentive mechanisms.

The evaluations presented in the reviewed primary research publications employed various methodologies and tools, including game-theoretical and mathematical analysis, agent-based simulators (NetLogo), network simulators (NS2, OMNeT++, SimPy, ONE, PeerSim, QTM, Bharambe, ProtoPeer, PlanetSim, GNUSim, p2pstrmsim, Query-Cycle), and experiments on large scale test-networks (PlanetLab, ProtoPeer). Our analysis of simulation software (Section 6) shows that the use of custom or no longer maintained software severely limits the reproducibility and comparability of the results reported in primary research publications. We recommend that future research includes detailed methodological descriptions and uses actively maintained simulation software, such as NS2, OMNet++, and SimPy, to improve the comparability and reproducibility of results.

In our review of the secondary literature, we found that prior literature reviews did not cover DLT and mostly focused on ad-hoc networks instead of fixed-topology peer-to-peer networks. On the other hand, reviewing the primary literature showed that DLT is a trending and important topic in peer-to-peer research and was applied widely to build incentive mechanisms. Especially monetary and reputation-based incentives can benefit from the distributed single source of truth.

Research gaps are most apparent for auction mechanisms. Combinatorial auctions have not yet been used for peer-to-peer computing networks, which surprised us, as rewarding the combined contribution of CPU cycles, memory, storage, and bandwidth appears appropriate. Moreover, incentive mechanisms for media streaming peer-to-peer networks have not yet used Dutch auctions, which seem ideal for such time-critical data streams. Anglo-Dutch auctions, which effectively reduce overpaying, could be considered for applications prone to overpaying, like Bitcoin's transaction reward scheme. Further, we expect VCG to be suitable for incentive mechanisms that reward participants with majority-dependent tokens, such as Proof-Of-Stake tokens or company shares.

We see *Service Discovery* as an underexplored application domain of service-based incentives, which future research should consider addressing. Publications we retrieved that employed federated learning predominantly utilized centralized entities to control contributing peers. Consequently, we excluded many of those publications from our review for not matching the requirement of presenting decentralized P2P incentives. In some cases, machine learning algorithms and game-theoretical simulations were used to improve incentive mechanisms for subsequent application in decentralized P2P networks. Substituting centralized control for machine learning use cases is another field worth exploring in future research.

8 CONCLUSION AND OUTLOOK

This systematic literature review analyzed primary and secondary literature on peer-to-peer incentive mechanisms between 1993 and 2022. After describing the criteria for including and excluding publications we reviewed the secondary literature. By analyzing relevant prior reviews, we synthesized a descriptive framework to analyze and compare incentive mechanisms. The framework considers the *Reward Type*, *Attack Resistance*, *Data Management* approach, *Contribution Model*, and subordinate properties. We applied the framework to analyze and present the 105 primary research publications in this review. Additionally, we gave an overview of the distribution of network types, evaluation and simulation tools, discussed the features of DLT, and applied our findings to select an incentive mechanism for a peer-to-peer academic network.

The findings and contributions of this review are as follows:

(1) Web of Science supported Boolean queries during our search, while DBLP did not. Google Scholar did not apply Boolean constraints strictly in the case of highly cited publications.
(2) Incentive mechanisms lack comparability. The framework we devised seeks to improve the comparability of future descriptions and evaluations of incentive mechanisms.
(3) The research on peer-to-peer incentive mechanisms exhibits the following gaps.
   (a) Prior literature reviews did not cover DLT and insufficiently addressed fixed-topology peer-to-peer networks.
   (b) Auction mechanisms have not yet explored combinatorial auctions for peer-to-peer computing networks, Dutch auctions for time-critical application areas like media streaming peer-to-peer networks, Anglo-Dutch auctions for overpay-afflicted networks using cryptocurrency, and VCG for schemes that reward participants with majority-dependent Proof-of-Stake tokens.
   (c) Service Discovery is an underexplored application domain of service-based incentives.
(4) The widespread use of custom or discontinued off-the-shelf simulation software severely limits the reproducibility of research results.
(5) A general trend towards decentralized services and incentive mechanisms is observable. We exemplified the selection of a peer-to-peer incentive for an academic network.

Future reviews should include gray literature on DLT not covered by Web Of Science. A promising source of gray literature on peer-to-peer DLT incentives is the overview of the top-100 cryptocurrency projects by market cap.[23] Reviewing this gray literature will require conceptual analysis and evaluation of incentives, and in many cases, code analysis as the literature does not always reflect the current state of the projects. The research on peer-to-peer incentives is evolving rapidly. We created a property framework to motivate and facilitate periodic future reviews of the literature to increase the comparability of research projects and support researchers in staying up-to-date with the fast-paced research progress in the field.

GLOSSARY

AB	Abstract. 5, 27
AK	Author Keywords. 5, 27
AWS	Amazon Web Services. 27
CBIM	Cluster-Based Incentive Mechanism. 27, 48
CDN	Content Delivery Network. 16, 27, 39
CMDP	Constrained Markov Decision Process. 27, 31
DBLP	Digital Bibliography & Library Project. 4, 27
DHT	Distributed Hash Table. 27, 30, 32, 41, 45
DLT	Distributed Ledger Technology. 3, 8, 10, 11, 18, 25–27
DPoS	Delegated Proof-of-Stake. 10, 27, 33
DTN	Delay-Tolerant Network. 3, 6, 7, 20, 27, 28, 30, 31, 50
EIB	Economic Incentive-based Brokerage. 27
ENISA	European Network and Information Security Agency. 27

[23] https://coinmarketcap.com/.

FL	Federated Learning. 6, 27
GCP	Google Cloud Platform. 27
GDPR	General Data Protection Regulation. 14, 22, 27
GMTP	Global Media Transmission Protocol. 27, 39
Iot	Internet of Things. 27, 34
IPFS	Interplanetary File System. 27
KP	KeyWords Plus. 5, 27
KYC	Know Your Customer. 15, 27
MANET	Mobile Ad-Hoc Network. 3, 6–8, 20, 27, 28, 36, 42, 50
MCC	Multi-Cell Cooperation. 3, 20, 27
MCC	Micro Computing Clusters. 27, 45
MEC	Mobile Edge Computing. 3, 20, 27
MSN	Mobile Social Network. 3, 20, 27, 36
MTTF	Mean Time To Failure. 20, 27
OppNet	Opportunistic Network. 3, 6, 7, 27
P2P	peer-to-peer. 2, 3, 5, 6, 10, 15–17, 25, 27, 36, 39
PBFT	Practical Byzantine Fault Tolerance. 10, 27
PCMP	Peer-to-peer Connection Management Protocol. 27, 29
PoB	Proof of Burn. 10, 27
PoET	Proof of Elapsed Time. 10, 27
PoS	Proof-of-Stake. 10, 27
PoW	Proof-of-Work. 10, 27
SP	Super Peer. 12, 27
TI	Title. 5, 27
ToB	Tickets of Bits. 16, 27
TS	Topic Search. 5, 27
TTL	Time-To-Live. 27, 36, 47, 50, 52
VANET	Vehicular Ad-Hoc Network. 7, 8, 27
VCG	Vickrey–Clarke–Groves auction. 11, 17, 25–27
WC	Web of Science Category. 5, 27
WoS	Web of Science. 4, 5, 8, 27
WSN	Wireless Sensor Network. 6, 27

APPENDIX

A SUPPLEMENTAL MATERIALS

A.1 Potential Biases of the Review

The quality of any literature review heavily depends on the methodical biases [2]. We aim to identify and mitigate biases wherever possible to improve our review quality. We state our identified biases transparently to make readers aware of any shortcomings.

Publication Bias is mitigated by comparing and selecting a search system with the most suited corpus for our research question, as described in Section 2.1. However, Web of Science's curation process is nontransparent, leaving the possibility that relevant papers are not included in our review. We accept the remaining blindspot as the answers to our research questions do not depend on individual articles.

We mitigate **Citation Bias** in our review by analyzing all retried articles which match our search term based on topic, content, and field of research. Search engine choice plays an essential role in preventing citation bias. Google Scholar, for example, introduces citation bias as it delivers often cited articles, even if they do not fit the search term perfectly [28].

Language Bias is a common bias in literature reviews. We only included non-English articles if an English abstract was provided, as our search term matches English results only. Grammar, punctuation, and spelling problems may arise as different conventions prevail in different English-speaking regions. Depending on the region, the word "decentralized" could also be spelled with an "s". However, by comparing the result sets of our primary literature search term using the alternative spelling, we confirmed that the spelling did not have any effect. Grammar and punctuation are irrelevant to our search terms.

Outcome Reporting Bias sets the scope toward a specific outcome. For our use-case, e.g., we aim for automatable results and apply an incentive mechanism to control user behavior. We willingly accept to miss implementations that rely on intrinsic motivation or other control methods. Further, we dismiss incentive mechanisms that do not specifically state a dependency on resources, bandwidth, or hardware to focus on digital and computational tasks.

A.2 Case Example: Incentive Selection

When picking the right incentive for the desired incentive type, we have to consider the incentive mechanism properties. An academic peer-to-peer network would leverage the existing network topology of universities and hence, does not need to address mobile peers and the associated change in bandwidth or connectivity like DTN or MANET. Further, we assume a single peer to be provided by each academic institution to keep individual costs low. Thus, due to immobile nodes, the network topology for academic peer-to-peer incentives can be considered fairly stable. Regarding the openness of the academic incentive mechanism, it is undesirable to implement a private consortium or permissioned network to match our scalability goals. The public design induces the complexity of mitigating identity-based attacks like Sybil attacks and white-washing attacks by tracking user identities and using message authentication. No anonymity/pseudonym requirements must be in place for academic peer-to-peer incentives, as no personal information needs to be processed. The incentivized service, on the other hand, has to protect personal-processed data and should provide anonymity/pseudonymity for users and data. False information attacks play an important role in our use case, as an illegitimate reputation could be built. We must pick a reputation-based incentive that is resistant or mitigates the risk of false information attacks. From a user's point of view, a multitasking-capable incentive would always be desirable, as the same incentive mechanism could handle multiple different participatory actions. However, this is a weak requirement, as a set of incentives could substitute this. We reduce the number of options for reputation mechanisms by focusing on general peer-to-peer network incentives with application area of computing or applicable to any application area. This leaves us with the 13 reputation mechanisms [19, 31, 39, 50, 54, 57, 69, 94, 102, 115, 121, 140–142]. Out of these mechanisms, we discard the ones which are not open for everyone to participate in and the ones with little information on attack resistance. We gain candidates that have mitigated or are resistant against at least three attack types [19, 57, 115, 142]. Additionally, we discarded Zhang et al., as it uses a combination of reputation and virtual currency, leaving us with Tian et al., Chang et al., and Karakaya et al.

Tian et al. [115] propose SuperTrust, a trust-based incentive mechanism for hybrid peer-to-peer networks. The approach uses a referral-based reputation system for peer selection. Super-peers accumulate all reputation scores and provide a rating for regular peers to supplement their own data. Regular peers are grouped by interest and assigned a single super-peer.

Chang et al. [19] propose a recommendation-based inventive mechanism for peer-to-peer systems. Recommendation information on the level of participation is exchanged and supplemented with the transaction history of the requesting participant to form a reputation value. A peer considers both its own past interaction and the recommendations of other peers for its peer selection. A credibility score helps to set each recommendation's quality and helps filter for false recommendations.

Karakaya et al. [57] propose an incentive to alleviate query traffic free-riding behavior in peer-to-peer networks. Free-riding is often tolerated up to a certain threshold, so participants can use resources initially before they start contributing. The incentive mechanism tries to maximize the connectivity of network contributors and simultaneously isolates free-riding peers that exceed the defined threshold. The approach splits the connections of a particular peer to another one in an IN and OUT part. The IN part represents query requests sent to the particular peer, and the OUT part represents queries that this peer issues against others. The reputation value of the connected peers is calculated according to the observed contribution. If this observed contribution does not hold a certain threshold, peers connect to a different, actively contributing peer.

The super-peer-based design of Tian et al. [115] is not suitable for our use case, as we aim for equality between all peers to maximize decentralization. The method of Karakaya et al. [57] was published in 2007 and introduced the Peer-to-peer Connection Management Protocol (PCMP) to prevent free-riding and promote contributions to the network. The method elegantly calculates a subjective reputation for each peer without generating overhead of reputation exchange. On the other hand, Chang et al. [19] introduce an overhead by sharing reputation measurements with other peers. This significantly reduces free-riding, as peers would reject even initial connection attempts with non-cooperating peers. Further, Chang et al. introduced an algorithm that reduces the message overhead for gossiping over time. We hence decide on Chang et al. for our academic peer-to-peer network.

A.3 Supplemental Categorization of Primary Research Publications

Table A.1. Overview of the Attack Vectors, Task Management, and Contribution Model Properties of Incentive Mechanisms Presented in Primary Research Publications

Ref.	Year	Authors	FI	SC	RA	IA	SA	CA	AC	AN	LNK	CONF	TA	MT	OPN	Notes
[48]	2022	Jaiman et al.	-	V	V	R	M	M	-	PS	Y	-	PR	N	Y	Smart contracts to conduct double auctions for file sharing
[74]	2022	Lin et al.	M	R	-	M	R	M	Y	PS	Y	-	PR	Y	N	Smart contracts to conduct double auctions for edge learning and wireless charging
[113]	2020	Sun et al.	-	V	V	R	M	M	-	PS	Y	-	RE	Y	-	Smart contracts to conduct double auctions
[29]	2020	Fang et al.	R	R	-	R	R	-	-	k	Y	-	RE	Y	Y	Task-based English auction depending on resource budget and task complexity
[20]	2020	Chen et al.	R	R	-	R	M	V	Y	N	Y	-	RE	-	N	Calculating a credibility score which all participants want to maximize
[76]	2020	Luo et al.	-	-	-	M	-	-	-	-	Y	-	RE	Y	Y	Organizes peers in micro computing clusters
[55]	2019	Kang et al.	V	R	-	-	-	-	Y	-	Y	N	RE	N	N	Reputation is calculated using each node's subjective interaction history
[40]	2020	Haq and Faheem	-	-	-	-	M	-	-	N	-	-	RE/PR	N	-	Double Auction using a digital currency for relaying file chunks
[127]	2019	Wong et al.	-	-	-	R	R	-	Y	N	Y	-	-	-	-	Uses BitTorrent tracker nodes to orchestrate bandwidth assignments and restrains free-riders and generally malicious nodes
[90]	2019	Mousavi and Klein	-	-	-	R	R	-	-	N	Y	-	RE/PR	N	Y	Payments based on received video quality with taxation scheme
[8]	2018	Aslani et al.	-	-	-	R	R	-	-	PS	Y	-	RE/PR	N	Y	TOBIM - a dynamic payment of chunks modelled as a constrained Markov decision process
[73]	2019	Lin et al.	V	V	-	-	V	-	Y	PS	Y	N	RE	Y	N	Knowledge trading market using a consortium blockchain coin
[41]	2018	He et al.	M	R	R	-	R	M	-	-	Y	Y	RE	-	-	Pricing strategy using cryptocurrency
[56]	2017	Kang and Yang	V	-	V	-	V	V	-	-	-	-	RE	N	-	Credit-based upload incentives
[27]	2017	Esfandiari et al.	-	-	-	-	R	R	-	-	Y	-	PR	Y	-	Collaborative filtering to select participants with similar interest on files
[133]	2015	Xin Kang and Yongdong Wu	V	-	-	-	V	V	N	-	Y	-	RE	N	Y	Uploaders set a fixed bandwidth price; Downloaders combine sources to achieve optimal bandwidths
[115]	2014	Tian et al.	M	-	-	-	M	M	-	-	-	-	RE	N	Y	Regular peers are grouped by interest, and assigned a super-peer
[53]	2014	Jin Teng et al.	M	R	-	M	-	-	Y	-	-	Y	RE	N	Y	AREX, a peer-to-peer black listing mechanism to penalize misbehavior
[19]	2014	Chang et al.	M	-	-	-	M	M	N	-	Y	N	RE	N	Y	A peer considers both, its own past interaction, and the recommendations of other peers for its peer selection
[120]	2014	Wang et al.	-	-	M	-	-	-	-	-	-	-	RE	N	Y	MuRIS considers historical encounters to estimate the paths to participants
[84]	2013	Meulpolder et al.	-	-	V	-	V	-	Y	-	-	N	PR	N	Y	Ratio-based upload selection mechanism prioritizes peers with the lowest sharing ratios among the known peers of each participant
[11]	2013	Belmonte et al.	R	-	-	V	R	M	N	-	Y	N	RE	N	Y	Forms coalitions by responsiveness/QoS
[140]	2013	Zhang and Antonopoulos	-	-	-	-	R	-	N	-	Y	-	PR	N	Y	Peers use their local transaction information to identify and block free-riders
[32]	2012	Gramaglia et al.	M	R	M	M	M	-	Y	N	Y	Y	RE	N	N	Delayed payments through digital cheques issued by banks
[129]	2012	Wu et al.	-	-	-	-	M	M	N	-	Y	-	PR	N	Y	Media block auctions where nodes might accumulate budget over time

(Continued)

Table A.1. Continued

Ref.	Year	Authors	FI	SC	RA	IA	SA	CA	AC	AN	LNK	CONF	TA	MT	OPN	Notes
[85]	2010	Mondal et al.	-	-	-	-	V	-	-	-	-	-	PR	N	Y	Bid-based data item allocation that pays replicating peers with virtual currency
[93]	1396	Nasab and Bidgoli	-	-	-	V	R	-	N	PS	Y	Y	RE/PR	N	Y	Utility function defines the reciprocal reputation mechanism
[134]	2016	Xu et al.	V	-	-	-	R	-	N	Y	N	Y	RE/PR	N	Y	A virtual currency that is used to pay for relaying service. A metric incorporates node buffer, node energy and the Time-To-Live (TTL) of the message to select peer
[95]	2016	Padhariya et al.	R	-	-	-	-	-	N	Y	N	Y	RE/PR	N	Y	Three virtual currency schemes under the umbrella of their “E-Top” system
[63]	2015	Kurve et al.	-	-	-	-	-	-	N	Y	N	Y	-	-	-	Chooses peers by physical proximity, semantic proximity, or at random
[43]	2014	Hu et al.	R	-	-	R	R	R	N	N	Y	N	RE/PR	Y	Y	Cooperation groups by common interests
[23]	2014	De Sales et al.	R	-	-	R	R	-	Y	N	Y	N	PR	N	Y	Peers gain “Ticket of Bits” for providing upload bandwidth
[25]	2014	del Val et al.	V	-	M	R	R	V	N	Y	N	N	RE/PR	Y	Y	Cost, benefit and reward scheme using virtual currency
[125]	2014	Weijie Wu et al.	-	-	-	-	R	-	Y	-	-	-	RE/PR	N	Y	A pricing scheme for video content provider
[96]	2013	Padhariya et al.	-	-	-	-	R	-	N	Y	N	-	RE/PR	Y	Y	Economic incentive-based brokerage where brokers maintain an index of data items stored at other peers
[142]	2012	Zhang et al.	R	-	-	R	R	R	N	PS	Y	N	RE/PR	Y	Y	An authority penalizes peers and falsely-penalized provider will not serve wrong accusers anymore
[102]	2012	Rius et al.	-	-	-	-	R	R	N	PS	Y	N	RE/PR	Y	Y	Uses super-peers that have an associated reputation value
[100]	2010	Park et al.	-	-	V	-	V	V	N	-	Y	-	PR	N	Y	Each peer optimizes its communication partners by checking the TTL of each video stream package and adds connections to random peers to create redundancy
[5]	2010	Allen et al.	-	-	-	M	M	-	N	-	Y	N	PR	N	Y	Uses a trust level based on previous tit-for-tat cooperation that groups nodes into social networks of similarly cooperative parties
[112]	2009	Sirivianos et al.	-	V	-	-	M	-	N	PS	Y	N	PR	N	Y	Dandelion, a hybrid approach of reciprocate cooperation and a centralized credit-based reward mechanism
[66]	2009	Li et al.	-	-	V	-	M	M	N	-	Y	N	PR	N	Y	Micro-payment incentive using a bank to manage the virtual currency
[86]	2009	Mondal et al.	-	-	-	-	R	-	N	-	Y	N	RE	N	Y	ConQuer, an auction mechanism with brokers selling routing information to mobile peers
[72]	2009	Lin et al.	R	R	R	M	R	-	N	-	Y	N	RE	N	Y	A game-theoretic framework with equalized reciprocity
[70]	2008	Lijuan Xiao et al.	-	-	-	-	M	-	N	-	Y	N	RE	Y	Y	A marketplace-based incentive that tracks the success rate of jobs in a computing grid
[33]	2008	Guang Tan and Jarvis	-	-	V	-	R	V	N	PS	Y	N	RE	N	Y	A first-price-auction-like procedure for data transmissions using virtual credits
[101]	2007	Pianese et al.	-	V	-	-	-	-	N	PS	Y	N	PR	N	Y	Prioritizes resource usage in the mesh network over fully reciprocal fairness
[62]	2007	Koo and Lee	V	V	R	-	M	-	N	PS	Y	N	PR	N	Y	Peers track the average received data from other peers and distribute their own capacity accordingly
[77]	2006	Ma et al.	-	-	-	-	R	M	-	-	-	-	PR	N	Y	Nodes self organize in groups of different contribution levels

(Continued)

Table A.1. Continued

Ref.	Year	Authors	FI	SC	RA	IA	SA	CA	AC	AN	LNK	CONF	TA	MT	OPN	Notes
[136]	2006	Yang	-	-	-	-	M	-	-	-	-	-	PR	N	Y	Uses a trust value composed of the contributed upstream traffic and online duration
[92]	2005	Nandi et al.	-	V	R	-	M	R	N	PS	Y	N	PR	N	Y	Blacklists peers if service is refused selfishly
[31]	2018	Goswami et al.	-	-	-	M	R	-	N	-	Y	-	PR	N	EF	Tracks resource allocation
[118]	2014	Wang et al.	-	-	M	-	R	M	N	-	Y	-	RE	N	-	Varies service quality depending on the contributions each peer is making
[83]	2013	Meng and Li	R	-	V	-	R	-	-	PS	Y	-	RE	N	Y	Every node provides its thresholds consistent to it capabilities to neighboring peers
[17]	2013	Centeno et al.	-	-	-	-	R	-	-	-	Y	-	PR	Y	-	Super peers rank available actions and set positive and negative incentives accordingly
[87]	2012	Montazeri et al.	-	-	-	-	R	M	N	PS	Y	-	PR	N	Y	Peers track each others' contribution amounts and share the measured amounts with neighbors
[65]	2012	Li et al.	M	-	-	-	R	-	N	PS	Y	N	PR	N	Y	Peers organize in different Quality of Experience layers depending on their latency demands
[145]	2012	Zhao et al.	V	-	-	-	R	-	N	PS	Y	-	RE	-	-	Reported reputation information gets rewarded with a payment scheme
[117]	2012	Vakili and Khorsandi	-	-	-	-	R	R	N	-	Y	N	-	-	-	Coordinates the upload-to-download ratio
[79]	2008	Manzato and da Fonseca	-	-	-	-	R	-	N	PS	Y	N	RE/PR	Y	Y	Nodes trade outgoing bandwidth for incoming bandwidth in a ratio that is determined via a cooperation-duration benefiting tax
[57]	2008	Karakaya et al.	R	-	R	V	R	-	N	PS	Y	N	RE/PR	Y	Y	If an observed contribution value does not hold a certain threshold the peers connect to a different peer
[36]	2006	Habib and Chuang	-	-	-	-	R	-	N	PS	Y	N	RE/PR	Y	Y	Limits the peer selection choices for free-riders according to their repudiation score
[135]	2006	Xue et al.	-	-	-	-	R	R	N	-	-	-	RE	N	Y	Resource allocation scheme that considers individual relaying costs and shared wireless channel bandwidth
[94]	2005	Neovius	-	-	-	R	R	-	N	PS	Y	-	-	-	-	Trust in a peer progressively increasing access to distributed resources
[138]	2004	Yu and Singh	-	-	-	-	R	-	N	PS	Y	-	RE/PR	Y	Y	Considers the quality of services provided by neighbors and adjust payments accordingly
[34]	2004	Gupta and Somani	-	-	R	-	R	-	N	-	-	-	RE/PR	Y	Y	Secure Vickrey Auction to determine resource prices in a ChordDHT
[119]	2003	Wang and Li	-	-	-	-	M	-	N	PS	Y	N	RE/PR	Y	Y	Dynamic payoff function that models cooperation as a *Cournot Oligopoly* game
[54]	2003	Kamvar et al.	-	-	-	M	R	-	N	PS	Y	N	RE/PR	Y	Y	A reputation score defines the bandwidth percentage a peer receives
[21]	2006	Cheng et al.	-	-	-	-	R	-	N	-	-	-	RE/PR	Y	Y	Auction cooperation incentive that differentiates peers by bandwidth and tries to benefit slow peers
[75]	2010	Liu et al.	-	-	-	-	R	-	N	PS	Y	N	RE/PR	Y	Y	Uses generosity that excuses misbehavior to a certain degree and maximizes interaction time of two parties due to initial payoff limitations
[132]	2012	Xiao et al.	-	-	-	-	R	-	N	PS	Y	N	RE/PR	Y	Y	Uses fixed time rounds where each subsequent round incorporates peer contribution information of the previous round to determine for how much resources that peer is eligible

(Continued)

Table A.1. Continued

Ref.	Year	Authors	FI	SC	RA	IA	SA	CA	AC	AN	LNK	CONF	TA	MT	OPN	Notes
[58]	2006	Kazatzopoulos et al.	M	R	-	M	R	M	N	PS	Y	N	RE/PR	N	Y	Reputation metric that tracks the degree of collaboration by issuing credits for answered requests and denials for unanswered secret sharing requests
[61]	2016	Kim	-	-	-	-	-	-	-	Y	-	-	-	-	-	Reciprocal grouping of users to balance efficiency and fairness
[47]	2016	Ismail et al.	-	-	-	-	-	-	-	N	Y	-	-	-	-	Joint radio resource allocation strategy for physically close-by peers
[147]	2014	Zou and Chen	-	-	-	-	-	-	N	-	Y	-	RE	N	Y	Credit-based content-aware auction algorithm tracking the marginal net utility
[16]	2013	Carra et al.	-	-	-	-	-	-	N	PS	Y	-	RE/PR	N	Y	Tit-for-tat incentive that asses credits to track participation in eMule
[42]	2013	Hu et al.	-	-	-	-	-	-	N	-	Y	N	PR	Y	Y	The tit-for-tat strategy dynamically compensates resource-poor peers by taxing the contingents of resource-rich peers
[24]	2013	del Val et al.	-	-	-	-	-	-	N	Y	N	N	RE/PR	N	Y	Social plasticity allows nodes to change their neighbors if they detect non-cooperative peers
[39]	2005	Hales and Edmonds	-	-	-	-	-	-	N	-	Y	N	PR	Y	Y	Participants organize themselves in different groups depending on their participation level
[71]	2004	Lin and Lo	-	-	-	-	-	-	Y	N	Y	-	RE	N	-	Dynamic prices that are set by super peers (base station providers)
[131]	2014	Wu et al.	-	-	-	-	-	-	N	PS	Y	-	RE	Y	Y	Nodes bid on or offer bandwidth in an auction using a centrally managed token
[109]	2020	Shen et al.	-	-	-	-	-	-	-	-	-	-	RE	N	-	Forms replica groups for different levels of storage reliability
[69]	2019	Li et al.	-	-	-	-	-	-	-	-	-	-	RE	Y	-	Uses Reciprocity-based perfect information (PRIM) and imperfect information (IRIM)
[52]	2015	Jin and Kwok	-	-	-	-	-	-	-	-	-	-	RE	N	Y	Reputation penalties designed for peers with different bandwidth capacities
[148]	2014	Zuo and Zhang	-	-	-	-	-	-	-	-	-	-	RE	N	Y	Per-replica payouts for nodes that state their utility honestly
[98]	2006	Papaioannou and Stamoulis	-	-	-	-	-	-	-	-	-	-	PR	Y	Y	Deploys policies for provider selection (*highest reputation*, *comparable reputation*, and *black list*)
[121]	2018	Wang	-	-	-	-	-	-	-	-	-	-	RE	-	-	Each peer can act as either a cooperator, reciprocator, or defector
[141]	2018	Zhang et al.	-	-	-	-	-	-	-	-	-	-	RE	-	-	Incentive policy where peers refuse to provide service for defectors
[68]	2018	Li et al.	-	-	-	-	-	-	-	-	-	-	RE/PR	-	-	Decentralized market setting for distributed energy sources
[38]	2016	Hadzibeganovic and Xia	-	-	-	-	-	-	-	-	Y	-	-	-	-	Evolutionary games using tag-based multi-agent system with contingent mobility
[106]	2016	Sayit et al.	-	-	-	-	-	-	-	-	-	-	RE	-	-	Multicast tree framework for video streaming incentivized by hierarchical clusters
[30]	2016	Gonçalves et al.	R	-	-	-	-	-	-	-	-	-	-	-	-	Non-linear regression model to predict cooperation in video streaming by graph-based OUT-degree metric with measures against false information attacks
[49]	2016	Jain et al.	-	-	-	-	-	-	-	-	-	-	-	-	-	Proposal of a communication protocol for multi-cell cooperation to coordinate spectral efficiency – not an incentive mechanism

(Continued)

Table A.1. Continued

Ref.	Year	Authors	FI	SC	RA	IA	SA	CA	AC	AN	LNK	CONF	TA	MT	OPN	Notes
[81]	2016	Martínez-Cánovas et al.	-	-	-	-	-	-	-	-	-	-	-	-	-	Proposal of a repeated game model to analyze cooperation emergence among rational agents for distributed service discovery – neither reputation nor monetary payoff; expected to be service
[130]	2012	Wu et al.	-	-	-	-	-	-	-	-	-	-	RE	-	-	Scheme selection game to improve cooperation in energy-constrained ad hoc Networks
[50]	2004	Jiang et al.	-	-	-	-	R	V	-	-	Y	N	-	N	Y	Reputation mechanism that supplements own interaction histories with recommendations of other peers
[60]	2010	Kim	-	-	-	-	-	-	-	-	Y	-	RE	-	-	Data replication strategy based on the self-reported relative meant time to failure metric – not an incentive mechanism
[14]	2020	Bhattacharya and Guo	-	-	V	R	M	R	N	-	Y	-	PR	N	Y	Incentive mechanism for contend delivery networks where seeding peers offer competitive pricing to requesting peers
[123]	2020	Wei et al.	M	M	-	M	R	-	-	N	Y	-	RE	Y	N	Hybrid incentive that leverages peer reputation and data quality to pay monetary rewards
[143]	2021	Zhang et al.	M	R	-	-	M	-	N	PS	Y	Y	RE	N	Y	Deterministic pricing incentive to reward participants in a federated learning system
[4]	2021	Al Ridhawi et al.	-	R	-	-	-	-	Y	-	Y	Y	RE	Y	Y	A multiple blockchain-based monetary reward mechanism for peer-to-peer computing enabled by smart contracts
[6]	2021	Ansari et al.	-	V	V	M	M	V	N	PS	Y	N	RE	N	Y	A score-based incentive mechanism (SIM) where scores are defined by upload capacity, video quality, control packets, and a peer's availability
[111]	2021	Singha and Singh	-	M	V	-	R	V	N	-	Y	Y	PR	N	Y	An incentive for wireless P2P networks where peers share their wired access to a backbone over a wireless connection if peers match their individual download requirements
[97]	2022	Pal et al.	M	V	-	-	M	-	N	-	Y	N	PR	N	Y	A utility function based on a users participation factor to control access time to a distributed cloud
[3]	2021	Adamu	R	V	-	R	R	R	N	PS	Y	N	PR	N	Y	A share-ratio based approach where deny-listing is conducted by tracker peers

FI: False Information attack; SC: Sniffing&Confidentiality attack; RA: Routing Attack; IA: Identity Attack; SA: Selfish Attack; CA: Collusion Attack | AC: Access Control; AN: Anonymity; LNK: Linkability; CONF: Confidentiality | TA: Task Assignment; MT: Multitasking; OPN: Openess | [V: Valuable; R: Resistent; M: Mitigated; Y: Yes; N: No; RE: Reactive; PR: Proactive; EF: Entrance Fee; k: k-anonymity; PS: Pseudonym].
Fields are left blank if the publications provide insufficent details on the property.

A.4 Supplemental Summaries of Primary Research Publications

This section provides a short summary of each primary research publication we analyzed. Descriptions of hybrid incentive models that fall into more than one category appear in each category.

A.4.1 Monetary:Auction.

File Sharing.

"An Incentive Compatible Mechanism for Replica Placement in Peer-Assisted Content Distribution". Bhattacharya and Guo [14] propose an incentive mechanism for content delivery networks. The network is an overlay to the BitTorrent file-sharing network. The approach uses a payout mechanism that allows the building of a budget. Seeding peers send reports of their costs to requesting peers. The requesting peers then select a subset of seeders, buy the resources from them, and pay the requested reward. Their experiments in R showed that the proposed decentralized incentive scheme improved the peer contributions even though peers are self-interested, and thus reduced the total cost of the content delivery in the content delivery network.

"A Group Strategy-Proof Incentive Approach for Eliminating Selfish Behaviors in Peer-to-Peer File Allocation". Zuo and Zhang [148] propose an auction scheme to prevent selfish behavior in peer-to-peer file sharing. Per-replica payouts are given to participants who state their node utility honestly. The authors provide formal proof using game theory that shows the correctness and effectiveness of the approach. Further, the approach achieves less delay and better quality of service in a peersim (Java) simulation. Due to the game-theoretic scope of the paper, the currency and payment channels are not explained.

"To Play or to Control". Wang and Li [119] propose an incentive mechanism model that ensures desirable system performance among peers in a peer-to-peer global storage system who want to maximize their net gains and are generally expected to act selfishly. The authors model the peer-to-peer system as a *Cournot Oligopoly* game and derive a control-theoretic solution for it. They derive a dynamic payoff function for each peer that also incorporates system performance goals. Wang and Li simulate their approach with 50 peers that have heterogeneous but constant storage contributions and bandwidth consumption. Their evaluation covers system capacity, bandwidth stress, and storage utilization.

"Incentive Mechanism for P2P File Sharing Based on Social Network and Game Theory". Wu et al. [131] propose NIM, a novel auction-based incentive mechanism for peer-to-peer file sharing and media streaming. The approach aims to eliminate free-riding and offers an alternative to the inefficient choking algorithms of Gnutella and BitTorrent. Each node can earn end spend counters, which are stored and managed by a central server. Nodes bid on bandwidth or offer files and streaming data in an auction. A game simulation is used to find the participant's Nash equilibrium and to evaluate the performance and free-riding resistance. The incentive presented in this paper uses a central server, a Distributed Hash Table (DHT), and supernodes. However, we assume that a distributed ledger could substitute the incentive's single point of failure to achieve decentralization.

"A Utility-Based Auction Cooperation Incentive Mechanism in Peer-to-Peer Networks". Cheng et al. [21] propose an auction cooperation incentive mechanism to mitigate free-riding behavior in peer-to-peer systems. The authors consider the "optimistic unchoking" algorithm in the BitTorrent network as unfair for weak peers in the system that do their best as free-riders get the opportunity to download without uploading. They introduce an auction mechanism that lets the source peer ask service providers in the network for their utility. The source peer then selects a

destination peer with the highest utility. The authors differentiate peers between fast (ADSL-like), slow (modem-like), and free-riders. They try to benefit slow peers and punish free riders with their incentive mechanism. The authors first motivate the necessity of their incentive mechanism by running experiments that prove the unbalanced "optimistic unchoking" algorithm. Then they show that their scheme improves the performance of slow peers while mitigating resource access for free-riders.

"A Peer-to-Peer Communication Based Content Distribution Protocol for Incentive-Aware Delay Tolerant Networks". Haq and Faheem in [40] propose an incentive mechanism for DTNs based on the exchange of a digital currency for data relay services. Their protocol is modeled after the Rubinstein Bargain model [104], which constitutes a sub-game perfect equilibrium. They mainly consider mobile devices, respective to their carriers, to represent network nodes that act rationally based on their battery level, worth of messages exchanged, and social ties to peers. Participants can be subscribed to messages of interest, and they are expected to be interested in disseminating these messages. This is different for messages they have not subscribed to, so the authors propose the exchange of a digital currency for relaying services. They particularly focus on the dissemination of large files because, in existing protocols, nodes request whole files at once, and if the link breaks, which is expected to happen frequently in DTNs, the partially received files are discarded. The proposed protocol is evaluated with simulations of up to 150 nodes. They propose a chunking mechanism to mitigate this problem. The authors solely focus on selfish nodes and don't consider other types of attacks that were discussed above. Further, it is unclear how the virtual currency infrastructure is architectured.

Video Streaming.

"Joint Bandwidth Allocation, Data Scheduling and Incentives for Scalable Video Streaming over Peer-to-Peer Networks". Zou and Chen [147] propose a bandwidth allocation and chunk scheduling strategy for scalable peer-to-peer video streaming to prevent free-riding and selfishness. The credit-based auction algorithm is mathematical proven and extensively simulated. Simulation results using 200 peers and 15 bidding rounds with a churn of 10 peers each round show that free-riders will run out of credits quickly and are denied service. The approach relies on a centralized directory server.

"Incentive Mechanism for P2P File Sharing Based on Social Network and Game Theory".

"A Payment-Based Incentive and Service Differentiation Scheme for Peer-to-Peer Streaming Broadcast". Tan and Jarvis [33] propose an incentive scheme to improve media quality in peer-to-peer live streaming. A virtual credit system (points) is used to bid in a first-price-auction-like procedure for data transmissions. Additionally, the number of earned points reflect a peer's cooperation level. Transmissions are established between nodes of similar cooperation levels. The approach assumes that a lightweight, secure payment mechanism among peers is in place. An event-driven simulator with 2,592 nodes demonstrates the effectiveness of the proposed mechanism.

"A Token-Based Incentive Mechanism for Video Streaming Applications in Peer-to-Peer Networks". In [8], the authors Aslani et al. propose a dynamic token-based payment scheme, named TOBIM, for improving video streaming quality of experience in a peer-to-peer network. Peers have demands for video chunks and pay these chunks through the means of digital currency. They are incentivized to earn such tokens by contributing bandwidth to the network. The tradeoff between earned tokens and bandwidth costs in their proposed system is modeled as a Constrained Markov Decision Process (CMDP) and evaluated through simulations. The approach is based on semi-trusted third parties and avoids distributed coordination algorithms.

"Auction-Based P2P VoD Streaming". Wu et al. [129] propose auction-based incentive for peer-to-peer video-on-demand streaming. The incentive aims to prevent selfish behavior and improve media block scheduling to maximize the overall social welfare of the system. Dynamic local auctions were used to reduce video playback deadlines and achieve a balanced block distribution. Large-scale empirical studies using PlanetSim with up to 3,000 simultaneous peers were conducted to validate the approach. A disadvantage is that peers can gain improved streaming quality by favoring peers with high bandwidth and storage. Further, peers with high bandwidth and storage can accumulate a large budget that is potentially never spent. An advantage of the concept is its effectiveness and ability to be fully decentralized by allowing each peer to create its own currency (Lightweight Currency Protocol [116]).

Any Task.

"An Incentive Driven Lookup Protocol for Chord-Based Peer-to-Peer (P2P) Networks". Gupta and Somani [34] present an incentive mechanism that limits the effect of selfish peers in the Chord DHT lookup protocol without requiring prior trust relationships. A peer who wants to request a resource issues lookup messages according to the Chord protocol. Multiple *Terminal* nodes that hold the association of resource to location IP will receive these messages and start a two-phase Secure Vickrey Auction mechanism to determine the price for the resource. The authors note that for rational nodes in selfish network topology, it is the best strategy to follow the Chord protocol. Unfortunately, the authors do not elaborate on the payment channel and payoff type.

Other Task.

"A Blockchain-Based Hybrid Incentive Model for Crowdsensing". Wei et al. [123] propose a blockchain-based monetary crowdsensing incentive to leverage peer reputation and data quality to maximize participation. Although this is a hybrid incentive, we categorize it by its primary motivator, the monetary reward. While the monetary incentive is the primary motivator, reputation is needed to reduce inaccurate data in the network. A bidding process is used to select workers for a sensing task. The lowest bidder receives the task if its reputation is sufficient. Peers are divided into requesters and workers. Requesters maintain the blockchain and request tasks, while workers are lightweight peers that only fulfill tasks. The performance analysis and simulation with 100 peers illustrates that the proposed hybrid incentive model is a reliable and efficient mean to promote data security and incentivize positive conduct on the crowdsensing application.

"Incentive Mechanism for Cooperative Authentication". Fang et al. [29] devise a cooperative authentication approach in mobile opportunistic networks for participatory sensing applications. The main goals of the mechanism are to prevent selfish behavior and incentivize nodes to authenticate messages for other nodes. Privacy leakage is another concern of the authors, whose strategy provides k-anonymity. To achieve these goals, the authors formulate an evolutionary stable strategy based on monetary rewards for authentication service providers and show its effectiveness via analytical and numerical evaluations.

"Joint Resource Allocation and Incentive Design for Blockchain-Based Mobile Edge Computing". Sun et al. [113] propose two double auction mechanisms to improve resource allocation in mobile edge computing without needing a trusted party. The solution relies on immutably stored auction data on a blockchain and smart contracts to conduct the auctions. Their qualitative evaluation shows significant performance benefits compared to single-task resource allocation methods under individual rationality, truthfulness, and budget balance constraints. Further, the mechanism offers payment and delivery guarantees through a custodial smart contract.

Routing and Relaying.

E-ARL.. Mondal et al. [85] propose E-ARL, an economic incentive scheme for mobile ad hoc networks. The approach reduces data availability problems caused by peers going offline or moving out of reach by introducing a bid-based data item allocation mechanism that compensates the replicating peers with virtual currency. The experiment uses 100 peers with 70% free-riders and 30% peers participating in the incentive scheme. The results show a better quality of service, better revenue and load balancing, better query response times, and query success rate. Although the pricing strategies are explained in detail, the payment channel is unknown.

"A Dynamic Incentive Pricing Scheme for Relaying Services in Multi-Hop Cellular Networks". Lin and Lo [71] propose a pricing scheme to motivate relaying in cellular networks. Mobile ad-hoc networks improve performance and maximize the revenue of the network provider by using mobile nodes to relay the communication to a base station. This communication can occur through multiple hops, and the pricing scheme must reward each hop. The proposed incentive uses dynamic pricing that varies with regard to the network's conditions. Prices are set by the network provider who maintains the base station. The scheme is a reverse auction, but the payment channels and implementation details remain undefined in the paper. An experiment validates the revenue increase for the network provider by simulating over 500 nodes.

"An Economic Incentive Model for Encouraging Peer Collaboration in Mobile-P2P Networks with Support for Constraint Queries". Mondal et al. [86] propose ConQuer, an incentive mechanism for mobile ad hoc peer-to-peer networks. The mechanism aims to provide fairness and motivate participation using an auction mechanism with brokers selling routing information to mobile peers. This broker-based query processing is optimized for cost and performance and evaluated using 100 peers that measure their response time, success rate, and data quality. The authors plan to use virtual currency that can be created by each broker [22, 26] but also reference an option secured by a trusted and tamper-resistant hardware module in each node [15, 146].

A.4.2 Monetary:Marketplace/Double Auction.

Peer-to-Peer Computing.

"Incentive-Based Scheduling for Market-Like Computational Grids". Xiao et al. [70] propose a marketplace-based incentive for grid computing to maximize successful job execution and minimize unfair profit allocation. Consumers announce jobs and collect bids from providers. Jobs need to be independent of each other and must be timebound. A competition degree metric is used to track the reliability of other nodes locally. The success rate is therefore calculated over the jobs that finished correctly in time. Experiments using 20 consumers and 80 providers show an improvement in successful-execution rate and fairness under synthetic and real workloads. The mechanism does not explain how the correctness of job results is proven, nor how workload is estimated and unsolvable jobs are prevented.

"Incentive Mechanism for Scheduling Jobs in a Peer-to-Peer Computing System". Rius et al. [102] propose an incentive mechanism to motivate the contribution of computational resources to jobs in different types of peer-to-peer networks. The authors envision a two-layered incentive approach. The first layer incentivizes participants via a credit-based scheme to discourage free-riding and cheating. The second layer circumvents the scalability limitations of the first via the concept of "super-peers" with an associated reputation value. Their simulation with 4,000 peers and 100,000 workers shows that the approach can eliminate the vast majority of free-riders in the system and is tolerant of changes in user behavior.

Other Task.

Blockchain-Based Incentive Energy-Knowledge Trading in IoT. Lin et al. [74] propose an edge learning and wireless charging market where edge devices cooperate in training a global model. While the training aspect uses a centralized node to hold the global model, the wireless charging market has no central dependencies. Edge devices and wireless power transfer nodes form a market of buyers and sellers of charging. The monetary vehicle is an energy/knowledge coin that peers pay to consume learning data or use charging. A permissioned DPoS blockchain is used to prevent double spending, facilitate transactions, and maintain the balances of each peer. Further, the authors designed a Stackelberg-game to validate the approach's market efficiency.

Making Knowledge Tradable in Edge-AI Enabled IoT. Lin et al. [73] propose a peer-to-peer knowledge trading market for Internet of Things (Iot) devices secured by a consortium blockchain. A knowledge coin is the core element of the incentive mechanism and marketplace. The marketplace holds knowledge such as learning results and models derived from Iot data. Proof of Trading is introduced as a green alternative to Proof of Work. Proof of Trading solves a hash puzzle and includes the number of owned coins as a stake to select the next block proposer. Numerical results using Python and MATLAB show a higher quality and more knowledge at the same costs compared to the non-incentivized methods. An adapting pricing strategy is used to achieve optimal security and efficiency.

"Integrating Distributed Grids With Green Cellular Backhaul". Li et al. [68] propose a method to request and allocate renewable energy from distributed energy sources in a decentralized market setting to provide green energy to cellular network providers. The method describes a pricing scheme that considers the competition and coalition between energy providers, leading to a hybrid Stackelberg game with coalition elements. The use case focuses on wireless backhaul connections, which connect cell towers to the network backbone of a service provider. Although the market is decentralized, energy consumers control where a market forms due to their oligopoly demand. The incentive is a simple market maker between demand and supply of energy. The numerical game theoretical evaluation shows that the method leads to forming coalition groups acting in Nash equilibrium. These coalitions between energy providers in local microgrids benefit both energy consumers and providers.

"Group Bargaining Based Bitcoin Mining Scheme Using Incentive Payment Process". Sungwook Kim [61] proposes an anonymous group bargaining scheme to allocate Bitcoin mining rewards. The scheme uses a reciprocal grouping of users and mining pools to deliver a suitable trade-off between efficiency and fairness. A game theoretical simulation using MATLAB validates the scheme against three alternatives (TNLB, GMTC, EEMC) and shows the superior efficiency of the proposed scheme.

Any Task.

"An Efficient Incentive Scheme with a Distributed Authority Infrastructure in Peer-to-Peer Networks". Zhang et al. [142] propose an incentive scheme that employs a distributed authority infrastructure, a key sharing protocol, and a contract verification protocol to promote cooperation and limit the impact of maliciously colluding participants in peer-to-peer networks. The authors combine reputation mechanisms with virtual currency. The authority infrastructure consists of a deterministic, pseudo-random set of nodes that act as a delegation for a certain peer. This group is responsible for keeping track of that said peer's credit balance and reputation information. The key sharing protocol ensures honest service contract negotiations employing the distributed authority infrastructure. The authors simulate their incentive mechanism with 100,000 nodes and varying

numbers of dishonest nodes. The results led them to conclude that their approach is capable of "solving the free-riders problem".

"An Incentive Mechanism to Reinforce Truthful Reports in Reputation Systems". Zhao et al. [145] propose an incentive to ensure trustworthiness in reputation systems. To increase system performance, the approach aims to prevent silent and lying strategies in repudiation systems. The reputation system is therefore supplemented by a currency (credits). Reported reputation information is rewarded with a payment scheme. The payment does not require other peers to verify the information's truthfulness. Only the paying peer adjusts the payment if undesired information is delivered. Extensive simulations show optimal welfare and truthful behavior; however, this game-theoretic model does not elaborate on the payment channel. Therefore, an essential component of the incentive stays unclear.

File Sharing.

"User Incentives for Blockchain-Based Data Sharing Platforms". Jaiman et al. [149] propose file sharing marketplace like incentive based on monetary payments using smart contracts. The authors focus mainly on simulations predicting the costs (gas) associated with smart contract execution on the Ethereum blockchain. The providing peers set the prices and rewards for file consumption and are expected to converge to economically sustainable costs for efficient peers. The results show that the longer a peer provides data, the higher the chances of making a profit. The paper lacks to discuss the prices of alternative blockchains. Smart contract-capable blockchains like Polygon[24] only require a fraction of a cent to execute a transaction, rendering the file-sharing marketplace much more efficient.

Routing and Relaying.

"An Incentive Mechanism for Message Relaying in Unstructured Peer-to-Peer Systems". Li et al. [66] propose a relaying and micro-payment incentive for peer-to-peer systems to prevent free-riding. The paper mainly focuses on the search protocol to find providers and leaves pricing and negotiations for provided data for future work. Further, a centralized bank is assumed to manage the virtual currency. A simulated testbed compares the approach against breadth-first-search and random walks and evaluates the system efficiency and peer utility. Onboarding and offboarding of peers (churn) during testing are not considered, and the routing and relaying are assumed to be reliable.

"Economic Incentive-Based Brokerage Schemes for Improving Data Availability in Mobile-P2P Networks". Padhariya et al. [96] propose a "glseib" scheme that motivates participants of mobile peer-to-peer networks to not only act as relaying nodes but also to proactively anticipate queries and searching for their results by maintaining an index of which data is stored at which peer. The authors also propose enhancements to this glseib scheme to facilitate load-sharing among broker peers. Brokers in the system are rewarded for each query they successfully process. This leads brokers to maintain an index of data items stored with other peers or even store the data itself. Data providers are incentivized to allow brokers to replicate often queried data because they will receive a royalty payment. If replicated, they will also get rewarded even when the data provider is offline. The three enhancement proposals to this scheme aim at incentivizing brokers to provide even better service and load-sharing by introducing different broker scoring strategies with different tradeoffs. The authors simulate their schemes with OMNeT++ and 1,000 network participants.

[24] https://polygon.technology.

They conclude that their proposals are indeed "effective in improving query response times, data availability, and query hop-counts at reasonable communication traffic cost".

"Channel-Relay Price Pair". Xue et al. [135] propose an incentive mechanism that leads to fair allocation of resources and cooperative behavior in a wireless ad hoc network of generally greedy and selfish participants. The authors argue that peers need to consider the two competing resources of individual relaying costs and shared wireless channel bandwidth. They invent a price pair that associates a cost with using the shared wireless channel and a reward with provided relaying services. The authors theoretically model their incentive mechanism game and state that the decentralized self-optimizing decisions maximize the optimal global network utility.

"Top-k Query Processing in Mobile-P2P Networks Using Economic Incentive Schemes". The authors around Padhariya [95] propose three credit-based incentive schemes under the umbrella of their "E-Top" system to improve the processing of top-*k* queries in a MANET. Two act on an individual basis where the payoffs are distributed equally or weighted. The third incentive scheme assumes the ad-hoc formation of peer groups but does not change the idea of using a virtual currency as a payoff vehicle. The authors back their schemes by running simulations in OMNeT++[25] modeling the mobility of 100 nodes according to a *Random Waypoint Model*. The authors conclude their performance evaluation by stating that their "E-Top" approach improves query response times and accuracy at a reasonable traffic cost.

"A Game Theoretical Incentive Scheme for Relay Selection Services in Mobile Social Networks". Xu et al. [134] devised a virtual currency-based incentive scheme to facilitate efficient relay selection in the environment of an MSN. They employed a bargaining game to model the transaction pricing for relaying services. Their goal is to prevent selfish nodes that don't participate in relaying services in the challenging network scenario of opportunistic P2P links. The mechanism is based on a virtual currency used to pay for relaying service and an approach to select a relaying node from the neighbors. The latter is based on the node status, which is a metric that incorporates node buffer, node energy, and the TTL of the message. The agreement price is modeled after a subgame Nash perfect equilibrium and put under test in simulations. The simulations with 20 MSN nodes show that their mechanism can outperform existing schemes to date in 2016 in a higher delivery ratio and lower delivery delay. They conclude that further research is needed to cover the effects of fraudulent nodes.

Video Streaming.

"Distributed Caching via Rewarding". Wu et al. [125] propose an incentive mechanism to encourage caching work in a P2P network targeted at video-on-demand services and minimize operational costs for content providers. Their incentive scheme is based on a stochastic, mean-field model to characterize the system in a limiting steady state. This lets them formulate an optimal pricing problem in which the content provider proposes a price for each video. They consider two design objectives for the pricing scheme. The first considers only the upload costs of content providers, and the second also factors in the caching payouts to the peers. They put their pricing models under test in extensive simulations of 10,000 nodes and most notably find that the order of video prices should be in reverse order of video popularity.

"Incentive Mechanism for the CoopNet Network". Manzato and da Fonseca [79] propose a credit- and reputation-based incentive mechanism to increase the quality of service of video streaming applications in the CoopNet network that is challenged by node churn and selfish behavior of

[25] https://omnetpp.org/.

participants. Reviewing the incentive patterns in [79, p. 17] the authors concluded that the "Barter trade" pattern is most suitable for the synchronous delivery application of video streaming applications. Nodes trade outgoing bandwidth for incoming bandwidth in a ratio determined via a cooperation tax. To motivate participants to stay longer in the network, the authors propose remuneration through a reputation mechanism that increases this cooperation tax for peers who stayed on the network for a short time. The authors simulate their incentive mechanism in a newly developed tool in different scenarios. Next to an increased quality of service, the authors conclude that the reputation aspect is only worth the overhead in a situation where many peers quickly join the network.

"Viewing Experience Optimization for Peer-to-Peer Streaming Networks with Credit-Based Incentive Mechanisms". Kang et al. [56] propose credit-based upload incentives for peer-to-peer multimedia streaming to prevent free-riding and motivate cooperation. The authors analyze how multimedia stream consumers should allocate their credits to uploaders to achieve an optimal streaming experience over a fixed time span. A simulation with 1,000 nodes is conducted to compare optimal credit allocation against three variants of suboptimal allocation strategies. The authors conclude that the credit-based incentive mechanism should complement a reputation system to prevent false information and selfish attacks.

Service Discovery.

"Strategies for Cooperation Emergence in Distributed Service Discovery". Del Val et al. [25] propose an incentive mechanism to stimulate cooperation in distributed service discovery processes. The authors abstractly model the query process to discover services with several cost, benefit, and reward factors. E.g., forwarding a query is costly but may bring a reward if successful in the form of a virtual currency. The authors performed experiments with 100 undirected networks and 1,000 agents where each agent was connected to 2.5 other agents on average and 40% were cooperators or 60% were cooperators. They found an increase in the degree of cooperation in both cases as the number of hops to reach a target agent was reduced.

"Promoting Cooperation in Service-Oriented MAS through Social Plasticity and Incentives". Del Val et al. [24] propose a hybrid incentive scheme that employs credit-based and social plasticity reputation-based mechanics to facilitate service discovery in peer-to-peer networks. The authors associate a cost and reward for, e.g., query forwarding actions that incentivize participants in the system to contribute resources. On the other hand, social plasticity allows nodes to change their neighbors if they detect non-cooperative peers. This adaptive combination of a social plasticity reputation scheme and credit-based incentives was simulated with 1 000 nodes and let the authors conclude that their approach yielded "better results [...] than other approaches proposed for promoting cooperation in networks [...]".

File Sharing.

"Incentive Mechanism Design for Heterogeneous Peer-to-Peer Networks". Kang and Wu [133] propose an incentive mechanism design to prevent free-riding in peer-to-peer networks. The authors model the peer's interactions as a Stackelberg Game (a leader moves first; other participants react). The uploader is considered the leader and sets a price for its bandwidth. Then, the downloaders react by determining their optimal download bandwidths. The incentive mechanism aims to maximize the utility for downloaders and uploaders. The proposed design is shown to be effective. However, for use in production systems, a mechanism for trust management must be added to the approach. Further, it is shown that the mechanism can adapt to dynamic events such as peers joining or leaving the network (churn).

A.4.3 Monetary:Deterministic.

File Sharing.

"Robust and Efficient Incentives for Cooperative Content Distribution". Sirivianos et al. [112] propose Dandelion, an incentive mechanism that motivates uploads and content distribution in peer-to-peer file-sharing protocols. The hybrid approach combines reciprocate cooperation of peers with a centralized credit-based reward mechanism. An experiment with 1,000 peers on 100 PlanetLab hosts validated its viability.

"Off-Line Incentive Mechanism for Long-Term P2P Backup Storage". Gramaglia et al. [32] propose a micro-payment incentive mechanism for peer-to-peer storage systems that allows peers to be offline for extended periods of time. The approach uses delayed payments through digital cheques issued by banks that compensate peers for the delegated storage of data chunks. A secure data verification mechanism ensures the storage of these chunks. An ad-hoc cycle-based simulator is used to validate the storage system's effectiveness, availability, and scalability.

"A Blockchain Based Truthful Incentive Mechanism for Distributed P2P Applications". He et al. [41] proposes a truthful cryptocurrency reward mechanism to prevent selfish actions and collusion in peer-to-peer networks. The method uses a secure content-protecting validation method and a pricing strategy to reward participants. Commutative encryption prevents individuals from decrypting content and, therefore, protects content from exploitation. The pricing strategy is designed to be robust against selfish behavior and collusion attacks. The game theoretical analysis and simulation show that selfish behavior is disadvantageous compared to cooperative behavior. However, collusion attacks depend on the network size and number of colluding participants, as a high probability of encountering colluding can be a vulnerability.

"Persuading Agents to Act in the Right Way". Centeno et al. [17] propose a generic incentive mechanism to maximize the utility of open multi-agent systems. A set of incentivators learn which actions are needed to maximize the system's utility. These incentivators punish and reward agents if certain actions are taken. The incentivators rank the actions and set positive and negative incentives accordingly. The approach uses a masternode-based architecture and a Q-learning algorithm to rank actions. A file-sharing scenario with a fee-based incentive is used to validate the approach. The experiment uses 70 peers with a bandwidth from 640 to 4096 Mb/s and 25 to 35% seeders and shows that the incentive adapts well to changing agent behavior and performs similarly to standard normative systems.

Any Task.

"Incentive Mechanisms for Peer-to-Peer Systems". Yu and Singh [138] present in their paper an incentive mechanism to mitigate free riding by agents that search a peer-to-peer network through referrals and get incentivized to contribute resources through a static and dynamic pricing scheme. Agents in a peer-to-peer network form a referral graph. In the static pricing scheme, a query issued by a particular peer incurs a cost for said peer if it gets answered by a neighbor. In the dynamic pricing scheme, the authors consider the quality of services provided by neighbors and adjust the payments according to it. The authors simulate their mechanism with 100 to 500 agents in a self-developed testbed for information access. They find that free-riders quickly run out of credits where the dynamic pricing mechanism leads to a zero balance 25% faster.

Other Task.

"Incentive-Driven and Privacy-Preserving Message Dissemination in Large-Scale Mobile Networks". Teng et al. [53] propose a coupon-based incentive mechanism to allow stores to reach a large

number of customers in a short time. The approach uses private key infrastructure to encrypt the transmitted data and protect the coupons from forgery. Two models are proposed, one where all forwarders benefit equally and another where a single forwarder benefits randomly. Further, the authors use AREX, a peer-to-peer denylisting mechanism, to penalize misbehavior. A prototype using six Symbian mobile phones was implemented, and an additional simulation of 5,000 participants was conducted to validate the approach's energy efficiency and coupon propagation capability.

"Refiner". Zhang et al. [143] propose Refinder, a deterministic pricing incentive to reward participants in a federated learning system. Peers collectively train an AI model of shared interest and are rewarded with a cryptocurrency (ERC20 token). Rewards are paid proportional to the contributions made by each peer. A smart contract controls an initially provided budget, and the incentive stops once the budget is drained.

"An Incentive-based Mechanism for Volunteer Computing Using Blockchain". Al Ridhawi et al. [4] propose a blockchain-based reward mechanism for peer-to-peer computing. Rewards are generated and paid as a token. A fog node selects candidates that perform the computing based on their stated resources, capabilities, and service requirements. A reinforcement learning process determines the reward value. OMENT++ and OverSim are used to simulate 500 peers and showed that the proposed solution provides adequate and fair distributed rewards to all participants in the blockchain formation process.

Routing and Relaying.

"Incentive Based Data Sharing in Delay Tolerant Mobile Networks". Wang et al. [120] propose MuRIS, a multi-receiver-based incentive mechanism for data sharing in delay-tolerant networks. The proposed reward mechanism considers historical encounters to estimate the closeness of participants as well as the possibly feasible paths to reach a certain participant. These two values define the expected reward. Frequent probe messages are used to explore the possible paths in the network. The simulation uses three publishing participants to generate 1,000 messages. Each peer has limited bandwidth but enough storage space to theoretically hold the entire set of files. The simulation shows an increased delivery ratio and transmission efficiency compared to three alternative approaches (Epidemic, RELICS, and Incentive).

"Generalized Connections and Incentives for Supporting CE Devices in Live Streaming Systems". De Sales et al. [23] propose the Global Media Transmission Protocol (GMTP) to facilitate efficient video streaming in a hybrid CDN/P2P network. Their incentive mechanism aims to motivate participants not interested in the streaming data to contribute relaying services to increase the network's welfare. Participants are usually devices with a stable IP, like home routers that provide services to dynamic mobile devices. The routers register in CDN servers to provide relaying services to gain "Ticket of Bits" for providing upload bandwidth. Based on the streaming quality that is relayed, the number of tickets is determined from the CDN server and assigned to the node. This currency (Tickets of Bits) can be used for other purchases outside this protocol. Simulations were conducted with over 10 000 nodes, and it was found that a significant improvement to the average startup delay compared to connected and unconnected mesh networks could be achieved.

"Decentralized Video Streaming in Multi-Hop Wireless Networks". In [90], Mousavi and Klein address the challenges associated with video streaming in Multi-Hop wireless networks by having one source and multiple receivers. They propose a monetary incentive mechanism that factors in different preferences regarding the video quality of the receiving peers and proposes a taxation

scheme to reward disseminating peers depending on their spent energy. Further, the authors propose a non-cooperative game theoretic model that is put to the test by extensive simulations.

A.4.4 Reputation.

Video Streaming.

"Score-Based Incentive Mechanism (SIM) for Live Multimedia Streaming in Peer-to-Peer Network". Ansari et al. [6] propose a **score-based incentive mechanism (SIM)** to improve resource utilization in P2P multimedia streaming. Rewards and punishments are used to increase or decrease a peer's score. This score is calculated by the upload capacity, video quality, control packets, and a peer's availability. The reputation of each peer is determined using score values of its recent and previous sessions. A simulation with OMNET++ and Oversim using 1,000 peers was used to validate the improvement in video quality and network performance. Metrics like end-to-end delay, playback delay, start-up delay, and frame redundancy were used to measure the performance. A tracker node is used to hold the scores of the peers. This node forms a single point of attack and should be replaced by a set of tracker nodes that peers can query to maintain decentralization. If individual scores vary significantly, peers could denylist certain trackers.

"Incentive Cooperation Strategies for Peer-to-Peer Live Multimedia Streaming Social Networks". Lin et al. [72] propose a reciprocity-based incentive strategy for live multimedia streaming over peer-to-peer networks. The approach aims to be cheat-free, attack resistant, and reliable by comparing Pareto-optimal, proportional fair, or absolute fair behavior. This paper proposes a game-theoretic framework where a player should not send more chunks than its opponent does for it. A game-theoretic framework is used for analytical and simulation-based evaluation.

"Incentive Cooperation in Peer to Peer Video Streaming Using Cooperative Game". Nasab et al. [93] present a Shapley value approach to increase cooperation and prevent free-riders in a peer-to-peer video streaming network. The authors propose a utility function for each peer in a reciprocal interaction scenario that is to be maximized and eventually stipulates resource sharing. The incentive mechanism consists of finding free-riders based on their willingness to cooperate and, second, motivating peers based on the reciprocal reputation mechanism. Gained profits are divided based on bandwidth contribution and their Shapley value. To evaluate their incentive mechanism, the authors conduct a simulation with 400 nodes to compare received video chunks of nodes that cooperate against those that don't. The authors conclude that their approach leads to uniform distribution of profits and resources, optimized usage of bandwidth, and a decreased error rate.

"COINS". Belmonte et al. [11] propose COINS, a coalition formation and incentive mechanism to improve the quality of service and download time in video streaming and one-click hosting peer-to-peer networks. The coalitions elect a manager that handles the task assignment in each coalition. A grace period defines when the system starts to punish a free-riding peer, and credits called *responsiveness bonus* reflect the overall contribution of every peer. The simulation used a population of 1,000 peers and 9,000 files of different sizes. It showed that COINS can prevent free-riding and promote contribution by allocating payments to peer coalitions of variable size.

"Predicting the Level of Cooperation in a Peer-to-Peer Live Streaming Application". Gonçalves et al. [30] measure the cooperation in the popular SopCast protocol and propose a new model to detect peers that report artificially inflated cooperation data based on their findings. Cooperation measurement uses the graph-based out-degree metric. Further, graphs are used to identify clusters of potentially colluding peers, and a model is trained to predict the expected cooperation level of

individual peers. The model, hence, offers a reputation mechanism to select and deny interactions with participants.

"Coercion Builds Cooperation in Dynamic and Heterogeneous P2P Live Streaming Networks". Jin and Kwok [52] propose practical incentives for peer-to-peer live streaming with reputation penalties designed for peers with different bandwidth capacities. The core of the incentive is a strategic peer selection with different selection probabilities for each peer. The example use case of time-critical peer-to-peer live streaming itself is not fully decentralized, as it uses unequal nodes, i.e., tracking nodes; the incentive mechanism, however, has no centralized aspects. The formulated game models are used to analyze the incentive effects of live streaming with performance, fairness, and robustness measures. Additionally, cycle-based event-driven package-level simulations are conducted for 1,000 peers to validate the game theoretical models.

"An Incentive Scheduling Mechanism for Peer-to-Peer Video Streaming". Montazeri et al. [87] propose ISSS+IRA, an incentive mechanism for mesh-based peer-to-peer video streaming networks. The approach aims to motivate peer cooperation to prevent free-riding and increase the perceived video quality. Peers track each others' contribution amounts in a distributed fashion. Not every package and video chunk is measured; instead, small contribution intervals are set. Each peer has a list of peers to monitor. Periodically, peers disseminate the measured contributions to other neighboring peers. The streaming source schedules the video quality according to the measured contribution amounts. Extensive simulations show an increase in video quality for cooperating participants and a decrease in free-riding. Additionally, a general approximation of big O complexity for DHT based, hierarchical, central-based, tit-for-tat, and EigenTrust incentives are given.

"Autonomic and Trusted Computing". Yang et al. [136] propose TPOD, a trust-based incentive mechanism for peer-to-peer live streaming. To achieve service differentiation, the approach uses a trust value composed of the contributed upstream traffic and online duration. The approach aims to improve service quality and prevent free-riding. Trustworthy peers are rewarded with better quality streaming, and low-performing peers are penalized by limiting their communication partners to other low upstream peers. The mechanism detects and exchanges trust and contribution level without central authority through a gossip-based overlay and are used to create composite trust indices. Experiments on PlanetLab with 300 active peers show that the average delivery ratio of packages increases significantly with the proposed incentive mechanism.

"PULSE". Pianese et al. [101] propose PULSE, a tit-for-tat extension to improve live media streaming in peer-to-peer networks. The approach aims to scale broadcasting infrastructure dynamically to varying numbers of receiving nodes while minimizing payout delay and improving media quality. Media quality, in this case, describes the completeness of data and the number of artifacts. The authors prioritize resource usage in the mesh network over fully reciprocal fairness to benefit global performance. A prototype was deployed to a testbench of 800 nodes on Grid'5000 and PlanetLab, where the outbound bandwidth was artificially limited. The experiments showed high resilience to churn and scalable performance.

"Efficient and Incentive-Compatible Resource Allocation Mechanism for P2P-Assisted Content Delivery Systems". Hu et al. [42] propose a tit-for-tat resource allocation mechanism for peer-to-peer file delivery and video streaming. The proposed strategy dynamically compensates resource-poor peers by taxing the contingents of resource-rich peers. A central instance adjusts this tax. Therefore, providing a more consistent service quality, even under fluctuating bandwidth. The packet level simulation shows satisfactory performance and improved robustness against dishonest behavior of up to 50% of the peers.

"How Much to Share". Xiao et al. [132] propose an incentive mechanism to stimulate fair resource contribution and consumption in a peer-to-peer network for video streaming applications. The authors define four key issues an incentive mechanism must consider. Namely: Asymmetry considerations, easy implementation emphasizing instant contributions, game-based model, and honest incentive implementation guarantees. They split the video streaming task into fixed time rounds where each subsequent round incorporates peer contribution information from the previous round to determine how many resources that peer is eligible for. Their incentive mechanism relies on a trusted third party to track peer contributions, and their work does not consider attacks from malicious nodes.

"Utilizing Layered Taxation to Provide Incentives in P2P Streaming Systems". Li et al. [65] propose CLT, a credit-line-based layered taxation incentive for peer-to-peer streaming systems. The approach aims to increase streaming performance by increasing individual and system utility. Peers pick different Quality of Experience layers depending on their latency demands. The top layers have fewer hops to the streaming source and receive the lowest latency stream. Participants can choose a layer by paying a corresponding tax. The taxation does not rely on a central entity; each peer maintains a taxation relationship with its neighbors individually, and remote attestation is used to verify the credit calculation. The approach is validated by trace-driven simulations showing free-riding elimination and performance improvement.

"Service Differentiated Peer Selection". Habib and Chuang [36] propose an incentive mechanism to increase the quality of service of media streaming in a peer-to-peer network by limiting the peer selection choices for free-riders. By contributing resources, the network participants can earn a score that maps to a certain rank. This rank orders peers relatively according to their contribution to the network and makes them eligible to select a higher utility peer that increases the quality of service. The authors simulate their incentive mechanism with the Planet-Lab test bed and find that their incentive mechanism yields a near-optimal quality of service for cooperative users until the bottleneck shifts from the source peers to the network itself.

File Sharing.

"Enhancing Tit-for-Tat for Incentive in BitTorrent Networks". Liu et al. [75] propose an incentive mechanism that enhances the tit-for-tat scheme prevalent in the BitTorrent network to mitigate free-riding behavior. The authors model the peer-to-peer environment in the BitTorrent network and deduce constraints for when tit-for-tat is an equilibrium strategy. Further, the authors extend the tit-for-tat strategy to incorporate factors that evolve from the dynamic network topology, like link failures or node churn. They also note that the classic BitTorrent tit-for-tat scheme is a stable strategy for repeated games. Still, in reality, peers choose their cooperation partner each round randomly; thus, it is a "random matching game". They solve both problems by introducing a sense of generosity that excuses misbehavior to a certain degree and by extending the interaction time of two parties as long as possible due to initial payoff limitations at the beginning of peer interactions. The authors simulate their incentive mechanism with 1,000 nodes in Matlab, proving its effectiveness. They also formally proved that their enhanced tit-for-tat strategy is a subgame-perfect equilibrium under certain conditions.

"An Incentive-based Architecture to Enable Privacy in Dynamic Environments". Kazatzopoulos et al. [58] propose an incentive mechanism for the collaborative hiding of confidential information in MANETs. The authors introduce a reputation metric that tracks the degree of collaboration by issuing credits for answered requests and denials for unanswered secret sharing requests. Credits **and** denial tokens make a peer eligible for secret sharing. The latter is important for newcomers to

the system. They introduce the concept of crawlers to track and monitor the truthfulness of credit claims of peers. However, it is unclear how crawlers are selected and how their truthful behavior is enforced. The authors measure the performance of their secret sharing architecture but don't verify the effectiveness of its incentive aspect.

"SocialTrust". Hu et al. [43] present an incentive scheme called "SocialTrust" where a distributed trust mechanism serves as a credit limit for data transfer quotas. To form a trust relationship, a peer finds a small number of "friend" peers with common interests to maintain a long-running connection. The trust value is derived from past interactions by counting exchanged packets and exchanging verifiable notification messages that state the current trust score. The authors further elaborate on transitive trust transfer to relax spatial and temporal interaction constraints. The authors perform experiments on the PlanetLab network as the implemented prototype is compatible with the BitTorrent protocol. They find that "SocialTrust can improve the file availability from 40 to 90% and reduce the median download time by about 25–50%".

"Optimizing Cluster Formation in Super-Peer Networks via Local Incentive Design". Kurve et al. [63] propose in their research article an incentive mechanism for optimizing load distribution among a set of "super-nodes" in a peer-to-peer network based on semantic similarities between content interests. They acknowledge the heterogeneous peer capabilities and focus on so-called "super-nodes", which have increased bandwidth capacities and computational resources. The authors propose a game theoretic framework that allows stable Nash equilibria to exist, which guarantees the convergence to an optimal, stable peer to "super-peer" assignment. The approach is optimal because the average content query resolution time is minimized. The proposed incentive scheme was tested in a modeled peer-to-peer file-sharing system based on a Gnutella-like system with 100 "super-peers", 10, 000 peers, and 500 content categories. The authors compared their local incentive-based approach's average hop count and average query resolution time with pure load balancing, pure semantic proximity, and an alternate cost-based approach. It was found that the local incentive base approach performs best in average query resolution time but slightly worse in the average hop count, whereas the pure semantic proximity-based approach performs best.

"COINS". Belmonte et al. [11] propose COINS, a coalition formation and incentive mechanism to improve the quality of service and download time in video streaming and one-click hosting peer-to-peer networks. The coalitions elect a manager that handles the task assignment in each coalition. A grace period defines when the system starts to punish a free-riding peer, and credits called *responsiveness bonus* reflect the overall contribution of every peer. The simulation used a population of 1,000 peers and 9,000 files of different sizes. It showed that COINS can prevent free-riding and promote contribution by allocating payments to peer coalitions of variable size.

"Scrivener". Nandi et al. [92] propose Scrivener, an incentive mechanism for fair bandwidth sharing in peer-to-peer content distribution networks. The approach ensures fairness, stability, and usability by detecting and preventing freeloading. Further constraints are low overhead and high robustness of the mechanism. Locally tracked credit and debt are used to motivate tit-for-tat behavior. Credits reflect the number of transferred bytes and are offered to neighboring peers based on the success and failure of past content requests. Transitive credit trade allows data retrieval from distant peers by creating a credit path. A simulation on 800 online nodes showed an effective limitation of service quality that is proportional to the past contribution amount of each participant.

"Incentive and Service Differentiation in P2P Networks". Ma et al. [77] propose RBM-IU, a resource allocation and incentive scheme for file transfers in peer-to-peer networks. The approach aims to

prevent *free-riding* and the resulting *tragedy of the commons* problem by maximizing the social welfare and willingness to share content. Participating nodes receive service based on their past contributions. Nodes self-organize by different levels of contribution. This contribution metric only tracks the file transfers and not the file search in the network. A convergence analysis is used to validate the bandwidth allocation and resource allocation. The approach is Pareto optimal for all source nodes and achieves a Nash equilibrium for all participating nodes.

"An Incentive-Compatible Mechanism for Efficient Distribution of Bulk Contents on Peer-to-Peer Networks". Koo and Lee [62] propose CAU a

seeing-is-believing

tit-for-tat incentive mechanism to improve content distribution over peer-to-peer networks. The approach incentivizes resource sharing and reduces free-riding. Peers track the average received data from other peers and distribute their own capacity accordingly. A simulation verified the content distribution efficiency using 2,000 nodes with bandwidth limitations according to three classes (10 Mbps, 128 kps,56 kbps).

"Cooperation through Self-Similar Social Networks". Allen et al. [5] propose a cooperation scheme for preventing free-rolling and improving updating and sharing content in peer-to-peer networks. The approach uses a trust level based on previous tit-for-tat cooperation that groups nodes into social networks of similarly cooperative parties. A high level of cooperation results in a higher quality of service as a payoff. The simulation conducted tests on network cooperation rates between 20% and 80% and validated the effectiveness and robustness of the approach while proving the applicability for autonomous decentralized systems.

"Efficient and Incentive-Compatible Resource Allocation Mechanism for P2P-Assisted Content Delivery Systems". Hu et al. [42] propose a tit-for-tat resource allocation mechanism for peer-to-peer file delivery and video streaming. The proposed strategy dynamically compensates resource-poor peers by taxing the contingents of resource-rich peers. A central instance adjusts this tax, therefore, providing a more consistent service quality, even under fluctuating bandwidth. The packet level simulation shows satisfactory performance and improved robustness against dishonest behavior of up to 50% of the peers.

"An Equity-Based Incentive Mechanism for Persistent Virtual World Content Service". Shen et al. [109] devise an incentive mechanism for reliable storage. Their goal is a marketplace for content storage in persistent virtual worlds. To achieve this goal, the reliability of content storage must be measurable as a metric, and users need to be motivated to maintain the content storage cooperatively. The proposed method is a tit-for-tat-like system with replica groups for different levels of storage reliability. In the experiment, 10 to 10^6 devices are simulated where each device fails randomly, and different reliability values are assigned to each device. It is effectively providing equally reliable storage service to each storage offering device.

Routing and Relaying.

"New Incentive Mechanism to Enhance Cooperation in Wireless P2P Networks". Singha and Singh [111] propose an incentive for wireless P2P networks where peers share their wired access to a backbone network with others over a wireless connection. The incentive assigns a cooperation level to each peer, defining the upper bound of receivable bandwidth. Peers decide individually if a peer matches its download requirements. The proposed incentive was analyzed using a game theoretic model that validated the assumption of a Nash equilibrium. Further, a simulation with 100 peers was used to confirm the model for 2,000 simulation rounds.

Peer-to-Peer Computing.

"Incentive Mechanism for Scheduling Jobs in a Peer-to-Peer Computing System". Rius et al. [102] propose an incentive mechanism to motivate the contribution of computational resources to jobs in different types of peer-to-peer networks. The authors envision a two-layered incentive approach. The first layer incentivizes participants via a credit-based scheme to discourage free-riding and cheating. The second layer circumvents the scalability limitations of the first via the concept of "super-peers" with an associated reputation value. Their simulation with 4 000 peers and 100 000 workers shows that the approach can eliminate the vast majority of free-riders in the system and is tolerant of changes in user behavior.

"Incentive-Aware Micro Computing Cluster Formation for Cooperative Fog Computing". Luo et al. [76] propose a tit-for-tat-like incentive mechanism to provide resources for low latency and energy-efficient mobile task execution. Coalitional game theory is applied to grouped participants, which represent Micro Computing Clusters (MCC). The MCC solution achieves top coalition, core solution, individual rationality, and computational efficiency. A decentralized and centralized architecture is simulated and shows a signaling overhead and MCC formation overhead that increases with the number of participants. The numerical simulation considers 50 MCC formation rounds and shows an efficient system performance and effective cooperation among devices with close proximity (500m).

"KeyPIn – Mitigating the Free Rider Problem in the Distributed Cloud Based on Key, Participation, and Incentive". Pal et al. [97] propose an incentive mechanism to control participation in a distributed cloud. A utility function based on a user's participation factor is used to define a reputation metric. Multiple key servers are used to control the access time of each peer to resources. A DHT is used to share the utility among the peers. This metric considers access time, capacity, cores, and availability. A simulation based on a modified Kademlia DHT with 10,000 peers was used to validate the incentive, showed effective isolation of free-riding peers, and achieved a Nash equilibrium.

Service Discovery.

"Reputation-Based Policies that Provide the Right Incentives in Peer-to-Peer Environments". Papaioannou and Stamoulis [98] propose reputation-based policies that improve peer selection in peer-to-peer services. Provider selection policies handle the selection of service providers based on their reputation. Contention resolution policies handle the serving of consumers from the provider's perspective. The policies take a reputation metric as input and select nodes based on the policies. Policies for provider selection are *highest reputation*, *comparable reputation*, and *black list*. For contention resolution the providers can apply *highest reputation* and a *probabilistically fair with respect to repudiation* policy. The approach is justified experimentally with an extensive series of simulation experiments that consider altruistic and egoistic nodes.

"Promoting Cooperation in Service-Oriented MAS through Social Plasticity and Incentives". Del Val et al. [24] propose a hybrid incentive scheme that employs credit-based and social plasticity reputation-based mechanics to facilitate service discovery in peer-to-peer networks. The authors associate a cost and reward for, e.g., query forwarding actions that incentivize participants in the system to contribute resources. On the other hand, social plasticity allows nodes to change their neighbors if they detect non-cooperative peers. This adaptive combination of a social plasticity reputation scheme and credit-based incentives was simulated with 1,000 nodes and let the authors conclude that their approach yielded "better results [...] than other approaches proposed for promoting cooperation in networks [...]".

Other Task.

"Cooperation Incentives and Downlink Radio Resource Allocation for Green Communications in a Heterogeneous Wireless Environment". Ismail et al. [47] propose a decentralized downlink joint radio resource allocation strategy to share and save bandwidth and power while satisfying the required quality of service of network subscribers. Nash bargain games are used to achieve cooperation between participants. Simulations for three distinct algorithms show a superior power consumption compared to single-network non-cooperative approaches. The incentives target network providers where no malicious actors are expected. The proposed strategy's main incentive is the win-win outcome of power savings; a second incentive layer to motivate mobile terminals to relay data is open for future work.

"Backhaul-Constrained Multicell Cooperation Leveraging Sparsity and Spectral Clustering". Jain et al. [49] looked at multi-cell cooperation strategies to mitigate interference at cell boundaries. They did not propose incentive mechanisms but rather a communication protocol between base stations to coordinate spectral efficiency.

"Cooperation Policy Selection for Energy-Constrained Ad Hoc Networks Using Correlated Equilibrium". Wu et al. [130] propose a correlated equilibrium-based cooperation scheme to achieve maximum energy efficiency in ad hoc networks. The cooperation scheme uses an adaptive relay selection strategy where each peer measures its individual regret and utility. Bad performance leads to a denylisting from the current play and a modification of the strategy. The scheme is evaluated using a simulation of 1,000 iterations and up to 20 peers and a Pareto optimal configuration with minimum regret value and increased utility.

"A Comprehensive Study of the Use of Advertisements as Incentives in P2P Streaming Systems". Wang et al. [118] propose a token-based advertisement incentive for peer-to-peer streaming systems. The authors define multiple schemes to generate tokens, exchange tokens, and calculate the required amount of advertisements. Unlike in typical streaming incentives, each participant receives the highest possible quality of service and only the amount of required advertisements varies depending on each peer's contributions.

"Coordination of Cooperation Policies in a Peer-to-Peer System Using Swarm-Based RL". Vakili et al. [117] propose a distributed reinforcement learning approach to stimulate cooperation and coordinate the upload-to-download ratio of a peer-to-peer network system in a self-organized way despite the participants having only a partial view of it. The authors model the system as a decentralized Markov Decision Process and abstractly frame the problem not only to coordinate the upload-to-download ratio but rather to generally optimize resource allocation policies. However, in their simulations of 1,000 interacting peers, the authors assess the performance of bandwidth coordination again. They find that the applied cooperation policies in individual peer-to-peer interactions are in line with the social welfare of the whole system.

"An Incentive-Aware Blockchain-Based Solution for Internet of Fake Media Things". In their article, Chen et al. [20] devise a platform that aims to provide integrity for digital content in the realm of the **internet of fake media things (IoFMT)**. The platform operates in a proof-of-authority-backed blockchain network and incentivizes participants to submit "real" news via calculating a credibility score which is assumed all participants want to maximize. The goal is the fair recognition of good and bad behaviors by the actors involved. They show a working prototype of the platform.

"Incentive Mechanism for Reliable Federated Learning". Kang et al. [55] propose an incentive mechanism and task management scheme for distributed and federated machine learning. The approach focuses on privacy and only shares updates to the machine learning model, while learning data is not shared among participants. The incentive uses reputation management. A consortium blockchain tracks the reputation and prevents repudiation. Reputation is calculated using each node's subjective interaction history. Experiments are run on a real-world dataset to validate the incentive mechanism and learning accuracy. The approach efficiently improves learning accuracy and performance scales with the number of participants.

Any Task.

"A Swarm Intelligence Learning Model of Adaptive Incentive Protocols for P2P Networks". Zheng Wang [121] proposes a swarm intelligence learning model of adaptive incentive protocols for general peer-to-peer networks to prevent selfish behavior and the tragedy of the common. Peers adapt strategies based on the current best strategy and the best strategy in history. Each peer can act as either a cooperator, reciprocator, or defector and would either mirror the incentive policy of an interacting peer, serve others with a probability equal to the requester's contribution ratio, or pick a linear incentive policy with constant behavior. Which strategy to take is defined using a swarm intelligence learning model. Extensive simulations evaluate the learning model against two existing learning-based models and show a faster convergence rate towards the quasi-optimum.

"Evolutionary Stability of Reputation-Based Incentive Mechanisms in P2P Systems". Goswami et al. [31] propose a reputation-based incentive mechanism for resource allocation in peer-to-peer systems. The proposed mechanism uses an entry fee to prevent free-riding and white-washing. Nodes that keep track of reputations receive entry fees. The payout of this fee can be of versatile forms, e.g., quality of service, but it is essential to achieve evolutionary stability. The simulation uses evolutionary dynamics to validate the performance and the ability to motivate cooperative behavior in any participant. A pairwise interaction game model is used to calculate each player's payoff.

"Trust and Cooperation in Peer-to-Peer Systems". Jiang et al. [51] propose a simplified incentive mechanism based on a decentralized repudiation-based trust model to prevent selfish behavior in peer-to-peer systems. The prisoner's dilemma is used to model the interactions in peer-to-peer systems. Peers use direct trust, recommender trust, and indirect trust to calculate a credit score for each interacting peer. Peers exchange trust information (Trust net) and hence, are able to calculate a credit score even for peers they did not interact with before. A simulation of 3,000 peers shows that stable cooperation emerges after limited rounds of interaction as long as at least half of all peers are potential cooperators.

"Applying a Socially Inspired Technique (Tags) to Improve Cooperation in P2P Networks". Hales and Edmonds [39] propose a tag-based incentive to improve cooperation in peer-to-peer networks. Participants organize themselves into different groups depending on their participation level. Each group is identified by a tag. Nodes can join and leave groups at any time, can be a member of multiple groups, and participate in each group at a different level. Extensive computer simulations using 200 to 51,200 nodes show an efficient reduction in selfish behavior and validate the approach's scalability, robustness, and decentralization.

"Incentives for Combatting Freeriding on P2P Networks". Kamvar et al. [54] propose an incentive mechanism based on their developed "EigenTrust" score as a measure for participation to mitigate freeriding behavior. The authors use their own "EigenTrust" score as an indicator for network participation and base bandwidth quota and query TTL on that score. The higher the score, the

more bandwidth percentage a user receives if he or she is competing with other participants for the bandwidth of a particular peer. Peers with a higher than average "EigenTrust" score are eligible for a higher query TTL and thus are able to reach more peers in the network. The authors simulate their incentive mechanism with 100 peers and find that, indeed, the "EigenTrust" score is an appropriate indicator for participation and also reduces query load on the network. It is important to note that free-riders are not entirely excluded from the network but can still participate in allowing those users to become active participators if they choose to.

"An Abstract Model for Incentive-Enhanced Trust in P2P Networks". Neovius [94] presents "an abstract model for incentive-enhanced trust" based on a degrading formula for mutual trust in a peer-to-peer network to mitigate free-riding and prevent the *tragedy of the commons.* The incentive mechanism assigns increasing trust in a peer, progressively increasing access to distributed resources. The author counters whitewashing behavior by considering a newcomer to the network as less trustworthy than a proven untrustworthy peer. The trust value is based on a formula from Whitby, Jøsang, and Indulska [126] and the merging of opinions about a peer. The author did not simulate his approach.

"A Connection Management Protocol for Promoting Cooperation in Peer-to-Peer Networks". Karakaya et al. [57] propose an incentive mechanism to alleviate query traffic free-riding behavior in a peer-to-peer network. They try to maximize network contributors' connectivity and isolate free-riding peers. The approach splits the connections of a particular peer to another one in an IN and OUT part. The IN part represents query requests that are sent to the particular peer, and the OUT part represents queries that this peer issues against others. The reputation value of the connected peers is calculated according to the observed contribution. If this observed contribution does not hold a certain threshold, the peers connect to a different peer that is a contributor. The authors simulate their incentive mechanism with a network of 900 nodes in the GnuSim peer-to-peer network simulation tool. The results show that the protocol indeed reduces the adverse effects on the network quality of service. A variety of attacks are discussed as well that don't render their mechanism ineffective.

"Trust-Based Incentive Mechanism to Motivate Cooperation in Hybrid P2P Networks". Tian et al. [115] propose SuperTrust, a trust-based inventive mechanism for hybrid peer-to-peer networks. The approach uses a referral-based reputation system for peer selection. Super-peers accumulate all reputation scores and provide a rating that regular peers use to supplement their data. Regular peers are grouped by interest and assigned a single super-peer. In extensive simulations (1,000 peers; 20 super-peers), the resistance against a number of attacks and file retrieval performance are evaluated.

"A Novel Bartering Exchange Ring Based Incentive Mechanism for Peer-to-Peer Systems". Zhang and Antonopoulos [140] propose a novel Cluster-Based Incentive Mechanism (CBIM) that uses dynamic rings in combination with a reputation system. Peers use their local transaction information to identify and block free riders. Peer selection works as a tit-for-tat-like reputation mechanism. The simulation was carried out on a 1,000-peer Gnutella network and showed an increase in successful requests and drastically reduced free-riding.

"An Incentive Compatible Reputation Mechanism for P2P Systems". Chang et al. [19] propose a recommendation mechanism for peer-to-peer systems. Recommendation information on the level of participation is exchanged and supplemented with the transaction history of the requesting participant. The outcome is a level of confidence for a recommendation value and a credibility score. A peer considers both its own past interaction and the recommendations of other peers for

its peer selection. The simulation consists of 10,000 participants, with up to 80% being dishonest, and shows an increase in the transaction success rate compared to two related mechanisms.

"RIMNet". Li et al. [69] proposed RIM, a reputation-based incentive mechanism to prevent the cooperation dilemma in peer-to-peer services. Acceptance and performance are evaluated theoretically through evolutionary game theory, and it is proven qualitatively that non-cooperative agents can be suppressed. Additionally, numerical and simulation experiments validate the theoretical claims. The experiment considers perfect information (PRIM) and imperfect information (IRIM) participants and benchmarks its performance against a number of reciprocity-based incentive mechanisms.

"An Efficient Incentive Scheme with a Distributed Authority Infrastructure in Peer-to-Peer Networks". Zhang et al. [142] propose an incentive scheme that employs a distributed authority infrastructure, a key sharing protocol, and a contract verification protocol to promote cooperation and limit the impact of maliciously colluding participants in peer-to-peer networks. The authors combine reputation mechanisms with virtual currency. The authority infrastructure consists of a deterministic, pseudo-random set of nodes that act as a delegation for a certain peer. This group is responsible for keeping track of the said peer's credit balance and reputation information. The key sharing protocol ensures honest service contract negotiations employing the distributed authority infrastructure. The authors simulate their incentive mechanism with 100 000 nodes and varying numbers of dishonest nodes. The results led them to conclude that their approach is capable of "solving the free-riders problem".

"A New Incentive Policy for Improving Data Service in P2P Networks". Zhang et al. [141] propose a method called Wise Incentive Policy to achieve robustness and availability in peer-to-peer networks, even with many defectors in the network. The method uses Wise-peers who refuse to provide service to defectors but altruistically provide service to other Wise-peers. A Wise-peer is, therefore, a mix of a cooperator and a reciprocator. The mathematical framework of Zhao et al. [144] is used, which classifies participants as either cooperator (altruistic), defector (selfish), or reciprocator (rational). The method was benchmarked against the Mirror Incentive Policy and shows that the Wise Incentive Policy can effectively prevent or exclude selfish nodes completely from a network of 500 peers.

A.4.5 Service.

"A Model for the Behaviors and Incentives of Users in a Decentralized Data-Sharing Network". Esfandiari et al. [27] propose a model to motivate collaboration in decentralized file-sharing networks. Collaborative filtering is used so users can select participants with similar interests in files. In contrast to popularity-based filtering, where the individual interest is served only when the majority of participants have the same interest, Esfandiari's approach does also filter files for minority interests. The approach is validated in a NetLogo simulation using 400 files and 60 peers with different subjective preferences (taste). Active participants have a clear advantage over free riders, and the approach shows improved resistance against attacks compared to the popularity-based method. Rational self-organizing peers eliminate the need for a central moderation system.

"The Problem of Upload Competition in Peer-to-Peer Systems with Incentive Mechanisms". Meulpolder et al. [84] propose a solution to unfair uploader competition in file-sharing networks caused by bandwidth inequalities. In protocols like BitTorrent, it is inherently impossible for slow peers to maintain high sharing ratios, which can cause the unjust banning of active participants from private networks, despite their participation willingness. The proposed ratio-based upload selection mechanism selects uploaders with the lowest sharing ratios among the known peers

of each participant. However, it is tempting for participants to subvert the protocol and choose peers with high sharing ratios to increase download speeds. For the validation, 1,000 peers were simulated. The setup uses centralized trackers but can be adapted to a fully distributed incentive system.

"On the Impact of Incentives in eMule - Analysis and Measurements of a Popular File-Sharing Application". Carra et al. [16] propose an alternative incentive for the file-sharing application eMule. The approach is a tit-for-tat-like mechanism that uses credits to track participation. The mechanism is validated through numerical simulation and extensive measurement on the deployment of the 2013 eMule/aMule system. The measurements on the state-of-the-art show starvation of peers with few resources, causing long delays for these peers. The improved incentive mechanism that prevents starvation is validated numerically, as well as deployed and evaluated as a modified aMule client.

"An Adaptive Peer-to-Peer Live Streaming System with Incentives for Resilience". Park et al. [100] propose Climber, a cooperation mechanism for peer-to-peer live streaming systems. The approach creates more resilience to churn and increases upload bandwidth contributions. Each peer optimizes its communication partners by checking the TTL of each video stream package. The created shortest streaming path is advanced using additional random edges. The more random edges a peer serves, the higher the redundancy in providing and receiving paths. Analytical modeling and a simulation of 3,000 peers is used to validate the approach. The mechanism is tested over 10,000 seconds and with a churn rate of up to 20%.

"The Impact of Incentive Mechanisms on Project Performance". Meng and Gallagher [82] propose an incentive mechanism for dynamic load balancing in structured peer-to-peer file-sharing networks. The incentive aims to encourage peers to accept load from neighboring participants to prevent load imbalance. Peers maintain lists of load thresholds for all connected peers. Every node provides thresholds consistent with its capabilities. Falsely claimed capabilities results in reduced service quality, as participants will not receive better quality of service than their capability allows. The evaluation uses a Peersim simulation with 1,000 nodes and 1,000 files to prove the effectiveness and efficiency of the load distribution of the approach.

"Quantum Game Analysis on Extrinsic Incentive Mechanisms for P2P Services". Wang et al. [150] propose a quantum game theoretic model for extrinsic incentive mechanisms such as reputation-based schemes. They quantitatively analyze how the reward strength influences the optimal strategy and expected payoff for each player. (No incentive mechanism.)

"A Novel Bilateral Incentive Mechanism Based on Social Relation and Evolutionary Game Theory". In [127], Wong et al. present the "Novel Bilateral Incentive Mechanism" to restrain free-riders and generally malicious nodes in the original BitTorrent network. Their main idea is to extend the network with an identification mechanism to make participants accountable for their potential misbehavior. The identification system should be managed by the tracker nodes prevalent in the BitTorrent network. The main mechanism to stipulate cooperation is by orchestrating bandwidth assignment. Suppose a node is identified to be misbehaving by not sharing its own bandwidth or sharing malicious files. In that case, the tracker is notified that the node is only allowed a decreased bandwidth for its own requested service.

"Cooperation and Strategy Coexistence in a Tag-Based Multi-Agent System with Contingent Mobility". Hadzibeganovic and Xia [38] use game theory, evolutionary computing, and agent-based simulation to validate their tag-mediated cooperation model for peer-to-peer networks. The model analyzed the mobility patterns of participants on an abstract level using a toroidal lattice of 10,000

nodes. Instead of an incentive for typical pay-off-based migration, reproduction-based migrations are used. The simulations show improved robustness over pay-off-based migration and the capability of integrating new participants quickly. Although the model is applicable to peer-to-peer networks like MANET and DTN, the game theoretical analysis lacks a practical implementation and evaluation of the incentive mechanism.

"Adaptive, Incentive and Scalable Dynamic Tree Overlay for P2P Live Video Streaming". Sayit et al. [106] propose a system to improve the quality of experience in the video streaming domain under high peer churn conditions. They devise a mechanism whose incentive is based on a scalable video codec that entangles video quality with bandwidth capacity or the network congestion level. Since their main contribution is a multicast tree framework with an incentive mechanism as a byproduct, their experiments did not focus on, e.g., free-riders, as seen in many other papers we investigated. Nevertheless, they conducted experiments with a maximum of 150 nodes in the PlanetLab environment and reported that their system provides "high" Quality of Experience to the peers.

"Relative MTTF-Based Incentive Scheme for Availability-Based Replication in P2P Systems". Kim [60] proposes a mechanism to ensure certain data availability guarantees in the presence of selfish and unreliable participants in a peer-to-peer network. The author introduces a "relative mean time to failure" that captures the probability that a neighboring node is online for an extended period of time. Nodes calculate their mean time to failure and exchange this information together with their network-join-time by piggybacking keep-alive messages between neighbors. This information is used to calculate the *relative* mean time to failure that is used to determine how and when data replicas need to be distributed. While the metrics of the authors increase replica availability, their metric cannot be considered an incentive but rather an indicator for smart data distribution to prevent data loss in the case when all nodes that replicate data leave the system.

"Share-Ratio-Based Incentive Mechanism for File Sharing With BitTorrent Protocol". Adamu [3] proposes a service incentive for BitTorrent file sharing. The approach uses each peer's individual share ratio to deny-list free-riding peers, encourage cooperation, and provide fairness for new participants. Deny-listing is conducted by tracker peers. A peer can hence only retrieve data if it is providing data at the same time. No reputation value is maintained; only the just-in-time share ratio is considered. Young peers need to ramp up their share-ration incrementally, such as only small data chunks are provided initially. Simulations using PeerSim and 80 peers are used to validate the effectiveness of deny-listing free-riding peers and fair cooperation.

A.4.6 Undefined Payoff Scheme.

"A Formal Model Based on Game Theory for the Analysis of Cooperation in Distributed Service Discovery". Mart ınez-C anovas et al. [81] propose a repeated game model to analyze under which circumstances cooperation among rational agents emerges for distributed service discovery. The authors anticipate a reward for forwarding search queries and weigh that against the cost of these actions. They stay on an abstract level and don't specify a concrete type of reward but repeatedly speak of payoffs, so it is reasonable to assume that a virtual currency was intended. Their game theoretical model facilitates the repeated game framework to formalize the agents' interactions and analyze when cooperation is in a stable state of the system. They tested the model by numerical simulations, determined when the strategy reaches a Nash equilibrium, and found out that there are reward values that stimulate cooperation but don't lead to an overall positive average utility value of the system.

A.5 Primary Review Paper Selection

Citation Key	Sim	DOI	Not Primary Research	IM Core Contribution	Computational Resources	Decentralized
ChenSPA20	☑	10.1016/j.ipm.2020.102370	☐	☑	☑	☑
SunLYW20	☑	10.1109/TWC.2020.2999721	☐	☑	☑	☑
ShenTGQ20	☑	10.1007/s11761-020-00297-8	☐	☑	☑	☑
FangSWL20	☑	10.1016/j.ins.2019.07.030	☐	☑	☑	☑
LuoCZC20	☑	10.1109/TWC.2020.2967371	☐	☑	☑	☑
WangSML20	☐	10.1109/TPDS.2019.2933416	☑	☑	☑	☑
ZhangZ20	☐	10.1109/TIFS.2019.2955891	☐	☑	☐	☑
YanCFQ20	☐	10.1109/ACCESS.2020.2979323	☐	☑	☑	☐
FanYL20	☐	10.1016/j.elerap.2019.100897	☐	☑	☐	☐
KangXNX19	☑	10.1109/JIOT.2019.2940820	☐	☑	☑	☑
LinLWL19	☑	10.1109/TII.2019.2917307	☐	☑	☑	☑
HaqF20	☑	10.1007/s11276-019-02167-4	☐	☑	☑	☑
RajuC19	☐	10.1007/s10586-017-1607-8	☐	☐	☑	☑
LiJGL19	☑	10.1016/j.knosys.2018.12.024	☐	☑	☑	☑
LiuZ19	☐	10.1186/s13638-019-1340-5	☑	☑	☑	☑
WongLEW19	☑	10.3966/160792642019092005011	☐	☑	☑	☑
MousaviK19	☑	10.1109/ACCESS.2019.2909740	☐	☑	☑	☑
ZhangZY18	☑	10.1007/s11277-018-5438-6	☐	☑	☑	☑
AslaniHD18	☑	10.1007/s11042-017-5051-9	☐	☑	☑	☑
LiZXZ18	☑	10.1109/ACCESS.2018.2883316	☐	☑	☑	☑
HeLCL18	☑	10.1109/ACCESS.2018.2821705	☐	☑	☑	☑
JenaSP18	☐	10.1080/03155986.2017.1361198	☐	☑	☐	☑
JulesS17	☐	10.1109/TSMC.2016.2578879	☐	☑	☐	☑
TampuuMKK17	☐	10.1371/journal.pone.0172395	☐	☑	☐	☐
PadhariyaMMK17	☐	Subscription 65$	☐	☑	☑	☑
KangY17	☐	10.1016/j.comnet.2017.01.005	☐	☑	☑	☑
NasabB17	☑	ISSN: 1692-343X	☐	☑	☑	☑
EsfandiariFKT17	☐	10.3233/WEB-170360	☐	☑	☑	☑
LuWCL17	☐	10.1109/ACCESS.2016.2630736	☑	☑	☑	☑
CorazzaDG16	☐	10.1109/TVT.2016.2530702	☑	☐	☑	☑
LuWXW16	☐	10.1016/j.knosys.2016.09.002	☐	☑	☑	☐
HadzibeganovicX16	☑	10.1016/j.knosys.2016.08.024	☐	☑	☑	☑
SayitDKT16	☑	10.1007/s12083-015-0390-7	☐	☑	☑	☑
Kim16	☑	10.1002/ett.3078	☐	☑	☑	☑
XuSG16	☑	10.1109/TVT.2015.2472289	☐	☑	☑	☑
PadhariyaMM16	☑	10.1007/s12083-015-0391-6	☐	☑	☑	☑

Citation Key	Sim	DOI	Not Primary Research	IM Core Contribution	Computational Resources	Decentralized
GoncalvesCVA16	☑	10.1007/s00530-014-0434-5	☐	☑	☑	☑
IsmailQS16	☑	10.1109/TVT.2015.2409191	☐	☑	☑	☑
GuoKJD16	☐	10.1007/s11227-016-1648-4	☑	☑	☑	☑
JainKG16	☑	10.1109/TWC.2015.2480392	☐	☑	☑	☑
ZhaoCYH16	☐	10.4018/IJWSR.2016010101	☐	☑	☑	☐
MengLHW16	☐	10.1007/s11277-015-3118-3	☐	☑	☑	☐
MartinezCanovasDBH16	☑	10.1016/j.ins.2015.06.043	☐	☑	☑	☑
CuiLWR15	☐	10.1002/cpe.3207	☑	☑	☑	☑
XinKangY15	☑	10.1109/TMC.2014.2343628	☐	☑	☑	☑
JinK15	☑	10.1016/j.comnet.2015.02.006	☐	☑	☑	☑
KurveGMK15	☑	10.1007/s12083-013-0206-6	☐	☑	☑	☑
ZuoZ14	☑	10.1002/dac.2556	☐	☑	☑	☑
ZouC14	☑	10.1007/s11042-013-1621-7	☐	☑	☑	☑
HuWZW14	☑	10.1007/s12083-013-0198-2	☐	☑	☑	☑
TianYZL14	☑	10.1016/j.comnet.2014.08.010	☐	☑	☑	☑
DeSalesMAP14	☑	10.1109/TCE.2014.7027333	☐	☑	☑	☑
JinTengBXZ14	☑	10.1109/TPDS.2013.158	☐	☑	☑	☑
ChangPXW14	☑	10.1007/s11227-014-1204-z	☐	☑	☑	☑
delValRB14	☑	10.1080/01969722.2014.894848	☐	☑	☑	☑
AriasCabarcosAGM14	☐	10.1007/s11277-013-1338-y	☐	☑	☐	☑
WeijieWuML14	☑	10.1109/TPDS.2013.94	☐	☑	☑	☑
WangCC14	☑	10.1109/TWC.2013.120413.130670	☐	☑	☑	☑
XianzhongXHB13	☐	10.1109/CC.2013.6723885	☐	☐	☐	☑
LinYYC13	☐	10.1080/00207721.2012.670295	☐	☑	☐	☑
CarraMSS13	☑	10.1109/JSAC.2013.SUP.0513009	☐	☑	☑	☑
KimSCI13	☐	10.1109/TWC.2013.071913.121996	☐	☑	☐	☑
HuDLW13	☑	10.1016/j.future.2012.08.008	☐	☑	☑	☑
HongXuB13	☐	10.1109/TMC.2012.62	☐	☑	☑	☐
PadhariyaMMK13	☑	10.1016/j.comcom.2013.01.012	☐	☑	☑	☑
MeulpolderME13	☑	10.1002/cpe.2856	☐	☑	☑	☑
delValRB13	☑	10.1016/j.jss.2012.09.031	☐	☑	☑	☑
MasegosaPV13	☐	10.1016/j.ins.2012.07.002	☐	☑	☐	☐
DingHWS13	☐	10.1080/18756891.2013.761777	☐	☐	☐	☑
BelmonteDPR13	☑	10.1016/j.jnca.2012.04.010	☐	☑	☑	☑
ZhangA13	☑	10.1016/j.future.2011.06.005	☐	☑	☑	☑
ZhangCMY12	☑	10.1016/j.jpdc.2012.08.003	☐	☑	☑	☑

Citation Key	Sim	DOI	Not Primary Research	IM Core Contribution	Computational Resources	Decentralized
PalomarARZ12	☐	10.1016/j.comnet.2012.08.012	☐	☐	☑	☑
NoroozOliaeeHG12	☐	10.1109/TWC.2012.080212.101834	☐	☐	☐	☑
GramagliaUM12	☑	10.1016/j.comcom.2012.04.017	☐	☑	☑	☑
RiusECS12	☑	10.1016/j.simpat.2012.02.007	☐	☑	☑	☑
ZhaoLC12	☐	10.1109/TNET.2011.2161770	☑	☑	☐	☑
WuCW12	☑	10.1109/LCOMM.2012.012412.11220	☐	☑	☑	☑
VakiliK12	☑	10.1016/j.jnca.2011.11.004	☐	☑	☑	☑
WuLQL12	☑	10.1145/2089085.2089091	☐	☑	☑	☑
TaghipourF12	☐	10.1080/0951192X.2011.646307	☐	☑	☐	☑
WangNVM11	☐	10.1016/j.comnet.2011.07.011	☑	☐	☑	☑
OkamotoTT11	☐	10.1587/transcom.E94.B.2732	☐	☐	☐	☐
RahmanVHP11	☐	10.1145/2043164.2018458	☐	☐	☑	☑
ZhouGJN10	☐	10.1587/transcom.E93.B.3656	☐	☐	☑	☐
YangSZ10	☐	10.1631/jzus.C0910727	☐	☑	☐	☑
XiaoSuD10	☐	10.1109/MIC.2010.119	☑	☑	☑	☑
MondalKK10	☑	10.1007/s10619-010-7063-6	☐	☑	☑	☑
ParkPK10	☑	10.1016/j.comnet.2009.10.022	☐	☑	☑	☑
AllenCW10	☑	10.1145/1671948.1671952	☐	☑	☑	☑
SirivianosXJ09	☑	10.1109/TNET.2009.2021655	☐	☑	☑	☑
LiYS09	☑	10.1016/j.elerap.2009.04.007	☐	☑	☑	☑
WangYL09	☐	10.1109/LCOMM.2009.091519	☐	☐	☑	☑
MondalMK09	☑	10.1007/s12083-009-0035-9	☐	☑	☑	☑
PeltaCG09	☐	10.1002/int.20363	☐	☑	☐	☑
ContrerasGAM09	☐	10.1016/j.dss.2008.12.005	☐	☑	☐	☐
LinZL09	☑	10.1109/TMM.2009.2012915	☐	☑	☑	☑
SharpSS09	☐	10.1109/TCOMM.2009.0901.070003	☐	☐	☑	☐
SatoHYS08	☐	10.1093/ietcom/e91-b.12.3821	☐	☑	☑	☑
LijuanXiaoYNZ08	☑	10.1109/TPDS.2007.70791	☐	☑	☑	☑
GuangTanJ08	☑	10.1109/TPDS.2007.70778	☐	☑	☑	☑
Manzatod08	☑	10.1007/s12083-007-0004-0	☐	☑	☑	☑
KarakayaKU08	☑	10.1016/j.comcom.2007.08.010	☐	☑	☑	☑
LianPYZ08	☐	10.1002/cpe.1190	☑	☑	☑	☑
PianesePKB07	☑	10.1109/TMM.2007.907466	☐	☑	☑	☑
DeshpandeL07	☐	10.1007/s10514-007-9044-9	☐	☐	☐	☑
KooL00	☐	10.1007/s11235-006-9021-1	☐	☑	☑	☑
MaLLY06	☑	10.1109/TNET.2006.882904	☐	☑	☑	☑

Citation Key	Sim	DOI	Not Primary Research	IM Core Contribution	Computational Resources	Decentralized
ChenSPA20	☑	10.1016/j.ipm.2020.102370	☐	☑	☑	☑
SunLYW20	☑	10.1109/TWC.2020.2999721	☐	☑	☑	☑
ShenTGQ20	☑	10.1007/s11761-020-00297-8	☐	☑	☑	☑
FangSWL20	☑	10.1016/j.ins.2019.07.030	☐	☑	☑	☑
LuoCZC20	☑	10.1109/TWC.2020.2967371	☐	☑	☑	☑
WangSML20	☐	10.1109/TPDS.2019.2933416	☑	☑	☑	☑
ZhangZ20	☐	10.1109/TIFS.2019.2955891	☐	☑	☐	☑
YanCFQ20	☐	10.1109/ACCESS.2020.2979323	☐	☑	☑	☐
FanYL20	☐	10.1016/j.elerap.2019.100897	☐	☑	☐	☐
KangXNX19	☑	10.1109/JIOT.2019.2940820	☐	☑	☑	☑
LinLWL19	☑	10.1109/TII.2019.2917307	☐	☑	☑	☑
HaqF20	☑	10.1007/s11276-019-02167-4	☐	☑	☑	☑
RajuC19	☐	10.1007/s10586-017-1607-8	☐	☐	☑	☑
LiJGL19	☑	10.1016/j.knosys.2018.12.024	☐	☑	☑	☑
LiuZ19	☐	10.1186/s13638-019-1340-5	☑	☑	☑	☑
WongLEW19	☑	10.3966/160792642019092005011	☐	☑	☑	☑
MousaviK19	☑	10.1109/ACCESS.2019.2909740	☐	☑	☑	☑
ZhangZY18	☑	10.1007/s11277-018-5438-6	☐	☑	☑	☑
AslaniHD18	☑	10.1007/s11042-017-5051-9	☐	☑	☑	☑
LiZXZ18	☑	10.1109/ACCESS.2018.2883316	☐	☑	☑	☑
HeLCL18	☑	10.1109/ACCESS.2018.2821705	☐	☑	☑	☑
JenaSP18	☐	10.1080/03155986.2017.1361198	☐	☑	☐	☑
JulesS17	☐	10.1109/TSMC.2016.2578879	☐	☑	☐	☑
TampuuMKK17	☐	10.1371/journal.pone.0172395	☐	☑	☐	☐
PadhariyaMMK17	☐	Subscription 65$	☐	☑	☑	☑
KangY17	☐	10.1016/j.comnet.2017.01.005	☐	☑	☑	☑
NasabB17	☑	ISSN: 1692-343X	☐	☑	☑	☑
EsfandiariFKT17	☐	10.3233/WEB-170360	☐	☑	☑	☑
LuWCL17	☐	10.1109/ACCESS.2016.2630736	☑	☑	☑	☑
CorazzaDG16	☐	10.1109/TVT.2016.2530702	☑	☐	☑	☑
LuWXW16	☐	10.1016/j.knosys.2016.09.002	☐	☑	☑	☐
HadzibeganovicX16	☑	10.1016/j.knosys.2016.08.024	☐	☑	☑	☑
SayitDKT16	☑	10.1007/s12083-015-0390-7	☐	☑	☑	☑
Kim16	☑	10.1002/ett.3078	☐	☑	☑	☑
XuSG16	☑	10.1109/TVT.2015.2472289	☐	☑	☑	☑
PadhariyaMM16	☑	10.1007/s12083-015-0391-6	☐	☑	☑	☑

Citation Key	Sim	DOI	Not Primary Research	IM Core Contribution	Computational Resources	Decentralized
XiaoZSG12	☑	10.1109/TPDS.2011.167	☐	☑	☑	☑
ShenLXL11	☐	10.1016/j.jnca.2010.06.003	☐	☐	☑	☑
WangNVM11a	☐	10.1016/j.comcom.2010.01.021	☐	☐	☑	☑
Kim10a	☑	10.1587/transinf.E93.D.3403	☐	☑	☑	☑
LiuPLC10	☑	10.1007/s12083-009-0043-9	☐	☑	☑	☑
BianchiniMAB10	☐	10.1007/s11280-009-0080-6	☐	☐	☑	☑
ChengLJM06	☑	10.1007/11807964_2	☐	☑	☑	☑
BenayouneL04	☐	10.1007/978-3-540-30197-4_33	☑	☑	☑	☑
KamvarSG03	☑	10.1007/978-3-540-45209-6_171	☐	☑	☑	☑
PalKTM22	☑	10.1186/s13677-022-00280-y	☐	☑	☑	☑
LuQQL22	☐	10.1109/TMC.2020.3008315	☐	☑	☐	☑
ZhangDMY21	☑	10.14778/3476311.3476313	☐	☑	☑	☑
YanMCY21	☐	10.1016/j.cor.2020.105130	☐	☑	☐	☑
XuLSL21	☑	10.1109/JIOT.2020.3025151	☐	☑	☐	☑
SinghaS21	☑	10.1007/s12083-021-01086-6	☐	☑	☑	☑
RiahlaGTH21	☐	10.4018/IJBDCN.286704	☐	☑	☑	☑
PanD21	☐	10.1155/2021/9947360	☐	☑	☐	☑
HeTF21	☐	10.1108/DTA-08-2020-0181	☐	☑	☐	☑
BaiDL21	☐	10.1155/2021/7500639	☐	☑	☐	☑
AokiLR21	☐	10.1109/MCOM.001.2001241	☐	☐	☐	☑
AnsariPGA21	☑	10.1007/s11042-021-10709-2	☐	☑	☑	☑
AlRidhawiAJ21	☑	10.1145/3419104	☐	☑	☑	☑
Adamu21	☑	10.1109/ACCESS.2021.3092277	☐	☑	☑	☑
WeiWL20	☑	10.3390/electronics9020215	☐	☑	☑	☑
MalikK20	☐	10.1109/ACCESS.2020.3046097	☐	☑	☐	☑
AslNajafiYN22	☐	*10.1016/j.compind.2021.103582*	☐	☑	☐	☑
LiuJ20	☐	10.1108/IMDS-05-2020-0295	☐	☑	☐	☑
BhattacharyaG20	☑	10.4018/IJSSCI.2020010104	☐	☑	☑	☑
LinWBL22	☑	10.1109/JIOT.2020.3024246	☐	☑	☑	☑
ThiKimLSN22	☐	10.1109/ACCESS.2022.3170709	☐	☑	☐	☑
ZenggangXXS22	☐	10.1007/s11265-022-01768-1	☐	☑	☑	☐
JaimanPU22	☑	10.1371/journal.pone.0266624	☐	☑	☑	☑
HuangZWL22	☐	10.23919/JCC.2022.07.022	☐	☐	☐	☐

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Received 3 June 2022; revised 31 October 2022; accepted 12 December 2022