

Appendix B Karma & Alternatives

In different literature fields, Karma is not employed as resource allocation mechanism, but in a multitude of other applications.

Karma is a network protocol and self-coordination mechanism for file resource sharing in large systems such as P2P computer networks.

Protocols are a set of predefined, formal rules which have to be adhered to by participants of some activity or process [1]. There are different protocol types, ranging from festive, diplomatic to communication protocols. Communication protocols, also known as network protocols, are protocols used by computers to exchange data (information which is encoded in a predefined format) over a network between two or more peers. For each peer, the communication protocol defines syntax, alphabet & language, order, and channel [1].

Networks are systems that can be modelled as graphs (a set of nodes and edges), where entities represent discrete objects that are related to each other. Networks are part of research in many fields ranging from computer networks, social networks, biological networks, semantic networks, to economic networks [2, 3].

Computer networks are networks of computers. Computers are usually connected to computer networks to share resources [4]. The physical and geographic connection (link) of computers in a network is referred to as network topology. Amongst the most common topologies, one differentiates bus networks, star networks, ring networks, mesh networks, fully connected networks, and tree networks [5].

Mobile networks are networks of computers that are connected wirelessly. One usually differentiates mobile ad-hoc networks (MANETs), where nodes are connected via mobile (vehicle-based) radio connection, and cellular networks, where nodes are connected via a cellular radio tower that covers a certain geographic area (the cell) [6].

Overlay networks are virtual networks that are built on top of other networks, and connect their nodes with virtual or logical links [7, 8]. Overlay networks enable distributed systems such as enterprise networks (intranets), the internet, internet of things and many others.

Distributed systems are computer networks on a overlay network to coordinate actions through communication [9, 10], and one usually differentiates four types of distributed systems in computer networks [11]: **client-server**, **three-tier**, **n-tier** and **peer-to-peer (P2P)**. In the client-server model, clients request resources from a server. In the three-tier model, clients request resources from a middle-tier that stores information on which client has access to which resource, and then in case of necessary authentication, forwards the request to a server that offers the resources. In the n-tier model there are multiple middle-tier servers, which is quite common in enterprise architectures. While the first three models are commonly used in commercial applications, the peer-to-peer model, in which every participant both provides and consumes resources, is more common in noncommercial, decentralized applications.

One usually differentiates **distributed and decentralized systems**, where the former means that a system spans a large number of nodes of a network, and the latter means that there is no central control / coordination / hierarchical organisation for these systems [12].

Karma is a resource allocation mechanism & sharing algorithm.

Resources are entities in our environment that enable to achieve goals, and can be grouped into: material and immaterial, renewable and non-renewable [13]. **Goods** are (processed) resources that (directly) satisfy human wants and needs, and provide utility to (production) processes [14].

Scarce resources are usually shared across networks. In traffic networks, resources such as priority at rider hailing, intersections or lanes can be shared [15–17]. In telecommunication networks, bandwidth and traffic volume can be shared. In (renewable) energy grid networks, producers supply many consumers with energy. In (economic, business) production & supply chain networks, supplying companies deliver their products to their customers. In computation grids, such as clouds, data centers and edge computing, computation jobs and VMs are managed within a cluster [18]. In computer networks one shares computer resources, such as contents (streams, files), memory space (disk storage, RAM), computation power (CPU), network access [19, 20], and network routing and packet forwarding [21, 22]. The most prominent examples include, in the aforementioned order, the file sharing systems Gnutella [23] and BitTorrent [24], the global-scale persistent storage OceanStore [25], and the distributed computing platforms Folding@Home, Genome@Home [26] and Seti@Home [27].

Resource allocation can be seen as a coordination mechanism for sharing scarce resources across networks. The question of how to allocate resources is a central question of economics [28], where many mechanisms have been approached: mainly one differentiates between market mechanisms and a regulated control mechanisms.

Karma is a self-contained, economic model, system, and proposal, that employs auctions and monetary markets.

Economics is the science to study the production, consumption and allocation of resources [13, 29], and focuses on two areas: (i) describing the behaviour of system participants such as single agents in markets (microeconomics), and (ii) describing an economic system on aggregated level to describe phenomena such as savings, economic output, inflation, growth and how governmental interaction can affect these (macroeconomics) [29].

Markets are spaces in which two groups of participants (suppliers and demanders) meet to negotiate and trade resources, and to make their own decisions [29]. Resources have a utility to the demander, which is why they are ready to exchange something (the cost) in order to receive the resource from the supplier. In early **barter markets** resources were exchanged for other resources, e.g. bread was traded for fish, while in **monetary markets** resources are exchanged for a mean of payment that is universally accepted by all market participants (**money**). In case resources are scarce, demanders are competing and costs rise, while in the opposite case, suppliers are competing and costs sink. The free and self-reliant decision making of market participants is a central concept to markets and includes to choose a peer to trade and negotiate with, and the assessment of how much cost one is ready to accept for a certain utility a resource offers. Markets can be seen as peer-to-peer systems for resource allocation.

Auctions represent a form of negotiation and trading peer selection in markets, where demanders can offer bids (costs they are ready to take) for a specific resource, and suppliers can based on the list of offers decide which demander(s) to choose in order to supply their stock of resources. Amongst the most common auction types the following five [30] auction types shall be discussed: (Open ascending) English auctions, (Open descending) Dutch auctions, Sealed-bid auctions, Vickrey auctions, and Double auctions. In English and Dutch auctions, bidders have transparency over the bids of others. In English auctions, buyer-bidding starts with a low price and increases, until no more bids are placed; consecutively the highest bid will win. In Dutch auctions, seller-bidding starts with a high price and decreases, until a buyer is willing to buy. In Sealed-bid auctions, the buyer-bidding takes place isolated and secret, only the seller has transparency over all bids; a common example are governmental construction contracts. The Vickrey auction is special type of Sealed-bid auctions, as the second-highest price wins the auction, and usually causes bidders to bid higher than they are comfortable with. The Double auction takes place on a board, list or order book; both buyers and sellers post acceptable prices and amounts to a board, and trades are executed only at desired prices and amounts; a common example is the stock exchange.

Credit is a form of **trust** and credibility, that allows monetary market participants to trade and exchange resources across temporal distances. Suppliers offer (useful) resources to demanders against money (which itself is not a useful resource). After a certain amount of time, the supplier himself can use the money to exchange it to (for himself) useful resources. Thus, the supplier needs to trust that this money can be used after a certain amount of time.

As a complementary side-note, Saito et al. [31] describe Karma as a possible enabler for local production and local consumption practices - a distributed and decentralized economic practice.

Karma is a solution to common problems in peer-to-peer networks, such as the free-riding problem, the hidden actions problem, the lotus eater attack, Sybil and Eclipse attacks, spoofing attacks and thus represents a mean to counterfeited selfish and malicious behaviours such as cheating.

Unfortunately, it is reported that a certain amount of participants is exhibiting undesirable, selfish or even cheating behaviours that peer-to-peer networks for resource allocation suffer from, which is leading to certain problems such as the free-riding problem, the hidden actions problem, lotus eater attacks, Sybil attacks, eclipse attacks and spoofing attacks.

The free-riding problem describes the selfish behaviour of (over-)consuming public goods - goods that are uncontrollably accessible for everyone - at no cost - meaning without giving something back in return. Economic examples include the pollution of the environment in countries without regulating legislation. In the context of P2P systems, it is reported that more than 70% of all users in file-sharing platforms such as Gnutella and BitTorrent do only consume (downloading files) and not share any content [32].

The hidden actions problem (also known as principal-agent problem) describes that actions taken by a participant to an exchange cannot be verified by the other. One example is the patient doctor relationship, in which the patient (principal) due to the lack of his knowledge cannot verify if the doctor's (agent) treatment is the medical most reasonable choice rather than the financially most reasonable choice. In the context of P2P systems, during the exchange of contents or payments, without any security mechanisms, one participant could receive a content and then just not pay, or another participant could receive a payment and then just not share [33].

The lotus eater attack describes the selfish behaviour of supplying only some peers (friends) while ignoring others to achieve a certain goal, and to disappear afterwards [34].

The Sybil attack describes the malicious behaviour of an agent to act with multiple active fake identities in order to hide previous misbehaviour in new encounters [35]. This can happen in P2P systems that are based on trust or reputation to counteract the free-riding problem.

The eclipse attack describes the malicious behaviour of isolating a certain victim with multiple identities by dominating and excluding its neighborhood from the main network [35].

The spoofing attack describes the malicious behaviour of an agent to pretend to be someone else in order to gain trust and access by and to others [36].

Karma is a fairness and altruism enforcing mechanism, as it stimulates, motivates, induces, encourages, enforces and promotes cooperation, contribution and participation. It is doing so by introducing an incentive scheme to peer-to-peer networks. Moreover, it can be seen as a form of contention management and a new class of games from a game theoretical perspective and as a mean to identify, to punish and to exclude selfish and Sybil agents.

Fairness or distributive justice in the context of resource allocation describes the socially just, morally preferable resource allocation across agents or groups of agents [37]. Distributive justice is a question heavily discussed in philosophy, sociology, and economics. Different concepts exist: procedural justice, egalitarianism, fairness of results (outcomes), distributivism (also distributism), and economy for the common good. **Procedural justice** defines an allocation of resources as just, as long as (legislative) rules and procedures during the trading process apply equally for all participants [38]. **Egalitarianism** defines fair as equal, meaning that societies with agents that all own the same are fair [39]. **Fairness of results (outcomes)** defines a fair allocation of resources as optimal, if the outcomes / results of the economic production maximizes the average welfare of each member of the society [40]. This implies the necessity of an optimal inequality, meaning an uneven allocation of (production) resources can be desirable, as the outcome (produced products) is better for everyone; e.g. countries that are more efficient in converting certain production factors to products with utility, should be given more of these production factors, so that in total more products can be produced, that are in turn more accessible and available to everyone as a result ¹. Different political and economic models relate to this fairness concept, such as capitalism, and the economy for the common good. **Distributivism**, after Pope Leo XIII and Pope Pius XI, advocates a decentralized, de-concentrated allocation of (production) resources, contrary to capitalism, where companies own production factors, and socialism, where the government owns all production factors [41, 42]. Distributivism aims in achieving monopoly free markets and a reciprocal society. **Economy for the Common Good** is an economic distributive justice theory focusing on public goods and advocating a resource allocation to optimize environmental impact, societal welfare and sustainability altogether [43]. In addition to that, Forsyth differentiates seven distributive norm types [44]: (i) equality, (ii) equity, (iii) power, (iv) need, (v) responsibility, (vi) entitlement, (vii) utilitarian. *Equality* refers to the earlier discussed egalitarianism. *Equity* considers a resource allocation as fair, if agents get an share of the output equal to share they gave as an input. *Power* advocates a resource allocation with more concentration on those holding power. *Need* advocates a resource allocation with more concentration on those being in more need. *Responsibility* advocates a resource allocation with more concentration on those having more (societal) responsibility. *Entitlement* advocates a resource allocation with more concentration on those being (legally) entitled (by societal norms). *Utilitarian* refers to the earlier discussed fairness of results (outcomes).

The literature on Karma generally differentiates between two approaches to solve the problems inherent to peer-to-peer networks: (i) incentive schemes that encourage / enforce cooperation and contribution [45–51], and (ii) mechanism to identify and punish / exclude selfish and Sybil agents [36, 52–57].

The incentive scheme that Karma offers is classified and described as in many different ways. Karma offers a **reputation based** incentive scheme, as the amount of Karma an agent possesses shows his contributions in the past and thus generates trust [58–60]. Karma offers a **mutual, monetary, credit, price, scrip, payment based** incentive scheme with a currency that is free-riding-proof [32, 55, 61–86]. Karma offers a **indirect-reciprocity** incentive scheme, as peers perform services for others indifferently (not distinguishing or discriminating them) to gain reputation for their own needs [34, 87, 88]. Karma offers a **direct-reciprocity based** incentive scheme, meaning they can choose with whom to cooperate by discriminating and penalizing selfish peers and by rewarding altruistic peers [89–91]. Karma offers a **persistent-history based** incentive scheme, as the history of actions and thus the reputation of an agent is persistent (or partially persistent) and available (or partially available) to all participants [34, 87, 88]. Karma offers a **shared-history based** incentive scheme, as the participants do not track their experiences they had with certain peers themselves, but by sharing their experiences publicly through the Karma score system [92–95].

Karma is a global, decentralized, distributed and secure technology that offers a reputation and credibility system, a trust system, a secure accounting and accountability system, a virtual, electronic, crypto currency system, a micro-payment system with a lightweight currency, a monetary, electronic, peer-to-peer trading system, a token economy, a non-tradeable, non-monetary credit scheme, and a scrip system. Karma is a technology based on other technologies such as security propagating technologies, information replicating and disseminating technologies, and blockchain technologies such as proof-of-work for minting with cryptographic puzzles, distributed ledger, hash tables and smart contracts.

¹This is a core assumption of international trade.

In order to apply the solutions and incentive schemes Karma offers to solve the problems inherent to peer-to-peer systems, certain infrastructure technology is necessary, namely a reputation and accounting system that is secured by cryptography and block-chain in order to make the infrastructure attack proof.

Accounting is the processing of economically-relevant, property-rights information, e.g. the amount of money, the real estate, the land, or the intellectual property rights an individual person, corporation or organization owns [96]. Karma is an accounting system to track the reputation / contributions of participants in peer-to-peer networks [97]. Karma itself uses a secure, global, distributed, decentralized crypto-currency to realize the accounting system [98].

A crypto-currency is an intangible, digital token, and its ownership is recorded using a distributed ledger infrastructure - the blockchain, using strong cryptography technologies. The original Karma paper [99] plays an important role in the crypto-currency and blockchain literature, as it made large contributions by proposing the combination of certain security mechanisms and technologies in order to achieve a secure currency; Karma is seen as an important ancestor [98, 100] to Bitcoin [101]. The probably most important contribution in this context was the proposition of proof-of-work during minting.

Minting / mining a crypto-currency is the process of generating new coins and can usually be achieved by proof-of-stake (by owning a large share of all coins during consensus mechanisms), proof-of-authority (authorization to due regulation and legislation), proof-of-capacity (by providing more storage capacity for the distributed accounting system) and proof-of-work (by providing more work, such as solving a computationally hard problem such as a cryptographic puzzle) [102].

A blockchain is a continuously expandable list of data sets stored in blocks. New blocks are generated using consensus algorithms based strong cryptography, and contain information on property transactions between identities (accounts). Thus block-chains represent a distributed ledger (book of all accounts, tracking all transactions) [103].

Micropayments are payments of small amounts of money of a currency, in order to trade goods on digital markets, such as in-game currencies, software licenses, music, video, news articles etc. Micropayments are characterized to occur more frequently but with smaller amounts compared to traditional payments on markets [104, 105]. Currencies used during micropayments are therefore usually called lightweight [106, 107].

Smart contracts are contracts based on network protocols to overcome the hidden actions problems and to enforce the execution of a contract - usually one trade consisting of two transactions: one payment, and one property transaction. Due to the application of smart contracts within the Karma system, Karma is described as a non-tradeable, non-monetary credit scheme [16, 17] as the credit (trust) cannot be traded or bought externally, and only be gained within the system through contribution. This is, why Karma is also described as a self-contained economy that cannot be circumvented from the outside [108]. Karma is discussed as the first smart contract [109].

Table B1 summarizes the definitions and references of Karma in the different fields.

We compiled all documents in our literature corpus in order to determine the most relevant concepts besides Karma, and grouped them into different concept areas for each literature field, which can be found in Tables B2, B3, and B4 as a summary.

In the fields of filesharing, network & technology, and economics we found: (i) resource allocation algorithms, (ii) systems, platforms or networks that use these algorithms in applications, and (iii) certain relevant, related network protocols around Karma. Mostly all discovered resource allocation and economic concepts were tailored for the domain of computation resources. Therefore, we chose to group the resource allocation algorithms into the different resource types they were designed for. We differentiate general works (on computation resources in general), and then more specifically into content sharing & streaming such as filesharing and video streaming applications, shared storage and backups, shared computing such as CPU and GPU sharing, and shared access management and sharing of DRM (digital rights media) rights. Similar to the algorithms, most resource allocation applications we found were tailored for computation networks. An overview of applications and implementations of algorithms in non-computing network applications will be discussed in the next questions. Amongst the most prominent file sharing and shared streaming platforms we found BitTorrent [110], GnuTella [111], eDonkey2000 [112] and KaZaA [113]. Besides, we find shared storage systems such as OceanStore [114], shared routing systems such as onion routing that plays an important role in the TOR browser [115], and collaborative downloading systems such as 2Fast [116]. In addition to that, there are many different shared, collaborative computation projects, commonly known as volunteering or social computing. In these kind of networks a large number of people voluntarily offer their computation resources, e.g. to contribute to public science and social computing projects. The largest distributed computing project in history is known to be Folding@Home² [26], where at its peak a computation power of 2.43 x86 exaFLOPS was reached and thus Folding@Home was the largest, reported supercomputer³. Last but not least, we also identified several, prominent network protocols in the realm of filesharing and resource allocation as an alternative to Karma, such as MultiCast [117], SeCond [118] and RADIUS [119, 120].

²Folding@Home is dedicated to understand the folding of proteins in order to better understand diseases and drug development. <https://foldingathome.org/>.

³<https://www.extremetech.com/science/308332-foldinghome-crushes-exascale-barrier-now-faster-than-dozens-of-supercomputers>. <https://venturebeat.com/ai/foldinghome-crowdsourced-computing-project-passes-1-million-downloads-amid-coronavirus-research/>. <https://arstechnica.com/science/2020/04/how-the-pandemic-revived-a-distributed-computing-project-and-made-history/>.

In the fields of behaviour and game theory we found: (i) fairness mechanisms, and (ii) incentive schemes. Within the incentive mechanisms we differentiate barter-based incentives, economy-based incentives, and differentiated services, following the structure of [55]. In barter-based incentive schemes agents exchange resources directly, and an important aspect of this group of incentive schemes is how to select a suitable peer for the barter. Direct-reciprocity incentive schemes require an agent to store information about previous experiences with other peers. Indirect-reciprocity incentive schemes usually offer a trust or reputation system, in which agents can orient on the reputation scores of their potential peers, and in which agents usually aim to maintain a high reputation by non-selfish behaviour. This facilitates peer-selection, as previous experiences are shared in the reputation system. In the economy-based incentive schemes, agents trade resources in for some form of tokenized currency, in order to buy resources at a later point; in this context the question of peer-selection vanishes, but multiple questions arise, such as pricing and auction mechanisms. While in barter-based schemes, one agent exchanges resources with another, selected peer, in economic-based schemes one agent can either set a price according to subjectively perceived value and see if there are still demanding peers in a certain period, or announce the offered resource and receive different bids by peers, and then select the peer with the highest bid. Economy-based schemes can be further classified into centralized and decentralized, depending on how the monetary currency, and payment system is organized. An advantage of economic-based over barter-based incentive schemes is also, that the amount of received entities such as currency, when trading in, is more related to the value of the resource provided; in barter-based contexts that is not necessarily the case. Some scholars also argue, that indirect-reciprocity-based incentive schemes with a reputation system can be seen as economic, as reputation can be seen as yet another currency [121]. Differentiated services use an approach considered as game-theoretic [83, 122–124], where service quality is reduced or throttled in case of misbehaviour of one agent's peer; for example the network bandwidth shared with a peer can be reduced in case of misbehaviour [125, 126].

In the field of blockchain, we found: (i) accounting systems, (ii) trust systems, (iii) reputation & credibility systems, (iv) cryptocurrencies, and (v) micropayment systems. Accounting systems are usually used to keep track of property rights and are applied in currencies and reputation systems; they can be classified into receipt-based, token-based, and Proof-of-Work-based accounting systems [127]. Trust systems are systems that enable agents to trust their peers through cryptographic technology, either by complicating or impeding cheating during resource exchange [99, 128, 129]. Reputation & credibility systems such as XREP [130], EigenRep [131] or BarterCast [132] keep record of the behaviours and agents' misbehaviours, their reputation score and usually apply an accounting system to achieve this. Trust and reputation systems have a lot in common, and several concepts can be seen as both [131, 133]. In addition to that, numerous cryptocurrencies and micropayment systems became possible by the contributions of Karma, such as Bitcoin [101], Ethereum [134], and Offline-Karma [128], to name a few.

Literature Field	Definition of Karma	References
Filesharing	<ul style="list-style-type: none"> > File sharing system for P2P networks > Self-coordination mechanism > Distributed, federated, large-scale, generic, wide-area system 	[135–143] [15] [144, 145]
Network & Technology	<ul style="list-style-type: none"> > Network protocol > Peer-to-peer system 	[93, 146–150] [151–153]
Economics	<ul style="list-style-type: none"> > Resource allocation mechanism > Market mechanism > Trading mechanism > Auction mechanism > Economic model 	[18, 108, 145, 154–163] [28, 82, 163–168] [169, 170] [171, 172] [31, 55, 158, 173–187]
Behaviour	<ul style="list-style-type: none"> > Solution to free-riding problem > Solution to hidden actions problem > Solution to lotus eater attack > Solution to Sybil and Eclipse attack > Solution to spoofing attack > Mean to counteract selfish behaviours such as cheating 	[32, 48, 51, 52, 57, 60, 60, 62, 65, 66, 68, 73, 74, 84, 89, 122, 132, 142, 145, 146, 149, 150, 152, 180, 185, 186, 188–250] [33, 166] [34] [35, 53, 251, 252] [36, 52, 53] [54–57]
Game Theory	<ul style="list-style-type: none"> > New class of games > Fairness and altruism enforcing mechanism > Cooperation and contribution stimulating mechanism > Incentive scheme (general) > Incentive scheme, reputation based > Incentive scheme, monetary based > Incentive scheme, indirect-reciprocity based > Incentive scheme, direct-reciprocity based > Incentive scheme, persistent-history based > Incentive scheme, shared-history based > Contention management scheme > Mean to identify, to punish, and to exclude selfish and Sybil agents 	[253] [45–51] [18, 79, 83, 123, 254–267] [79, 100, 106, 121–124, 129, 132, 154, 162, 173, 175, 179, 183, 184, 188, 197, 203, 207, 208, 214, 228, 236, 241, 245, 246, 250, 256, 258, 263, 268–342] [58–60] [32, 55, 61–86] [34, 87, 88] [89–91] [34, 87, 88] [92–95] [56] [36, 52–57]
Blockchain	<ul style="list-style-type: none"> > Reputation system > Trust system > Accounting system > Crypto currency system > Micropayment system > Monetary trading system > Token economy > Non-tradeable, non-monetary credit scheme > Scrip system > Security, information replicating and disseminating technology > Blockchain technology, proof-of-work, distributed ledger > Smart contracts 	[47, 58, 71, 72, 75, 87, 91, 132, 143, 211, 212, 217, 232, 247, 250, 270, 314, 336, 337, 343, 343–352] [102, 339, 353, 354] [28, 97, 127, 152, 177, 182, 224, 230, 307, 337, 353, 355–367] [11, 58, 64, 65, 67, 98, 100, 128, 147, 156, 165, 166, 168, 178, 179, 197, 218, 219, 244, 259, 279, 283, 286, 289, 290, 290, 302, 304, 307, 331, 368–422] [60, 60, 62, 74, 79, 93, 106, 151, 170, 176, 189, 205, 223, 230, 232, 234, 235, 240, 242, 247, 248, 254, 262, 266, 284, 285, 291, 293, 301, 307, 330, 335, 337, 353, 356, 373, 392, 404, 411, 414, 423–442] [58, 146, 165, 183, 184, 187, 188, 313, 334, 419, 443–445] [69, 86, 97, 223, 272, 317, 340, 446–451] [16, 17] [34, 174, 194, 196, 199, 200, 202, 215, 221, 231, 233, 287, 388, 452] [102, 281, 453, 454] [35, 93, 148, 151, 369, 377, 393, 395, 411, 455–457, 457–470] [109, 467, 470–474]

Table B1 Definitions of Karma in different fields

Literature Field	Concept Area	Alternative Concepts to Karma
Filesharing Network & Technology Economics	Resource allocation mechanisms > General (computation resources)	Tycoon [475], SWIFT [176], eOS [476], SHARP [477], BAR gossip [478], i-WAT [479], Market-Like Computation Grids [480], MMAPs [449], SOA Accountability Architecture [481], PlanetLab [482], Egg [483], Irwin et al. 2004 [484], Shneidman et al. 2005 [379]
	> Content sharing & streaming	SplitStream [485], SeAl [486], KaZaA [113], GnuTella [111], BitTorrent [110], AntFarm [162], Dandelion [304], Bullet [487], SCRIBE [488], Liu et al. 2007 [489]
	> Shared storage & backups	BOINC [490], Samsara [491], Hadoop [492], FAR-SITE [493], PAST [494], PASTICHE [495], Lillibridge et al. 2003 [496]
	> Shared computing	OurGrid [497], BOINC [490], CompuP2P [365], Nimrod [498], Nimrod-G [499], MapReduce [500], GridletEconomics [343], Mirage [501], Mitra et al. 2005 [159]
	> Shared access management	SeAl [486], Rajasekaran et al. 2005 [502]
	Resource allocation applications > Content sharing & streaming	Napster [503], BitTorrent [110], GnuTella [111], KaZaA [113], eDonkey2000 [112], Kademia [504], Samsara [491], SHARP [477],
	> Shared storage & backups	OceanStore [25]
	> Shared routing	SPROUT [505], Tribler [506], TOR Onion Routing [115]
	> Collaborative downloading	2Fast [116]
	> Volunteering & social computing	Folding@Home [26], BOINC [490], Genome@Home [26], Seti@Home [507], Rosetta@Home [508], AlphaFold [509], POEM@home [510], MindModeling@Home [511], Einstein@home [512], Find-a-drug [513], ClimatePrediction.networks [514], GIMPS [515], GFPS [515], OurGrid [497], POPCORN [516], FreeHaven [517]
	Network protocols	CREW [518], SeCond [118], POPCORN [516], OneHopReputation [347], Kadcast [148], Bread & Pudding [519], RADIUS [119, 120], eDonkey2000 [112], BitTorrent [110], Gnutella [111], FastTrack [520], EigenTrust [131], Maze [521], MultiCast [117]

Table B2 Alternative concepts to Karma (1 / 3)

Literature Field	Concept Area	Alternative Concepts to Karma
Behaviour Game Theory	Fairness mechanism	EigenRep [131], EigenTrust [131], Scrievener [50], Offline Karma [128], Treat-before-Trick [129], SocialCloud [522], GridletEconomics [343], Vector Trust [523], FOX (Fair optimal Exchange) [524], FairTorrent [63], FairPeers [356], Ramaswamy et al. 2002 [525], Ledlie et al. 2003 [526], Yacobi et al. 2001 [527], Feldman et al. 2004 [137], Halkes et al. 2010 [528], Locher et al. 2009 [204], Ngan et al. 2003 [529, 530], Levin et al. 2006 [531], Rodrigues et al. [336]
	Incentive scheme	
	> Barter-based	
	> Direct-reciprocity	SeCond [118], Tribler [506], BAR Gossip [478], BitTorrent Tit-for-Tat [110], Multilevel Tit-for-Tat [532], Odd-for-Even [533], Treat-before-Trick [129], KazaA [113], P2P Bartering [534], PlanetLab [482], SLIC [535], N-Way Exchange Base [334], T-Chain [536], O-Torrent [537], Paysense [538], FOX (Fair Optimal Exchange) [524], Wang et al. 2005 [429], Anagnostakis et al. 2004 [334]
	> Indirect-reciprocity	R-Agents [539], Credence [254], EigenTrust [131], OCEAN [114], Scrivener [50], PowerTrust [540], GossipTrust [541], TrustMe [542], OneHop Reputation [347], BarterCast [132], Core [543], S-String [544], ARA [545], SHARP [477], Sam-sara [491], EigenRep [131], PeerTrust [546], Net-Bill [547], Maze [521], FARSITE [493], PAS-TICHE [495], PAST [494], XenoTrust [548], Have-laar [72], Blue [549], Yan et al. 2007 [550], Landa et al. 2009 [551], Satsiu et al. 2009 [83], Dewan et al. 2009 [552]
	> Economy-based	
	> Centralized	SPRITE [553], ExpressSystem [554]
	> Decentralized	Nuglets [22, 555], ARM [556], MARCH [398], Dandelion [304], eMule [557], Hausheer et al. 2003 [558], eCash [407], Scrip [174, 221, 388], MojoNation [559], Offline-Karma [128], Digicash [560], Millicent [561], LightweightCurrencyParadigm [107], Ppay [562], SIP [563], Liebau et al. 2005 [364], Golle et al. 2001 [564], AntFarm [162], Fileteller [565], Who-Pay [566], Aperjis et al. 2008 [397], Egg [483], PeerMart [337], PeerMint [357],
	> Differentiated services	Ma et al. 2004 [125], Ma et al. 2006 [126], Cohen et al. 2003 [110], Kung et al. 2003 [567], Papaioannou et al. 2006 [568], Yeung et al. 2008 [569], Feldman et al. 2004 [137], Kang et al. 2014 [570], SplitStream [485],

Table B3 Alternative concepts to Karma (2 / 3)

Literature Field	Concept Area	Alternative Concepts to Karma
Blockchain	Accounting systems > Receipt-based	eMule [557], KaZaA [113], SeAl [486], Swift [176], GridBank [571], Escrow [137], RADIUS [119, 120], CDNs (Content Distribution Networks) [572], Peer-Mint [573], BuckingFreeriders [574], Zhang et al. 2006 [575], 2007 [481]
	> Token-based	Ppay [562], Trading in Stamps [133], MojoNation [559], Offline Karma [128], MMAPS [449], KOM Token Accounting [364]
	> Proof-of-Work-based	MicroMint [104], Payword [104], Bread & Pudding [519]
	Trust systems	Treat-before-Trick [129], VectorTrust [523], Samsara [491], EigenTrust [131], NICE [576], P-Grid [577], PeerTrust [546], TrustMe [542], Trustos [578], StampTrading [133], PeerTrust [546], Scrubber [579], ExtendedScrubber [580], BinaryTrust [577]
	Reputation systems	XREP [130], X ² REP [581], BIONETS [354], ROCQ [582, 583], ARM [556], CREPS [584], BarterCast [132], P2PRep [585], EigenRep [131], FreeHaven [517], OneHopReputation [347], Credence [254], DCRC [586], CORC [586], Havelaar [72], Liu et al. 2006 [587], Jurca et al. 2002 [588], Selcuk et al. 2004 [589], Damiani et al. 2002 [590]
	Cryptocurrencies	Bitcoin [101], Ethereum [134], Hashcash [591], Zero-coin [592], ZeroCash [593], Decentralized Anonymous Payment (DAP) [593], Ripple [594], IOU [594], i-WAT [479], Ppay [562], Mixcoin [595], Stamp Trading [133], B-Money [596], BitGold [597], MintedCoin [598], QuorumSystems [599, 600], PeerMint [573], PeerMart [337], CPay [441], Tycoon [475], Offline-Karma [128], Payword [104], RPOW [601], Nuglets [22, 555], NetPay [602], Sprite [553], MANET [554], DigiCash [560], Peppercoin [603], DigitalCash [604], SIP [563], VEN [605], LindenDollar [606]
	Micropayment systems	Payword [104], Micromint [104], Ppay [562], Net-Bill [547], MojoNation [559], Fileteller [565], Dandelion [304], Tycoon [475], Lightweight currency paradigm [107], CoBank [363], Offline-Karma [128], HostCast [607], MARCH [398], MMAPS [449], WhoPay [566], Token as Micropayment (TaM) [608], P2P File Market [609], Lottery [610], FairPeers [356], Tit-for-Tat [110], AntFarm [162], BitStore [611], PACE [397], HAWK [612], MicroiKP [613], Millicent [561], SubScrip [614], PayTree [614], UBOT [614], Jalda [614], Bitpass [615], GridBank [571], POPCORN [516], Chaum 1983 [616], untraceable electronic cash [617], Yu & Singh 2003 [618], Golle et al. 2001 [564], Figueiredo et al. 2005 [619], Cohen et al 2008 [620], Friedman et al. 2006 [174], Tran et al. 2010 [348], Marbach et al. 2005 [621], Crowcroft et al. 2004 [622], Chaudhary et al. 2009 [431]

Table B4 Alternative concepts to Karma (3 / 3)

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