Are you a DePIN? A decision tree to classify decentralized physical infrastructure networks

***Abstract*—Decentralized physical infrastructure networks (DePINs) are an emerging vertical within web3 replacing the traditional way how physical infrastructures are constructed. Yet, the boundaries between DePIN and traditional ways of building crowdsourced infrastructures such as citizen science initiatives or other web3 verticals are not always so clear cut. In this work, we systematically analyze the differences between DePIN and other web2 and web3 verticals. For this, the study proposes a novel decision tree for classifying systems as DePIN. This tree is informed by prior studies and differentiates DePIN from related concepts using criteria such as the presence of a three-sided market, token-based incentives for supply, and the requirement for physical asset placement in those systems.**

The paper demonstrates the application of the decision tree to various blockchain systems, including Helium and Bitcoin, showcasing its practical utility in differentiating DePIN systems.

This research offers significant contributions towards establishing a more objective and systematic approach to identifying and categorizing DePIN systems. It lays the groundwork for creating a comprehensive and unbiased database of DePIN systems, which will inform future research and development within this emerging sector.

***Index Terms*—DePIN, web3, blockchain, classification, crowdsourcing**

I. Introduction

Distributed infrastructure has a long history, with systems like distributed.net and SETI@home pioneering distributed computing in the late 1990s. SETI@home, launched in 1999, allowed volunteers to contribute idle computer processing power to analyze radio signals for signs of extraterrestrial intelligence, making it one of the earliest and most successful examples of distributed infrastructure for scientific research [1]. Grid computing emerged around the same time as a means to harness the collective power of geographically dispersed computers for large-scale tasks. Systems like the Globus Toolkit [2] and the European DataGrid [3] were instrumental in developing distributed computing infrastructures. Peer-to-Peer (P2P) sharing networks like Napster also relied on distributed infrastructure, enabling users to share files directly without a central server. More recently, blockchain technology, popularized by cryptocurrencies like Bitcoin, has utilized distributed infrastructure to create secure and tamper-resistant networks.

Within blockchain and the web3, systems like Helium [4] pioneered a new wave of three-sided markets [5] that bootstrap the supply of infrastructure, i.e. deployment of specialize hardware, incentivized by payment in blockchain tokens [6]. This combination of cryptocurrency and distributed infrastructure has birthed a new sector in the blockchain realm, commonly noted as Decentralized Physical Infrastructure Networks or 'DePIN'. Prior to the use of the term 'DePIN', similar 'real-world' blockchain systems were referred to by several different terms such as MachineFi, Proof of Useful Work, Token-Incentivized Phsyical Infrastructure Networks (TIPIN), Economy of Things, etc. Based on an informal Twitter (now X) poll, the term DePIN was then adopted by research firm Messari [7]. Since the publishing of this poll, the term has been widely adopted as a 'catch-all' for systems based on blockchain incentives and a replacement of Web2 services. Although the term is widely adopted, a standard definition has not be agreed upon with any consensus. This has led to a a proliferation of use of the term in marketing materials or application to systems such as Bitcoin and other traditional Proof of Work mining. Even Messari has equivocated on the original application of the term by proposing two sub-sectors, Physical Resource Networks (PRN) and Digital Resource Networks (DRN) [8], whereas it would appear the use of 'Physical' in the PRN term is redundant and possibly contradictory, and an admission that DePIN may not have been the best choice as an umbrella term. Others have proposed a similar bisected taxonomy based primarily on the idea of fungibility of the resources. The designations of DePIN and DeReN (Decentralized Resource Networks) were coined to describe these two sub-sectors [9]. A more recent Messari research report has claimed there are greater than 650 'DePIN' systems [10]. However, this report has offered no definitive definition of 'DePIN'. A review of some of the referenced systems indicates inclusion of blockchains such as IoTex and Peaq that, although designed and marketed to DePIN systems, are not exclusive to this sector. A system can choose to build on these Layer 1 (L1) blockchains, regardless of sector designation. Other systems even do not require the contribution of physical elements such as versasity[1] or Braitrust[2]. Thus, in absence of specific criteria for inclusion, we are left with the "I know it when I see it" explanation famously used in the US Supreme Court Case Roth v. United States which is often criticized as being arbitrary [11].

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[1]https://verasity.io/, last access: 2024-03-05

[2]https://www.usebraintrust.com/, last access: 2024-03-5

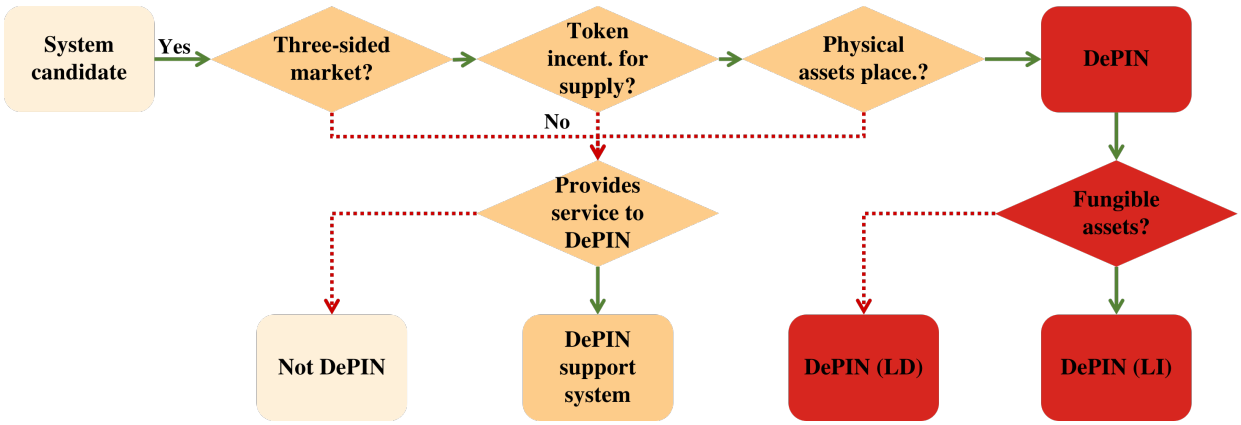

Fig. 1. Proposed decision Tree for DePIN identification.

This research seeks to create an unbiased, objective, and repeatable 'litmus test' to determine if systems are eligible for listing in a database that strives to be a neutral clearinghouse of systems within the DePIN sector. This clearinghouse strives to be uncluttered by marketing claims and focus on providing clear information for those who may be interested in a specific system type. In particular, in order to create a neutral database of systems, objective criteria for system inclusion are required. Absent of this, subjective decisions regarding inclusion may be considered as arbitrary and potentially biased.

This work contributes such criteria in form of a decision tree, illustrates its application in case studies to blockchain systems such as Bitcoin, Helium and Akash, and discusses its implication on terminology and highlights limitations.

II. Related Work

In previous blockchain/web3 research, a decision tree has been used to distinguish between previously undefined or not clearly delineated terms such as DeFi/CeFi [12].

In the context of DePIN, several definitions and contributions have been presented from which such a distinction possibly could be derived. A previous study established a useful taxonomy to describe the various components and attributes of DePIN systems [6]. This taxonomy does not seek to provide a definitive definition of DePIN; rather, it suggests that "whenever the incentivized action in a system involves the placement or contribution of physical infrastructure elements, such as a camera or storage drives, it can be defined as a DePIN system." This aligns with the proposal to define DePIN as networks using blockchain-based token incentives to build real-world physical infrastructure networks [10, 13] which further specify the token-incentivized nature of the DePIN supply-side. This token incentivization has actually been stated as a differentiation criteria between DePIN and web2 participatory sensing systems [14].

Furthermore, it has been proposed to differentiate between DePIN and DeREN systems, distinguishing between the fungible and non-fungible nature of assets comprising an infrastructure network [9].

However, to our knowledge, clear criteria for classifying a system as DePIN that combine and extend these different definitions have not yet been established. This work combines and extends the above definitions of DePIN systems into a decision tree for DePIN classification.

III. Methodology

The decision tree in this study was derived through convenience sampling, by analyzing systems and suggestions crowdsourced from a DePIN database website[3]. The DePIN community suggested 140 systems as DePIN or DePIN support systems to the authors. This dataset was extended by systems from other web3 and web2 verticals. Using this training set, criteria were developed to unambiguously classify the systems in the database as DePIN, thus executing one iteration of the 'empirical-to-conceptual' step in an established taxonomy development methodology [15].

IV. Decision Tree

Figure 1 illustrates the decision tree. A system candidate has to fulfill the following three requirements in order to be considered a DePIN:

Three-sided market: DePIN systems can be characterized as three-sided markets consisting of a supply, a service and a demand side [5]. In particular, in a DePIN system the supply is provided by different actors than those maintaining the platform/ service of the system. This differentiates DePIN systems from L1 blockchain networks where the miner/ consensus participants directly provide the supply to users, hence exhibiting a two-sided market layout. Also, the service provided by a DePIN system should target non-web3 systems and users.

Token-based incentives for supply: The supply side is incentivized to provide infrastructure to the network by earning blockchain-based tokens. These tokens can represent value within the network and can be used for various purposes such as accessing services, voting on governance issues, or

[3]The name is anonymized and will be published in final publication

trading on exchanges [6]. This criteria is required to differentiate DePIN from web2 citizen science/ participatory sensing initiatives [14].

Incentivized core economy action is physical assets placement: The incentivized action in the core economy [6] is the placement or contribution of physical infrastructure assets to the system. These physical assets can take many forms such as sensors, cameras, storage drives, and processors. This criteria is required to differentiate DePIN from other web3 verticals such as regenerative finance (ReFi) or DeSci (decentralized science).

In case a system does not fulfill one of these criteria, but provides a service specific to a DePIN, it is considered a DePIN support system.

Systems that meet all of these attributes can effectively, and for the purpose of this research, be referred to as DePIN. Within this broader scope and based on the definition provided by Nystrom [9] and following the reasoning in given by Gala and Kassab [10], these systems can be further delineated in two sectors based on the following criteria:

Fungible assets: Fungibility illustrates in this context the interchangeability of the physical assets that are placed in the system. In case a placed physical asset can be simply replaced by the contribution of another physical asset in the system, then the system is referred to as DePIN-LI (location independent). In case assets are not interchangeable, the system is referred to as DePIN-LD (location dependent). For example, in a decentralized storage system such as Filecoin[4], the specific location of the storage drive is not relevant, and if that storage goes offline, it can be replaced with another storage drive in any location with no real loss of utility. On the other hand, we can examine a system like DIMO[5]. DIMO is specific to a vehicle and removal of that device would result in loss of that specific data from the system.

V. Discussion

A. Case Studies

Table I illustrates a selection of systems in alphabetical order that could potentially fall under the term DePIN:

The Akash Network is a decentralized cloud computing platform that aims to provide a more efficient and cost-effective alternative to traditional cloud providers (e.g. Amazon Web Services). There are several other decentralized compute and storage systems that offer a similar type of supply to the market for compute services and the Akash assessment can serve as a proxy for these other similar services. Akash creates a three-sided market place between suppliers and users of compute by providing a marketplace for connecting the suppliers and users. Contribution of physical compute assets are incentivized with the blockchain-based AKT token. Because the compute assets are fungible, Akash is classified as a DePIN-LI.

[4]https://filecoin.io/, last access: 2024-03-05

[5]https://dimo.zone/, last access: 2024-03-05

TABLE I
Classification of systems based on the decision tree illustrated in Figure 1.

System	**Criteria**					**Class.**
	Three-sided market	*Tokens for supply*	*Phy. assets place.*	*Fungible*	*DePIN Service*	
Akash	Yes	Yes	Yes	Yes		DePIN-LI
Bitcoin	No	Yes	Yes	Yes	No	Not DePIN
CCC	Yes	No	Yes	No	No	Not DePIN
Data Lake	Yes	Yes	No	No	No	Not DePIN
Grass	Yes	Yes	Yes	Yes		DePIN-LI
Helium	Yes	Yes	Yes	No		DePIN-LD
IoTeX	No	Yes	Yes	Yes	Yes	Support
Peaq	No	Yes	Yes	Yes	Yes	Support
WiHi	Yes	Yes	Yes	No		DePIN-LD

The Climate City Cup (CCC) [16] is a citizen science/ participatory sensing initiative to crowdsource air quality data in cities by incentiving a friendly competition among the participating parties. On the supply side are the sensors placed by citizens, the service side is provided by CCC which aggregates the data and on the demand side sit policy makers. Though the initiative motivates the placement of physical non-fungible sensors, it does not incentivize participation with blockchian-based tokens. In the literal sense, this would be a decentralized infrastructure network, which, however, as already mentioned, does not correspond to the purpose of the currently observed designation 'DePIN', which requires token-based incentives.

Data Lake is a decentralized science (DeSci) system that incentivizes the sharing of patient data with researchers. Though it uses blockchain-based tokens to crowdsource data (supply), it does not incentivize the placement of physical infrastructure, thus it is not considered a DePIN.

Grass markets itself as selling an unused resource (e.g. extra internet bandwidth). Essentially, the software uses your IP address and internet connection to 'scrape' the web on behalf of the market side buyers. On the supply side are users who provide a computing device with capability to run a web-browser. Grass provides the service and sells to businesses that are interested to use the web scraped data (e.g. using it to train AI). Contributed computing assets are fungible, thus making Grass a DePIN-LI system.

Helium started as a decentralized wireless network focused on IoT (Internet of Things). Helium is now divided into two networks governed by separate sub-DAO. In this case, we are examining the IOT network (with IOT token as utility) but the findings are generally the same for the Mobile network (MOBILE token). Not surprisingly, Helium IOT is an uncontroversial DePIN system. As shown in Figure 1, it meets all the attributes to be a DePIN, and specifically a DePIN-LD.

Bitcoin can certainly be considered physical (in terms of miners), decentralized, and token-incentivized (earn BTC). However, the spirit of DePIN, is that the service within the three-sided market is provided by others than those contributing the supply. In particular, Bitcoin can be considered as a two-sided market where those contributing the supply make up the platform that is given as a service to customers.

IoTeX and Peaq are L1 blockchains purposely built to service DePIN[6]. What differentiates these from other L1s are the 'add-ons'. For example peaq refers to these as "easy-to-use Modular DePIN Functions". Despite these DePIN-centric extras, like Bitcoin, these blockchains can be considered a two-sided market where those contributing the supply make up the platform that is given as a service to web3 customers, thus not meeting the first criteria. However, both explicitly offer DePIN-focused services and have DePINs built on them, which classifies them as DePIN support systems.

WiHi[7] consists of a three-sided market that collects weather data via physical non-fungible weather stations on the supply side and applies machine learning to it via its expert community; both are offered to users as a service. The supply side is incentivized with a token, making WiHi a DePIN-LD.

B. Terminology and Criteria

It seems the community has identified the need to differentiate between DePIN-LI and DePIN-LD [9, 10] as done in this work. To make the terms more accessible, it could be beneficial to follow the suggestion of Nystrom [9] and refer to the former as DeREN and to the latter as DePIN. Both categories could then be summarized in the umbrella term of *Decentralized and Token-Incentivized Infrastructure Systems (DeTIS)*. Moreover, within each of these two categories, further sub-categories could be identified/ defined such as computate and storage in DeREN or Sensors and DeWi in DePIN. A potential route forward could be to do this categorisation via the *Device* attribute in the previously introduced DePIN taxonomy [6].

Also, the three-sided market criteria could further be split into a criteria requiring that the demand side addresses non-DePIN/ non-web3 users to highlight the real-world impact a DePIN system should have.

In addition, one could loosen the requirement of token-based incentives and extend it to scenarios where the blockchain technology is used for coordination (e.g. via DAO governance). In particular, tokens are one instance of this capacity to coordinate human behavior.

Moreover, we have the intuition that "Fungibility" is only a proxy for a broader concept potentially better described by "location specificity". Some programs such as Grass noted above, or some dVPN systems (e.g. Mysterium) require a residential IP address which is a form of 'location'. For the system to work, the physical device contribution must be in a specific 'location', which perhaps could be more broadly defined (e.g. in a car, at a residential IP, at a specific geolocation, etc.) and may be more conceptually acceptable than the 'interchangeability' as defined under 'Fungibility". Looking at the earlier example of DIMO, although the network is more valuable with additional vehicles, the value of any individual unique vehicle is hard to define. If you took away that vehicle and interchanged with another similar vehicle would their be a significant loss of utility? Perhaps the defining attribute is that the device is 'located' inside of a unique vehicle. Or consider Helium. It is not that you cannot replace one device with another nearby and have the network work normally. It is that there is a specific type of 'location' where it must be placed in order to contribute.

C. Limitations

Though the training set for the identification of the decision tree has been crowdsourced by the community, due to the involvement of the authors in this process, there is an inherent bias present in the considered overall systems and those that are identified as DePIN/ DeTIS.

Moreover, the decentralized nature of DePIN systems is currently not part of the criteria, potentially leaving room for systems to be included that are not decentralized when it comes to the access to contribute supply-side physical assets. In an initial version of the decision tree, this was considered by having the criteria of supply-side "Actor Permission" [6] in the core economy to be required to be 'open'. Such a system was not found in the analyzed dataset[8] and thus this criteria was removed, but could be re-added once required. Also, in general, one can raise the question if a DePIN is decentralized in cases where, for instance, the governance of the network is centralized as it has been found to be the case in some DePIN systems [6].

VI. Outlook

This work contributes a decision tree for identifying DePIN systems based on the three criteria of three-sided market, token-based incentives and physical asset placement, illustrates its applicability to classify blockchain systems as DePIN and discusses its implications and limitations. This decision tree is seen as a work in progress which will be refined in iterative interactions with the community. In particular, a community-wide evaluation of the decision tree is envisioned to strengthen its usefulness. For instance, the three-sided market nature of DePIN systems and the fungibility criteria could be further differentiated as discussed.

Such a decision tree is a necessary building block to create an objective dataset of DePIN systems that will inform and support further research in this emerging web3 vertical. In particular, such a dataset could be used to identify key design decisions in DePIN systems by analyzing design configurations of DePIN systems and thus help interested parties understand and innovate the ecosystem. Also, the started categorization into DeREN and DePIN could be extended into further subcategories that would eventually provide a comprehensible overview of the DePIN landscape.

References

[1] E. Korpela, D. Werthimer, D. Anderson, J. Cobb, and M. Leboisky, "Seti@ home-massively distributed computing for seti," *Computing in science & engineering*, vol. 3, no. 1, pp. 78–83, 2001.

[6]https://docs.iotex.io/, https://docs.peaq.network/docs/quick-start/what-is-peaq/; last access: 2024-03-05

[7]www.wihi.cc, last access: 2024-03-05

[8]Some systems due to their immature state maintain waitlists for supply-side onboarding. Due to their expressed plan to open this in the future, we classified them as open.

[2] I. Foster, "Globus toolkit version 4: Software for service-oriented systems," *Journal of computer science and technology*, vol. 21, pp. 513–520, 2006.
[3] B. Segal, F. Gagliardi, L. Robertson, and F. Carminati, "Grid computing: the european data grid project," 2000.
[4] D. Jagtap, A. Yen, H. Wu, A. Schulman, and P. Pannuto, "Federated infrastructure: usage, patterns, and insights from" the people's network"," in *Proceedings of the 21st ACM Internet Measurement Conference*, 2021, pp. 22–36.
[5] M. C. Ballandies. (2023) Depins are three-sided markets — an evaluation guide for investors to access decentralized physical infrastructure networks. [Online]. Available: https://medium.com/wihi-weather/depins-are-three-sided-markets-an-evaluation-guide-for-investors-to-access-decentralized-8f82273c8d02
[6] M. C. Ballandies, H. Wang, A. Chung Chee Law, J. C. Yang, C. Gösken, and M. Andrew, "A taxonomy for blockchain-based decentralized physical infrastructure networks (depin)," *Center for Law & Economics Working Paper Series*, vol. 3, 2023.
[7] Messari. (2022) Web3 physical infrastructure needs a name! [Online]. Available: https://x.com/MessariCrypto/status/1588938954807869440?s=20
[8] S. Kassab. (2023) Navigating the depin domain. [Online]. Available: https://messari.io/report/navigating-the-depin-domain?utm_medium=organic_socialutm_source=twitter-_messariutm_campaign=navigating_depin_domain
[9] M. Nystrom. (2023) Depin and deren: Toward a better classification of decentralized infrastructure networks. [Online]. Available: https://variant.fund/articles/depin-deren-toward-better-classification-decentralized-infrastructure-networks/
[10] S. Gala and S. Kassab. (2024) State of depin 2023. [Online]. Available: https://messari.io/report/state-of-depin-2023
[11] P. Gewirtz, "On i know it when i see it," *Yale LJ*, vol. 105, p. 1023, 1995.
[12] K. Qin, L. Zhou, Y. Afonin, L. Lazzaretti, and A. Gervais, "Cefi vs. defi–comparing centralized to decentralized finance," *arXiv preprint arXiv:2106.08157*, 2021.
[13] S. Gala and S. Kassab. (2023) Depin: What are decentralized physical infrastructure networks? [Online]. Available: https://www.peaq.network/blog/what-are-decentralized-physical-infrastructure-networks-depin
[14] M. T. C. Chiu, S. Mahajan, M. C. Ballandies, and U. V. Kalabić, "Depin: A framework for token-incentivized participatory sensing," 2024.
[15] R. C. Nickerson, U. Varshney, and J. Muntermann, "A method for taxonomy development and its application in information systems," *European Journal of Information Systems*, vol. 22, no. 3, pp. 336–359, 2013.
[16] M. M. Dapp, D. Helbing, and S. Klauser, *Finance 4.0-Towards a Socio-Ecological Finance System: A Participatory Framework to Promote Sustainability*. Springer Nature, 2021.