Decentralized Wireless (DeWi): which perspectives for Blockchain-based mobile networks?

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***Abstract*— The convergence of telecommunications and blockchain have paved the way for a new generation of networks, called "Decentralized Wireless" (DeWi). These networks leverage blockchain technology and cryptoeconomics to deliver wireless coverage and connectivity through decentralized peer-to-peer networks, built and operated by individuals. In this paper, we present an overview of the DeWi sector, including its background, operation, enablers, and ecosystem participants. We also delve further into cellular DeWi, outlining the potential business opportunities and upcoming research and industry insights for this category of DeWi.**

Keywords—Decentralized Wireless, cryptoeconomics, DeWi, 5G, 6G, Cellular, blockchain, Helium, Pollen Mobile.

I. INTRODUCTION

Decentralized Wireless (DeWi) are a new generation of wireless networks that rely on blockchain's capabilities of decentralization, distribution, programmability and ability to operate in trustless environments. They are implemented as geographically dispersed mesh networks, deployed and operated by *people*, to provide wireless coverage for *people*. With roots in cryptoeconomics, DeWi leverages cryptocurrency to bootstrap the network and incentivize the participants [1]. DeWi spans over a plethora of wireless technologies, however, in this paper, we exclusively focus on the cellular DeWi market, which represents the biggest revenue-generating opportunity for DeWi (vast number of cellular network users, multiple lucrative business models, and collaboration opportunities with legacy networks).

The academic research literature has very few papers that discuss the topic of DeWi. The authors of [2] provide a quick overview of the *Helium* Long-Range Wireless Area Network (LoRaWAN) architecture and components. Meanwhile, in [3], the paper goes further, by discussing *Helium*'s governance and incentivization, and achieving empirical testing of the network's coverage and basic functionalities. Moreover, the authors of [4] provide a real-world experiment and analysis of the *Helium* LoRaWAN network. To the authors' knowledge, no research paper has provided a thorough analysis of DeWi networks in general, nor cellular DeWi in particular. The only existing works (the above mentioned references), focus on the case of the *Helium* LoRaWAN network, without any mention of the DeWi movement aspects. Nonetheless, multiple blog articles have thoroughly discussed DeWi networks, including cellular DeWi. The most complete one is [5], which presents the background of the DeWi movement and ecosystem, compares DeWi to traditional telcos, and provides market insights for 5G DeWi. However, this article is business-oriented, meanwhile, ours is research-oriented, as we focus on the impact that DeWi can have on the current and the future research works on blockchain and cellular technologies. We also cover how the state-of-the-art telecom norms and business models may be impacted by these emerging networks. To the best of our knowledge, we are the first academic study to provide a comprehensive overview of DeWi networks, with focus on cellular DeWi. The main contributions of this paper are:

- A presentation of DeWi background, operation and ecosystem actors.
- A presentation of the technological and business enablers of DeWi.
- An enumeration of the potential business opportunities for DeWi in the 5G market.
- Research and industry insights and directions for cellular DeWi.

The rest of the paper is structured as follows: Chapter II presents a general overview on DeWi. Chapter III suggests potential business model opportunities for DeWi in the 5G market. Chapter IV sets forth research and industry insights and directions for cellular DeWi. Finally, a conclusion sums up the paper.

II. DEWI: A HIGH-LEVEL OVERVIEW

A. DeWi Background and operation

The first hints of the DeWi movement started back in 2013 with the foundation of the *Helium Network*, aiming to democratize Internet-of-Things (IoT) connectivity. In 2020, the *DeWi Alliance* was launched as a staple stakeholder in the *Helium* ecosystem, with a mission of "*connecting to the internet all that can be connected to the internet*" by providing ubiquitous, cost-effective and blockchain-powered connectivity [6]. This alliance later morphed into the *Helium Foundation*, responsible of administering the *Helium*-based DeWi networks: IoT and Mobile [7]. As in the first quarter of 2023, the *Helium* IoT network, encompassed a total of 990,074 onboarded hotspots. deployed in over 50,000 cities and 175 countries [8]. Meanwhile, the *Helium* Mobile network, currently only available in the United States of America (USA), encompassed a total of 7465 online radios.

The DeWi movement, originally intended for IoT, spread like wildfire to other wireless networks. New companies emerged and followed the steps of *Helium* to create blockchain-based networks owned and operated by *people*, to serve *people*, earning the appellation of "*The Telecom Cowboys*" [5]. Currently, DeWi networks include: LoRaWAN (e.g., *Helium*, *Chirp*), Wi-Fi (e.g., *WayRu*), Bluetooth (e.g., *Nodle*), Hybrid networks, which combine several access technologies (e.g., *Althea*) [5]. Particularly, in this paper, we shed light on cellular DeWi networks, which support both 4G/LTE and 5G mobile access technologies. Five DeWi networks are operating on this market: *Helium* and *Pollen Mobile* providing data-only networks, *Xnet* promising to deliver full cellular network services including phone numbers, cellular phone calls and messages, as well as emergency calls, *Karrier One* planning to operate on both licensed and unlicensed spectrum, and *REALLY DeWi* (early stage development).

Conventional cellular networks require significant investment from large-scale telecom players, such as Mobile Network Operators (MNO), for the deployment and maintenance of the RAN infrastructure, the associated real estate commitment and the licensing costs. Instead, DeWi networks are bootstrapped by thousands of low economic capital individuals, who deploy and operate DeWi antennas on their properties in exchange for crypto-rewards, resulting in an outsourced RAN infrastructure. Moreover, DeWi cuts on the costs of spectrum licensing by utilizing shared spectrum bands. A DeWi network is composed of three types of participants:

- **Miners**. They are specific antennas, deployed and operated by individuals. They should be plugged to a power source and connected to an Internet service Provider (ISP)'s router for data backhauling and internet access (e.g., in *Pollen Mobile* network these miners are called *Flowers*). Once deployed, these antennas start providing cellular coverage and data backhauling in exchange for a crypto-reward. Several types of cellular DeWi antennas are available on the market, they vary in hardware design, coverage capacity and other attributes [9].
- **Validators**. They have the responsibility of verifying the coverage of the miners by sensing the network coverage and relaying the corresponding statistics (such as location and signal strength) to specific functionalities in the network core, in exchange for a crypto-reward (e.g., in *Pollen Mobile*, the validators are called *Bees*) [9].
- **End-users**. They are mobile devices equipped with the appropriate DeWi network eSIM. They consume the antennas' connectivity (e.g., *Pollen Mobile*'s end-users are called *Hummingbirds*) [9].

The miners that make out the DeWi network, connect to a core network that manages multiple networking services such as the registration and authentication of users, billing, access control, routing functionalities, as well as the management of spectrum access. On its turn, the core network connects to a blockchain system dotted with a specific consensus mechanism. The most famous mechanism for DeWi is Proof-of-Coverage (PoC), used by *Helium* and *Pollen Mobile*. In this protocol the validators function as witnesses, which verify the reliability of the coverage information declared by the miners. Miners with successful coverage verification are rewarded with digital tokens and can contribute to the appending of the blockchain with a new block. The blockchain component of a DeWi network is used for multiple network functions, such as the management of miners' identities through linking their network identifiers to their blockchain wallet in an anonymous manner (e.g., *Pollen Mobile* maps users' identities to their respective Non-Fungible Token wallets on the blockchain). Blockchain is also the main component for the DeWi payment process, as it incentivizes the miners based on their coverage reliability. Finally, blockchain provides an environment where untrusted entities are encouraged to behave with integrity through its incentivization mechanism.

Each DeWi network has its own specific crypto-currency (e.g., *Pollen mobile* uses *PollenCoin* ($PCN)). This currency is used to compensate validators for validating coverage, and miners for providing network coverage and for transmitting users' data. Users pay for using the DeWi network with cryptocurrency. They can also receive crypto-rewards for using the network (e.g., in the first phase of *Pollen Mobile* deployment, users were compensated for using the network). A DeWi network can also choose to provide its participants with hybrid payment, meaning that a portion of the payment can be in real money, like US dollars (e.g., in the second phase of *Pollen Mobile* deployment, the users can choose to pay for their data in $PCN, US dollars, or in both). When a customer pays for using the DeWi network, the payment fees get divided between multiple parties. A portion of the fees gets transferred to the miner, meanwhile other portions can be used to pay multiple parties in the network (e.g., In *Pollen Mobile*, 80% of the fees paid by the customer get transferred to the *Flower*, 10% of the fees get paid to the mobile core administrator, and 10% get paid to the network maintenance bank) [9].

Fig. 1 illustrates a general high-level architecture for cellular DeWi. This architecture is inspired from *Pollen Mobile* architecture, which was natively designed for cellular connectivity provision [9].

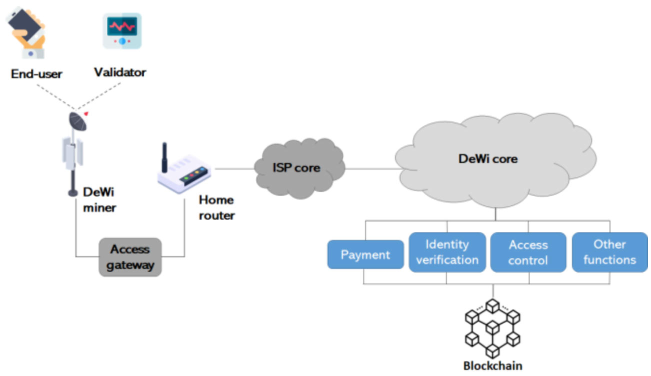

Fig. 1. A general high-level architecture of cellular DeWi networks.

B. *DeWi enablers*

1) Technological enablers

Spectrum sharing. Spectrum Access Sharing allows spectrum licensees to share their idle spectrum resource with secondary users. For instance, in the USA, the Citizens Broadband Radio Service (CBRS) band is open for public use and sharing between the federal government (incumbent users), MNOs (Priority Access Licensee "PAL") under a license requirement, and General Authorized Access (GAA), where users are granted opportunistic access to spectrum holes [10]. By removing the requirement for capital to purchase spectrum licenses, spectrum sharing aids in democratizing spectrum access and reducing the costs of connectivity, as spectrum licensing fees are usually passed on to end-users. *Helium* and *Pollen Mobile* use the CBRS band to provide cellular coverage.

Blockchain. This technology was initially exploited for financial purposes. However, the advent of smart contracts in 2010 opened up a wider range of potential applications, allowing it to create completely automated and self-managing distributed applications (Dapps). Multiple reasearch works have proven the efficiency of blockchain and smart contactss in addresing some of the current issues facing the telecom sector [11]. Through a number of features, including the ability to operate in untrusted environments, the elimination of middlemen, cryptographic foundations, and cryptocurrency, blockchain has the potential to establish decentralized systems and networks. With the help of a consensus mechanism, blockchain enables the development of mutualized open systems and the establishment of transactions between actors without the need for prior trust establishement, thus, reducing the security risks brought on by trust violations. Moreover, blockchain offers the fundamental cryptographic foundation for user identification, authentication, and data encryption. Additionally, blockchain provides a crucial component for DeWi, which is the "incentivization mechanism", where a "digital currency" is utilized to reward participants for effectively and reliably contributing to network growth. Finally, blockchain enables system auditability due to its ability to immutably preserve transaction history. *Helium* and *Pollen Mobile* currently use the *Solana* blockchain.

Openness and open-source. Telecom hardware and software manufacturers are embracing the principle of oppenness, enabling the development of interoperable and provider-agnostic systems. This would encourage innovation, increase ecosystem flexibility and adaptability, and promote healthy competition. The Open Radio Access Network (O-RAN) concept, which proposes a RAN design built on a set of disaggregated, virtualized, softwarized, and cross-vendor compatible components using open and standardized interfaces, is a prominent example of openness in the telecom industry. On the other hand, the concept of "open-source" enables the development of software that is publicly accessible and open to modification and improvement. It offers several advantages, including lower maintenance costs and greater accessibility to the general public. Additionally, it enables greater product adaptability through fast and agile product modification without the need to go through effort- and time-intensive legal and administrative processes [12]. For instance, *Magma core*, an open-source *Linux Foundation* project, provides an open-source next-generation converged core network for multiple access technologies: LTE, 5G and Wi-Fi. *Helium* and *Pollen Mobile* are both built using the *Magma core*.

Softwarization. Multiple functions that were previously ensured by hardware have been simplified to software on computers or virtual machines, through softwarization and virtualization technologies. These functions can, also, be available to users as cloud-based programs and services. For instance, Subscriber Identity Module (SIM) cards can be softwarized into dematerialized SIM cards known as "eSIM", which come embedded inside the users' end-devices. Many end-devices include numerous eSIM slots, allowing the users to install several cellular carrier eSIMs on the same device [5].

Miniaturization. Advancements in electronics have led to producing equipment that is smaller in size, lighter in weight, less expensive, and less energy-greedy, all while effectively maintaining the same level of quality, performance and reliability. This has enabled the provision of equipment that is portable, compact, and suitable for installation on small areas and buildings. An exmaple of this is small-cell antennas.

2) Business enablers

Market democratization. The advent of 4G, has opened the telecom market to multiple new entrants, notably service providers (e.g., *Amazon*). On the other hand, MNOs began handing off portions of their value chain to subsidiaries and third parties, in order to focus on their core activities (connectivity provision and related services). Furthermore, to fund the rollout of 5G, MNOs proceeded in monetizing their infrastructure assets (real estate and towers) and tightly collaborating with Tower Companies (TowerCos). As a result, the telecom industry is becoming more accessible to new competitors and collaborators like micro-operators and other business of smaller scale and capital [13]. The entry barrier to the telecom sector is getting lower, providing businesses with opportunities to enter the market with innovative concepts.

Value delivery and consumption. The conventional approach that MNOs used for value delivery lacked customization to end-user needs, and involved the commercialization of connectivity and services through select mobile plans that the customers paid for regardless of their actual usage. Recent changes in value delivery and consumption habits are disrupting the telecom industry. From one perspective, platformization—where businesses create value through the cooperation of third parties—is growing to include end customers in the value creation process (e.g., *Airbnb*). Additionally, servitization—the practice of proving customers with different network features and services on demand (such as Network-as-a-Service)—has grown in popularity. From another perspective, clients prefer flexible payment structures where they only pay for the services and data they actually use, avoiding long-term commitments. While maintaining value for money and strict privacy standards, they also look for a better user experience, a greater Quality of Service (QoS), and tight customisation of connectivity and services. Finally, they demand for environmentally-sustainable networks and equipment with lower power consumption and environmental footprint [13].

C. Decentralized Wireless ecosystem

The geographical spread of DeWi networks and their expansion to multiple wireless access technologies, has enabled the creation of a whole DeWi ecosystem, involving multiple actors [5]:

DeWi Networks. They are open and decentralized blockchain-based wireless networks. Any individual with (relatively) limited finances can contribute to the deployment of these networks by acquiring and using particular types of antennas that provide DeWi coverage.

Owners of antennas, called “stakeholders”, receive digital token rewards whenever an end-user uses their connectivity. This reward mechanism motivates more individuals to sign up for the network, widening DeWi coverage.

Hardware manufacturers. They produce DeWi equipment like hotspots, antennas, and cells. These equipment can be deployed in an individual's property, indoor (e.g., an office) or outdoor (e.g., a house rooftop). DeWi devices have gained popularity due to their compact size, low price and simplicity of usage. They have made it easier for people to deploy DeWi networks by reducing the capital needed for real estate, as well as removing the need for any operation expertise. Initially, *Nova Labs* provided equipment for *Helium* LoRaWAN. Currently, the market is open to any other business, especially after *Helium* released the HIP19, which outlines the approval procedure for third-party producers. These manufacturers can serve as suppliers for several DeWi networks, opening up the system and increasing their profit. This would aid in network expansion, stimulate innovation, and boost competition, all of which would enhance network capabilities and speed up the transition to more sophisticated models. Leader DeWi hardware manufacturers are *BAIcells*, *BLiNQ* and *mosolabs*.

Gateway providers. They offer the essential software to enable the connection of the DeWi RAN equipment to the DeWi core network. The "gateway" includes multiple functionalities such as: spectrum access, security, access control, and privacy. For some DeWi networks, the gateway is embedded inside a separate device that must be linked to the radio equipment. In other cases, the gateway is integrated within the DeWi device along with the radio equipment (e.g., *Pollen Mobile Flowers*). The market leader in DeWi gateways is *FreedomFi*, which offers multi-protocol gateways for various DeWi networks [14].

Third-party distributers. They are third-party companies in charge of retailing, selling, leasing and marketing DeWi equipment. They provide shipping to numerous geographic areas, installation assistance, and post-purchase services. They also sell and lease pre-installed equipment that is ready for operation, so that the customers only receive ownership without having to install the equipment. Famous DeWi distributers are *CalChip* and *HeliumDeploy*.

Enterprise deployers. They are centralized businesses with the primary objective of deploying and managing DeWi networks on a bigger scale. They work closely with a wide range of DeWi ecosystem stakeholders, as well as with tower and real estate owners for the installation of antennas. Enterprise deployers are in charge of installing, configuring, controlling, and managing DeWi hardware. They have the needed expertise to provide optimal large-scale deployment of DeWi, by meticulously arranging the placement of hardware installation to offer the best possible coverage and maximize revenue. Overall, they serve a key role in tying together the ecosystem players on top of an underlying DeWi network [15]. Enterprise deployers can evolve to offer private networks or customized networks for verticals, based on their expertise in DeWi deployment. *Hexagon Wireless* and *LongFi* are examples of leader enterprise deployers.

Service providers/ tools/ marketplaces. These emerging actors offer tools and services for managing, operating, and monitoring DeWi networks. They offer user-friendly applications for network data visualization, payment management, profit maximization strategies and device location optimization, in order to maximize network capabilities. This makes DeWi hotspot management and monitoring easier for stakeholders who have deployed multiple DeWi hotspots across various locations [16]. DeWi marketplaces create a common space for DeWi actors to exchange services. For instance, enterprise deployers can commercialize their services via these marketplaces. Examples of this type of actors are *Hotspotty* and *Airwave*.

Blockchain providers. They provide the foundational blockchain frameworks essential for constructing DeWi networks and integrating their functionalities. The introduction of blockchain providers into the DeWi ecosystem simplifies market entry for businesses, as they will not need to possess the necessary expertise to create their own native blockchains.

Identity Providers. They develop DeWi SIM/eSIM cards, which are essential for user identification, authentication and billing while connecting to a mobile network. These eSIMs hold the International Mobile Subscriber Identity (IMSI) code, which uniquely identifies each subscriber within the network.

Regulators. Currently, DeWi networks follow the same telecom and market regulations that govern the operations of conventional telecoms. However, due to the particularity of these networks, some DeWi took the initiative of creating their own ethical charts underlining the obligations and guidelines that all involved parties should abide to. For instance, the Manufacturing Compliance Committee (MCC) has published "Maker ethics" which outlines ethics for *Helium* hardware producers [17].

III. POTENTIAL BUSINESS OPPORTUNITIES

The 5G market represents the greatest revenue and business opportunity for DeWi (e.g., the cellular market represents 88.9% of *Helium*’s wireless market opportunities [18]). 5G introduces several business model opportunities, which can be divided into two major categories. In the first category, A DeWi network can function as a “neutral host” supporting MNOs' 5G networks. Meanwhile, in the second category, a DeWi network operates as a full-time crypto-empowered 5G operator under the title of "cryptocarrier" [5].

A. The Neutral Host business model

5G coverage expansion. Due to MNOs' large-scale business models, they concentrate their network infrastructure in revenue-generating areas. As a result, it becomes economically unviable for MNOs to expand their RAN to rural or low-revenue areas, with a small customer base or where the population is less likely to fully utilize MNO services. Nonetheless, to align with 5G’s objective of delivering ubiquitous coverage and realizing digital inclusion, DeWi can establish their infrastructure in these areas, which can be a profitable investment to them, contrary to MNOs. This positions DeWi as neutral hosts contributing to the expansion of MNOs' networks. In this scenario, users could sign up for a specific MNO mobile plan, where the DeWi network supplies the actual network connectivity. Hence, the MNO manages all the commercialization, legal and business procedures, as well as the spectrum provision to the DeWi neutral host. Meanwhile, the DeWi manages the provision and expansion of connectivity through their crowdsourced RAN. The benefits will be proportionally shared between the MNO and the DeWi.

5G network capacity. A key goal of 5G is to achieve enhanced Mobile Broadband (eMBB), by attaining larger data rates through the augmentation of bandwidth [19]. This can be fulfilled through "network densification", but it could be costly for MNOs, as they would need to acquire additional spectrum bands and install more antennas in already covered areas. DeWi could capitalize on this opportunity by operating as neutral hosts and supporting MNO networks by managing their traffic peaks, especially in densely populated areas (e.g., metropolises) or during congested events (e.g., football games). DeWi can enhance MNO broadband in three diverse ways. The first approach is through "spectral densification", wherein the DeWi network manages the traffic of MNO clients on a different spectrum frequency than the MNO's. The second approach is "spatial densification", wherein the DeWi network densely deploys cells in a specific area while sharing MNO's spectrum. The third approach is a combination of the first two: the DeWi network densifies the MNO network both spatially and spectrally, by deploying additional cells and using additional spectrum bands.

5G small cell densification. Up to 80% of 5G network is expected to rely on small cell technology [5]. Small cells transmit data at higher frequency bands and achieve lower latency, yet they are constrained by shorter transmission ranges, which requires additional cell densification. MNOs, who have invested significantly in their legacy macro-cell infrastructure, might consider investing in densified small cell infrastructure as an expensive expenditure, particularly given the extensive scope of their networks. Consequently, DeWi networks can provide small cell infrastructure to enhance the density of MNO networks. Therefore, MNOs would offer conventional coverage using their macro cell infrastructure, whereas DeWi would operate small cell infrastructure to offer more ubiquitous coverage with greater network quality and performance.

B. The cryptocarrier business model

Roaming. A DeWi cryptocarrier can provide coverage for MNO customers when they roam outside their operator's coverage area. Compared to MNO-MNO roaming agreements, MNO-DeWi roaming agreements can be more cost-effective. Consequently, roaming expenses—which were typically passed on to customers—can be reduced. On the other hand, a DeWi network can establish roaming agreements with an MNO, to allow DeWi subscribers to continuously benefit from coverage when they leave their DeWi coverage zone. This is particularly relevant, given that cellular DeWi coverage is still in its initial deployment stages. This also would ensure a certain level of ubiquity in the DeWi service, helping to attract more customers and stakeholders. For instance, in the USA, *Nova Labs* and *T-Mobile* entered into a 5-year roaming agreement so that *Helium* subscribers would receive *T-Mobile*'s 5G coverage in regions lacking *Helium* 5G coverage.

Small and customized networks. DeWi has the potential to function as micro-operators, establishing networks in small geographical regions tailored to specific user needs and performance standards. DeWi networks can offer private 5G solutions for businesses, ensuring a high degree of customization, privacy, and security. The verticals market represents a promising opportunity for DeWi to consolidate this business model. For instance, hospitals, transportation firms, and other enterprises could access DeWi connectivity and services at reduced costs. Moreover, these enterprises may become DeWi stakeholders by installing DeWi equipment on their property, to provide connectivity for their own operations and customers and/or sell it to third-party individuals.

IV. Research and industry insights and directions

The four pillars of cellular DeWi are: a democratized spectrum access, a cost-effective network infrastructure, a decentralized mobile core and an incentivizing blockchain platform [20]. These components are both affected by and affecting the emergence of cellular DeWi. Regulation is another essential element that has a substantial impact on framing the activities within the DeWi ecosystem.

Spectrum. Spectrum sharing between licensees and secondary users helps alleviate the timely and costly spectrum licensing procedures, opening the spectrum market to non-operators and small-capital companies. This has contributed to the emergence of DeWi by removing the need for capital to buy spectrum licenses. Thereby, DeWi could afford to provide low-cost connectivity, gaining a huge advantage over traditional MNOs, who typically pass on the costs of spectrum licensing to their customers.

As the CBRS band is shared on three levels, there is a higher risk of channel congestion and interference between GAA users, which do not benefit from any interference protection. As more users share the CBRS band, research efforts must focus on identifying effective strategies to regulate the sharing of this band. Artificial intelligence and machine learning can offer viable solutions for real-time dynamic spectrum allocation and interference management, with high adaptability and security standards. Furthermore, the CBRS band is managed by a centralized spectrum access system, which makes it vulnerable to corruption, single point of failure, and privacy violations. To address these threats, research could leverage blockchain and smart contacts to decentralize the spectrum access system. Blockchain properties can be exploited for auditing, access control, and identity verification. Simultaneously, spectrum assignment procedures can be enforced via smart contacts.

Currently, cellular DeWi networks mostly operate in the USA where they utilize the CBRS band (USA-exclusive spectrum). However, as DeWi aims to expand its presence across different global regions, the acquisition of new spectrum becomes imperative, notably through spectrum sharing as it has proven to be a practical and cost-effective option. For instance, the two spectrum sharing mechanisms utilized in Europe, Licensed Shared Access and Authorized Shared Access, can be seen by DeWi as counterparts to CBRS in the USA. Nonetheless, additional research is essential to adapt the DeWi spectrum access service to operate following different spectrum sharing mechanisms, given their differences in shared frequencies and operation methods. For example, *Karrier One* is conducting a proof of concept for Band53 in Canada, intended for enterprise solutions [21]. Another option to boost DeWi's growth and expansion, is to collaborate with MNOs for the usage of their licensed spectrum in exchange for rewards. For instance, *Karrier One* is conducting a proof of concept in collaboration with the Canadian MNO *ICE wireless* to use their licensed spectrum [21].

Spectrum management bodies could consider unlocking new spectrum bands for sharing. For instance, the *CBRS Alliance* has rebranded as the *OnGo Alliance*, with the goal of supporting worldwide spectrum sharing activities through the use of several 3GPP access methods. This suggests that multiple bands will be accessible for spectrum sharing, in the same fashion as the CBRS band [22]. These bands could be used by DeWi to pursue their goal of global expansion. Furthermore, specific bands can be exclusively allocated for DeWi activity. In this scenario, the band license would be assigned to a particular organization responsible for subleasing it to DeWi. This concept could be further enhanced by designating this organization as a participating node in the DeWi blockchain, allowing it to share a portion of the stakeholders' rewards for providing connectivity. This would eliminate the need for DeWi to acquire spectrum licenses, since customers would pay for the spectrum as they use it. Spectrum will be treated in the same way as any other network feature that is already accessible to users on demand or as-a-service. This would lead to additional consequences for MNOs, whose spectrum licenses have allowed them to gain a key position in the telecom market. They could embrace this new business model in which they acquire spectrum assets with the purpose of subleasing them to DeWi. This would contribute to further democratize the market for small-scale companies.

Radio Access Network (RAN). The compact design and the plug-and-play installation of the DeWi equipment comes at the expense of coverage range, necessitating further network densification. Thus, DeWi networks are not capable of offering ubiquitous coverage in locations with dispersed buildings (e.g., rural areas), where the distance between buildings exceeds the range of a DeWi hotspot. To address this concern, DeWi may consider the installation of bigger hotspots with expanded coverage. However, this sort of equipment comes in a larger size and a more expensive cost, which makes it unpractical for installation by individuals. To encourage the installation of this category of equipment, DeWi could offer bigger crypto-rewards for the owners of bigger hotspots. They can be individuals or enterprises with higher buildings, as well as enough revenue to acquire the hotspot (e.g., enterprise deployers).

The positioning of hotspots is another direction that might be explored to enhance and optimize DeWi coverage. As DeWi networks are growing in popularity, people are eagerly acquiring and setting up DeWi hotspots. However, this can cause a significant discrepancy in coverage. Certain areas may become oversaturated by hotspots, meanwhile others may be undersaturated. As the crypto-reward is shared among the hotspots deployed within the same cell, it is probable that hotspots in a less dense cell receive more substantial rewards compared those deployed in a denser cell. To achieve fair incentivization of hotspots, enhanced optimization and load-balancing algorithms can be explored to permit the equitable distribution of users over hotspots. In the same context, it is important to highlight that stakeholders would install their hotspots in locations with greater user activity to optimize their return on investment. Indeed, in areas with less user frequentation, stakeholders would struggle to generate enough revenue for hotspot operation and maintenance.

With the expansion of DeWi networks, hotspot manufacturers may consider producing antennas that support multi-network Access Gateways. This would enable connectivity for multiple DeWi networks through the same antenna, following the demand of the stakeholder. To illustrate this, for a specific event, a stakeholder has the ability to switch their antenna's connectivity to link up with the DeWi network that is expected to be majorly used by the public. The stakeholder could also participate in densifying a specific MNO's network for a limited period of time. This would help maximize the stakeholders' profits, detaching them from exclusive reliance on a particular MNO network. A DeWi hotspot's functionality could be further enhanced by offloading certain functions to cloud-hosted services. For instance, *Pollen Mobile* recently released *Greenhouse*, a cloud-hosted Access Gateway, which further simplified the DeWi equipment setup as plug-and-play.

Ultimately, DeWi should consider a customizable strategy for maintaining hotspots to ensure the consistent performance of the equipment. This can be achieved by equipping the Access Gateway with sophisticated algorithms that ensure the proactive and reactive maintenance of the embedded software. Such algorithms could also foresee potential hardware failures, and provide stakeholders with detailed guides on how to fix the issue themselves, or whether it requires the expertise of a technician.

Core network. The *Magma core*, used by *Helium* and *Pollen Mobile*, has its own architecture that is independent of the 3GPP standards. The internal components communicate using the gRCP protocol (providing more reliability), meanwhile the core can be extended with 3GPP components through edge-based 3GPP interfaces. This enhances DeWi networks' adaptability, allowing them to work with numerous antenna and hotspot providers (provided they support 3GPP interfaces). *Magma*'s architecture was designed considering a flexibility-performance tradeoff. Due to the lack of 3GPP-standardized connections within the *Magma core*, the internal architecture of *Magma* cannot be modified by attaching additional network components from other constructors, thus limiting contributions to the project and restraining its openness to other telecom communities. Nonetheless, this architecture enhances performance and reliability by decentralizing multiple 3GPP functions on the edge. Despite its divergence from 3GPP standards, *Magma* conforms to a set of technical and performance requirements for mobile core networks in order to fulfill certain use-cases [23].

Magma's divergence from the constraints of standardization has the potential to boost innovation within the telecom sector. In particular, due to the prevalent centralized nature of the standardized telecom procedures, which lack the necessary requirements for decentralization. This raises the question of whether the current standards truly align with contemporary system requirements and advancements. As DeWi is still emerging, standardization initiatives are still not considered, yet it is crucial to emphasize that any attempt at standardization must be carefully thought, to provide sufficient room for innovation, and facilitate engagement from businesses/organizations. Additionally, DeWi can suggest novel telecom paradigms that would reshape the existing standards to match this innovative telecom state-of-the-art that DeWi has introduced.

The reliance of DeWi networks on ISP’s core network for data backhaul, can constraint DeWi performance, particularly DeWi connectivity customization, as it is limited by the QoS ceiling offered by the ISP. With the proliferation of DeWi, ISPs may establish new policies and rules for data backhauling. Although, DeWi LoRaWAN, which operates at a lower data rate, is the most widespread DeWi network, cellular DeWi expansion could urgently lead ISPs to further explore this direction. Additionally, DeWi's reliance on ISP backhaul, limits DeWi expansion to "hole zones", which are not served by the ISP's wired connection. This would encourage the DeWi community to think about novel methods to enable backhauling through wireless links. Moreover, DeWi should carefully consider user privacy and network security when using the ISPs core for backhauling. For instance, *Pollen Mobile* architecture includes, an Internet Egress Privacy Service, which replaces the ISP’s Internet Ingress Point to ensure the encryption of communications and avoid data interception and network data analysis by hostile parties [24].

Blockchain. A DeWi network’s underlaying blockchain platform should be able to accommodate the DeWi use-case by providing scalability, the ability to manage traffic peaks, increased robustness, and resiliency. *Helium* Network, for example, recently migrated from its *Helium*-native blockchain to the *Solana* blockchain in order to improve overall performance and scalability, particularly as the *Helium* network evolved to provide both IoT and cellular connectivity. A potential research direction would be to design blockchain platforms that are particularly tailored for DeWi use-cases.

Helium has embraced a new blockchain structure, known as “Decentralized Autonomous Organization (DAO): Network of Networks”. With this restructuring, *Helium* would be able to expand and control the spread of its network across several wireless access technologies (mobile: LTE/5G and IoT: LoRaWAN). While adhering to the general rules enforced by the *Helium* DAO, these networks will develop into subDAOs, each with its own governance mechanism and digital tokens. As a result, the network would benefit from more decentralization and openness to commercial collaborations [25]. An intriguing direction would be to further investigate the DAO concept in order to increase network efficiency, capacity for scaling, and customization of services.

The consensus algorithm (PoC) utilized in DeWi, leverages the primary objective of wireless networks: the delivery of reliable coverage. PoC functions by validating the location, configuration, and coverage of DeWi hotspots [26]. Research could delve into investigating novel consensus methods that take advantage of additional DeWi network attributes. For instance, in the case of 5G DeWi, the work algorithm may, besides coverage, assess other attributes, like hotspot signal latency and maximum simultaneous connections. Another active research question is the development of work algorithms with a reasonable security-latency tradeoff. The more miners participate in the work algorithm the more secure the blockchain system becomes. Nevertheless, this would significantly increase the system’s latency as a whole. This tradeoff is particularly important for 5G, as it introduces strict requirements for both latency and security. A viable approach is to precisely tailor consensus algorithms to the unique network use-case and user requirements. Moreover, considering the limited battery life and/or the restricted computation and storage resources of DeWi hotspots and devices, work algorithms in the context of DeWi should prioritize efficiency. Additionally, this would make the equipment environment-friendly, improving DeWi's sustainability and public image.

While DeWi networks rely on cryptocurrency for user rewards, significant concerns emerge due to the fluctuations of cryptocurrency values and their complex financial aspects, which are not well understood by a large portion of the population. For instance, *Pollen Mobile* has introduced US dollar, alongside *PollenCoin*, for data payment and stakeholder reward, a decision thought to be economically viable. This raises the question of whether the cellular sector is truly prepared to accept the use of cryptocurrency, and extends the debate of which currency (real or virtual) is most economically sustainable for DeWi.

Regulation. DeWi networks are subject to both blockchain and telecom regulations due to their location at the junction of both sectors. On one hand, several blockchain regulations have been issued over the world. For instance, The *Federal Reserve Bank of Boston* suggests a “supervisory node” that should participate in all blockchain platforms to oversee compliance with federal standards, auditing, payment, and data reporting. Moreover, the *European Union Blockchain Observatory and Forum*, formed by the *European Commission*, has published a report on the *Legal and Regulatory Framework for Blockchains and Smart Contracts*, to advocate for regulating the blockchain ecosystem, as well as to emphasize the entailed challenges and the need for quality and technology assurance. Regarding the regulation of crypto assets, the *Council of the European Union* has issued the *Markets in Crypto-Assets* (MiCA) regulation, which provides a regulatory framework for crypto-assets and service providers. Another example is Dubai’s *Virtual Assets Regulatory Authority* (VARA), which regulates and oversees the crypto-asset activities. Malta has gone even farther, aligning blockchain and smart contract regulation with their underlaying technological features. The Maltese *Financial Intelligence Analysis Unit* (FIAU) ordered all operators offering services based on cryptocurrencies to employ crypto-forensic tools to trace the origin and movement of crypto-assets [27].

On the other hand, several regulations legislate the telecom industry, such as the European Union’s *General Data Protection Regulations* (GDPR) and the USA’s *Privacy Act*, to protect the privacy of users’ personal data. Additionally, Competition and anti-trust policies, such as the European Union’s *Digital Market Act* (DMA) and the USA’s *Platform Accountability and Customer Transparency* (PACT) Act to regulate the telecom market operations, ensure fair competition, and prevent market manipulation [13]. With the growth of the DeWi ecosystem, the establishment of a DeWi regulatory framework has become necessary. Such a framework could have roots in both blockchain and telecom legislation, with adjustments to suit the DeWi sector. Even if DeWi networks assert that their blockchain foundation provides important levels of security and transparency, corruption and fraud may still occur in other areas of the network or at the business and commercialization levels. This emphasizes the need for DeWi-specific sectorial regulatory bodies, each specializing in a specific aspect of DeWi.

The remarkable growth and expansion of DeWi networks, is in part attributed to the lack of DeWi regulation. Nonetheless, this leaves the sector particularly vulnerable to unethical manipulation, highlighting the importance of enacting policies and regulations that would not stifle innovation in the sector nor limit its growth. All while establishing a prosperous and ethical environment for all actors to grow and evolve through healthy competition.

V. Conclusion

The DeWi movement represents a significant advancement towards the democratization of telecommunications. It promotes digital inclusion in two ways: by providing business opportunities to small-scale and low-capital firms, and by offering connectivity to isolated populations. With their expansion to the 5G market, DeWi networks are embracing a significant role in the telecom scene, encouraging the other players to reshape their roles and strategies to make profit of this new entrant. For instance, we have recently witnessed collaborations between MNOs and DeWi networks (the roaming agreement between *Helium* and *T-Mobile*). Cellular DeWi is now operational in the USA, and particularly shaped for this market. Thus, expanding to other regions, like Europe, must be carefully considered, due to market regulation, service pricing and competition. Furthermore, DeWi should anticipate strategies to handle the potential risks associated with cryptoeconomics, which have been a key incentive for stakeholder participation. This raises the concern of whether DeWi would survive without cryptoeconomics. The DeWi industry and research communities can offer insights into this matter. Amidst all these uncertainties, it is clear that "*the telecom cowboys have already started their rodeo and do not seem to be holding their horses any time soon*".

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