A Decentralized Connectivity Network

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The Internet is predominately centralized. A small set of governments and multinational companies control the primarily cable-based terrestrial and submarine Internet infrastructure, thus enabling censorship and creating a single point of failure for individual end users. The entities controlling the infrastructure can prevent end-user access to the entire web or specific censored websites or deny others access to you, thus undermining net neutrality and degrading freedom of speech and expression online. This centralization of power undermines the original vision of a free and open Internet.

The solution to this centralization of power is an utterly decentralized embodiment of global internet infrastructure that would allow online communications to be sent directly from one party to another without relying on a trusted third (centralized) party. Modern wireless networks and their various embodiments (such as mesh wireless architecture topology) provide a partial solution; however, existing Commercial Off the Shelf (COTS) WiFi routers tend to be limited to short coverage ranges, such as 100 m^2. As a result, true decentralization of internet access and communications is impossible because the network must rely on centralized, privately owned, terrestrial, or submarine cable infrastructure.

In contrast, Spacecoin is a decentralized network of nodes that will provide trustless web connectivity on a global scale from a Low Earth Orbit (LEO) constellation of Small Satellites. This approach lifts long-haul networking off-world. As the Aerospace industry continues towards lower cost commoditization of launch services and small satellite buses, it has become economically viable to deploy this constellation of satellites that continuously and globally provide coverage for a large city or region in which user devices can connect to a spaceborne 5G service directly from existing mobile User Equipment (UE).

Additionally, satellites can provide targeted coverage to specific regions and large cities without extending cables, offering coverage to remote areas. Blockchain technology allows decentralized nodes to work together without trusting each other. The network tracks the coverage of each satellite, and users bid to utilize their coverage to transmit data to the desired region. These ask and bid orders are matched and settled on a blockchain without trusting a counterparty.

Like Satoshi invented Bitcoin to create trustless money, we are building Spacecoin to create trustless internet connectivity, thus eliminating counterparty risks. This innovation will transform global communications by enabling secure and universal access to information and provide a resilient global communication infrastructure that is less prone to censorship, single points of failure, or other forms of centralized intervention.

1. Introduction

Internet access is widely recognized as a fundamental human right, essential for accessing information, services, and opportunities; it plays a critical role in modern society.[1] To realize this ideal is not a simple task, however, as it is highly fragmented and often under centralized control by various organizations across disparate legal and regulatory jurisdictions.[2] This can be problematic as centralization opens up the potential for single points of failure to form and enables these providers to either censor or deny service to specific users perniciously.[3] For example, millions of Canadians experienced a 19-hour service outage due to a network failure by Rogers Telecom,[4] and over 900 million internet users in China live under the notoriously restrictive measures of the Great Firewall.[5] Centralization also exacerbates the digital divide by the centralization of internet infrastructure investments in more affluent countries, leaving poorer regions with inadequate coverage and access, thereby perpetuating economic and social inequalities.[6]

Addressing these challenges necessitates the development of a decentralized physical infrastructure network (DePIN) for reliable internet access that is both economically competitive and capable of offering coverage in challenging locations. You can build a new network and link it to the global internet (e.g., Guifi.net),[7] or go even further and decentralize aspects of its operations (e.g., Helium).[8] However, terrestrial systems inherently have limited coverage–a typical Wi-Fi router barely covers 100 m^2,[9] while the theoretical coverage of a cell tower is limited to 40 km^2.[10] In contrast, Low-Earth-Orbit (LEO) satellites can cover 1,000,000 km^2,[11] suggesting that a network of 511 satellites can effectively and efficiently offer coverage around the world.[12]

This white paper proposes a solution to decentralize internet connectivity infrastructure using a LEO satellite network to provide global, high-speed coverage powered by a public blockchain to decentralize the network.

Crucially, incorporating a native token into the Spacecoin framework facilitates transparency and peer-to-peer transmissions while mitigating the drawbacks that inevitably arise in centralized endeavors. Furthermore, the network of decentralized nodes ensures open and transparent operations and introduces incentives for participants to deploy new satellites or augment bandwidth in targeted areas.[13]

2. Decentralized Satellite Network

Fundamentally, the Internet is a vast interconnected network of computers forming a unified global addressing system, packet format, and routing methods. Cellular networks, on the other hand, are networks of specialized computers connected via terrestrial antennas. Since satellites are essentially computers in orbit, they can function as specialized computers forming a cellular network from space.

The 3rd Generation Partnership Project (3GPP) is the mobile communications standard body known for LTE and 5G. 3GPP proposes a non-terrestrial network (NTN) standard as the solution. An NTN consists of spaceborne (GEO, MEO, LEO) or airborne (UAS and HAPS) vehicles that function as relay nodes or base stations. Non-terrestrial access enables service delivery in regions without terrestrial coverage, enhancing service scalability and ubiquity.[14]

Building on top of the 5G-NTN standard, we propose creating a decentralized 5G-NTN composed of cubesats. The decentralization enhances resistance to censorship and increases overall network security,[15] improving net neutrality. With a construction cost of approximately $5,000 and a launch cost of $30,000 per unit, cubesats have democratized satellite technology accessible to even the smallest enterprises and nations.[16] After years of collective research and development, forming a decentralized satellite network is now economically feasible.

Of course, the problem of a decentralized network is coordinating without having to trust the counterparty. Spacecoin addresses this problem by leveraging deterministic smart contracts to enforce the fine-tuned incentive mechanisms that ensure decentralized consensus around a transparent ledger of accounts.[17]

3. Transmissions

The Spacecoin network is a 5G-NTN, and each node

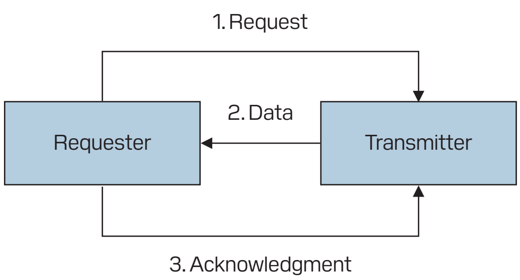

Figure 3.1. Requester and Transmitter

has a unique pair of asymmetric keys.[18] At a minimum, the Spacecoin network data transmission will involve two nodes: a Requester and a Transmitter.

$$R = Requester$$

$$T = Transmitter$$

$$K_X = public\ key\ of\ X$$

$$E_K(M) = M\ encrypted\ with\ K$$

$$D_K(M) = M\ decrypted\ with\ K$$

$$V_K(M, S) = verify\ M\ against\ S$$

$$r_i = i^{th}\ data\ request\ between\ R\ and\ T$$

$$f_i = transmission\ fee\ proposed\ by\ R\ for\ r_i$$

$$d_i = data\ retrieved\ for\ r_i$$

$$ACK_i = i^{th}\ acknowledgement\ between\ R\ and\ T$$

$$(1)\ E_{K_R}(r_i, f_i) = m_{R,i}$$

$$(2)\ E_{K_T}(m_{R,i}, d_i) = m_{T,i}$$

$$(3)\ E_{K_R}(m_{T,i}, f_i) = ACK_i$$

$$(4)\ V_{K_R}((m_{T,i}, f_i), ACK_i) \rightarrow \{True, False\}$$

Transmitters will offer data transmission services on the Spacecoin network. (1) Requesters select a transmitter for a data transmission service. (2) Once the Transmitter fulfills the request with the requested data, (3) the Requester returns an acknowledgment (ACK) to the Transmitter. ACK is the cryptographic proof generated with the Requester's private key that proves that the Transmitter has fulfilled the request. (4) The Transmitter submits the receipt to the Spacecoin blockchain network to retrieve the promised fee.

The problem is that the Transmitter must trust that the Requester will pay to fulfill the data request. A standard solution is for the Requester to trust the Transmitter with a prepaid plan or for the Transmitter to trust the Requester with a contract plan. Using the same solution would defeat the purpose of building a decentralized network. Section 3.1 will elaborate on a more effective mechanism.

3.1 Escrow

We propose blockchain escrow as the solution, which only allows withdrawals if specified parameters are met.[19] First, the Requester escrows Spacecoin tokens via the Spacecoin network's smart contracts before requesting. Spacecoin's blockchain is a public ledger, and Transmitters can verify the escrowed assets independently. When a Transmitter submits the receipt to the blockchain, the promised fee is automatically released to the Transmitter.

In step (3) above, Spacecoin Requesters digitally sign messages with their private keys and generate receipts. The message includes the transmission fee the Requester wants to pay the Transmitter. When the Transmitter submits the receipt to the escrow system, the network can verify it with the Requester's public key, verify that the Requester sent the message, and verify that the message has not been modified. At this point, the escrow system can safely release the fee to the Transmitter.

In some cases, the Requester may not submit the ACK after the Transmitter fulfills a request, which is known as the 'Free Rider Problem.' On-chain credit systems such as Creditcoin solve this problem by logging reputations and flagging free riders, which is described in more detail below.[20]

3.2 Credit System

Regarding free riders, Requesters are incentivized to send the ACK because the benefit is outweighed by the cost of potentially getting cut off from the network. Depending on the granularity of the payment schedule, the Requester might only benefit up to 64 bytes of data for free.[21]

$$C = cost\ of\ a\ burner\ node$$

$$v_{i,R} = value\ of\ d_i\ to\ R$$

$$n = expected\ number\ of\ successful\ request$$

$$(5) \sum_{0}^{n} v_i = V$$

$$(6) \sum_{0}^{n} f_i = F$$

In addition, Transmitters can file a report to the network stating that they have had a free rider problem by submitting proof to a credit rating system: the original data request and the retrieved data ($m_{T,i}$). When enough reports are collected against the Requester, Transmitters can collectively reject requests from the alleged free-riding Requester.

Since Transmitters can identify the Requester socially and physically, creating a burner identity in Spacecoin will be costly. While all messages transmitted through the Spacecoin network are secured by 5G security standards such as encryption and network slicing,[22] individual nodes are as identifiable as any other 5G network. Devices (e.g., satellites, cellular phones) and SIM cards have identifiers exposed to the network. Once you get on the block list, you must spend C to get back online. If C>F, it is rational to believe R to return ACK.

Of course, the Transmitter can choose to submit a report against the Requester regardless of the ACK. However, the Transmitter will have to spend the cost of retrieving the data and won't be able to collect fees for its work. It will be in both the Requester's and Transmitter's economic interest to behave nicely in the system.[23]

4. Governance

The governance model of a cryptocurrency specifies the framework and processes through which decisions are made regarding the cryptocurrency network's operation, development, and future direction. This includes how changes to the protocol, updates, and rules are proposed, debated, approved, and implemented. Governance models are crucial for cryptocurrencies' sustainability, adaptability, and security, as they directly affect how efficiently and effectively a network can evolve and respond to challenges and opportunities.[24]

4.1 Beta Governance

In the initial stages, the Spacecoin Foundation will lead the development of Spacecoin until it reaches its full functionality. During this time, the Spacecoin Foundation will coordinate efforts to ensure the decentralized data transmission network's successful implementation, deployment, and operation. We will consider the fully functional Spacecoin network as the first official version of the protocol.

4.2 Production Governance

Once the Spacecoin network is fully functional with a constellation of satellites deployed to Low Earth Orbit and the mainnet is officially launched, Spacecoin's governance will transition to a decentralized model. This decentralized model will distribute decision-making power among stakeholders such as users, node operators, and token holders.

On-chain-level Governance: Protocol upgrade decisions will be made by voting amongst the Spacecoin holders. Each upgrade proposal will go through a voting round. If the proposal gains the majority vote, the upgrade will happen. The steps to make the decision are as follows:

1. Proposal Submission
2. Voting Period
3. Quorum
4. Decision Making
5. Feedback Loop

Off-chain-level Governance: Other decisions will be made outside the blockchain network through various forms of community engagement, such as forums, developer meetings, and social media. Bitcoin and Ethereum primarily use off-chain governance, where changes are debated within the community, and consensus is reached informally before any technical proposals are implemented.

The Spacecoin Foundation will continue to participate in each level of governance as part of the ecosystem. It will coordinate and facilitate discussions, ensure transparency, and provide technical support.

5. Future

5.1 Roadmap

Short Term	Space-Ground connectivity Serving live customers in production
Mid Term	Space-Space connectivity Diversification from connectivity-only to aerospace data and secure connectivity
Long Term	Interplanetary connectivity Becoming the global standard in aerospace data transmission

5.2 Ideas

The decentralized network of satellites enables a new horizon of possibilities. However, as Apple created the iPhone, not Instagram, it is difficult to speculate on what might be built atop the Spacecoin network. However, there are several concepts worthy of exploration which are clearly emerging:

5.2.1 Multi-Planetary Internet

As our species makes strides in becoming multi-planetary,[25] we will inevitably deploy telecom and blockchains on each planet we live on, and it will be crucial to connect them.[26] The Spacecoin network will facilitate the expansion of each planet's ground network to satellite communications, facilitating interplanetary communications and operations.

5.2.2 Proof of Location

Similar to device localization based on triangulation from cell towers[27] or wifi routers, one can localize a device connected to the Spacecoin network.[28] Further, given that the network is decentralized, the localization can be used not only to know your location but also as a Proof-of-Location (PoL) to a third party. PoL can significantly impact supply chain, logistics, mobility, land registry, and security solutions.[29]

5.2.3 Non-Virtual Private Network

A private network is a network where the devices within it are connected and communicate exclusively with each other without outside access. A Virtual Private Network (VPN), on the other hand, extends a private network across a public network, such as the Internet. It allows users to access the private network from remote locations securely.

VPNs use encryption and tunneling protocols to create a secure connection between the user's device and the private network.[30] We use VPNs because we can not create a private network between two remote areas. However, we can create a non-virtual private network between two remote areas using satellites, enhancing security.

5.3 Challenges

5.3.1 Scalability Challenges

While specific numbers of data requests and responses of the current Internet are challenging to pinpoint without current data from major network operators and content delivery networks (CDNs), it's safe to say that the figure reaches into the trillions daily. For perspective, as of Q2 2023, Cloudflare's network processes an average of 46 million HTTP requests per second, peaking at 63 million. Daily, this amounts to handling approximately 2.1 trillion DNS queries.[31]

5.3.1.1 Hardware (CPU) Scalability

The node needs to be powerful enough to encrypt and decrypt the data at a rate of data packets transmitted through the satellite. Our research confirmed that the scalability of off-the-shelf CPUs for cubesat is capable enough for our purpose.

As satellites simply forward data packets from ground stations to end-users in full duplex, satellites can also wrap these packets in metadata and sign sets of them with an asymmetric public/private key pair. We looked into a Rad-Hard (Radiation hardened) Cortex-A9 dual-core ARM CPU[32] in its 5G Radio computer.

Based on our conservative estimates of comparative signing rates of a Cortex-M4 with a NIST 256-bit ECDSA curve,[33] a single core of the onboard A9 can achieve a signing rate of 33 signatures per second. With this signing rate, we can feasibly sign sets of all data packets transmitted through the satellite, thus enabling scalable proof to the Spacecoin network of which satellite transmitted which packets.

Ground stations can then use this metadata and the associated signatures to report data transmission ACKs between parties to the Spacecoin protocol via control nodes for Spacecoin distribution (charging end-users and distributing payments on the protocol). Considering that the Ground Stations will be running the majority of the 5G virtualized components and thus will hold the keys used to communicate to the UEs (like mobile devices), they will also have the ability to prove which packet was sent or received by each UE via the 256 bit AES keys used per the 5G standard.

5.3.1.2 Software (Blockchain) Scalability

The blockchain needs to support enough throughput at a rate of ACKs submitted through the Spacecoin network.

$$f_{nonce,i} = fee\ proposed\ by\ R\ for\ r_i$$

$$ACK_{nonce,i} = i^{th}\ ACK\ between\ R\ and\ T$$

$$(5)\ E_{K_R}(m_{T,i}, \sum_{0}^{i} f_i, nonce) = ACK_{nonce,i}$$

$$(4)\ V_{K_R}(\left(m_{T,i}, \sum_{0}^{i} f_i, nonce\right), ACK_{nonce,i}) \rightarrow \{T, F\}$$

The Transmitter can reduce the number of ACKs submitted to the Spacecoin network by merging fee-collection transactions. To merge multiple fee collections into one, the Transmitter can choose to accumulate fees from the same Requester by repeating to serve without submitting each ACK to the Spacecoin network and collecting fees. (5) Instead, the Transmitter will get the Requester to increase the fee amount of the latest ACK.

We can prevent the Transmitter from submitting multiple ACKs by giving ACK a nonce. (6) The Transmitter can submit an ACK with a unique nonce only once to the escrow and collect the fee.

The required TPS will drop drastically if the Transmitter merges and submits ACKs daily.

5.3.2 Aerospace Challenges

Building a global small satellite constellation to provide 5G Internet to ground users presents various technical challenges. First and foremost are the inherent risks associated with spaceflight. Small satellites are subjected to harsh conditions in space, including radiation, micrometeoroids, and extreme temperature variations.[34] Ensuring the reliability and longevity of these satellites while navigating these spaceborne hazards is a formidable challenge, requiring robust engineering solutions and redundancy in critical systems.

Another technical challenge lies in the bleeding edge of antenna-design research for enabling direct-to-mobile connections on 5G-NTN (New Radio Non-Terrestrial Network). Achieving efficient, high-speed data transmission to mobile devices from space-based satellites requires antenna designs that are compact yet highly effective and high gain. Typical patch antennas for cubesats offer a gain of up to 9db.[35]

Integrating a traditional centralized telco operation with a decentralized governance model for making critical performance decisions in the 5G Control Plane[36] poses a unique challenge. Balancing centralized control for network management with decentralized governance for equitable decision-making requires well-defined protocols and coordination mechanisms. Striking the right balance ensures efficient network management, low latency, and responsiveness to user demands.

Furthermore, operating a powerful RF (Radio Frequency) amplifier in a small satellite while managing thermal regulation by limiting transmission time is a complex technical endeavor. Overheating poses a significant risk to the satellite's components and can jeopardize mission success. Therefore, designing an efficient thermal management system and carefully managing the amplifier's operation are essential to maintain satellite health and ensure consistent performance.

Lastly, deploying the satellites from a space tug to insert them into the correct unique orbit with a low inclination presents another challenge. Precise orbital insertion is critical for achieving desired coverage areas and minimizing launch costs. Coordinating the deployment of multiple satellites to create and maintain a global constellation demands precise timing and maneuvering capabilities, adding complexity to the mission planning and execution. Overcoming these technical challenges is essential to realizing the vision of a global small satellite constellation providing 5G internet to ground users and enabling connectivity on a truly global scale.

5.3.3 Telecommunications Challenges

In our journey toward building a fully decentralized network, we've encountered two significant points of centralization that stand out: the necessity of obtaining spectrum licenses from governmental authorities and the role of the 3GPP in maintaining the root certificate authority (CA) for all SIM and eSIM activations. While exploring how to navigate these centralized aspects, we've uncovered some promising pathways toward decentralization.

5.3.3.1 Spectrum License

To obtain a spectrum license, an entity must apply through the relevant governmental regulatory body, such as the Federal Communications Commission (FCC) in the United States.[37] This process involves submitting a detailed application, participating in spectrum auctions or allocation processes, and adhering to strict regulatory requirements and fees. The process is highly centralized, as it is controlled by government authorities, limiting access and flexibility for network operators.

To initiate operations, we can partner with third-party entities that already possess spectrum licenses. This approach allows us to leverage their existing infrastructure and regulatory compliance, facilitating quicker deployment. The Spacecoin network can serve as a long-haul backhaul solution for these partners, enhancing their network reach and efficiency. This symbiotic relationship enables us to bypass the complexities of acquiring spectrum licenses while providing our partners with advanced, decentralized connectivity options through our satellite network.

NR-U (New Radio-Unlicensed) allows 5G networks to operate using unlicensed spectrum, providing several advantages for decentralized 5G deployment. It supports both license-assisted and standalone use of unlicensed spectrum, enabling mobile network operators to enhance network performance and coverage without being constrained by licensed spectrum availability.[38] The introduction of 6 GHz unlicensed spectrum further expands these capabilities, facilitating easier deployment of private 5G networks with scalable capacity.

5.3.3.2 SIM

The process of decentralizing SIM/eSIM certification involves a nuanced understanding of the Global System for Mobile Communications Association (GSMA) standards and requirements. To achieve GSMA certification, an organization must rigorously align its offerings with these established standards, which span technical specifications, security protocols, and operational best practices.

Partnering with third-party entities already possessing GSMA certification initially presents a practical solution, allowing us to utilize their services for SIM procurement.

However, looking forward, the idea of creating a new entity to manage root CAs and autonomously sign eSIMs/SIMs offers an exciting avenue for further decentralization. This approach suggests that while the 3GPP plays a central role in this process, alternative, more decentralized methods are feasible.

Furthermore, this discussion has highlighted the GSMA standards as a centralization point within the network. By establishing our entity for SIM/eSIM certification, we introduce a potential model for decentralization that operates on two levels. The first level allows any entity interested in becoming an ISP to manage their root CA and sign their eSIMs/SIMs, effectively decentralizing this aspect of network operation. The second level proposes an open standard that could function independently of 3GPP involvement, relying instead on adherence to GSMA Standards.

6. Conclusion

Spacecoin is a system for data transmission without relying on trust. We began with satellite-based internet infrastructure, which provided extensive coverage but lacked coordination among decentralized nodes. We introduced a blockchain system to match data transmitters with requesters to solve this, enabling service exchange and payment without requiring trust. Digital signatures offer verifiable proof of participation in each data transmission. The network transparently lists nodes' track records and availability and identifies free riders.

Spacecoin's network must be location and specification-agnostic, allowing any node to join by following the protocol to realize the goals above. Nodes can participate as data transmitters, but they only earn fees if selected by requesters and if they fulfill the transmission request. The token incentivizes increased data transmission capacity where demand exists. Participants vote with their token stake for protocol upgrades, signaling acceptance of new versions. The consensus mechanism allows for any necessary protocol changes while aligning the incentive with token ownership.

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