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Blockchain: Building Consensus and Trust across the Space Sector

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ABSTRACT

Blockchain, the technology which underpins cryptocurrency, offers businesses and governments the means to decentralize intermediaries and conduct peer-to-peer transactions using a distributed ledger and secure immutable records. The general press and business media continue to spotlight blockchain and how it will revolutionize the business enterprise. This paper examines blockchain and distributed ledger technologies, its relevance in the space sector, and describes the potential for a gradual adoption trend over the next few decades.

Blockchain for space systems may offer compelling advantages by reducing complexity across a range of business, operational, and security applications, including:

- Fund raising and venture financing
- Smart contracts
- Supply chain management
- Intellectual property rights management
- Networking and space community resourcing
- Identification management and data access

In addition to the above applications, it is reasonable to expect that various space sector regulatory/compliance blockchain initiatives could emerge over time, including: export licensing, spectrum allocation and licensing, cybersecurity and information assurance applications, commercial imaging licenses and launch certification and permitting.

The more transformative the change, the longer the time to integrate into the space business ecosystem and regulatory structures. As blockchain (or the more general term, distributed ledger technology, or DLT) gains traction in various applications, many space sector centralized third-party trust organizations focused on financial, legal, security and logistical oversight functions will likely consider adapting their operating models to gain some of the advantages and value that DLT offers.

INTRODUCTION

Blockchain technology was introduced during 2008 when an anonymous and mysterious person going by the name "Satoshi Nakamoto" released the whitepaper "Bitcoin: A Peer-to-Peer Electronic Cash System." Although the true identity of S. Nakamoto has never been revealed, the public debut of the Bitcoin white paper spawned a revolution in digital trust applications. Today, Bitcoin and other cryptocurrencies represent just one of many practical applications for digital trust solutions involving consensus based protocols. This is a "foundational" capability and holds transformative power across many industrial sectors – including space. Unlike disruptive technologies, foundational technologies (classic examples are electricity or TCP/IP protocol) exert influence gradually. Foundational technologies must first overcome technological, organizational, regulatory, and political barriers.

Most of today's space sector blockchain implementations are conceptual or nascent. A BCG survey conducted jointly with the Aerospace Industries Association confirms that blockchain is in the very early stages in the aerospace and defense industry. According to the survey, only 20% of respondents indicated that their firms are assessing blockchain in a meaningful way, half were unsure what their companies were doing about blockchain, and the remaining 30% said that their companies were not pursuing the technology.[1]

This paper explores the various application areas where digital trust solutions offer potential for advancement throughout various parts of the space value chain – including: concept design, acquisition, manufacturing, assembly, operations, and related user applications. Before delving further, it is important to address the definition of blockchain and some confusing lexicon that has emerged over the past decade.

WHAT IS BLOCKCHAIN?

Blockchain is a type of distributed ledger technology (DLT) storage system which preserves digital information and its provenance. Underlying DLT are the following key elements:

- **Distributed database** – Every node on the network maintains its own copy of the transaction data and other data on the "block", and each node updates when someone submits a new transaction.
- **Peer-to-peer transmission** - There is no central point of storage, such as a server. Instead, information is being recorded and interchanged between participants (or nodes) on the network.
- **Trust** – A new record's authenticity can be verified by the entire community.
- **Transparency** – Transaction history available to those with ledger permissions.
- **Immutable records** - Any one person is prevented from altering the legitimacy of the information.
- **Embedded logic** – Enables process automation, algorithms and rules automatically trigger transactions between nodes.

Figure 1 provides a general diagram for how blockchain works.

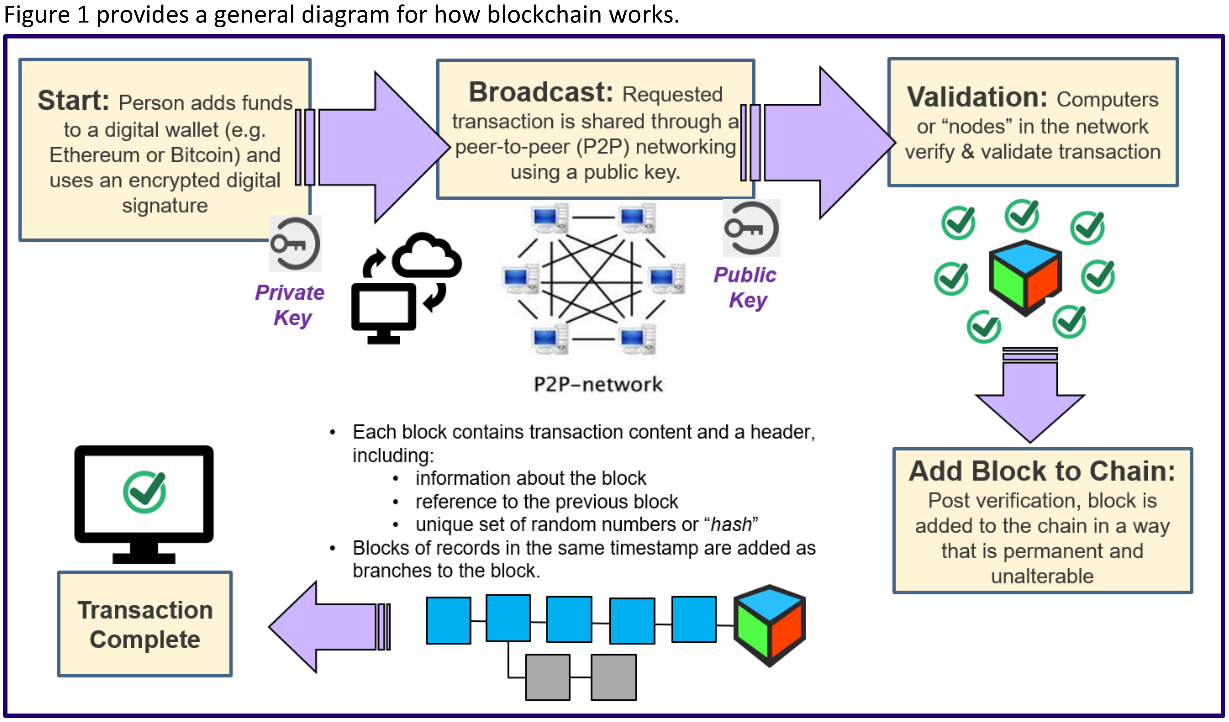

Figure 1: Blockchain – How it Works: Blockchain involves a ledger or record of digital transactions. The distributed database maintains a growing list of data records or "blocks'" that are cryptographically linked on a "chain".

What is the difference between DLT and blockchain?

Blockchain related lexicon has grown and continues to change rapidly. Many terms are overlapping which can increase general confusion. To clarify, blockchain is a subset or type of Distributed Ledger Technology (DLT) which includes cryptographically linked "blocks" (e.g. list of transactions), and a "chain" where each block is timestamped and placed in chronological order.

A DLT is a more general term and may not necessarily include a construct of cryptographically linked blocks. The ledger is stored across many servers, which then communicate amongst themselves to ensure that the most accurate and up-to-date record of transactions is maintained. In this paper – we will use the term "distributed ledger technology" as it is less specific and more applicable to the space sector.

Both DLT and blockchain are distributed databases which seek to achieve consensus efficiently and without the use of a centralized authority.

DLTs – Different Types of Permissions and Access

*A*n open DLT allows anyone to participate. There are two types – open and closed participation (see Figure 2). Beyond fundraising applications, the space industrial base will most likely adopt permissioned DLT due to unique space sector concerns such as security, export control, and proprietary technologies.

Open Participation/Open Ledger - This is the most open DLT and "any user" can manage the ledger. Bitcoin and Ethereum are two prominent examples. Nodes on the blockchain network apply some type of consensus model which allows mutually distrusting users to work together. "Proof of work" and "Proof of Stake"* are common consensus models, although new consensus models continue to emerge.

Open Participation/Permissioned Ledger – For permissioned ledgers, nodes need permission from a central entity to access the network and make changes to the ledger. Ripple, created for banks and payment networks, is an example of an open permissioned or "trusted" ledger which acts as a transaction validator. The main idea of Ripple was to create a system of direct asset transfers in real-time which would be cheaper, and more transparent[2]. Another example of permissioned DLT is Sovrin, managed by the Sovrin Foundation (Salt Lake City, UT), which claims to be a new open source standard for digital identity and decentralized global public network. The Sovrin Network is operated by independent stewards (rather than open permissions) and "uses the power of a distributed ledger to give every person, organization, and thing the ability to own and control their own permanent digital identity".[3]

A closed DLT controls both who participates and who maintains the ledger.

Closed Participation/Permissioned Ledger - A closed ecosystem requires that participants have permission to access that DLT.[4] The owner group maintains a private ledger. This type of system might include a consortium or private enterprise which restricts access to an authorized set of participants. A closed or permissioned ledger is accessible only to members (e.g. of the consortium) or different divisions or subsidiaries (e.g. of the enterprise).

* Proof of Work requires nodes on the network to solve a problem. This requires an immense amount of energy and computational usage. As a result, Proof of Stake (POS) is gaining in popularity. POS replaces miners with validators who must lock up some of their coins as stake.

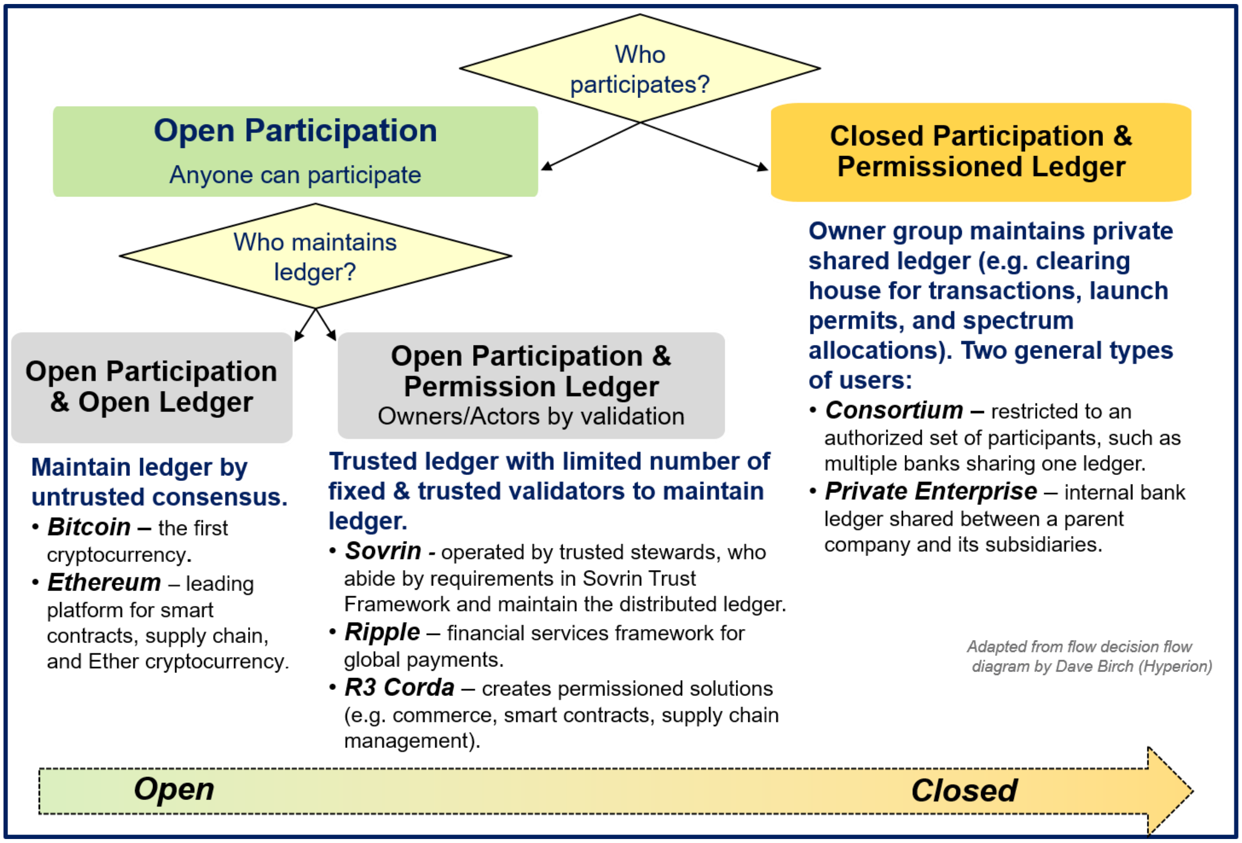

Figure 2: Distributed Ledger Technologies (DLT) can be initially categorized by who can participate and how the ledger is maintained.

DRIVERS AND BENEFITS

Need for consensus and security – removing centralized trusted authorities (e.g. "middle men")

A DLT implementation is designed to disintermediate or replace existing trusted and centralized authorities with a new model for decentralized authentication with speed, cost, and security benefits. Over the next several years, it is reasonable to expect that DLT will cut out the "go-between" in many industries. In fact, cryptocurrencies are already thriving and propagating without any central bank authority. Any entity who is currently playing a role as a third-party ledger manager, guarantor, or trusted authority should view DLT as a potential disruptor of their own position.

Space sector participants should ask themselves – where do I rely on a trusted central authority and where should I seek lower transaction costs, greater security, and efficiency? Similar to other industries, space sector DLT can be applied across the entire value chain (see Figure 3). This paper outlines business applications rather than regulatory functions – since the government has not yet implemented DLT into its governance models and there are few examples at this early stage. All space sector DLT applications discussed in the following section, seek one or more of the following benefits:

***Transparency* -** DLTs can be set up openly or privately. Open ledgers (Figure 2 – left side) allow anyone without special permission to review transaction history. By contrast, closed or permissioned ledgers still allow for a degree of transparency and accountability within a group or enterprise.

Efficiency - DLT technology can automate and improve business processes and organizational efficiencies (e.g., self-executing contracts)**.**

Privacy and Access – Privacy and permissioned access are facilitated by a confluence of cryptography and data decentralization.

New Products and Services – Decentralizing traditional models can create new cooperative business models. It remains to be seen what might emerge in the space sector since most efforts are in concept or demo phase. Etherisk (Switzerland) has established a blockchain based insurance protocol to build new decentralized insurance products. Perhaps satellite underwriters could adopt this new model? As discussed below, new business models could include: transitioning single operator satellites into "multi-tenant satellites" or leveraging open source networking standards and DLT to share resources such as ground station networks.

SPACE SECTOR APPLICATIONS

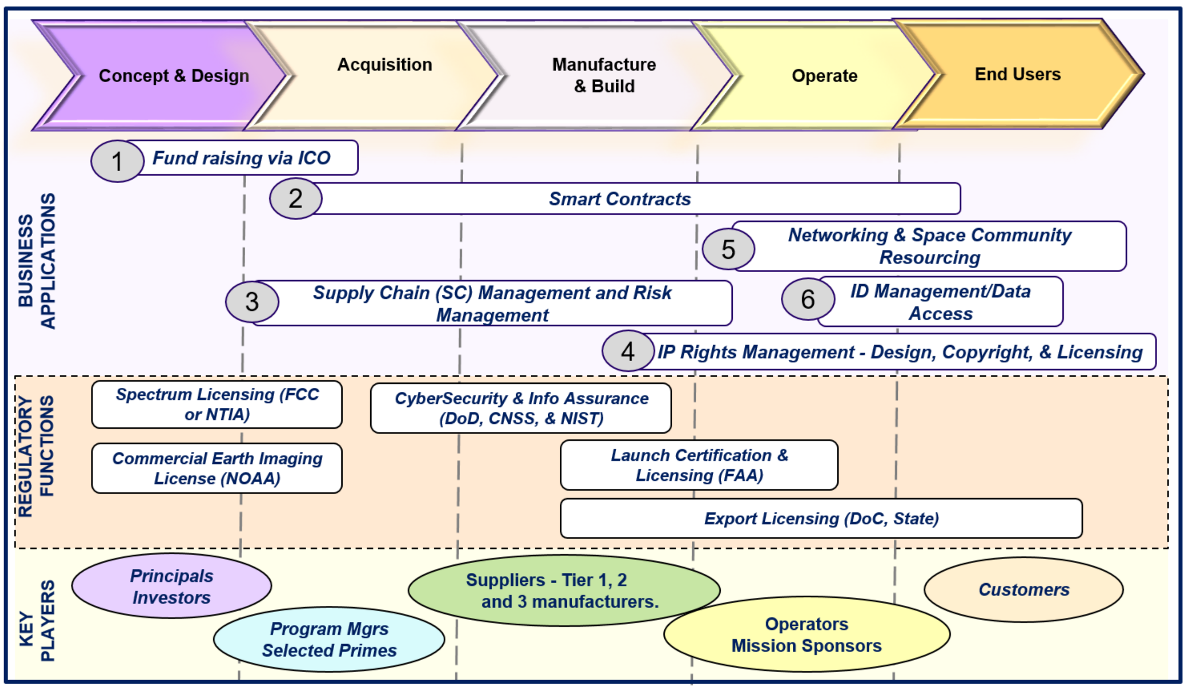

Figure 3: Potential DLT Applications across the Space Value Chain. This chart outlines six business applications, five regulatory functions and key players for each segment of the space value chain.

1 - Financing New Ventures through Initial Coin Offerings (ICOs)

With the introduction of Indiegogo (2008), Kickstarter (2009), Crowdfunder (2010), and other "crowdsourcing" internet-based models, new start-ups have threatened to eliminate the middlemen or traditional fundraisers and venture capitalists. Internet-based crowdfunding boasts impressive yields. According to "Fundly", a site which tracks crowdfunding statistics, over $34 billion was raised by crowdfunding during 2017.[5] However this internet based crowdsourcing model still introduces inefficiencies. Crowdsourcing players typically charge a 5% platform fee and a 3% credit card transaction fee.

Fundraising in the form of cryptocurrency "tokens" now competes with internet crowdsourcing, even though crowdsourcing is relatively new and still considered disruptive. DLT can introduce greater efficiencies. The Ethereum blockchain platform, for instance, has introduced a platform called "Acorn" which seeks to create an open global community and marketplace for crowdfunding. The platform incorporates a peer-to-peer "smart contract" based upon a governance structure and service, like cryptocurrencies, that can overcome geographic, political, and economic borders.

With the advent of blockchain, the crowdfunding landscape changes. Are venture capitalists concerned? Hardly. Instead they are embracing the new technology and introducing decentralized DLT-based "crypto-funds". That said, financing new ventures through ICOs may not always be the best application for DLT. The Harvard Business Review[6] notes that ICOs can introduce some negative unintended consequences. During the early stages the benefits to the venture founders are mixed, because an ICO gives decision control to the community for "speed, focus and collaborative effort." This reduces flexibility and decision-making. If a space start-up venture considers using an ICO for early fund raising, they should also consider the merits of starting with a "centralized" governance structure to encourage agile decision making and to protect confidentiality (e.g. business plans, proprietary information). Later, after the project gains traction and demonstrates success, exposure to a larger investment community makes sense.

Space Decentral

Space Decentral is one example of fundraising using DLT. This self-described "Decentralized Autonomous Organization" uses blockchain to "reinvigorate the push for space exploration with the public in control"[7]. Space Decentral intends to design space missions collaboratively, share research for peer review, crowdsource citizen science efforts, and crowdfund projects that lack national budgets. Space Decentral plans to use blockchain technology to coordinate workflows and business logic and use self-executing smart contracts and tokens. While Space Decentral's progress at this point has not stretched beyond building a community of interest and a draft white paper – its strategy is worthy of mention as it seeks to broaden the participation and investment in the space industry to include private citizens, entrepreneurs, space enthusiasts, and the public at large.

2 - Smart Contracts

Smart Contracts, or self-executing contracts, digitally facilitate, verify, or enforce the negotiation or performance of a contract. They rely on a set of IF / THEN statements that automatically trigger events when certain conditions are met. Given the complexity of participants involved in space, from launch to orbit, and the number of stakeholders who must monitor their vested equities, it is reasonable to expect that the space sector presents many opportunities to use smart contracts.

European Space Agency – Space 4.0

The European Space Agency (ESA) is looking at how space will evolve with a diverse and complex set of actors including commercial space companies, academia, the private sector, citizens and various countries. The World Economic Forum's "Fourth Industrial Revolution" model describes the planet's future in terms of "fusing the physical, digital and biological worlds, impacting all disciplines, economies and industries, and even challenging ideas about what it means to be human". [8] ESA has established an analogous framework for space called *Space 4.0* which represents the complex and automated interactions between governments, private sector, society and politics. ESA focuses on "administrative" DLT applications for accurate payments, procurement, supplier agreements, and automated smart contracts[9]. ESA envisions a sustainable space sector closely connected with the fabric of society and economy – and DLT could become an enabling technology to support this vision[10].

3 - Supply Chain Applications

A DLT integrated supply chain network for space systems offers compelling advantages – including a forensic audit trail and a single source of truth. The supply chain data is encrypted and sealed which makes it very difficult to alter. In addition, digital transactions on the blockchain can be easily audited and various risks can be monitored, such as the hazards posed by used or counterfeit parts.

Supply Chain Management

DLT can stretch beyond one company's tracking or enterprise system to include all supply chain participants: raw materials, parts, components, system (both operations and retirement). For example, if a counterfeit part is discovered on a satellite bus, perhaps even years after deployment in space, the satellite prime contractor could use the DLT record system to trace back the part, upstream to the source. Other DLT supply chain participants could also receive alerts and they could determine whether they too have used this part.

A cradle to grave approach can solve several supply chain concerns for the space industry as various participants can share technical information about parts and materials including:

- Detection of cyber threats
- Managing accurate inventory levels
- Responding to product recalls in a timely manner
- Detection of parts and components fraud (e.g. counterfeit parts)

It is still unclear who the DLT pioneers will be for space systems. However, some companies that are involved in both aviation and space, such as Boeing and Airbus, are already making progress. Boeing, for instance, has embarked upon an ambitious plan to digitize its aviation supply chain which extends to over 50 states and 140 countries. Boeing spends over spends $43 billion buying more than 1 billion parts per year. Three million parts arrive at Boeing facilities every day from 5,400 suppliers.[11]

Off-the-Shelf (OTS) Quality Control

The space sector is currently moving towards shorter duration (< 5-year missions) and production of greater numbers of satellites quickly in support of large low earth orbit (LEO) constellations and small satellite swarms. Builders of smaller, lower cost and short duration satellites are looking at off-the-shelf (OTS) parts as a means to gain competitive advantages to produce greater numbers of satellites quickly in support of swarms and constellations.[12] As the space sector expands it use of OTS, it is conceivable that DLT applications for supply chain management and supply chain risk management will become increasingly critical and perhaps a competitive discriminator within the commercial space sector.

Supply Chain Risk Management

Supply chain risk is the vulnerability that an adversary may sabotage, maliciously introduce an unwanted function, or otherwise compromise the design, integrity, manufacturing, production, distribution, installation, operation, or maintenance of a system. From a supply chain risk management (SCRM) perspective, the Department of Defense Inspector General (DoD-IG) identifies the need to: "improve the accuracy of the requests for supplier threat assessments and require the prioritization of the critical components on the requests and the inclusion of all key information needed… to conduct the assessments". [13]

Recognizing the DoD posture towards SCRM, a recent Aerospace report noted that blockchain mediation represents a superior technological and process solution toward mitigation and recommends that Air Force and DoD continue to build expertise in blockchain technology.

4 - Intellectual Property Rights (IPR) Management for Design, Copyrights and Data Licensing

Transfers of intellectual property do not necessarily require government registration to be effective. Yet if enforcement action is necessary, it is difficult to prove the transfer (e.g. assignor and assignee, transfer date). DLT could address this challenge by creating an immutable record involving the intellectual property – including records from original owner and the complete chain of ownership. The U.S. legal system, U.S. Patent Office, and other intellectual property rights organizations could consider DLT as a form of indisputable evidence for property rights. In fact, it appears that the country of Iran might be the first to adopt DLT for copyright protection.[14]

In addition to government registration of intellectual property, blockchain technology could be used to "tokenize" digital rights. Digital tokens could be bought and stored in a digital wallet with a software license encoded – this is referred to as Token-as-a-License (TaaL)[15]. A Taal could be used to simplify the distribution of satellite generated data, analytics, or imagery – essentially removing data brokers or middlemen from the transaction. These tokens, representing licenses for the use of satellite data, products and services, could be customizable to fit the needs of the business and would work like a smart contract.

5 - Networking and Space Community Resourcing

DLT presents many opportunities for the space sector to coordinate space based data across sensors and missions. NASA and the commercial sector are exploring how to combine artificial intelligence, DLT, spacecraft, and sensors to efficiently manage space-based infrastructure and missions. A few examples are discussed below:

Deep Space Networking and Computing – Basic Research

NASA recently provided $300,000 grant funding for a research project, named the "Resilient Networking and Computing Paradigm", led by Dr. Jin Wei-Kocsis of University of Akron's Department of Electrical and Computer Engineering. Dr. Wei-Kocsis indicated that the long-term goal is to "achieve scalable decentralized cognitive networks in deep space".

Thomas Kacpura, Advanced Communications Program Manager at NASA Glenn Research Center[16], noted that "Blockchain is one possible engine that can drive cognitive outcomes for autonomous operations. We are currently examining enabling technologies for trusted autonomous operations in space and looking to develop a simple representative distributed system which will emulate how far apart nodes in deep space can work as a distributed blockchain to ensure trusted autonomous operations." The idea is to decentralize NASA's future network of nodes in deep space – to allow for a more resilient and responsive network. This research project could lead to decentralized processing among NASA's space network nodes.

NASA "SensorWeb"

NASA is looking to use smart contracts on the Ethereum blockchain in the agency's SensorWeb program. The main objective of the program is to create an interoperable environment for a diverse set of satellite sensors via the use of software and the Internet (see Figure 4). [17]

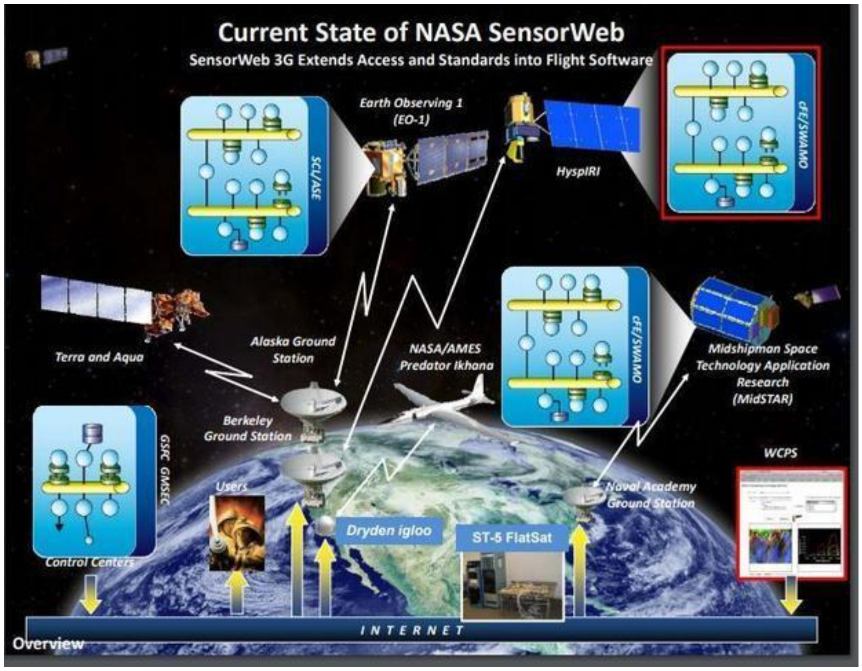

Figure 4: NASA SensorWeb – An Interoperable Environment for a diverse set of Satellite Sensors
(Source: NASA website – Goddard Space Flight Center)

Network of Blockchain Nodes in Space – "SpaceChain"

SpaceChain describes itself as a "decentralized space agency that partners with other organizations". SpaceChain has created smart hardware that can be installed onto satellites with SpaceChain OS. The first satellite blockchain node was launched into space on February 2, 2018. On March 2018, Spacechain completed and integrated Qtum, an open sourced blockchain application platform on the SpaceChain OS. By September 2018, Spacechain completed partnerships with over 10 space and blockchain companies.[18] The universal space OS "converts single-operator satellites into multi-tenant ones, while the blockchain provides a highly secure sandbox between multiple space applications. That way, users will be able to develop different types of space-based applications on a single satellite, maximizing the efficiency from this expensive resource".[19] SpaceChain aims to establish a community incentive model using tokens which act like tickets to upload and execute space-based apps, and store data onto the SpaceChain network.

Open Source Networking Standard for Ground to Space Communications - "EtherSat"

EtherSat, Inc. (San Jose, CA) is developing an open source networking standard for ground to space communications to make communication with spacecraft more efficient. The "blockchain-enabled satellite communications network" aims to improve utilization of existing ground station networks to save new space companies considerable capital investment and deployment time.

6 - Identification Management (IdM)

In 2017, more than 2.9 billion records were compromised from security incidents across various industries. These damaging and costly security breaches are, in part, a consequence of the Internet being developed without a true identity layer. To address this infrastructure flaw, a consortium called the Decentralized Identity Foundation (DIF), a 503c standards organization, is actively developing industry standards, protocols, open source technical components, and implementations. DIF seeks to define the "foundational elements necessary to establish an open ecosystem for centralized identity and to ensure interoperability between participants"[20] – using DLT.

Two types of IdM have emerged in two categories[21]:

Self-Sovereign Identity - Here, the identity is controlled by the owner. Examples include Sovrin, uPort, and OneName. The Sovrin Network, for instance, is an open-source decentralized identity network built on permissioned DLT. The validators or nodes could be banks, academic institutions, or another trusted institution. Sovrin adds the missing identity layer to the Internet and provides a complete approach to identity from the distributed ledger to device, making secure and private self-sovereign digital identity possible for the first time in history.

Decentralized Trusted Identity - Decentralized trusted identity provides a proprietary service that performs identity proofing of users based upon existing trusted credentials (such as a driver's license or passport) and records identity validation by DLT. ShoCard, for instance, is a mobile-identity platform using biometrics for authentication. ShoCard integrates biometric recognition technology and DLT based data.

How will the space sector adopt IdM enabled by DL? It might not be that different from other institutions. For example, NASA may want to adopt this type of technology for better identification and authentication of their employees. The commercial satellite industry may apply this technology to ensure that their networks of users are legitimate customers. The space sector is currently experiencing increased integration across infrastructure, networks, and cloud analytics. The ecosystem of cooperative partnerships and players is expanding horizontally. As more companies emerge from their vertical silos – increased identification management will be necessary.

Space Sector Application Summary

Table 1 summarizes the various DLT applications in the space sector and general industry. Non-space DLT applications are maturing faster than space applications. Within the space sector, DLT maturity ranges from early R&D phase (e.g. supply chain management and IP management) to a more mature growth phase such as financing new space ventures.

Application	***Example***	***Phase*** *(R&D, Demo, Growth, Mature)*
1 - Financing New Ventures	Fund raising via Initial Coin Offerings (ICOs) ***Space Decentral***	Non-space – Growth/Mature Space - Demo
2 - Smart Contracts	European Space Agency – ***Space 4.0,*** and practical administrative DLT applications.	Non-space - Growth Space - Demo
3 - Supply Chain Management	Applications could include efficient cross enterprise inventory management, tracking of faulty or counterfeit parts.	Non-space - Growth Space – R&D
4 - IP Management	Applications could include managing licenses for image and data providers.	Non-space – Demo (Iran) Space – R&D
5 - Networking & Space Community Resourcing	- NASA - ***Resilient Networking and Computing Paradigm*** - NASA – ***Sensor Web*** - Blockchain Nodes – ***SpaceChain*** - Open Source Networking - ***EtherSat***	Non-space - Growth Space - Demo
6 - ID Management	Non-space sector maturing rapidly. ID applications include - Sovrin, uPort, OneName and ShoCard. Space sector will most like follow and adopt commercial ID management solutions over time.	Non-space - Growth Space - Demo

Table 1: DLT Applications – Examples and Lifecycle Maturity Phase

CONCLUSION: GRADUAL ADOPTION WITH SPACE INDUSTRY COLLABORATION

Foundational technologies, such as distributed ledger technologies (DLT), require time to build and take hold.

DLT has been described as a "foundational technology" rather than a disruptive technology[22]. Like TCP/IP, upon which the internet was built, DLT will require broad coordination and "the level of complexity -- technical, regulatory and social – will be unprecedented" – according to the Harvard Business Review[23]. Unlike disruptive technology, foundational technologies establish new models, often requiring years or even decades to take hold. For example, TCP/IP gained traction slowly and it took over 30 years to replace circuit switched[†] technology. DLT could require as much time to evolve and gain broad industry adoption.

Such a long adoption time might seem surprising given that cryptocurrencies, such as Bitcoin and Ethereum, based upon blockchain technologies, were introduced and proliferated rapidly after 2008. However, the evolution of cryptocurrencies did not require complex interactions across industry sector players. Instead, the cryptocurrency model allows anyone to participate and offers immediate utility to those who chose to trade. By contrast, the establishment of a space sector wide DLT will require the cooperation of many commercial and government space players and they will likely opt for additional security measures and controls. Most DLT examples discussed in this paper (smart contracts, supply chain management, IP management, networking, and ID management) are probably best suited as closed DLT systems[‡] because the general public is not typically involved in these types of applications in the space sector.

DLT establishes trust through collaboration (peer to peer sharing) and encryption – this is a new paradigm. There is no trusted central authority. It will require time for various industries to determine whether this new type of trusted network works for them. The gaming and financial industries are recognized early adopters of blockchain. Other industries ripe for blockchain transformation include healthcare, legal, music and real estate. It is reasonable to expect that the space sector will slowly adopt DLT -- first starting with "localized" demonstrations, and later expanding to enterprise models. Eventually, for some applications, industry wide consensus models could emerge with DLT as the enabling technology. While there are many drivers that will push the space industry in the direction of decentralized authorities, an industry wide collaboration requires time for coordination, stakeholder involvement, legal and regulatory acceptance and standards setting.

The Center for Space Policy and Strategy continues to examine the potential for DLT applications in the space sector. We welcome input and additional case study examples. Please contact Karen Jones, karen.l.jones@aero.org.

[†] Circuit switching involves establishing a connection between two points using a specific path on a network for the duration of a message exchange.

[‡] Closed participation and/or permissioned ledger where an owner group maintains the ledger.

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