Blockchain meets space, space meets blockchain

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Abstract

Distributed Ledger Technology (DLT) refers to the technological infrastructure and protocols that allow simultaneous access, validation, and record updating in an immutable manner across a network that is spread across multiple entities or locations. In other words, DLT is a protocol that enables the secure functioning of a decentralized digital database, providing trust and transparency to data and processes.

Blockchain (although just a type of DLT, blockchain and DLT are often used interchangeably) now touches virtually every sector of human activity, so it is no surprise that the European Commission has established The European Blockchain Services Infrastructure (EBSI), a network of distributed blockchain nodes across Europe that will deliver cross-border public services to ultimately enhance the way citizens, governments and businesses interact. Another pan-European initiative is Blockchain for Industrial Transformations (#Blockchain4EU), a forward-looking exploration of existing, emerging, and potential applications based on blockchain and other DLTs for industrial/non-financial sectors, including space.

Being space the next frontier for business innovation, the space industry in general and the SatCom one in particular are not an exception to this trend, and GMV is actively investigating both how satellite operations (SatCom in particular) can benefit from blockchain and the other way around, how blockchain can benefit from satellite communications.

In this context we have analysed in detail a series of use cases where blockchain could benefit from SatCom, including Spectrum Management (SM), Space Situational Awareness (SSA), tokenization of SatCom-related assets, the satellite manufacturing supply chain, frequency interference management, and the use of blockchain to establish a global communication network. Use cases where SatCom could benefit from blockchain were also assessed, including ledger fingerprint broadcast, ledger delivery, proof of location and space-based data centers.

Not only technical aspects are covered, but also programmatic, regulatory and ethical.

Along the way, we are also defining a satellite candidate system architecture for the applications of some of those scenarios regarding satellites and DLT usage.

In this paper we report on the above-mentioned activities.

Keywords: distributed ledger technology, blockchain, SatCom

Acronyms/Abbreviations

AN	=	Application Notification
AUEB	=	Athens University of Economics and Business
BCT	=	Blockchain Technology
#Blockchain4EU	=	Blockchain for Industrial Transformations
CN	=	Coordination Notification
CREAM	=	Collision Risk Estimation and Automated Mitigation
DAO	=	Decentralised Autonomous Organisations
DFS	=	Distributed File System
DLT	=	Distributed Ledger Technology

DG CNECT	=	Directorate-General for Communications Networks, Content and Technology
DGs	=	Directorates-General
DSM	=	Dynamic Spectrum Management
EBSI	=	European Blockchain Services Infrastructure
Eidas	=	Electronic Identification, Authentication and trust Services
ESA	=	European Space Agency
EU	=	European Union
HAPS	=	High Altitude Pseudosatellite
ITU	=	International Telecommunication Union
ITU-R	=	International Telecommunication Union Radiocommunication Sector
LFB	=	Ledger Fingerprint Broadcast
NRAs	=	National Regulatory Authorities
PBFT	=	Practical Byzantine Fault Tolerance
P2P	=	Peer to Peer
PoA	=	Proof of Authority
PoET	=	Proof of Elapsed Time
PoL	=	Proof of Location
PoS	=	Proof of Stake
PoW	=	Proof of Work
SatCom	=	Satellite Communications
SM	=	Spectrum Management
SSA	=	Space Situational Awareness
SST	=	Space Surveillance and Tracking
R&D	=	Research & Development
RR	=	Radio Regulations
SSA	=	Space Situational Awareness
WRC	=	World Radiocommunication Conference

1. Introduction

DLT refers to the technological infrastructure and protocols that allow simultaneous access, validation, and record updating in an immutable manner across a network that is spread across multiple entities or locations. In other words, DLT is a protocol that enables the secure functioning of a decentralized digital database, providing trust and transparency to data and processes.

Blockchain (although just a type of DLT, blockchain and DLT are often used interchangeably) now touches virtually every sector of human activity.

Being space the next frontier for business innovation, the space industry in general and the SatCom one, in particular, is it necessary to analyse and investigate the potential benefits / potential applicability between blockchain technologies and SatCom systems, identifying the most promising use cases where blockchain solutions could benefit current and next generation satellite communication systems or vice versa. SatCom is a player with an extremely high potential across the DLT and both can benefit from each other.

2. Blockchain overview

A blockchain is a time-stamped series of immutable records of data that is managed by a cluster of computers not owned by any single entity. Each of these blocks of data (i.e., block) is secured and bound to each other using cryptographic principles (i.e., chain). Every user in the network has a copy of this digital ledger and, hence, is able to see and monitor all transactions; in addition, some nodes are also validating nodes that can validate the updates to the digital ledger.

The following diagram from [1] depicts in a nutshell how blockchain technology works.

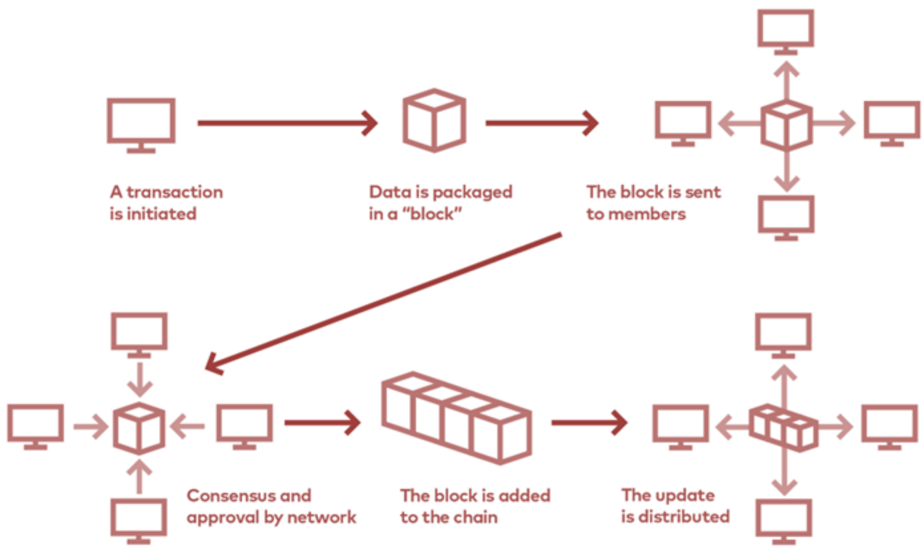

Fig. 1. Blockchain in a nutshell, from [1]

The main five key **characteristics** of public blockchains (as inspired by [2][3] and our own experience) are summarized in Table 1 below.

Table 1. Key characteristics (benefits) of (public) blockchain-based distributed ledgers

Benefit		Description
	Decentralization	Each node has a copy of the ledger in which transactions are recorded. The distributed ledger is protected against single point of failures, and it makes the ledger highly available even if some nodes become inaccessible.
	Trust	A trusted third party or intermediary is not needed to validate the transactions (this is referred to as 'trustless'), neither should one node need to trust others before they can transact. The consensus algorithm in the blockchain is used to validate and record the transactions in a more democratic manner than the centralized approach.
	Transparency	Every node can access and verify the history of transactions stored in the blockchain as well as the governing algorithms.
	Immutability	It is extremely difficult to change data recorded on a blockchain. One-way cryptographic hash functions ensure that any modification of previous blocks in a blockchain invalidate all the consequently generate.
	Security	All transactions in the ledger are cryptographically signed with a private key before being broadcasted. The authentication of transactions can thus be verified by others via the corresponding public key which is accessible to all nodes. Since the private key is kept by its owner, one node cannot masquerade as others to initiate transactions and any verified transaction cannot be denied by its initiator (non-repudiation).

Further, there are five key blockchain **architectural aspects** as follows:

- **Governance model**. The governance model of a DLT determines who and how is maintained the ledger. Benefits and limitations of private and public blockchains were considered. A brief comparison is given in Table 2 below.

Table 2. Comparison of public and private blockchains.

	Public blockchain	Private blockchain
Access	Anyone can access	Access controlled by a single organization
Participation	Pseudo-anonymous	Permissioned Identities known to the controller
Security	Consensus mechanism	Pre-approved participants

	Public blockchain	Private blockchain
	• Proof of Stake • Proof of Work	• Voting/multi-party consensus
Performance	Slow transaction speed	Fast transaction speed

- **Access model**. The access model of a DLT determines who and how can be accessed the ledger.
- **Consensus mechanisms**. Proof of Work (PoW) and Proof of Stake (PoS) were considered.
- **Integrity models**. Ensuring data integrity by keeping all the records on the chain and distributing them to network participants.
- **Application models**. Each ledger system is usually developed for certain functions, at which it excels, at the cost of other features unnecessary for the intended purpose [7]. Three general categories of blockchains can be classified as:
  - integrity providers,
  - payment (or more generally, asset tracking) methods, and
  - general programmability networks.

The main **challenges** that this technology presents and with which we must live today [2][4][5][6] are summarized in Table 3.

Table 3. Main challenges of (public) blockchain-based distributed ledgers

Benefit		Description
	Agreement	The very main advantage of blockchain and DLTs, namely its decentralization nature, is sometimes a handicap for its adoption as certain players would lose their privileged role in certain stages of the process.
	Difficult development and maintenance	Design, develop and maintain blockchains is far more difficult than using centralized databases.
	Resources intensive	Each replica node in the conventional blockchain network must process and store a copy of the completed transaction data which requires significant processing resources and storage.
	Difficult scaling	Scaling a blockchain is hard, often several orders of magnitude harder than in traditional centralized systems
	Legal and regulatory challenges	Such as personal data challenges (e.g., replication of data in nodes vs. the data minimisation principle under EU law), contractual challenges (e.g., automation and smart legal contracts vs. the need for human intervention), consumer protection challenges (e.g., distributed trust vs. consumer protection), governance (including with relation to decentralised autonomous organisations (DAOs)), classification of tokens, intellectual property, territoriality and enforceability of regulations to actors in the chain, liability, among others.

3. Objectives and preliminary analysis

The objectives we had at the beginning of this work were to:

- Identify potential use cases and applications for DLT that can be implemented by future SatCom systems.
- Identify features of the SatCom market that could benefit from the use of DLT applications.
- The other way around: identify features of the DLT that could benefit from the use of SatCom systems.
- Assess the feasibility, performance, and benefits of satellite based DLT systems.
- Define the system architecture most suited for the implementation of the identified DLT use cases, considering the regulatory environment and governance for such systems.
- Inform the community about the capabilities and feasibility of the DLT use cases in SatCom systems and define technology developments necessary to make them a reality.

In the first part of the activity, we analysed the benefits and potential applicability of DLT applications to SatCom systems. This was done by identifying and analysing what unique features of this market suit to the use of blockchain technologies (BCT) and the most promising use cases where blockchain solutions could benefit from current and next generation satellite communication systems. As a result of this analysis, the following list of SatCom use cases were preliminary identified (see Table 4).

Table 4. Preliminary list of uses cases where SatCom can benefit from DLT

Use Cases	Description
Spectrum Management (SM)	The spectrum sharing and management involves multiple entities with rights to use the spectrum. It is critical for spectrum sharing mechanism to provide transparency and traceability of the trading process so as to enable the system to detect, and hence eliminate, unauthorized access by non-authorized users. Further, it is important to facilitate the communication and coordination among the different actors involved in the different processes of sharing and management, allowing users to coexist without interference.
Space Situational Awareness (SSA)	SSA is an essential aspect of space operations. Its purpose is to characterise the space environment and how it affects in-orbit activities. It is usually divided into three main areas, Space Weather, Near Earth Objects and Space Surveillance and Tracking (SST). Topics here involve decentralized network of sensors, catalogue and SSA services provision.
Tokenization of satellite/space assets	Space asset tokenisation refers to the enabling of a crypto token-based ownership of, or other right over, space assets including spacecrafts, satellites among others. The goal here is to facilitate convenient transactions of satellite products and space resources.
Satellite manufacturing supply chain	A supply chain is essentially the network of people and organizations that move products from one point to another, or from creation to consumption. Increase traceability and reduce paperwork and administrative burden are the goals of this use case.
Frequency interference	Spectrum monitoring and interference detection are crucial for satellite service performance and the revenue of SatCom operators. Interference is one of the major causes of service degradation and deficient operational efficiency. This use case considered how to publish interferences and broadcast usage and support frequency hopping.
Global Network	A global network is any communication network which spans the entire Earth, using a global constellation. This use case considered the use of blockchain for cooperative projects in setting up a global network, for communication purposes among participating satellites, for authentication in LEO networks and for satellite distributed data storing.

All six use cases above were characterized considering the current state of the art and addressing specifically the key characteristics, architectural aspects and main challenges highlighted in section 2. Blockchain overview above. This preliminary analysis was the starting point for the in-depth work carried out and described in the next section.

4. Use case analysis

For the analysis of the DLT and SatCom use cases we organized a stakeholder workshop. The goal was to assess the end user perspectives and feedback on the proposed DLT/SatCom applications to gain stakeholders' insights on their professional experiences, record specific feedback and opinions on the status-quo in DLT and SatCom operations and explore high-level potential gap-closure avenues.

The workshop participants included both SatCom and DLT/blockchain experts from relevant institutional, industry and R&D including (in alphabetical order): Aalto University, Airbus, Athens University of Economics and Business (AUEB), European Space Agency (ESA), eCustoms, GEASPACE, Hispasat, Indra, INMARSAT, Nanoavionics, Sfera Technologies Ltd., SKUDO, University of Malta, University of Luxembourg, Usyncro, Guardtime, GMV and VdA.

During the workshop the preliminary six use cases were analysed and four further ones were discussed as follows:

- **Blockchain Ledger Fingerprint Broadcast** (**LFB**). A distributed ledger demands a single version of it shared by all users. Nobody should be able to convincingly present two different versions to two different users. Satellite-based solutions could be used to broadcast a digital fingerprint of the current agreed state of the ledger.
- **Blockchain data delivery**. In many blockchain-based systems, access to the complete history of transactions (the full ledger) is needed to operate a node in any meaningful sense. This presents a challenge in setting up, and keeping up, such a node in areas with poor connectivity, where SatCom could be a solution.
- SatCom as part of **DLT Proof of Location** (**PoL**) **consensus**. In several application domains, it would be desirable to be able to provide strong evidence of the physical location of some entity or asset.

- **Secure data storage** on the orbital "data center". For a handful of specific scenarios, it could be desirable to employ satellite-based "data centers" for secure storage. The objective is improved data security achieved by moving the data far away from potential attackers.

The resulting ten use cases were benchmarked considering their feasibility, performance, legal aspects, and benefits to help the selection of the ones that could be significantly enhanced by the SatCom system.

As a result of the investigations and the stakeholders' workshop, which served as a critical and valuable input, it was concluded that **Space Situational Awareness** (**SSA**) and **Spectrum Management** (**SM**) were the most appropriate topics for further analysis and activities in the future regarding blockchain solutions leveraging SatCom.

For the use cases leveraging SatCom systems for the benefit of blockchain, no clear business case was identified but the workshop attendees considered that **Ledger Fingerprint Broadcast** (**LFB**; combining the highest level of technical feasibility with the second-highest business value) and **Proof of Location** (**Pol**; with the highest expected business value) have a great potential for application in SatCom systems.

It should be noted that although the SSA use case was highly valued during the workshop, it was identified that some related activities were already ongoing, and so, in order to not to duplicate efforts, it was decided not to further work on this use case.

Thus, three use cases (SM, LFB and PoL) were downselected for further evaluation including system architecture analysis.

5. Architecture

In this part of the work, we tackled the architectural aspects of the intersection between the blockchain and the SatCom worlds. The goal was to define the system architecture most suited for the implementation of the largest possible subset of DLT use cases identified previously. This task addressed issues such as technical needs while also considering users and mission requirements. The possible appropriate architecture(s) for the main use cases identified previously are further elaborated in the following sections.

5.1 Spectrum Management (SM)

The key objective regarding the Spectrum Management use case is the creation of a network that allows the secure sharing of data between entities and satellites and the implementation of a consensus that allows self-management without the system being controlled by any single entity and yet still acting as a single system in terms of being synchronized across all participants. We focus our system architecture on the International Telecommunication Union (ITU) regulatory and coordination process, specifically in the Application Notification (AN) coordination procedure.

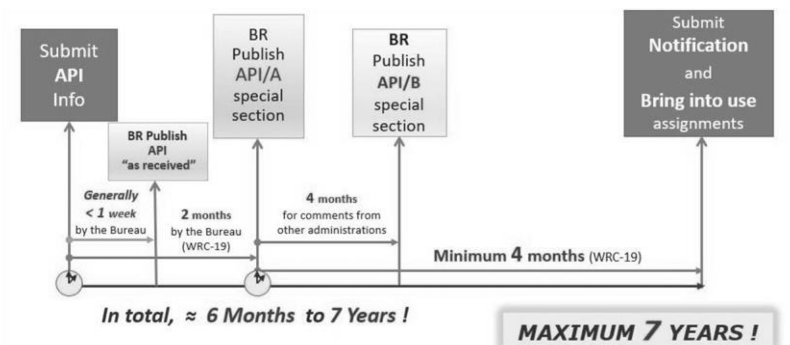

Fig. 2. ITU Application Notification (AN) coordination procedure, from [8]

An architecture that would support the specific use case within spectrum management and that could be the basis for future extensions was designed. Our proposal for a platform based on blockchain that allows us to secure, automate and streamline current processes is shown in Figure 3:

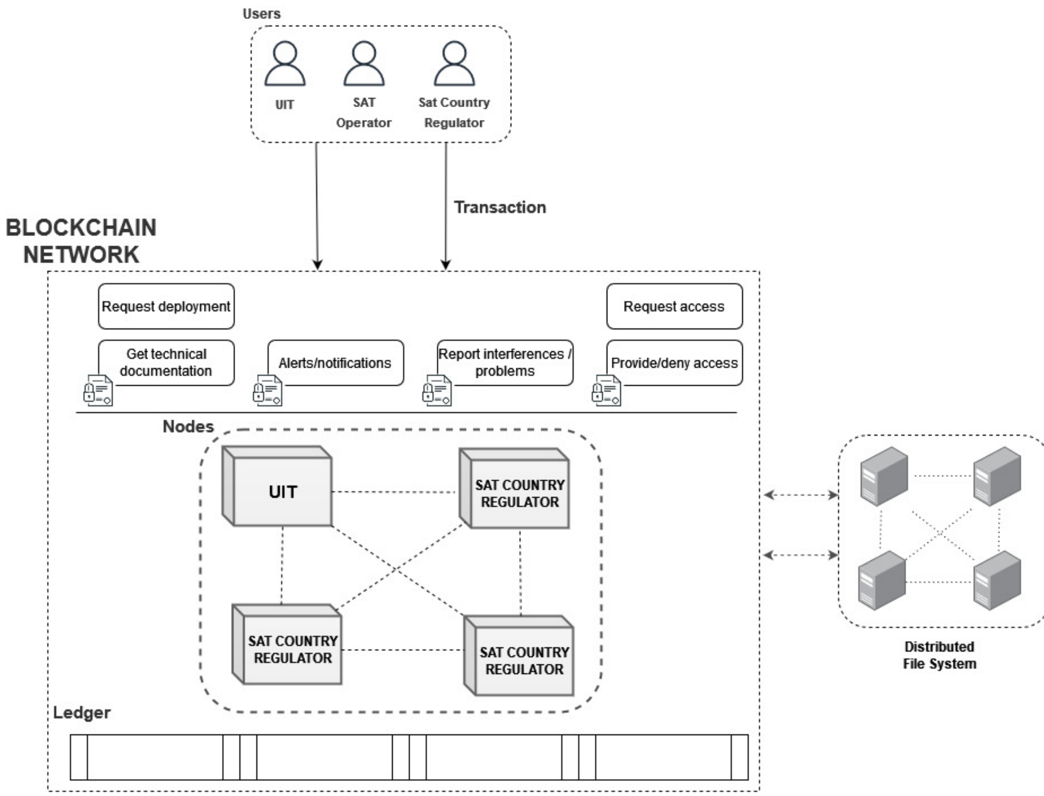

Fig. 3. Spectrum Management (SM) use case proposed architecture

The components that make up the architecture are the following:

- **Transactions**: concrete actions carried out in the network.
- **Smart contracts**: functional endpoints that will allow interaction with the blockchain and support each use case.
- **Nodes**: entities that are currently part of the validation process and that in this platform will be part of the network consensus.
- **Ledger**: record of each and every one of the operations and transactions that are carried out within a blockchain. With this, the ledger becomes one of the fundamental pieces of transparency, security, and confidentiality of the network.
- **Distributed file system**: physical storage of documents indexed in the blockchain, distributed across the different nodes participating in the network.

The physical storage of the content that we index on the network will be made up of a distributed file system (DFS) and the network should be constituted as a private permissioned or consortium network, where users are explicitly authorized to participate. With relation to the consensus algorithm used in the platform, where a certain level of trust between users is assumed since they have been authorized to participate in it, some options such as Proof of Elapsed Time (PoET), Practical Byzantine Fault Tolerance (PBFT) or Proof of Authority (PoA) were considered. Regarding suitable technologies where the proposed solution could be implemented, we considered at this moment the following possibilities: Hyperledger Fabric, Hyperledger Sawtooth, Corda Community Edition or Ethereum Private Networks.

5.2 Proof of Location (PoL)

General requirements and possible system architectures for integrating satellite-based Proof of Location services into blockchain and distributed ledger technologies were mapped. Since the concept of a proof of location is very general, it could be relevant in multiple application domains as well as a component service of the blockchain infrastructure itself. The requirements and the proposed architectures are very high-level and additional research will be needed before the necessary components can be specified in sufficient detail for even prototype implementations.

Some possible system architectures along with a brief analysis of the strengths and weaknesses of each one are outlined below:

- **Single-satellite assertions**. The main benefit of this approach is the minimization of both communication and computational resources required on the satellite to provide the location service, although there is a possible trade-off between computation and communication costs. One option would be to process the raw radio signal obtained into a location assertion on the satellite and to relay only the final verdict to the ground station for posting to the ledger. An alternative would be to relay the raw radio signal and leave the processing to the ground station. The main drawback of this simple architecture is that the accuracy of the location as determined by a single satellite is significantly worse than what would be achievable in a multi-satellite formation [9].

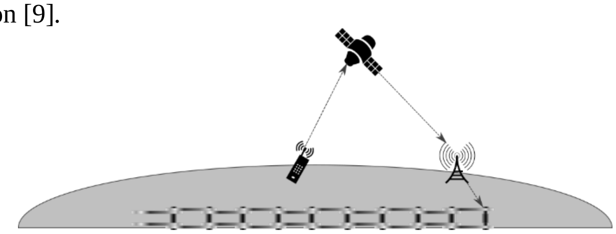

Fig. 4. Proof of Location (PoL) use case single-satellite assertions proposed architecture

- **In-space consolidation.** The main benefit of this approach is the improved accuracy and precision of the location data. Achieving a consensus among the satellites regarding the location of the tracked asset necessarily implies in-space processing of the raw radio signals into location data. To take advantage of the multi-satellite consensus, each satellite should also sign its agreement with the jointly computed results before relaying them to the ground station. Then it would make every sense for the ground station to post the final location assertion with the signatures of all the consenting satellites for the ledger users to be able to also verify the consensus agreement. The main drawback of this approach is the high amount of computation and communication that all satellites must perform. This includes the requirement that the satellites must be able to communicate among themselves, in addition to the client and the ground station. Typically, this implies additional antenna arrays on the satellites, with the need to power and orient them.

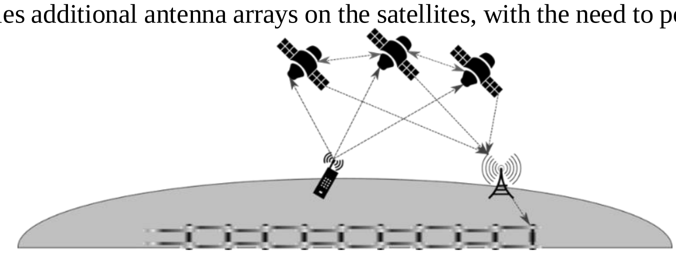

Fig. 5. Proof of Location (PoL) use case in-space consolidation proposed architecture

- **On-ground consolidation**. The main benefits of this approach are the improved accuracy and precision compared to the single-satellite architecture and the avoidance of inter-satellite communications compared to the previous multi-satellite architecture. For the ground stations to be able to obtain the accuracy and precision benefits of the multi-satellite approach, they must download more detailed information about the received signals than just individually computed estimates of the client's locations [9].

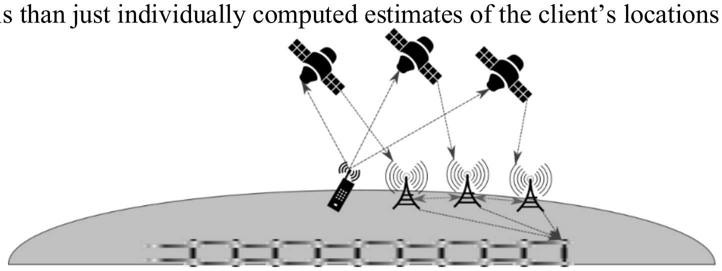

Fig. 6. Proof of Location (PoL) use case on-ground consolidation proposed architecture

- **Hybrid-satellite architecture**. A design variation that can be applied to any of the architecture models outlined in previous sections is to use HAPS or LEO satellites as the primary recipients of the client positioning requests and GEO satellites instead of ground stations as the secondary layer to collect the positioning data from the primaries for posting to the ledger. The benefit of using HAPS or LEO satellites as the primary recipients would be that they are closer to the ground and therefore have higher relative changes of signal angles and time differences when the client moves by the same absolute distance, which in turn improves the accuracy of client positioning. The benefit of using GEO satellites instead of ground stations is that just a few GEO satellites can provide global coverage for the HAPS or LEO satellites whereas a much larger number of ground stations would be needed for global coverage.

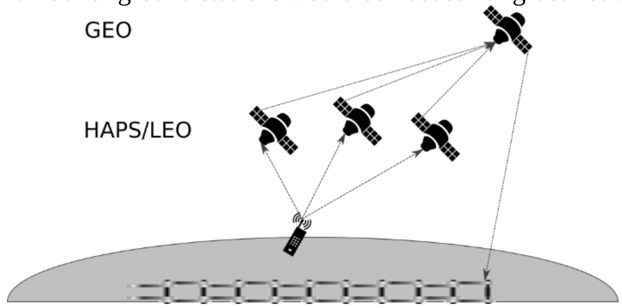

Fig. 7. Proof of Location (PoL) use case hybrid-satellite proposed architecture

5.3 Ledger Fingerprint Broadcast (LFB)

For ledger fingerprint broadcasting, the benefits, and the best use cases for the DLT depend on the blockchain type: either a public blockchain with unrestricted read and write access for anyone or one with restricted access (permissioned blockchain). In both cases satellites act as broadcasters.

A possible architecture for LFB by leveraging SatCom infrastructure is sketched in Figure 8.

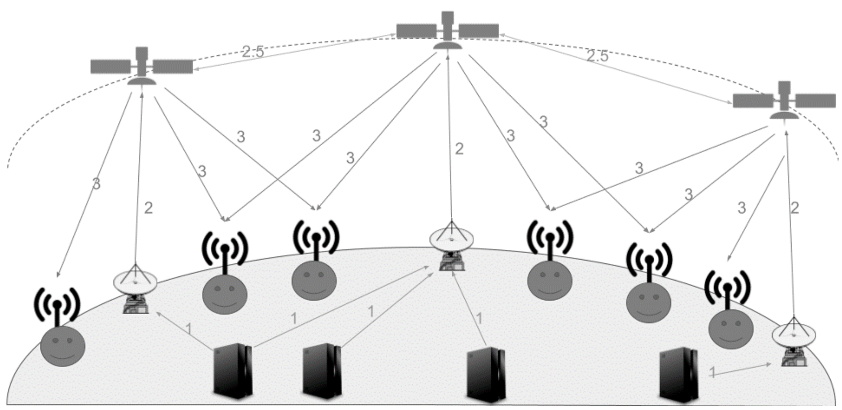

Fig. 8. Ledger Fingerprint Broadcast (LFB) use case proposed architecture

This architecture is characterized as follows:

- **Components**.
  - Blockchain full-nodes, miners/block-proposers: these are full nodes that produce valid candidate blocks to extend the ledger.
  - Satcom gateways: Satellite communication up-link ground stations. Their job is to accept valid candidate block propositions from the block proposers, authenticate and verify the block proposals, then send up fingerprints (hashes) of the candidate blocks to satellites for further re-broadcasting.
  - Satellites re-broadcast the fingerprints back to ground receivers as well as to other satellites
  - Blockchain light/full nodes, ground receivers: receive fingerprints via down-link from the satellites and acquire candidate blocks via conventional broadband Internet connection.
- **Procedure.**
  1. Blockchain miners/block-proposers create new candidate blocks and broadcast them through the blockchain Peer to Peer (P2P) network. Moreover, the miners/proposers sign and send the blocks to the satcom gateways.
  2. SatCom gateways, upon receiving new candidate blocks, authenticate and authorize the respective block producers and validate the candidate blocks. Then, the gateways deliver the fingerprints of the candidate blocks onto the satellites via an up-link communication channel.

3. Satellite infrastructure takes care of broadcasting all the fingerprints for all the authorized and validated blocks all over the world
4. Any full or light node may be equipped with the receiver capable of receiving the fingerprints. In this manner, every node that is capable of receiving the fingerprints will be aware of all the candidate blocks that are supposed to be fetched through the P2P blockchain network.

- **Economy.**
  The block proposers are paying for the SatCom fingerprint broadcast service. Hereby, the gateways authenticate and authorize candidate block proposers based on their identity and satcom service payment plans. The block proposers cover the cost of blockchain fingerprint broadcasting service through transaction fees and mining rewards (in case of permissionless networks) like any other operational costs (electricity bills, Internet connection, co-location/hosting of mining equipment, etc.). In case of permissioned networks, coverage of the satcom service costs depends on a given use case.

6. Roadmap

This part handled the development, timescales, and the approximate roadmap that must be completed to successfully perform each of the two most promising use cases, namely Spectrum Management (SM; focused on the AN scenario) and Ledger Fingerprint Broadcast (LFB). The Proof of Location (PoL) use case was discarded due to its broader scope and lack of maturity.

The high-level phases required for the deployment of the system defined for the SM and LFB use cases are presented in the following Figures 9 and 10:

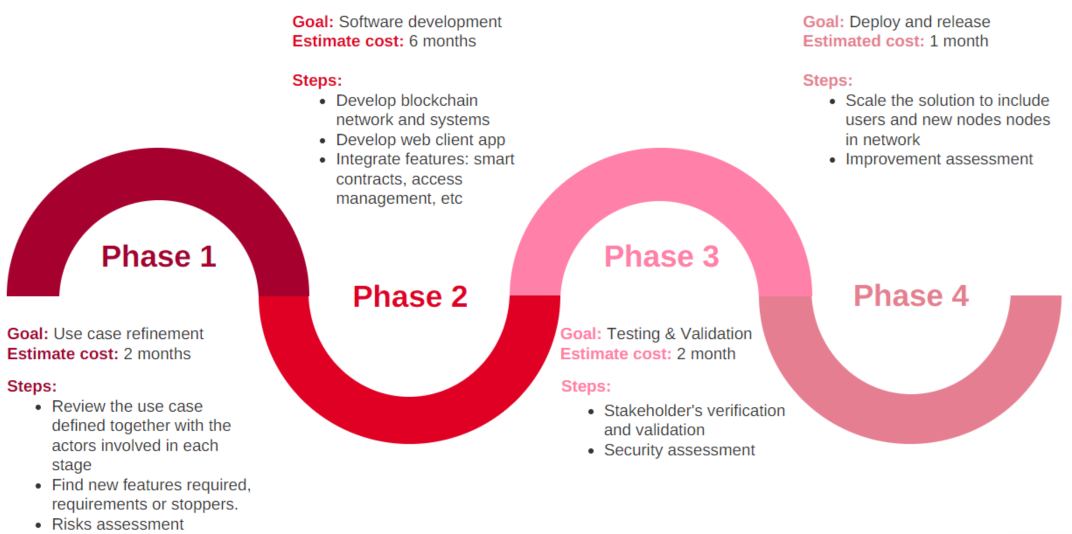

Fig. 9. Technical roadmap for Spectrum Management (SM) ITU Application Notification (AN) use case

Fig. 10. Technical roadmap for Ledger Fingerprint Broadcast (LFB) use case

Concerning LFB, the biggest uncertainty in time comes from the first phase of the mission where the interested stakeholders are found and consulted on the exact user requirements. No technical or satellite resource barriers exist for both use cases with an estimated implementation time of approximately 11 and 12 months for SM and LFB, respectively.

7. Development gaps

In this final part of the project, the aim was to conduct, develop and detail the activities, including notably from a legal and regulatory perspective, with relation to the SM and LFB use cases, as it was considered that they had the greatest potential to be implemented. An overview of the identified technological and regulatory gaps (regulatory, political and/or financial) towards implementing and operating the system identified previously by 2025 was given.

Taking into consideration the roadmap above indicated (Figures 9 and 10), they were further detailed with the integration of proposals for legal and regulatory steps. Some additional technical aspects were also included:

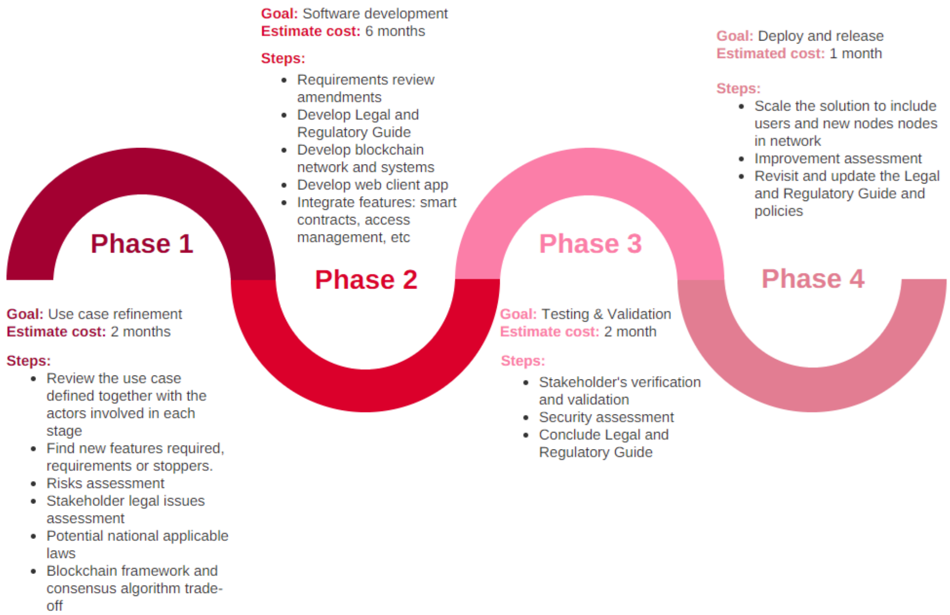

Fig. 11. Legal and regulatory roadmap for Spectrum Management (SM) ITU Application Notification (AN) use case

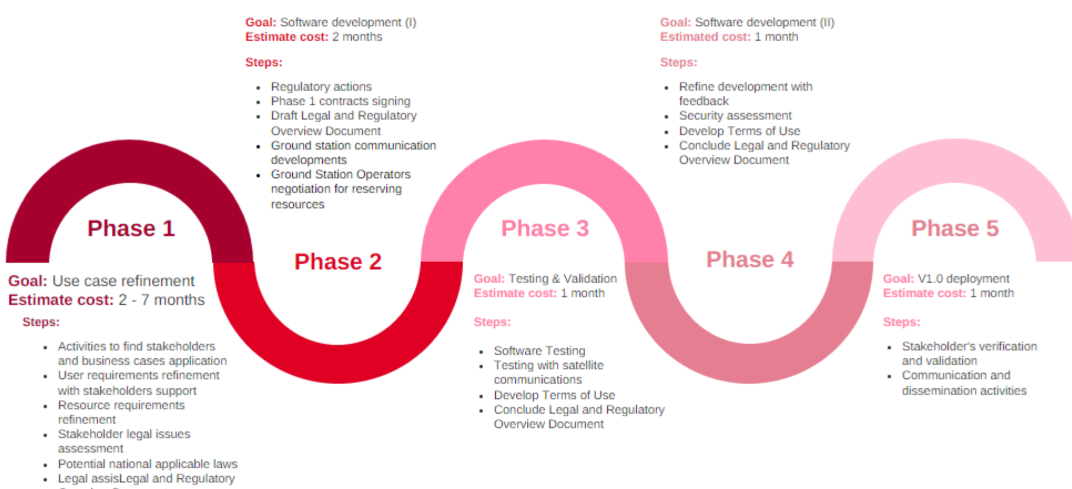

Fig. 12. Legal and regulatory roadmap for Ledger Fingerprint Broadcast (LFB) use case

Though the main legal framework that would apply to the use cases was assessed at the international (ITU in SM) and EU (LFB) levels, it was considered, in both use cases, that a further survey of potential applicable laws would be further required as an element for their refinement, whilst at the same time such refinement (including with relation to scope and involved stakeholders, at the beginning and further down the road) would be essential for the better assessment of the legal and regulatory implications of the use cases.

In any case, both use cases seem to be feasible from a legal point of view, though special care would have to be taken in their refinement to ensure legal compliance in all relevant jurisdictions and/or to prevent or mitigate risks arising from laws and regulations.

Internal policies and rules for the SM use case, and conclusion of necessary contracts for the LFB use case, are also important legal aspects that would have to be addressed for the deployment of both use cases.

8. Recommendations and conclusions

8.1 Recommendations

The recommendations, suggested after the completion of the work, are presented with relation to legal aspects and with relation to line of work, following what was highlighted in the various use cases.

8.1.1 Legal framework

I. At the international level, assess with ITU the ITU Radio Regulations and potential need for amendments or clarifications to allow the use of DLT for Spectrum Management taking into consideration also current Resolutions (such as Resolutions 86, 811; Agenda for the 2023 WRC) and 812 (preliminary agenda for the 2027 WRC) and Recommendation 76 (on use of cognitive radio systems).

II. At EU level:

   a. Assess with the relevant bodies within the EU (including the competent Directorates-General (DGs), the EU Blockchain Observatory & Forum and European Blockchain Services Infrastructure (EBSI)) the potential need for amendments or guidance when it comes to blockchain and SatCom, in light of the full range of legislation, including the following:
      - The electronic communications legal framework.
      - The data legal framework, both personal data and non-personal data – data governance and sharing.
      - The legal framework on platforms / intermediaries.
      - The crypto-assets legal framework.
      - The property and registration legal framework.
      - The contracts legal framework.
      - Legal frameworks in several sectors containing rules on reports, inspections and processes for licenses, certifications, and others.
      - The Electronic Identification, Authentication and trust Services (EiDAS) legal framework.

   b. Assess with Directorate-General for Communications Networks, Content and Technology (DG CNECT) and EBSI, the use of EBSI to test additional use cases that integrate SatCom, such as for SM, data sharing in SSA and registration of space assets, among others.

8.1.2 Line of work.

From a point of view of line of work, and in line with what was presented in the use cases, we suggest the following recommendations: to refine, develop, and implement the proposed use cases. All these actions will be performed through the following main steps:

I. In relation with the Spectrum Management use case:
   - Contact ITU (Radiocommunication Sector, ITU-R, and its executive arm, the Radiocommunication Bureau) to present the use case.
   - Define a strategy, together with ITU, for the further refinement and implementation of the use case, including (i) stakeholders to be involved, notably National Regulatory Authorities (NRAs) as possible nodes, suppliers and service providers, and ESA – and corresponding roles (ii) legal and regulatory issues to be addressed, namely in relation to the Radio Regulations and potential applicable national laws, (iii) technology and financial points to be addressed.
   - Develop the use case in line with the approved strategy, including technological, financial, and legal developments (platform/software, contracts, policies, guidelines).
   - Test the use case and deploy it.

II. Ledger fingerprint broadcast use case:
- Contact stakeholders (SatCom operators, broadcasters) to present the use case, define suitable business case and conclude partnerships.
- Refine use case from a technical, business, and legal point of view.
- Develop the use case, including technological, financial, and legal developments (platform/software, policies, guidelines).
- Test the use case and deploy it.

8.2 Conclusions

The main conclusions that have been obtained after analysing how satellite operations (SatCom in particular) can benefit from blockchain and, conversely, how blockchain can benefit from satellite communications can be resumed as follows:

- DLT is key in the current technological and economic landscape.
- DLT is fertile ground for a large number of SatCom cases.
- Furthermore, DLT could also benefit from SatCom, specifically for poorly connected areas.
- The Dynamic Spectrum Management (SM) AN use case is suitable to be implemented in a short time frame, although further requirements refinement, and participation/leadership, would be needed from specific stakeholders, notably ITU.
- Regarding the LFB use case, although there are no technical blockers, further analysis is required to define a suitable business case.

9. Future work

After everything presented previously in this article and once all the recommendations and conclusions have been assessed, it must be said that there is still a great deal of work to be done.

Under this premise, GMV keeps actively investigating both how satellite operations (SatCom in particular) can benefit from blockchain and the other way around, how blockchain can benefit from satellite communications.

Regarding Space Situational Awareness, ESA has ongoing projects and prototypes including BCT, i.e. for Collision Risk Estimation and Automated Mitigation (CREAM), and this is considered a field with high potential where BCT could improve the current processes (Sensor Networks, Data Processing and Service Provision). A specific scenario within SSA should be identified to check BCT feasibility.

The Spectrum Monitoring area has been identified as a great field where BCT could play an important role. In addition to AN, other specific scenarios such as Coordination Notification (CN) ITU process for Spectrum Management and Dynamic Spectrum Sharing (DSM) have been identified as feasible and with clear benefits.

The immediate next step for the AN scenario should consider performing a focused workshop, including ITU and other relevant stakeholders as SatCom operators, to check the possibility about a future development of the solution.

Ledger Fingerprint Broadcast and/or Proof of Location are considered use cases of high potential value in an abstract setting, but further work and consultations are required to find end users for the specific use case. A different stakeholder workshop to the one that was held in November 2021 could benefit this activity.

For PoL work on location determination algorithms for different types of satellite architectures would be necessary after having some input for required accuracy from interested stakeholders.

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