SPACE TRAFFIC COORDINATION MONITOR

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ABSTRACT

Coordination of collision avoidance, negotiation and agreement is a resource-intensive, time-consuming and a complex process involving several entities. Collision Risk Estimation and Automated Mitigation (CREAM), a complex system of systems, aims at connecting different actors into a single network where communication between the actors is simplified, standardised, and coordination of conjunctions are automated. One such system is the Space Traffic Coordination Monitor (STCM), which monitors and manages space traffic coordination systems exchanging data related to collision avoidance between the involved entities in a secure and trusted way. This article gives an overview of the results achieved in the ESA project S1-CR-04 Prototype of Space Traffic Coordination Monitor.

1 INTRODUCTION

Today, coordination of collision avoidance is a routine activity part of spacecraft operations. Together with the negotiation and agreement on spacecraft manoeuvres it is a resource-intensive and time-consuming process. Flight dynamics engineers monitor up to 100 upcoming close approaches per satellite per week simultaneously and have to identify the ones that could exceed a threshold of collision probability likelihood and require planning and execution of an avoidance manoeuvre. A lot of effort and time is spent on analysing and monitoring alerts that in the end do not require attention; however, all alerts must be considered equally.

Manoeuvre plans, as well as orbit predictions, are currently directly exchanged between spacecraft operators for each event individually. However, as more and more large constellations are deployed, the problem becomes worse year by year.

The increasing number of operational satellites creates the necessity to establish and follow a more streamlined, pre-defined, standardised, and thus more efficient and timely information exchange mechanism between multiple actors in the affected orbital domain.

A novel concept to alleviate the previously mentioned resource-intensive work and increase safety in space traffic management has been proposed by ESA. Collision Risk Estimation and Automated Mitigation (CREAM) aims at connecting different actors, including spacecraft operators, conjunction analysis and collision avoidance service providers, space catalogue owners and others, into a single network where communication between the actors is simplified, standardised, and coordination of conjunctions is automated.

The CREAM platform consists of several components and can be regarded as a complex system of systems, consisting of a communication network, coordination framework, monitoring solution and others. Space Traffic Coordination Monitor (STCM) is one of such systems.

2 SPACE TRAFFIC COORDINATION MONITORING

As the congestion in space increases, clear and efficient rules and regulations are needed now more than ever to monitor and manage space traffic coordination systems exchanging relevant data in a collision avoidance process between the involved entities in a secure and trusted way. These entities include operators, catalogue and conjunction data providers as well as service and/or supporting entities, such as expert centres. Such data exchange needs to comply with the needs of the various actors, e.g. in terms of limiting data visibility to restricted collection of other entities, as well as ensure that data is unaltered during the communication process and sending and the reception of messages is logged in a verifiable way. Space Traffic Coordination Monitor uses traditional monitoring architecture relying on Guardtime's KSI, a proprietary blockchain-based timestamping service, to assure data integrity in the peer-to-peer communication network.

2.1 Architecture

In general, the Space Traffic Coordination Monitoring system works as a network of independent decentralised proxy applications where requests from one party to another are relayed and additionally secured and

Proc. 9th European Conference on Space Debris, Bonn, Germany, 1–4 April 2025, published by the ESA Space Debris Office
Editors: S. Lemmens, T. Flohrer & F. Schmitz, (http://conference.sdo.esoc.esa.int, April 2025)

analysed. Fig. 1 illustrates the overall architecture of Space Traffic Coordination Monitor, displaying all parties and communication links between them. Every party using the STCM system is required to have a service called STCM Agent running on the premises of a party that relays messages sent and received from other integrated parties that also have the STCM Agent installed. Therefore, each party can communicate directly as well, without having to contact the central platform; however, such communication is not directly monitored.

The agents are configured to be aware of instances installed on other systems. The following communication diagram in Fig. 2 illustrates the data exchange between an actor and the central coordination platform. Note that

data exchange itself and for a regular user performing their work on their premises the work of the STCM service should after the initial set-up be almost invisible. Created proofs are saved on the Actor's STCM Service and sent from the actor's premises STCM service to the Coordination Platform's STCM Service, and the latter saves the proofs as soon as they are received.

Upon the successful receival of the data itself, STCM Agent on the Coordination Platform premises signs the data that has been received and creates a proof of receiving. Created proofs of the received data and the receival fact are then sent to the Actor's STCM Service. At the same time, created proofs are also saved on the Coordination Platform's STCM Service.

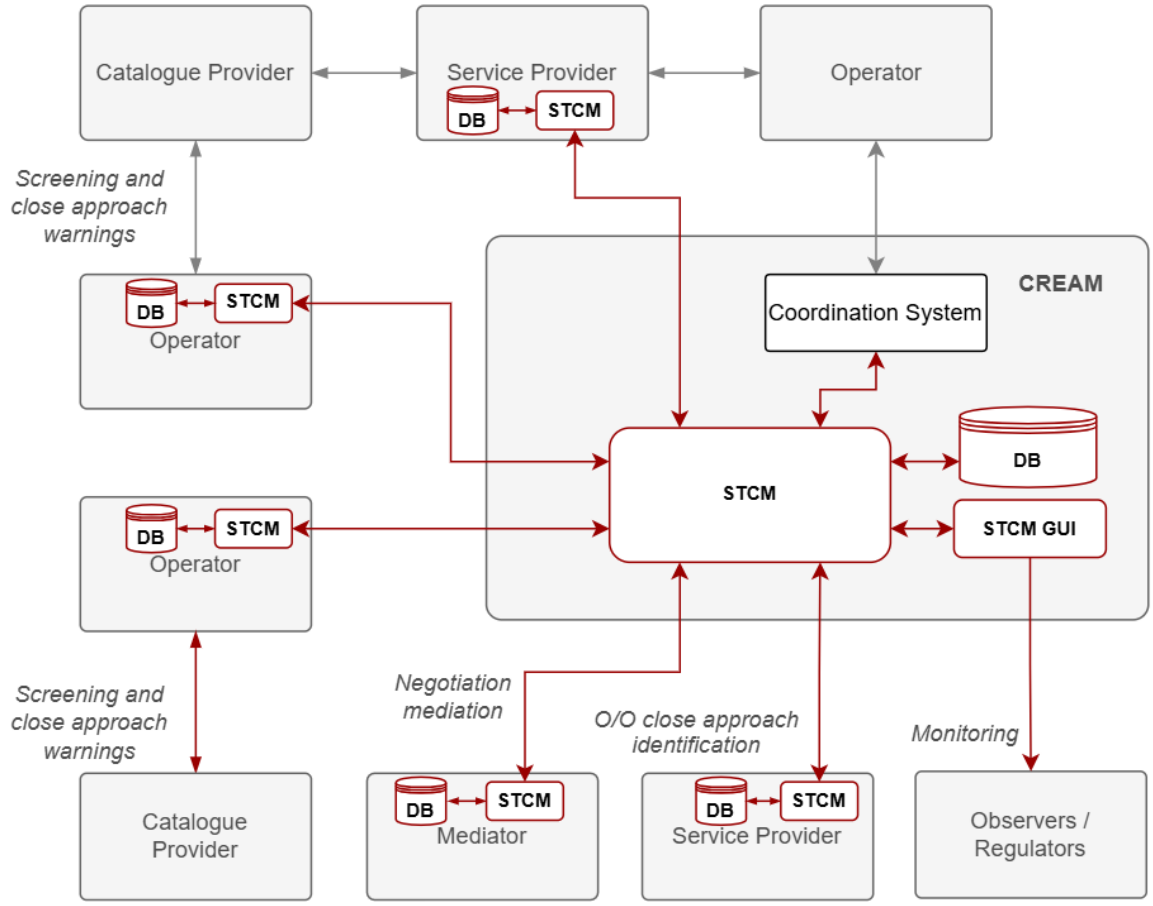

Figure 1. Space Traffic Coordination Monitoring architecture with communication flows.

the STCM Service is running on both premises.

As soon as an actor sends the data to the coordination platform, STCM Agent on the actor's premises gets an indication that the data is being sent out, signs it (creates the data integrity proof) and creates a proof of sending. The important part is that during the signing and the creation of the aforementioned proofs, the data itself is being sent to the coordination platform unhindered - STCM does not interfere with the communication and the

At the end of the communication, both parties should have the data itself and 4 different proofs: data integrity proof created on the sender's premises, proof of the fact that data has been sent, data integrity proof created on the receiver's side and proof of the fact that the data has been received. This gives many an opportunity for verification: first, if the proofs themselves are correct, second, whether the data integrity proofs (signatures A and B) match the data (the sent data on the sender's side

and the received data on the receiver's side) and finally whether the data integrity proofs match between each other. Any mismatch would clearly indicate a problem that requires an investigation. Note, that the receival of the proofs from the sender and receival of the actual data, are two different, asynchronous events - although in normal circumstances they do occur almost simultaneously. So, if the difference in time between receival of the proofs from the sender's side and the receival of the actual data from the sender's side is longer than some technically acceptable threshold, it may be an indicator for additional need for investigation.

running. Overviews and detailed views visible on the STCM dashboard give clear information about the data exchange between different parties and communication performance related statistics and metrics, including also safeguarding information related to all data exchange situations and data provisions.

In the data exchange, each message sent or received by the agents is cryptographically safeguarded using KSI, a blockchain-based time-stamping service designed, implemented and operated by Guardtime. This functionality is useful in resolving or even preventing

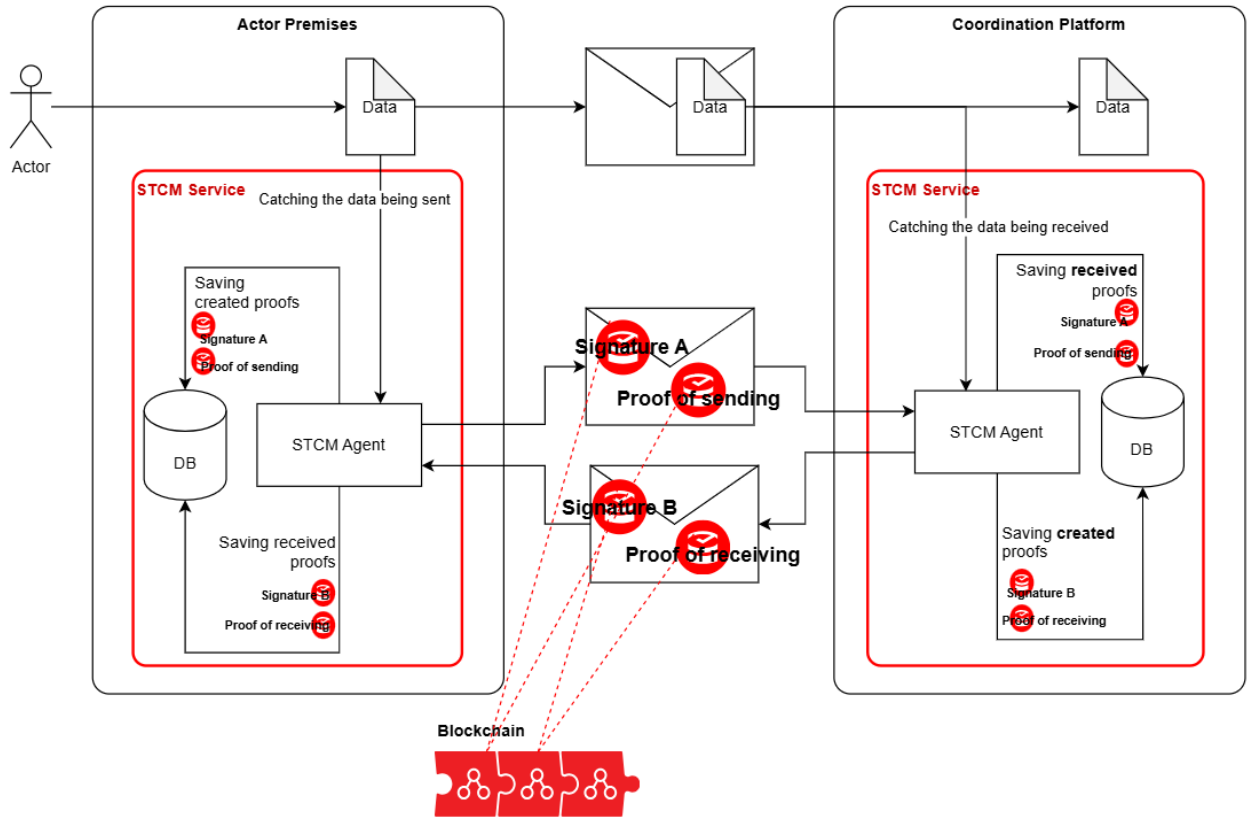

Figure 2. STCM Communication safeguarding overview.

2.2 Features

The goal of STCM is to be an efficient monitoring platform that provides both general and specific overviews of the communication and data exchange performed in real-time and historic conjunction events while also providing seamless automated safeguarding of the data exchanged and the communication performed between different parties.

The monitoring objective is supported and provided already by the STCM design itself - with the assumption that ideally all parties participating in the resolution of conjunction events shall have STCM service up and

some disputes between parties. Having cryptographic proof that data was transmitted and received by the intended recipient eliminates false claims that some data was not available, or it was not presented in a timely manner. Safeguarding the communication channel is essential against false claims of unavailable connectivity. One party cannot claim it was impossible to fulfil its obligations or respond to events due to unavailable communication.

In addition to safeguarding and monitoring communication, STCM service monitors the availability of the communication channel itself between the STCM Agents. This effectively generates long-term proofs that the communication was, in fact, available (or was not).

Moreover, the system identifies problems and issues in the communication framework within the CREAM network.

The STCM safeguarding and monitoring functionalities were created with the aim to cover the following real-life scenarios, which can be broadly divided into 2 groups:

1) Scenarios regarding different aspects of safeguarding, safety and security of the data exchange and possible malicious activity. Here, basic safeguarding scenarios have been described, possible breach in the communication system and failure in the data exchange scenarios have been assessed and demonstrated.

2) Scenarios regarding the monitoring of the event coordination and resolution, activities of the different parties involved, recommendations provided, and statistics gathered. These scenarios consist of various overviews of the data exchange with different deadlines between parties involved in the event negotiation process, along with the situations where relevant automated recommendations are provided.

3 STCM COMPONENTS

3.1 Agent

STCM Agent is the main backend component of the entire system. It is responsible for the safeguarding and verification of the data exchanged between the parties involved and safeguarding the communication that is due to take place during the whole conjunction event negotiation and resolution process. STCM Agent is the application that clients integrate on their premises to connect and interact with the coordination platform and with each other - however the regulation of the coordination process will require.

Note that STCM Agent does not provide coordination facilities. Its main goal is to secure the communication and to be run on the premises of all the included parties, including the coordination platform.

3.2 Dashboard

Every STCM Agent component can see only the data exchange passing through that specific instance. Assuming that most data exchange should pass through the coordination platform providing means for the resolution of any conjunction event, the STCM Agent running on the coordination platform premises is in an advantageous position to see most of the data exchange and provide the most comprehensive overviews and statistics. Therefore, the STCM dashboard of the STCM Agent on the coordination platform premises is a suitable Graphical User Interface (GUI) for STM authority and other relevant regulators and potential mediators.

Such an STCM Dashboard GUI consists of two different dashboards: one for the main user and one for the administrator. There are also different overviews with full filtering possibility and detailed views for both user groups. Moreover, the automated recommendation engine (described below) is a logical part of the dashboard.

3.3 Recommendation engine

Considering the information visible to the STCM Agent on the coordination platform premises, it is natural that general regulatory recommendations are a logical part of the STCM Dashboard there. The purpose of the recommendation engine is to provide automated suggestions to the relevant user or user groups - regarding their performance, data exchange timeliness, nature of the regulations in place, etc. For this first implementation of the recommendation engine, rules for recommendations are much simplified and rather static - with the main goal to provide a proof for the recommendation engine principle to work. Actual rules are expected to be much more complex, depending on the parties involved and their specifics and they would also be a subject to change by the STCM administrator, basing on the changes in regulations, practical solutions in real-world events and gathered statistics of actual conjunction events.

Recommendations and suggestions themselves should be based on three important components:

1) regulations and rules provided by relevant authorities or suggested and therefore provided by the systems involved in the conjunction event coordination and resolution.

2) practical rules and agreements which may be formed and agreed between actors/participants.

3) statistics and metrics of the conjunction events gathered over a period by the monitoring platform(s) such as the STCM.

Naturally, recommendations and suggestions provided by the STCM system can vary greatly—from actor-specific recommendations to actual suggestions for a change in some general regulation/rule. Also, such recommendations and suggestions are themselves subjects to change – statistics are analysed against the current rules and regulations, so if the latter change (and it is very natural that they will), so will change the nature of the automated recommendations of the STCM platform itself. Actors using the platforms/systems involved are expected and will quite possibly want to provide the feedback, which may also lead to the change in agreed rules and the automated recommendations.

In this realization, 3 different automated recommendations were designed to be provided by the recommendation engine whenever the conditions for these recommendations were fulfilled:

1) Recommendation to include the mediator - in a situation, where the deadline for event negotiation has arrived and there is no request for mediator from any of the parties, nor from the coordination platform, and there is no final resolution reached for this event, it is highly advisable to include a competent mediator to still have a realistic opportunity to resolve this particular event in time.
2) Recommendation to address the possible mediation overuse by a satellite operator - any actor participating in the conjunction event has an opportunity to ask for an independent mediation. However, if there seems to be a tendency for a particular actor to ask for mediation regardless of the situation, a suggestion to address this matter is raised. Mediation overuse tendency recommendation for an actor is triggered, if an actor having participated in a specific number of events has asked for mediation in 90% or more of the cases.
3) Notification for a satellite operator about their satellite being on a conjunction-prone orbit/altitude. As the statistics for different satellites/objects in near-space are gathered over time, it may be possible to notice how often any satellite is participating in a critical conjunction event - i.e. in an event that would need a resolution to avoid collision. If, for example, a satellite/near space object has participated in the conjunction events at least x times during a period of y, a notification to reconsider altitude/orbital positioning for this object is raised.

Note that all automated recommendations have been implemented to showcase the possibility of providing them to different actors using the STCM service and GUI. Thresholds, periods, and different numeric indicators can be changed (and made configurable) in accordance with the possible regulations and suggestions from both participating and monitoring parties.

3.4 Simulator

An assumption was made at the beginning of this activity, that a coordination system and operators exist in the end-to-end coordination sphere, however, no actual integrations were done. Due to this isolated engineering approach taken in this activity, the communication, data exchange and processing of the conjunction event resolution all had to be simulated as closely to the real-life scenario as possible. The simulator component was a logical part of the activity to fulfil this goal and to understand if the scenarios between different parties may work, the essential part of it being provision of additional information and simulation of the existence of additional parties involved.

4 CONCLUSION AND FUTURE WORKS

As a result of the Space Traffic Coordination Monitor activity, a prototype platform was implemented to demonstrate the concept of monitoring coordination activities in space traffic management. However, there are plenty of use-cases that can be developed and explored further in order to make the most of both the safeguarding and coordination monitoring functionalities provided.

Integrations with actual different parties involved in the coordination process are to be tested and streamlined into a simple process for any party wishing to have STCM Agent on their premises.

There are data integrity and communication safety verification scenarios that shall be additionally assessed, with inclusion of possibilities for handling and responding to different types of various potential malicious situations.

STCM dashboard with its automated recommendations, notifications and alerts is designed keeping in mind the STCM Agent operating on the coordination, central platform premises, however there is a clear need for similar, so-called local dashboard and automated recommendations for every party's own STCM Agent involved in the coordination process. These may be slightly different GUIs depending upon the types of users and their needs.

Automated recommendations assessment is in its entirety a separate and quite complicated topic as there are many different types for the automated recommendations and when and where these recommendations should appear. As the regulations for this subject are not in place yet, the best practices should be gathered and analysed before some major automated recommendations may be implemented.

Further work in this domain shall be undertaken as part of S2P CREAM Period 2 activity. That activity foresees the pilot use and expansion of decision support and coordination systems, where the existing applications of the overall coordination platform are integrated together into an end-to-end solution. Space Traffic Coordination Monitor plays a crucial role in the complete integrated platform with the data and communication security features. Moreover, STCM shall be extended to support direct communication between operators, exchange coordination situational awareness information with other coordination systems, and other novel features.

5 ACKNOWLEDGEMENTS

This activity has been carried out under the ESA funded project S1-CR-04 Prototype of Space Traffic Coordination Monitor, under S2P programme.