Asia-Pacific Space Cooperation Organization

APSCO CubeSat Competition (ACC)

Team Introduction and Mission Proposal Report

SPARCS Mission

IR-iSSS

Sharif University of Technology
(Iran)

SPARCS
Spacecrafts for Advanced Research and Cooperative Studies

Team Name	IR-iSSS (Sepehr Space Systems student initiative)

	Name	Institution
Supervisors	Mohammad Ali Torkaman Asadi	SUT
	Amir Hossein Khodabakhsh	SUT

	Name	Institution	Country
Participants Information	Danial Rezaei	SUT	Iran
	Ali Moradi	SUT	Iran
	Farzaneh MohammadiMajd	SUT	Iran
	Seyyed Mohammad Mahdi Mosavati	SUT	Iran
	Ali Sina Khorsandi	SUT	Iran
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1 Team Introduction

Table 1- Team general information

Team Title	**IR- iSSS**[1]
Mission (Project) Title	**SPARCS**[2]
Member State	Iran
Affiliating Entity	Sharif University of Technology (SUT)
Contact point of the team	Mohammad Ali Torkaman Asadi, ali.torkaman@live.com, torkaman-asadi@ae.sharif.edu (+989128309568)

Table 2- Team members list

	Member full name (first middle surname)	Responsibility	Status (Student/head)
1	Mohammad Ali torkaman Asadi	supervisor	supervisor
2	Amir Hossein Khodabakhsh	supervisor	supervisor
3	Danial Rezaei	TBD	Student
4	Ali Moradi	TBD	Student
5	Farzaneh MohammadiMajd	TBD	Student
6	Seyyed Mohammad Mahdi Mosavati	TBD	Student
7	Ali Sina Khorsandi	TBD	Student
8	Mehdi Abbaszadeh	TBD	Student

Considering that the team members are selected from talented undergraduate students, their specialized field of activity and their responsibility will be determined after gaining more insight, experience, and knowledge in the field.

[1] Sepehr Space Systems student initiative
[2] Spacecrafts for Advanced Research and Cooperative Studies

Table 3- Team members introduction

Supervisors:

Full Name	*Mohammad Ali torkaman Asadi*	
Date of birth	06/09/1986	
Pass ID	J48726538	
Email	ali.torkaman@live.com, torkaman-asadi@ae.sharif.edu	
Full educational status	PhD, Aerospace Engineering, SUT, Tehran, Iran.	
Brief resume	As PhD candidate in aerospace engineering at SUT, I entered the field of satellite design since 2014. Reaching the final stage of China's microsatellite design competition in 2018 with SUT team is one of the achievements of my activities. Also, I had this chance to be a participant member of APSCO SSS project.	

Full Name	*Amir Hossein Khodabakhsh*	
Date of birth	08/06/1991	
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Email	a.h.khodabakhsh@gmail.com khodabakhsh@ae.sharif.ir	
Full educational status	PhD, Aerospace Engineering, SUT, Tehran, Iran.	
Brief resume	PhD candidate of flight dynamics and control at Sharif University of Technology. More than ten years of software development experience in C/C++, Java, C#, JavaScript, Python and MATLAB languages. Has expertise in multi-objective optimal design, adaptive linear and nonlinear controls, aeroservoelasticity, embedded control software and machine learning.	

Team Members:

Full Name	*Danial Rezaei Alahabadi*	
Date of birth	30/09/2001	
Pass ID	-	
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Full educational status	Student of the Fourth year, Aerospace Engineering, SUT, Tehran, Iran	
Brief resume	Motivated student with a strong interest in space and flight dynamics and control. Enthusiastic about leveraging AI and Machine Learning in the aerospace field. I passionate about programming with languages such as C, Python, and MATLAB. Interested in control system design using Simulink and Arduino for building controller systems. Work experience with STK, Ansys Fluent, and SolidWorks software.	

Full Name	*Farzaneh MohammadiMajd*	
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Pass ID	L62337078	
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Full educational status	Third year of Aerospace Engineering ,Sharif / KNTU, Tehran, Iran	
Brief resume	Skills: Advanced at: Arduino , SOLIDWORKS , (Adobe) Aftereffects, Photoshop , illustrator , Premier , (Microsoft) Word , PowerPoint , Animating , VFX , Digital Painting , English Language . Intermediate : Cinema4D Microsoft Excel , MATLAB , CMD , Fortran . AI Researcher since 2020 , Robotics Researcher since 2017 Fluent at Giving lectures , Conferences & Article Writing.	

Full Name	*Seyyed Mohammad Mahdi Mosavati*	
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Full educational status	Student of the second year, Aerospace Engineering, SUT, Tehran, Iran.	
Brief resume	Interested in space engineering, including space transportation systems and space project management. A conceptual study of multiple documents on the launch history and moon orbiter subsystem, from 1959 to the present.	

Full Name	*Ali Moradi*	
Date of birth	31/3/2002	
Pass ID	4890474579	
Email	alimoradi.ir2002@gmail.com	
Full educational status	Undergraduate Student of the Fourth year, Aerospace Engineering, SUT, Tehran, Iran	
Brief resume	Rank 133 in entrance exam of 2020 in the third region, Interested in space engineering and satellite technology, Beginner with Python and NumPy and Pandas library, Work with MATLAB and Simulink, Work with Arduino, Programming in C language, Work with CAD software such as SolidWorks and AutoCAD, Work with STK software, Robotics teaching qualification from robotics and mechatronics student union of Iran (NURMSA).	

Full Name	*Ali Sina Khorsandi*	
Date of birth	22/03/2003	
Pass ID	U43448508	
Email	alisina.khorsand@ae.sharif.edu	
Full educational status	Student of the second year, Aerospace Engineering, SUT, Tehran, Iran.	
Brief resume	Interested in Space engineering. Research on Electric Solid Propellants, System engineering and...	

Full Name	*Mehdi Abbaszadeh*	
Date of birth	1/11/2001	
Pass ID	-	
Email	mohammad.mosavati003@sharif.edu	
Full educational status	Student of the fourth year, Electrical Engineering, SUT, Tehran, Iran.	
Brief resume	Interested in space engineering, including electronic systems for satellites and space project management. Rank 85 in entrance exam of 2021 in the second region, Experience: Farateif Pouya, Internship, BandarAbbas, Simulating some protocols (such as UART, SPI, GMII) using VHDL. Atlas Samaneh, Internship, Tehran, Embedded linux using a zynq board Computer skills: Basic Java, Python, Linux, Intermediate Verilog, VHDL, C++, CUDA, Latex	

2 Mission Proposal

welcome to a mission that we hope to push the boundaries of satellite technology and pave the way for future space exploration. Sepehr Space Systems student initiative (iSSS) is thrilled to introduce an advanced scientific yet practical and manageable innovative mission in the realm of CubeSats, one that promises to develop our understanding of space environment, communication and connectivity. In this remarkable endeavor, two 1.5U CubeSats will join forces to embark on a journey that will not only challenge the design team, their knowledge and capabilities but also will provide invaluable insight into the possibilities of the distributed space systems in the near future. These small but mighty satellites are equipped with state-of-the-art technology that will enable them to not only communicate but also form a dynamic and adaptive network in the vastness of space. The iSSS represents an eager and motivated team of students at Sharif University of Technology seeking opportunities to learn and innovate. With a wealth practical experience, our team represents the Spacecrafts for Advanced Research and Cooperative Studies (SPARCS) mission. With novel ideas in the distributed cooperative system architecture design, we believe this project would be a valuable asset for both scientific and practitioner communities alike.

In what comes next, we will review the following topics:

1- Project management:
  - Our team members along with brief resumes and capabilities
  - The main activities and our proposed schedule

2- Introducing the mission:
  - The SPARCS mission statement
  - The value and achievements of the SPARCS mission
  - How we would like the SPARCS mission to turn out

3- Infrastructures needed to design and build a cubic satellite in order to fulfill the mission goals:
  - We prove the feasibility of our proposition by studying somehow similar successful CubeSat projects all around the world
  - Availability of required infrastructure is analyzed
  - And of course, cost estimation

2.1 Mission statement

The SPARCS mission aims to enhance interest and capabilities in the exploration of Low Earth Orbit (LEO) Commercial Off-The-Shelf (COTS) nano satellite systems. This will be achieved through the evaluation and development of innovative and reliable InterSatellite Links (ISLs) and ElectroDynamic Tether (EDT).

2.2 The SPARCS Mission ConOps[1]

Managing complex projects in various industries requires a systematic and integrated approach that considers the high level of technology, cost, and risk involved. Such projects demand interdisciplinary collaboration among designers, engineers, and other experts to bridge the technical and non-technical gaps.

[1] Concept of Operation

Complex system theory and practice provide a valuable framework for analyzing and integrating all project elements, reducing risk, complexity, and financial and technical costs, and enhancing the success rate. As technologies grow and develop or market demand changes, structured management is needed to offer new insights and overcome the challenges of project management.

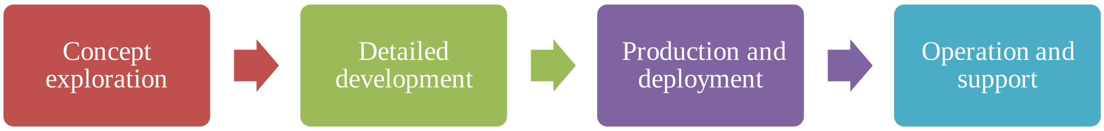


Figure 1- The Space Mission Life Cycle

Our position in the space mission life cycle is a key factor for making decisions about how to advance the mission. This cycle offers a structured framework for planning, risk management, testing, operation, and data analysis of the mission. Knowing our position in this cycle helps us increase our chances of achieving our objectives. Moreover, this cycle indicates that the work process starts with concept exploration and ends with operation and support. This implies a gradual and progressive process in which our system knowledge increases at each step, and our decisions and even overall goals may change according to the mission statement. This is not a problem but rather a sign of maturity in teamwork and dynamic functioning to fulfill team desires. Our team has conducted extensive studies on concept exploration and has acquired a good understanding of the mission goals and concepts, the development of innovative technologies, potential requirements, and the evaluation of mission architecture. This shows the broad perspective of our team regarding its own situation and the scientific environment.

The first step to design the SPARCS space mission in a systematic way is to establish the overall goals of the project and the constraints that will be faced along the way. Space missions can have various purposes, such as exploring other planets or launching satellites into geostationary orbit. Each purpose will have its own specific set of goals and constraints. Besides the technical constraints, there are also financial and regulatory constraints that need to be taken into account. As a student team, especially, we have limited financial resources and we have to follow the competition rules and regulations. By clearly defining the goals and constraints of the space mission, we can develop a plan that is both realistic and affordable. This will improve the chances of success and help to ensure that the mission achieves its objectives. Figure 2 shows the suggested design process by SMAD[1].

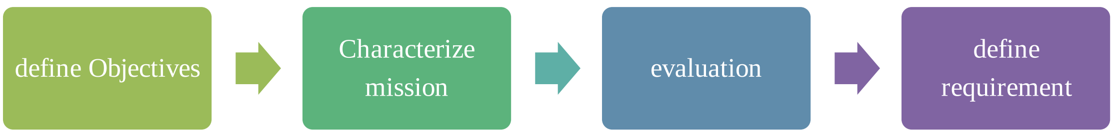


Figure 2- Design process as proposed by SMAD

The SPARCS mission planning process involves defining objectives and mission-level requirements, which is a crucial step in the project. This process requires arranging the essential components of the mission and bridging the gap between thoughts and ideas. Requirements and constraints play a significant role in mission planning and execution, and they must be aligned with the mission statement at various levels. Non-technical requirements are also essential and can have a significant impact on the SPARCS mission

[1] Space Mission Analysis and Design by Larson and Wertz

definition. For instance, the APSCO ACC competition, is organized in collaboration with space agencies of member countries to develop young and energetic scientific workforce through student projects under the supervision of international experts. This goal has been adopted as a mission-level requirement for the SPARCS project.

The Mission Concept Elements is also a crucial statement that outlines the process of acquiring and delivering data to the end user. However, in our student-based project, the concepts of the end user, developer, and sponsor differ slightly from other operations. This concept comprises five main components: (1) Communication Architecture, (2) Data Delivery, (3) Tasking Scheduling and Control, (4) Level of Autonomy, and (5) Mission Timeline. By specifying the requirements and constraints in each part, we can have a comprehensive description of the reasons for project selection and its performance.

(1) Communication Architecture

is an important component of the SPARCS Mission Concept Elements. Distributed space-based communication architectures are a type of communication architecture that uses multiple satellites to transmit data between different points on Earth, between Earth and space, or between satellites via inter satellite link (ISL). This type of architecture can provide a number of advantages over traditional ground-based communication systems, such as increased coverage, improved reliability, and lower latency. During our extensive research, two concepts in this area seemed more interesting with special potentials for the future of space systems, i.e., mesh and star networks. In a mesh network, each satellite is connected to multiple other satellites. This allows data to be routed through multiple paths, which can improve reliability and reduce latency. On the other hand, in a star network, all of the satellites are connected to a central hub satellite. This is a simpler architecture than a mesh network, but it can be less reliable.

(2) Data Delivery

is another critical component of the Mission Concept Elements. One of the key characteristics of mission elements is their impact on mission complexity and costs. In various trade-offs, we observe a significant difference in the level of technology used, ultimately resulting in noticeable differences in team costs. Data delivery is divided into two categories: housekeeping data and mission data, and the information from both categories has a significant impact on each other. Housekeeping data is obtained by sensors placed in the platform or the payload. This information includes satellite orbit or attitude, temperature, battery charge, and other notable data about satellite conditions in space. The main feature of this information is its low data rate, which makes monitoring easier. On the other hand, mission data is the information that can be shared between satellites by means of the ISL. As we mentioned in the communication architecture element, with the installation of the ISL system, we have an onboard data delivery from space. This choice offers advantages such as suitability for long-duration missions (to reduce human resource costs and errors on the ground), increased autonomy, and reduced data latency. However, one of its drawbacks is the limited communication bandwidth, which means that the information to be exchanged between two satellites or transmitted to the ground does not have a high rate.

(3) Tasking Scheduling and Control

is another important component of the Mission Concept Elements. There are two types of planning in space operations: long-term planning and short-term tasking. Long-term planning involves the long-term objectives desired by the satellite developer. In our case, a plan such as orbit correction or satellite de-orbiting. Short-term tasking involves what the satellite is currently doing in the moment. This includes tasks such as battery charging, attitude correction, or data transmission to the ground station.

(4) Level of Autonomy

is a critical component of the Mission Concept Elements. Satellites that have a high level of autonomy can be either the cheapest or the most expensive type of satellites. The low-cost category is typically planned for short-term objectives. Their level of autonomy is set to perform most of the short-term fixed objectives without the intervention of ground systems, which reduces mission costs. However, what makes high-level autonomy missions costly is their requirement for specific and reliable decision-making capabilities. There are three main factors that significantly affect autonomy in mission control: controlling the payload, controlling the attitude and appendages, and controlling the orbit. By utilizing housekeeping data and the functionality that will be explained later, we address orbit correction or satellite de-orbiting.

(5) Mission Timeline

is the final component of the Mission Concept Elements. The mission timeline is the overall schedule from concept definition through production, operations, and ultimately replenishment and end of life. Two distinct, potentially conflicting, demands can drive planning and production. One is the demand for a particular schedule or time by which the system must be operational.

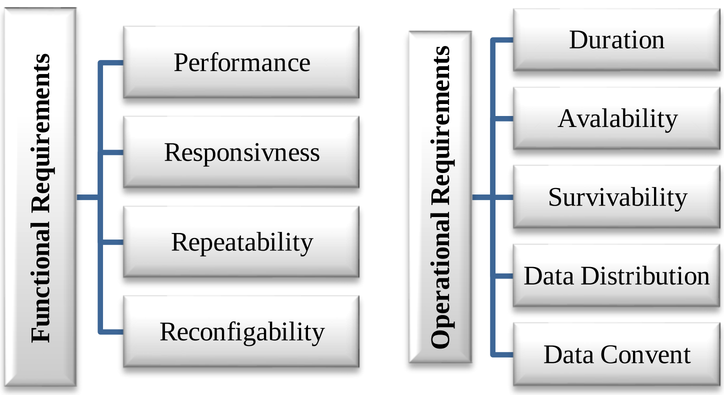


Figure 3- General Requirements Considered in SPARCS Mission Definitioin

We all know the saying that there is strength in numbers. The next revolution in space technology could be the use of swarms of CubeSats, that work together to achieve things greater than what any lone spacecraft can. CubeSats, assemble!

There are two types of swarms you could consider. One is a distributed swarm, in which many CubeSats fly in formation, connected by inter-satellite links and using onboard data processing techniques to generate a single output that gets sent back to Earth. The alternative is an aggregated swarm, in which separate CubeSats rendezvous and dock together, potentially with a larger central hub, to form a larger modular spacecraft that can autonomously (re)assemble itself. Both types of swarms allow us to overcome the size and weight constraints of the rockets that carry them to space, and could challenge classical spacecraft design methods and operations.

Swarms could be particularly useful for applications in astronomy, heliophysics, Earth observation and telecommunication. For example, a swarm could function as a large in-space telescope, or it could measure how solar wind varies across space. This can be done either close to Earth or in deep space. Swarms could also provide improved, cheaper or novel forms of telecommunication and remote sensing for Earth science and commercial applications[1].

To define the SPARCS mission statement, we focused on four fundamental objectives that is known to be essential for the future distributed space systems:

1. **Redundancy and Resilience Objective:** The mission should seek to enhance the redundancy and resilience of the space communication systems. This objective aims to ensure mission continuity even in the event of communication link failures.
2. **Efficient Data Distribution Objective:** The mission should focus on efficiently distributing data within the satellite constellation or network using ISLs. This objective enhances data sharing and processing capabilities among satellites to optimize mission outcomes.
3. **Expandable Network Architecture:** Similar to many wireless networks currently available for everyday use, the future mega constellations rely on Expandable Network Architecture (ENAs). The SPARCS mission shall provide a means to test ENAs for the future cooperative swarm space systems by means of effectively implementing and testing an efficient ENA framework. This capability could also offer global coverage, reduced latency, and high bandwidth capacity, which of high demamnd. Considering the future's economy-centric approach to space, utilizing low-cost cooperative systems such as CubeSats offer unique opportunities.
4. **Active Debris Removal Objective:** The mission shall not produce space debris and shall actively and effectively remove itself from Earth's orbit.
5. **Scientific Experiments Objective:** The mission should enable the team to conduct scientific experiments in the space environment using regarding the technologies used to ensure the aforementioned goals and objectives. This indicates that the systems shall provide reliable in-orbit reconfiguration capabilities

2.3 Mission objectives for SPARCS project

The mission statement for the SPARC project can be stated as follows:

- The design and construction of two CubeSats that collectively shall satisfy the 3U volumetric and mass requirements (ACC requirement).
- Implementation of a expandable mesh network via Inter-Satellite Links (ISL) that shall be reconfigurable adaptively from the ground station. (Mission Functional Requirement).
- Implementation of a orbit maneuvering and de-orbiting scheme to comply with international standards for space debris mitigation and innovative propulsion by ElectroDynamic Tethering (EDT) system. (Mission Functional Requirement).

It should also be noted that another important objective for the SPARCS mission is to successfully design and build the aforementioned CubeSats through a collaborative effort, incorporating unique student

[1] https://spaceref.com/newspace-and-tech/esa-wants-your-ideas-for-cubesat-swarms/

characteristics. Given the future of the space industry and the investments made in this new space era, it is evident that the utilization of Low-Cost systems is prevalent. Notable features of these systems include lower risk and greater scalability.

2.4 Mission description

In the following, the missions defined for SPARCS are described in more detail.

2.4.1 Phase A: Inter Satellite Link

The SPARCS mission begins with the launch of two 1.5U CubeSats (SPARCS-A and SPARCS-B) into Earth's orbit. These miniature marvels are not alone; they are tightly interconnected via an innovative Inter Satellite Link (ISL). This technology will allow them to share data, coordinate maneuvers, and create a collaborative framework in the microgravity environment of space. SPARCS A and B will be connected to each other during their orbital life via ISL. The ISL represents a critical step towards distributed satellite systems, enabling real-time information sharing and enhancing our ability to achieve mission goals and hopefully someday further explore and understand the cosmos.

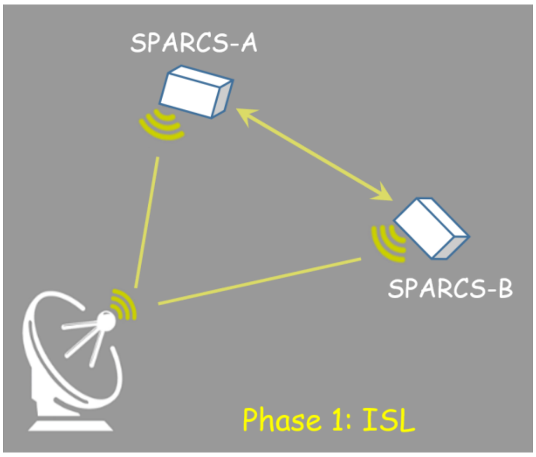


Figure 4- CubeSats state in Phase A

2.4.2 Phase B: Electrodynamic Tethered Link (EDT)

We're not stopping there. In a daring move, one of the 1.5U CubeSats (SPARC-B) will embark on a new phase of the mission. This satellite will deploy its daughter module and seperates into two distinct components connected by a tethered link. This tethered link will open up new possibilities for cooperation and experimentation in the harsh conditions of space.

Imagine the possibilities – SPARC-B, a tethered CubeSat, will be able to conduct coordinated maneuvers, gather data from different vantage points, and perform endless scientific and engineering experiments that exteremly affordable, offered by the CubeSat Platforms. This mission will demonstrate the potential for tethered systems in future space exploration, pushing the boundaries of what we thought possible in CubeSat technology.

As we prepare to launch this pioneering mission, we invite you to join us on this extraordinary journey. The future of satellite technology and space exploration is unfolding before our eyes, and together, we are pioneering the path to new discoveries, innovative solutions, and a deeper understanding of the universe.

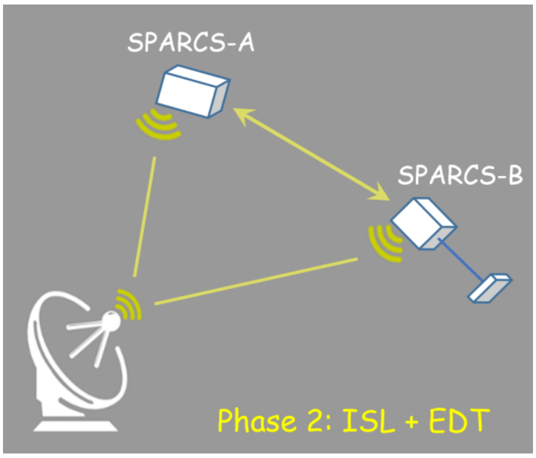


Figure 5- CubeSats state in Phase B

2.5 The Expected Achievements of The SPARCS Mission

The SPARCS mission has the potential to help the scientific community and the young, ambitious minds shaping the future of space science and exploration. By providing a low-cost platform to test various space network architectures, SPARCS is paving the way for us to develop innovative methods of communication and collaboration in the vast expanse of space. Even more, SPARCS could also help us test new advanced concepts, such as relative navigation and sensor networks data fusion. And let's not forget about the ElectroDynamic Tethers concept. With SPARCS, we have a unique opportunity to refine this concept, which could completely transform how we power and maneuver future generations of spacecraft.

Here are some specific details about how the SPARCS mission could help space science and practitioners:

- Space network architectures: SPARCS could help us explore different distributed satellite systems connectivity architectures in space, leading to more efficient and reliable networking methods.
- Advanced concepts: With SPARCS, we can test advanced concepts like relative navigation and sensor networks data fusion. This could open up new possibilities for tracking and controlling spacecraft and analyzing space data.
- ElectroDynamic Tethers: SPARCS provides a platform to test and refine the ElectroDynamic Tethers concept, which could change how we power and maneuver spacecraft.

Overall, the SPARCS mission has the potential to make a significant impact on space science and exploration. By providing a low-cost platform to test new technologies and concepts, the mission could help us develop new ways to explore and utilize space.

2.6 SPARCS Mission Feasibility

The chose our plan in a way to meet the requirements of the design according to the demands of the competition. Also, parts and equipment will be used that meet the cost requirements and the possibility of supplying parts while fulfilling the defined mission.

The current design is based on successful pioneer CubeSats with creative ideas. Among them, several top ideas are selected to prove and showcase the feasibility of SPARCS mission. The mission is focused to technologically practical.

As mentioned earlier, the mission for STARCS is devided into two main phase:

- Phase A: Test Inter Satellite Link among two 1.5U CubeSats.
- Phase B: Test Electrodynamic Tether technology.

We investigate the feasibility of these phases in this section.

2.6.1 Phase A: Inter Satellite Link

In a CubeSat swarm, where multiple small satellites work together, communication between these satellites is crucial. Inter-satellite links are the connections that allow these satellites to exchange information. This communication is not only essential for achieving the primary mission goals (such as scientific observations) but also for ensuring that the swarm of satellites can operate autonomously, making decisions and coordinating actions without direct human intervention.

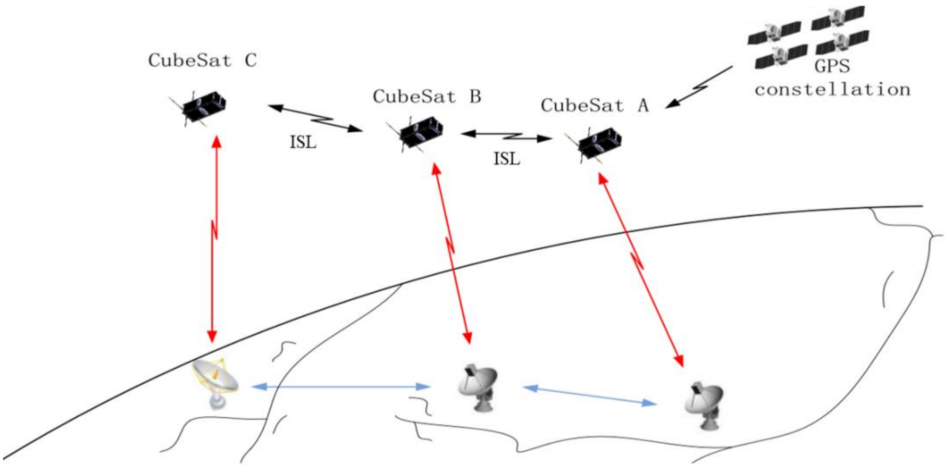


Figure 6- Network of Small Satellites by ISL

2.6.1.1 Case Study of Implemented Projects

- ***QB50 mission***

The QB50 project plan to use 50 (or more) 2U/3U CubeSats that will collect data individually, process it in a distributed manner, and then send the results to a base station on Earth. The satellites will be grouped in a swarm-like formation, and will function as a wireless sensor network (WSN) with the peculiar aspect that its nodes will be spread somewhere in space.

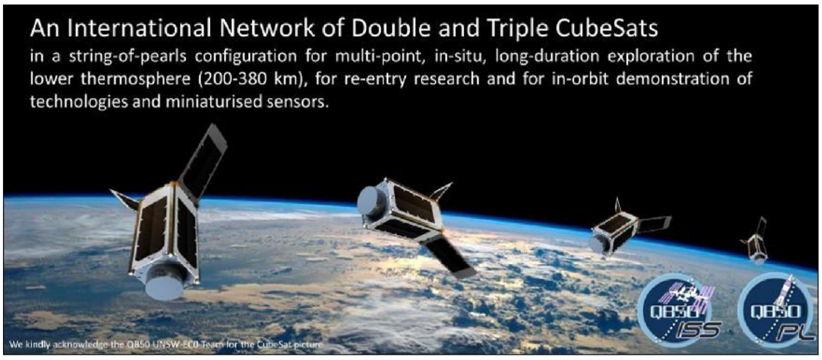


Figure 7- The QB50 constellation[1]

In order to ensure the robustness and reliability of the system, all the satellites should assist in the swarm's tasks: scientific observation, distributed signal processing, and uploading the processed data to Earth. Each member of the swarm is required to gather relevant information, share it with its peers, process part of it, and then downlink the result to a base station. Figure 1 illustrates the functional organization of a small satellite and the corresponding signal flow.

The communication layer of the QB50 swarm, particularly the inter-satellite links (ISLs), is one of its most important aspects as it is critical for both fulfilling the primary goal (scientific observation) as well as for ensuring the autonomy of the system. Satellites will share the observation data alongside timing, positioning and other meta information, using radio-frequency (RF) links. Intersatellite communication will have to overcome the CubeSats limitations in terms of size and power, and fulfill the system requirements.

- ***<u>TIM/TOM mission</u>***

The Telematics International Mission (TIM) and Telematics Earth Observation Mission (TOM) are two multinational efforts to combine multiple nanosatellite mission in a larger formation, aiming at different remote sensing applications. In TIM, institutes from around the world join by contributing with their own satellite formations and ground infrastructure. In TIM project, partners from the Regional Leader Summit (RLS) of partner states from 5 continents, cooperate under the technical leadership of Zentrum für Telematik.

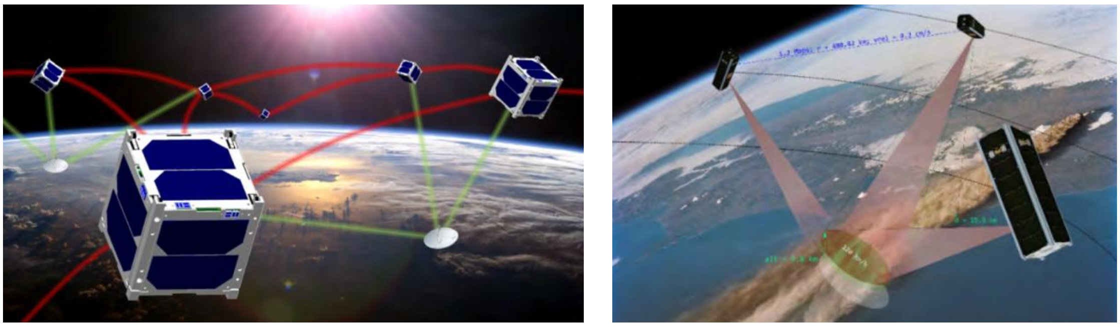


Figure 8- The TOM and TIM formation scans the earth's surface

TIM will primarily focus on Earth observation using a nanosatellite formation. This enables observation of target areas on the Earth's surface from different perspectives. Threedimensional surface maps can this way

[1] https://www.eoportal.org/satellite-missions/iss-nanoracks-qb50#17-qb50-cubesats-deployed-in-the-nrcsd-12-cycle-of-nanoracks

be generated by photogrammetric methods. The TIM formation, thereby, presents solutions to cutting edge problems such as the identification of sea vessels, monitoring thermal anomalies or 3D earth observation.

The planned communication channels in TIM as depicted in Figure 9. The UHF Band is used for TT&C and low speed data transfer. The Inter-satellite link (ISL) will also operate in UHF. S-Band is used for high speed downlink of the payload data. Additionally, OSIRIS is an experimental optical downlink that is a used on the German TOM satellites for payload data downlink.

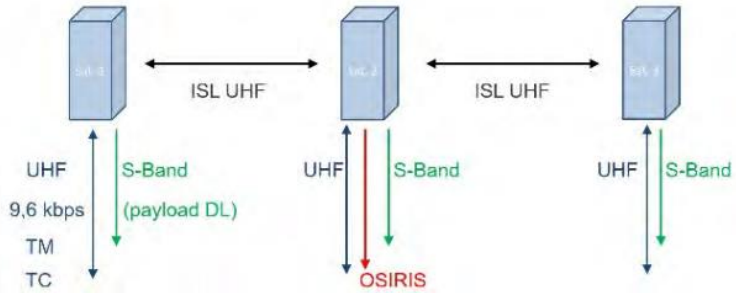


Figure 9- Communication channels in TIM[1]

- ***CubeSat 5G NTN***

A Similar program to our mission is two 1.5U CubeSats that is developed by 5GSpaceLab[2]. In this project, the Earth-orbiting scenario will focus on a CubeSat 5G NTN experimentation mission. The communications payload will be based on a space-ready Software Defined Radio (SDR) from GOMSPACE (already available in the SatComLab). The SDR communications payload enables the development of flexible experimentation architectures such as bent-pipe, node-relaying or coherent distributed communications (twin payload). These payload requirements and capabilities will be co-designed in accordance with a suitable mission and spacecraft architecture for a single satellite or a small formation of CubeSats and interfaced with the Engineering Model (EM) available in the CubeSatLab in view of a future SnT mission.

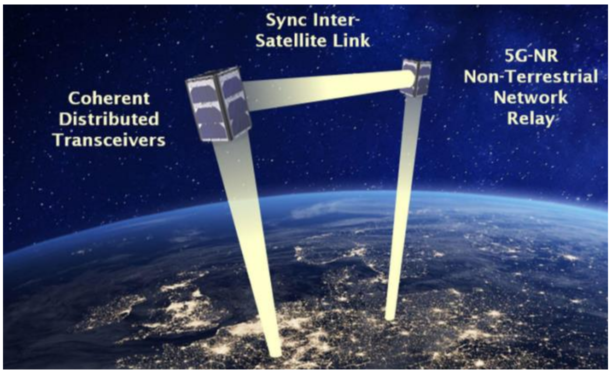
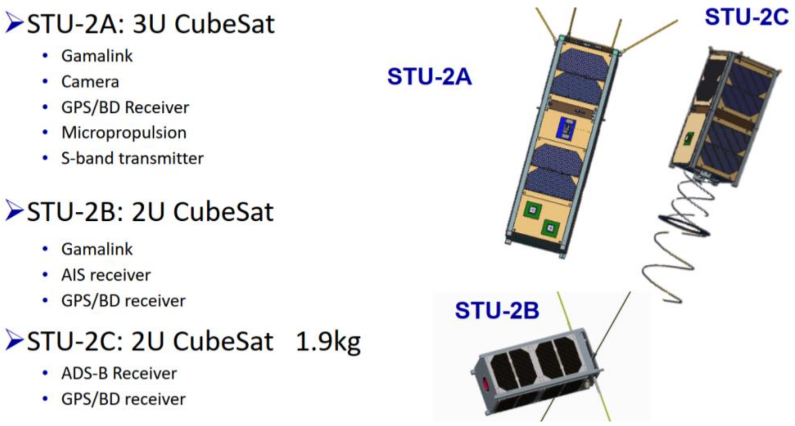


Figure 10- CubeSat 5G NTN project

[1] TIM - Telematic International Mission Newsletter 2020
[2] https://6gspacelab.uni.lu/5GforSpace/ntn.app/ntn.app/

- ***STU-2***

The STU-2 mission with three CubeSats has been launched successfully into space on Sept 25th, 2015, on-board a newly developed small launch vehicle in China. This mission is designed and being implemented by a consortium led by the Shanghai Engineering Centre for Microsatellite in China, together with partners including the Nanjing University of Science and Technology (contributed for STU-2B platform), the GomSpace from Denmark (ADS-B and AIS receiver, as well as CubeSat components), the NanoSpace from Sweden (contributed the MEMS micro-propulsion module), and the Tekever Space from Portugal (contributed the Gamalink). The authors would like to express sincere appreciation and many thanks to these partners, together with them this mission has been made feasible and successfully implemented.



	STU-2A (3U)	STU-2B (2U)	STU-2C (2U)
Payloads	Camera Gamalink BD2/GPS	AIS Receiver Gamalink BD2/GPS Receiver	ADS-B Receiver BD2/GPS Receiver
ADCS	MTM, MTQ, Propulsion, 3 Wheels, Fine Sun Sensor, Star Tracker, GPS/BD APE 1.8° Stability 0.03°/s	MTM, MTQ, Sun Sensor, Momentum biased with wheels APE 8° Stability 0.04°/s	Magnetic control APE 13° Stability 0.04°/s
TMTC Comm	UHF: 4.8kbps S-band：125kbps	UHF: 4.8kbps	UHF: 4.8kbps
Mass/Power	2.9kg/2.9 W	2.2kg/2.9W	1.7 kg/2.0W

Figure 11- STU-2 Mission Configurations

2.6.1.2 Challenges for the ISLs

Creating a network between satellites requires extra transceivers, which add to the weight and power consumption of the flying units. However, that does not apply in the case of a swarm of small satellites. Just as in nature, the swarm takes its strength from the interaction between its members and only by task and data distribution for using CubeSats to fulfill complex missions.

High-throughput optical and RF ISLs have been proposed in the literature for transferring information between satellites. What is more, some active low and medium Earth orbit satellite systems use RF links to ensure a good quality of service and global coverage. For example, in the Iridium constellation, the satellites use RF transceivers in the 22.55–23.55 GHz band to route traffic via the intra-plane and inter-plane neighboring satellites. Nevertheless, existing solutions are not applicable to the case of a

communication link between CubeSats. Size and power limitations, coupled with requirements imposed by the swarm's functionality, mandate use of an application-specific communication system.
Therefore, in designing the ISLs for a swarm of CubeSats, both CubeSat-specific and swarm-specific requirements have to be taken into consideration. CubeSats have a limited volume and mass for their payload, as described in the standard. This issue limits the available power for communication and processing to several Watts. Another important aspect to consider is the variable attitude that CubeSats have towards each other.
Some critical points for ISL are mentioned as below and we will attention to them in detail design phase

- **Modulation and Coding Scheme:** Communication in space faces unique challenges due to the limitations of CubeSat size and power. The text suggests that for efficient communication, a baseband signal processing scheme is used. Baseband processing involves manipulating the raw data signals before they are transmitted. This scheme uses basic modulation techniques like amplitude, frequency, and phase modulation. These techniques are chosen because they are simpler and more power-efficient for CubeSats compared to more complex adaptive modulation and coding approaches.

  Additionally, an LDPC coding block is added to the communication scheme. Coding is a method of adding extra information to the transmitted signal to help correct errors that may occur during transmission. LDPC[1] codes are a type of error-correcting code. The text suggests that LDPC codes are chosen because they strike a good balance between reducing errors (important in noisy environments) and requiring less extra information, which is crucial for power-constrained CubeSats.

- **Antenna System Design:** CubeSats are very small, and therefore, their surface area for accommodating antennas is limited. However, to achieve communication in all directions, a creative antenna design is needed. The text proposes using six individual antennas, each placed on different faces of the CubeSat. This arrangement allows the CubeSat to establish communication links in all directions (a full sphere or 4π solid angle), even though the physical space for antennas is restricted.

- **Antenna System Control:** Managing the antenna system is essential for ensuring effective communication. The control of the antenna system involves deciding how the antennas should transmit and receive signals. The text discusses two options: RF transceiver integration and digital baseband control. RF transceivers are complete communication units that can handle both transmission and reception. On the other hand, digital baseband control involves using software and hardware to control the process of transmitting and receiving signals. This approach offers more flexibility and precision, but it might require more complex hardware. The controller's role is to make sure that the right antennas are being used at the right time and that the signal is directed toward the intended target.

[1] Low-Density Parity-Check

- **Validation and Testing:** Before deploying the proposed communication and antenna system in space, it's crucial to validate its functionality through experiments. The text describes an evaluation platform that mimics a simplified version of the proposed communication setup. This platform includes hardware components that replicate the communication system within a CubeSat. The experiments on this platform help confirm that the proposed design works as intended and can effectively establish communication links.

Conclusion: Based on a deep serache in the literature, interconnect CubeSats via ISLs is a pioneering approach to address the communication challenges faced by CubeSat swarms. By employing efficient modulation and coding strategies, optimizing antenna system design, and validating these concepts through experimentation, this mission aims to enhance the communication capabilities of CubeSats, leading to improved scientific achievements and advancements in small satellite technology.

2.6.1.3 STK Simulation for Orbits and Distane analysis

Maintaining the proper distance between satellites is one of the main challenges in satellite swarm systems. Generally, in large satellites, this is done by using propulsion subsystems. However, in CubeSats, due to the lack of space, the use of propulsion will cause a significant part of the useful volume to be occupied. By studying similar projects, it was observed that propulsion system were not used in these projects to maintain the formation of the swarm.

We simulated our two 1.5U CubeSats using the STK software to show that in mission duration, their distance will be accepted to have ISL connection. The simulation was conducted using the STK software and has provided valuable insights into the orbital decay of a 3U CubeSat, as well as the orbital decay of two 1.5U ISL CubeSats along with their separation distances. For this simulation, a sun-synchronous polar orbit with an altitude of 550km has been employed. The corresponding Two-Line Element (TLE) for this orbit is provided in Figure 12. Furthermore, in the simulation related to the two 1.5U CubeSats, it has been assumed that the separation of the two ISL CubeSats occurs through a spring mechanism with a velocity of 10 m/s from one POD.

```
1 99999U          23235.35416667  .00023061  00000-0  12154-2 0 00008
2 99999 097.6127 331.2982 0008665 239.8923 125.9855 15.07413900000014
```

Figure 12- The corresponding TLE Data

The orbital simulation of a 3U CubeSat illustrates that over the course of a one-year mission, an approximate orbital decay of 63 kilometers is observed. The data in Table 4 presents the orbital altitude values at monthly intervals for this CubeSat.

Table 4- Altitude Changes of 3U CubeSat Orbit Over One Year

3U CubeSat	
Date	Altitude(km)
Aug 2025	550.1
Sep 2025	531.7
Oct 2025	533.9
Nov 2025	535.0
Dec 2025	521.1
Jan 2026	531.0
Feb 2026	523.9
Mar 2026	505.9
Apr 2026	503.3
May 2026	513.5
Jun 2026	509.2
Jul 2026	487.2
Aug 2026	498.9

The data provided in Table 5 showcases the orbital altitude values of the two CubeSats along with their separation distance over monthly intervals. During the separation process of the two CubeSats, SPARCS A and SPARCS B undergo an increase and decrease in velocity, respectively.

Table 5- Altitude Changes and Distance between two CubeSats Over One Year

Two 1.5U ISL CubeSats			
Date	Altitude of SPARCS A (km)	Altitude of SPARCS B (km)	Distance between two CubeSats (km)
Aug 2025	550.142	550.137	0
Sep 2025	528.327	528.300	21.8
Oct 2025	534.869	534.946	35.1
Nov 2025	519.032	519.125	45.7
Dec 2025	524.986	524.873	50.1
Jan 2026	521.393	521.302	53.8
Feb 2026	505.170	505.017	59.1
Mar 2026	508.578	508.708	64.4
Apr 2026	488.087	488.267	75.4
May 2026	478.588	478.353	90.0
Jun 2026	464.001	463.920	103.0
Jul 2026	456.868	456.833	111.3
Aug 2026	463.297	463.488	114.4

It can be seen that the orbital simulation of two 1.5U ISL CubeSats demonstrates an approximate orbital decay of 93 kilometers for each CubeSat throughout the duration of a year-long mission as illustrated in Table 5. Furthermore, at the end of the mission (one year), the separation distance between these CubeSats reaches 114.4 kilometers. Also, in the below figures, STK simulations are shown

The analysis leads to the conclusion that the spacing between two CubeSats in the absence of a propulsion system remains within acceptable parameters for conducting an Inter-Satellite Link testbed in space. As previously mentioned, our primary objective is the advancement of technology for educational experience. Therefore, if we can establish ISL communication just during the initial few months of the mission, it will be considered a successful achievement.

After that, we will start phase B of the mission which is testing a tether system.

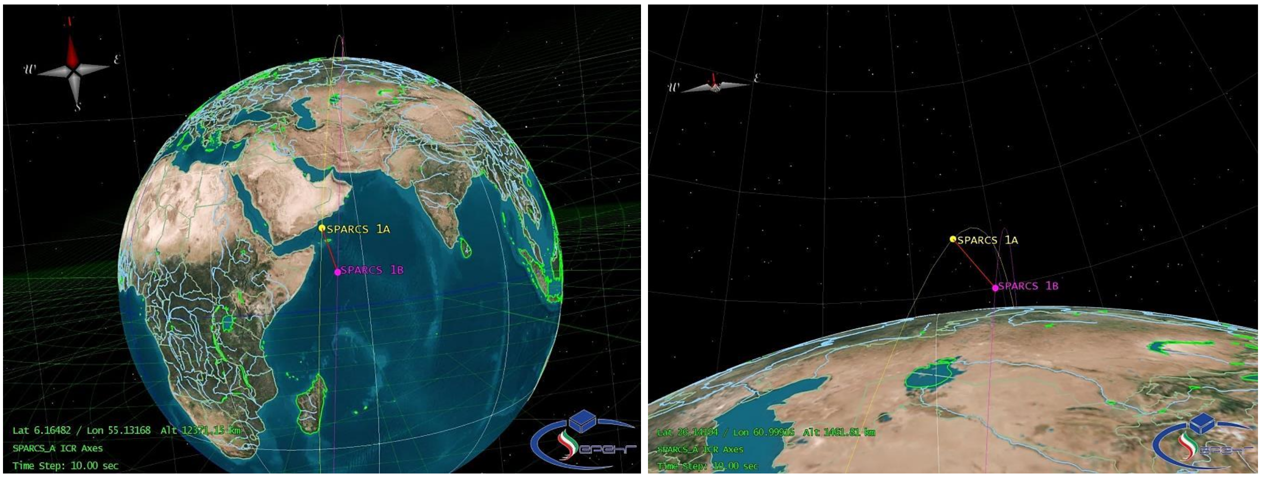


Figure 13- Snapshots of STK simulation results for 1.5U CubeSats

2.6.2 Phase B: Tethered mechanism in a CubeSat

In recent decades, the field of satellite technology has witnessed remarkable advancements and innovations. Among these innovations, the concept of "Tethered CubeSats" has emerged as a promising avenue for expanding the capabilities of CubeSats and enabling diverse space missions. Tethering involves the use of a connecting cable (tether) to link two or more CubeSats, enhancing its functionalities and mission possibilities. This technology has the potential to revolutionize various aspects of space exploration and utilization. Space Tethers have become an increasingly popular research topic in recent decades because of their numerous space applications from propellantless propulsion to energy generation.

Tethers have potential for many space applications such as:

- **Energy Augmentation and Sharing**: Tethering give the ability to share and augment energy resources among interconnected CubeSats. Energy-surplus satellites can act as power hubs, transferring energy to those with limited power generation capabilities. This synergy enhances the operational endurance of energy-constrained CubeSats, enabling extended missions and deeper explorations.
- **Orbit Adjustments**: Tethers can modify the orbits of satellites through the principle of electrodynamic propulsion (EDT). By generating an electric current along the tether in the presence

of a magnetic field, a force is exerted on the tethered satellite, altering its trajectory. This can be employed for orbital adjustments, deorbiting, or even station-keeping.

- **Deorbiting and Space Cleanup**: Tethered systems can contribute to active debris removal. By deploying tethers to non-operational satellites, they can be nudged into lower orbits, expediting their reentry and reducing the risk of collision with operational satellites.
- **Formation Flying and Interferometry**: Tethering facilitates intricate formation flying, enabling precise spatial configurations of satellites. This capability is pivotal for creating distributed sensor networks or interferometric telescopes. Tether-controlled relative motion enhances data collection, enabling advanced scientific observations.
- **Data Relay**: Tethered CubeSats can act as data relays, transferring information between satellites. This can enhance data collection capabilities, particularly for remote sensing and Earth observation missions.
- **In-Situ Assembly and Manufacturing**: Tethering sets the stage for in-situ assembly and manufacturing of larger structures in space. This technology can enable the construction of complex, modular structures by connecting individual units in orbit, which holds potential for large-scale infrastructure projects.
- **Space Science and Research**: Tethered systems can facilitate unique space science experiments, such as creating artificial gravity gradients for microgravity research or enhancing particle collection for cosmic ray studies. By adjusting the length and tension of the tether, researchers can manipulate gravitational forces in ways previously unattainable.

2.6.2.1 EDT technology

EDT or Electrodynamic Tether technology in CubeSats involves the use of a conductive tether to interact with Earth's magnetic field, exploiting electrodynamics to achieve various functions. The basic principle of EDTs is to generate a current within the tether, which then interacts with the earth's magnetic field to produce a Lorentz force. This force can then be controlled (via current) to either boost or deorbit a spacecraft. The current itself can be generated by collecting electrons from the ambient plasma at the anode (the mother satellite orbiting at a higher altitude) of the tether and emitting them back into the plasma at the cathode (the daughter satellite orbiting at a lower altitude) forming a closed loop (Figure 14). EDT technology allows CubeSats to generate propulsion without carrying onboard propellant. By controlling the current flow through the tether, the satellite can adjust its trajectory, altitude, or orbit. Additionally, The electric current induced in the tether can be used for generating electrical power.

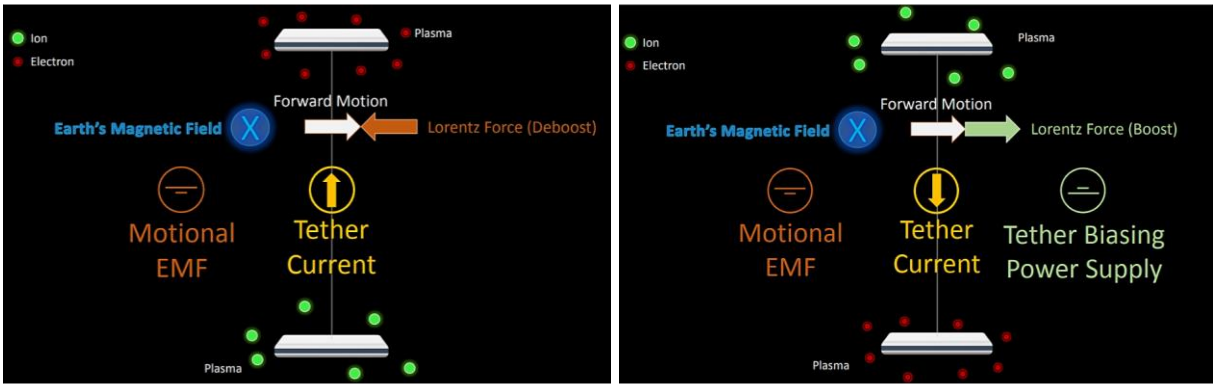


Figure 14- The method of power generation in tethered CubeSats (image credit: MiTEE)

2.6.2.2 Case Study of Implemented Projects

- ***MiTEE CubeSat***

MiTEE[1] is an example of projects, that focusing on tethering system. The Miniature Tether Electrodynamics Experiment (MiTEE) is a pioneering project that explores the integration of tethering technology with CubeSats to harness electrodynamic forces for propulsion and energy transfer. It led by the university of Michigan. MiTEE aims to advance our understanding of the electrodynamics of tethers in space and demonstrate their practical applications. They are developing a CubeSat with a 10-meter miniature EDT attached to its end-body. This EDT is designed to characterize and demonstrate miniature EDT technology. The mission goals of MiTEE are:

- Provide a hands-on multidisciplinary educational experience rooted in faculty driven research.
- Understand the impact of hands-on multidisciplinary participation in faculty research on STEM education for undergraduate and graduate students.
- Understand the functionality of miniature electrodynamic tethered systems.

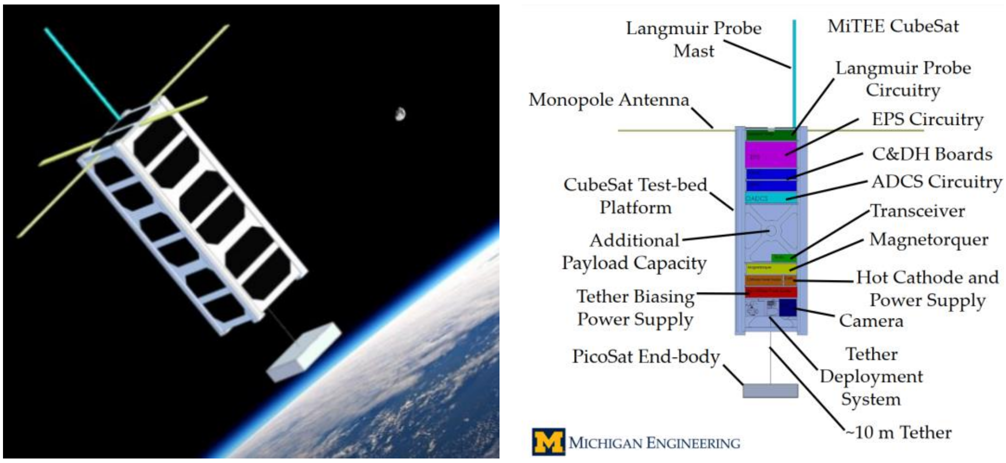


Figure 15- MiTEE CubeSat with a miniature EDT technology

[1] http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3293&context=smallsat

- ***STARS-C CubeSat***

Another example is STARS-C[1] project. It was launched from the International Space Station (ISS) on December 19, 2016. The system consisted of two 1U CubeSats of total mass 2.66 kg. The tether was made of Kevlar. Its diameter was 0.4 mm and length 100 m.

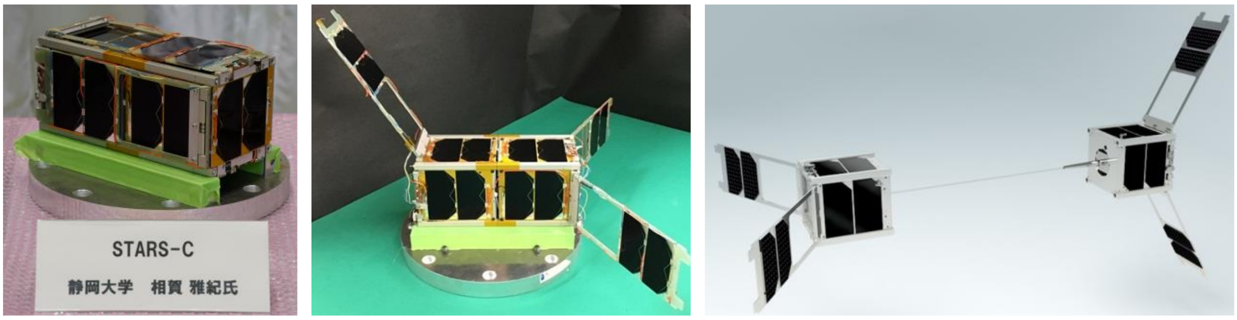


Figure 16- STARS-C Project

- ***TEPCE CubeSat***

TEPCE (Tether Electrodynamics Propulsion CubeSat Experiment)[2] is a tethered spacecraft being built by U.S. NRL (Navel Research Laboratory) to demonstrate electrodynamic propulsion in space. The spacecraft, in its orbital configuration, will consist of two CubeSat with a 1 km of electrically conducting tether.

Electrodynamic propulsion works on electromagnetic principles similar to an electric motor. The magnetic field in an electric motor attracts an electric current that flows through the windings of the armature causing the armature to spin. In space, the Earth has a naturally occurring magnetic field and for TEPCE, the tether wire serves the purpose of the armature. By inducing an electric current to flow along the tether, a mutual attraction between the Earth's magnetic field and the tether will occur. This electromagnetic attraction can propel TEPCE to higher altitudes or to change the orientation of its orbit.

TEPCE is a 3U CubeSat demonstration of emission, collection, and electrodynamic propulsion. Two nearly identical endmasses with a stacer spring between them are used in TEPCE, which separate the endmass and start deployment of a 1 km long braided-tape conducting tether. TEPCE will use a passive braking to reduce speed and hence recoil at the end of electrodynamic current in either direction. The main purpose of this mission is to raise or lower the orbit by several kilometers per day, to change libration state, to change orbit plane, and to actively maneuver.

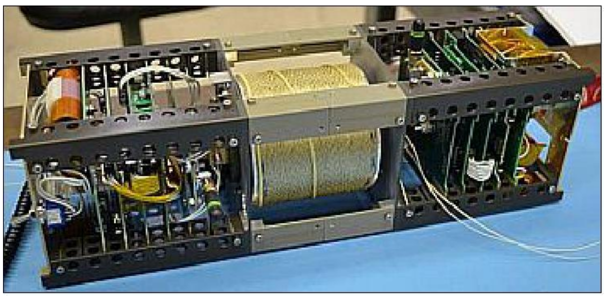


Figure 17- Photo of NRL's TEPCE 3U CubeSat (image credit: NRL)

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[1] https://www.gaussteam.com/wordpress/wp-content/uploads/2018/02/IAA-AAS-CU-2017-12-05-ArunMISRA.pdf

[2] https://www.eoportal.org/satellite-missions/tepce#launch

TEPCE uses a stacer spring to energetically push the ends apart, to pay out a 1 km conductive tether stowed around the stacer. It can use either the tether or 5 m EDDE-like metal tapes at each end to collect electrons from the plasma, and EDDE-like hot wire emitters at each end to emit electrons into the plasma.
Each endmass has isolated high voltage supplies, magnetorquers, GPS, a camera, and plasma sensors. TEPCE has too little power to counteract drag near ISS altitude, and will reenter within a few days after tether deployment. But that is enough to test hardware operation and measure plasma interactions.

2.6.2.3 Challenges for EDT

Tethered CubeSats, despite their potential benefits, also come with a set of challenges that need to be addressed for successful implementation. Here are some key challenges associated with tethered CubeSats:

- **Tether Deployment and Stability**: Deploying a tether in microgravity requires careful engineering to ensure controlled and stable deployment. Avoiding tangling or unwanted oscillations in the tether during deployment is crucial to mission success. Tangling of tethered CubeSats refers to the unwanted entanglement, twisting, or snaring of the tether as it deploys in space. This phenomenon can pose significant challenges to the success of tethered missions, as it can affect the satellite's stability, functionality and mission objectives. The causes of tether tangling in tethered CubeSats can be attributed to microgravity dynamics, tether length, deployment Speed, and environmental factors. This phenomenon has consequences, including propulsion inefficiency, loss of stability and control, and ata and communication disruption. Schumatic of possible motion of tether and satellites after fully deploying tether and then its wounding around mother satellite and daughter satellite is shown in Figure 18[1].

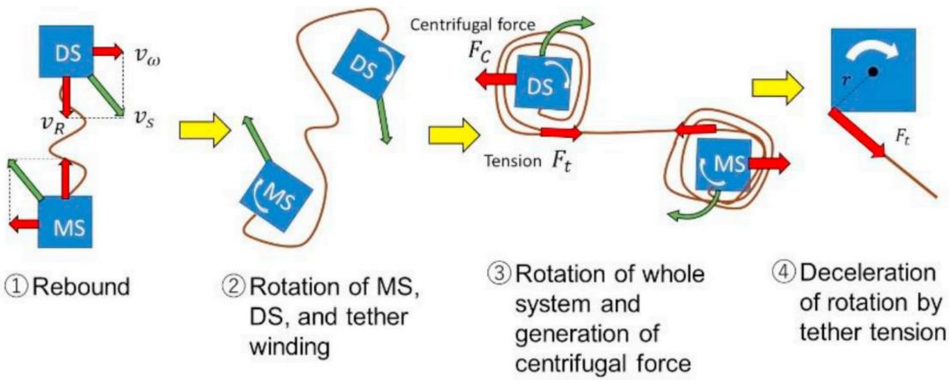

Figure 18- Possible motion of tether and satellites after the tether was fully.

Figure 19 shows the variation in satellite separation velocity with satellite distance when the MS and DS each rotate 0–90°, 0–180°, 0–270°, 0–360°, and 0–380°, assuming the average deployment resistance of these angles.

[1] https://www.sciencedirect.com/science/article/abs/pii/S0094576519314687?via%3Dihub

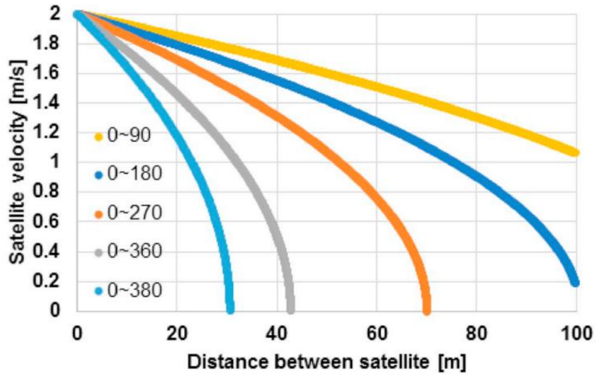

Figure 19- Variation of satellite separation velocity with distance when MS and DS rotate

- **Increase in the drag Area**: The tether wire causes an increase in drag area, which in turn results in a greater orbital decay compared to a scenario without the tether wire. For instance, the drag area of the tether wire in the STARS-C project has been approximately twice that of the drag area of two CubeSats. Figure 20 illustrates the altitude variation of STARS-C CubeSats in comparison to a similar scenario but without the tether (AOBA).
- **Electromagnetic Interference**: The electric current induced along the tether can potentially interfere with the satellite's onboard systems and instrumentation. Managing these electromagnetic interactions and decreasing their impact is essential.
- **Tether Oscillations**: Oscillations in the tether can arise due to its interactions with the magnetic field and other forces. These oscillations can impact mission accuracy, stability, and energy transfer.
- **Orbital Dynamics**: Accurately predicting and modeling the interactions between the tethered CubeSat and the space environment is critical for achieving desired propulsion and maneuvering outcomes.
- **Control Systems**: Developing robust control systems to manage the deployment, tension, and interactions of the tether is essential for maintaining the desired mission trajectory and avoiding unintended complications.

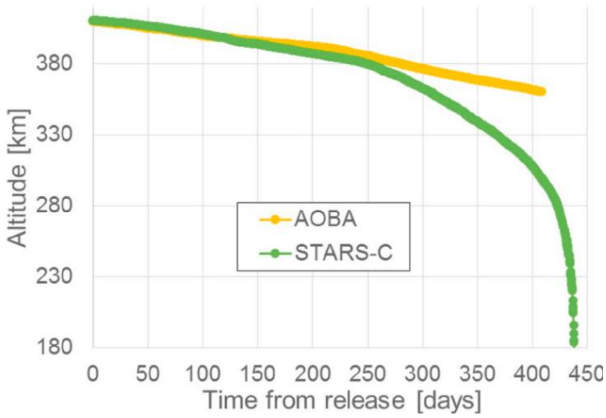

Figure 20- Variation history of STARS-C altitude[1]

[1] https://www.sciencedirect.com/science/article/abs/pii/S0094576519314687?via%3Dihub

In Our plan, STARCS B will be separated into STARCS B-MS and STARCS B-DS with connect to each other by a cable with about maximum 10 m length. The phenomena of EDT should analysis carefuly, if we want to keep accepted distance between STARCS A and B for ISL.

2.7 Availability of the technology, Consistency with student capability and Practicability

Prior CubeSat projects on the proposed technologies have been extensively studied, many of which were 1U-3U CubeSats university projects and student-built. Proving the feasibility of design. Here are the three sections that demonstrate the practicability of the SPARCS CubeSats:

- Availability of the technology:
  - The required technologies for performing the proposed mission are commercially available and affordable
  - Components and test infrastructures are available, most of which readily available at Sharif University of Technology

- Consistency of the mission with student capability:
  - Eventhough the mission is novel and interesting, the TRL of the chosen technology easily allows a student team, with the support of a consultant from the industry, to design, build, and test an Engineering Model (EM) of the proposed CubeSats.
  - We chose the mission with excessive emphasis on the student essence and intention of the project, as ACC is an educational activity.

- Practicability of performing the mission by a 3U CubeSat:
  - The extensive study of prior CubeSat projects, their success in various educational and research contexts, and the defined limitations on physical characteristics all contribute to the feasibility of the proposed SPARCS mission in a 3U CubeSat.

The SPARCS CubeSats mission is designed to be practical and feasible for student teams to design, build, and test. The required technologies for the proposed mission are commercially affordable, and the CubeSats can perform the mission with the limitations of a student team characteristics in mind, indicating the EM can be designed, built, and tested in Sharif University of Technology under APSCO supervision.

2.8 Cost and time estimation

The requirement for providing the cost of the engineering model is the complete transparency of the plan. However, according to the initial estimate made by the team, the cost of the engineering model will not exceed the ceiling of $100,000 set by APSCO.

The detailed design phase of the project is expected to be completed in less than a year. This phase includes two important reviews, the Preliminary Design Review (PDR) and the Critical Design Review (CDR). The PDR, also known as Phase-A Preliminary Design, will be conducted when the allocated baseline has been achieved, allowing the detailed design of hardware and software CIs to proceed. The PDR is a critical review in our design procedure since it addresses and resolves system-wide issues before detailed design begins. On the other hand, the CDR, also known as Phase-A Completion of The Design Phase, presents the final designs through completed analyses, simulations, and other relevant data. The engineering model preparation and design review cycles are estimated to take another year, considering the worst-case scenarios.

The PDR and CDR are two of the most important reviews in our design process, and they provide assurance that the SPARCS satellites and the SPARCS mission are mature and will meet performance requirements. Establishing a stable design at the project's CDR is critical, and it signifies when the SPARCS program is ready to start building production-representative prototypes.

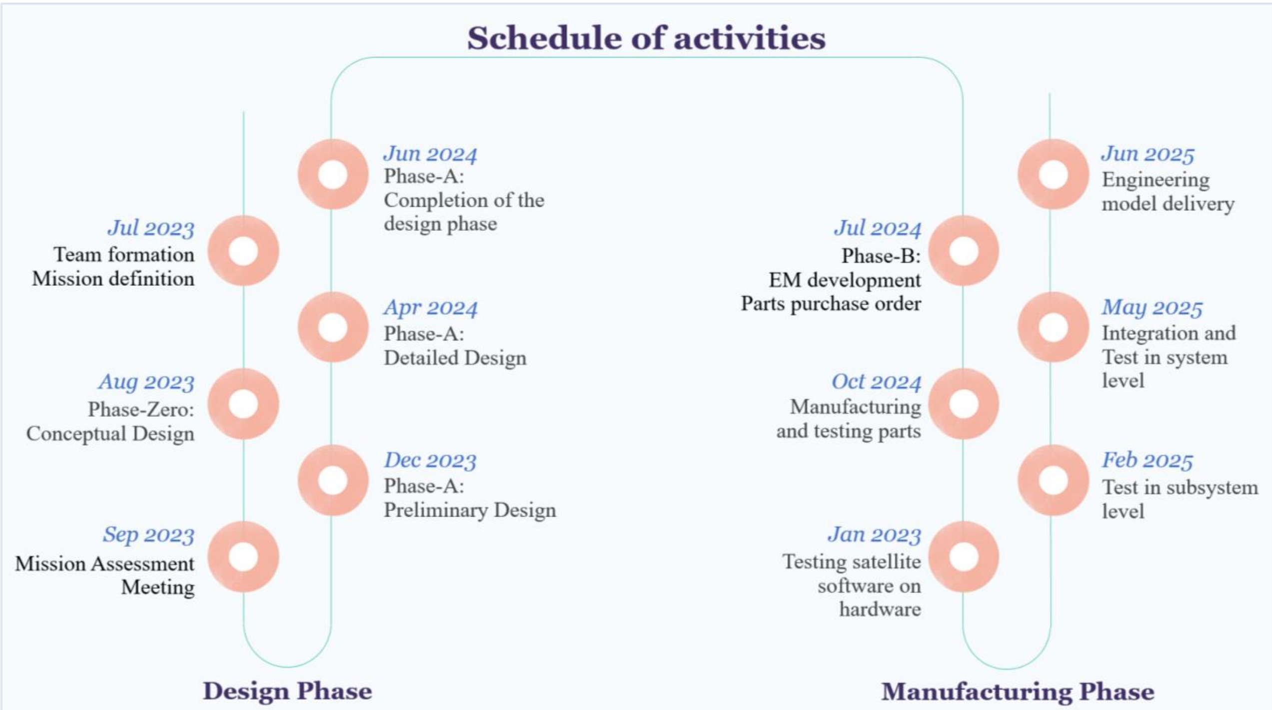

Figure 21- Schedule of activities for STARCS project

3 Concluding Remarks

In recent century, humanity stands at the threshold of a new era in satellite technology, one where small, agile spacecraft can collaborate and adapt in real-time, fostering unprecedented connectivity and data sharing among them.

In the grand tapestry of space missions, the SPARCS represents a combination of various innovations that stretch toward the cosmos. With these CubeSats, we embark on a journey that goes beyond the confines of our planet.

The SPARCS mission begins with the launch of two 1.5U CubeSats (SPARCS-A and SPARCS-B) into Earth's orbit. These miniature marvels are not alone; they are tightly interconnected via an innovative Inter Satellite Link. We're not stopping there. After a peioud that we test ISL successfully, in a daring move, one of the 1.5U CubeSats (SPARC-B) will embark on a new phase of the mission. This satellite will deploy its daughter module and seperates into two distinct components connected by a tethered link. This tethered link will open up new possibilities for cooperation and experimentation in the harsh conditions of space. Although the integration of our mission ideas has not yet been implemented in other projects, we tried to prove the feasibility of our proposition by studying somehow similar successful CubeSat projects.

Finally, it should be noted that this project is not just about the satellites themselves; it's about the spirit of exploration, the relentless pursuit of knowledge, and the boundless curiosity that drives us to reach for space.

To us at iSSS, this is more than just a competition;

it's a testament to the human spirit of exploration and discovery.

Ad maiorem autem gloriam purae universalis rationis