ISSN 2518-1726 (Online),
ISSN 1991-346X (Print)

ACADEMIC SCIENTIFIC JOURNAL OF COMPUTER SCIENCE

№3
2025

ISSN 2518-1726 (Online),
ISSN 1991-346X (Print)

CENTRAL ASIAN ACADEMIC RESEARCH CENTER

ACADEMIC SCIENTIFIC JOURNAL OF COMPUTER SCIENCE

3 (355)

JULY – SEPTEMBER 2025

PUBLISHED SINCE JANUARY 1963
PUBLISHED 4 TIMES A YEAR

ALMATY, NAS RK

Academic Scientific Journal of Computer Science
ISSN 2518-1726 (Online),
ISSN 1991-346X (Print)
Owner: «Central Asian Academic Research Center» LLP (Almaty).
Certificate **№ KZ77VPY00121154** on the re-registration of the periodical printed and online publication of the information agency, issued on **05.06.2025** by the Republican State Institution «Information Committee» of the Ministry of Culture and Information of the Republic of Kazakhstan
Subject area*: information and communication technologies.*
Currently: *included in the list of journals recommended by the CCSES MSHE RK in the direction of «Information and communication technologies».*
Periodicity: *4 times a year.*
http://www.physico-mathematical.kz/index.php/en/

Academic Scientific Journal of Computer Science
ISSN 2518-1726 (Online),
ISSN 1991-346X (Print)
Меншіктеуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы).
Ақпарат агенттігінің мерзімді баспасөз басылымын, ақпарат агенттігін және желілік басылымды қайта есепке қою туралы ҚР Мәдениет және Ақпарат министрлігі «Ақпарат комитеті» Республикалық мемлекеттік мекемесі **05.06.2025** ж. берген **№ KZ77VPY00121154** Куәлік.
Тақырыптық бағыты: *ақпараттық-коммуникациялық технологиялар*
Қазіргі уақытта: *«ақпараттық-коммуникациялық технологиялар» бағыты бойынша ҚР БҒМ БҒСБК ұсынған журналдар тізіміне енді.*
Мерзімділігі: *жылына 4 рет.*
http://www.physico-mathematical.kz/index.php/en/

Academic Scientific Journal of Computer Science
ISSN 2518-1726 (Online),
ISSN 1991-346X (Print)

Собственник: *ТОО «Центрально-азиатский академический научный центр» (г. Алматы).*

Свидетельство о постановке на переучет периодического печатного издания, информационного агентства и сетевого издания **№ KZ77VPY00121154.** Дата выдачи **05.06.2025**

Тематическая направленность: *информационно-коммуникационные технологии.*

В настоящее время: *вошел в список журналов, рекомендованных КОКСНВО МНВО РК по направлению «информационно-коммуникационные технологии».*

Периодичность: *4 раза в год.*

http://www.physico-mathematical.kz/index.php/en/

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ACADEMIC SCIENTIFIC JOURNAL OF COMPUTER SCIENCE
ISSN 1991-346X
Volume 3. Namber 355 (2025). 243–257

https://doi.org/10.32014/2025.2518-1726.375

IRSTI 49.03.03
UDC 654.165

A. Temirbayev[1], N. Meirambekuly[2*], N. Uzbekov[2], A. Beisen[2], L. Abdizhalilova[2], 2025.
[1]Cluster of Engineering and High Technologies, Al-Farabi Kazakh National University, Almaty, Kazakhstan;
[2]Center of Space Technologies, Al-Farabi Kazakh National University, Almaty, Kazakhstan.
E-mail: amirkhan@kaznu.kz

CUBESAT-BASED APRS DIGIPEATER: DESIGN, FEASIBILITY AND MISSION CONCEPT

Temirbayev Amirkhan — PhD, General Director of Cluster of Engineering and High Technologies at Al-Farabi KazNU, Almaty, Kazakhstan,
E-mail: amirkhan@kaznu.kz; ORCID ID: https://orcid.org/0000-0001-6759-2774;
Meirambekuly Nursultan — PhD, Senior Lecturer, Al-Farabi Kazakh National University, Almaty, Kazakhstan,
E-mail: nurs.kaznu@gmail.com, ORCID ID: https://orcid.org/0000-0003-2250-4763;
Uzbekov Nursultan — Senior Researcher, Al-Farabi Kazakh National University, Almaty, Kazakhstan,
E-mail: uzbekov.nursultan@gmail.com, ORCID ID: https://orcid.org/0009-0007-9956-0102;
Beisen Asset — Researcher, Al-Farabi Kazakh National University, Almaty, Kazakhstan,
E-mail: Beisen.Asset@kaznu.kz, ORCID ID: https://orcid.org/0009-0000-5144-2616;
Abdizhalilova Lazzat — Junior Researcher, Al-Farabi Kazakh National University, Almaty, Kazakhstan,
E-mail: abdijalil.lazzat@bk.ru, ORCID ID: https://orcid.org/0009-0000-5965-7195.

Abstract. This article investigates the feasibility of using an Automatic Packet Reporting System (APRS) payload on a CubeSat platform to function as a digital digipeater in low Earth orbit. APRS is a packet-based communication protocol widely used by amateur radio operators for real-time messaging, telemetry, and position reporting. While APRS is traditionally implemented using terrestrial IGates and digipeaters, extending its functionality to a satellite platform offers significant advantages in coverage and accessibility, especially for remote or infrastructure-deficient regions. *Results.* The proposed system is designed to receive APRS packets in the VHF band (typically at 145.825 MHz), perform optional store-and-forward buffering, and transmit the data either back to APRS-compatible ground users or to Internet-connected IGate stations. The study includes detailed architectural design of the satellite payload, system requirements for communications, power, and processing, and an overview of mission operations. *Scientific novelty.* Analytical calculations confirm the viability of this CubeSat APRS concept, demonstrating the ability to provide up to 18.6 million km² coverage per pass, handle up to 700 packets per communication window, and maintain sustainable power consumption within the constraints of a 1U CubeSat. The system architecture also supports private or targeted delivery of information to specific stakeholders, such as agricultural operators monitoring large tracts of farmland. *Practical value.* This work contributes to the ongoing effort to bridge terrestrial and space-based IoT and amateur radio applications, particularly for disaster mitigation, environmental monitoring, and telemetry services. The paper concludes by identifying system-level trade-offs and outlines several promising directions for future development, including multi-satellite constellations, dual-band communication, onboard intelligence for packet filtering, and practical flight demonstrations.

Key words: APRS; CubeSat; communication; environmental monitoring, AX.25 protocol

А.А. Темирбаев[1], Н. Мейрамбекұлы[2*], Н.Ш. Узбеков[2], Ә.Н. Бейсен[2], Л.Б. Абдижалилова[2], 2025.

[1]Инжиниринг және жоғары технологиялар кластері, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Казақстан;

[2]Ғарыш технологиялары орталығы, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Казақстан.

E-mail: amirkhan@kaznu.kz

CUBESAT НЕГІЗІНДЕГІ APRS ҚАЙТА ТАРАТҚЫШЫ: ЖОБАЛАУ, ІСКЕ АСЫРУ МҮМКІНДІГІ ЖӘНЕ МИССИЯ ТҰЖЫРЫМДАМАСЫ

Темирбаев Амирхан Адилханович — PhD, Инжиниринг және жоғары технологиялар кластерінің бас директоры, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Казақстан,
E-mail: amirkhan@kaznu.kz; ORCID ID: https://orcid.org/0000-0001-6759-2774;

Мейрамбекұлы Нұрсұлтан — PhD, аға оқытушы, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Казақстан,
E-mail: nurs.kaznu@gmail.com, ORCID ID: https://orcid.org/0000-0003-2250-4763;

Узбеков Нұрсұлтан Шалаханұлы — Аға ғылыми қызметкер, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Казақстан,
E-mail: uzbekov.nursultan@gmail.com, ORCID ID: https://orcid.org/0009-0007-9956-0102;

Бейсен Әсет Нұрболұлы — Ғылыми қызметкер, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Казақстан,
E-mail: Beisen.Asset@kaznu.kz, ORCID ID: https://orcid.org/0009-0000-5144-2616;

Абдижалилова Лаззат Бахтиярқызы — Кіші ғылыми қызметкер, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Казақстан,
E-mail: abdijalil.lazzat@bk.ru, ORCID ID: https://orcid.org/0009-0000-5965-7195.

Аннотация: Бұл мақалада кіші ғарыш аппараттарында, атап айтқанда CubeSat платформасында APRS (Automatic Packet Reporting System) пайдалы жүктемесін Жердің маңындағы төменгі орбитада цифрлық қайта таратқыш ретінде пайдалану мүмкіндігі қарастырылады. APRS – бұл радиоәуесқойлар арасында нақты уақыттағы хабарламалармен, телеметриямен және позициямен алмасуға арналған пакетке негізделген байланыс протоколы болып табылады. APRS дәстүрлі түрде жердегі IGate және ретрансляторлар арқылы жүзеге асырылғанымен, оны жер серігіне енгізу шалғай немесе инфрақұрылымы әлсіз аймақтар үшін байланыспен қамту мен қолжетімділікті айтарлықтай арттыру мүмкіндігін ашады. *Нәтижелер*. Ұсынылған жүйе аса жоғары жиіліктер (АЖЖ) ауқымында (әдетте 145.825 МГц жиілігінде) APRS пакеттерін қабылдап, оларды уақытша буферлеуге және кейін жердегі IGate станцияларына немесе басқа пайдаланушыларға жеткізуге арналған. Зерттеу жерсеріктік пайдалы жүктеменің архитектурасын, байланыс пен қуат талаптарын, сонымен қатар миссияның жалпы операциялық моделін сипаттайды. *Ғылыми жаңалығы.* Аналитикалық есептеулер нәтижесінде CubeSat платформасы негізіндегі APRS жүйесінің тиімділігі келесідей дәлелденді: ғарыш аппаратының бір ұшып өтуінде 18.6 миллион км² аумақты қамту, 700-ге дейін пакетті өңдеу және 1U CubeSat ғарыш аппараты шеңберінде тұрақты қуатпен жұмыс істеу мүмкіндігі анықталды. Бұл жүйе деректерді нақты алушыларға бағыттауға мүмкіндік береді, мысалы, ауыл шаруашылығымен айналысатын субъектілер үшін. *Практикалық маңыздылығы.* Бұл зерттеу жердегі және ғарыштағы IoT технологиялары мен әуесқой радио жүйелерін біріктіру жолындағы маңызды қадам болып табылады. Қорытынды бөлімде қуат, масса және өткізу қабілеттілігі шектеулері сияқты жүйелік деңгейдегі шектеулер талқыланады.

Түйін сөздер: APRS; CubeSat; радиобайланыс; қоршаған ортаны бақылау, AX.25-протоколы

А.А. Темирбаев[1], Н. Мейрамбекұлы[2], Н.Ш. Узбеков[2], Ә.Н. Бейсен[2], Л.Б. Абдижалилова[2], 2025.

[1]Кластер инжиниринга и наукоемких технологий, КазНУ им. аль-Фараби, Алматы, Казахстан;

[2]Центр космических технологий, КазНУ им. аль-Фараби, Алматы, Казахстан.

E-mail: amirkhan@kaznu.kz

ЦИФРОВОЙ РЕТРАНСЛЯТОР APRS НА БАЗЕ СПУТНИКА CUBESAT: ПРОЕКТИРОВАНИЕ, РЕАЛИЗУЕМОСТЬ И КОНЦЕПЦИЯ МИССИИ

Темирбаев Амирхан Адилханович — PhD, Генеральный директора Кластера инжиниринга и наукоемких технологий, КазНУ имени аль-Фараби, Алматы, Казахстан,
E-mail: amirkhan@kaznu.kz; ORCID ID: https://orcid.org/0000-0001-6759-2774;

Мейрамбекұлы Нұрсұлтан — PhD, старший преподователь, КазНУ имени аль-Фараби, Алматы, Казахстан,

E-mail: nurs.kaznu@gmail.com, ORCID ID: https://orcid.org/0000-0003-2250-4763;
Узбеков Нұрсұлтан Шалаханұлы — Старший научный сотрудник, КазНУ имени аль-Фараби, Алматы, Казахстан,
E-mail: uzbekov.nursultan@gmail.com, ORCID ID: https://orcid.org/0009-0007-9956-0102;
Бейсен Әсет Нұрболұлы — Научный сотрудник, КазНУ имени аль-Фараби, Алматы, Казахстан,
E-mail: Beisen.Asset@kaznu.kz, ORCID ID: https://orcid.org/0009-0000-5144-2616;
Абдижалилова Лаззат Бахтиярқызы — Младший научный сотрудник, КазНУ имени аль-Фараби, Алматы, Казахстан,
E-mail: abdijalil.lazzat@bk.ru, ORCID ID: https://orcid.org/0009-0000-5965-7195.

Аннотация: В данной статье рассматривается возможность использования полезной нагрузки APRS (Automatic Packet Reporting System) в малых космических аппаратах, в частности, на платформе CubeSat для функционирования в качестве цифрового ретранслятора в низкой околоземной орбите. APRS – это протокол пакетной радиосвязи, широко применяемый радиолюбителями для обмена сообщениями, телеметрии и передачи координат в реальном времени. В то время как APRS традиционно реализуется с использованием наземных IGate-станций и ретрансляторов, его расширение на спутниковую платформу открывает новые возможности охвата, особенно в удалённых и труднодоступных районах. *Результаты.* Предлагаемая система предусматривает приём APRS-пакетов в VHF-диапазоне (обычно на частоте 145.825 МГц), их буферизацию и последующую передачу другим пользователям или наземным IGate-станциям с выходом в интернет. Исследование включает детальный обзор архитектуры полезной нагрузки, требований к связи, питанию и обработке данных, а также общую концепцию миссии. *Научная новизна.* Расчёты подтверждают жизнеспособность концепции: спутник способен обеспечивать покрытие до 18,6 млн км² за один пролёт, обрабатывать до 700 пакетов за сеанс связи и поддерживать стабильное энергопотребление в рамках платформы 1U CubeSat. Архитектура также допускает выборочную доставку данных конкретным получателям, что особенно актуально для приложений в агромониторинге и других чувствительных сценариях. *Практическая ценность.* Работа вносит вклад в развитие интеграции наземных и спутниковых IoT и радиолюбительских систем связи. В заключение обсуждаются компромиссы системного уровня включая ограничения по мощности, массе и пропускной способности.

Ключевые слова: APRS; CubeSat; радиосвязь; мониторинг окружающей среды, протокол AX.25.

Funding.*This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP27510563).*

Introduction. The Automatic Packet Reporting System (APRS) is a global digital communication protocol used by amateur radio operators to transmit location, telemetry, and brief data messages over radio frequencies (Bruninga, 1999). APRS operates primarily on the 145.825 MHz VHF band and uses the AX.25 protocol to format and exchange information packets (Beech et al., 2008).

The fundamental components of the APRS terrestrial system include: 1) GPS-equipped mobile or fixed station – which periodically sends its position and data, 2) AX.25 modem and radio transceiver – which encode and transmit the packets, 3) Digipeaters – digital repeaters that receive, store, and retransmit APRS packets over extended distances, 4) IGates (Internet Gateways) – ground stations that collect RF packets and relay them to the APRS Internet System (APRS-IS), 5) APRS-IS and visualization services – which provide real-time global mapping and data analysis capabilities (APRS Working Group, 2000).

This setup allows APRS to serve as a lightweight and decentralized system for:

• Real-time location tracking of vehicles, weather balloons, or portable users;
• Environmental and weather monitoring via sensor beacons;
• Short-text emergency messaging in areas lacking cellular service.

Figure 1 illustrates the standard terrestrial APRS communication architecture, demonstrating the interaction between transmitting stations, digipeaters, IGates, and internet services. This architecture enables APRS users to visualize moving objects on maps, receive weather data from remote sensors, and communicate short text messages over long distances without the need for cellular networks.

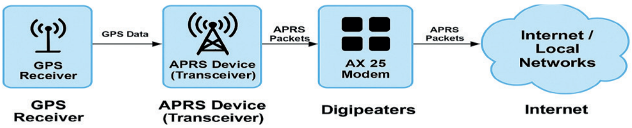

Figure 1. Terrestrial APRS communication system architecture

However, this ground-based system is inherently limited by the availability of infrastructure and internet access. In remote deserts, mountainous terrain, vast oceans, or agricultural expanses such as those found in Central Asia, traditional IGates and repeaters are often absent.

To extend APRS coverage beyond terrestrial boundaries, several missions have experimented with placing digipeaters on satellites in Low Earth Orbit (LEO) (Patmasari et al., 2018). These space-based systems enable global packet forwarding independent of ground-based internet or relay networks. This paper explores the feasibility, design, and deployment of a CubeSat acting as an APRS digipeater. The goal is to receive APRS packets from ground stations, retransmit them for extended coverage, and support global amateur radio communication without dependence on internet-based infrastructure. We focus on the necessary onboard systems, communication parameters, mission constraints, and operational strategies that enable this function in the CubeSat platform. Unlike an IGate that forwards packets to the internet, a digipeater retransmits packets via RF to other users within line of sight, making it simpler to implement and better suited for decentralized environments. This study will serve as a foundational investigation for developing space-based amateur packet networks and enabling resilient, infrastructure-independent communication systems.

Review of Existing APRS Satellite Missions. The application of APRS in satellite communication has evolved significantly since the early 2000s, contributing to amateur radio innovation and emergency communication infrastructure. This section reviews the scientific literature, technical reports, and documented satellite missions that demonstrate the relevance, feasibility, and lessons learned from space-based APRS systems.

Bruninga (2019), the originator of APRS, documented the foundational concept of using LEO satellites to support packet radio communication independent of terrestrial repeaters. This concept was practically realized with PCSAT (NO-44), the first APRS-enabled satellite, launched in 2001 by the U.S. Naval Academy. Its success in real-time digipeating and telemetry inspired follow-up experiments such as PCSAT-2, temporarily deployed on the ISS in 2005, and documented in NASA technical briefs and Naval Academy mission debriefs.

A noteworthy study by Salces et al. (2020) BIRDS-2 Project, Kyushu Institute of Technology explores the development and testing of an amateur radio payload on a 1U CubeSat platform. The payload, operating on 145.825 MHz using AX.25 protocol, was designed to support both digipeater and store-and-forward (S&F) modes using primarily commercial-off-the-shelf components. Despite partial mission success – where only beacon reception was confirmed – this study offers insights into CubeSat constraints such as uplink reliability, power budget, and spatial limitations. The authors present a detailed failure analysis and recommend the best practices for future CubeSat APRS designs.

More recently, operational payloads like ARISS APRS on the ISS have continued to deliver reliable APRS coverage globally (ARISS, n.d.), further validating the utility of space-based digipeaters. Missions such as GO-32, AO-51, and Falconsat-3 contributed experience with 9600 baud operations and dual-mode payloads, offering design alternatives for future systems (Bruninga, 2010).

A recent study by the Indonesian team on Surya Satellite-1, the country's first undergraduate-developed CubeSat, presents a relevant application of APRS technology (Prahyang et al., 2018). Designed for disaster mitigation, this satellite operates on VHF and UHF amateur radio bands and includes an APRS module for remote communication with ground stations in disaster-prone zones. This mission demonstrates the versatility of CubeSat-based APRS for region-specific objectives using low-cost commercial hardware.

Another Indonesian satellite, LAPAN-A2 (LAPAN-ORARI), launched in 2015 by the Satellite Technology Center of Indonesia’s National Institute of Aeronautics and Space, includes payloads for amateur communication, such as APRS and voice repeaters. The mission highlighted the usage of APRS not only for emergency messaging but also for transmission of telemetry, weather updates, and beaconing.

An innovative aspect of this work is the proposal to replace expensive decoding hardware with a Raspberry Pi-based solution, enabling broader adoption of APRS ground stations (Rizal et al., 2021).

In addition, there are other scientific papers on the possibility of using APRS in the field of satellite and educational technologies (Un et al., 2022; Chopparapu et al., 2025; Addaim et al., 2005; Addaim, Kherras & Zantou, 2008; Linton, 2016).

Collectively, these sources form a knowledge base that informs the present work. Our proposed CubeSat APRS digipeater builds on this prior art while introducing hybrid functionality such as selective packet forwarding to IGates and support for private telemetry applications in remote sectors such as agriculture and environmental monitoring.

System Requirements and Architecture. The design of a CubeSat-based APRS digipeater system must meet specific mission objectives while operating within the constraints of size, weight, power, and communications. This section defines the key system requirements and presents a high-level architectural breakdown. Table 1 presents the mission-level requirements that guide the definition of operational objectives and system constraints. These include orbital parameters, communication standards, and minimum lifetime targets, which are critical for evaluating feasibility and regulatory compliance.

Table 1 – The main Mission Requirements

Subsystem	Components and Functions
Communication Subsystem	VHF transceiver (1200 baud AFSK), deployable antenna, optional SDR module
Processing Subsystem	Onboard computer (AX.25 decoding, packet scheduling), watchdog timer, error handling
Power Subsystem	Solar panels, MPPT charger, Li-Ion/LiPo battery pack
Data Handling & Storage	Buffering memory, timestamping, packet prioritization
Ground Segment Interface	IGate compatibility, selective forwarding, optional API connectivity
Satellite Bus & Structure	1U/2U CubeSat frame, thermal coating, mechanical deployer interface

Table 2 provides an overview of the key functional subsystems within the CubeSat. Each subsystem is defined by its primary roles and hardware components, ensuring a modular and scalable architecture suitable for amateur radio satellite missions.

The APRS CubeSat digipeater system integrates an RF front-end with onboard logic for packet processing and conditional storage. During a pass over ground stations, the satellite listens for APRS packets. Depending on mission configuration, it may retransmit these immediately (digipeating) or store them and later downlink to designated IGates or internet-connected ground stations. The architecture supports future expansion such as dual-band operation, packet authentication, and integration with IoT gateways.

Table 2 – The main Functional Subsystems

Subsystem	Components and Functions
Communication Subsystem	VHF transceiver (1200 baud AFSK), deployable antenna, optional SDR module
Processing Subsystem	Onboard computer (AX.25 decoding, packet scheduling), watchdog timer, error handling
Power Subsystem	Solar panels, MPPT charger, Li-Ion/LiPo battery pack
Data Handling & Storage	Buffering memory, timestamping, packet prioritization
Ground Segment Interface	IGate compatibility, selective forwarding, optional API connectivity
Satellite Bus & Structure	1U/2U CubeSat frame, thermal coating, mechanical deployer interface

A block diagram illustrating the system's main components is shown in Figure 2. The diagram illustrates the operational model of an APRS-enabled CubeSat payload with combined digipeater and store-and-forward (S&F) capabilities. During orbital passes over the Earth, the CubeSat receives APRS packets from a variety of ground sources, including APRS transmitters, portable stations, and environmental sensors. These packets may either be:

- Instantly retransmitted (digipeated) to other users within the satellite's footprint,
- or temporarily stored and forwarded to specific IGate ground stations during future passes.

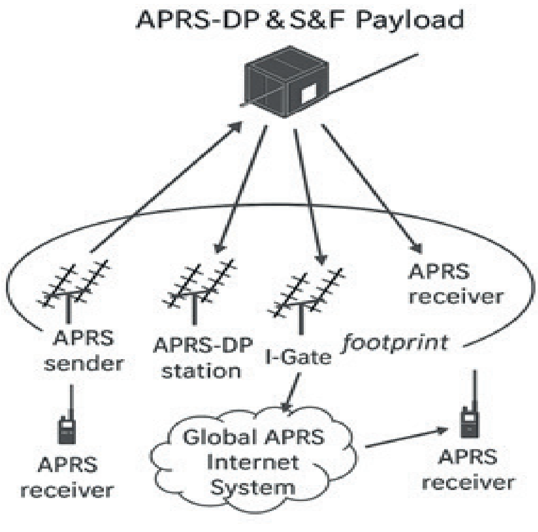

Figure 2. APRS CubeSat digipeater and store-and-forward operational concept

The received and relayed information can then be uploaded into the Global APRS Internet System, making it available to downstream services. This dual-mode approach extends APRS coverage to underserved areas and enables both public and private data use cases (e.g., SAR coordination, agricultural telemetry, or environmental monitoring).

Methods and Tools Used

To evaluate the feasibility and performance of the CubeSat-based APRS digipeater system, a combination of analytical modeling and software-assisted visualization techniques were employed.

Analytical Modeling

Coverage Area: The maximum footprint of the satellite's APRS VHF signal was calculated using great-circle geometry, assuming a circular area visible from a 550 km low Earth orbit. The angular radius was derived from the formula:

$$\theta = \arccos\left(\frac{R_E}{R_E + h}\right)$$

where R_E is the Earth's radius and h is the orbital altitude. This enabled the estimation of a coverage radius of approximately 2,435 km, corresponding to a ground area of ~18.6 million km² per pass.

Packet Throughput Estimation: The number of APRS packets processed per orbital pass was estimated by considering time-over-ground, packet duration, and channel sharing assumptions.

Visualization and Mapping Tools

To visualize the spatial coverage and support analysis, we used the following tools:

- Python 3.11 as the main programming environment
- Matplotlib for 2D plotting of coverage geometries
- Cartopy for map-based visualization of satellite footprints on actual geographic backgrounds
- NumPy for numerical computations and coordinate transformations

A dedicated example of APRS coverage over Kazakhstan was rendered using Cartopy with overlaid circular footprints to demonstrate the regional feasibility of such systems. The corresponding diagram (see Figure 3) reflects both theoretical visibility and realistic geographic integration.

Results. This section presents the analytical results that demonstrate the operational feasibility and effectiveness of the CubeSat-based APRS digipeater mission. Calculations are performed based on standardized orbital parameters and conservative hardware assumptions. The results are summarized in Tables 3, 4, and 5, which respectively highlight the satellite's coverage capability, communication throughput, and power system performance. To validate the feasibility and expected performance of the CubeSat APRS digipeater mission, several analytical estimations and simulations were performed. The results provide insights into coverage, communication window duration, packet relay capacity, and power budget margins under typical low Earth orbit (LEO) conditions. Table 3 provides a quantitative summary of the CubeSat's expected ground coverage and access opportunities for APRS communication. The satellite's line-of-sight radio coverage is derived from its orbital altitude, yielding a large footprint suitable for wide-area communication. Additionally, the number of daily passes over a specific location and their durations are estimated to help forecast service availability.

Table 3 – Orbital Coverage Estimates

Parameter	**Value**
Orbital altitude	550 km
Radio footprint radius	~2,435 km
Ground coverage area	~18.6 million km²
Passes per day (per location)	4-6
Typical pass duration	6-10 minutes

For a CubeSat operating in a 550 km sun-synchronous orbit: The satellite's radio footprint (line-of-sight radius) covers approximately 2,400-2,600 km, encompassing a circular area with a ground diameter of ~5,000 km. Each ground location experiences 4-6 passes per day, depending on latitude. Typical access duration per pass is 6-10 minutes, depending on elevation angle and antenna gain.

The figure 3 illustrates the ground coverage area of an APRS-enabled CubeSat in a 550 km low Earth orbit, centered over Kazakhstan. The red circle represents the satellite's theoretical radio footprint with a radius of approximately 2,435 km, calculated based on the Earth's curvature and orbital altitude. The coverage zone encompasses a vast region, including all of Kazakhstan and parts of neighboring countries, demonstrating the satellite's capability to support wide-area communication, particularly in underserved or remote locations.

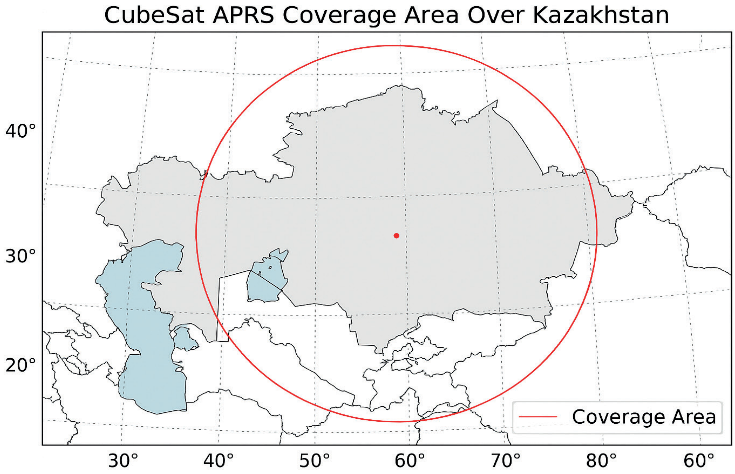

Figure 3. CubeSat APRS coverage area over Kazakhstan

Figure 4 illustrates the relationship between the number of CubeSats in the constellation and the average latency, defined as the time interval between two successive passes over a given ground location during which data packets can be received. The analysis assumes a circular orbit at an altitude of 550 km with an orbital period of approximately 95 minutes and an average communication window of 10 minutes per pass.

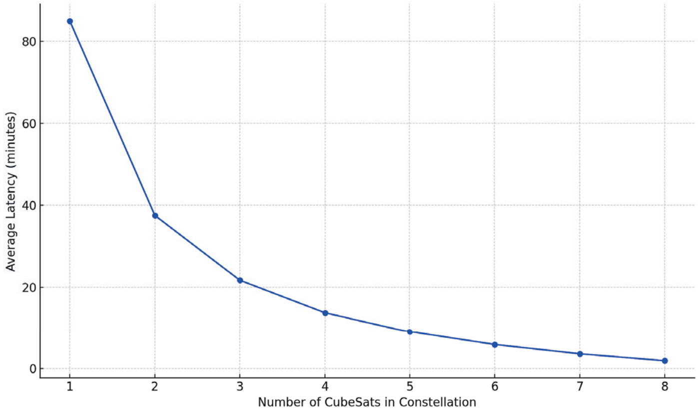

Figure 4. Average packet delivery latency vs. number of CubeSats

As the number of satellites increases, the latency decreases significantly due to more frequent overpasses. The graph demonstrates a steep drop in latency for the initial increase in constellation size, followed by a gradual leveling-off trend. When the number of satellites reaches 8, the average latency drops below 1 minute, effectively enabling near real-time data acquisition for ground-based users.

This finding highlights an important design trade-off: while increasing the number of satellites improves system responsiveness, the marginal benefit diminishes beyond a certain point. A constellation of 8 satellites offers a practical balance between complexity and performance, ensuring frequent packet reception while keeping deployment costs and orbital congestion within reasonable limits.

This result supports the feasibility of using a small CubeSat constellation to provide timely delivery of APRS data from remote users and assets, especially in scenarios requiring low-latency transmission, such as environmental monitoring or disaster response.

Table 4 presents a model of communication throughput, considering packet size, modulation scheme, and estimated channel efficiency. These calculations provide insight into the number of APRS packets that the CubeSat can reasonably relay during each orbital pass. The values suggest strong potential for both live digipeating and temporary message storage without overwhelming the onboard system.

Table 4 – Communication Load Estimates

Parameter	Value
Modulation	AFSK 1200 baud

Packet size	256 bytes
Channel efficiency (est.)	~60%
Average packets per minute	~100 packets/min
Maximum per 7-min pass	~700 packets
Practical digipeat throughput	1-2 packets/sec

Assuming APRS packets are 256 bytes long and AFSK 1200 baud modulation: Effective channel throughput: ~100 packets per minute (accounting for overhead and latency). In a 7-minute pass, the satellite can process ~700 packets, with filtering to discard redundant or malformed frames. Maximum digipeated packet rate: 1-2 packets per second (with safety margin).

Table 5 summarizes the estimated power consumption and generation capabilities of a 1U CubeSat. With realistic assumptions about solar panel efficiency, orbital sunlight duration, and system duty cycles, the energy balance indicates that the APRS payload can operate effectively during all sunlight periods and remain partially active during eclipse phases. This ensures mission continuity and reliable digipeater availability throughout each orbit.

The power generation and consumption for a 1U CubeSat were estimated:

- Power generation (sunlight): ~2.5 W average
- Power consumption during RX/TX: 1.8-2.2 W
- Duty cycle support: >50% active digipeater time per orbit with proper battery management.

Table 5 – Power Budget Summary

Component	Value
Power generation (avg)	~2.5 W
Power consumption (TX/RX)	1.8–2.2 W
Idle power consumption	~0.6 W
Operational duty cycle	>50% during sunlight
Battery capacity (1U est.)	10-12 Wh

Figure 5 illustrates how the total daily energy consumption of the CubeSat increases with the number of communication sessions per day. The energy is divided into three components:

Total Energy (black line): the sum of all energy usage per day.

Active Energy (blue dashed line): energy consumed during active transmission, assuming a 10-minute session duration.

Standby Energy (red dashed line): background energy used when the satellite is in idle mode.

This breakdown allows evaluating mission feasibility in terms of power budget management.

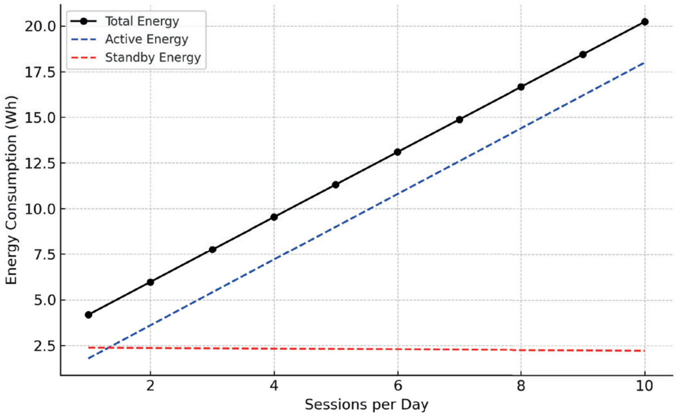

Figure 5. Daily Energy Consumption vs Number of Sessions

Figure 6 shows the theoretical relationship between the signal-to-noise ratio (SNR) and the probability of successfully receiving APRS packets. As expected, the success rate grows rapidly beyond 0 dB, reaching near certainty above 10 dB. This curve helps define minimum operational link budget requirements for reliable uplinks.

These results support the conclusion that the CubeSat can operate reliably in real-world APRS use cases, including support for multiple users per pass and storage of data for scheduled downlink to IGates in hybrid missions.

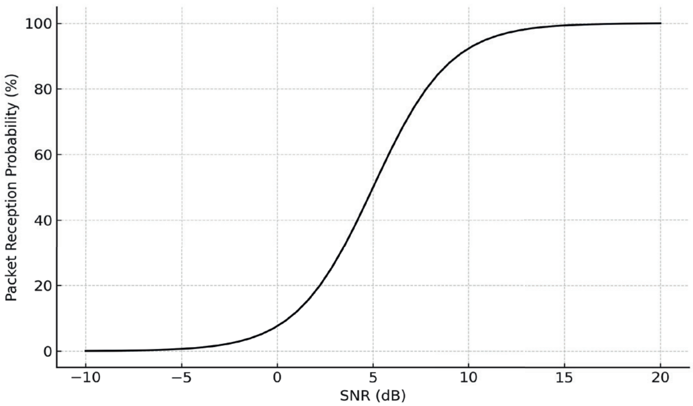

Figure 6. Packet reception probability vs signal-to-noise ratio (SNR)

Discussion. The results obtained from this study demonstrate the practicality of deploying a CubeSat-based APRS digipeater system for wide-area amateur radio communication. The mission design provides meaningful coverage for rural and remote regions and maintains compatibility with existing APRS protocols and equipment.

One of the key takeaways from the analysis is that even a 1U CubeSat, when placed in a 550 km sun-synchronous orbit, can provide reliable access to APRS ground transmitters several times per day. The use of store-and-forward functionality offers increased flexibility, enabling data relay even when no IGate is directly in range during a pass. This functionality makes it feasible to support use cases such as environmental monitoring, agricultural telemetry, and emergency communication in areas with limited terrestrial infrastructure.

The results also highlight important trade-offs, particularly between power availability and communication duty cycle. While the energy budget suffices for basic APRS operation, the system would benefit significantly from energy-efficient components and optimized transmission scheduling.

Furthermore, the selective forwarding of data to designated IGates, as discussed in the system design, enables a semi-private mode of operation, which is crucial for use cases involving sensitive or proprietary data (e.g., land monitoring by private agricultural enterprises).

Conclusion. This paper explored the design and feasibility of deploying an APRS digipeater payload on a CubeSat platform. By integrating low-power communication hardware, a modular onboard computer, and standard VHF APRS protocols, a compact and scalable architecture was proposed.

Through analytical modeling and subsystem-level evaluation, we demonstrated that such a satellite can:

- Support APRS packet reception and retransmission at usable rates,
- Maintain sufficient power levels within a 1U form factor,
- Cover wide geographic areas with multiple daily access windows.

These findings confirm that CubeSat-based APRS relays represent a valuable extension to the terrestrial APRS infrastructure, especially in regions lacking IGate coverage. Future work may focus on flight testing of prototype payloads, security extensions, dual-band operation (VHF/UHF), and long-term constellation planning to enable continuous APRS coverage.

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ISSN2518-1726 (Online),
ISSN 1991-346X (Print)

Директор отдела издания научных журналов НАН РК *А. Ботанқызы*
Редакторы: *Д.С. Аленов, Ж.Ш.Әден*
Верстка на компьютере *Г.Д.Жадыранова*

Подписано в печать 25.09.2025.
Формат 60x881/8. Бумага офсетная.
Печать –ризограф. 20,0 п.л. Заказ 3.

Национальная академия наук РК
050000, Алматы, ул. Кунаева 132