Senior Design Final Report

SMTP Gatewaying Across Delay Tolerant Networks

Version 0.1.0-alpha

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1. Introduction:

1.1. Background:

This study is a collaboration between California State University, Los Angeles and NASA JPL (National Aeronautics and Space Administration's Jet Propulsion Laboratory) to find a solution to interplanetary email. The project was proposed to explore extending existing networking applications to work for astronauts who cannot immediately access Earth's Internet. The first target in this goal was to extend email. With assistance from earlier works, we studied how email works on Earth and the obstacles that prevent the existing email architecture from working in deep space environments. The main tool we utilized is NASA's ION (Interplanetary Overlay Network) software implementation of DTN (delay-tolerant networking). ION implements a variety of protocols to deal with long delays, punctuated connectivity, and data loss which is prevalent in deep space environments. The team developed software that interfaces between existing email software and ION to enable email as it currently exists to work over a delay tolerant network. To test this solution to interplanetary email, the team developed a testbed that simulates discrete Internets on remote worlds that are separated by deep space. The team conducted baseline performance benchmarks on the testbed and drafted plans for rigorously testing if their solution meets the project's requirements.

1.2. Design Principles:

The existing email architecture is tightly coupled to the TCP/IP protocol suite which forms the foundation of the Internet. TCP/IP makes assumptions about the environment which hold on Earth but do not hold in deep space (for example, short round-trip times andstable end-to-end connectivity).

While we cannot solely use protocols from the TCP/IP suite to send emails between celestial bodies, TCP/IP can still function well on a celestial body. If celestial bodies can have their own TCP/IP internetworks, then the challenge is bridging these networks to communicate with each other. The Interplanetary Networking Special Interest Group has found that delay-tolerant networking is the architecture that will provide this bridge [IPNSIG].

An email travels from the sender to its recipient with the Simple Mail Transport Protocol (SMTP) from the TCP/IP suite. To enable SMTP to work over a delay-tolerant network, our solution is to freeze a SMTP transaction one one celestial body, deliver the frozen transaction to the other world with delay-tolerant networking, and then to thaw the transaction at the other celestial body where the transaction can resume to arrive at the recipient's mailbox.

Another major component used in email and the Internet is the Domain Name System (DNS). Networking conditions preclude any hope of syncing DNS information between celestial bodies. Our solution relies on an interplanetary DNS model proposed by Scott Johnson [I-D.johnson-dtn-interplanetary-dns].

1.3. Design Benefits:

Currently, no serious implementation for interplanetary email exists. Extending traditional Internet applications to work in space is a major goal for space agencies and is uncharted waters. Any investigation and implementations on this subject will create fruitful lessons which will help extend more complicated applications than email.

1.4. Achievements:

In this research, we developed a prototype interplanetary email system leveraging DTN to address the inherent challenges of long-delay, disruption-prone space communication. By constructing a rudimentary testbed that simulates communication between Earth and Mars using Raspberry Pi nodes, we validated the feasibility of our proposal under space-like conditions. Our work builds upon foundational concepts proposed by Scott Johnson, extending them into a practical implementation. While the technology remains in its early stages, our results demonstrate a strong foundation for future development. This work represents a meaningful step toward extending email to work in space.

2. Related Technologies:

2.1. Existing Solutions:

The first contributor is Scott Johnson’s draft, "A Method for Delivery of SMTP Messages over Bundle Protocol Networks" [I-D.johnson-dtn-interplanetary-smtp], specifically Section 3.1.1, which talks about planet-to-planet use cases. Johnson’s idea assumes both Earth and Mars have independent Internets where email can work locally. Since IP does not connect the two networks, Bundle Protocol (BP) is used to link both networks. At a gateway, emails originating from Earth destined for Mars are handed to a Bundle Protocol Agent (BPA) for bundling and transmission over a deep space link. Once received at Mars, the gateway parses the bundle payload and submits the message into the world's local SMTP environment, where delivery to the mailbox happens over TCP/IP.

The second contributor is Marc Blanchet with his draft "Encapsulation of Email over DTN using the BP" [I-D.blanchet-dtn-email-over-bp]. It can be thought of as a simple method to be able to transfer email data from Earth to Mars by sending a batch SMTP object. The “application/batch-SMTP” MIME type contains the client side of an SMTP/ESMTP transaction, including RCPT TO, DATA, and MAIL commands. Assuming the gateways aren’t separated by a deep space link, this represents what Earth’s gateway Message Transfer Agent would send to Mars’ gateway mail server. The batch SMTP object would then be extracted by the receiving BPA and queued for delivery. The recipient gateway’s MTA capabilities must be known in advance before the sending gateway begins its process, due to batch SMTP being non-interactive.

Our solution was developed amidst conversations between Scott and Marc, where Scott adopted Marc's batch SMTP idea into his draft. Our project is an implementation based on Scott's draft since we found Marc's design to rely on a DNS model that didn't seem scalable in the long run.

2.2. Reused Products:

Name	**Description**	**Goal**
ION (v4.1.3s)	Software implementation of DTN by NASA JPL that enables store-and-forward communication using BP	Transfers our data in bundles with authenticity guarantees
BIND9 (v9.18.8)	A DNS server is used to translate domain names into IP addresses	DNS servers with IPN RRTYPE support
Exim (v4.96)	Configurable MTA used to route, send, and receive emails via SMTP	Generates and processes batch SMTP
Thunderbird	An open-source email client used to send/receive emails using standard protocols	Compose and read emails

Raspberry Pi 5	Small, affordable single-board computer commonly used for prototyping and testing	The hosts that make up our network
Ubuntu (v24.04 LTS)	User-friendly operating system known for its stability and security in development and server setups	Most software we use is for Unix-like OSes
docker-mailserver (v14)	Full-stack mail server including Postfix and Dovecot	Simulates mail servers on the Internet that are unaware of DTN

3. System architecture:

3.1. Overview:

3.1.1: Hardware:

In order for us to emulate an end-to-end connection up in space, we decided upon a setup that involves five Raspberry Pi 5s and two network switches. Each switch symbolizes a planet's network and will connect to three Pi's each. Two Pis will be used to replicate a client node and a gateway node. One Pi will connect to both switches and act as a DTN relay node so that users can send emails from one planet to another.
All PIs will be connected to a USB-C power supply. The four non-relay nodes Pi's will have one Ethernet cable connected to their respective switch. The relay node Pi will utilize two USB-to-Ethernet adapters so that it can be connected to both switches. In order for us to access the GUI of these Pis, we have two options. We can use a setup where we connect the Pi to a keyboard and mouse, and a monitor using a micro-HDMI. We can also simply SSH into a Pi using Windows' remote desktop feature.

3.1.2: Software:

3.2. Data Flow:

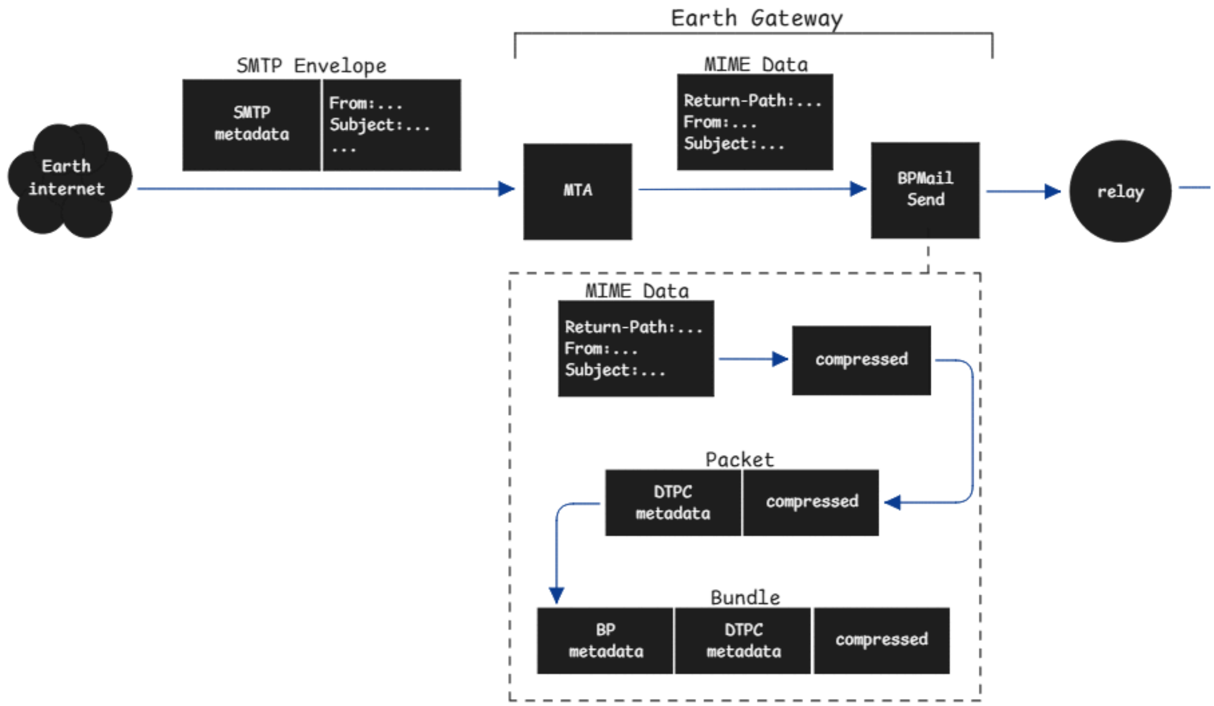

Figure 3.2.1. The process of sending a message from the sender to the relay node.

At the sending side of the email sending processes, the mail client somewhere within the Earth's internet will send an SMTP envelope to the MTA located on the gateway. The MTA then turns this SMTP envelope into MIME data. Using BPMail Send, the MIME data will first be compressed. Then, DTPC and BP metadata headers will be added to the compressed data into one bundle. This bundle then gets sent from the Earth gateway to the relay node.

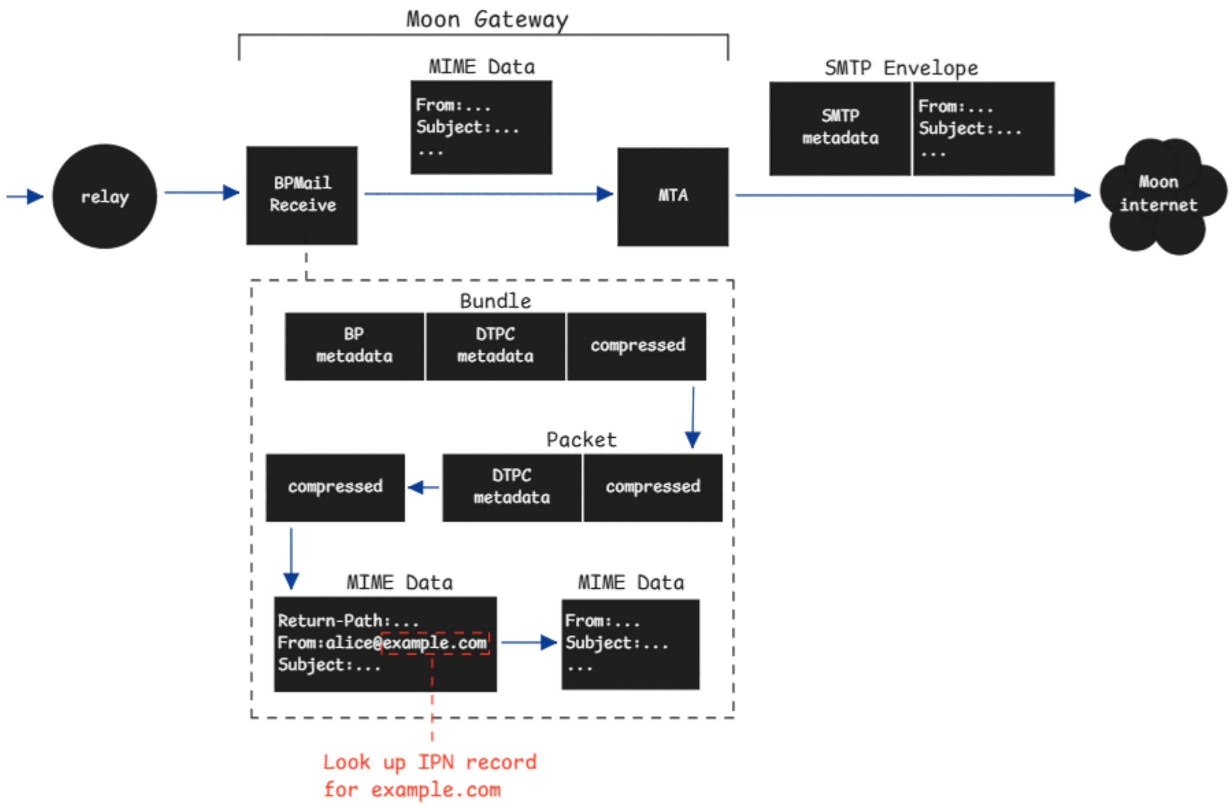

Figure 3.2.2. The process of the message going from the relay node to the recipient.

Once the relay node sends the bundle to the other celestial body's gateway, the gateway will receive the bundle using BPMail Receive. BPMail Receive will essentially reverse the process done earlier with BPMail Send. The bundle will have its BP and DTPC metadata headers removed, and then the compressed data will be turned back into MIME data. Inside this MIME data, there will be a "from:" form which will include the address that we can verify using an IPN record lookup. Once this MIME data is sent to the gateway's MTA, the MTA will then revert it back to an SMTP envelope and send it to the respective mail server.

3.3. Implementation:

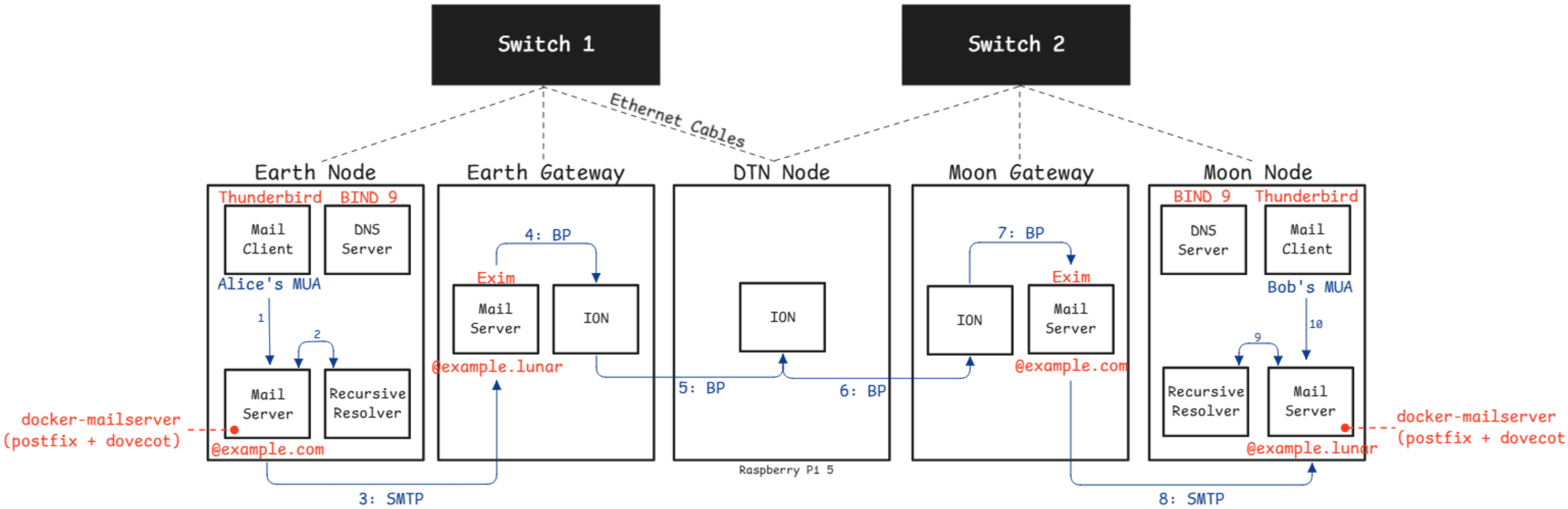

Figure 3.3. This diagram showcases the flow of sending a message from the Earth Node to the Moon Node. We see which Raspberry Pi 5s are connected to which switch and the specific software we used for different components (i.e. Thunderbird for the Mail Clients).

4. Conclusions:

4.1. Results:

Successfully built a working prototype of an interplanetary email system leveraging Delay Tolerant Networking (DTN) protocols, specifically the Bundle Protocol (BP), to enable asynchronous communication between Earth-based nodes and nodes simulating a remote celestial body (e.g., Moon or Mars).

To validate the system, a rudimentary testbed was constructed that emulated interplanetary conditions. This involved setting up two isolated networking environments (simulating Earth and the celestial body).

The prototype proved that reliable email delivery is feasible. It laid a foundation for further enhancements such as authentication, routing optimization, and integration with real spacecraft systems.

4.2. Future:

Test Case	Goal	Expected Outcome
Email Timing Test	Measure 5-hop delivery time (En → Egw → Gs → Mgw → Mn) with delay and disruption	Emails arrive successfully, even with delay and loss
Bandwidth Stress Test	Analyze system behavior under low-bandwidth caps (e.g., 64kbps)	Longer delivery times, but no lost emails
Outage Recovery Test	Verify bundle forwarding after a node temporarily disconnects	Email is delivered after the node recovers without needing the user to resend
File Integrity Test	Confirm file attachments survive DTN transmission	Files open normally without errors

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