MEMORANDUM

Date: \_\_\_<due signed, before first thesis slot>\_\_\_

From:  Cervando Banuelos

Section(s): 368

To:  Program Officer, Computer Science

Via:  (1) Thesis Advisor, Marcus Stefanou

(2) Co-Advisor or 2nd Reader:

(3) SFS Program P.I.

(4) Academic Associate, CS Department

(5) Chair, CS Department

Subj: THESIS PROPOAL

Encl: (1) Computer Science Thesis Proposal

(2) Institutional Review Board (IRB) Student Research Checklist

1. Tentative Title of Proposed Thesis: Development and Implementation of Information Assurance Protocol for Low Bandwidth Nanosatellite Communications

2. General Area of Proposed Thesis Research: IP based communicaitons information assurance

3. Enclosure (1) is the Thesis Proposal with a milestone plan of dates and events for research and thesis completion.

4. I expect that my thesis will be considered[[1]](#footnote-1) UNCLASSIFIED.

5. I reviewed the IRB webpage concerning the use of humans in research. This research does NOT involve human subject research.

6. I anticipate NO travel or other extraordinary requirements.

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Student Signature Second Student Signature <if joint thesis>

1. Forwarded, recommending approval: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_

Thesis Advisor Date

2. Forwarded, recommending approval: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_

Co-Advisor or 2nd Reader (circle) Date

3. Forwarded, recommending approval: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_

Cynthia Irvine, SFS P.I. Date

4. Forwarded, recommending approval: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_

Academic Associate, CS Dept Date

5. Forwarded, recommending approval: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_

Chair, CS Department Date

6. Approved, and retained:  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_

Program Officer, CS Department Date

COMPUTER SCIENCE THESIS PROPOSAL

A. General Information

1. Name: Cervando A. Banuelos II

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3. Curriculum: Computer Science (368)

4. Thesis Advisor: Dr. Marcu Stefanou

5. Co-Advisor or 2nd Reader: Jim Horning (co-advisor)

6. Academic Associate, CS Department: Dr Alan Shaffer

7. Chair, CS Department: Dr. Peter J. Denning

8. Date of Graduation: September 2017

B. Area of Research

This thesis investigates the development of a low-bandwidth reliable network protocol that supports a high-assurance cryptographic system for encrypted communications between ground stations and nanosatellites, specifically CubeSats. This protocol uses commercial off-the-shelf (COTS) components in continuation of the precedent set by CubeSat developers, is easy to manufacture, allows for a high degree of assurance in the information being relayed from the satellite, and includes functionality that facilitates the retransmission of lost packets while reducing the data overhead typically associated with the transport control layer (TCP) protocol to maximize the bandwidth usage. Nanosatellites are currently constrained by their low power communication devices, and the limited bandwidth these provide. This thesis investigates software based methods to reduce the power and bandwidth consumption in these devices.

Due to the popularity and increasing use of CubeSats, several protocols to ensure the communication between the CubeSat and the ground station exist. While some of these protocols account for limited operational bandwidth, there is no clear protocol that integrates encryption with bandwidth efficiency. One such protocol is the AX.25 Amateur Packet-Radio Link-Layer Protocol which provides a mechanism for the reliable transport of data between two signaling terminals. The CubeSat Space Protocol (CSP) is in place to facilitate network and transport layer delivery of internet protocol packets from CubeSats to the corresponding base station. The CSP is analogous to the TCP/IP model, and contains a lightweight 32-bit header with the appropriate information for relaying. The CSP also includes using a block cipher for encrypted packets with eXtended Tiny Encryption Algorithm (XTEA) block cypher in counter mode. While these are two examples of nanosatellite communication schemes, there is no clear standard for communication with these devices that is bandwidth efficient and secure.

UHF (ultra-high frequency) and VHF (very-high frequency) bands employed by these satellites, use TCP/IP connections to transmit their data. While TCP is a connection-driven protocol that ensures all of the data arrives, it also comes at a cost of bandwidth. Every packet sent by the server to the client has to be acknowledged by the client. Otherwise the server assumes the packet is lost and will automatically retransmit the packet if there is a timeout. A key observation is that TCP packets require a steady and reliable connection that is not often available in UHF and VHF signals being sent by these nanosatellites. Furthermore, due to the noise and error rates in the space-to-ground nanosatellite packets, TCP requires a large number of retransmissions from the server on the satellite to the client on the ground. This can be either from delayed or lost acknowledge signal packets or from lost or delayed payload packets being sent from the server. These retransmits further saturate the bandwidth and thus decrease the amount of data received by the ground station.

This research compares processing power requirements and security attributes of a one-time pad, and the vulnerabilities in the block cipher XTEA. A one-time pad is an encryption technique that cannot be cracked, and relies on a symmetric randomly generated pre-shared key. The thesis also researches the development of a standard protocol that combines the reliability of TCP, but reduces the data overhead from large numbers of acknowledge signals and large TCP headers. This protocol will combine the low data overhead of the user datagram protocol (UDP) with the reliability of TCP. For this research the protocol developed is classified as a reliable UDP (RUDP) and seeks to provide a network layer solution for nanosatellite communications. The thesis research also supports the development of a lightweight easily accessible and distributable encryption scheme that allows nanosatellites to use much stronger encryption schemes, potentially allowing them to be deployed as space assets and be used to relay the data they collect in a secure manner. This encryption scheme may be used independently of the RUDP protocol, but the RUDP protocol has the encryption scheme as a central tenet of its standard.

C. Research Questions

The thesis examines the feasibility of a low-cost (processing-wise) high assurance encryption scheme that can be deployed in short-lived nanosatellites with low bandwidth operating at the UHF, VHF, and S-Band frequencies by using COTS components and one-time pads. The notional lifetime of these satellites is typically around 2 years, while the average measured lifetime is approximately 200 days. The resulting encryption protocol will provide high confidentiality of the cybersecurity triad (confidentiality, integrity, availability) in communication channels with these satellites. Additionally, the thesis develops a standard for reliable communications with nanosatellites that reduces the data overhead and has an encryption algorithm built into the protocol. These research goals will seek to characterize the current baseline of CubeSat communication protocols from a reliability and bandwidth efficiency perspective and identify the potential areas for improvement:

* What are the processing, data overhead, and encryption costs of current communication protocols?
* What are the processing and storage costs associated with using a one-time pad for encryption in nanosatellite communications?
* Are the costs more or less than current XTEA standards?
* Does the new network standard that combines the reliability of TCP, the low data overhead of UDP, and integrates security from a one-time pad reduce the amount of data overhead and increase payload transfer?

D. Discussion

Cybersecurity of nanosatellites is important as these devices are becoming a cheap platform to host space-based research and development. Currently CubeSats communication is achieved largely through the use of UHF, VHF, and other radio frequencies, and there is no clear or decisive authority on communication standards of CubeSats or nanosatellites. As these nanosatellites become more prominent and less expensive, the confidentiality of the data transmitted needs to be taken into consideration. To this end, satellite encryption may be accomplished using the most secure cipher, a one-time pad. One-time pad ciphers are the strongest ciphers since they are based on randomly generated symbols for each of the characters that the packet wishes to relay and can only be decoded by the other individual that has the same one-time pad. The drawback to the mass deployment of one-time pads in day-to-day operations is that both receiver and transmitter need to physically exchange the one time pad before it can be used. This drawback has led to other verification mechanisms like public key infrastructure, Diffe-Hellman key exchange methods, and other bandwidth-heavy mechanism.

Since nanosatellites are developed and deployed using COTS parts and assembled by the agency that seeks to capture the data, the challenge of both parties being present to exchange one-time pads is null, and therefore it can be used as a secure and light weight method to communicate over open channels. Such a cryptologic strength could be used to garner more support for the deployment of nanosatellites and the relay of sensitive information through them. Furthermore, the limited life-span of these satellites ensures that once the satellite’s operational life expires and reenters the atmosphere, the one-time pad will be destroyed and the communications will be indecipherable to an adversarial party.

Limited and noisy bandwidths also cause large packet loss that requires constant retransmission of packets. These packets each come with a large header, 20+ bytes, and can aggregate to a large data overhead. The current approach to send data from a satellite to a ground station uses TCP over a connectionless internet protocol (IP) header, similar to those used by internet connections on the ground. While these protocols work with larger satellites, due to the low bandwidth and poor connection with the nanosatellites, TCP accrues a larger data overhead from retransmits and acknowledgement messages that saturate the channel on which it is communicating. Furthermore, the TCP header has a minimum data overhead of 20 bytes, with a maximum header of 60 bytes. In order to mitigate errors from noise, these satellites focus on small payloads per packet, increasing the number of packets being sent over the connection. This exacerbates the problem since the data overhead is multiplied by every packet sent. By developing a standard that uses a lighter data overhead, reduces the number of ACK messages that need to be sent, but still allows for the reliability of retransmission of dropped packets, nanosatellites could send more data with the same limited bandwidth.

E. Scope of the Thesis

This thesis focuses on the amount of processing and size of packets generated with the encryption mechanism, seeking to reduce or maintain the size of the data being transmitted by these satellites while significantly increasing their security at the application data and packet payload layer at a minimal cost to processing power. In addition, the thesis focuses on researching and developing a new software driven standard for nanosatellite communication that allows for packet retransmission at a lower bandwidth cost, and will natively incorporate the one-time pad encryption mechanism to provide a standard for secure low-bandwidth communications in nanosatellites.

Research is also limited to nanosatellites whose communication bands are UHF, VHF, and S-Band. These are the bands in which bandwidth is most limited, and could benefit the most from lower bandwidth and power consumption.

F. Methodology

1. Review literature on current communication protocols and methods for nanosatellites.
2. Encryption:
   1. Build encryption/decryption software platform prototype using python and TCP/IRC channel and netcat as a prototype and compare it to plain text generation.
   2. Test robustness of the mechanism by adding noise to the signal and randomly inserting errors (deletion, replacement, insertion) and by verifying the strength of the encryption mechanism.
   3. Testing encryption scheme using randomly generated data
   4. Project the time needed to encrypt data and send data at various bandwidths and processing capabilities.
3. RUDP:
   1. Development of RUDP to reduce the data overhead
   2. Test RUDP in combination with randomly generated data for one-time pad
   3. Simulate packet loss to trigger RUDP reliability mechanisms
   4. Conduct small scale experiments using FM radio and minimodem using Raspberry Pi 3 model B.
4. Conduct usability study of encryption mechanism by analyzing the collected data sets.
   1. Comparison of processing time for developed encryption mechanism and XTEA
   2. Comparison of data storage costs to current standards
   3. Comparison of data overhead between RUDP and TCP
   4. Error recovery and retransmission
5. Make analysis and recommendation of the encryption mechanism and encapsulating protocol.

Metrics:

The success of this thesis will be largely determined by, the comparison of data sizes of the ciphertext and the plaintext, the strength of the encryption mechanism and the processing requirements needed to crack the keyspace, the processing power required to encrypt the plaintext, and the reduction of data overhead in total data transferred. Research does not focus on improving the data transfer rate (bits per second) in the given bandwidth nor reducing the error rates in data transfer,

G. Chapter Outline

Tentative Chapter Outline:

I Introduction

A. Research Domain

B. Research Problem and Motivation

C. Research Questions

D. Scope

E. Approach

F. Thesis Structure

II Background

1. Problem Space: Low bandwidth in UHF/VHF/S radio frequencies
   1. Interference
   2. Packet Loss
2. Current communication standards with nanosatellites
   1. Data Overhead
   2. Connection problems
3. The need for cybersecurity in nanosatellites
   1. Data usage in nanosatellites
   2. Current nanosatellite communication protocol information security standards
   3. Information security vulnerability assessment in nanosatellite communications
4. Encryption and One-Time Pads  
   1. Evaluating the Strengths of One-Time Pads
   2. Limitations of One-Time Pads
   3. Data Usage of Nanosatellite and Size of Pad
5. Chapter Summary

III Encryption Algorithm

1. Goals of Encryption Algorithm
2. Development of Encryption Algorithm  
   1. Platform development and description
   2. Performance over IP protocols
3. Measuring Performance  
   1. Data sizes of plaintext and ciphertext
   2. Processing time
4. Measuring Robustness to Error
   1. Insertion of Data Errors
   2. Deletion of Data Errors
   3. Replacement of Data Errors
5. Mechanisms Developed to Overcome Error Propagation  
   1. Insertion of Data Errors
   2. Deletion of Data Errors
   3. Replacement of Data Errors
   4. Data Loss Tolerances
6. Chapter Summary

IV RUDP Development and Structure

1. Packet Structure
2. Reliability Mechanisms
3. Reducing Data Overhead
4. Benefits and Drawbacks to Other Protocols
   1. UDP
   2. TCP
   3. CSP
5. Chapter Summary

V FM Band Testing Results and Analysis

1. System Architecture
2. Testing
   1. Testing Environment
   2. Testing Results
   3. Extrapolation to Larger Communication Schemes
3. Chapter Summary

VI Results and Analysis

1. System Performance and Evaluation
   1. Size of data being transmitted in comparison to existing plaintext protocols
   2. Usage of bandwidth
   3. Error robustness
2. System Costs
   1. Financial
   2. Processing Power Costs
      1. Processing Speed of AES, 3DES, and One-Time Pad on Raspberry Pi 3 Model B and Raspberry Pi Zero
      2. Analysis and comparison
3. Vulnerabilities
   1. Strength of encryption mechanism
   2. Impact on availability and integrity
4. Chapter Summary

VII Conclusions and Recommendations

A. Main Conclusions and Recommendations

B. Main Contributions

C. Future Work

Appendices

Bibliography

1. Schedule

|  |  |
| --- | --- |
| **Thesis Stage (Corresponding Methodology Stage)** | **Completion Target Date** |
| Literature review (1) | Mid April 2017 |
| Development of prototype encryption algorithm and robustness to error measurments completed (2.a-b) | Mid April 2017 |
| Protoype is updated to account for error, RUDP development completed (2.c-d, 3.a-c) | May 2017 |
| FM Band Testing Complete (3.d) | Mid May 2017 |
| Data analysis completed (4.a-d) | June 2017 |
| Draft thesis to advisor(s): (5) | July 2017 |
| Final thesis submission for signatures: | August 2017 |

1. Benefits of Study

The benefits of nanosatellites and picosatellites are still being discovered in research and development, education, and military applications. Unfortunately, due to their power constraints their communication capabilities are limited and amateur radio frequencies are largely used to send and receive both control and experiment data. The disadvantage of these frequencies is the large availability of potential listeners with access to equipment capable of listening to the broadcasts, sending malicious logic and data to the satellites, and the limited bandwidth and processing power of these satellites that are being built with commercial, lightweight, off the shelf components.

Using microcomputers like Raspberry Pi and Arduino, these satellites have limited processing capabilities, are designed to be low cost, and have varying mission life expectancies. To this end, a low processing power, low-bandwidth, high assurance encryption mechanism is needed.

Nanosatellites are still in their infancy, and are gaining popularity. They provide a cost effective alternative for space research, and could be deployed as potential assets even with short mission high altitude balloons. Currently the security of their communications has not been standardized and this could lead to potential theft of data, sabotage of satellites, or hijacking of the satellites for malicious purposes. By developing a high assurance standard that has the strongest and simplest encryption scheme, the operators of these satellites can be sure that the data is secure without having to worry about processing power.

Currently there is no clear standard for reliable, encrypted communication with nanosatellites. By researching the feasibility of developing a protocol with the desired characteristics that also reduces the current data overhead, researchers will be able to obtain larger amounts of data from nanosatellites using the strongest encryption possible.

Ultimately an encryption scheme like the one developed could also have multiple uses and deployments where low bandwidth and low power communications are desired. Uses could extend to covert operations messaging, or the development of picosatellites that are even smaller and yet have a high information security standard.

Preliminary Bibliography

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1. If classified, I have read Chapter V of NAVPGSCOLINST 5510.2, and the NPS Research Admin web page (http://intranet/ResAdmin/research1.html) concerning Classified Thesis. [↑](#footnote-ref-1)