Using Cognitive Communications to Increase the Operational Value of Collaborative Networks of Satellites

Ryan B. Linnabary
Dept. Electrical and Comp. Eng.
The Ohio State University
Columbus, OH, USA
linnabary.24@osu.edu

Andrew J. O'Brien
Dept. Electrical and Comp. Eng.
The Ohio State University
Columbus, OH, USA
obrien.200@osu.edu

Graeme E. Smith
Dept. Electrical and Comp. Eng.
The Ohio State University
Columbus, OH, USA
obrien.200@osu.edu

Christopher Ball
Dept. Electrical and Comp. Eng.
The Ohio State University
Columbus, OH, USA
ball.51@osu.edu

Joel T. Johnson
Dept. Electrical and Comp. Eng.
The Ohio State University
Columbus, OH, USA
johnson.1734@osu.edu

Abstract—

- **Distributed satellite missions of small satellites are the future**
- **Simple networks are simple. But real advantage come from adaptive and collaborative satellites operating autonomously**
- **Dramatically increased complexity of the control and decision making. How to utilize this flexibility to increase the operational value from the network**
- **Machine learning could be utilized in the high-level decision making of a communication system for DSM**
- **Such a system represents a cognitive communication system, but operating at high-level of comm system, i.e. the collaborative distribution of information**
- **This paper will show cognitive comm model with ML and example case study results**

Keywords— Autonomy, Sensor Network, Software, Remote Sensing, OSSE

I. Introduction

It is envisioned that NASA's future space systems will be composed of large, inhomogeneous networks of small satellites and autonomous platforms. These resource constrained systems, carrying an array of different instruments, will be expected to operate autonomously and collaboratively to achieve mission and science goals. Unfortunately, current and near-future inter-satellite communications are highly constrained in terms of link availability, reliability, power and bandwidth. Although future technologies (such as free space optical links) may alleviate some constraints, it is expected that future instruments will rapidly expand in both data volume and sensor reconfigurability. In this way, it is not sufficient to simply increase the capabilities of the communication links. Rather, it is also necessary to improve the complex decision making that communication systems perform, such as deciding when to transmit, what information is valuable to nodes of the network, and how to adapt local operations following the reception of new information.

Recently, cognitive space communication algorithms have been proposed as a solution to address the complexity of future inter-satellite communication systems. Typically, these cognitive algorithms have tried to address communications at a low level and include decision making regarding modulation, power and bandwidth, and error rate. However, it is reasonable to expect that cognition may also offer an improvement in the complex, higher level decisions of communication in the context of mission and science objectives. At this level, cognition is applied to the operation of the network with the decision making primarily influenced by the constraints of the space communication network links.

In this work, we show results of simulation studies to explore the advantages that cognition could offer for collaborative small-satellite networks. Under a NASA Advanced Information System Technology program, we are currently developing an open-source C++ library for the simulation of autonomous and collaborative networks of adaptive sensors. This library and accompanying utilities allow for the efficient simulation of networks of satellites with realistic constraints in communication, power, and measurements. A key focus of this software is the simulation of sensors that operate adaptively. Adaptive sensors must make intelligent decisions regarding their configuration based on their own measurements as well as the measurements provided by other sensors in a network. However, the extreme complexity of the decision space makes

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the development of optimal decision-making systems very difficult. Thus, an approach based on cognition could offer an appealing solution. We investigate how our simulation tools could be useful for production of large training datasets that capture the operation of collaborative, adaptive networks of small satellites. We then investigate how such a dataset could be combined with machine learning techniques to train neural networks that could make intelligent decisions about when and what to communicate. Results from our investigation will be presented, and the applicability of these methods to future cognitive space communication will be discussed.

II. Overview of Collaborative Networks of Adaptive Sensors

Standard stuff from the AIST proposal and IGARSS papers

III. Cognition and High-Level Communications

A. Cognitive Communications

- What is cognition
- What is cognitive communications
- Example references of how it has been applied
- What it means for low-level and high-level communications
- Cognitive communications for high-level communications
- What are high-level aspects of comm: when and where to move information given large scale constraints on the network. What are tuning parameters at this high level?
- Table of low level and high level comm issues
- Summary of different methods for dealing with this problem. Can ML help?

TABLE I. Communication Model Paramters

Table Head	Table Column Head		
	Table column subhead	***Subhead***	***Subhead***
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B. Application of Machine Learning for Communicaitons

- What is ML?
- How can ML be utilized in this problem: high level comm decision making and tuning
- Highlight types of ML solutions/tools that are applicable to this specific problem
- Identify particular tool that will be used to solve problems in the paper (i.e. classification problem solving using k-means blah blah)

- Insert figure showing flow chart of problem formation and solution using the ML approach
- Generation of training data, training of the NN, application of the NN to the system. What are input and outputs. What are the steps? List of steps in proposed procedure if needed

Fig. 1. Proposed cognitive communcaitons flow chart.

IV. Generation of Training Data of Collaborative Satellite Constellations

- To train the neural network, it is necessary to generate large training datasets.
- Contents of training data should include ....

- Collaborate Software Overview. What it is collaborate
- What it simulates. What features it supports
- Key is that it can output large sets of collaborative and adatpive simulation results.

- Using Collborate to generate traning data
- Collaborate simulates complex algorithms that take a long time to execute to make good decisions
- Concept will be to replace these algorithms with an efficient NN.

- What was specifically generated for the case studies ...

V. EXAMPLE CASE STUDIES

Description of examples and why they were chosen.

A. Example 1

First, ...

B. *Example 2*

First, ...

VI. Summary and Next Steps

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