Deep Learning Cognitive Cooperative Data Scheduling Protocol for Small Spacecraft Swarms

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Introduction

Swarms of small-spacecrafts in LEO orbits, which have many benefits from low cost, to shorter development time and more. But may have low data rates and limited link duration in comparison to larger GEO space-crafts.

We propose a method that involves using recurrent Neural Networks (RNN) along with co-operative scheduling in order to deliver data back at a faster rate to reduce delay.

SMALL-SPACECRAFT NETWORK MODEL AND THE PROBLEM FORMULATION

Our considered Satellite and Station model

- A cluster of K LEO small-spacecrafts orbiting the earth
- Each spacecraft is capable of communicating with L Ground Stations along with M geo-stationary (GEO) satellites.
- The LEO spacecraft swarm is able to coordinate and cooperate among themselves over cross-link communications.
- We assume that the LEO spacecrafts have dedicated hardware and antennas capable of handling these three forms of communication.

SMALL-SPACECRAFT NETWORK MODEL AND THE PROBLEM FORMULATION

The Satellite cluster functions

- Assume the satellite cluster is on an Earth monitoring mission.
  - Each satellite generates an arbitrary amount of data each orbit location.
    - This data will be dependent on the type of sensors and the particular mission.
  - There are limits to how much data can be sent from a satellite.
    - R_{L2E}, R_{L2G}, R_{L2L} will represent the link capacities from LEO to Earth, LEO to GEO station and LEO to LEO, respectively, in terms of packets per epoch.

The data we are considering.

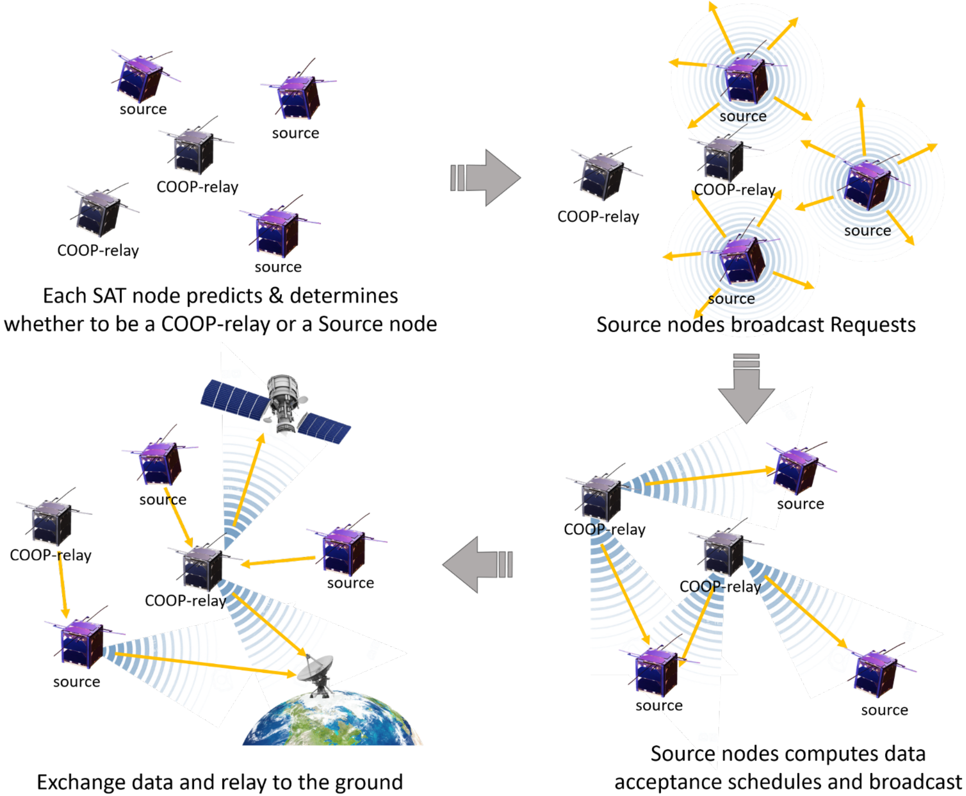
- In this paper we consider the observed data to be the earth's land-to-water percentage.
- Note this decision was for the purpose of evaluation, the protocol does not depend upon the type of data. It will learn from the data that has been received.

THE COGNITIVE COOPERATIVE DATA SCHEDULING PROTOCOL

Our scheduling methodology, implemented on a periodic basis, but can be modified to be aperiodic and event-driven.

1. Each node predicts and determines it's total expected buffer size.
   a. Each node accomplishes this through determining it's access capacity through links to the Earth, either through the Ground Stations or GEO Stations. Each node will also predict how much packets will be generated and compute the total buffer size to be delivered during the scheduled period
2. With this information each node shall determine whether it will be a COOP relay node or a source node.
3. This information is broadcasted to the other nodes.
4. Priority will be given to specific nodes depending on the criteria used. Delay based prioritizes nodes with data older than a specified limit, and Fairness based prioritizes nodes that have larger buffer sizes (more data).

Cooperative Cognitive Scheduling (CCDS) Protocol

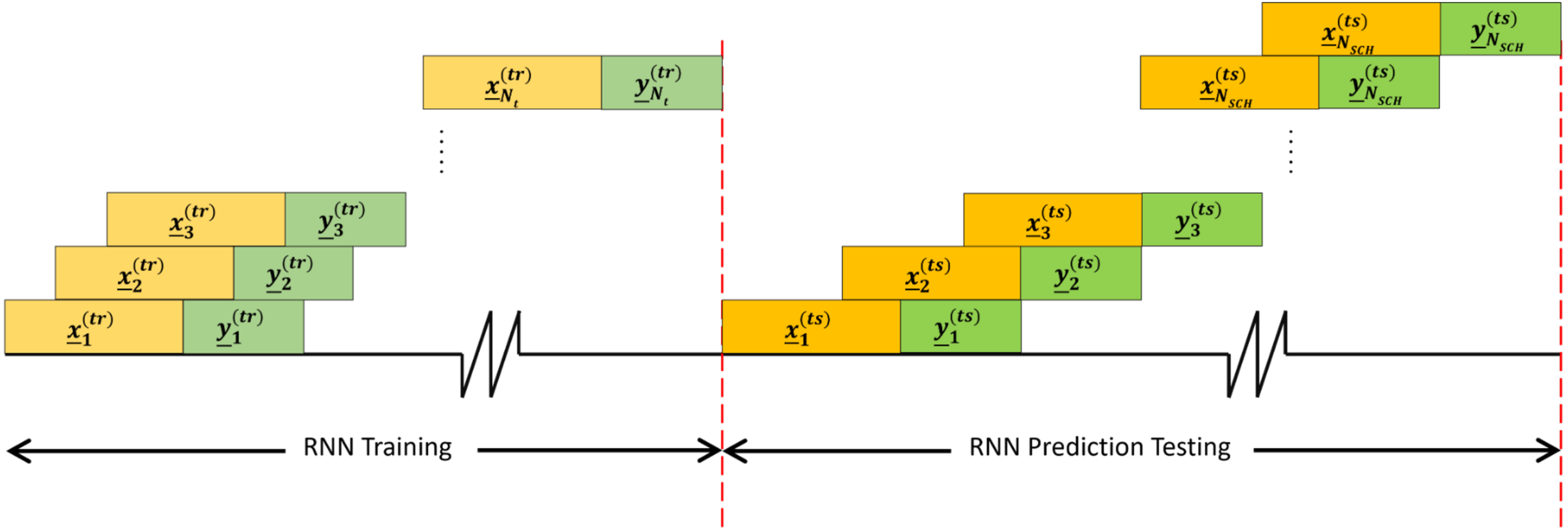


Recurrent Neural Network (RNN) Data Prediction

At scheduling times, each node predicts its expected amount of data during the scheduled period using an RNN:

- At the beginning of each scheduling period Each satellite's RNN uses an input made of normalized location data along with N past observation values. It will then predict the observed values and use those to determine the amount of data generated for that node.
- After the training phase the RNN only predicts data at the start of the each scheduling period.

RNN Methodology Figure



Legend :

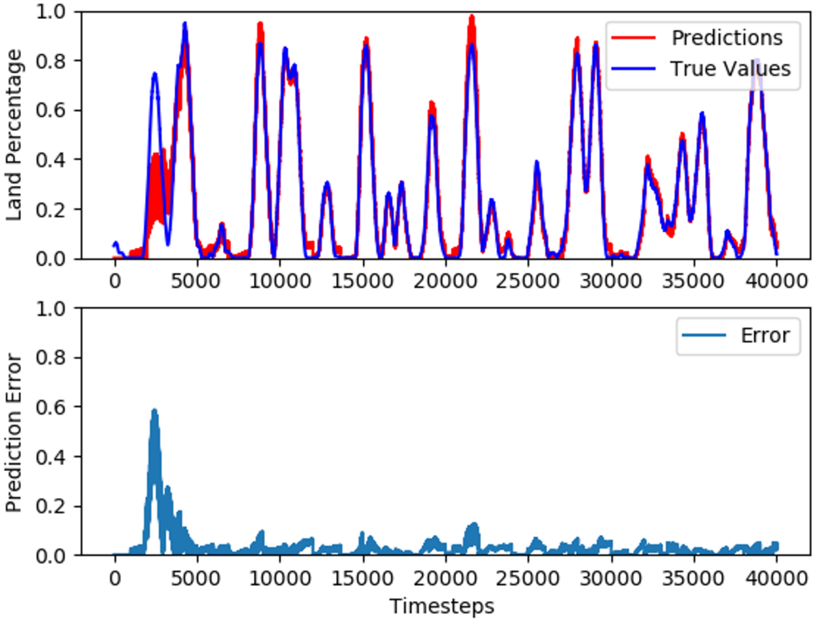
$(\underline{x}_n^{(tr)}, \underline{y}_n^{(tr)}) \triangleq$ n'th training input and corresponding target output

N_t $\triangleq$ Number of training inputs

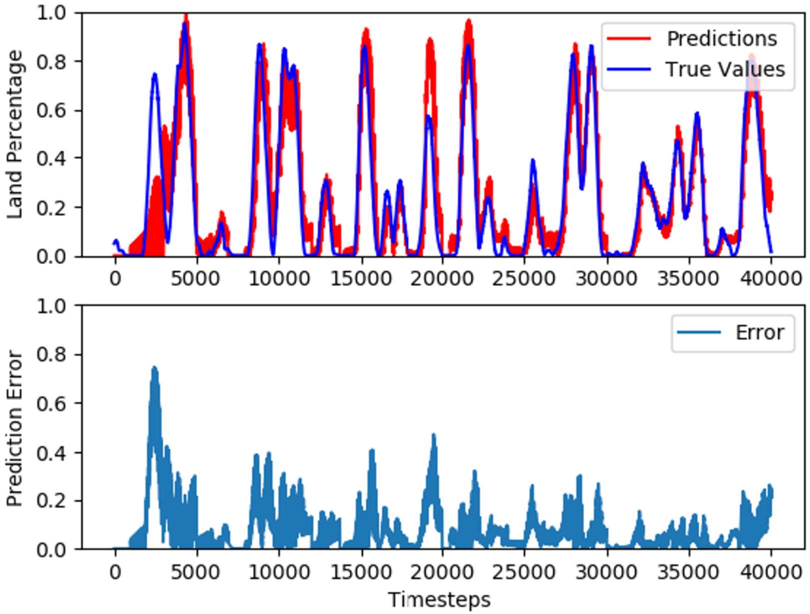
$(\underline{x}_m^{(ts)}, \underline{y}_m^{(ts)}) \triangleq$ m'th test input and the corresponding output

N_{SCH} $\triangleq$ Number of test inputs

RNN Results



Scheduling length of 10 time steps



Scheduling length of 100 time steps

SOFTWARE IMPLEMENTATION

For our results we considered a small-satellite network consisting of 5 LEO satellites, 2 Ground Stations, 2 GEO satellites. The Ground Stations are located at Diego Garcias Island and the White sands Complex in New Mexico.

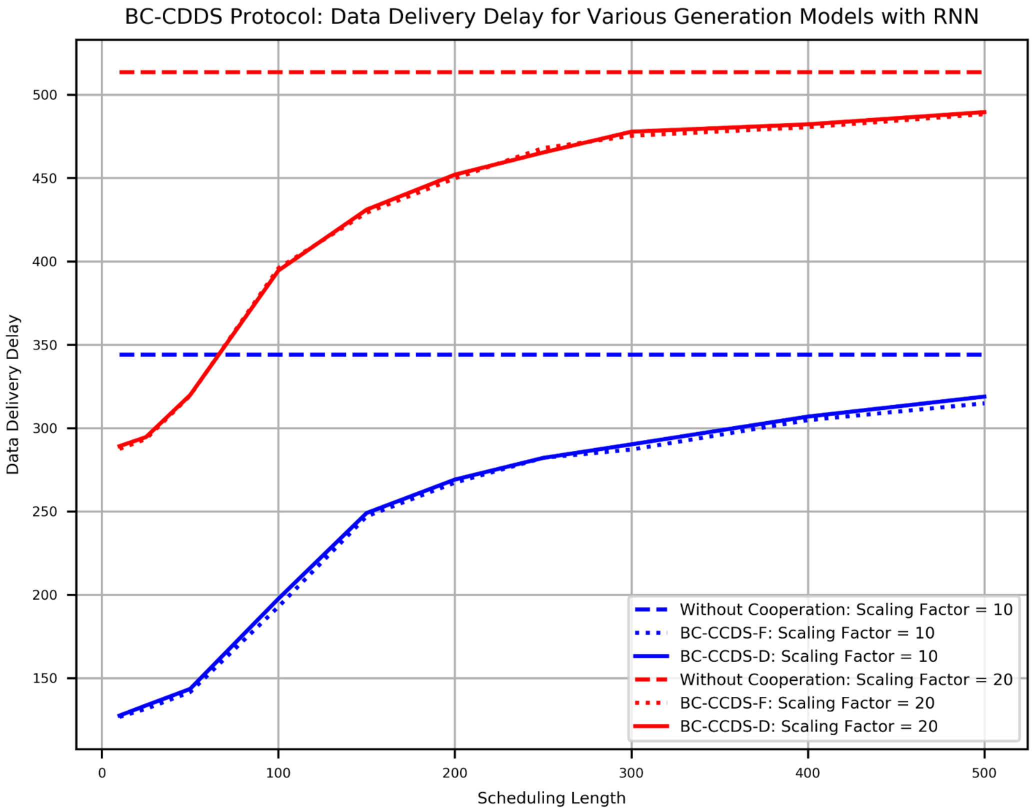
We used NASA's General Mission Analysis Tool (GMAT) to generate the orbiting patterns of the satellite cluster along with information on when and where each satellite will have links to each other as well as to the Ground or GEO station.

We use a data communication rate of R_{L2E}, R_{L2G}, R_{L2L} = 10 packets-per-channel use (these can be scaled for practical values).

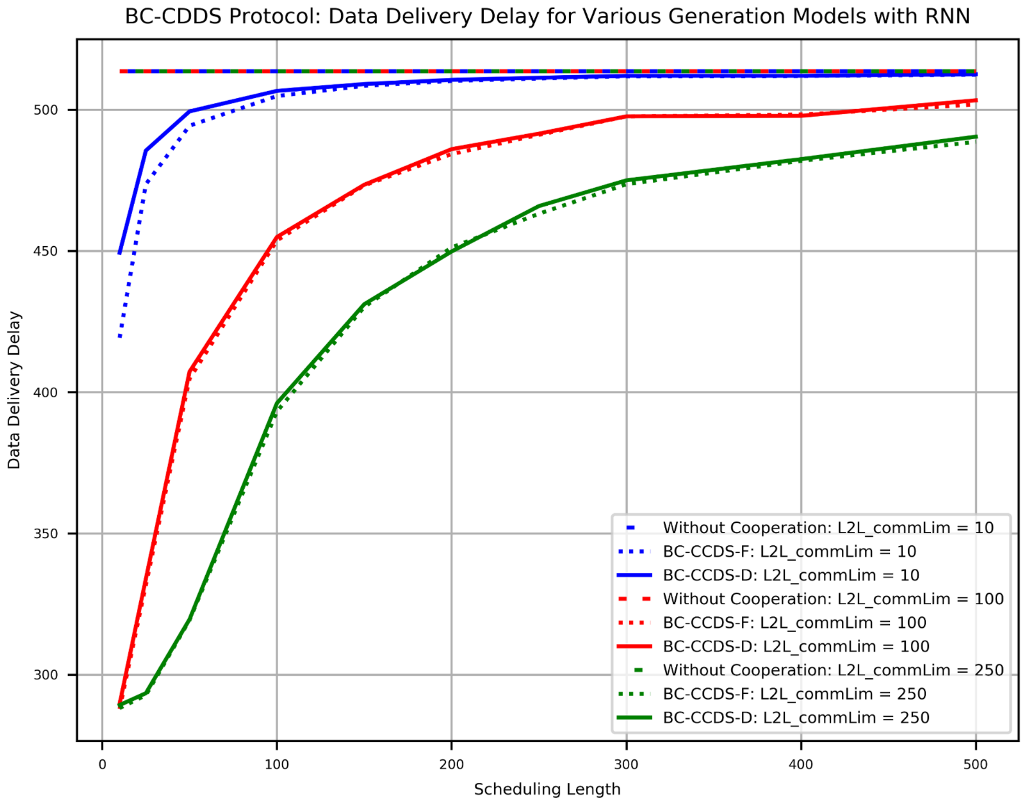
There are two different scaling factors for multiplying the land-to-water calculations used in the RNN.

We consider a similar cluster that does not use the CCDS scheduling protocol for comparison.

Software Results



Software Results (cont.)



Conclusion

A cognitive cooperative data scheduling protocol for small satellite networks is proposed and with this protocol in place we can see significantly improved delay performance in comparison to a similar cluster of satellites that don’t take advantage of cooperative scheduling.

The protocol uses RNN to predict the expected data payload and this RNN can work in periodic or event-driven situations.

The protocol has successfully been implemented in software to show the effectiveness of using it.

Any Questions/Comments?