Towards an efficient ground-based monitoring of the arctic tundra through a distributed system, the DAO-CPS approach

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The arctic tundra, a fragile eco-system

The arctic tundra

- A good indicator for climate change
- Very sensitive to climate change
- Hard to reach and monitor

Observations are essential

- Less than 1% is observed
- Need recording
- Need to be fine grain
- For both flora and fauna
- Monitor multiple environmental parameters

The Arctic Biodiversity Data Service

The current monitoring solutions

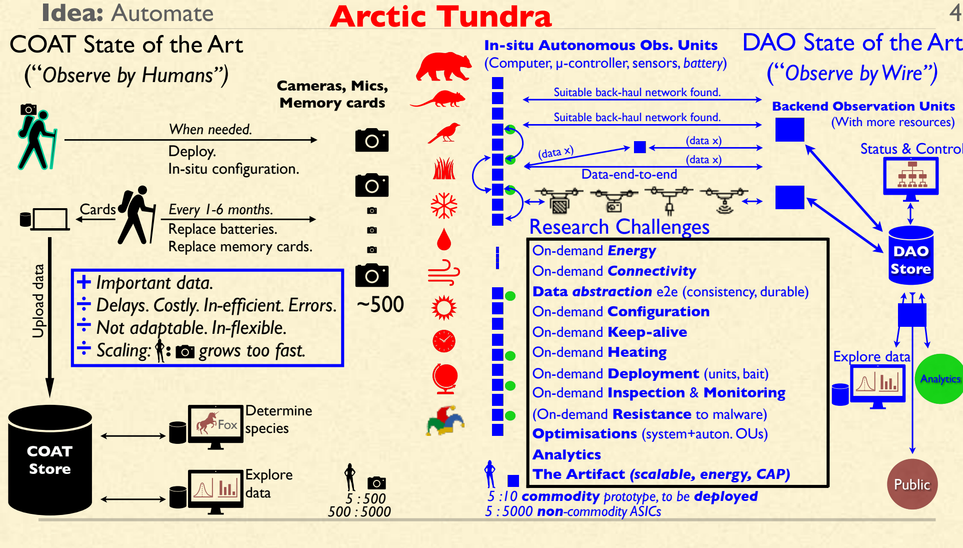
Two main directions

- Satellite observations
- Stand alone instruments humanly deployed, COAT[1]

Main problems

- Too coarse grain
- Doesn't scale

[1] https://www.coat.no/, ecologist colleagues


Idea: Automate
Arctic Tundra
4
COAT State of the Art
("Observe by Humans")
Cameras, Mics, Memory cards
When needed.
Deploy.
In-situ configuration.
Cards
Every 1-6 months.
Replace batteries.
Replace memory cards.
Upload data
+ Important data.
÷ Delays. Costly. In-efficient. Errors.
÷ Not adaptable. In-flexible.
÷ Scaling: : grows too fast.
~500
COAT Store
Fox
Determine species
Explore data
5 : 500
500 : 5000
In-situ Autonomous Obs. Units
(Computer, µ-controller, sensors, battery)
Suitable back-haul network found.
Suitable back-haul network found.
(data x)
(data x)
(data x)
Data-end-to-end
DAO State of the Art
("Observe by Wire")
Backend Observation Units
(With more resources)
Status & Control
DAO Store
Research Challenges
On-demand Energy
On-demand Connectivity
Data abstraction e2e (consistency, durable)
On-demand Configuration
On-demand Keep-alive
On-demand Heating
On-demand Deployment (units, bait)
On-demand Inspection & Monitoring
(On-demand Resistance to malware)
Optimisations (system+auton. OUs)
Analytics
The Artifact (scalable, energy, CAP)
5 :10 commodity prototype, to be deployed
5 : 5000 non-commodity ASICs
Explore data
Analytics
Public

Outline

1rst contribution: Experiences Building and Deploying Nodes

2nd contribution: Trading data size for CNN confidence score

3rd contribution: Impact of loosely coupled data dissemination policies

Observations

"Experiences Building and Deploying Wireless Sensor Nodes for the Arctic Tundra" [2]

In this paper we

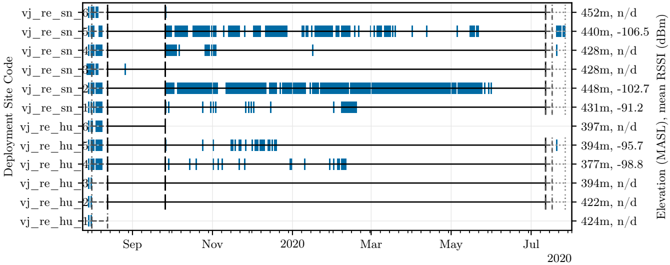
- Present the design and implementation of a prototype that we built and deployed to measure carbon dioxide
- Report on our experiments on deploying a set of nodes in the AT
- Expose the lessons learned

CO2 units real life deployment

(a) (b) (c)

Figure: A co2 observation unit being deployed. (a) The CO2 unit OU (b) placed in the wall of the camera trap box (c) covered with stones for protection and camouflage.

Time-line of observation unit contact with back-end server



Observations

- Deployment between summers 2019 - 2020
- Based on the coverage map, they should ALL have good LTE coverage

Lessons learned

- Error Handling: micro-controllers are limited. Under pressure when the common scenario is handling errors and unexpected events
- Storage failure: SD cards can break. From a file system perspective, as fragile file systems like FAT are usually used. But also from a physical perspective
- Connectivity: Don't believe the coverage map. Use every possible network technology available.
- Updates: There will be bugs. The update mechanism HAS TO be extensively tested.
- Autonomy: nodes have to be able to monitor themselves and take decisions based on their own state first
- Monitoring: overhead of monitoring should be evaluated.

Outline

"Trading Data Size and CNN Confidence Score for Energy Efficient CPS Node Communications" [3]

In this paper we

- Reduce energy consumption by only leveraging the size of the data sent
- Combine a CPS and a CNN to reduce the communication costs: energy, storage, bandwidth usage
- Document a significant reduction in energy for insignificant impact on confidence score
- Document the relationship between image size and communication related energy savings

The analysis of images: a trained CNN

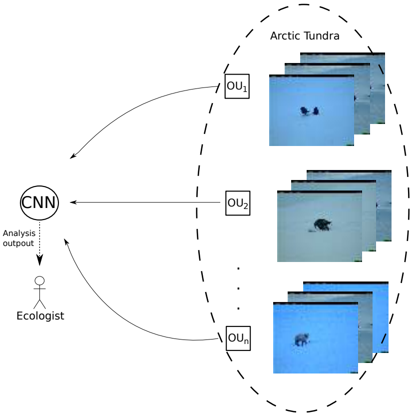
About the CNN

- Using a Single Shot MultiBox Detector (SSD)
- Outputs, for each image, a list of predictions with given confidence scores

Implementation details

- Original Caffe Python implementation
- Pre-trained model using ImageNet
- About 8000 images, annotated by COAT

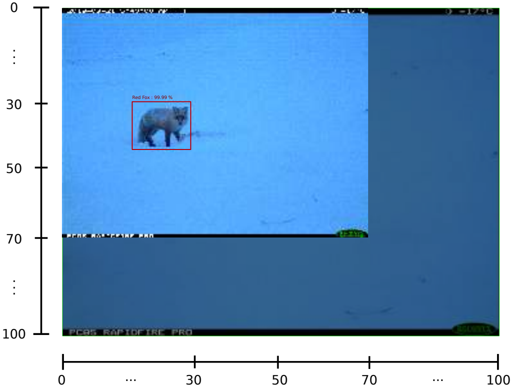
OUs to CNN communication model



Assumptions

- Direct interaction from OUs to the CNN application
- Connected with LTE or LTE Cat M1

The reduction of images dimensions: "image resize" leverage



Assumptions

- The picture is taken at a given size, not resized
- Here, resize goes from original dimensions (2048x1536) to 70% of original dimensions (1437x1075)

Key results, advantages and future work

Key results

- Between 31% and 98% of energy saved, compared to sending full images.
- For scale between 20% to 90%, predictions derivate by 10% to 1% in avrg

Advantages of leveraging image size

- Wide variety of energy savings, for negligible change in confidence scores
- Wide variety of potential usage
- Increased lifetime of OUs on the field
- All studied scenarios could benefit from this leverage

Future work

- Implement this leverage in a real deployment
- Other approaches to lossy compression of images [4]
- Study of other possible filters, on other type of data

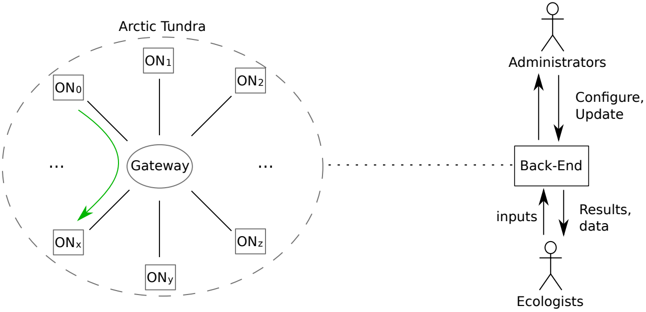
Outline

"Impact of loosely coupled data dissemination policies for resource challenged environments" [1]

In this paper we

- Applying loosely coupled policies for data dissemination on a unique use-case
- Document and evaluate the effect of loosely coupled data dissemination policies in scarce-resource environment
- Quantify the impact of these policies on energy and uptime through simulation of previous environment
- Underline a range of possible trade-offs between energy overhead and successful distributions under various scenarios

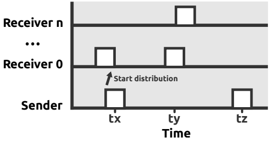
Overview of the system



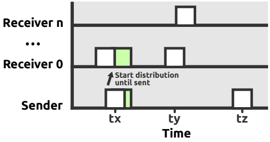
Assumptions

- The gateway is available when 2 nodes need to communicate in a P2P way
- The gateway helps in forming a star topology, i.e nodes can reach each other directly
- Connectivity between the back-end and nodes on the field is sparse and unexpected

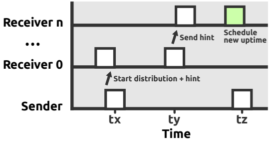
Data dissemination policies



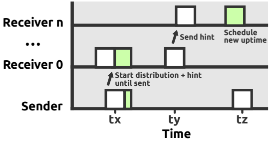
(a) Baseline



(b) Extended



(c) Hints



(d) Combination Hints and Extended

Assumptions

- Baseline: nodes wake up randomly, once every hour for a fixed duration
- Extended: when an exchange starts, it finishes
- Hints: when an overlap occurs a hint can be sent to others about the next uptime of the sender
- Combination: extended and hints combined

Simulation parameters

Bandwidth (Ltnc)	LoRa NbIoT	50kbps (0s) 200kbps (0s)
Energy states	P_{idle} LoRa NbIoT	0.4W +0.16W (+32mA at 5V) +0.65W (+130mA at 5V)
Uptime	Long Short	3 min/hour 1 min/hour
Data size	1MB	
# Receivers	12	

Simulator, advantage

- Flow level network and energy simulator
- Saves time compared to real prototypes (e.g we simulate 8 year of deployment in this paper)
- Offers reproducibility
- All simulation parameters are extracted from the literature and our own calibrations

Lessons learned

Simulation results observations

- Extended is expensive in terms of energy for the sender but not for the receivers.
- Hints adds a non negligible amount of accumulated uptime to the receivers.
- Combination has an overhead closer to Extended for the sender and receiver, for a number of successful delivery closer to Hints.

For a CPS like the DAO-CPS

- Deployed in a scarce resource environment
- Nodes should be independent
- Nodes should have an energy consumption that depends mostly on their actions
- Combination seems like the best trade-off

Outline

Observations

Between prototyping and simulation

- Prototyping is very time-consuming and higly error prone
- Simulation can be difficult and misleadings if not done properly
- In such a context, both are needed

A scientific observatory testbed is needed

- To reduce the time on prototyping
- To reduce the time on calibrating
- To re-use prototypes done by previous contributors

References I

Otto Anshus Issam Rais Loic Guegan. "Impact of loosely coupled data dissemination policies for resource challenged environments". In: *2022 22th IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (CCGRID)*. 2022. DOI: tobepublished.

Michael J. Murphy et al. "Experiences Building and Deploying Wireless Sensor Nodes for the Arctic Tundra". In: *2021 IEEE/ACM 21st International Symposium on Cluster, Cloud and Internet Computing (CCGrid)*. 2021, pp. 376–385. DOI: 10.1109/CCGrid51090.2021.00047.

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Steffen Randrup et al. "Impact of image compression on CNN performance metrics for CPS nodes at the Arctic Tundra". In: *2021 IEEE International Conferences on Internet of Things (iThings) and IEEE Green Computing Communications (GreenCom) and IEEE Cyber, Physical Social Computing (CPSCom) and IEEE Smart Data (SmartData) and IEEE Congress on Cybermatics (Cybermatics)*. 2021, pp. 290–297. DOI: 10.1109/iThings-GreenCom-CPSCom-SmartData-Cybermatics53846.2021.00055.