

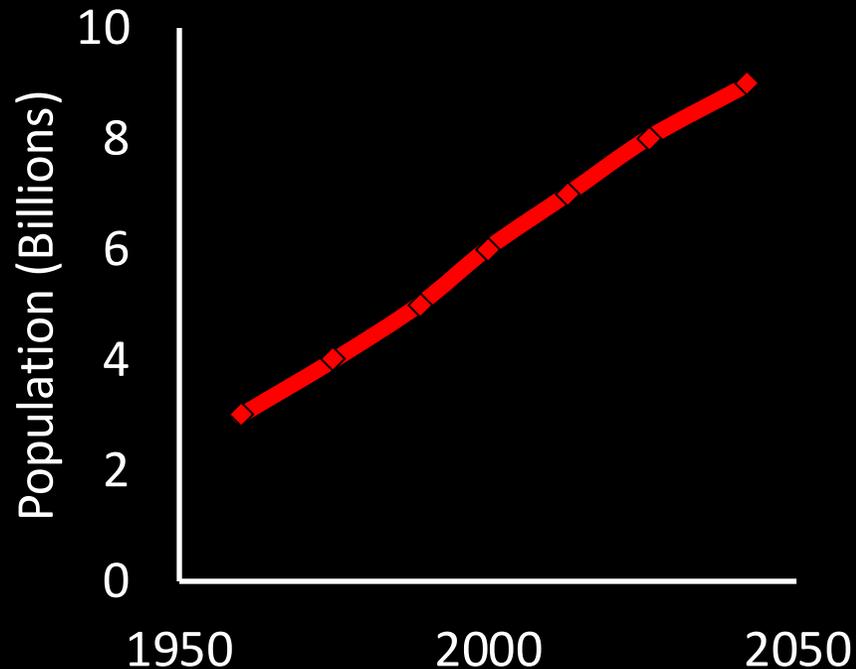
FarmBeats: AI & IoT for Agriculture

Deepak Vasisht

The Ag Challenge

Agricultural output needs to **increase by 70% by 2050** to meet the demands

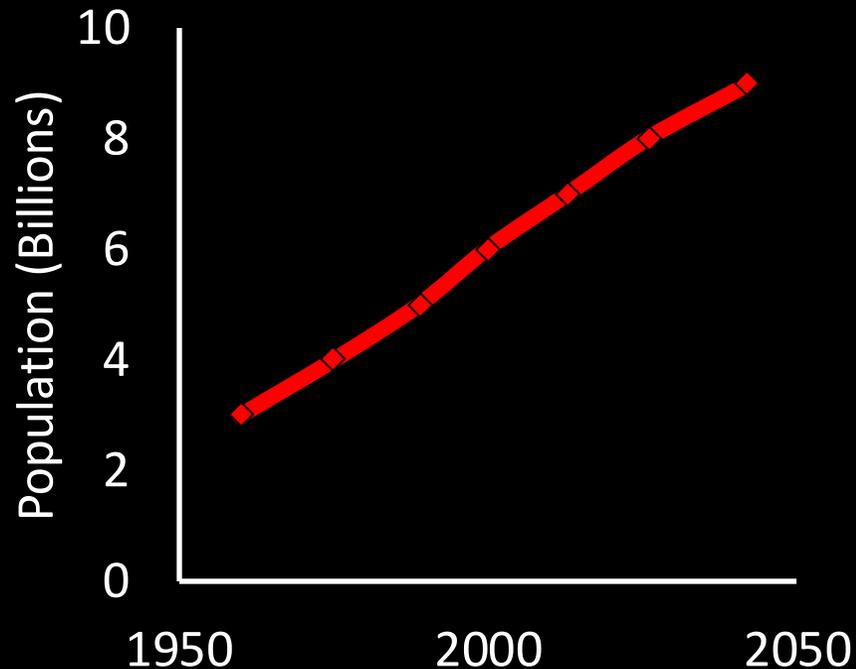
– United Nations¹



¹: United Nations Second Committee (Economic & Financial²), 2009

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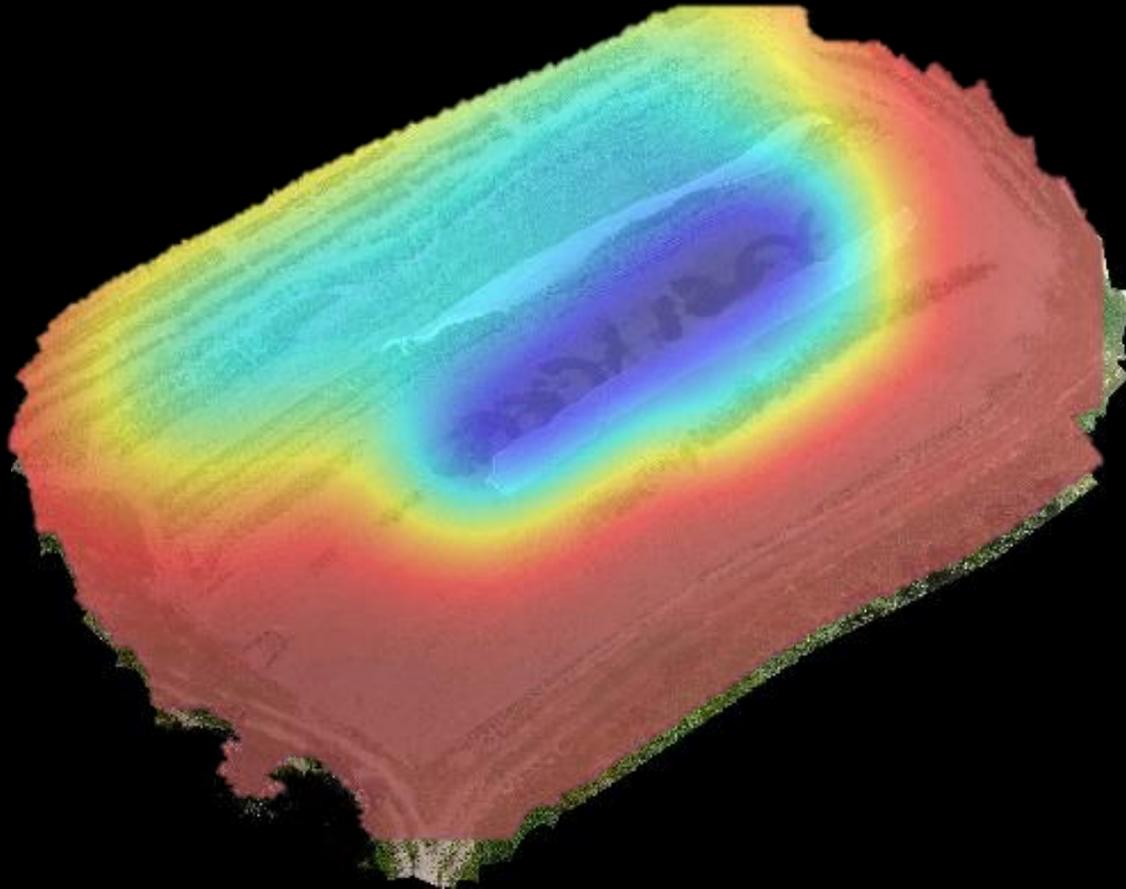


But...

- Water levels are receding
- Arable land is shrinking
- Environment is being degraded

¹: United Nations Second Committee (Economic & Financial³), 2009

Data-Driven Agriculture



Ag researchers have shown that it:

- Improves yield
- Reduces cost
- Ensures sustainability

But...

According to USDA, **high cost of manual data collection** prevents farmers from using data-driven agriculture

IoT System for Agriculture



Challenge: No Internet Connectivity

- Most farms don't have any internet coverage
- Even if connectivity exists, weather related outages can disable networks for weeks

Challenge: No Power on the Farm

- Farms do not have direct power sources
- Solar power is highly prone to weather related outages

Challenge: Limited Resources

- Need to work with sparse sensor deployments
 - Physical constraints due to farming practices
 - Too expensive to deploy and maintain

Beyond Agriculture

Smart Cities



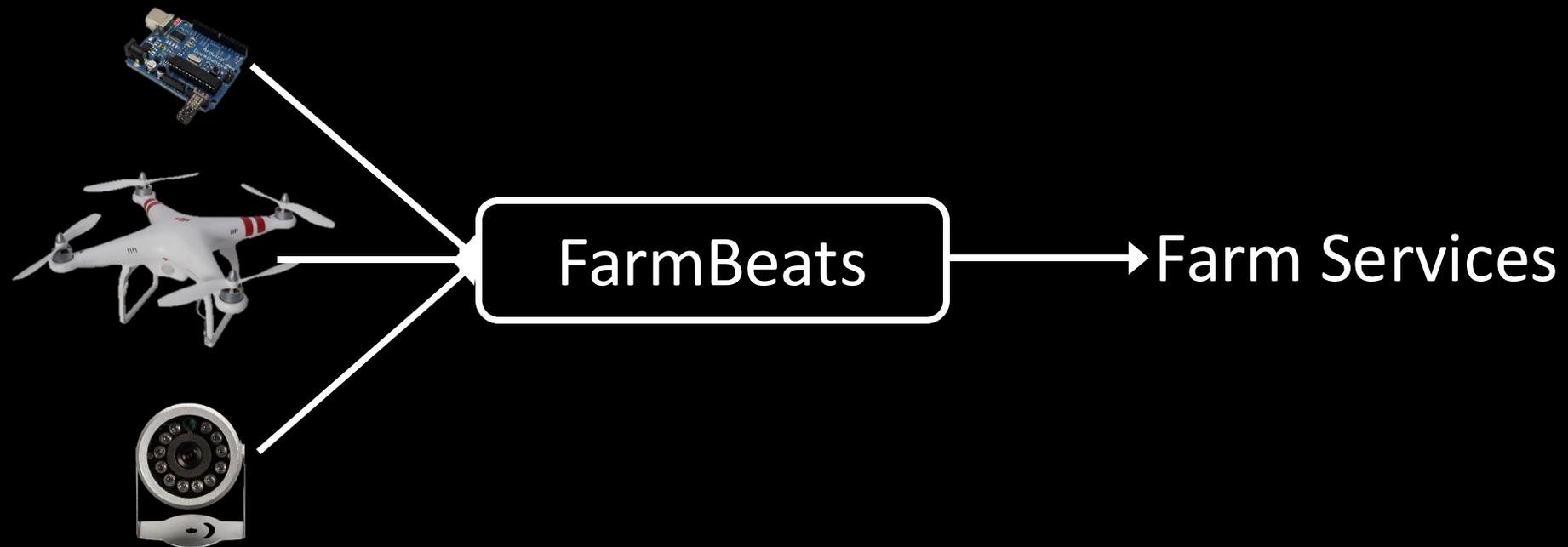
Oil Fields, Mining, etc



How can one design an IoT system in challenging resource-constrained environments?

Our Solution: FarmBeats

- FarmBeats: An end-to-end system that enables agricultural sensing at 2 orders of magnitude lower cost

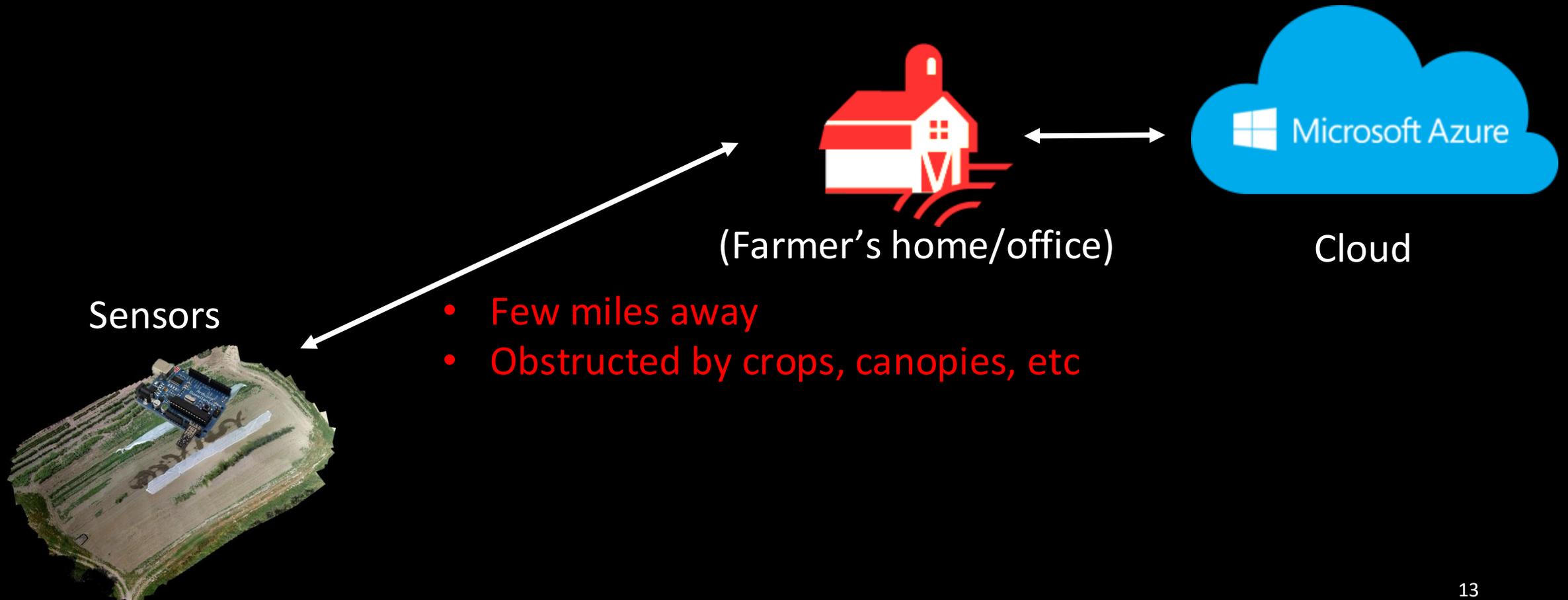


Challenge 1: Internet Connectivity

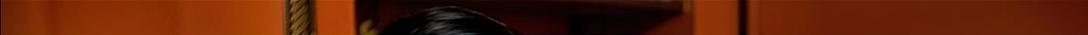
Sensors



Challenge 1: Internet Connectivity



Connectivity is critical for Digital Agriculture



**But.. over half the farmers in the US
do not have adequate Internet access on farms**



**Fundamentally, farm of the future cannot be realized
without connectivity solutions of the future**



**Rural broadband connectivity for
agriculture can contribute 500 billion
USD additional global GDP by 2030**



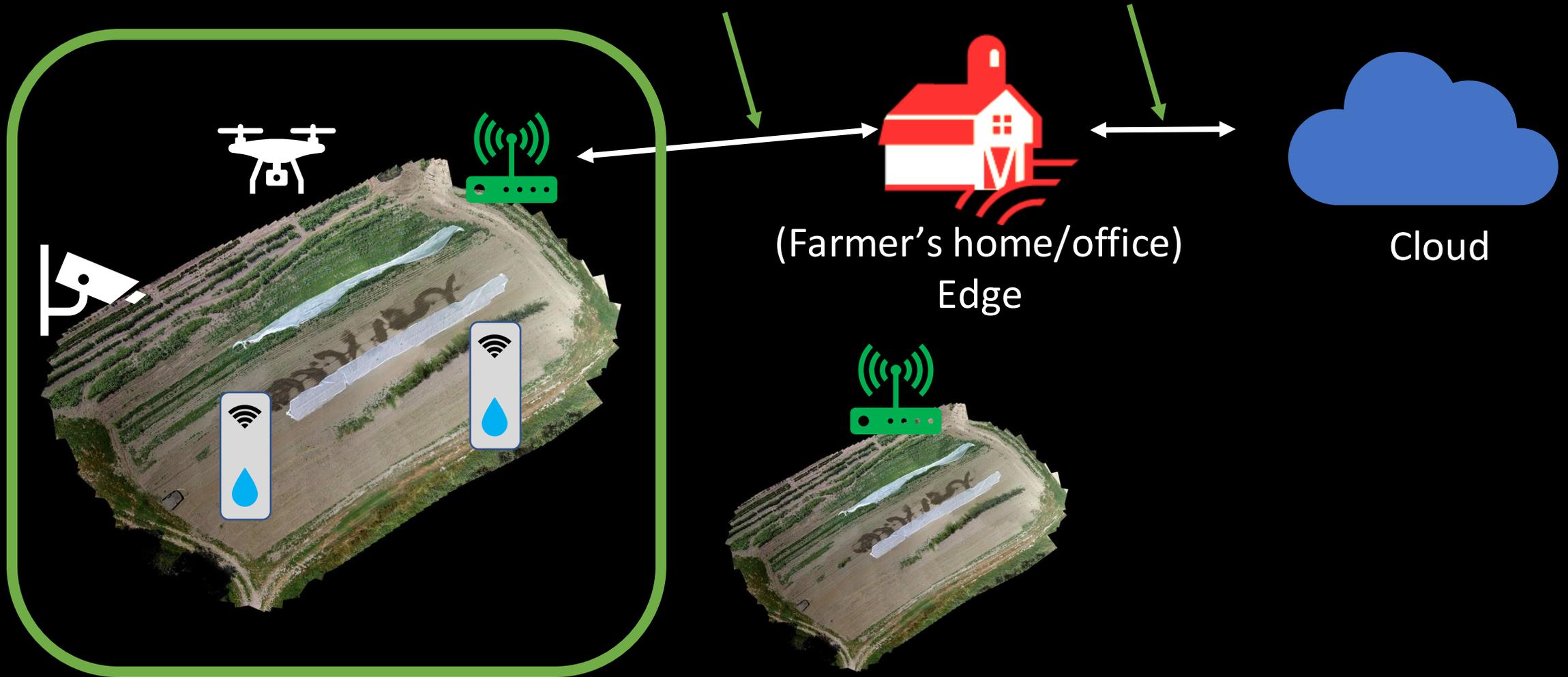
**Pandemic-induced shifts to education
necessitate e-learning adoption**



Example Applications for Rural Connectivity

- **Need continuous connectivity for tele-operation**
- **Need to stream videos collected on the field for intelligence**
- **Cannot be supported by rural connectivity solutions today**

Farm Network Setup



Applications & Requirements: High Bandwidth Tasks



Sensor	Data Volume	Frequency	Use cases
RGB Camera	50-200 MB per hectare 20 - 81 MB per acre	Multiple times a day	Visual inputs for farmer
Thermal Camera	30 MB per hectare 12 MB per acre	Multiple times a day	Water storage, heat stress
Multi-spectral Camera	1-5 GB per hectare 0.4 - 2 GB per acre	Once a week	Plant health, yield, disease prediction

Table Credit: Ammar Tahir

Applications & Requirements: Realtime Tasks



Sensor	Bandwidth	Latency required	Use cases
Teleoperation	4-10 Mbps	<100 ms	Remote operation for berry picking, virtual walkthroughs
Edge-controlled Robots	10s of Mbps	<100 ms	Complex manipulation tasks like weeding

Table Credit: Ammar Tahir

Connectivity Challenges

Range

- Lower range increases cost and reduces deployability
- Example: Wi-Fi mesh over 100 acres, requires 10-15 devices (200 m range)

Connectivity Challenges

Crops and canopies

- Reduces range and bandwidth
- Effect even higher for below-canopy sensors and robots
- As low as 30m for under-canopy, 5GHz Wi-Fi

Connectivity Challenges

Usability

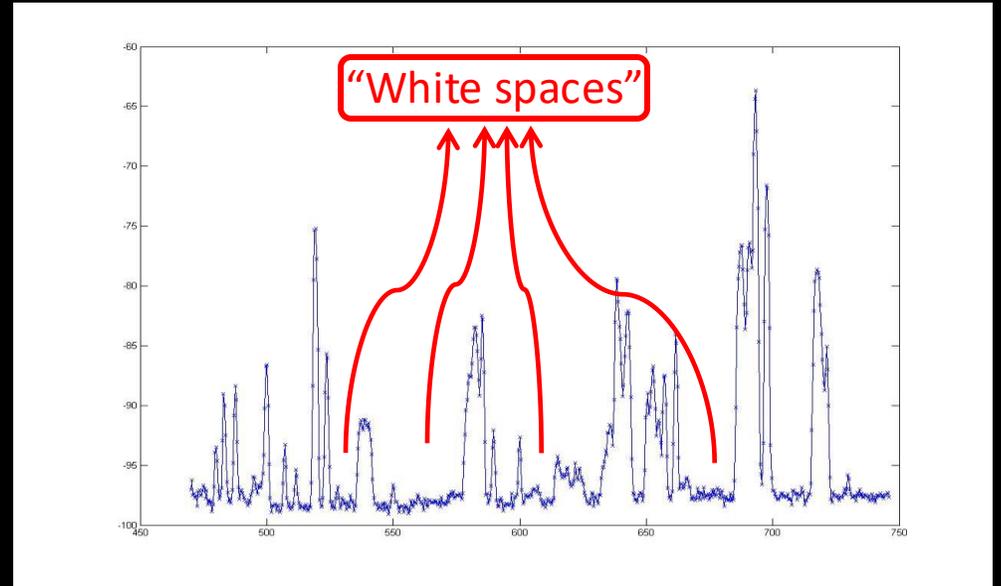
- Power
- Setup and debugging
- Network management

Connectivity Challenges

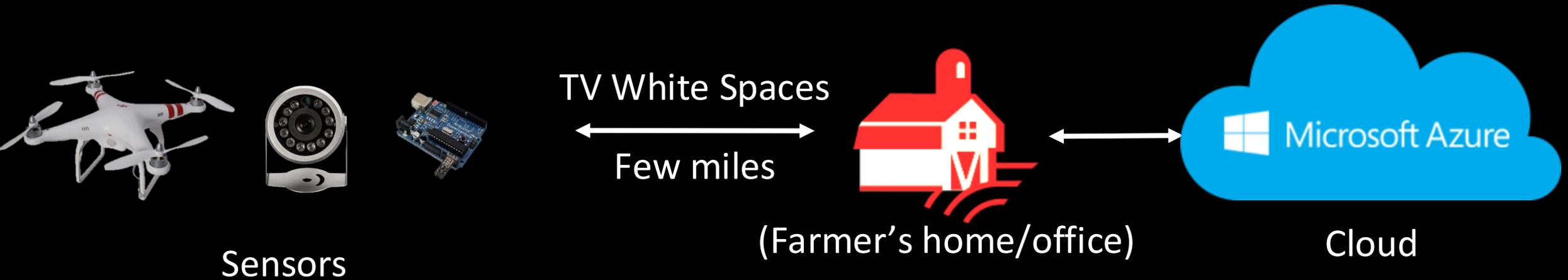
	Availability	Long Range	High bandwidth	Mobility
Cellular				
LoRA <i>Long Range</i>				
Satellite				

TV White Spaces in the Farm

- What are the TV White Spaces?
 - Unused TV channels
- Benefits over Wi-Fi, Zigbee, etc
 - High throughput at long range
- Key insight for farms:
 - “lots” of TV spectrum is available, more than 100 MHz
 - Just like Wi-Fi router covers the home, TVWS base station can cover the farm

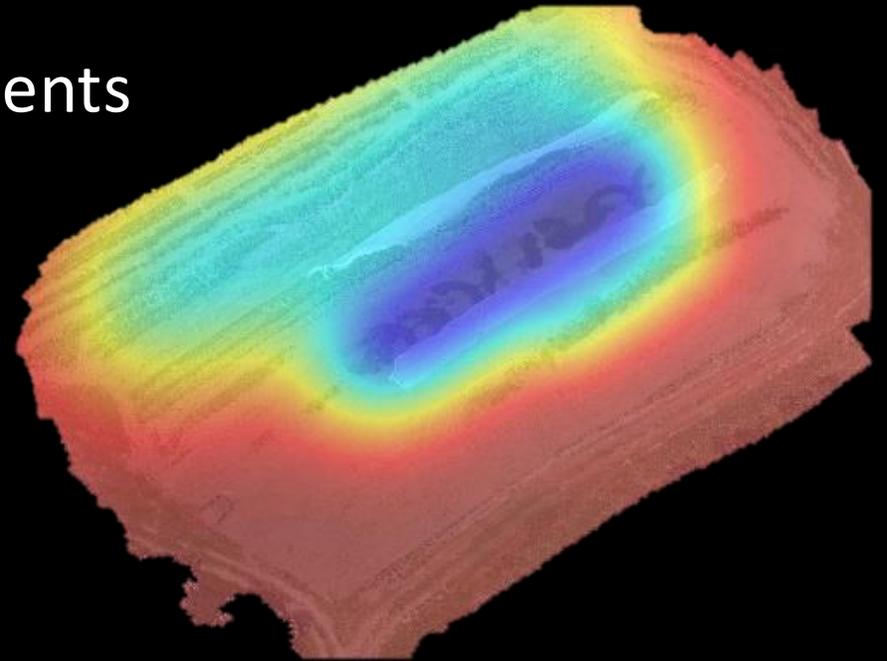


Idea: Use TV White Spaces



Challenge 2: Limited Resources

- Need to work with sparse sensor deployments
 - Physical constraints due to farming practices
 - Too expensive to deploy and maintain



- How do we get coverage with a sparse sensor deployment?

Idea: Use UAVs to Enhance Spatial Coverage

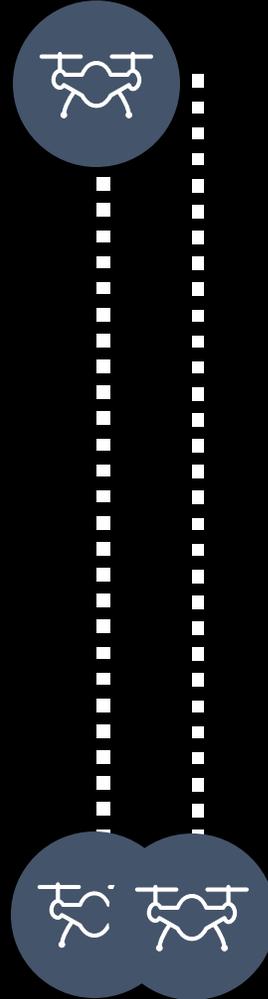
- Drones are ~1000 dollars and automatic
- Can cover large areas quickly
- Can collect visual data

Combine visual data from the UAVs with the sensor data from the farm

Aerial imagery in precision agriculture



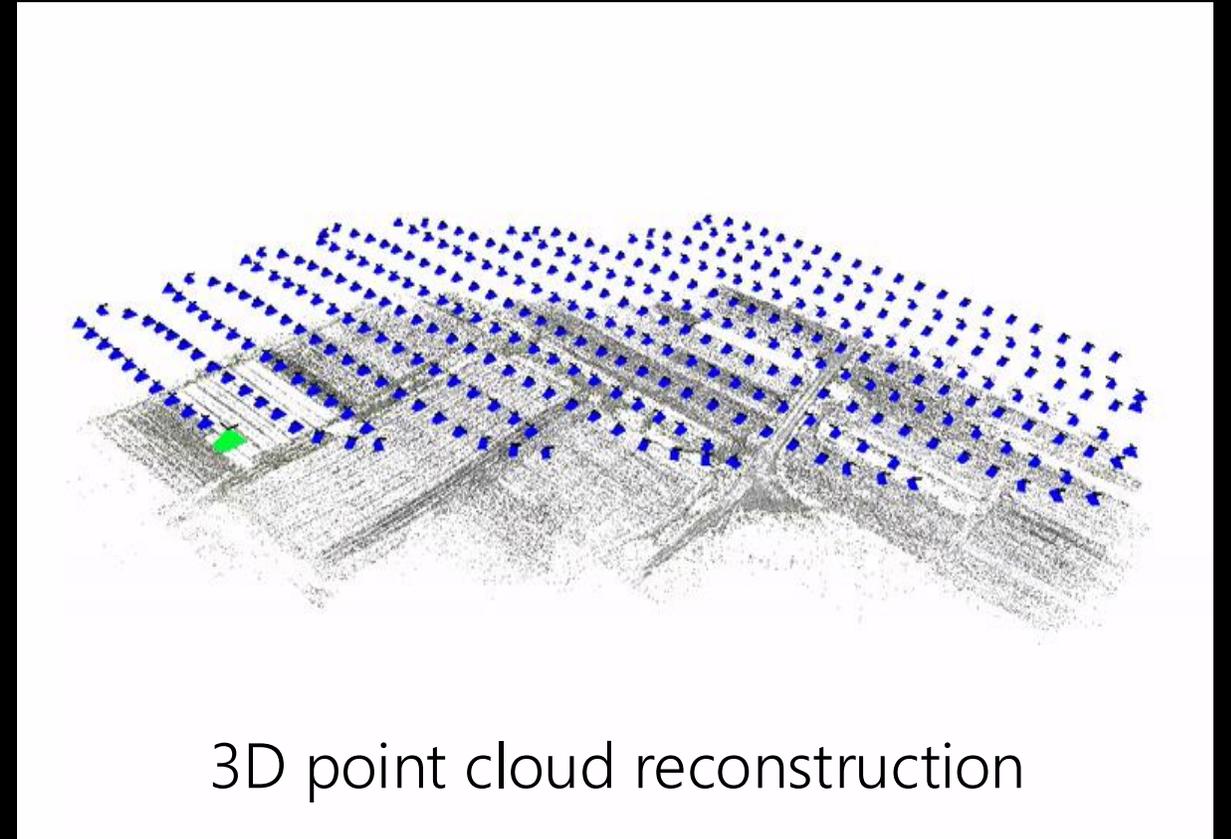
Drone Video



Processing RGB & multi-spectral imagery

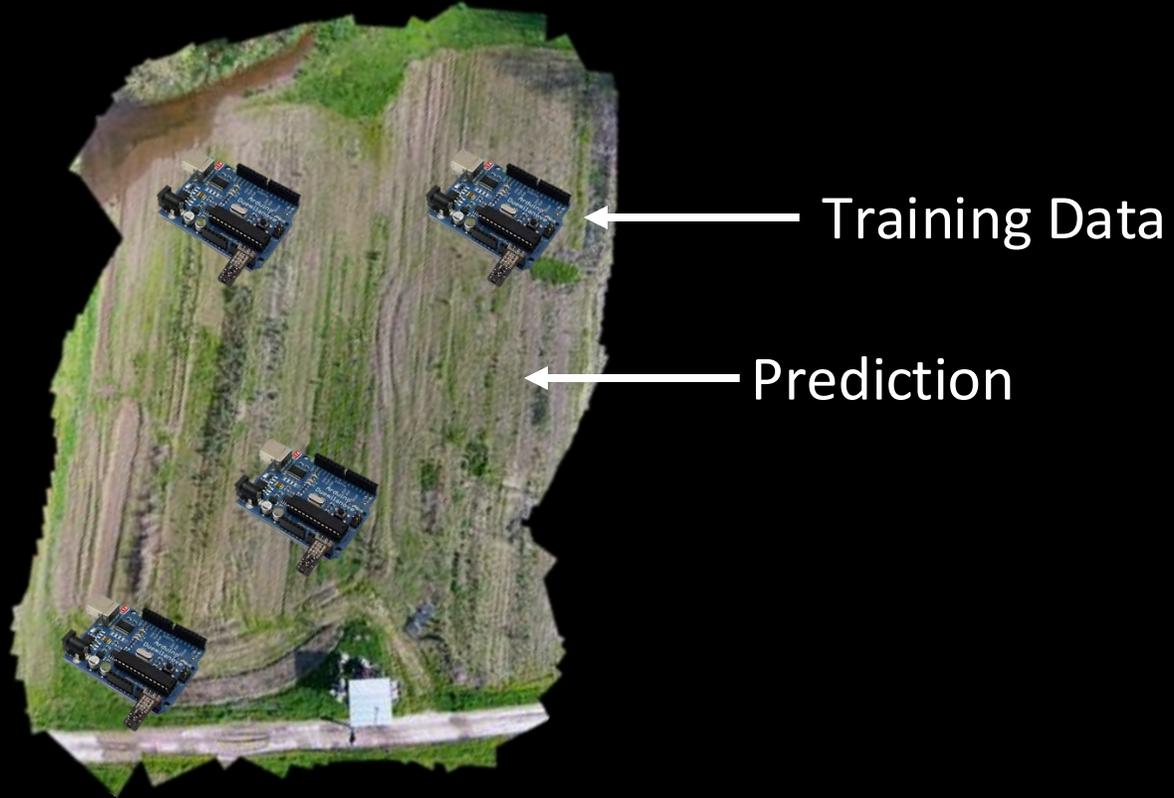


Aerial footage



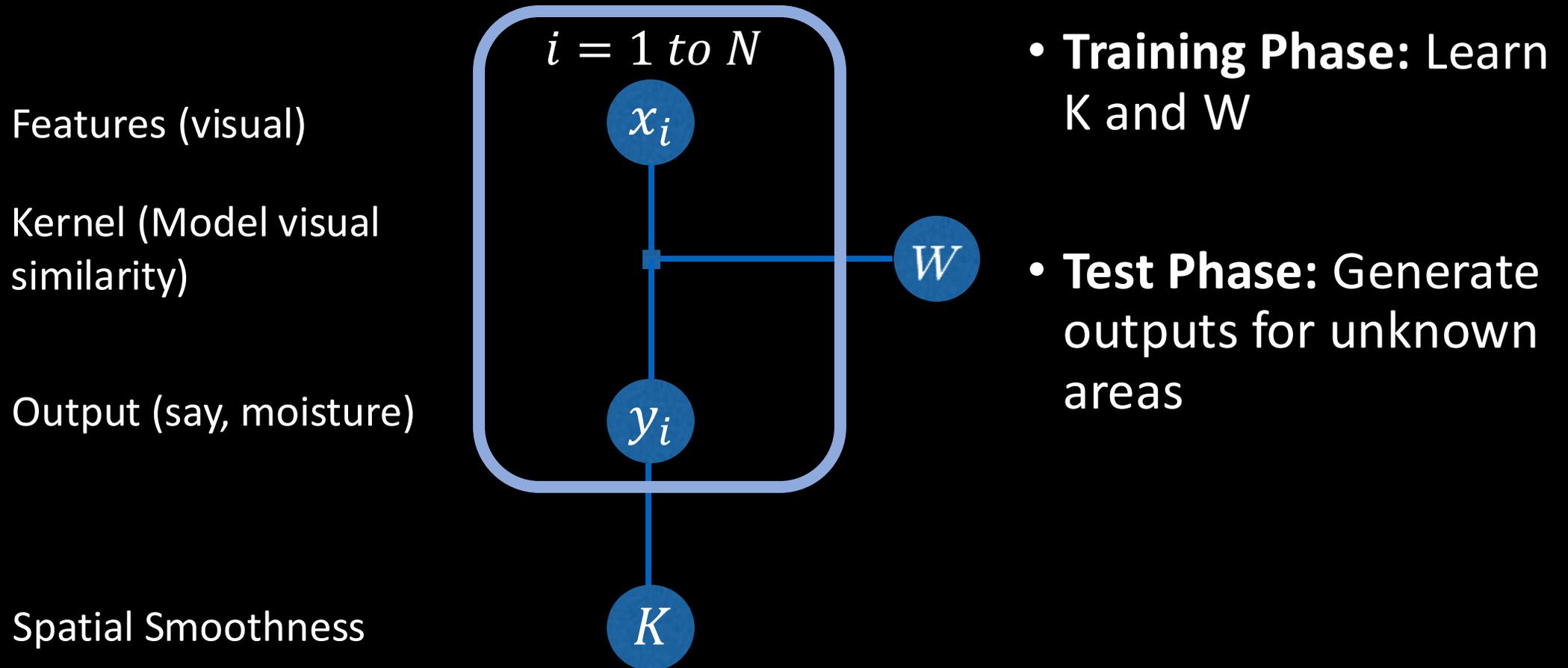
3D point cloud reconstruction

Formulate as a Learning Problem

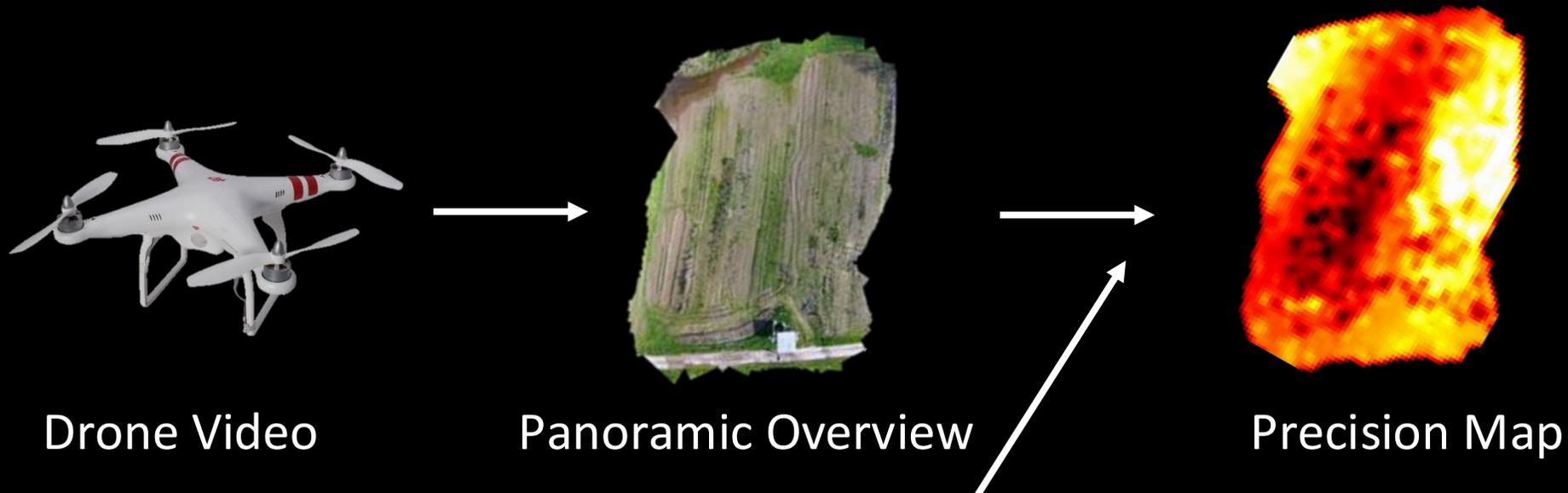


Panoramic Overview

Gaussian Process Model



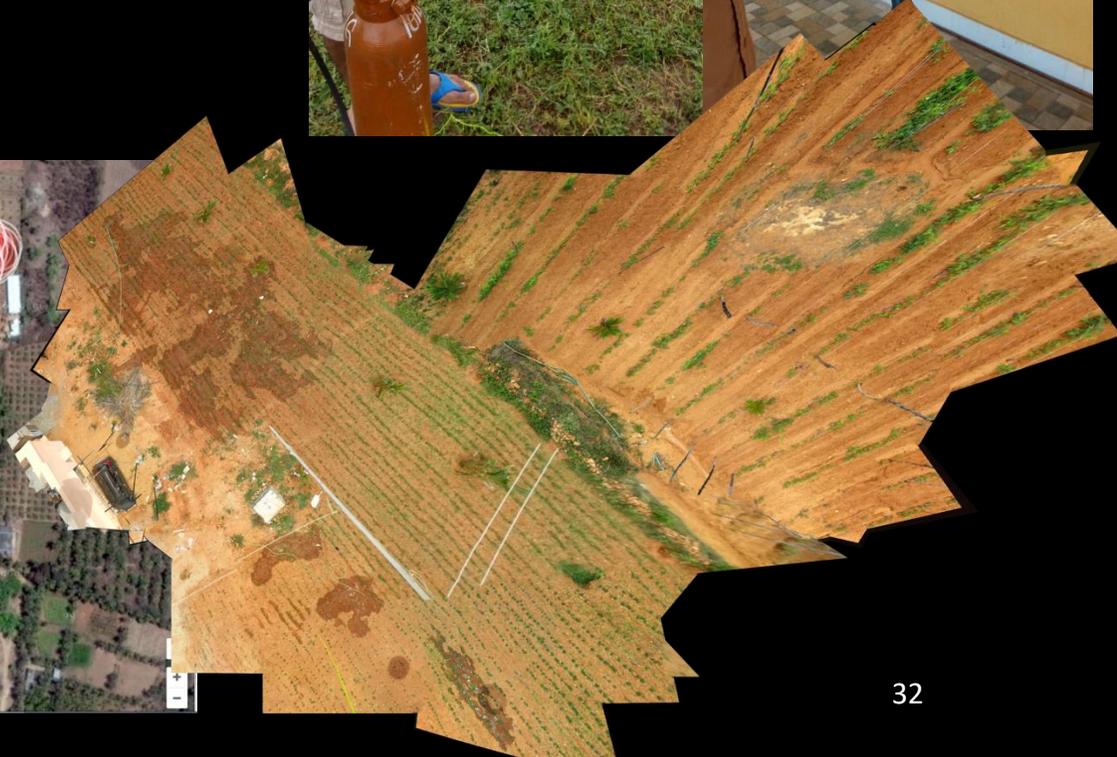
Idea: Use Drones to Enhance Spatial Coverage



FarmBeats can use drones to expand the sparse sensor data and create summaries for the farm

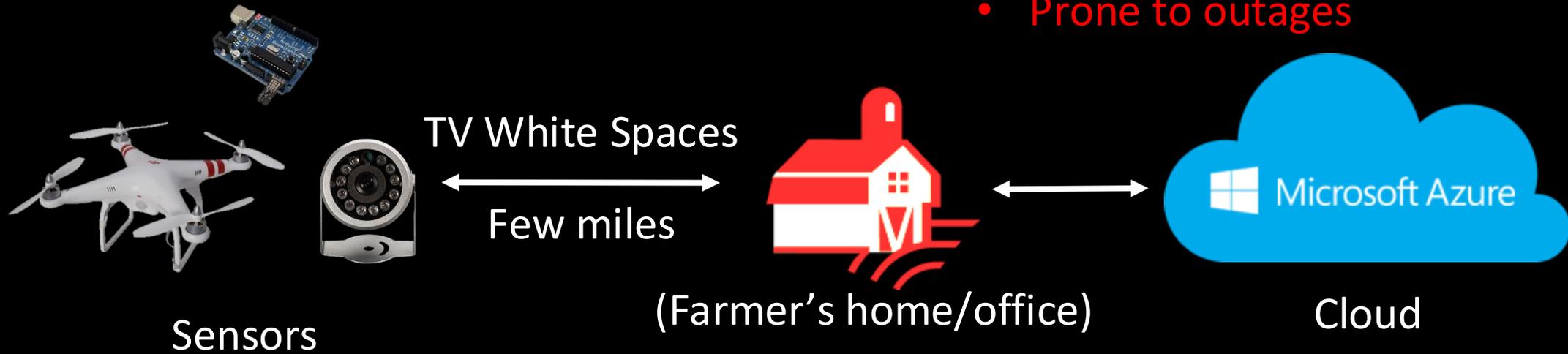
Low-cost Aerial Imagery: Tethered Eye (TYE)

- UAVs have a few limitations in developing world:
 - limited battery life
 - Regulatory concerns
 - Cost > 1000 dollars



Challenge 3: Cloud Connectivity

- Weak Connectivity
- Prone to outages



Service characteristics

Large inputs

Data source	Daily size
Sensor	70K
Drone video	10G
Drone image	4G
Camera	28M

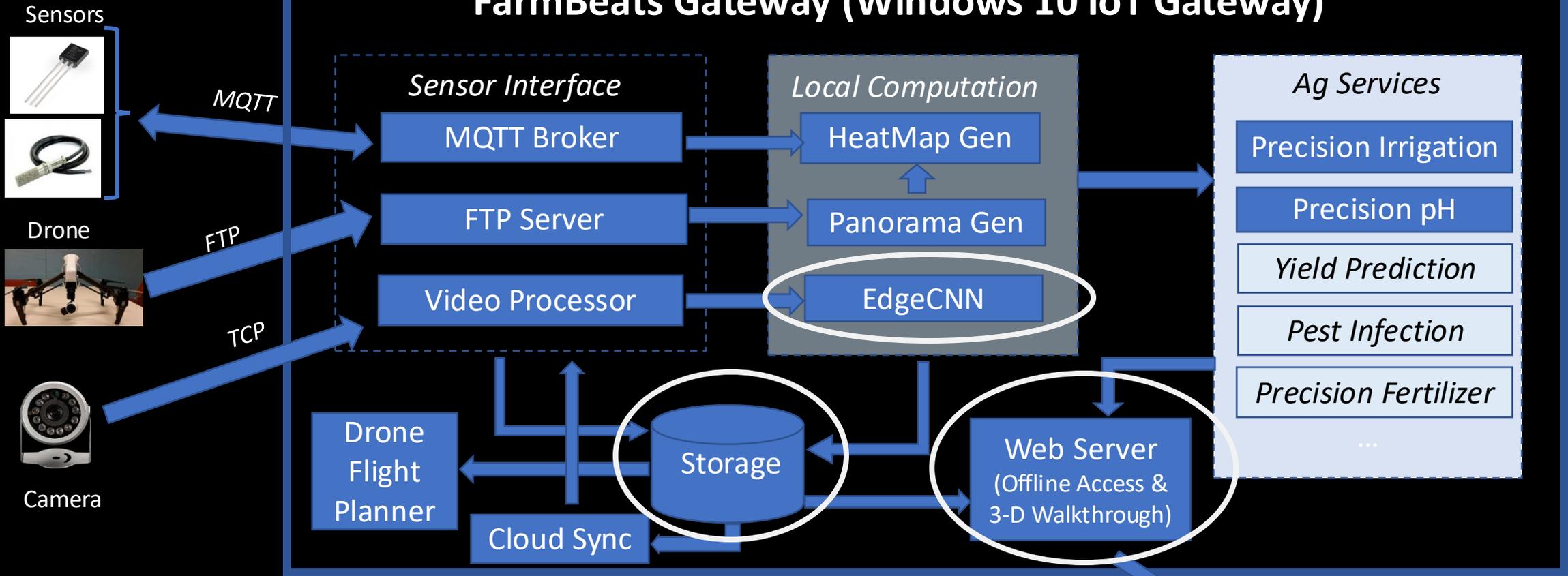
Latency constraints

Service	Latency
Query sensor data	seconds
Livestock monitoring	seconds
Irrigation schedules	hours
Pest inspection	hours
Variability analysis	Days

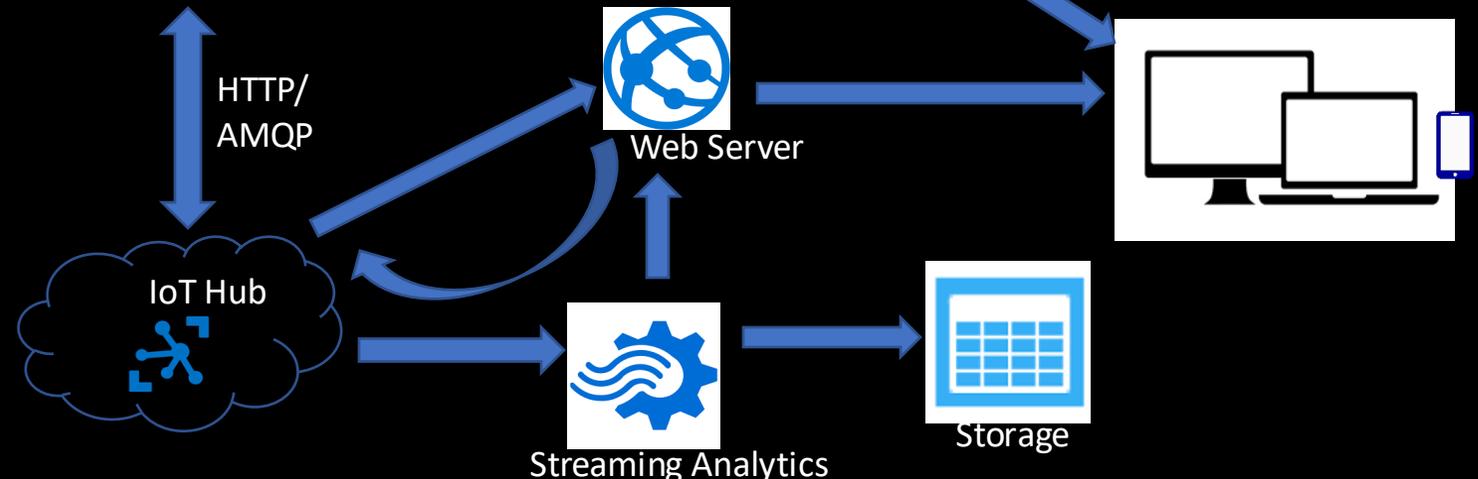
Idea: Compute Locally and Send Summaries

- PC on the farm delivers time-sensitive services locally
- Combines all the sensor data into summaries
- 2-3 orders of magnitude smaller than raw data
- Cloud delivers long-term analytics and cross-farm analytics

FarmBeats Gateway (Windows 10 IoT Gateway)



- Can run offline
- Unique Gateway services
- Deep Learning at Edge
- Component Migration



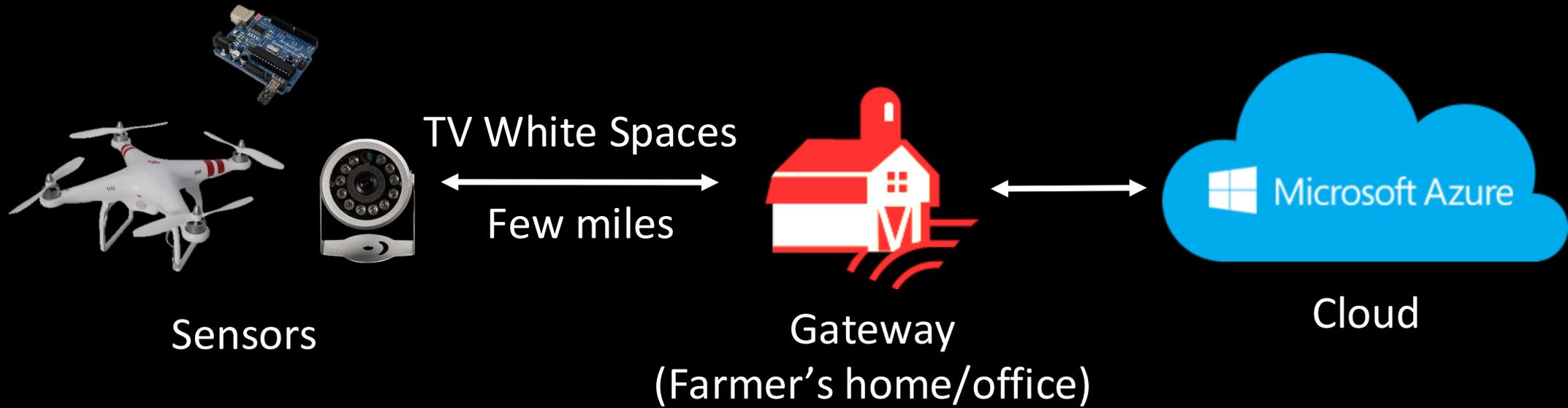
Challenge 4: Power Availability is Variable

- Solar powered battery saw up to 30% downtime in cloudy months
- Miss important data like flood monitoring

Idea: Weather is Predictable

- Use weather forecasts to predict solar energy output
- Ration the load to fit within power budget

FarmBeats: Overview

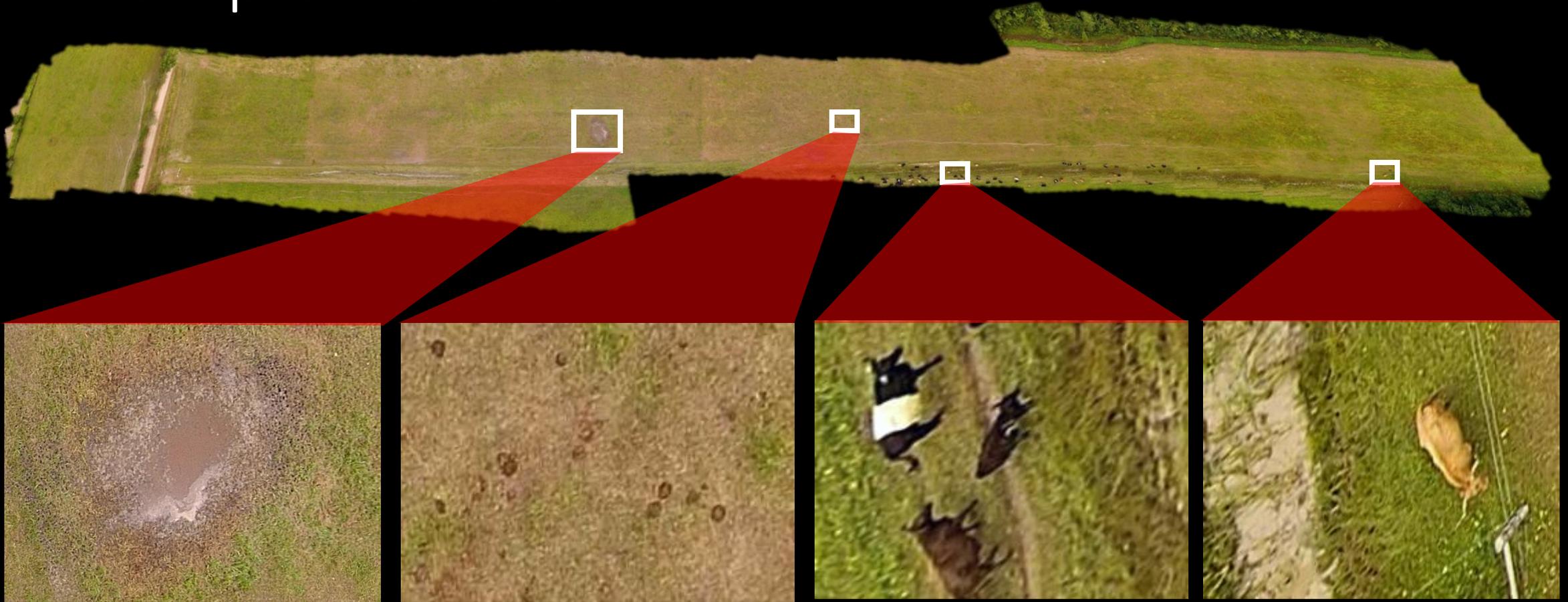


Deployment Example

- Deployments in many farms: Upstate NY (Essex), WA (Carnation)
- The farm sizes are 2000 acres and 5 acres respectively
- Sensors:
 - DJI Drones
 - Particle Photons with Moisture, Temperature, pH Sensors
 - IP Cameras to capture IR imagery as well as monitoring
- Cloud Components: Azure Storage and IoT Suite



Example: Panorama



Water puddle

Cow excreta

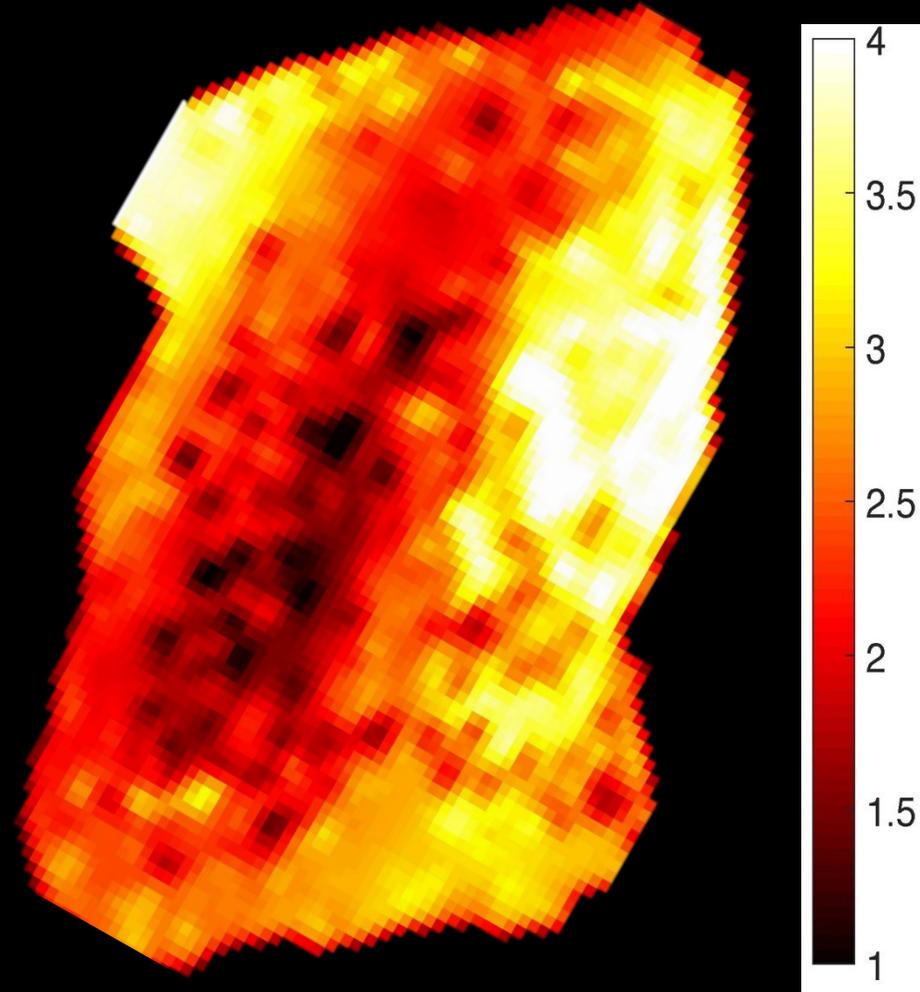
Cow Herd

Stray cow

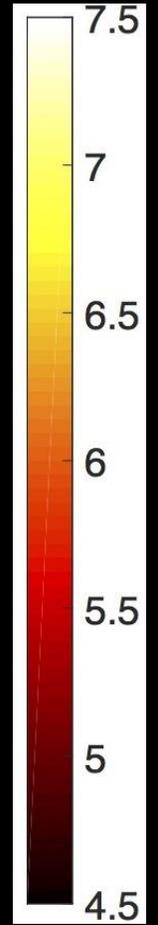
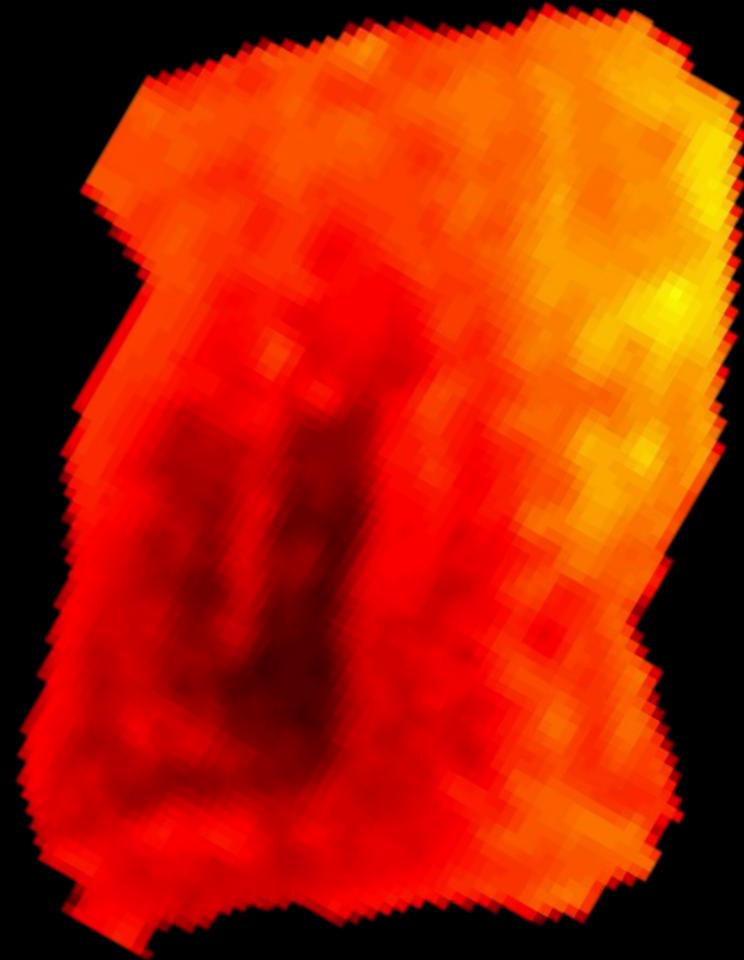
Precision Map: Panorama Generation



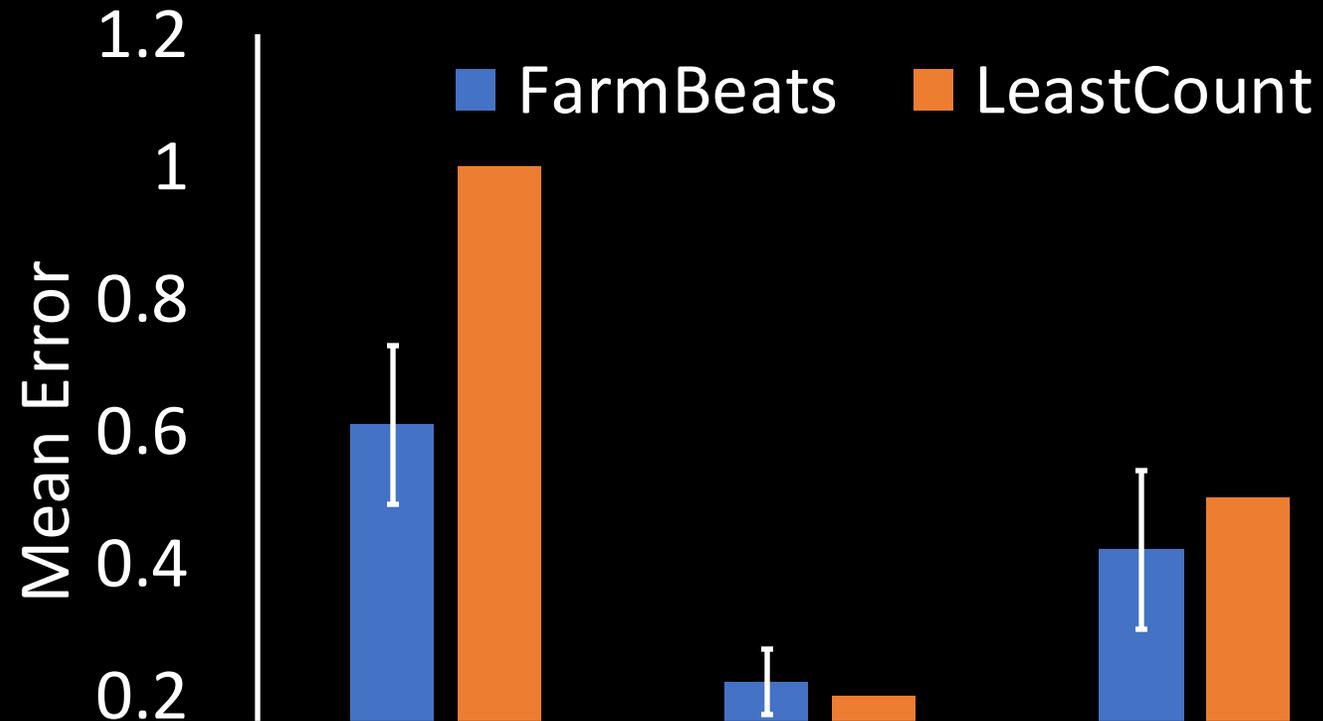
Precision Map : Moisture



Precision Map : pH



Precision Map: Accuracy

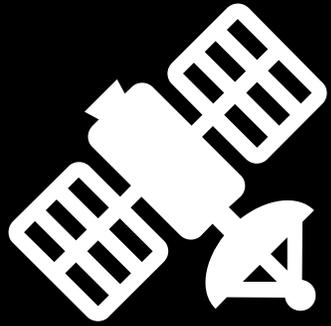


FarmBeats can accurately expand coverage by orders of magnitude using a sparse sensor deployment

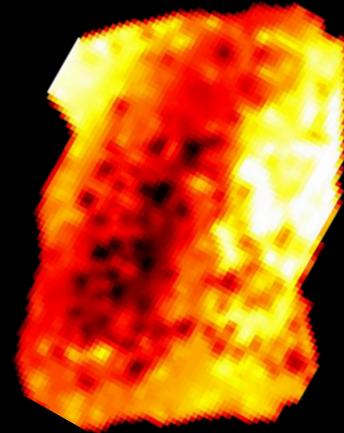
Application: Cow-Shed Monitor



New Direction: Satellite Imagery



Panoramic Overview



Precision Map



Sparse Sensor Data



New Direction: Soil Sensing

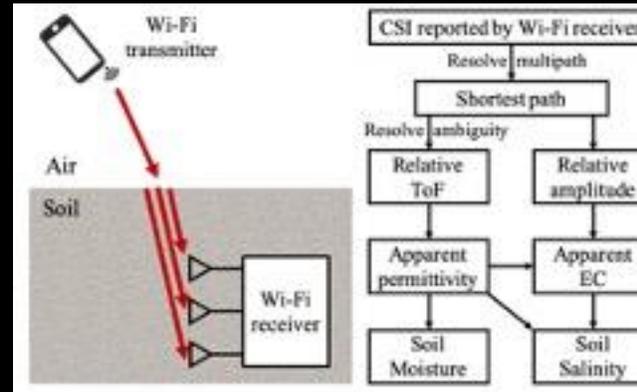
Motivation: existing sensors are expensive

- ~100s of dollars

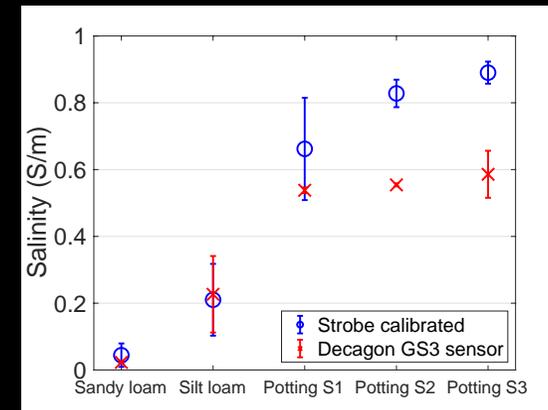
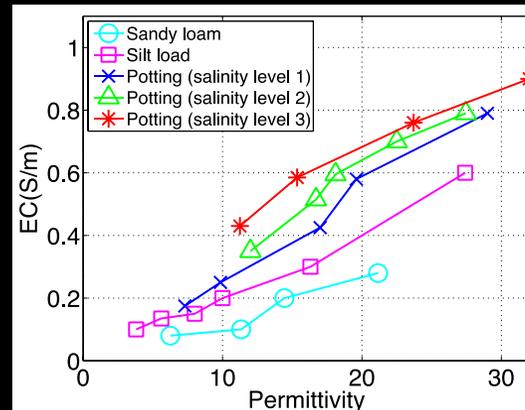
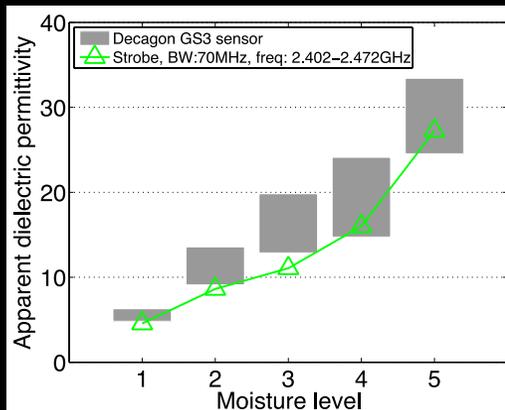


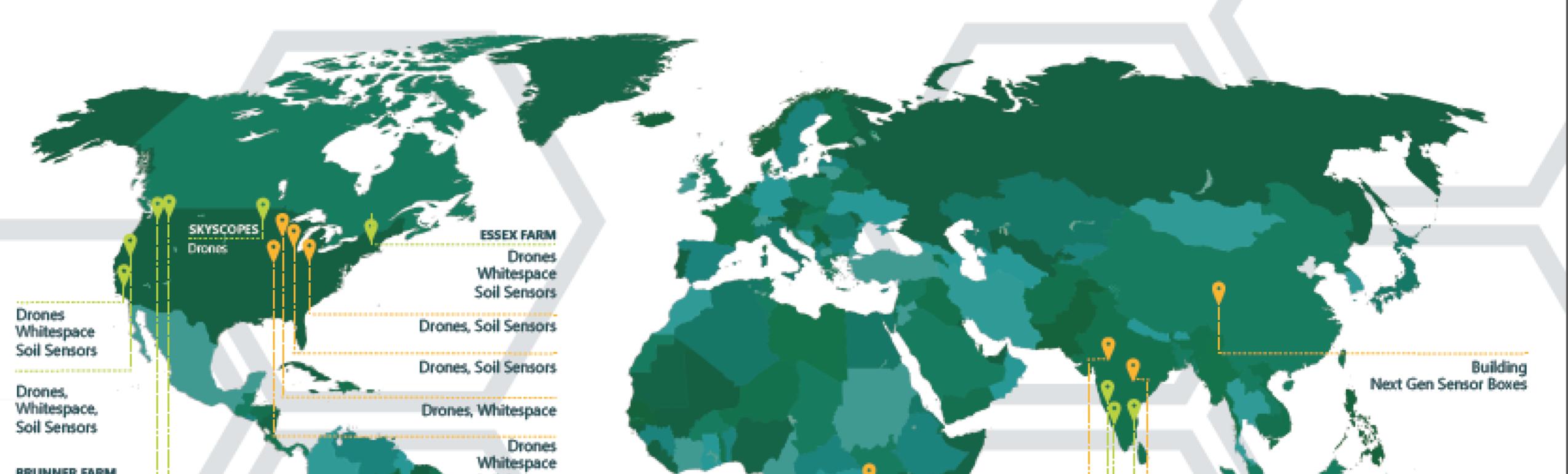
Strobe design: Wi-Fi cards with 2+ antennas

- Relative phase & amplitude



Results: Strobe can accurately detect moisture and EC change in soil





Farmers self-reported increased yields and reduced inputs (30-45%)

Private Preview released by Microsoft in January 2019
Now in Public Preview

The people and projects that inspired me in 2017

Published on December 21, 2017



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16,655



318



1,233

gatesnotes The blog of **Bill Gates**



Democratizing AI for farmers around the world





FarmBeats: Experiences



Conclusion

- FarmBeats: End to end IoT system for environments constrained by:
 - Limited internet connectivity
 - Weather related variability
 - Sparse sensor deployment
- Acts as a tool to enhance farm and farmer productivity
- Used by farmers for applications beyond precision farming

Questions

Zerina Kapetanovic (UW), Jong-Ho Won (Purdue), Xinxin Jin (UCSD), Vasuki Narasimha Swamy (Berkeley), Michael Grant (WSU), Rahul Sharma (IIIT Hyderabad), Akshit Kumar (IIT Madras), Rohit Shetty (PESET), Aditya Jain (IIIT Delhi), Ranveer Chandra, Manohar Swaminathan, Sudipta Sinha, Ashish Kapoor, Akshay Nambi, Anirudh Badam, Peeyush Kumar, Peder Olsen, Raghuram Lanka, Madhu Sudarshan, Cameron Phillips, Heping Shi, Akash Devgun, Raji Kommineni (Microsoft)