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Whisper: IoT in TV White Space Spectrum

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Today’s IoT connectivity

Smart city

Farm

Energy

Supply chain

Performance of mainstream IoT solutions?

Experience with mainstream IoT solutions

FarmBeats: IoT for agriculture

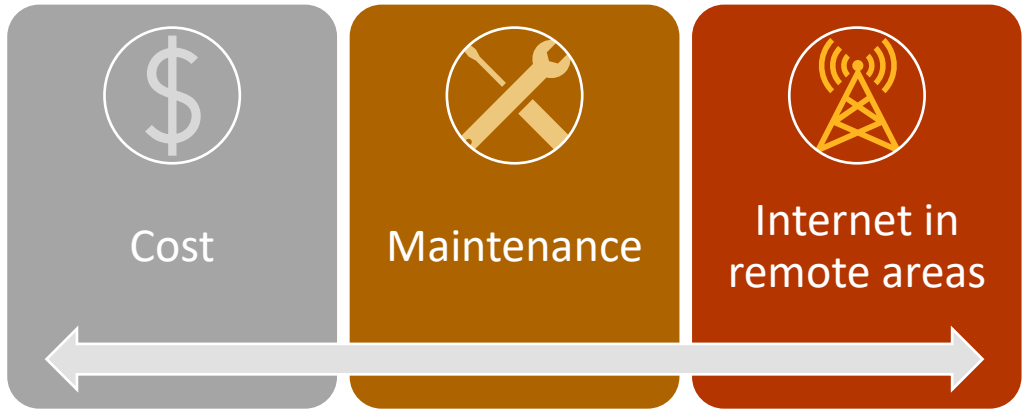
30+ deployments across globe

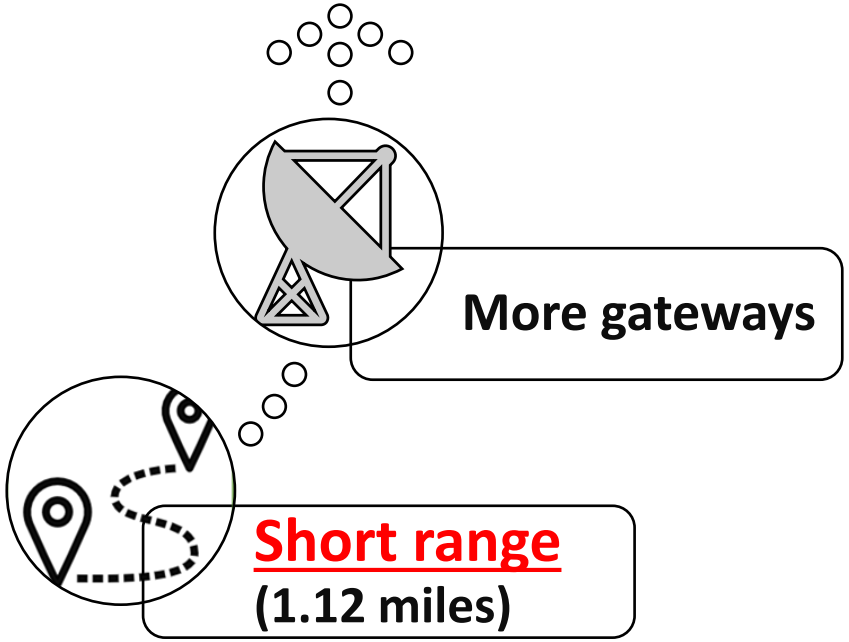
LoRa in ISM 800/900 MHz

Experience with mainstream IoT solutions

Network for **SENSOR DATA** aggregation

Need for a **LONGER** range

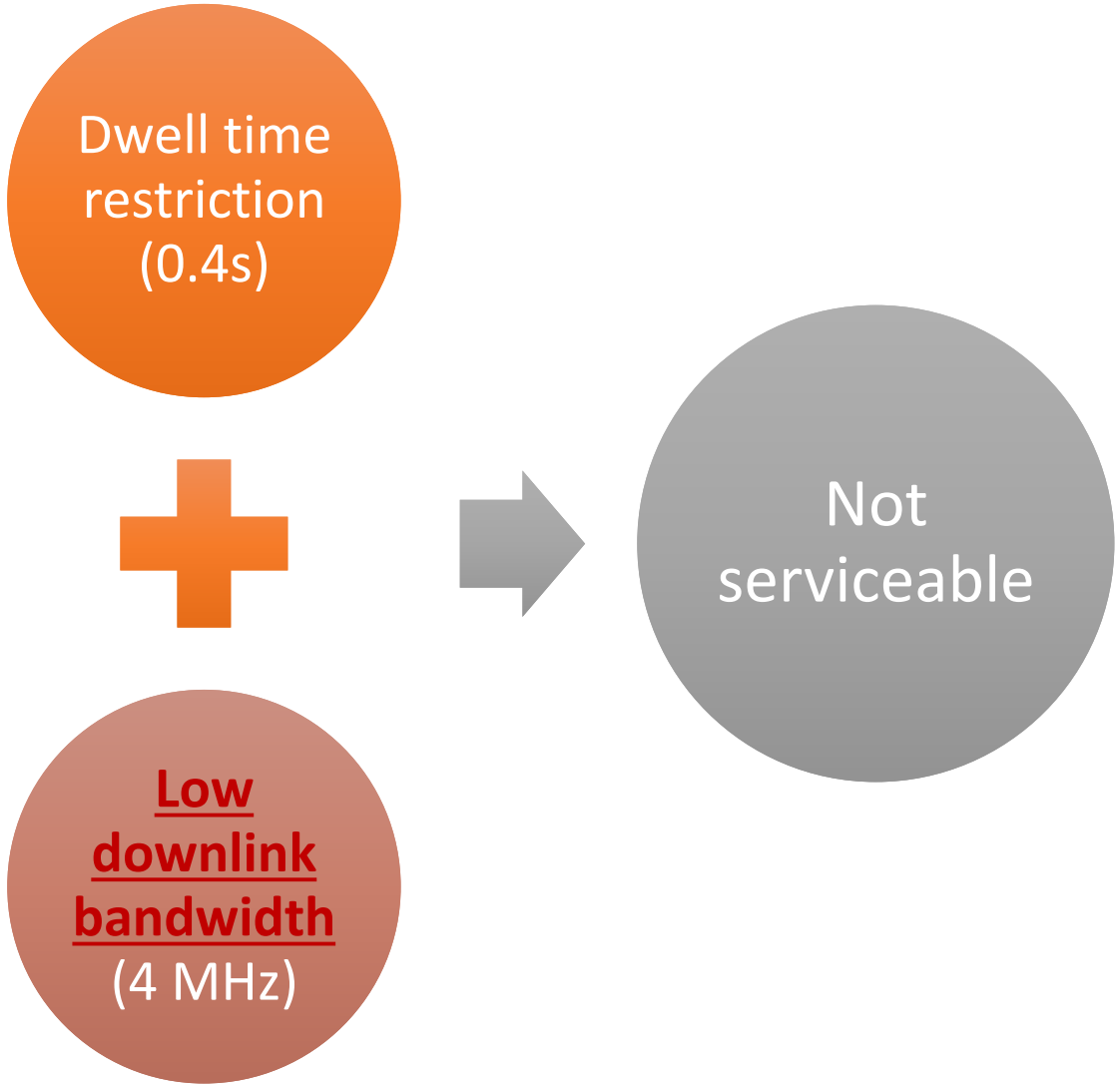




Experience with mainstream IoT solutions

Network for **IMAGE** aggregation over **US915**

Need for **LARGER** bandwidth

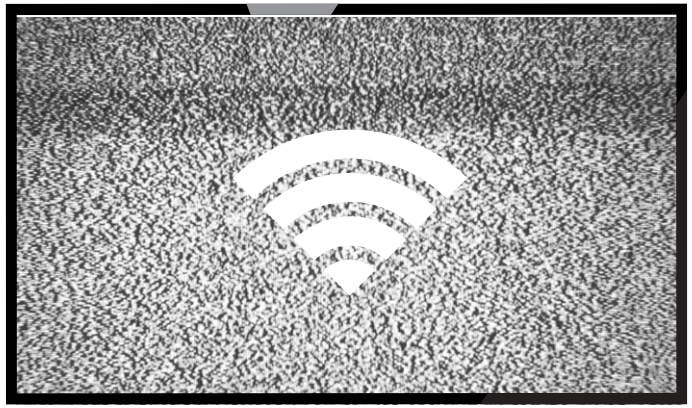


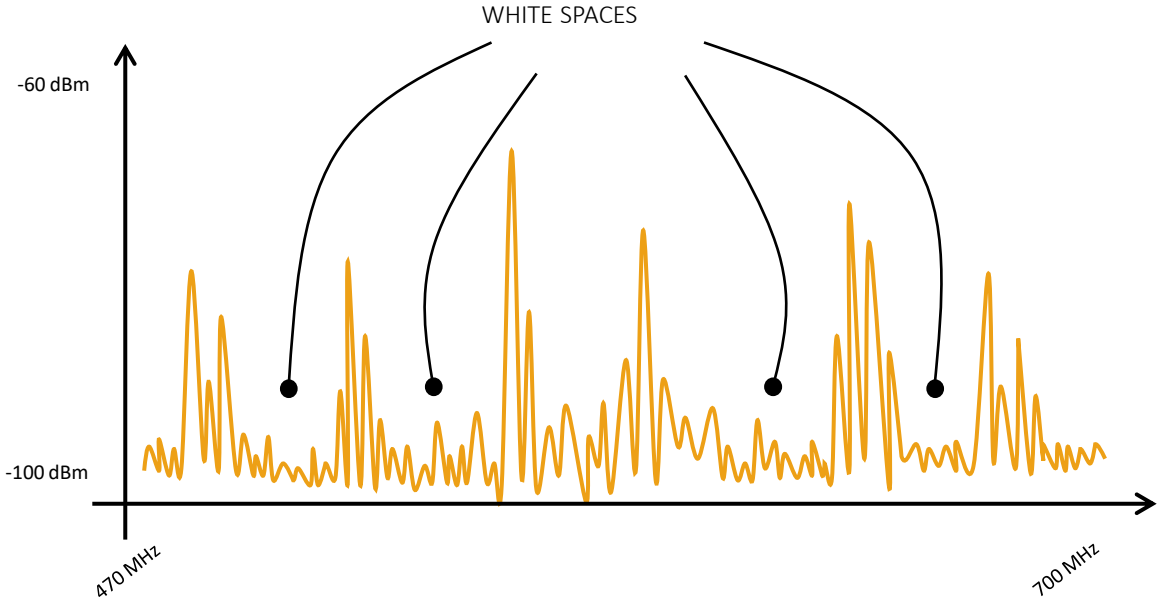
How to bridge the gap?

IoT in TV White Spaces (TVWS)

What are TV White Spaces?

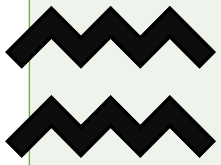
> Unused TV channels



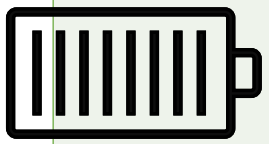


Why TVWS?

Longer range (10s mi)
→ lesser #gateways



More bandwidth



Low-power TX at long distance

Challenges with TVWS

Regulatory

Incumbents must be protected from interference

Utilization of b/w

Mainstream IoT protocols cannot make the best utilization of wide TVWS spectrum to handle large traffic

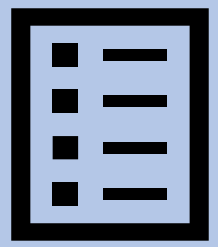
Spatiotemporal dynamism

Availability and quality of white TV channels vary with location and time

Carrier sensing

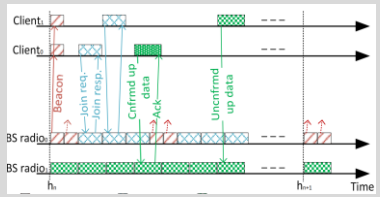
With LoRa modulation, measuring RF energy level does NOT work to detect RF interference

Whisper and our contributions



Petition for rulemaking at FCC*

IoT H/W for TVWS



New IoT protocol for TVWS

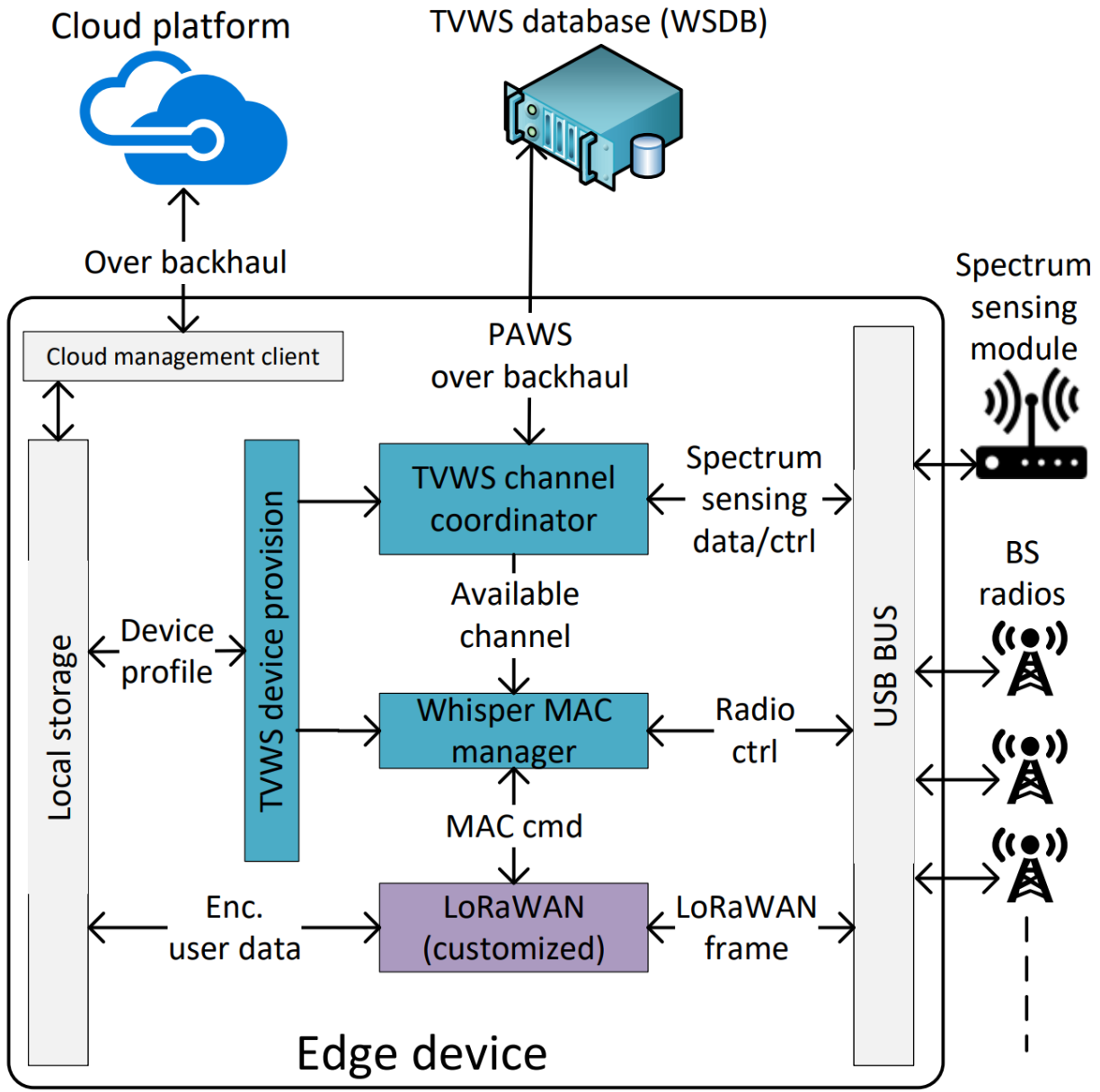
Real-world deployment for >2.5 months

*FCC: US Federal Communications Commission

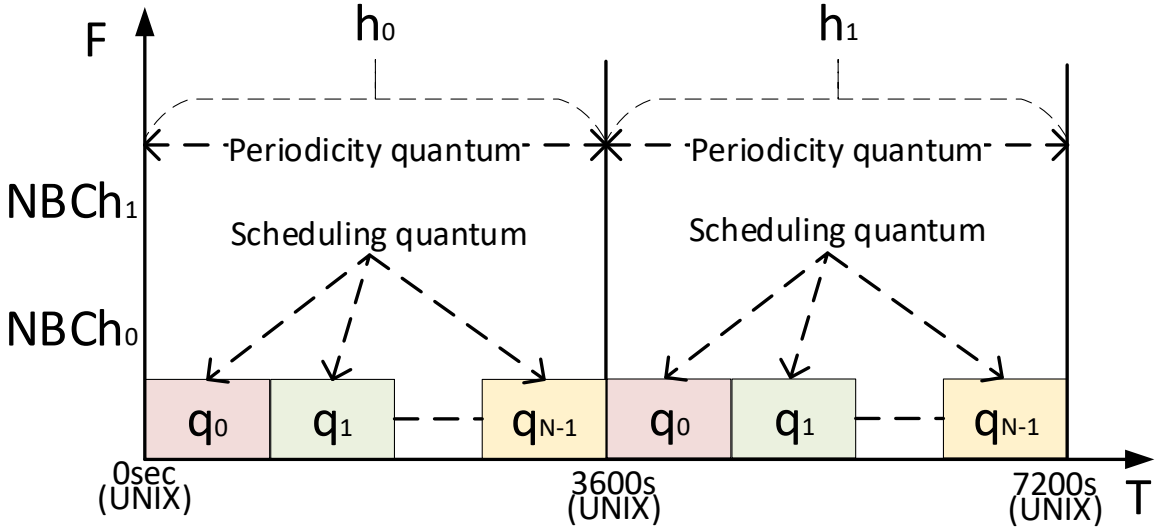
Whisper IoT radio

- Continuously operates from 150 to 960 MHz
- Onboard GPS
- LoRa modulation
- Interface for external sensors and MCU

Whisper gateway



Whisper MAC protocol: FTDMA core



Periodicity quantum

Periodicity of a periodic slot is multiple of ***"periodicity quantum"***

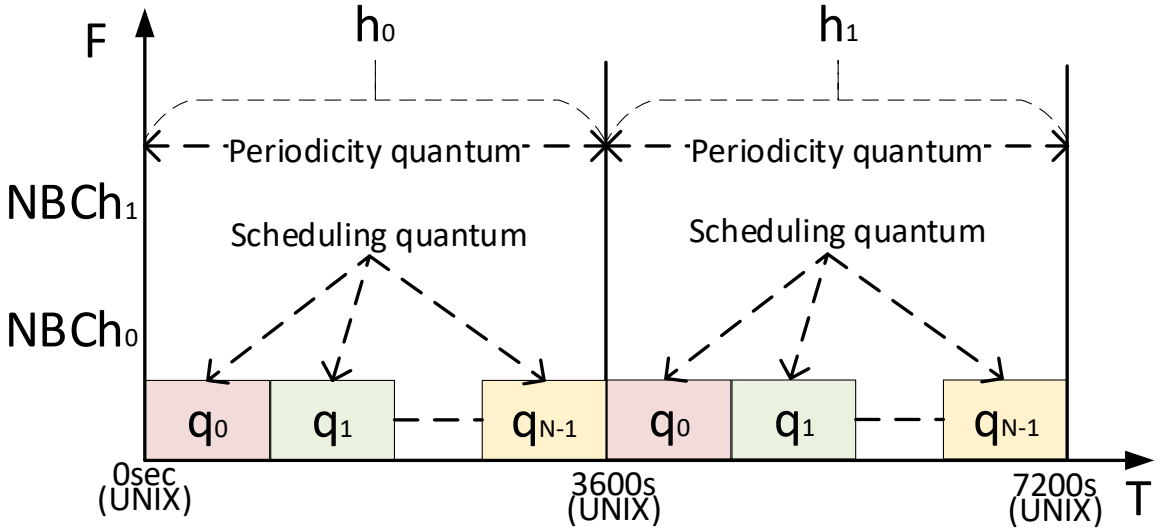
Scheduling quantum

"Scheduling quantum" is the min time precision required in the scheduling

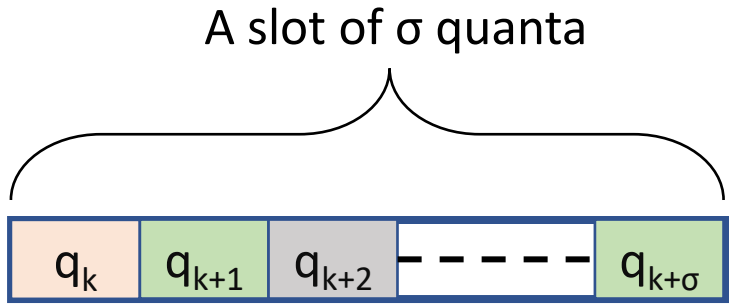
Relation between these two?

Each periodicity quantum has same number of scheduling quantum

Whisper MAC protocol : FTDMA core



Slot allocation



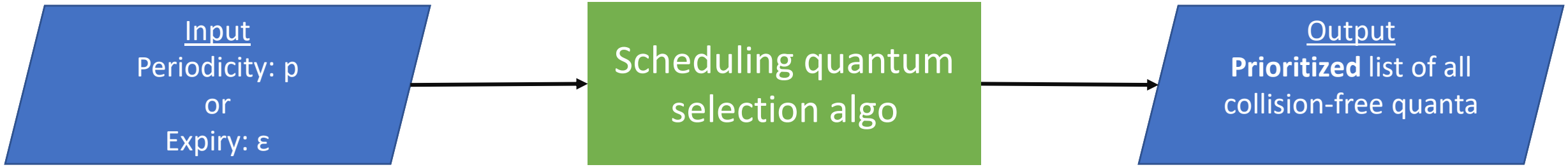
What is a slot?

Each radio is allocated slot(s) for communication

How is a slot allocated?

Three steps of slot allocation process:
1. Scheduling quantum selection
2. Channel selection
3. Slot selection

Whisper MAC protocol: Slot allocation process



Goal	**Underneath concept**	**Optimization target**
Find collision-free quanta at “p” periodicity or before “ε”	Linear Diophantine equation	Accommodate as much request as possible

Whisper MAC protocol: Slot allocation process

Goal

Find a channel in compliance with FCC duty cycle limit

Underneath concept

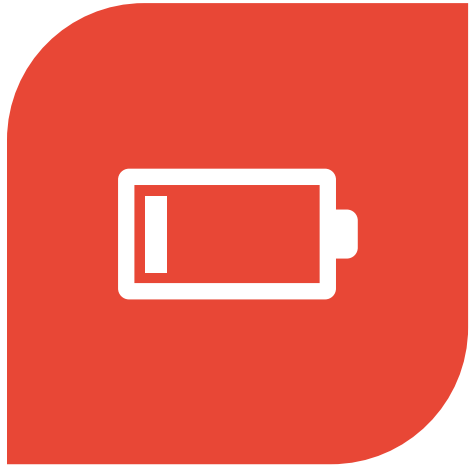
Dynamic binary counting table based on linear Diophantine equation

Optimization target

Maximum utilization of bandwidth

Dynamic spectrum access: Challenges

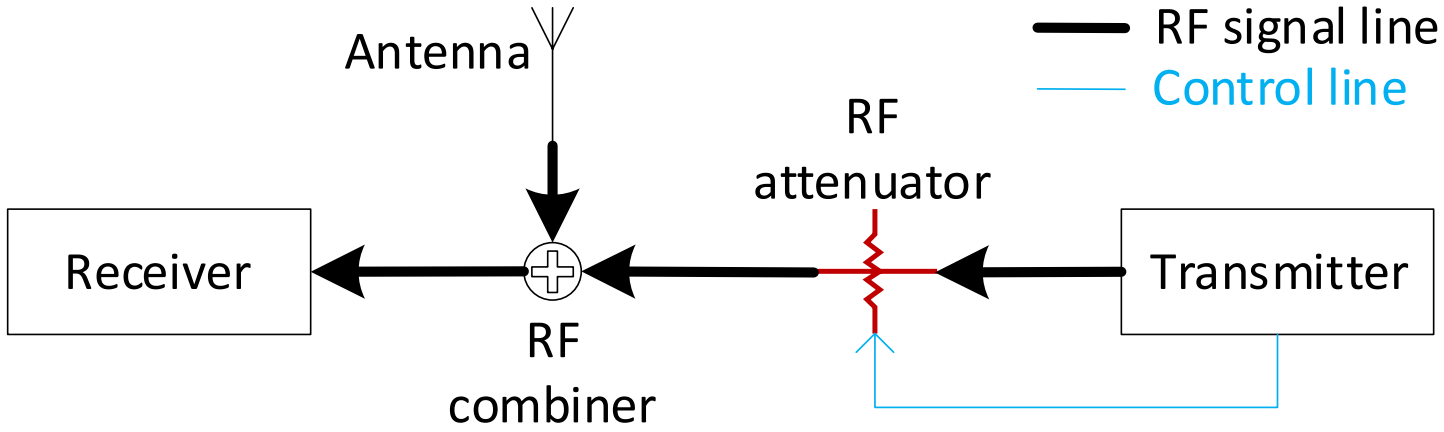
Long distance between gateway and clients



Power constrained IoT device

Dynamic spectrum access: Spectrum awareness

Enabling spectrum awareness at gateway through **carrier sensing**



Why NOT conventional RF energy measurement?

Frame can be received even below the noise floor by Whisper radio having *very low MDS*

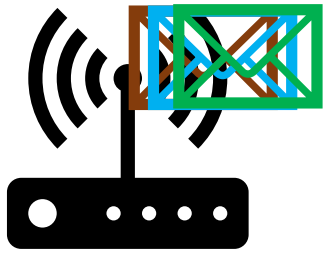
Job of RF attenuator?

Attenuate the signal to emulate a TX from a remote IoT device

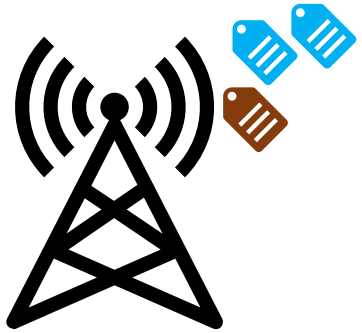
How RF combiner helps?

Combines the ambient RF signals with the emulated TX

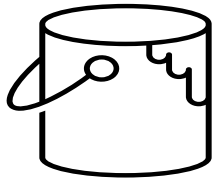
Dynamic spectrum access: Spectrum exploitation

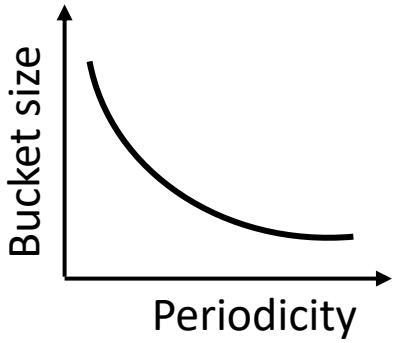


IoT client device



Gateway





Why NOT carrier sensing on client side?

IoT client devices are power constrained

How's the bucket filled (emptied)?

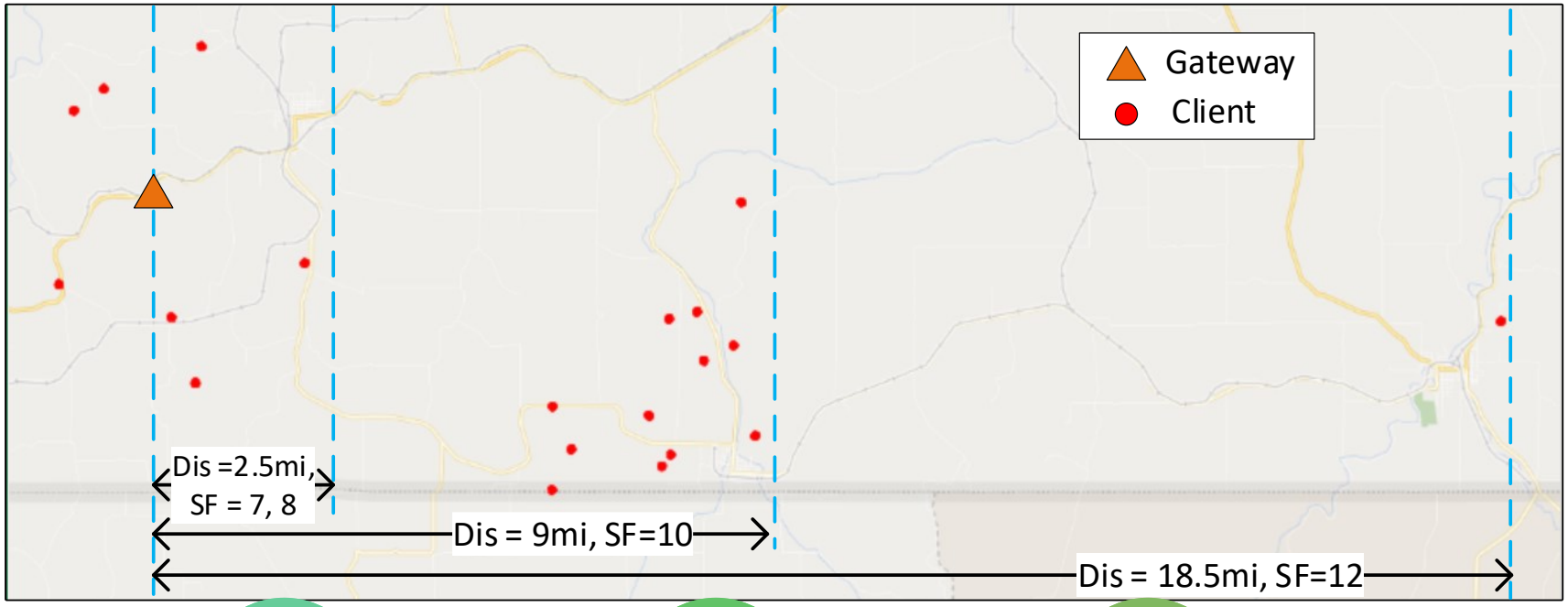
Num of added (removed) Tokens = Num of consecutive successful (failed) frame reception from a client

How does the bucket size play a role?

Small size + short-term interference = faster overflow

Large size + Long-term interference = slower response

Evaluation in real-world: Setup



Farm
- 8500 acre, 17 fields
- Eastern Washington

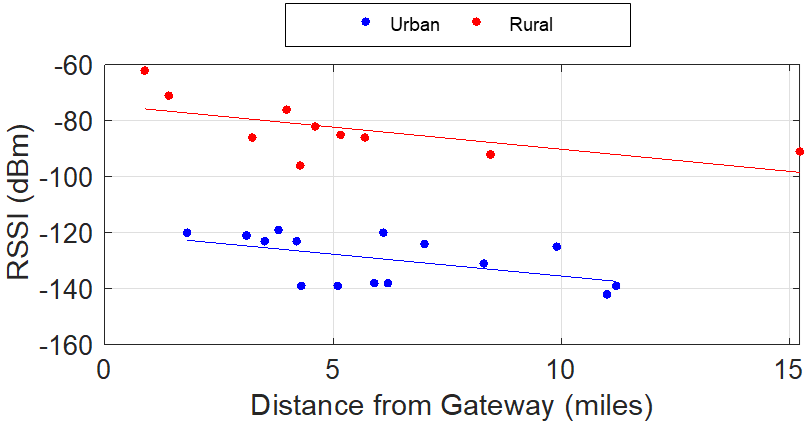
Setup
- 1 gateway
- 20 IoT clients

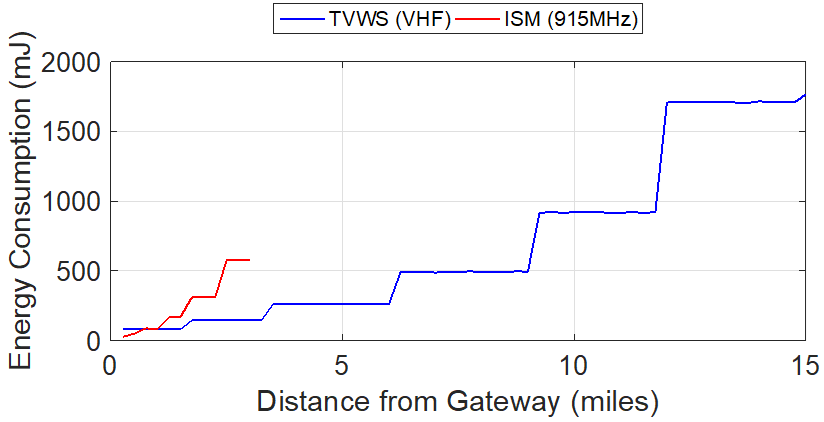
Timeline
- 2.5 months
- Ongoing

Usage
- Third party user
- Agri, food tracing, CO2 monitoring

Gateway
- RPi for edge computing
- TVWS broadband for backhaul

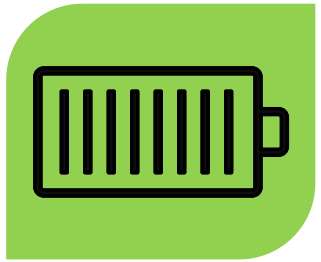
Evaluation in real-world: Results





Avg. over 24hr	Avg.	Max	Min
Throughput (bps)	0.062	0.068	0.06
FDR (%)	98.4	100	97.1
Latency (sec)	2.39	2.43	2.37

- **5x** range than ISM bands
- **>15 miles** in rural settings
- **>12 miles** in urban settings



Power consumption is **less** than ISM US915 band

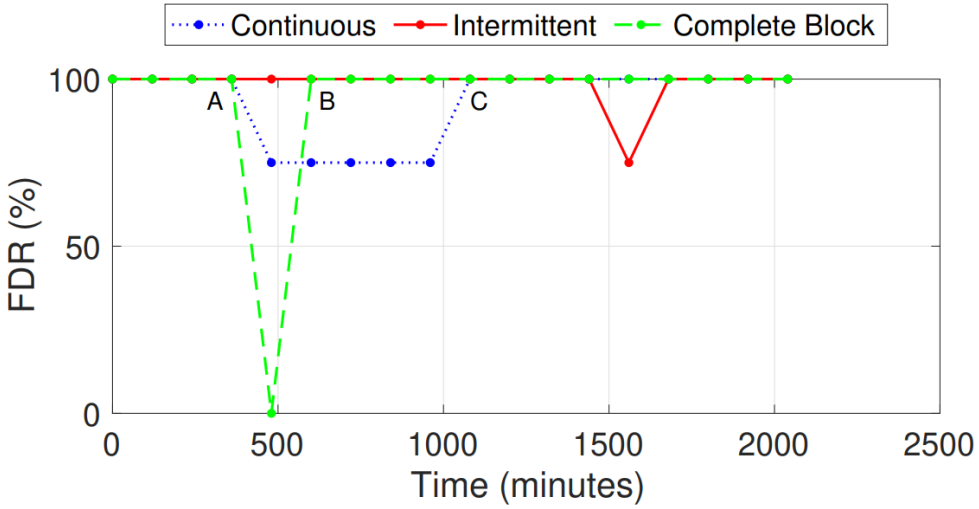
Up to the mark performance in standard networking metrics

Evaluation in real-world: Results

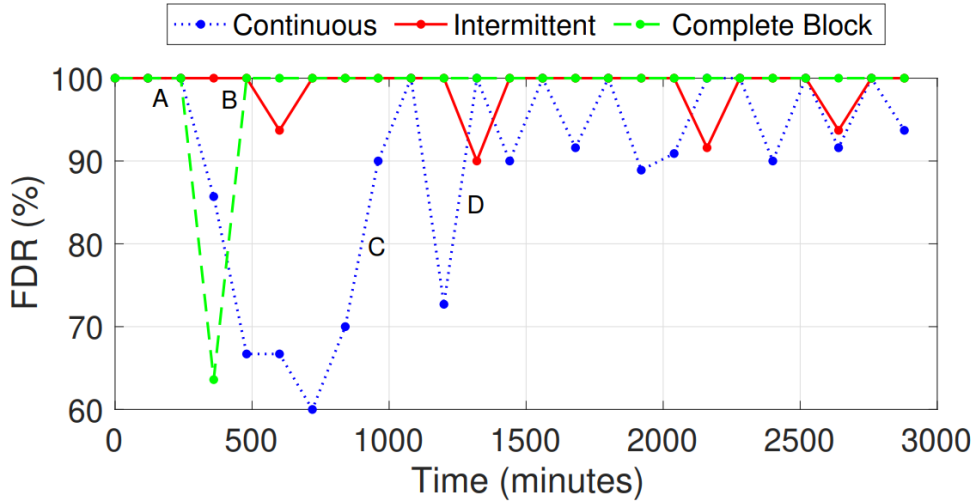
Performance in presence of interference

> **Channel switching** has been triggered by the DSA handler

Interference
near an IoT client



Interference
at the gateway

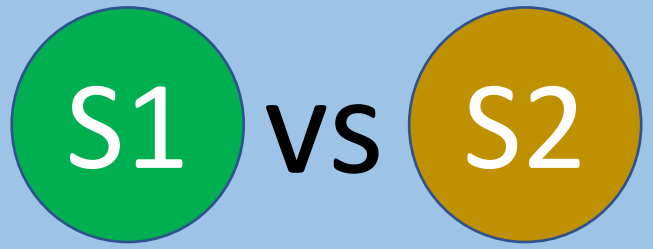


Simulation: Setup

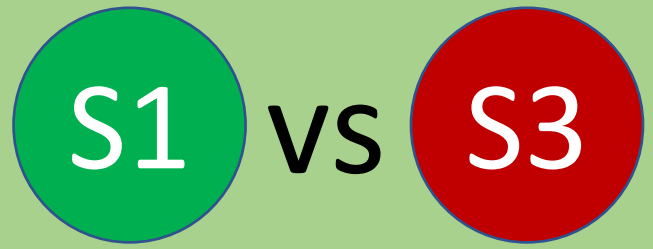
Whisper MAC in TVWS spectrum

Whisper MAC in ISM band

ALOHA in TVWS spectrum

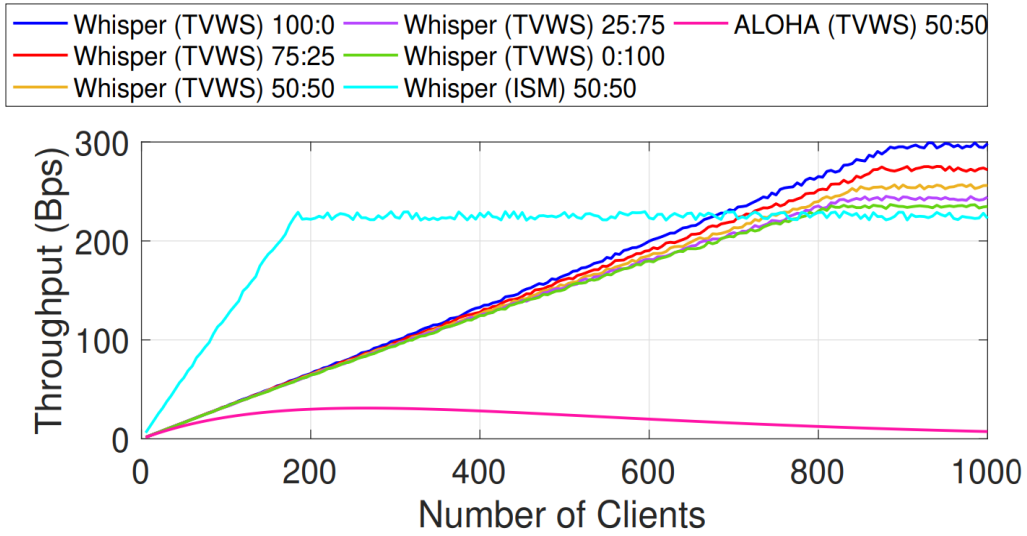


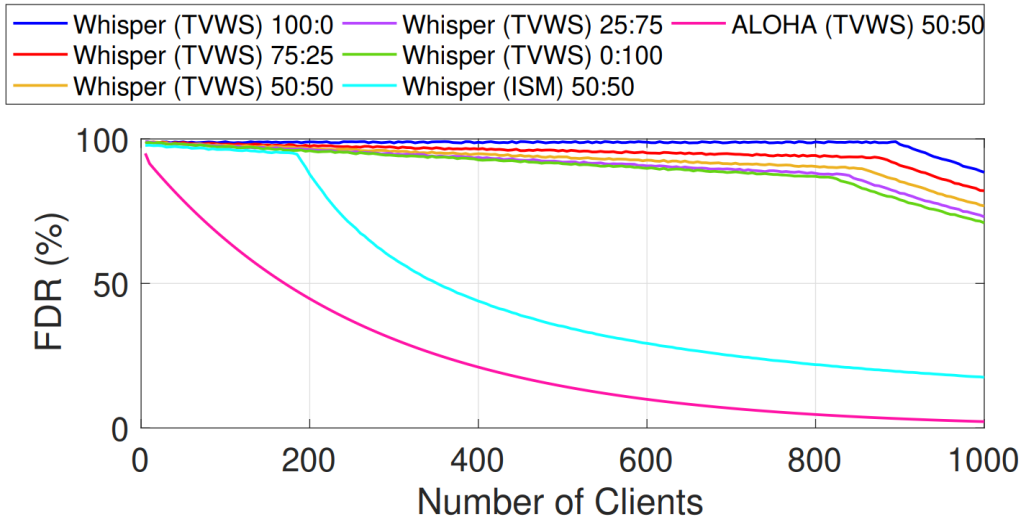
→ Role of **wide** TVWS spectrum in **scaling**



→ Whisper MAC vs mainstream IoT MAC

Simulation: Results





More traffic in TVWS spectrum

- **5x** more traffic than US915 with TV channels

Whisper MAC performs better

- **8x** better than mainstream IoT MAC protocols

Summary

Mainstream IoT solutions in ISM bands are bottlenecked by range and bandwidth

We've developed Whisper, the first IoT solution that operates over TVWS

We made a 2.5-month-long real-world deployment of Whisper

We have achieved very long-range communication at low-power

Thank you!

Question?

Microsoft

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