Frequency Configuration for LP-WANs in a Heartbeat

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Find out more about Chime at : https://www.witechlab.com/chime.html

Future City-Scale Internet-of-Things

Low-Power
Wide-Area Networks
(LP-WANs)

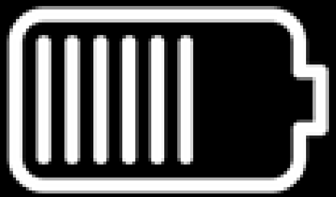
LoRaWAN
Operates in 915 MHz ISM band

Bandwidth
125 KHz

Range
1-10 kms

Battery Life
10 years on AA battery

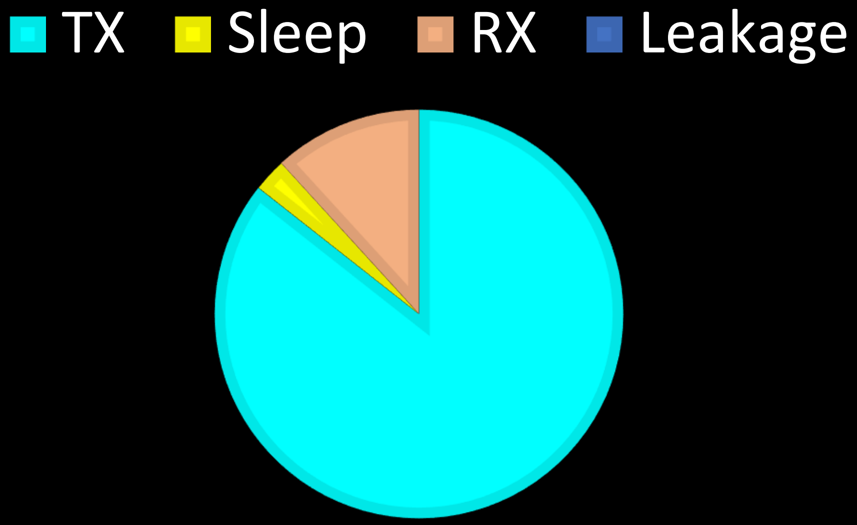
Battery Life of a LP-WAN client



Battery Life
10 years on AA battery

Fastest Data Rate Only

BATTERY USAGE



Wireless Communication
97% of battery usage

Urban Wireless Impairments ⇒ Significantly Lower Battery Life

Saving power in LP-WANs

↑ Received Signal Power ↑ Higher Datarate ↓ Transmit Time ↓ Battery Consumption

Factors affecting the received signal power

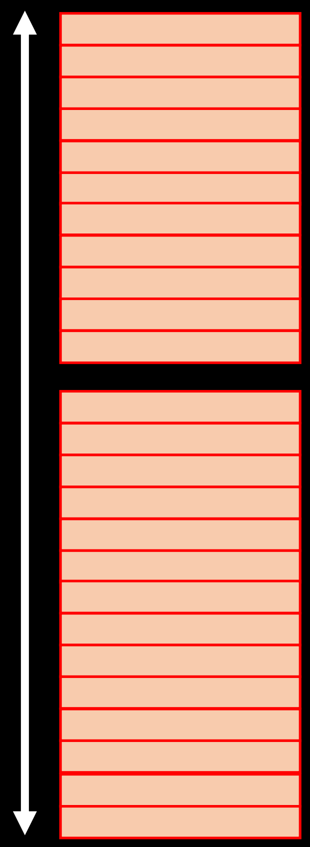
Fading
Interference
Obstructions
} Client cannot control

Frequency of Operation
Datarate
} Client Config

Frequency Configuration

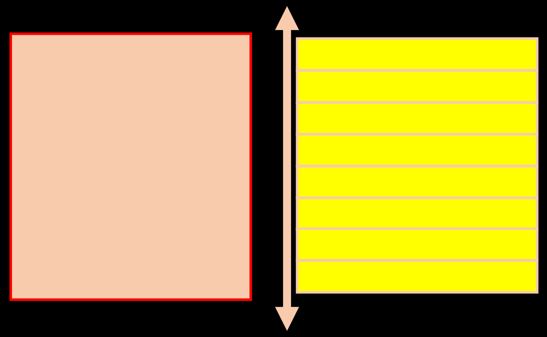
902 MHz

915 MHz
ISM Band



928 MHz

915 MHz



916 MHz

26 MHz
x 8 freq configs per MHz

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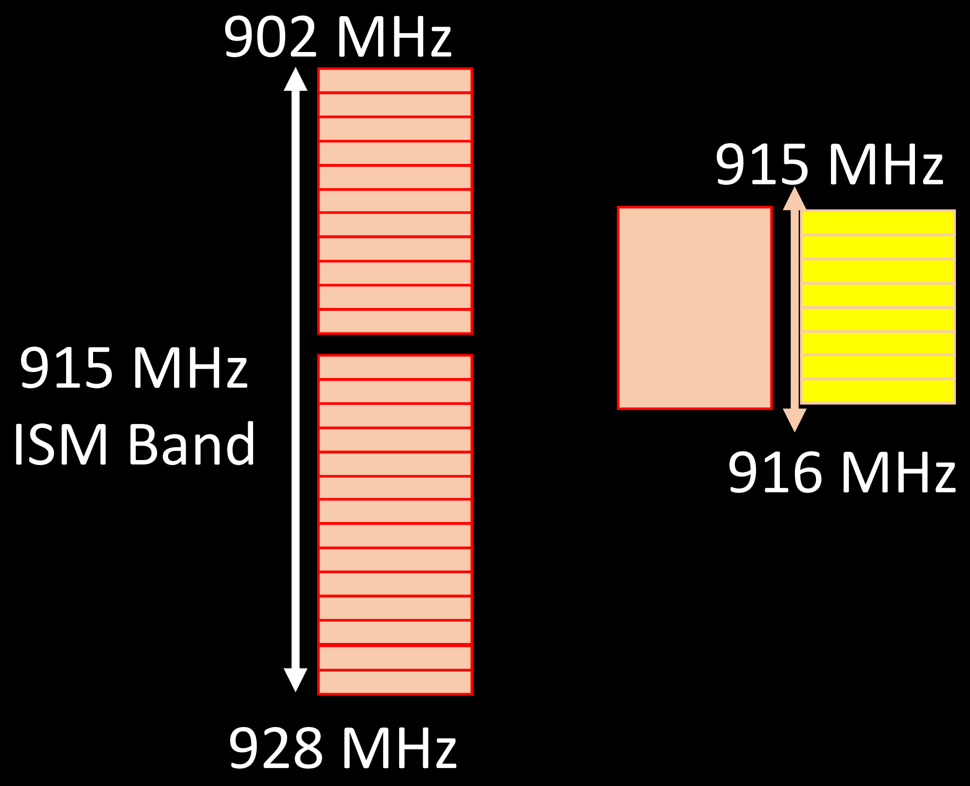
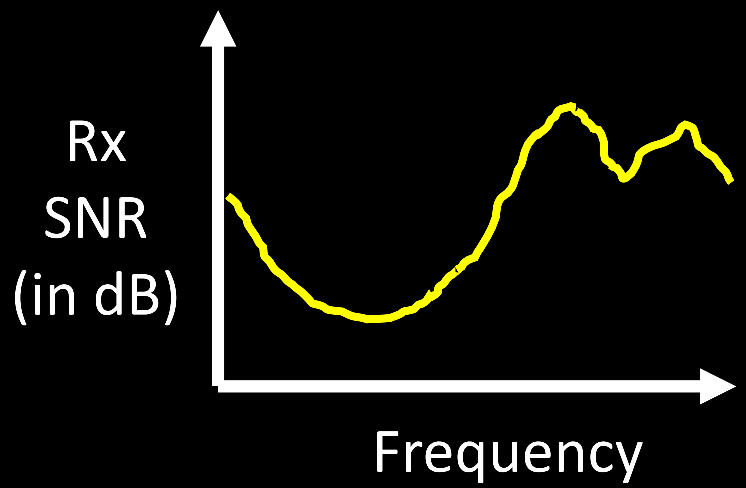
208 frequency configurations

Frequency Configuration

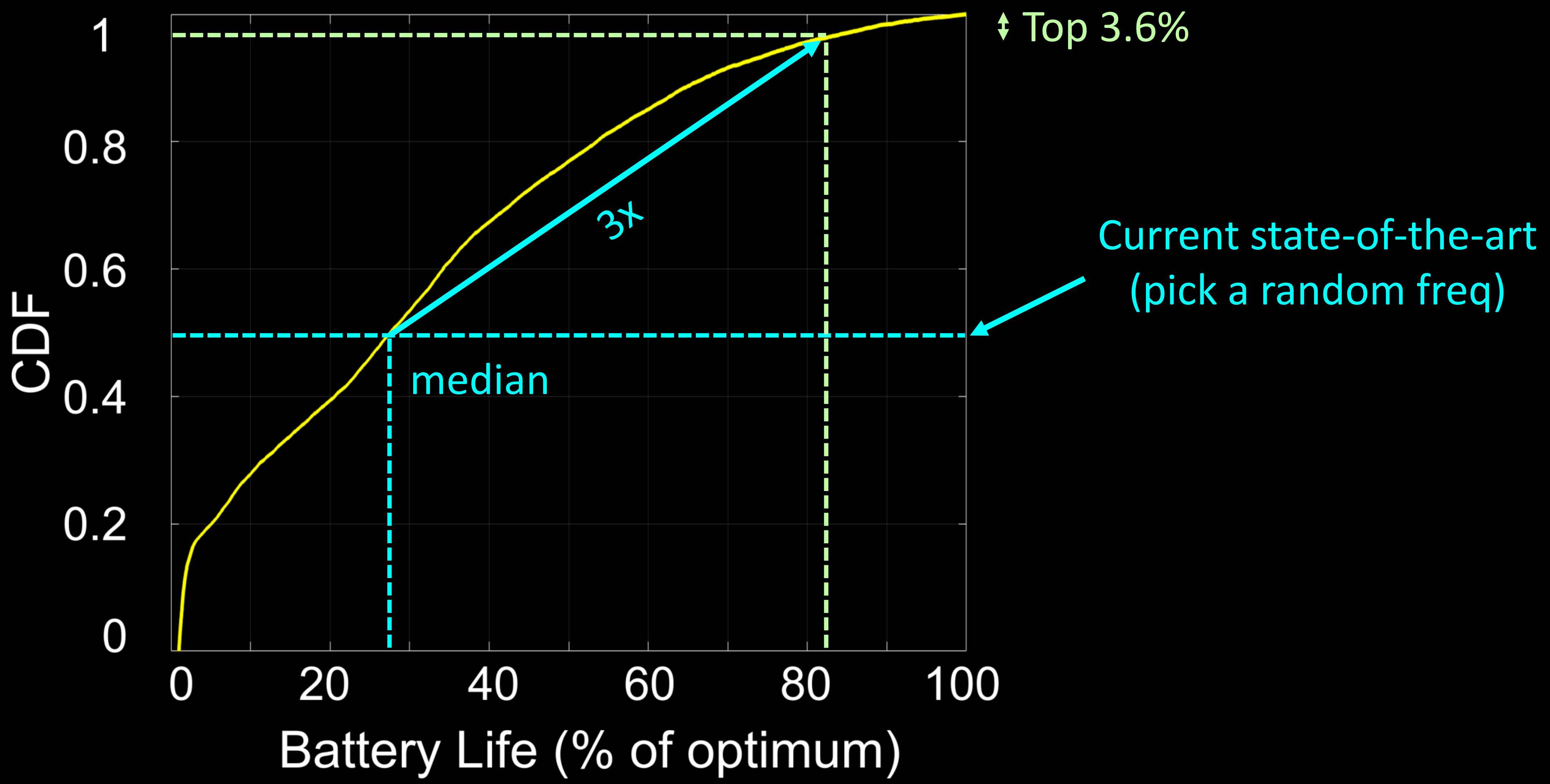
Too many frequency configurations to choose from



Large variations in received signal power



Campus-Scale Motivation Study

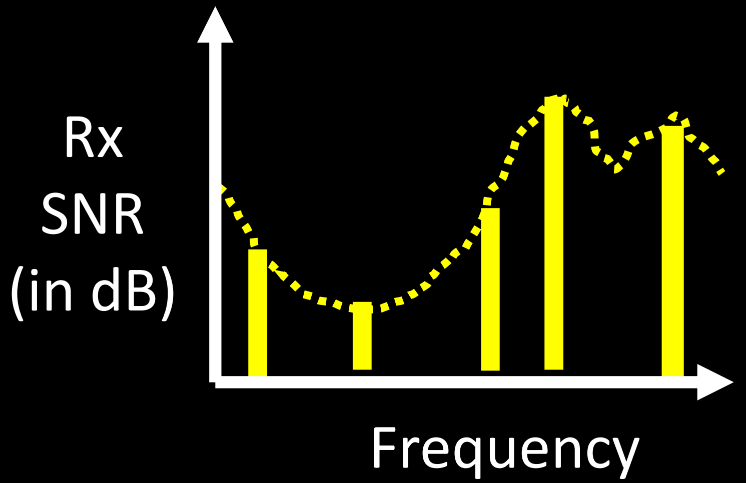


Brute force approach for frequency configuration

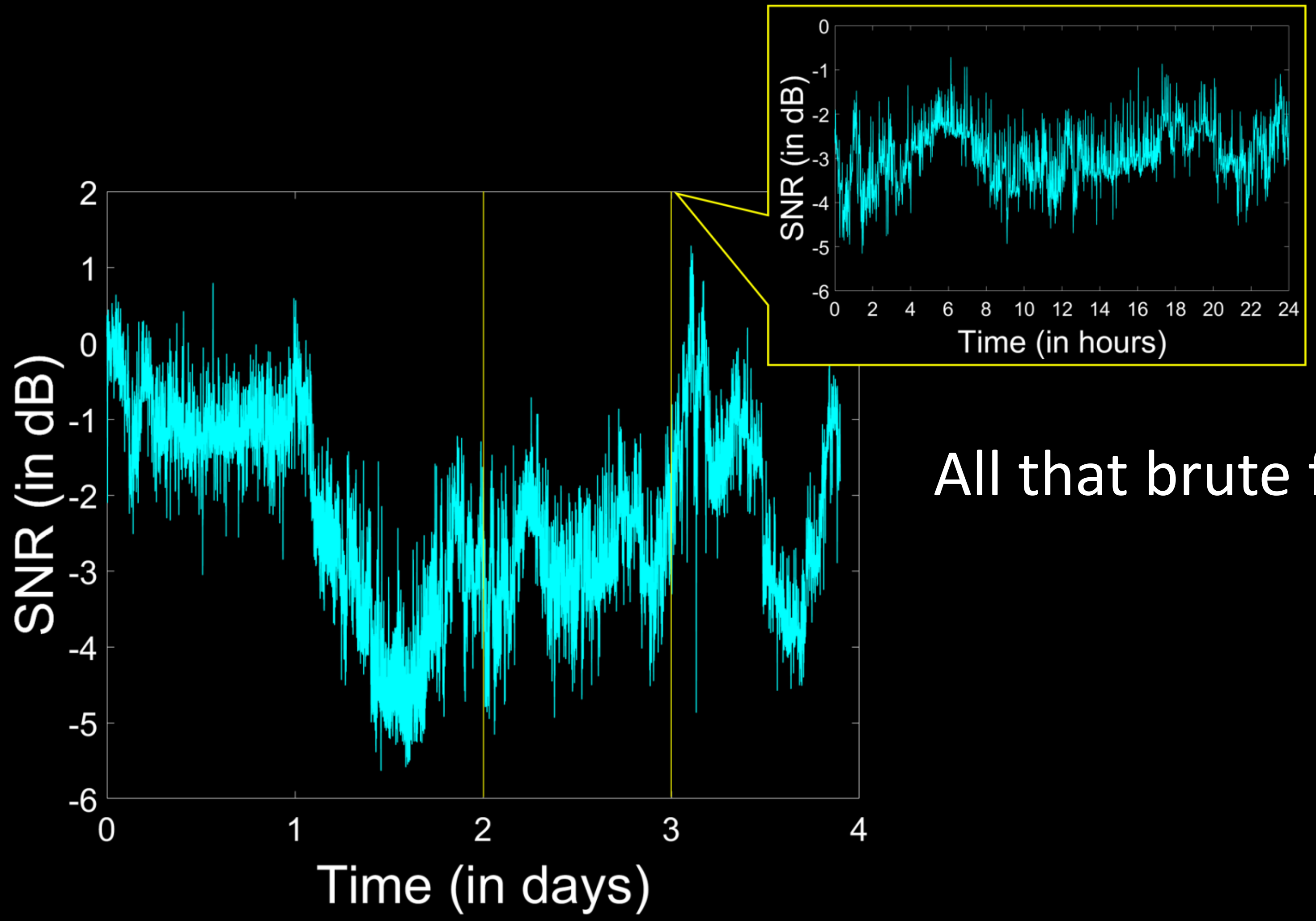
\# 100s of packets

45 minutes

6.6% battery capacity



Wireless channel quality changes every few minutes



All that brute force effort rendered futile

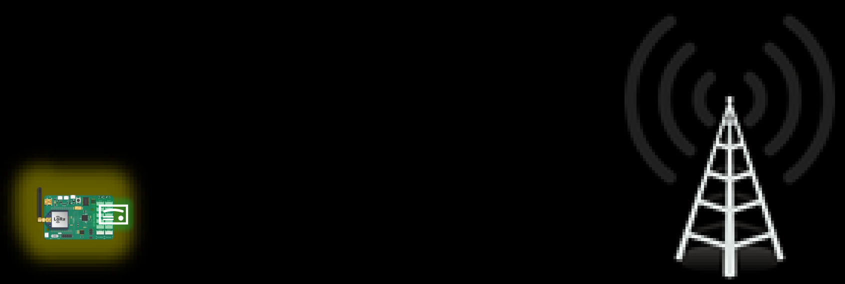
In fact, even interpolation-based methods are ineffective in estimating a good frequency.

Can low-power clients find a good frequency-of-operation, without sacrificing their battery life?

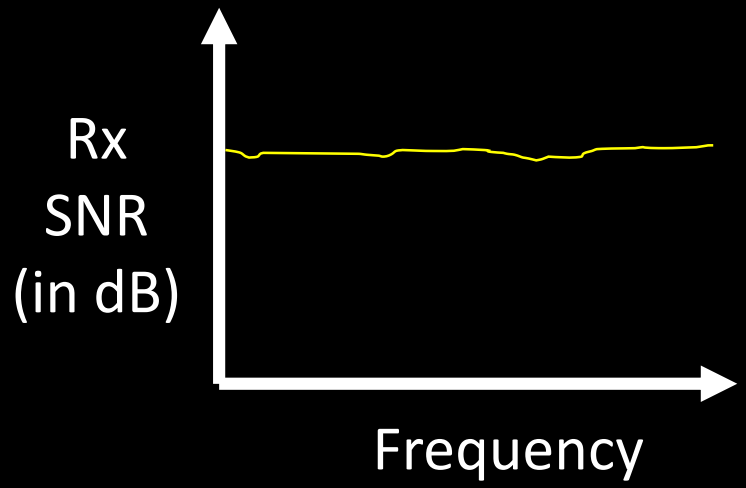
Chime – Frequency Configuration for LP-WANs in a Heartbeat

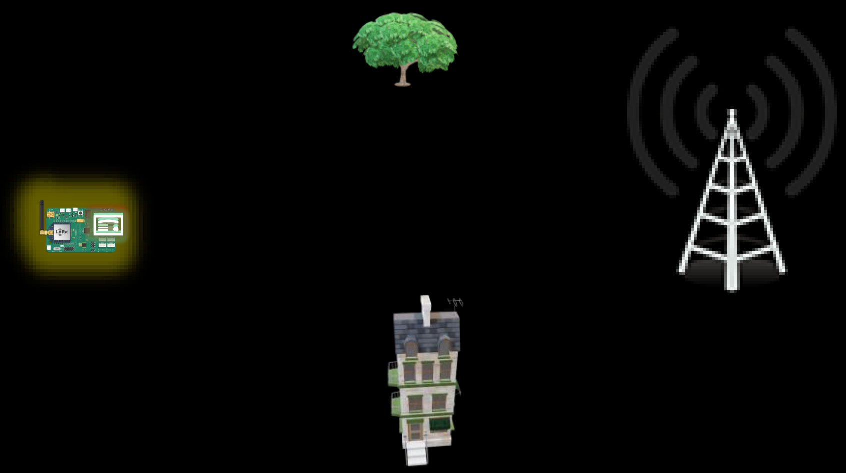
- First system which can estimate an optimal frequency using one packet
- Evaluated over a 0.329 sq.km. testbed at CMU campus in Pittsburgh.
- Achieved average 230% improvement in client battery life

What causes signal power to vary across frequencies?

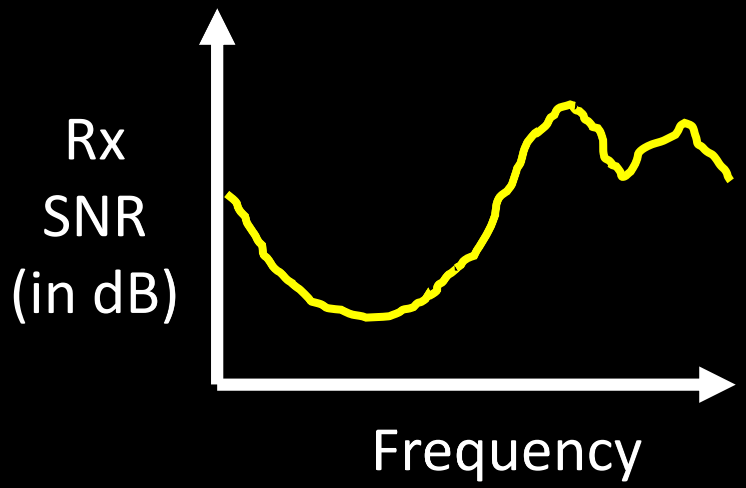


RX signal power flat across frequencies

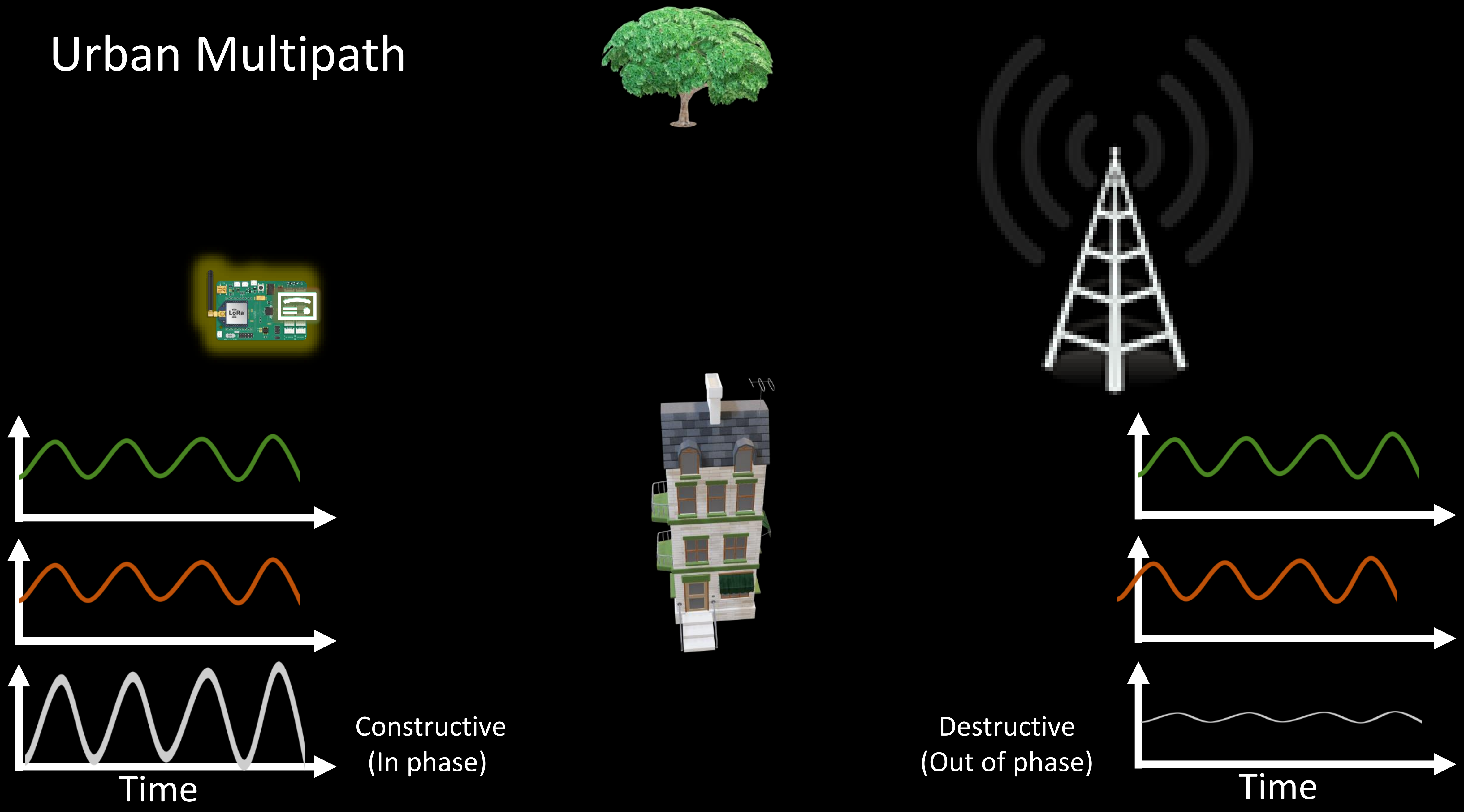




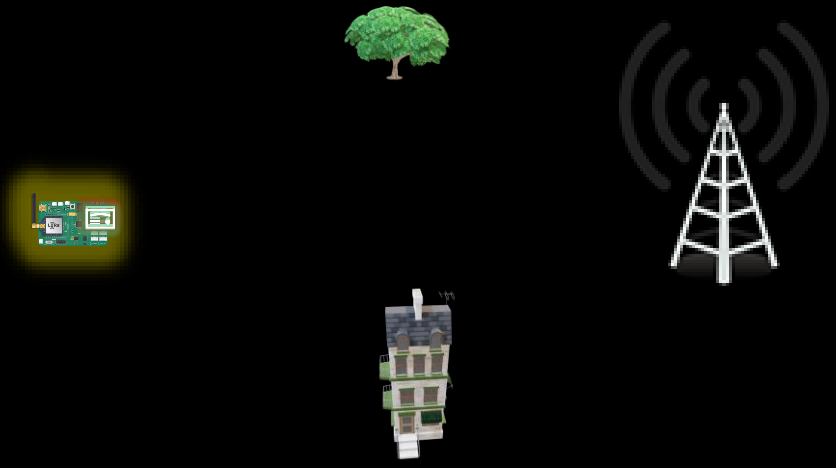
RX signal power varies across frequencies



Urban Multipath



Urban Multipath

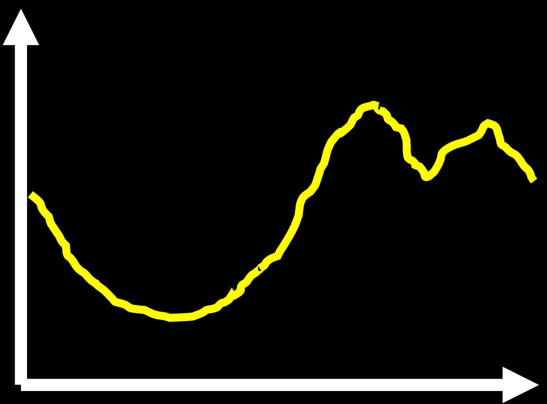


Constructive
(In phase)

Destructive
(Out of phase)

Phase of each path = $2\pi f \tau$

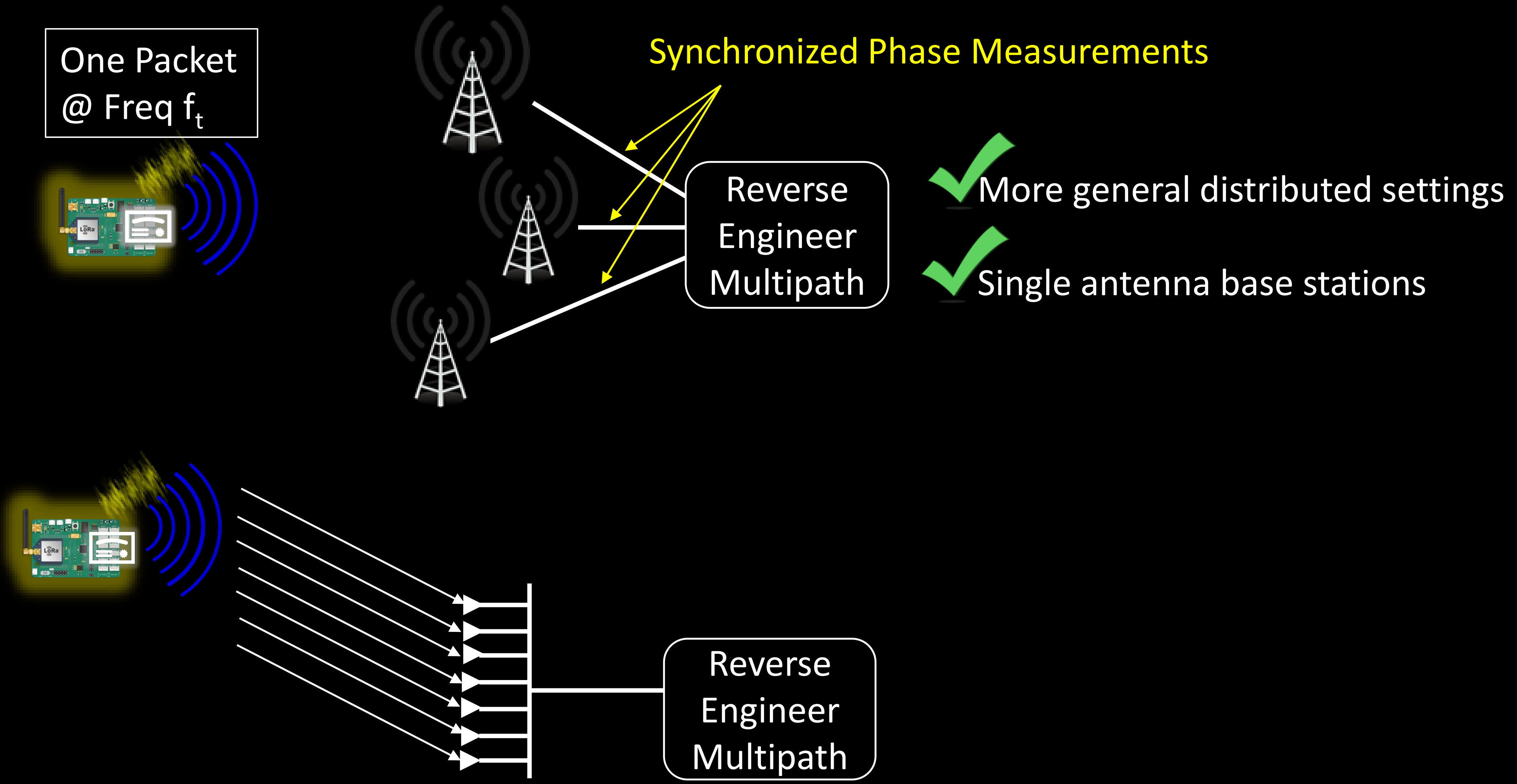
Time-of-flight



Chime's approach

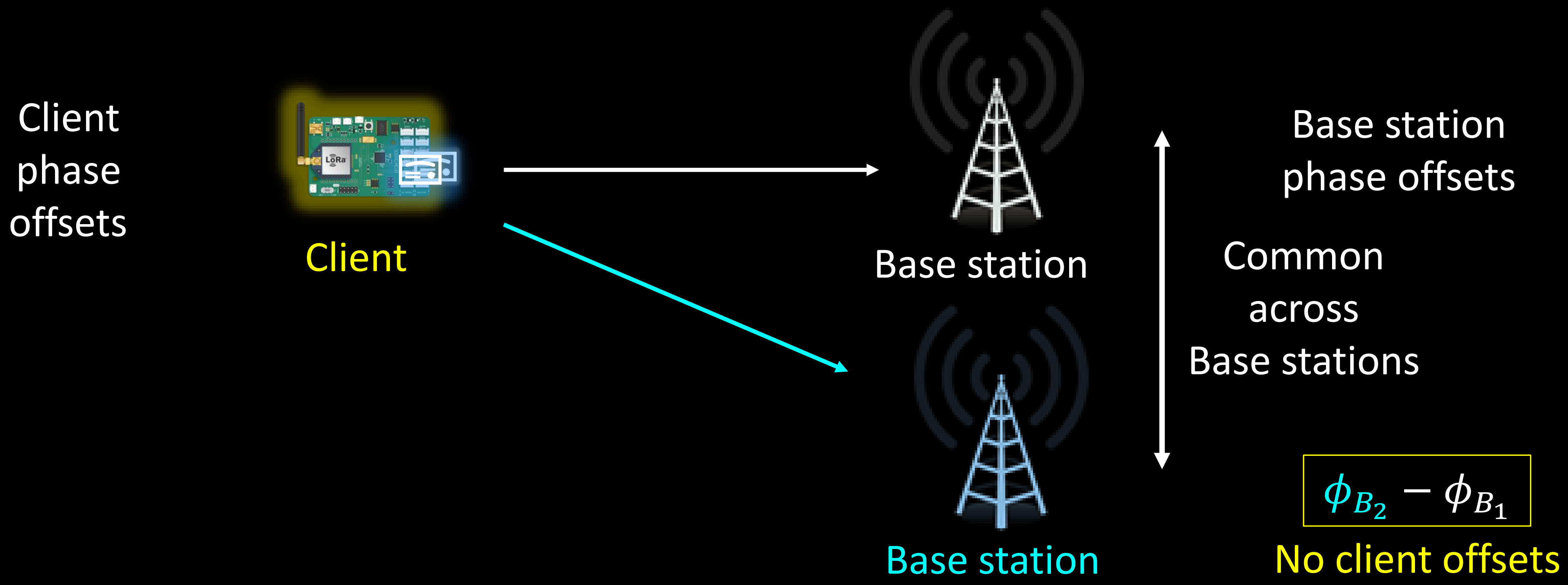
Estimate the multipath $\Rightarrow$ Estimate Rx SNR across frequencies

Chime – Frequency Configuration for LP-WANs in a Heartbeat

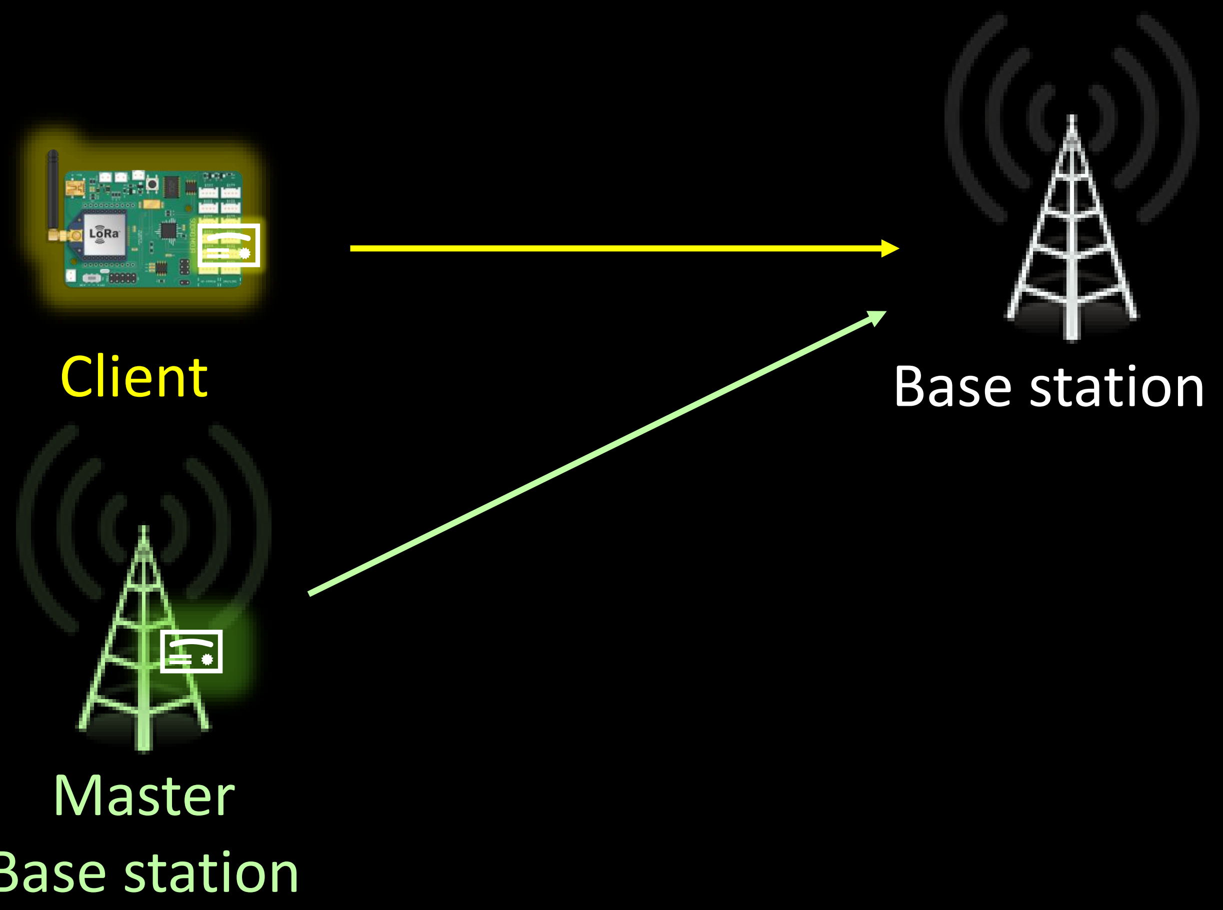


Typical approach to identify multipath
(R2F2)

Synchronized Phase Measurements



Synchronized Phase Measurements



Each base station adds different offset

Master base station removes base station offsets

Need to measure phases of both at the same time and frequency!

Need to measure phases of both at the same time and frequency!

1. Transmit at same time and frequency

COLLISION!

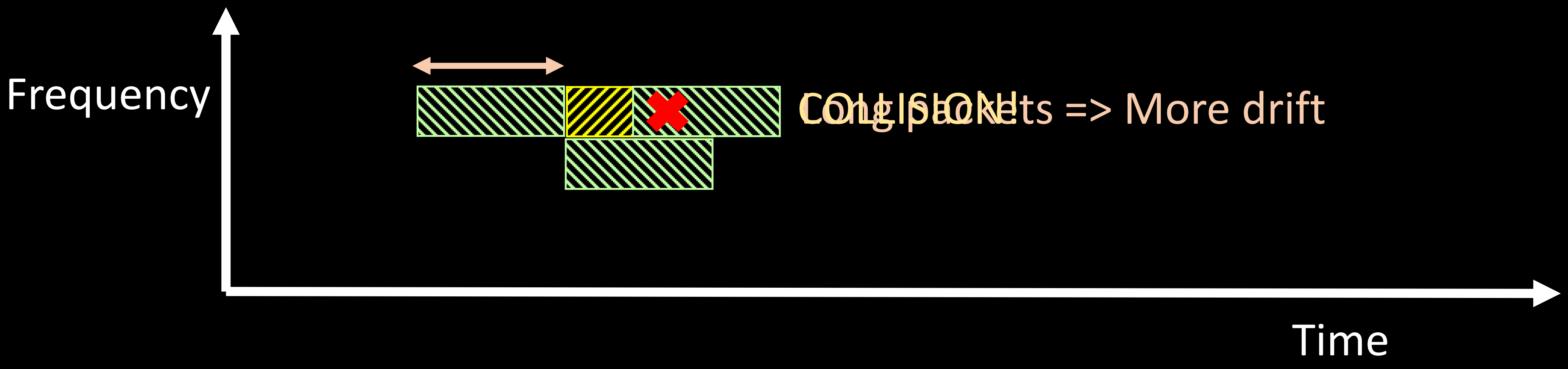
2. Transmit before/after the packet

LP-WAN packets long - Too much drift

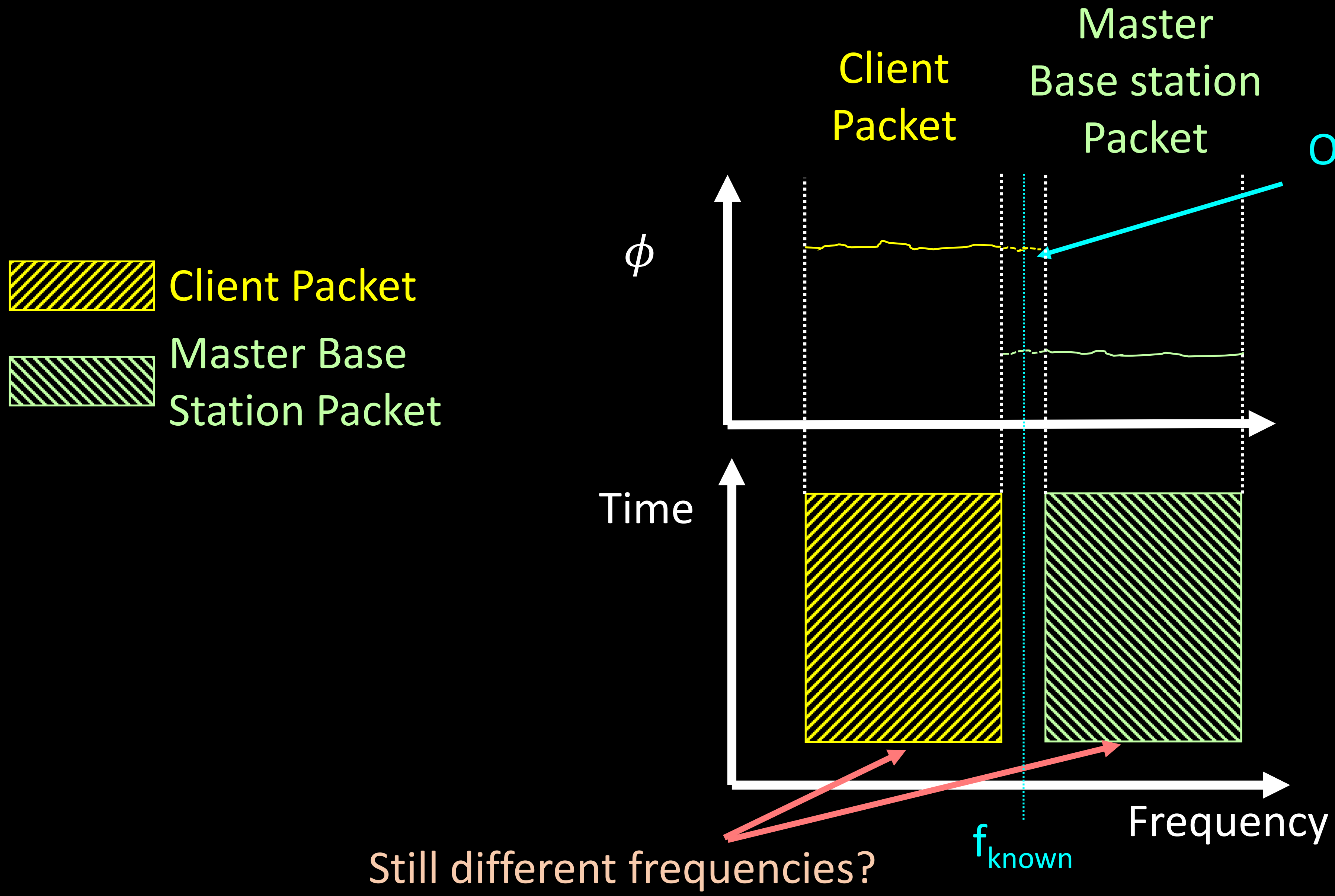
3. Transmit in adjacent frequency band => Chime

Client Packet

Master Base Station Packet



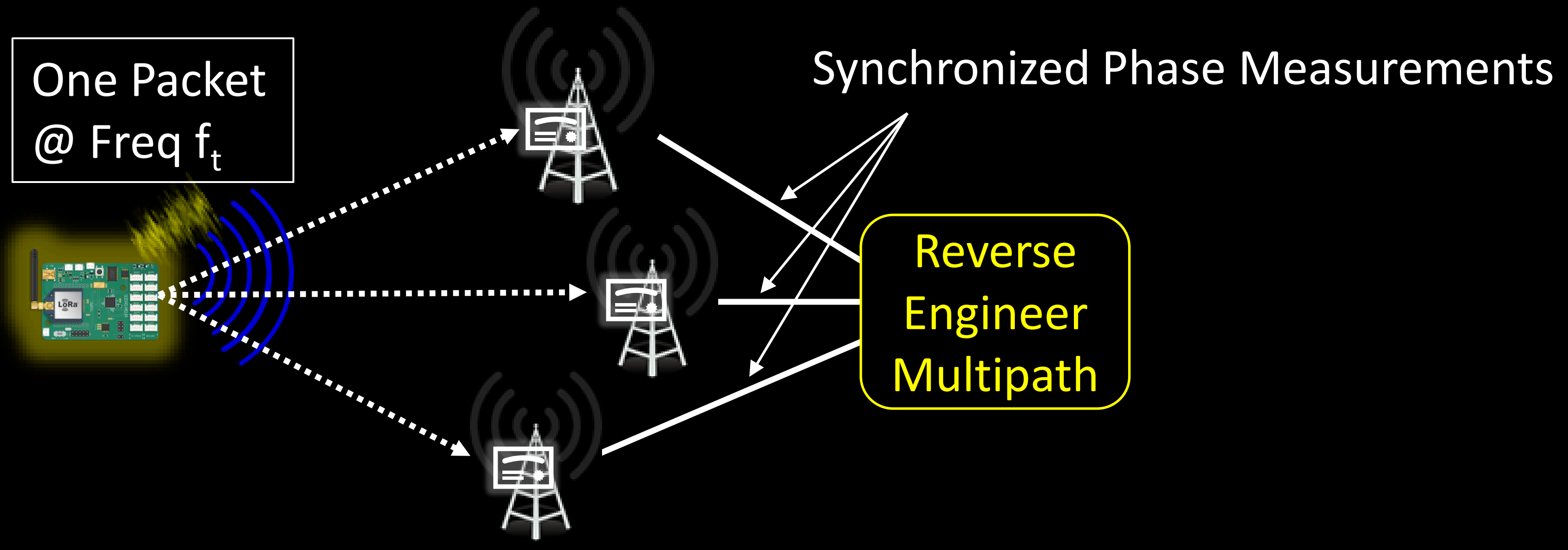
Need to measure both phases at the same time and frequency!



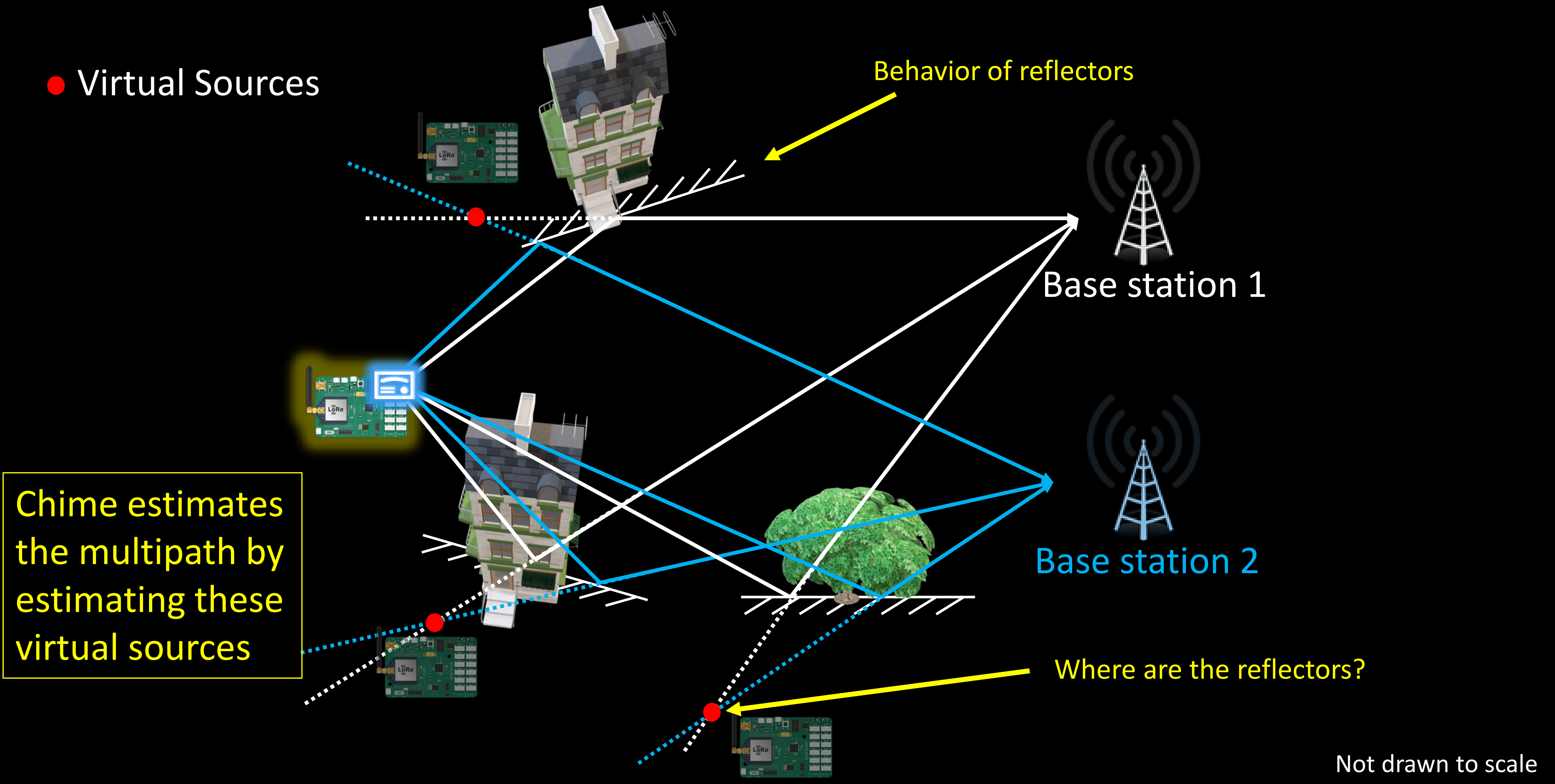
$\phi_{B_M} - \phi_C$

No base station offsets

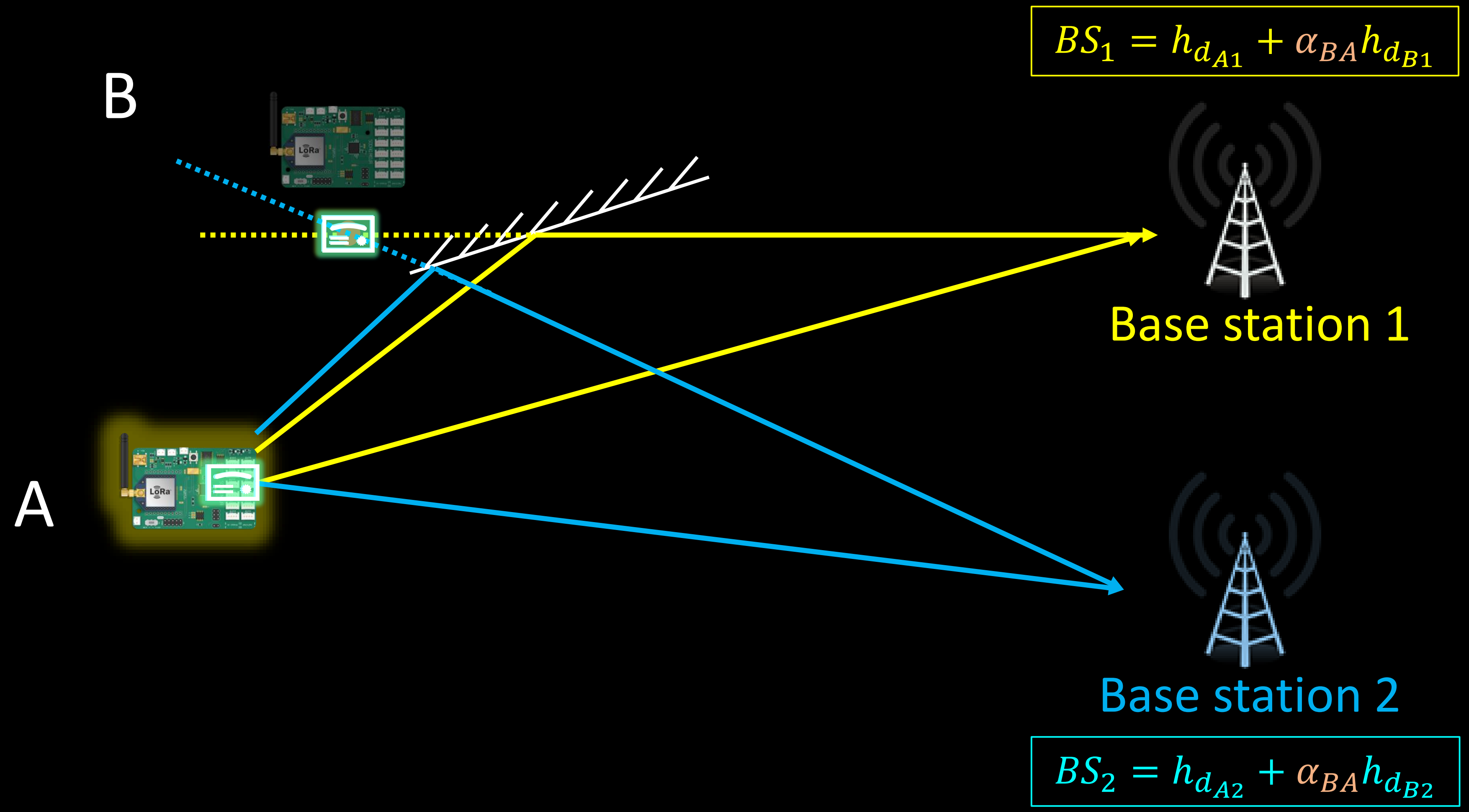
Chime – Frequency Configuration for LP-WANs in a Heartbeat



Reverse Engineer Complex Web of Multipath



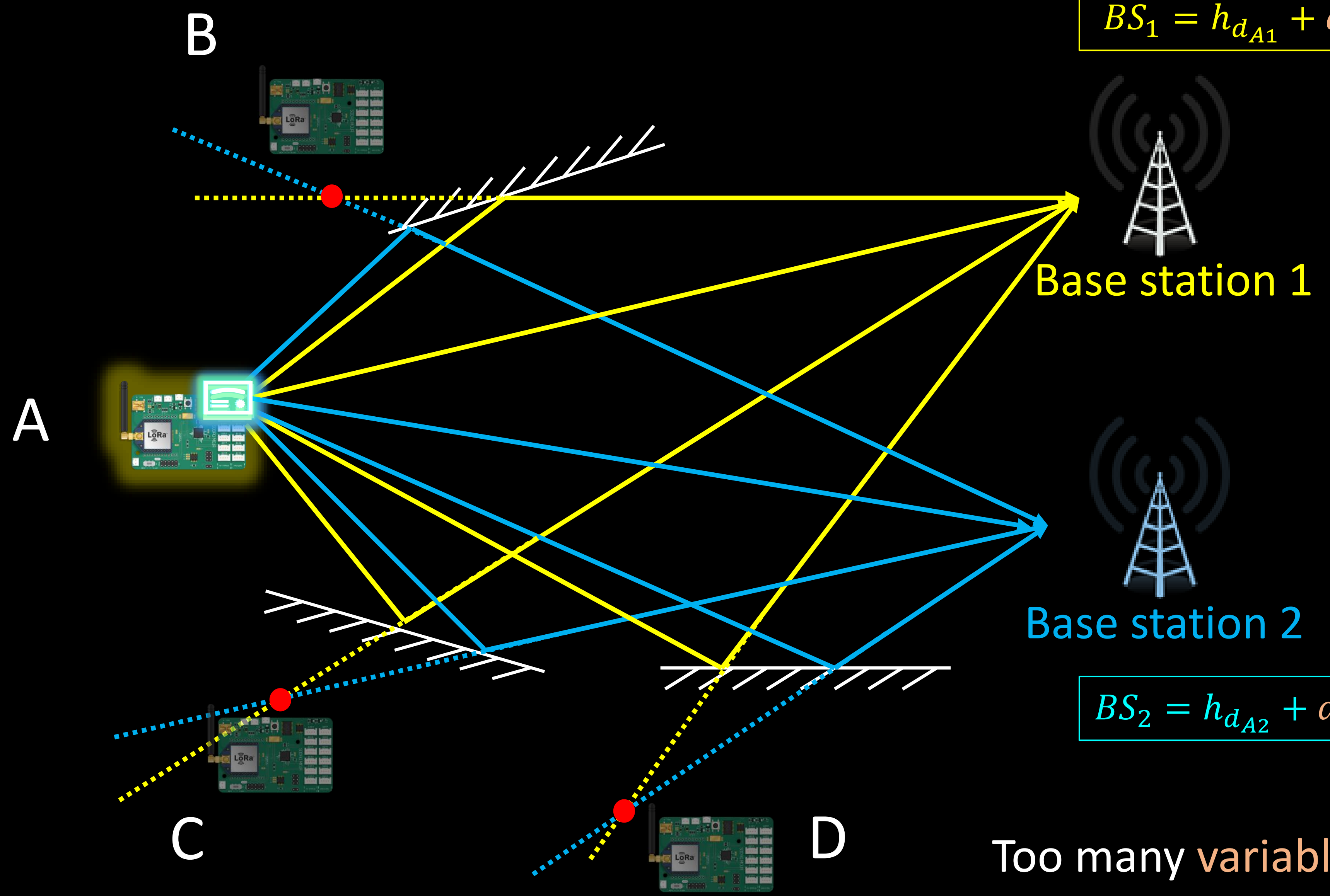
Estimate the behavior of reflectors



Given the location of A and B, we can estimate α_{BA}

Estimate the behavior of reflectors

$$BS_1 = h_{d_{A1}} + \alpha_{BA} h_{d_{B1}} + \alpha_{CA} h_{d_{C1}} + \alpha_{DA} h_{d_{D1}}$$



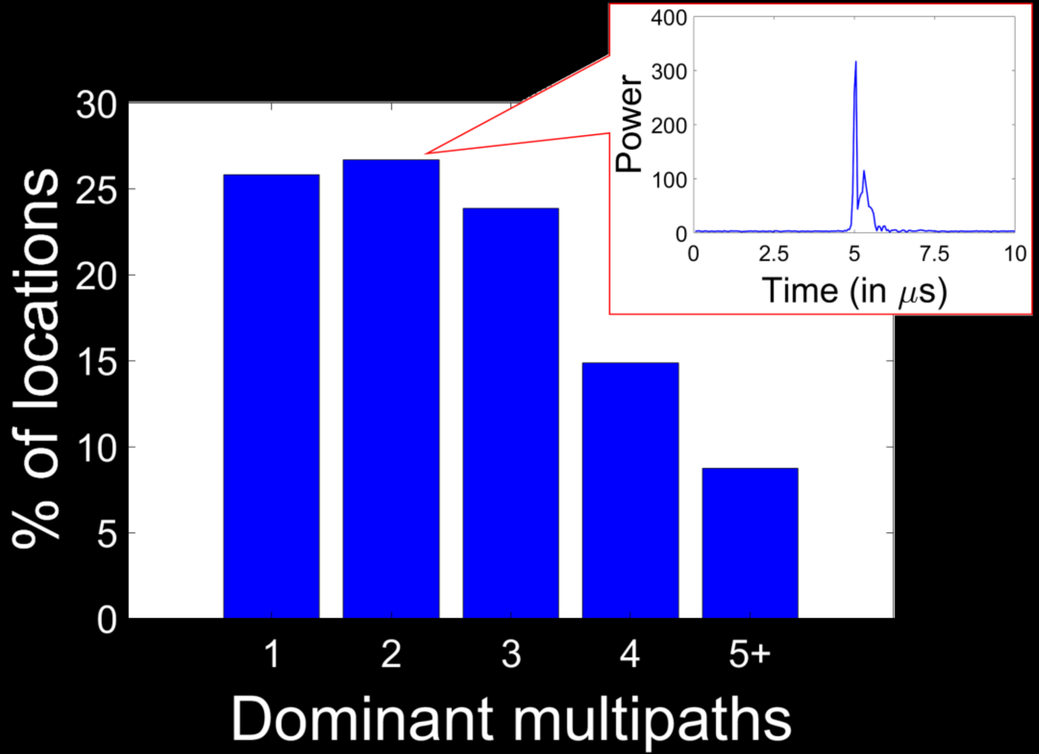
$$BS_2 = h_{d_{A2}} + \alpha_{BA} h_{d_{B2}} + \alpha_{CA} h_{d_{C2}} + \alpha_{DA} h_{d_{D2}}$$

Too many variables, too few equations

Feasibility of multipath model

Multipath model only works if # reflectors < # base stations

Base station



75% of locations only require us to estimate 2 – 3 dominant paths

Where are the reflectors?

$BS_1 = h_{d_{A1}} + \alpha_{BA} h_{d_{B1}}$ $BS_2 = h_{d_{A2}} + \alpha_{BA} h_{d_{B2}}$

Given the location of A and B, we can estimate α_{BA}

For all virtual source locations A and B

Calculate $\{h_{d_{A1}}, h_{d_{B1}}, h_{d_{A2}}, h_{d_{B2}}\}$

Estimate α_{BA}

Check goodness-of-fit $G(A, B) = \frac{1}{\sum_{i=1}^{2} \left| BS_i - h_{d_{Ai}} - \alpha_{BA} h_{d_{Bi}} \right|^2}$

End

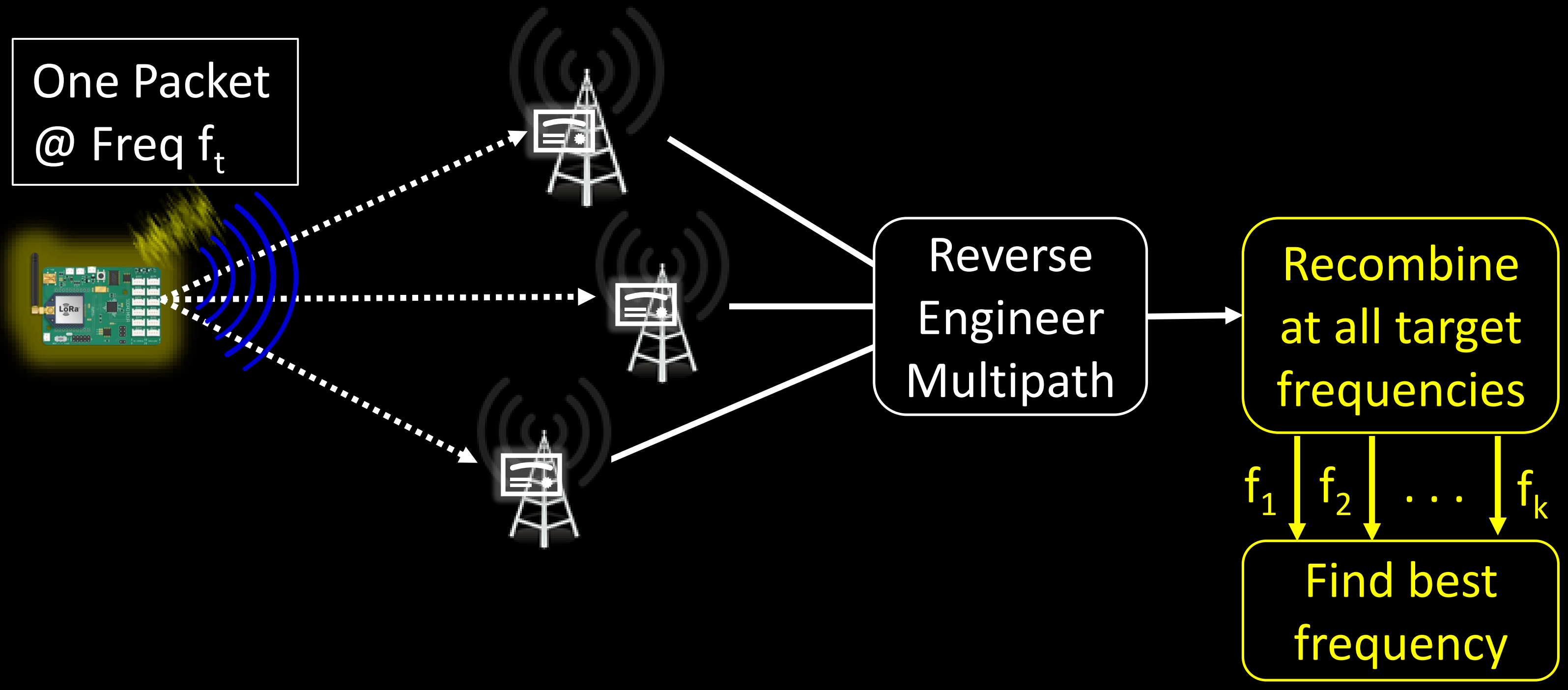
Choose A,B,α_{BA} = $\underset{A,B,\alpha_{BA}}{\operatorname{argmax}} G(A, B)$

Locally convex

Speed up using SGD

(More details in the paper…)

Chime – Frequency Configuration for LP-WANs in a Heartbeat



Chime – Estimating optimal frequency of operation

- For each path,

$$h_{f_1} \rightarrow h_{f_2}$$

- Channel of multiple paths

$$h_{f_2} = h_{f_2@p_1} + h_{f_2@p_2} + h_{f_2@p_3} + \cdots$$

- Channel quality across frequencies

$$\left|h_{f_2}\right|^2 = h_{f_2} h_{f_2}^{\ *}$$

- Choosing optimal frequency-of-operation

$$f_{opt} = \underset{f}{\operatorname{argmax}} \frac{\left|h_f\right|^2}{\text{interference}_f + \text{noise}_f}$$

What about interference and noise?

Wideband base station can measure it to make an informed decision

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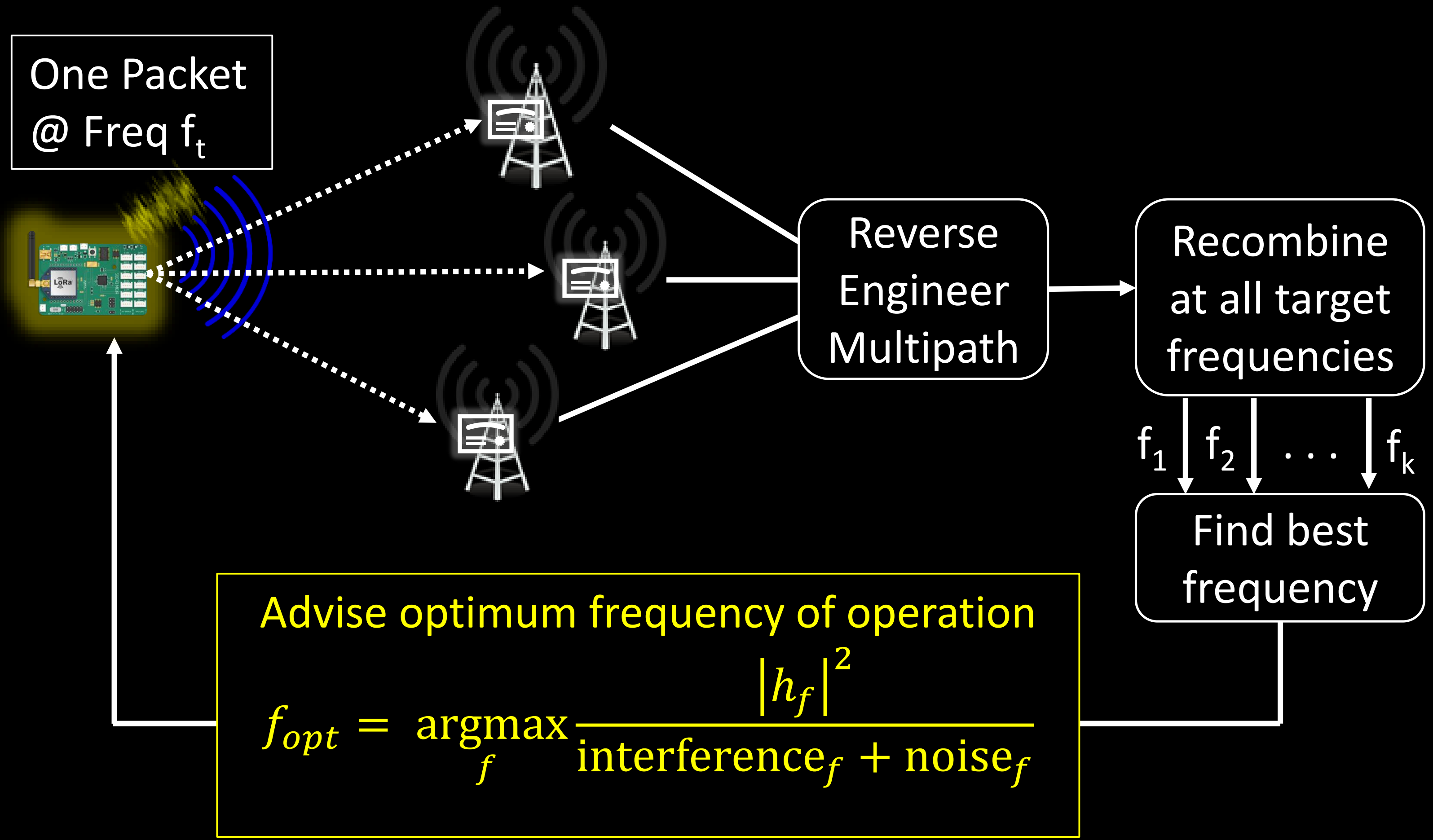


1 packet

few seconds

0.0024% of battery capacity

Implementation and Evaluation

Base station

USRP

GPSDO Clock

Client device

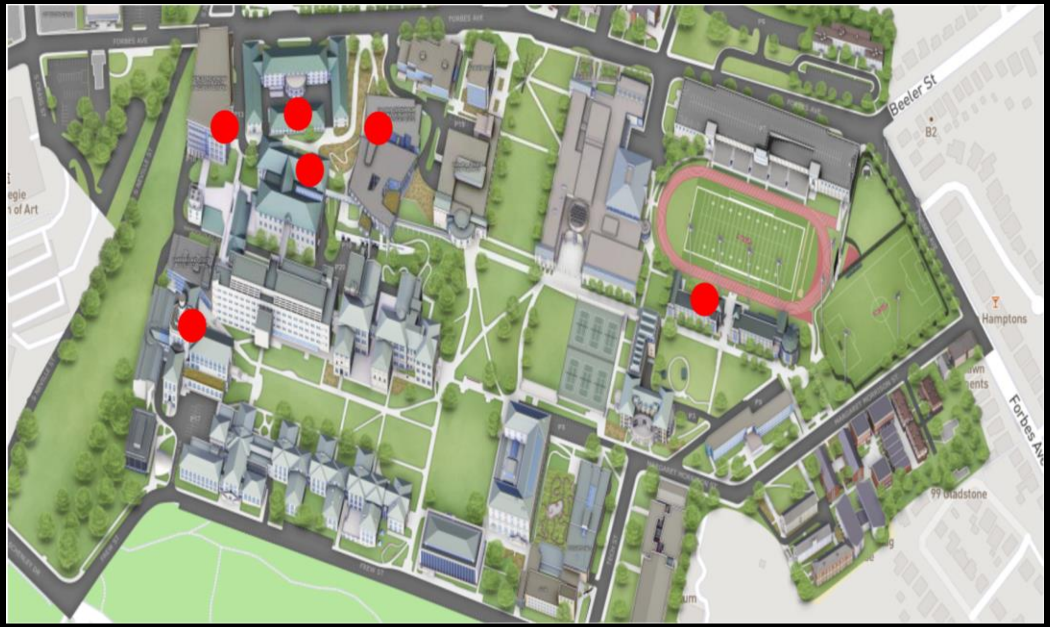
Semtech SX1276
LoRaWAN transceiver

Key facts

SF 10 | 125 KHz BW
Processing in the cloud

Evaluation Testbed

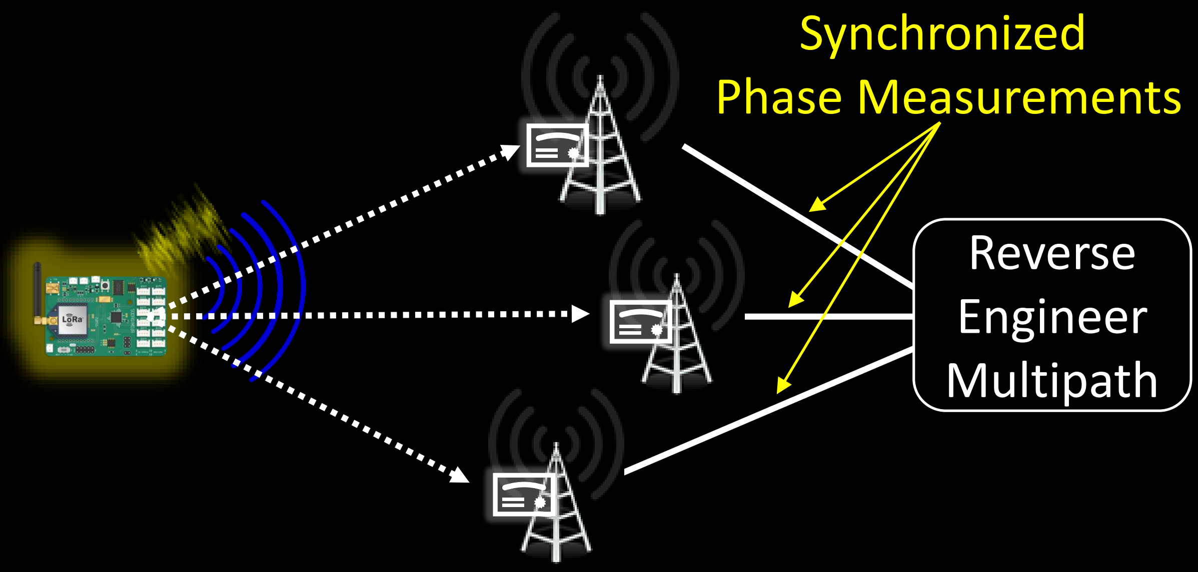
0.5 km

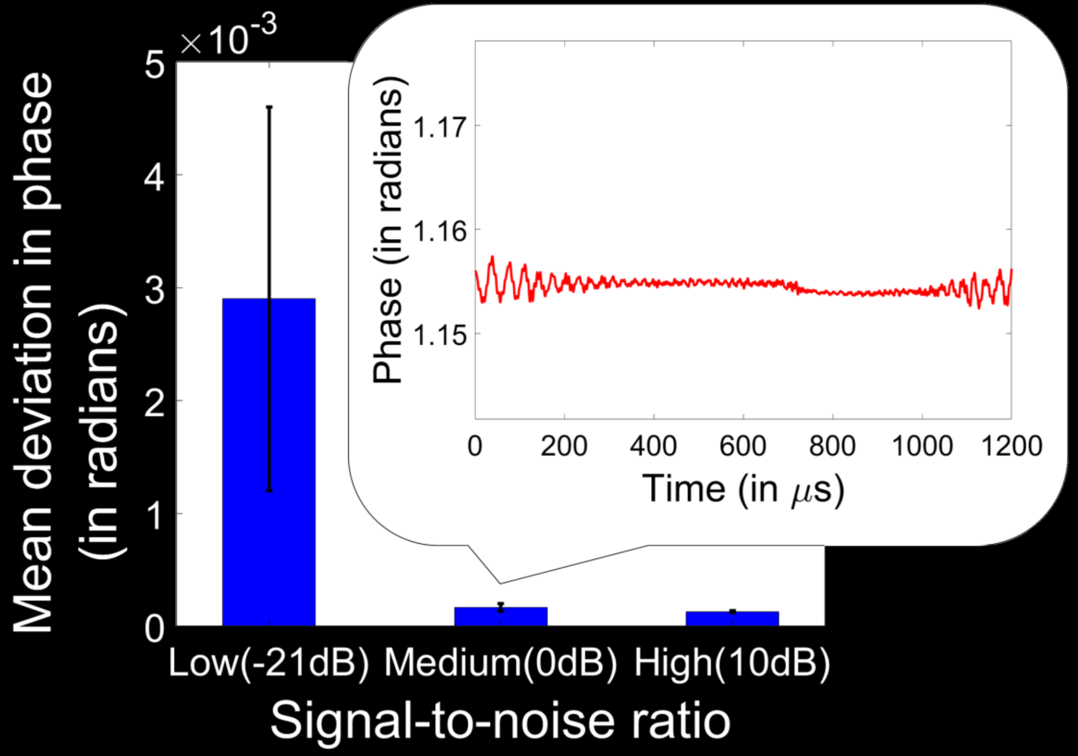


0.7 km

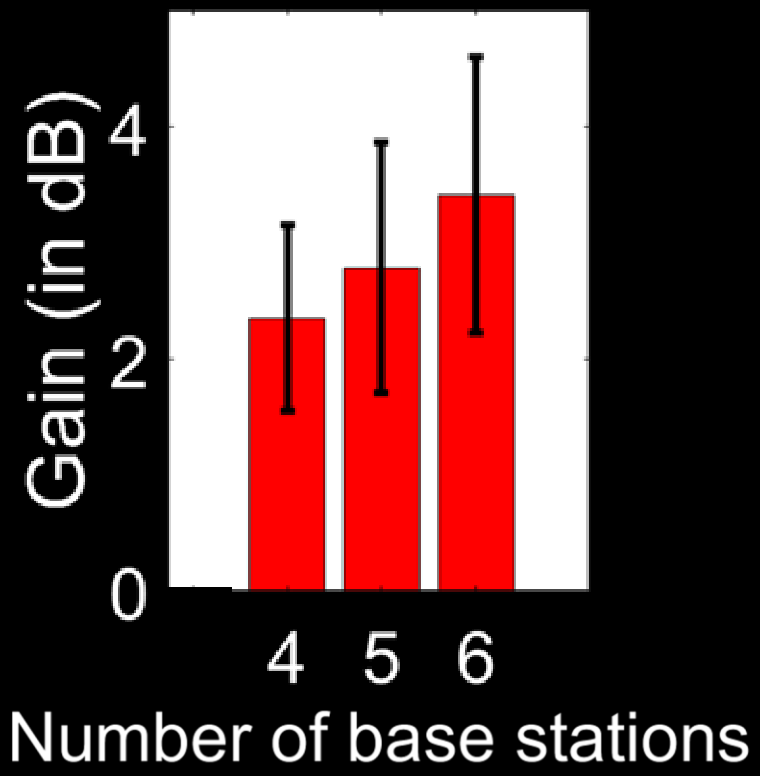
● Base stations

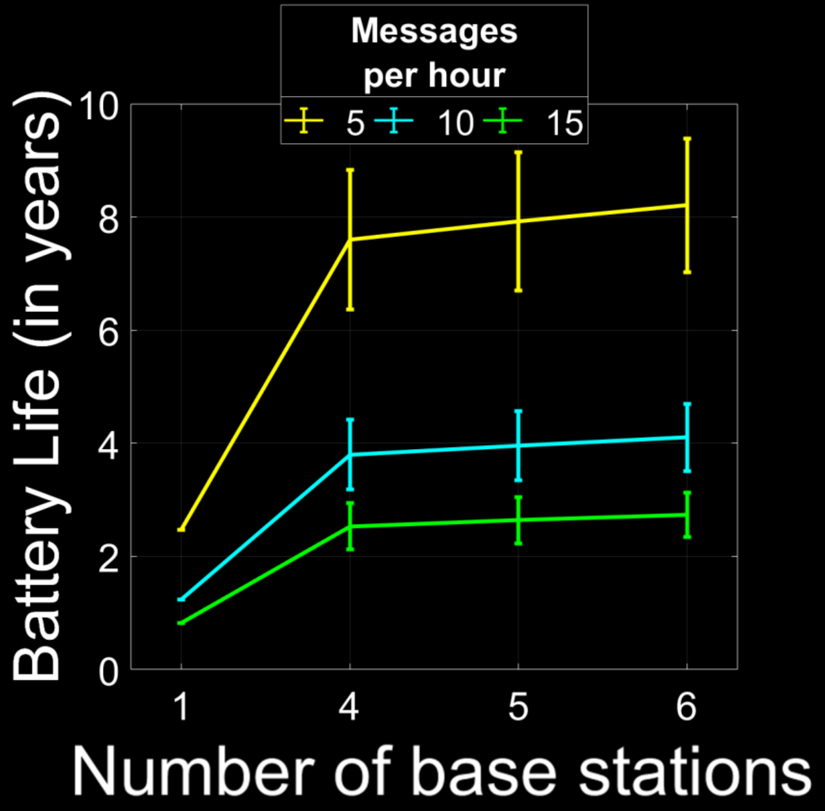
Variation in synchronized phase measurements





Battery Life Benefits

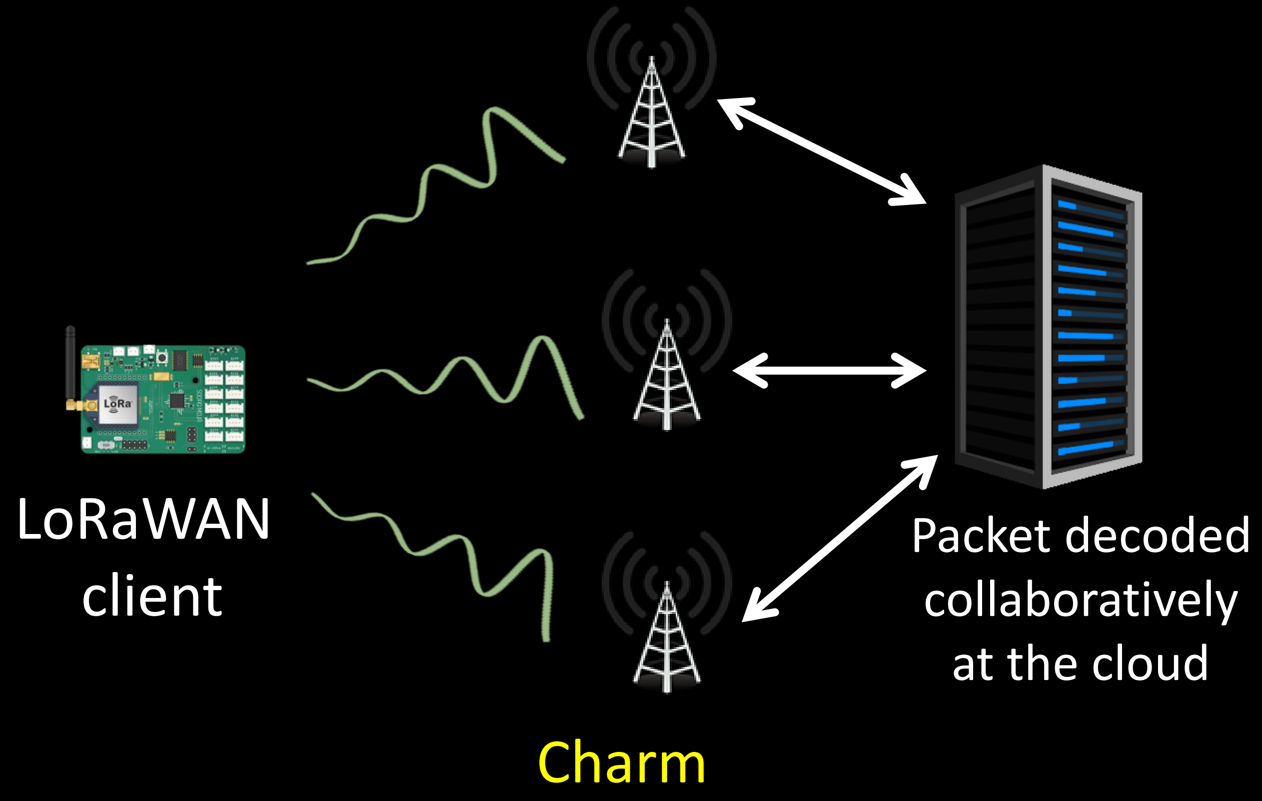


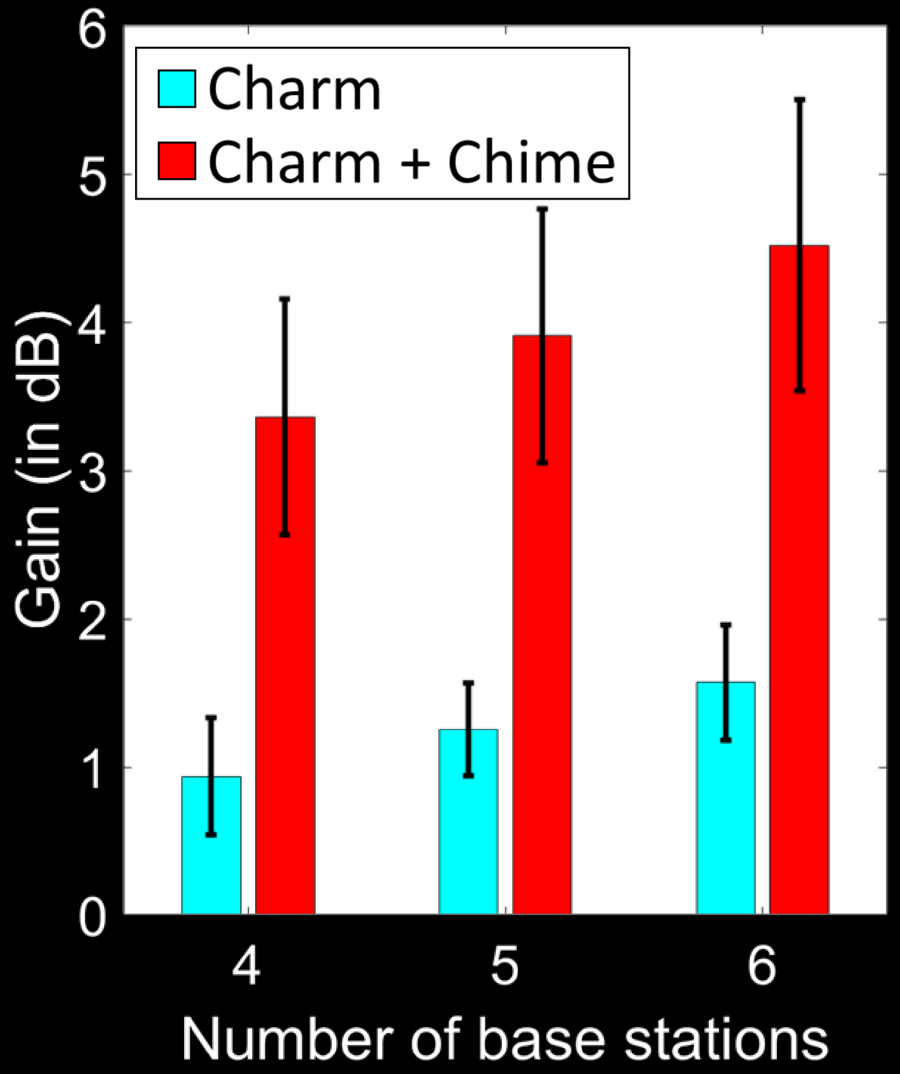


3.4 dB of SINR improvement over median frequency of operation => 230% increase in battery life*

*Based on battery life model for transmit only clients from Charm

Coherent Combining





Other Results

- Comparison with interpolation using multiple frequencies
- CDF of accuracy of predicted SINR
- Ability to identify frequency nulls

More details in the paper …

Related Work

	Synchronizing Base Stations	Estimating multipath	Frequency Configuration
WiFi	MegaMIMO 	Chronos Frequency Hopping to estimate multipath	Brute force approach
Cellular	Argos Uses a reference antenna for MU-MIMO systems	R2F2 Measures uplink channel using downlink channel (Uses massive antenna array)	
LP-WAN	More drift over longer packets	Narrow bandwidth Single antenna base stations	100s of choices

Limitations

- Mobility of clients
- Leverages sparsity of multipath in urban settings
- Does not model fleeting reflectors

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