GPSMirror: Expanding Accurate GPS Positioning to Shadowed and Indoor Regions with Backscatter

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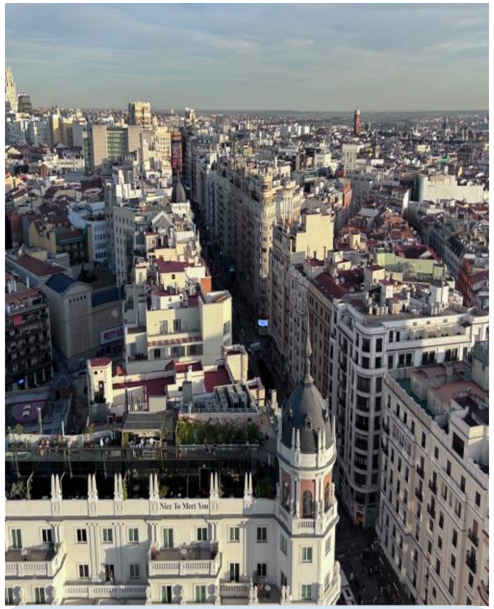
GPS services fail in shadowed region

Conventional GPS provides localization with high error (hundreds of meters[1]) or even cannot localization[2] in these shadowed regions.



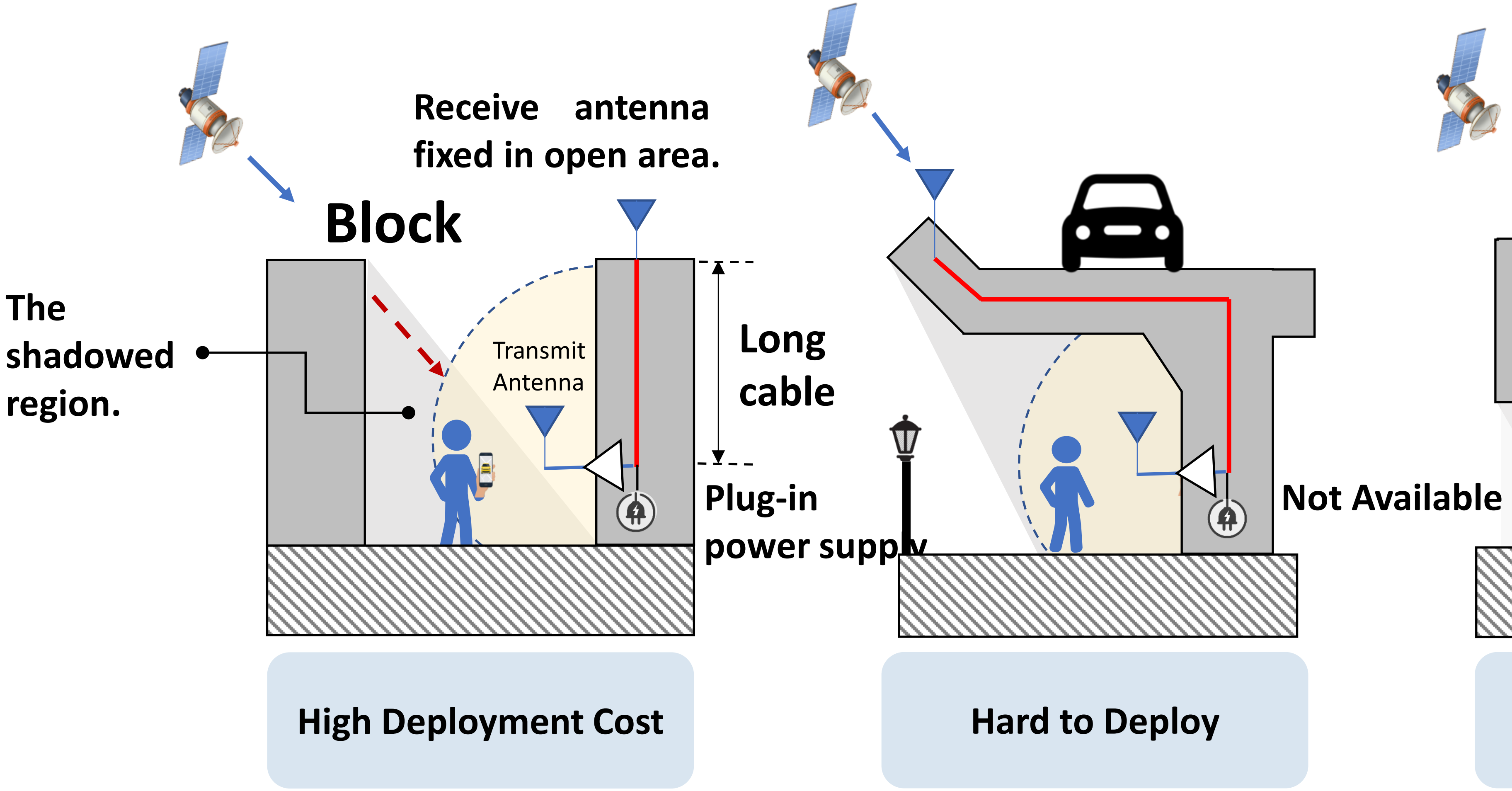
Urban Canyon

Flyover Shadow

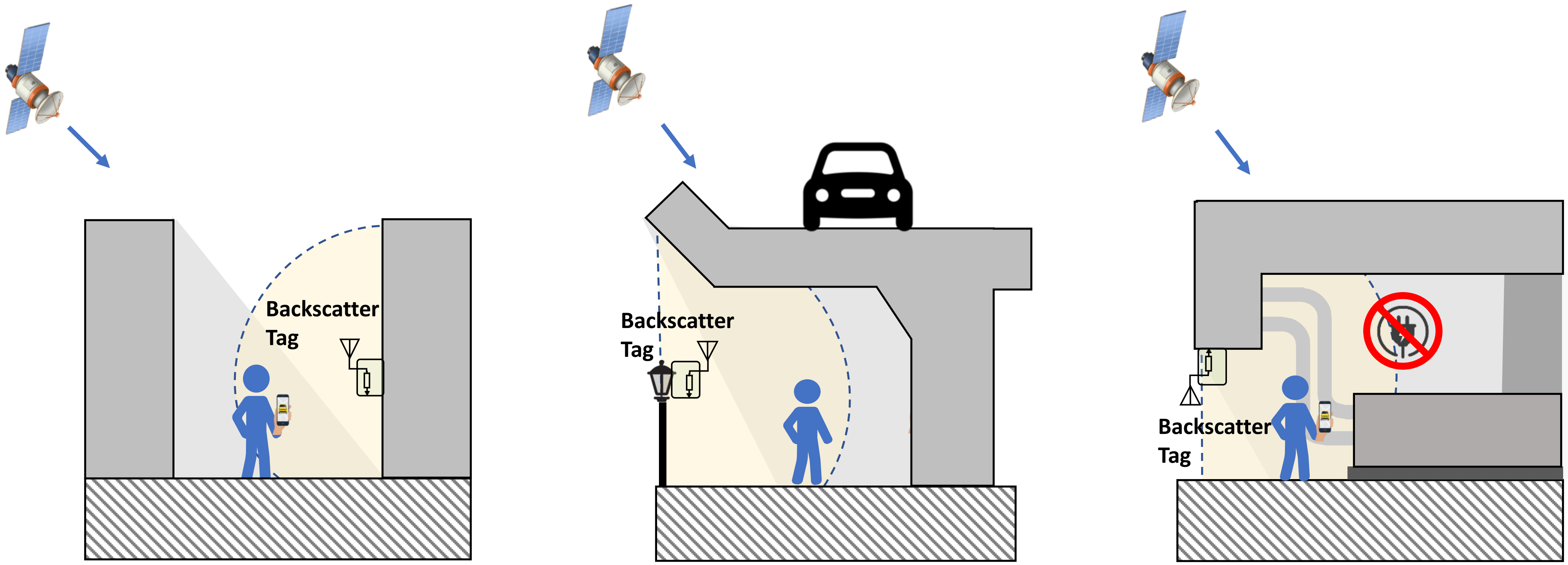
Gas/Dust Factory

[1] K.Chen and G.Tan. 2018. BikeGPS: Accurate Localization of Shared Bikes in Street Canyons via Low-Level GPS Cooperation. MobiSys '18.
[2] S.Nirjon, J.Liu, G.DeJean, B.Priyantha, Y.Jin and T.Hart. 2014. COIN-GPS: indoor localization from direct GPS receiving. MobiSys'14.

GPS relays are hard to deploy

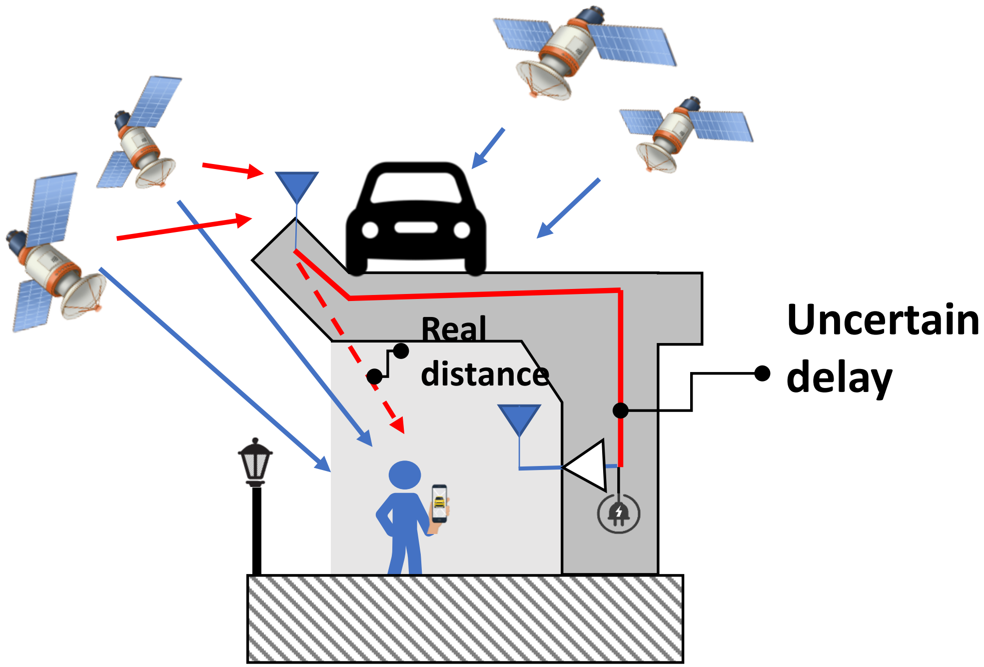


Our Idea: Ultra-low-power backscattering

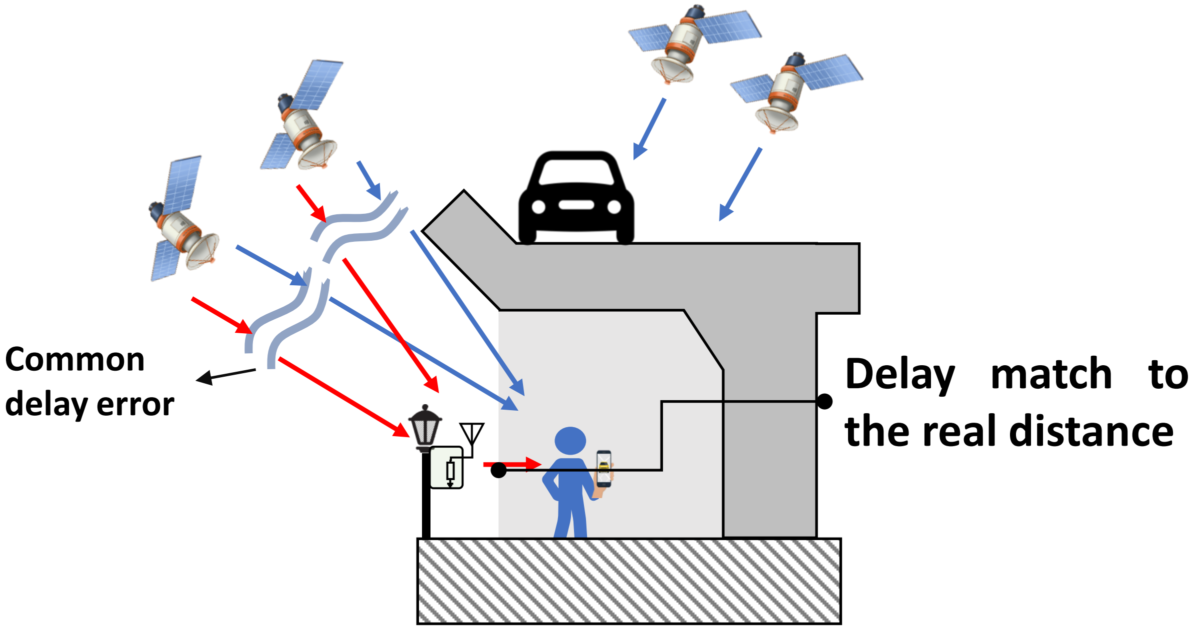


Design a uW-level backscatter tag that provides comparable coverage to commercial relays.

New positioning opportunities of backscattering GPS

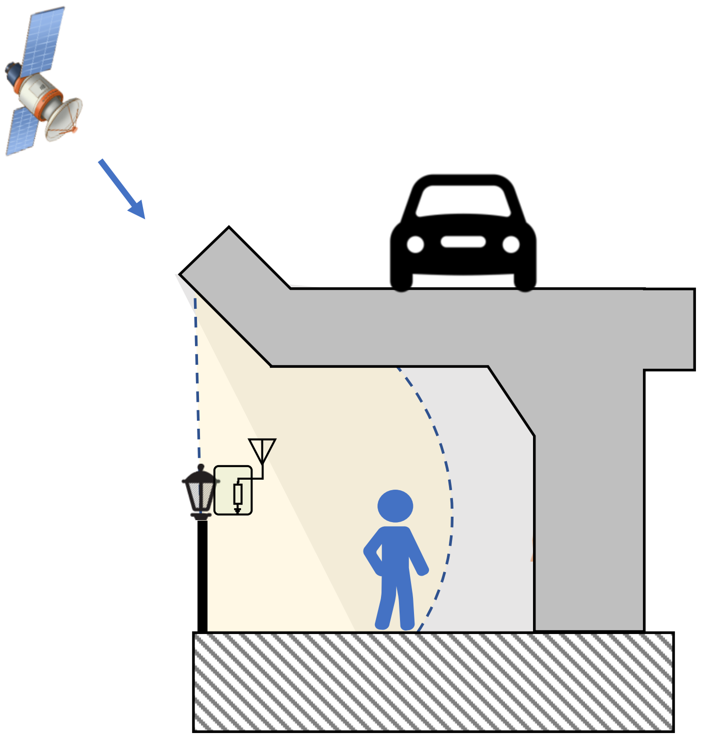


The relayed GPS signals cannot collaborate with non-relayed GPS signals since they contain different propagation delay.



The scattered and non-scattered GPS signals can collaborate to provide better positioning service.

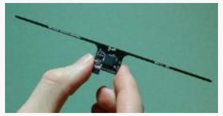
Requirements on scattering the GPS signals



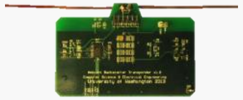
Power	uW-level power consumption for easy deployment.
Gain	Comparable coverage to commercial GPS relays.
Bandwidth	Flat gain over GPS L1 band.
Sensitivity	Sensitive to scatter weak GPS signals (-125dBm).

Existing backscatter devices

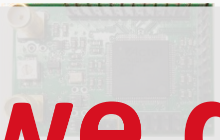
RF switch-based backscatters



WISP Platform
TIE'08



Ambient Backscatter
SIGCOMM'13



FS Backscatter
SIGCOMM 2016

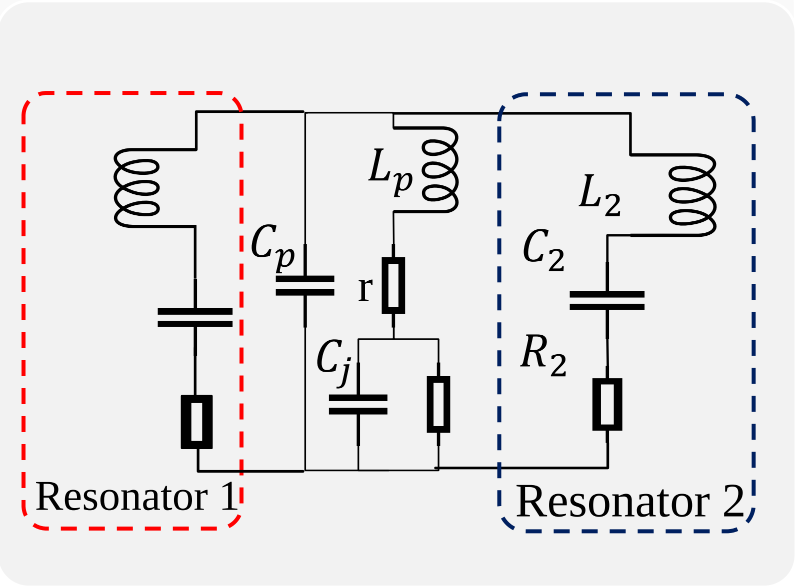
MobiCom'22

Existing tunnel diode-based backscatters

Can we design a backscatter system to meet all the requirements?

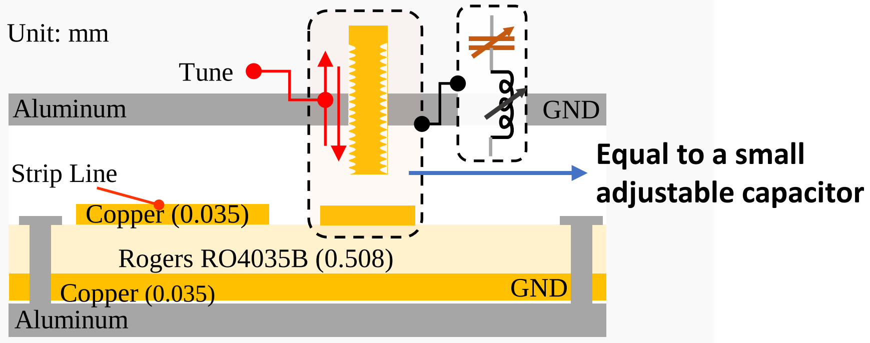
Challenge: Bandwidth

Design 1: Matching Parasitic Parameters.



Design 2: High-precision impedance control.

Tunable structure for precisely resonance control



Challenge: Sensitivity

Reported threshold for injection-locked amplify of the SOTA tunnel diode-based backscatter:

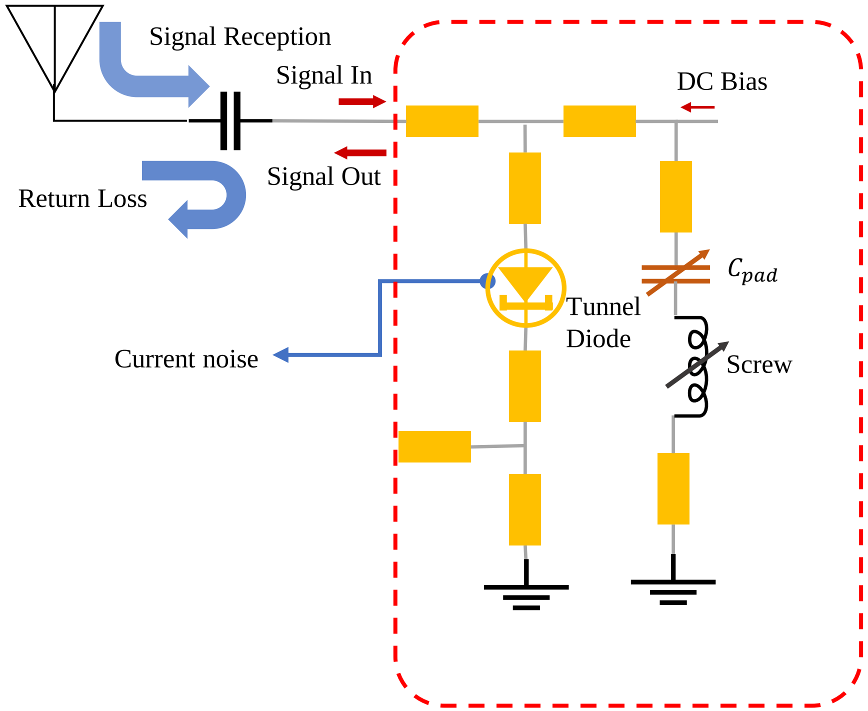
-90 dBm ~ -100 dBm

Tunnel Emitter MobiCom'20

GPS signals at the ground

~ -125 dBm

Tunnel diode amplifier



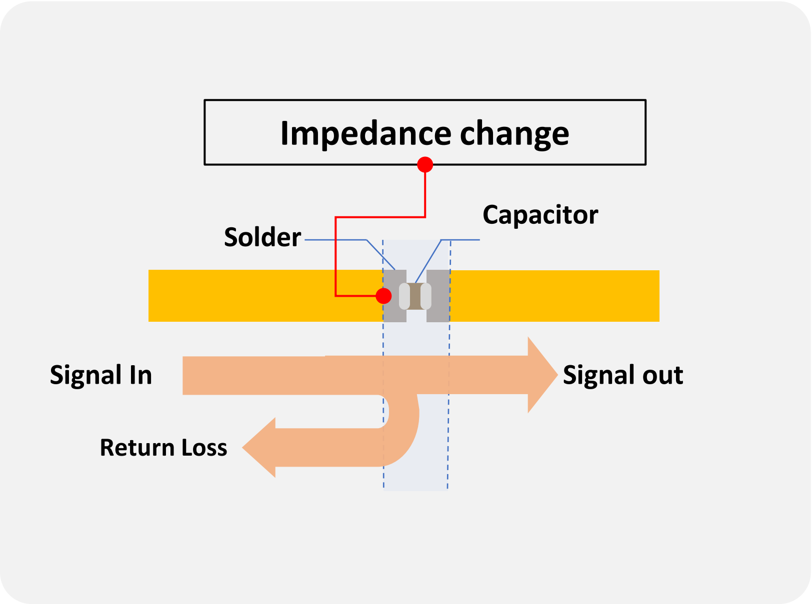
Our insight:

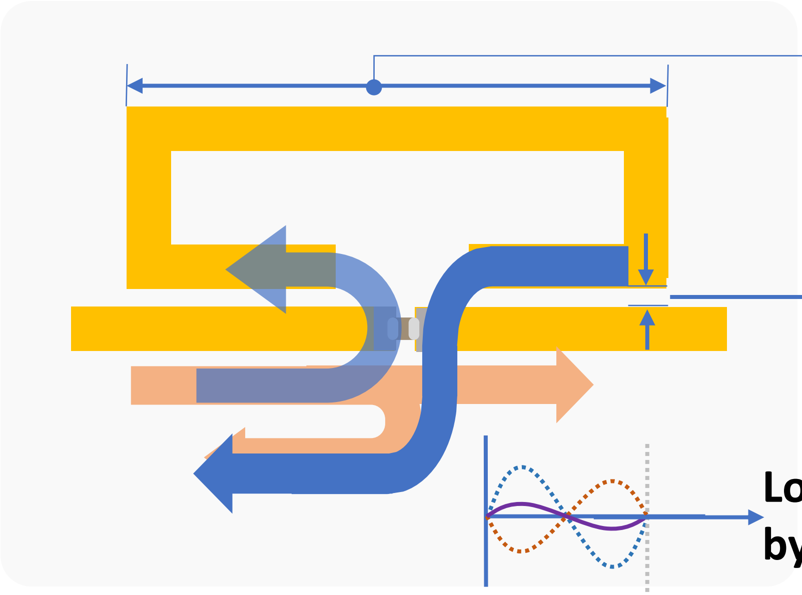
Minimizing the circuit loss, noise and maximize the signal reception.

Challenge: Sensitivity

Design 1:

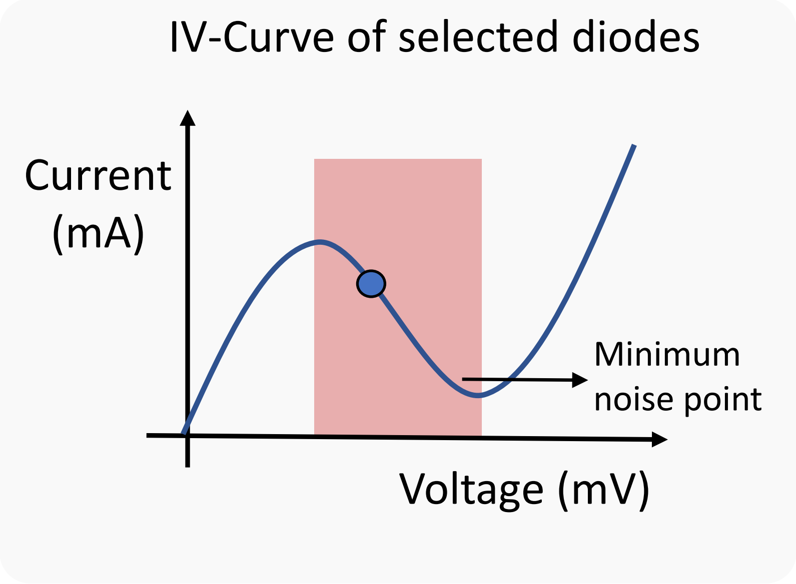
Reduce the return loss caused by components solder.



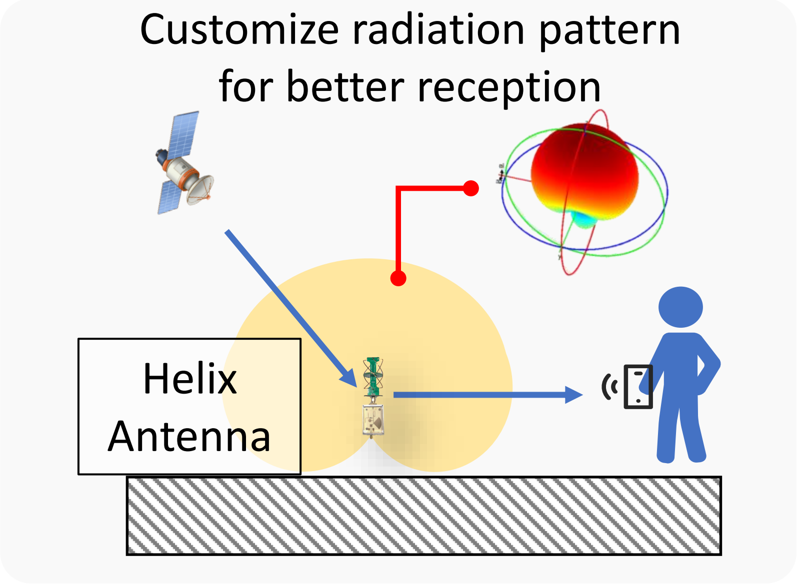


Challenge: Sensitivity

Design 2: Search the minimum noise operation point

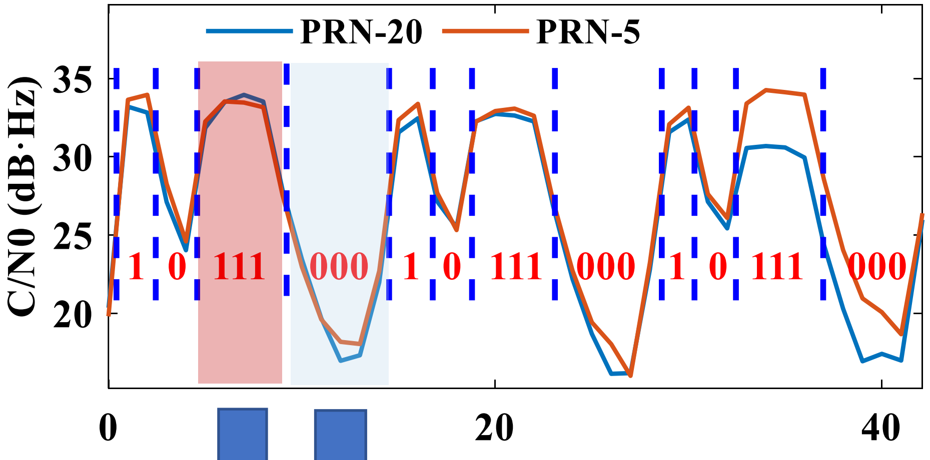


Design 3: Customized radiation pattern for better reception



Localization under inadequate satellites

A piece of "Carrier to Noise Density Ratio (C/N_0) " raw measurements of scattered and non-scattered GPS signals



C/N_0 measurements of non-scattered GPS signals

C/N_0 measurements of scattered GPS signals

Separate distance raw measurements (PrM， AdrM) with the same index.

X_{PRN-5}: PrM_1， $AdrM_1$

X_{PRN-5}': PrM_1'， $AdrM_1$ '

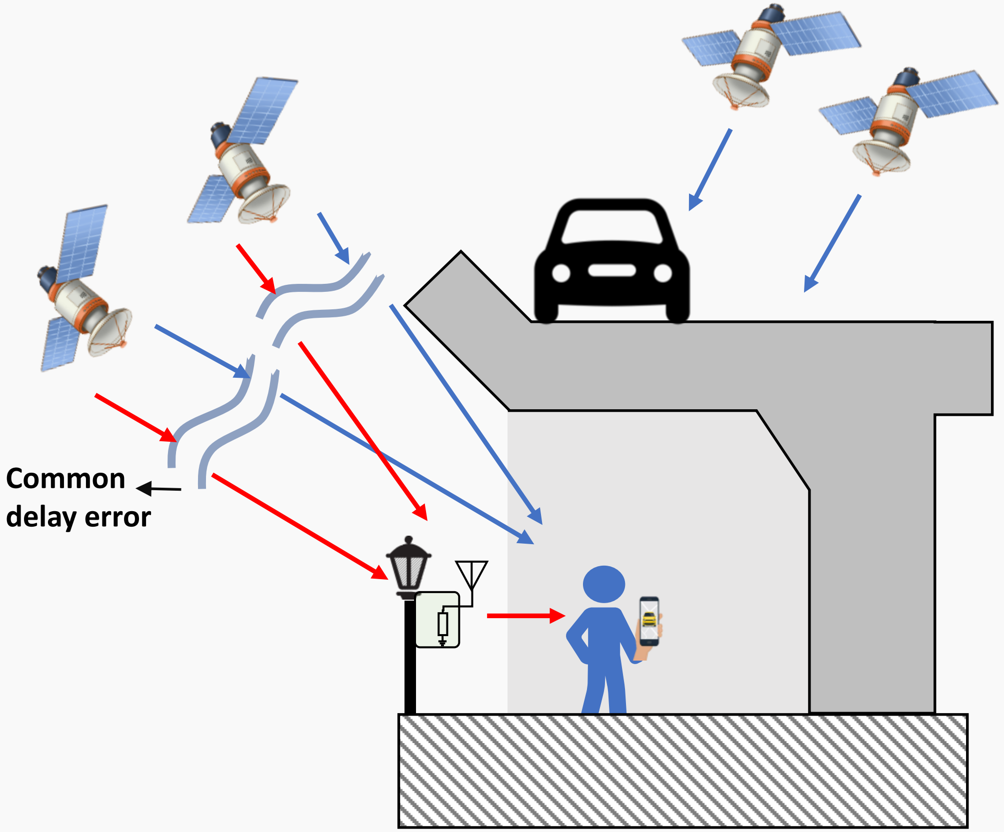
X_{PRN-20}: PrM_2， $AdrM_2$

X_{PRN-20}': PrM_2'， $AdrM_2$ '

From Virtual Satellites

Duplex the measurements for GPS localization under inadequate satellites.

Differential positioning for accuracy improvement



Capable to eliminate the common delay error in distance measurements of GPS signals.

Eliminate Common Error by differential

$$\Delta X_1 = X_1' - X_1$$
$$\Delta X_2 = X_2' - X_2$$
$$\dots$$
$$\Delta X_n = X_n' - X_n$$

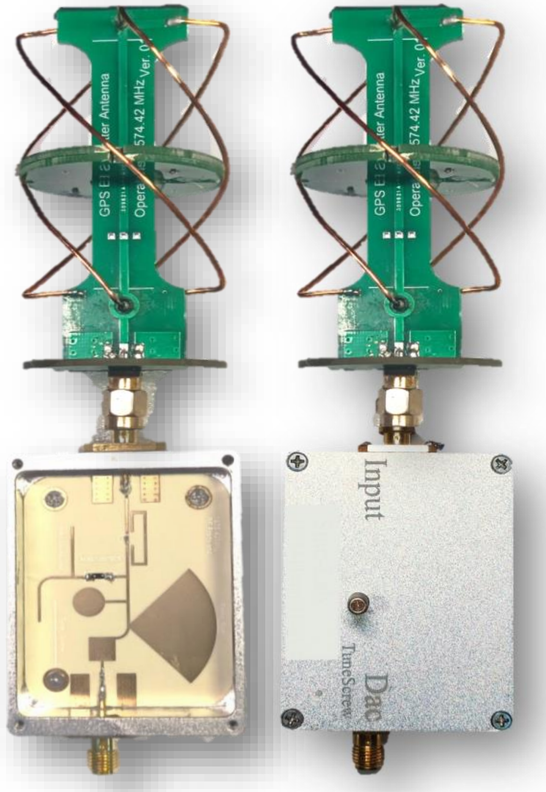
Modelling the vector ***b*** from a GPSMirror tag to smartphone

$$\boldsymbol{b} \propto \frac{\sum_{i=1}^{n} W_i \Delta X_i}{n}$$

Differential positioning

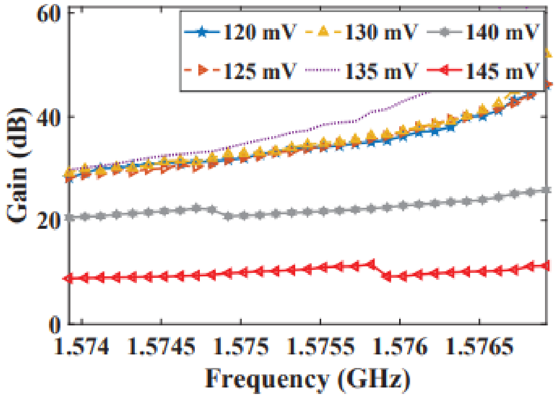
$$\begin{bmatrix} \delta b \\ c\Delta T \end{bmatrix} = \left(\left(G^T W G\right)^{-1} G^T\right) W S_{\Phi}$$

Implementation and hardware performance

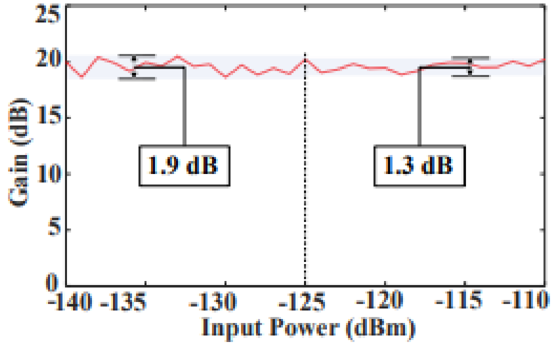


GPSMirror Tag

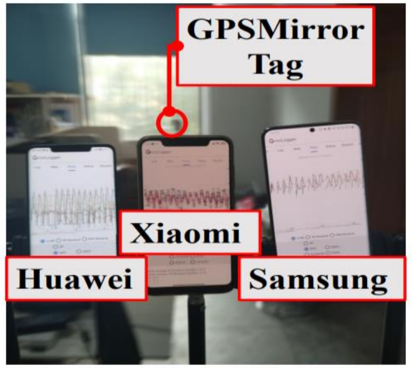
~ 126uW power consumption



0-30dB adjustable gain.

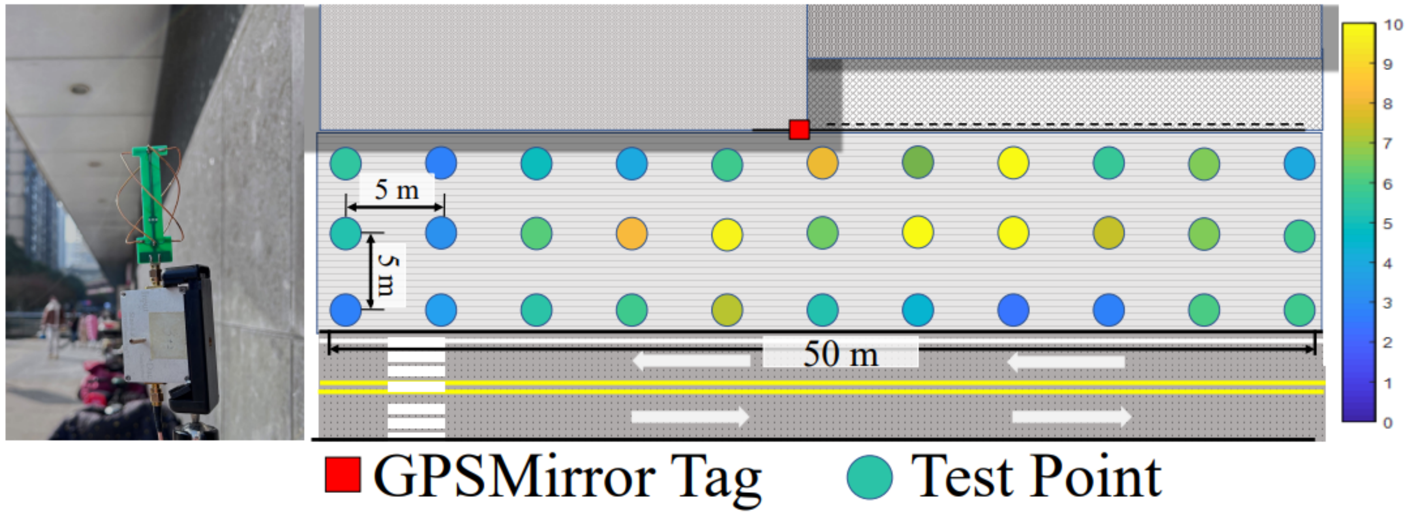


-125dBm Sensitivity with variance less than 1.3dB.



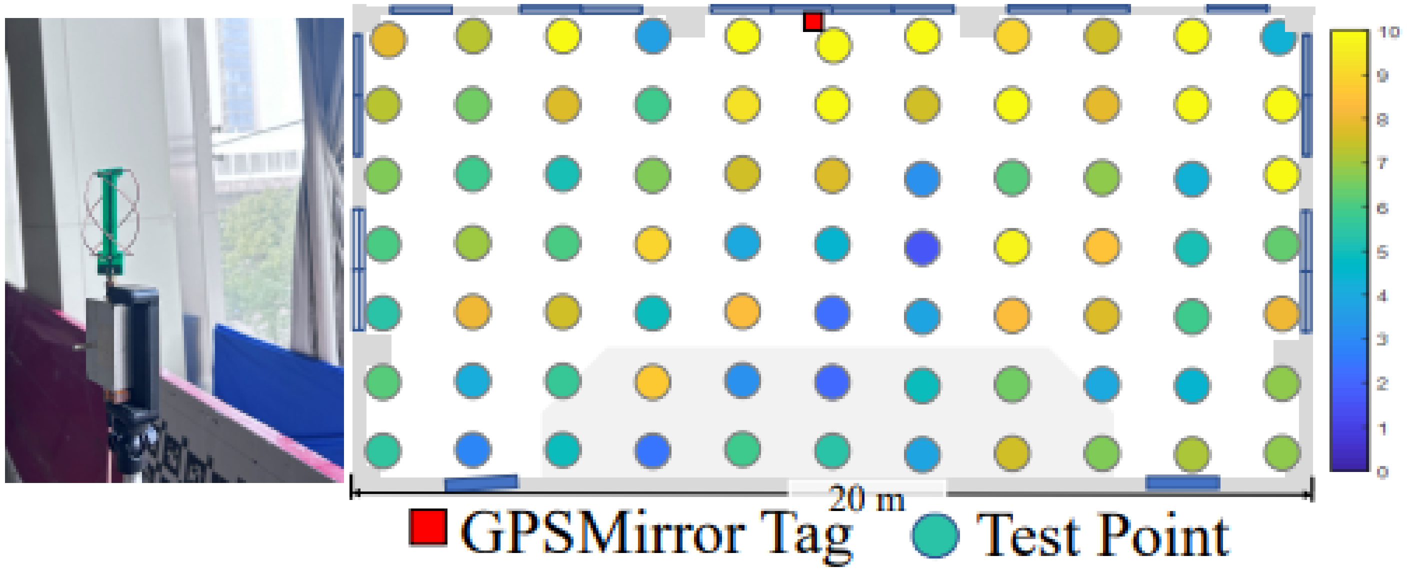
Compatible with smartphones.

Coverage performance



Urban Canyon

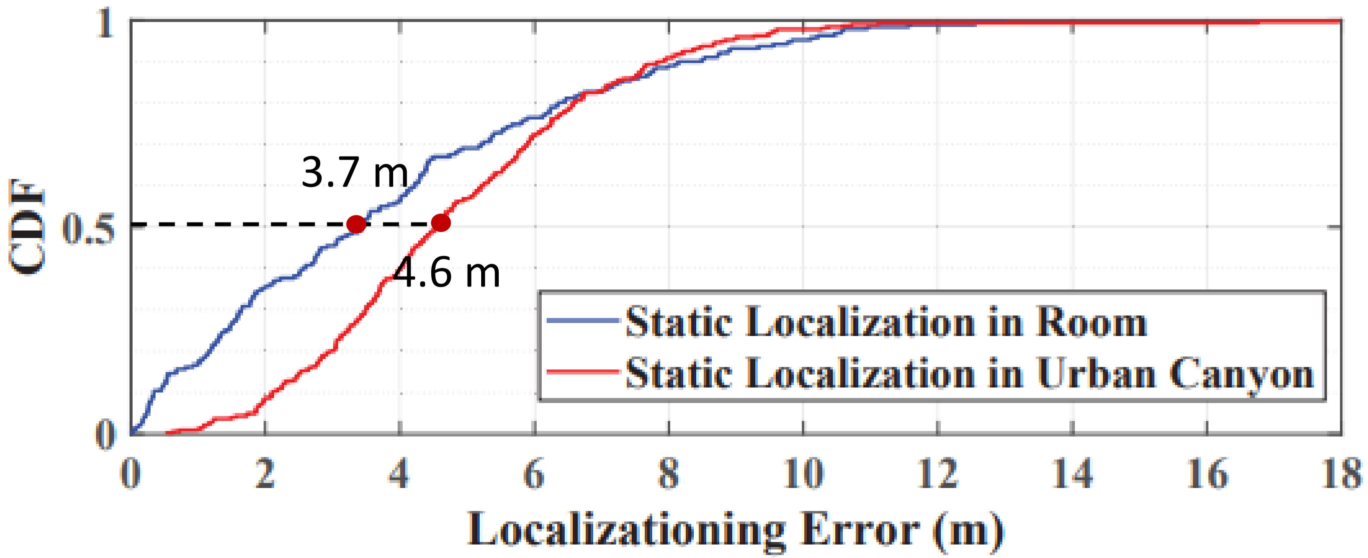
27.7 m away from the tag with about 4 dB gain in C/N_0



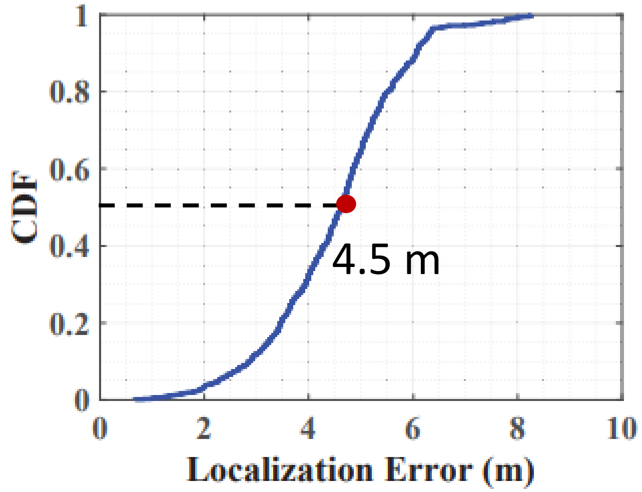
Flat Room

A 20m×14m room can be covered by a single GPSMirror tag with > 3dB gain in C/N_0

Localization accuracy



Static Localization Error



Dynamic Localization Error Indoor

Thanks!

Q&A