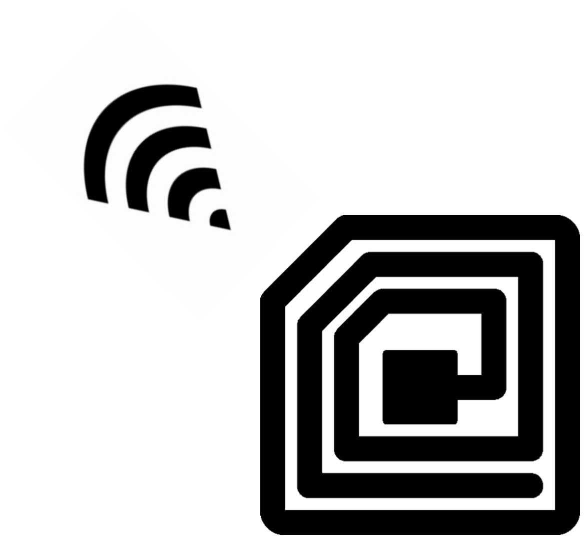
RFind: Ultra-wideband localization techniques for deployed RFID Tags



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Outline

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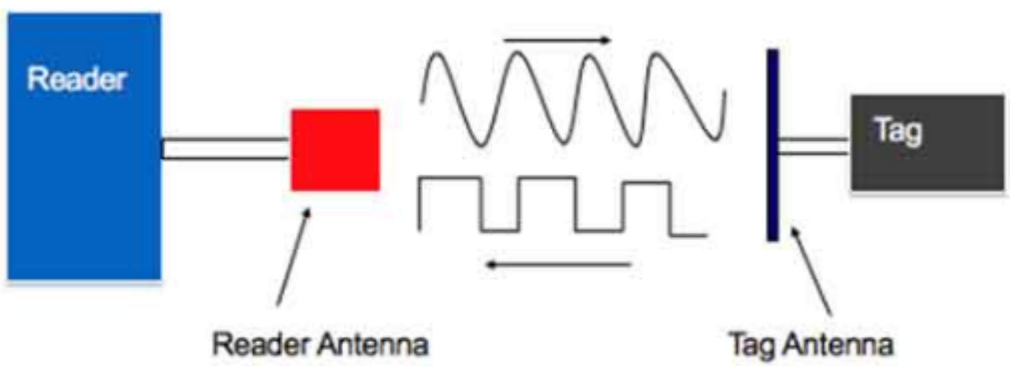
- Previous Work
- Challenges
- RFind Localization Strategy
  - Frequency Agnostic Modulation
  - Decoupling Sensing & Power Delivery
  - Localization using large virtual bandwidth.
- Experimental Results
- Possible Future Improvements

Introduction and Motivation

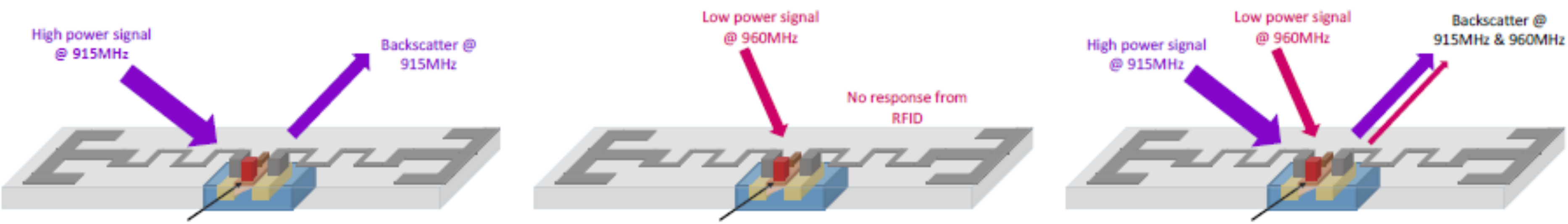
- RFind is a localization technique which uses battery-less stickers called RFIDs to get sub-centimeter localization in 3D space.

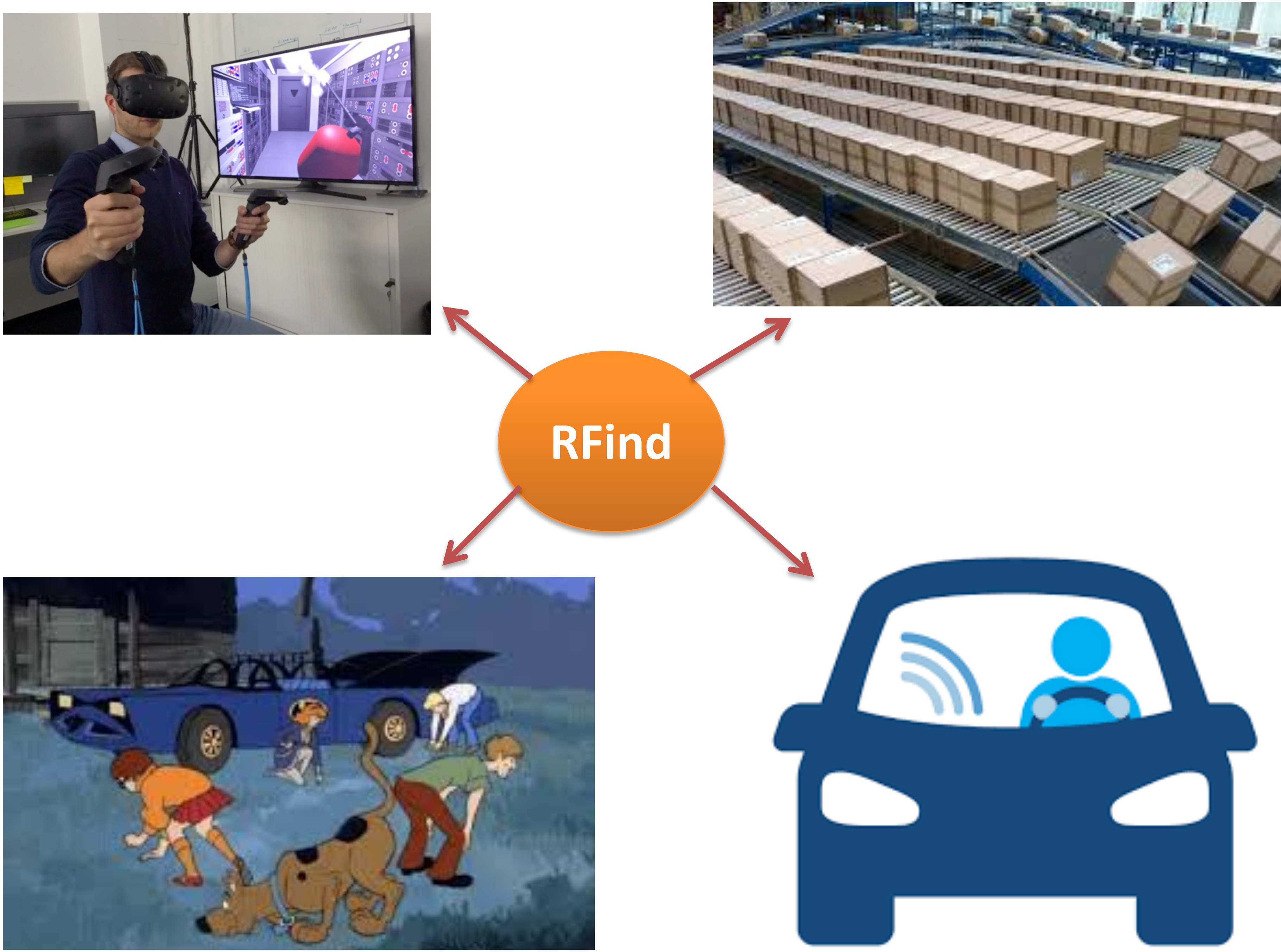
- RFIDs communicate with a wireless reader by switching their impedance when the reader excites them with a specific carrier frequency. RFind uses this property to compute the time of flight (TOF) for localization



Introduction and Motivation

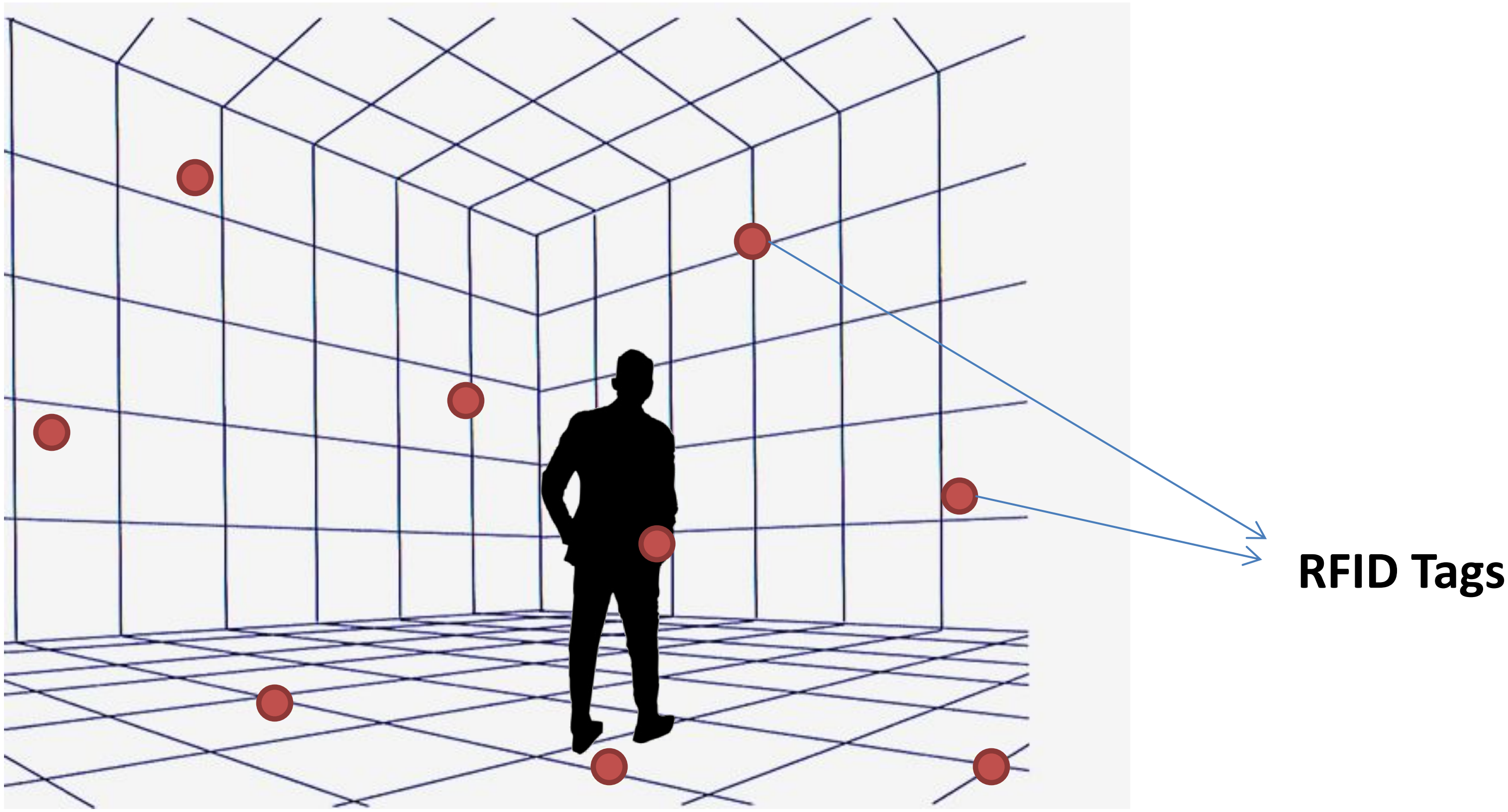
- RFind's modulation is frequency agnostic which allows it to de-couple the RFID communication bandwidth from the *virtual* localization bandwidth and this allows RFind to emulate a large bandwidth which can be used to get higher precision while performing localization.




RFind

Previous Work

- Previous attempts at localization using RFIDs required them to be spread at various locations in the environment and then the user location was evaluated by matching his position with one of the reference tags inside a grid.



Previous Work

- Another approach performed localization by moving either the RFID or the reader in a predefined trajectory over several wavelengths.

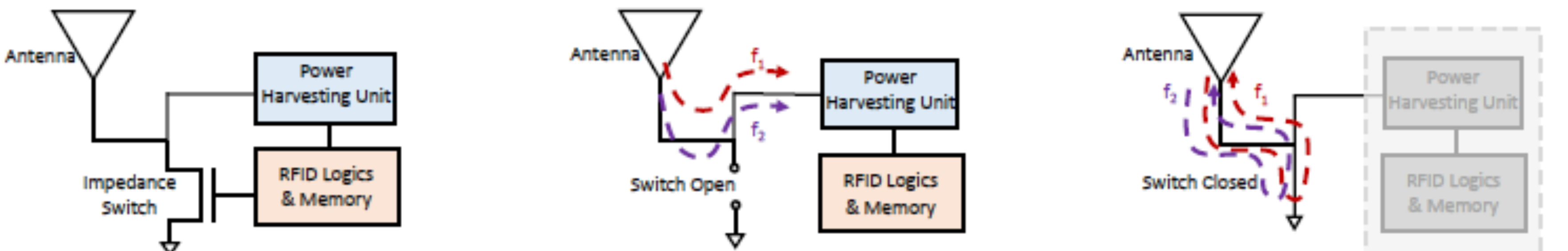
- Other solutions designed new expensive hardware for RFIDs to get large bandwidth for accurate localization which is not only non-compliant with FCC regulations but it also renders all current RFIDs useless.

Challenges

- Using a large bandwidth would require expensive hardware such as high speed ADCs
- The ISM band for RFID (28MHz) is not sufficient to get sub-centimeter localization accuracy and if RFind transmits in the band outside the ISM band then it must limit itself to an extremely low power to remain compliant with FCC regulations
- High accuracy localization cannot be done due to multipath from various objects surrounding the item of interest.

RFind Localization Strategy

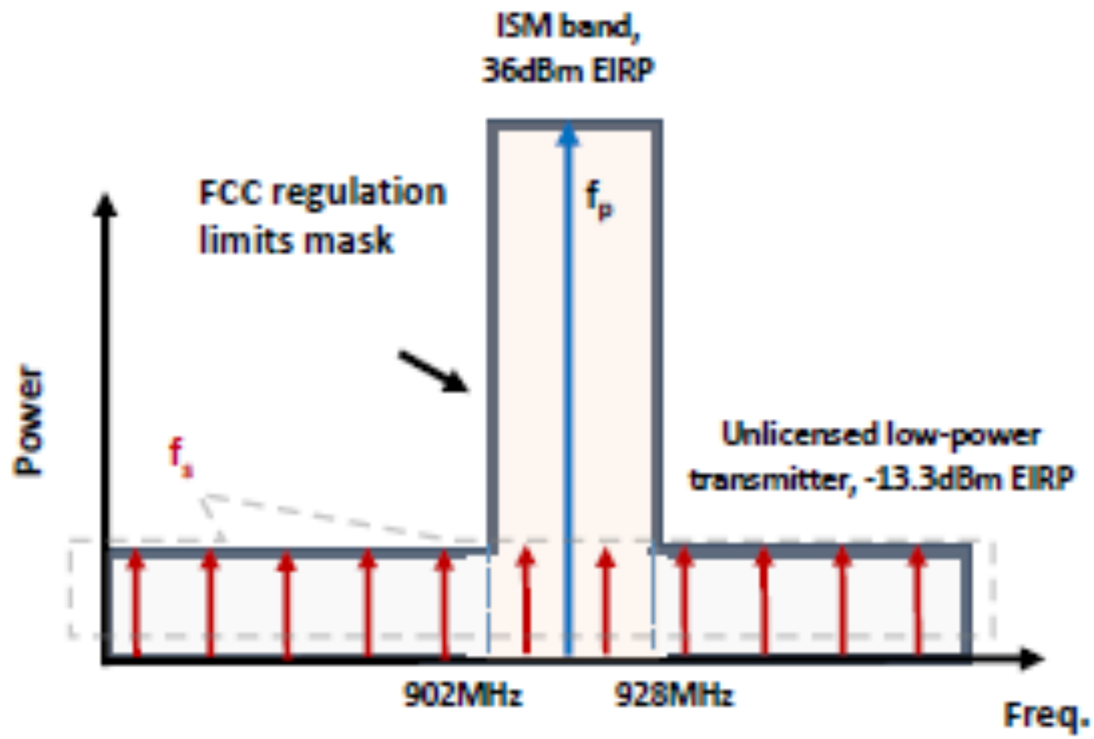
- Frequency Agnostic Modulation



(a) RFID tag system diagram (b) Non-reflective state when antenna switch is "off" (c) Reflective state when antenna switch is on

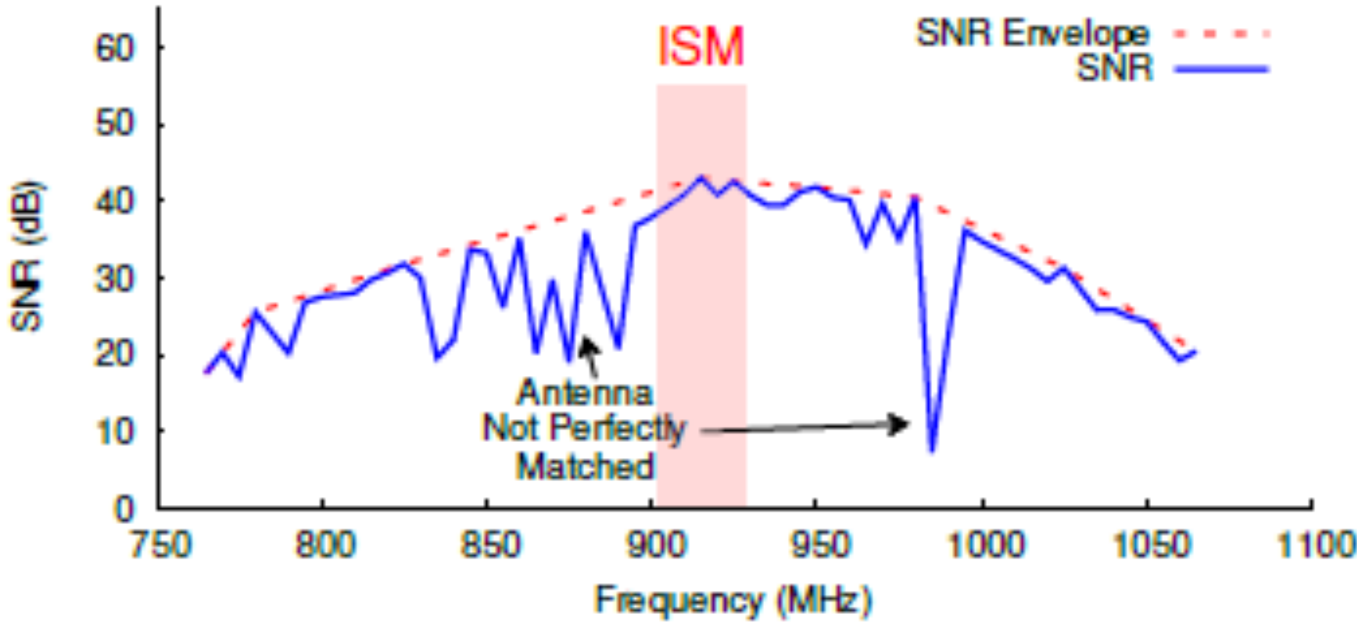
RFind Localization Strategy

- Decoupling Sensing & Power Delivery



RFind Localization Strategy

- Decoupling Sensing & Power Delivery



RFind Localization Strategy

- Localization using large virtual bandwidth

Channel Estimation (in frequency domain):

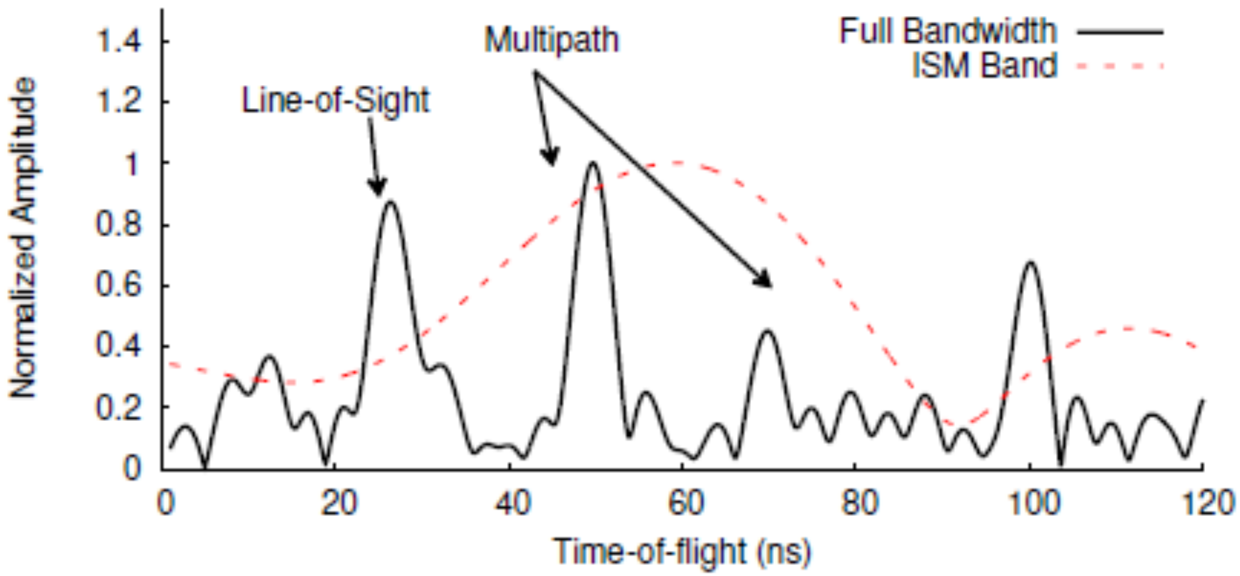
$$h_k = \sum_t y_t p_t^*$$

Identifying the LOS path:

$$S(\tau) = \sum_{k=1}^{K} h_k e^{j2\pi(k-1)\Delta f \tau}$$

RFind Localization Strategy

- Localization using large virtual bandwidth



$$\sum_{i=1}^{L} a_i sinc\left(B(t-\tau_i)\right)$$ → Main lobe width = 1/B

RFind Localization Strategy

- Super Resolution Algorithm

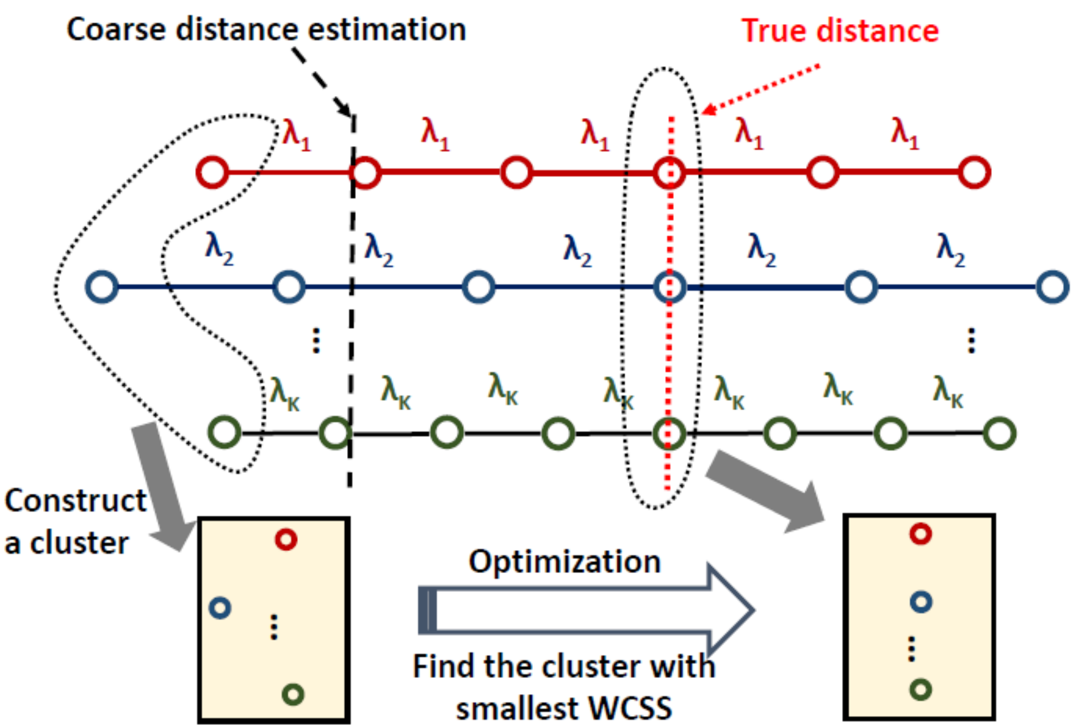
$$\phi_k = \frac{2\pi}{\lambda_k} d \mod 2\pi$$

$$\downarrow$$

$$\theta_k = \angle \sum_{i=1}^{K} h_k e^{j\frac{2\pi}{c}(f_i - f_k)\tilde{d}_0^c}$$

RFind Localization Strategy

- Super Resolution Algorithm

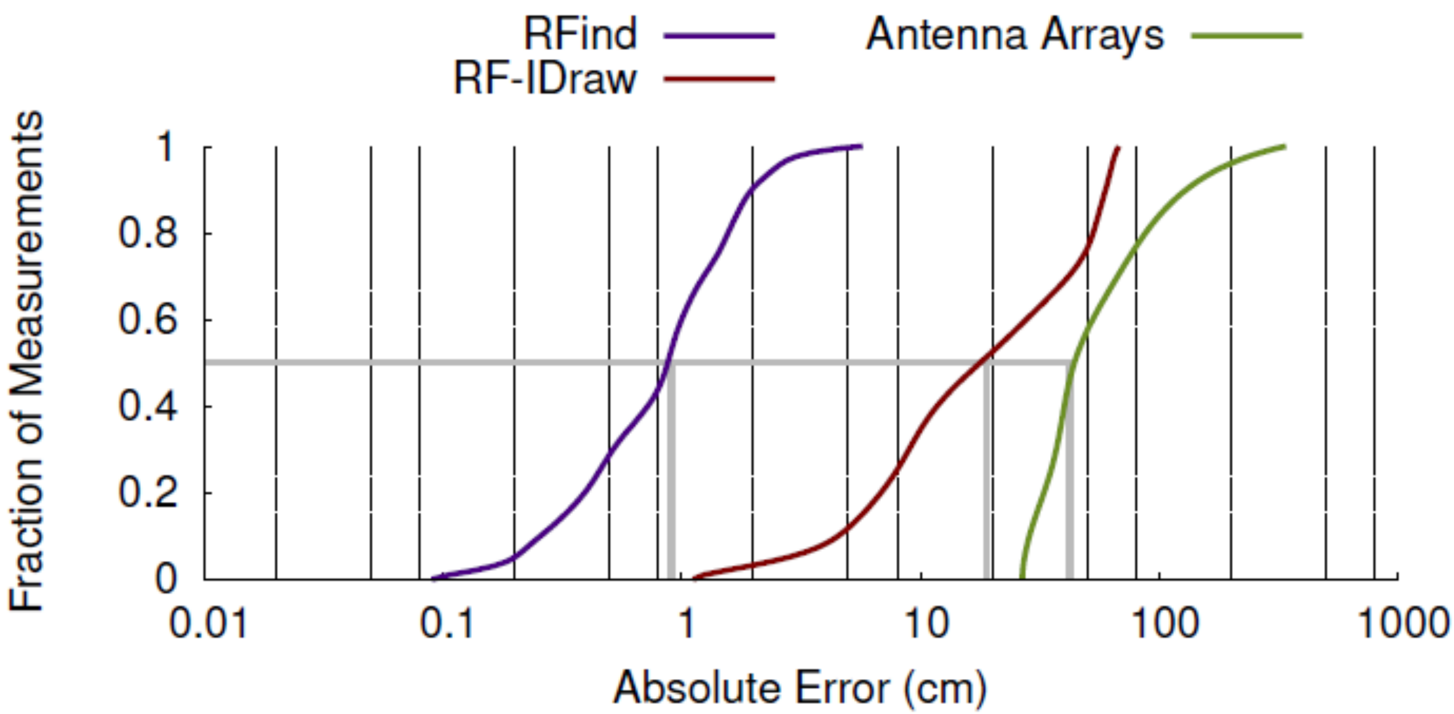


$$\#\ \text{candidates} = \frac{c}{B\lambda}$$

$$\arg\min_{\boldsymbol{C}} \sum_{\hat{d} \in \boldsymbol{C}} |\hat{d} - \mu|^2$$

$$\tilde{d}_0^s = \mu$$

Experimental Results

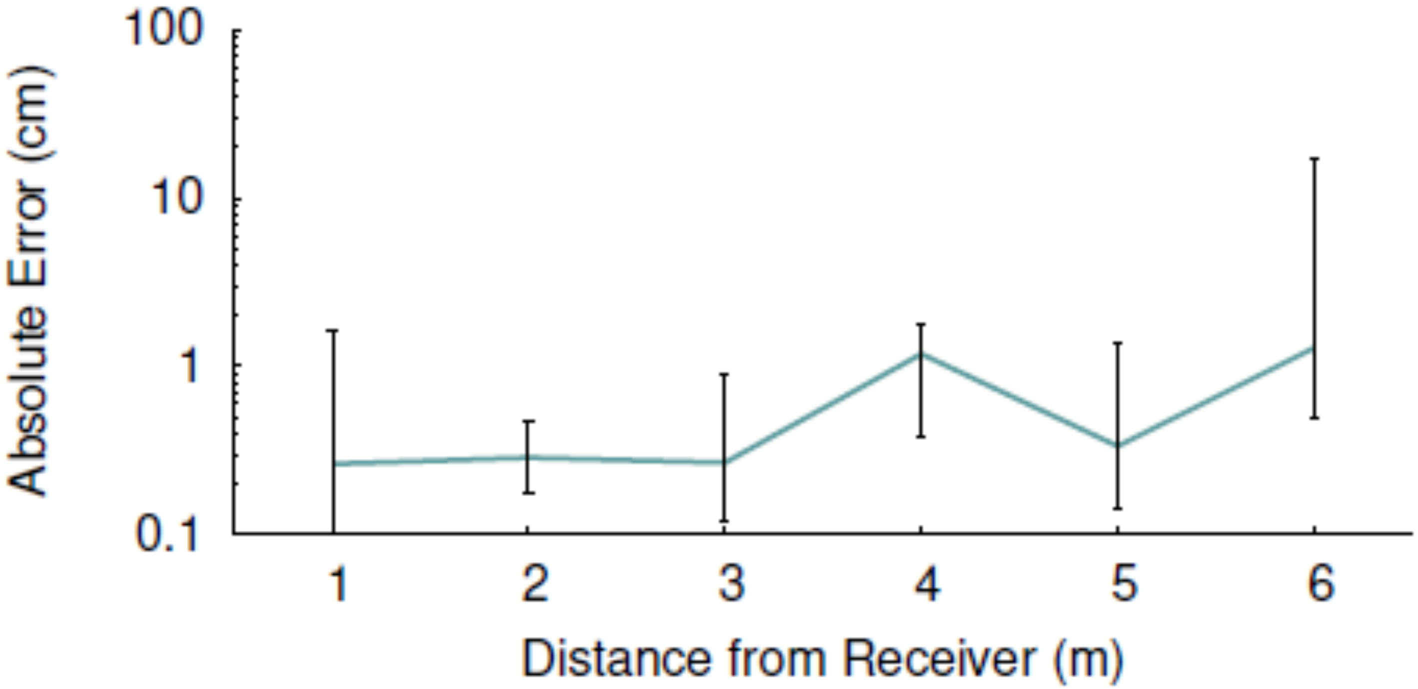


RFind : 90th Percentile Error = **1.92cm** and Median Accuracy = **0.91cm**

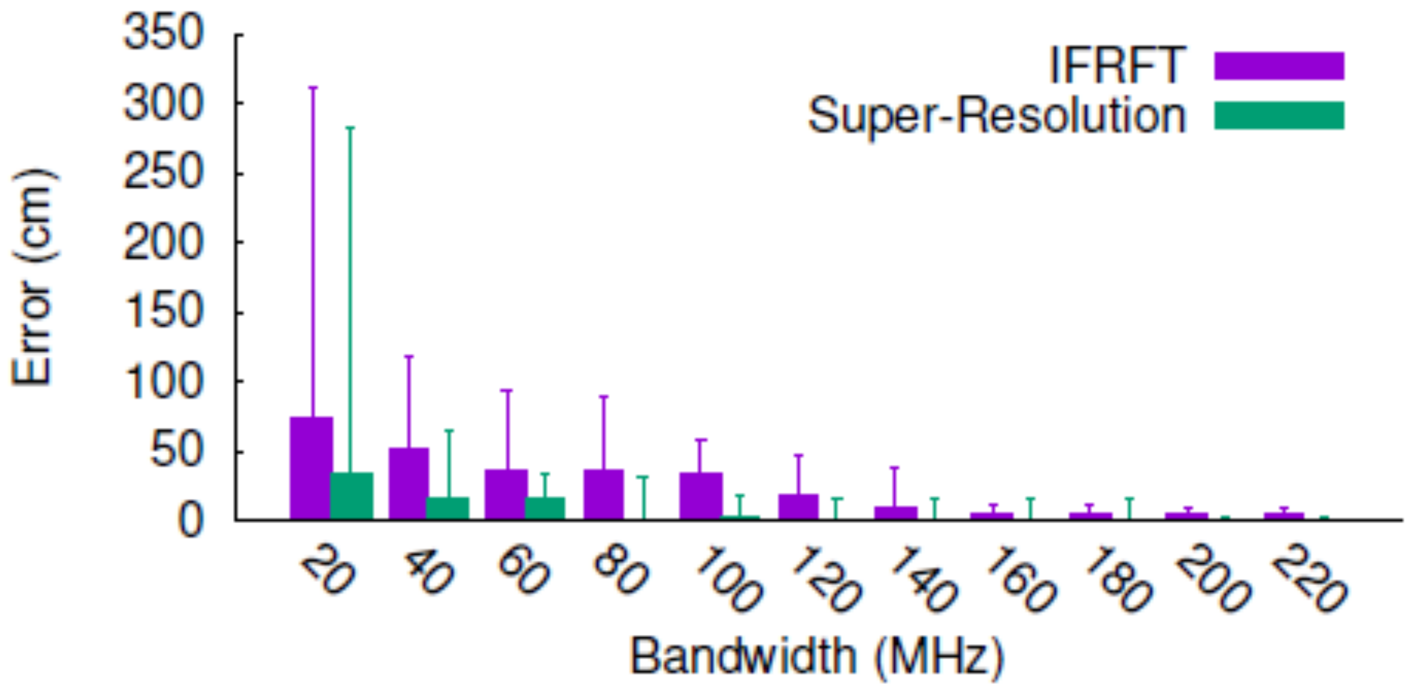
RFIDraw: 90th Percentile Error = **61.6cm** and Median Accuracy = **19cm**

AoA: 90th Percentile Error = **129cm** and Median Accuracy = **42.4cm**

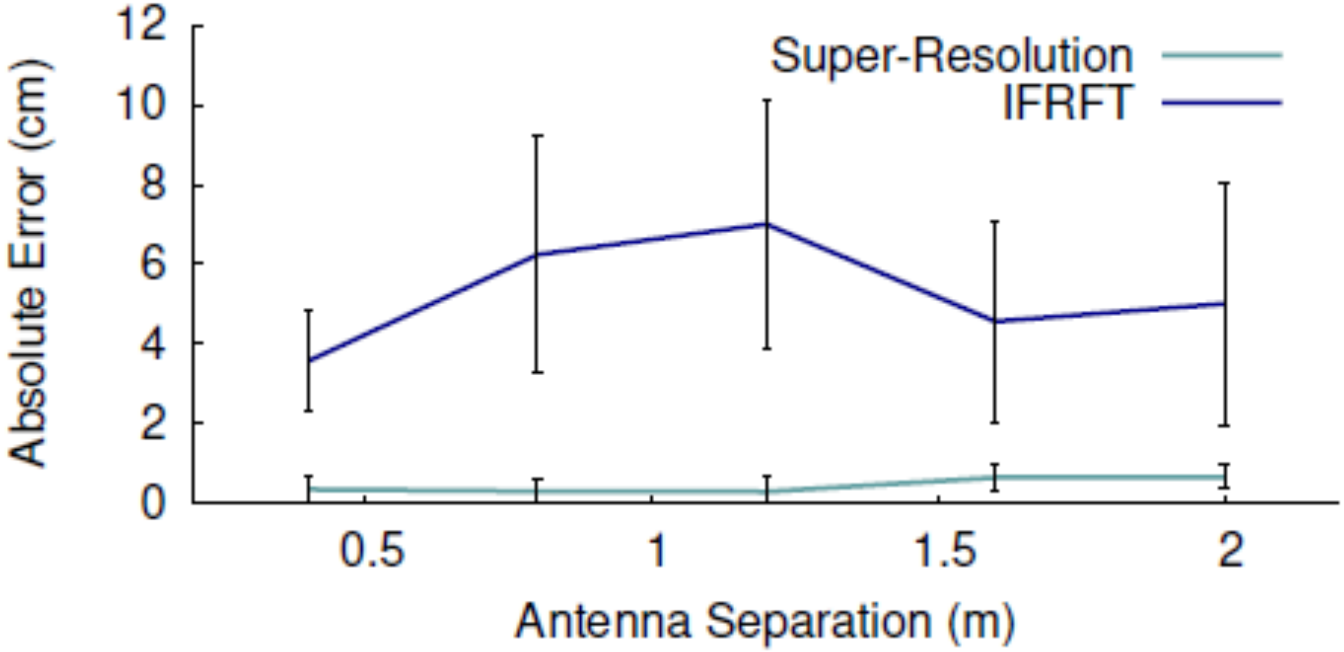
Accuracy vs. Distance



1D Error vs. Bandwidth



2D Error vs. Antenna Separation



"Perfection is the willingness to be imperfect"

- *Lao Tzu*

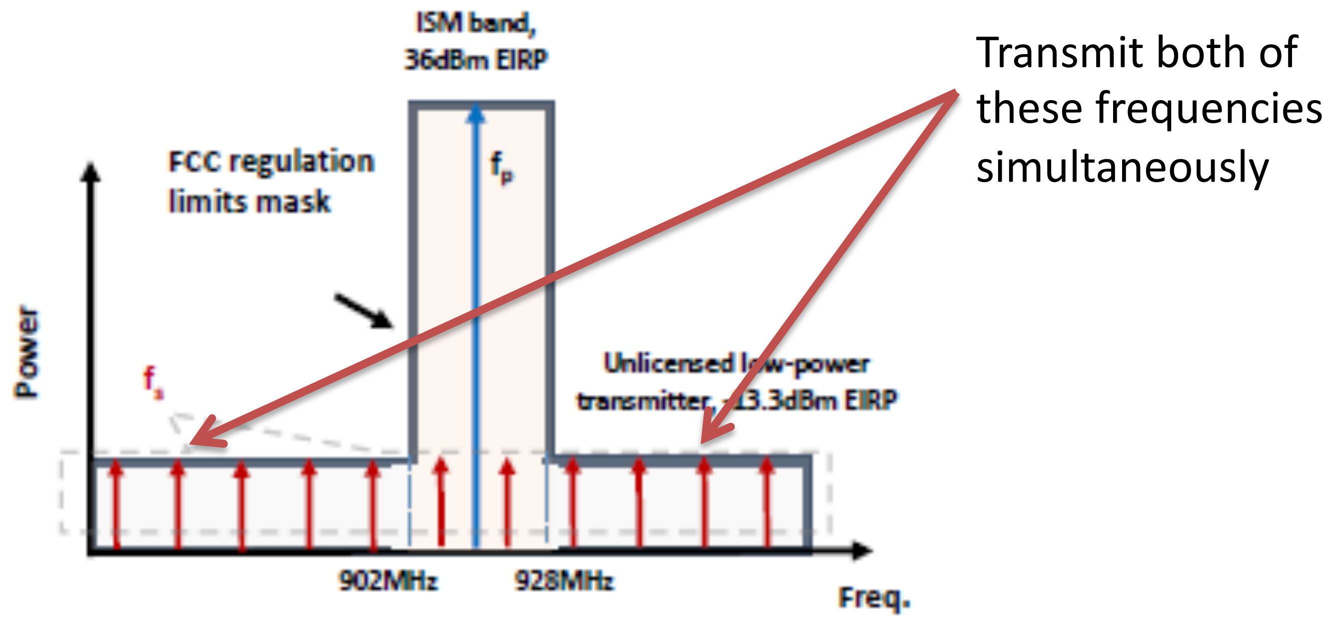
RFind - Drawbacks

- “Current implementation requires 6.4 seconds to output a location and this delay is primarily due to RFinds frequency hopping pattern”

- Even though RFind is “FCC Compliant, marketing it commercially requires formal FCC certification

- # Possible Solution for #1:

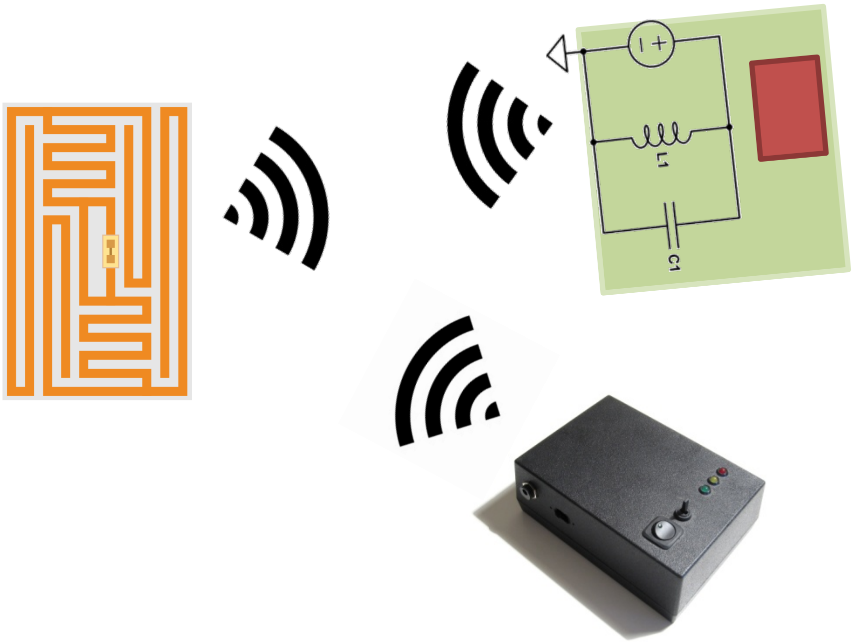
Instead of transmitting one frequency each time (to sweep the entire bandwidth of 300MHz) we can instead use an orthogonal signaling scheme and transmit two frequencies simultaneously (centered around fp) Since the signals with two different frequencies would not mix with each other so we can extract the channels from both frequencies at the reader after downconverting them using the relevant fs frequency. This would reduce the overall time by a factor of half.



•The solution presented in the paper uses USRPs which are expensive so it is difficult to deploy RFind commercially. The paper suggests that the same solution can also be implemented using regular RFID readers with firmware modifications but that would require technical knowledge about RFID readers.

Possible Solution:

$$f = \frac{1}{2\pi\sqrt{LC}}$$



References

- [1] Y.Ma, N. Selby and F. Adi. Minding the Billions : Ultra-Wideband Localization for Deployed RFID Tags in MobiCom, 2017