Backscatter Bundle

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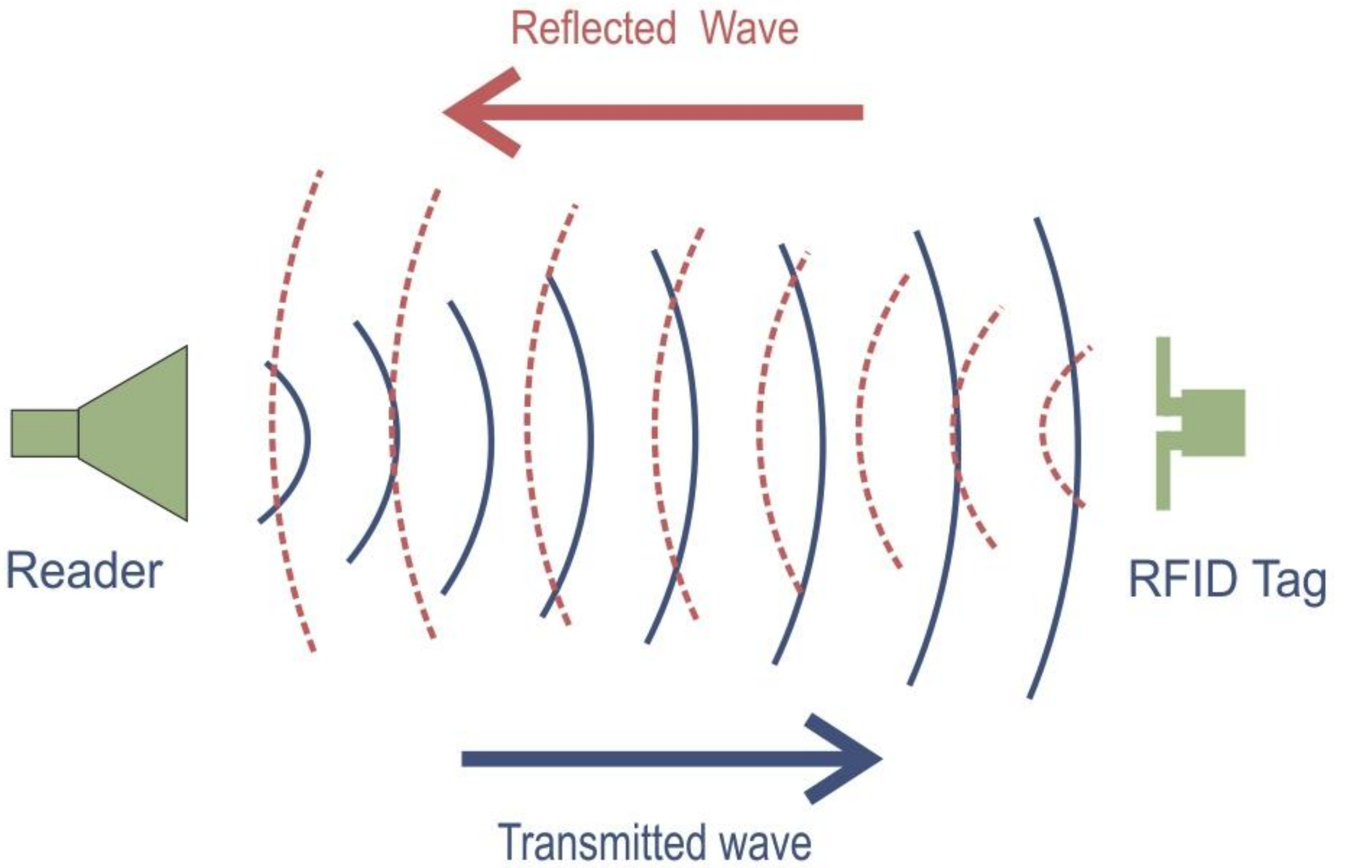
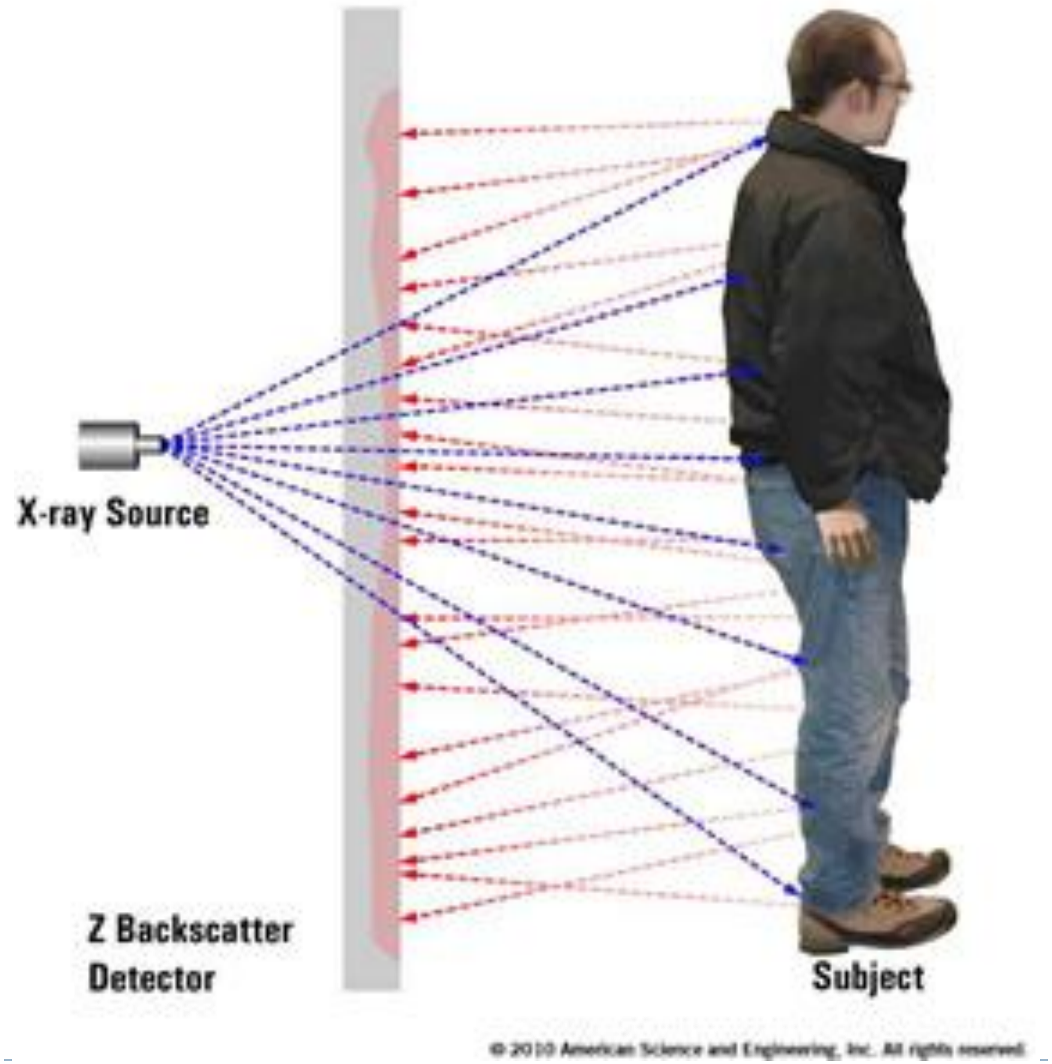
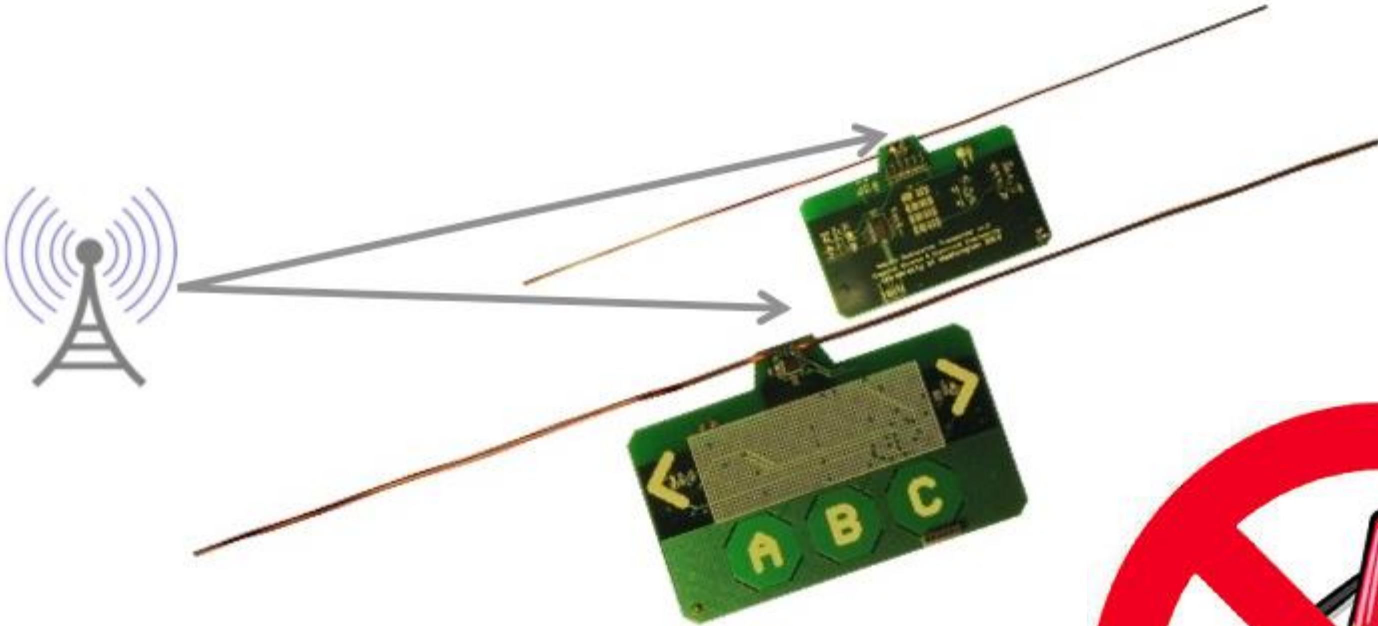
What is backscatter?



Scanning devices

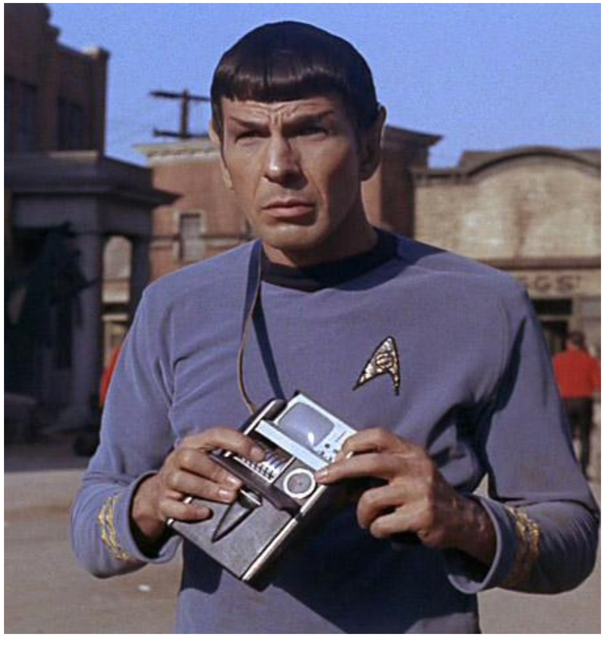


Battery free wireless communication



Outline

- Full Duplex Backscatter:
  - Transforming our smartphone into Star Trek’s Tricoder

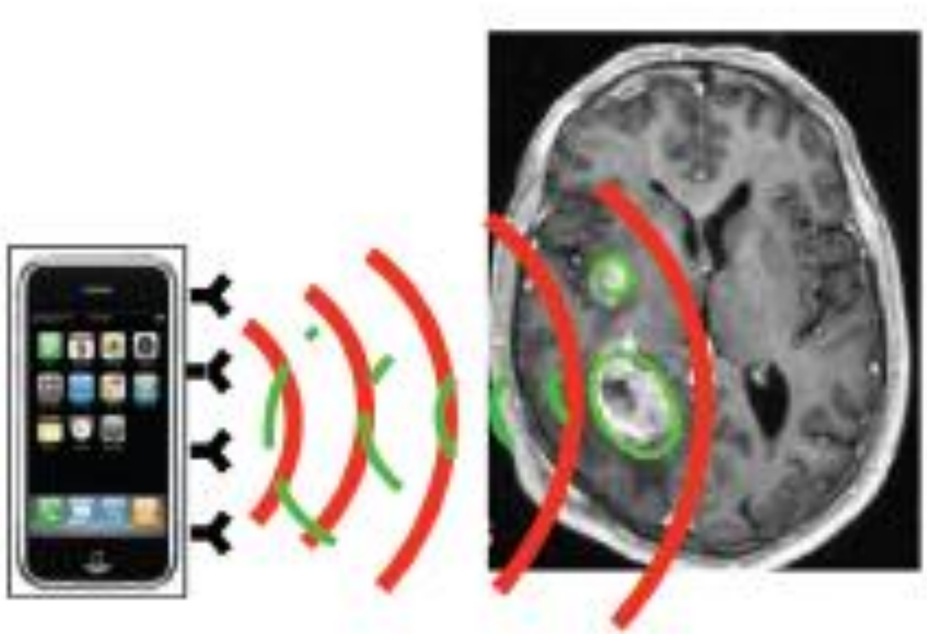


Outline

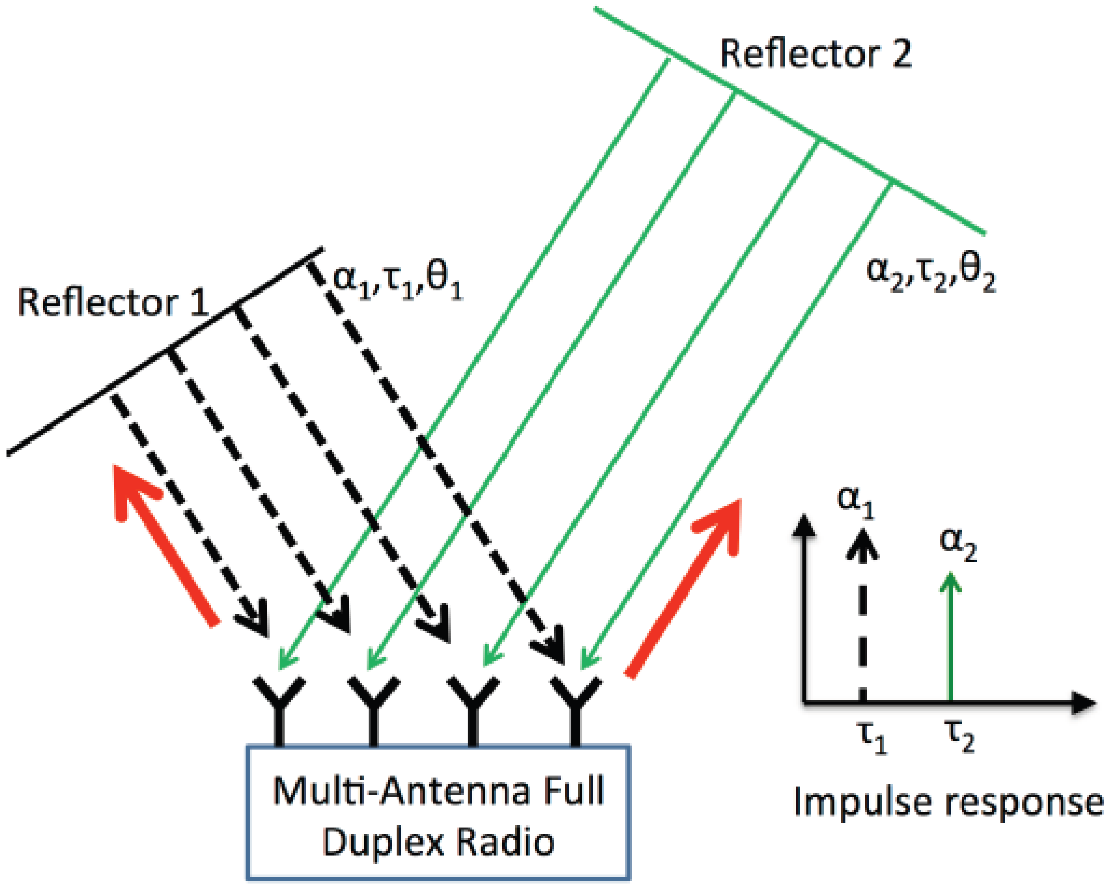
- Full Duplex Backscatter:
  - Transforming our smartphone into Star Trek’s Tricoder
- Ambient Backscatter:
  - RF battery free communication

Full Duplex Backscatter

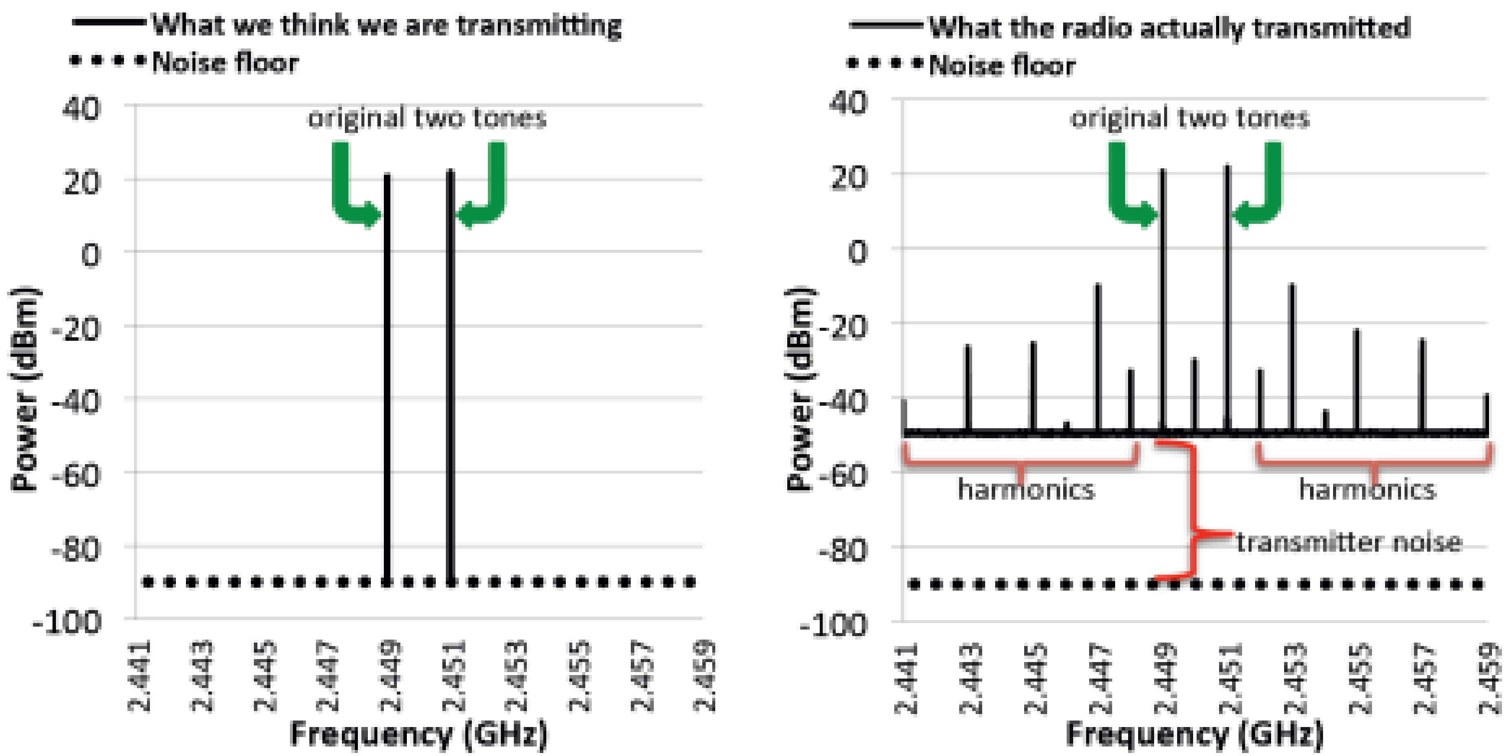
- Transforming our smartphone into a futuristic Tricoder



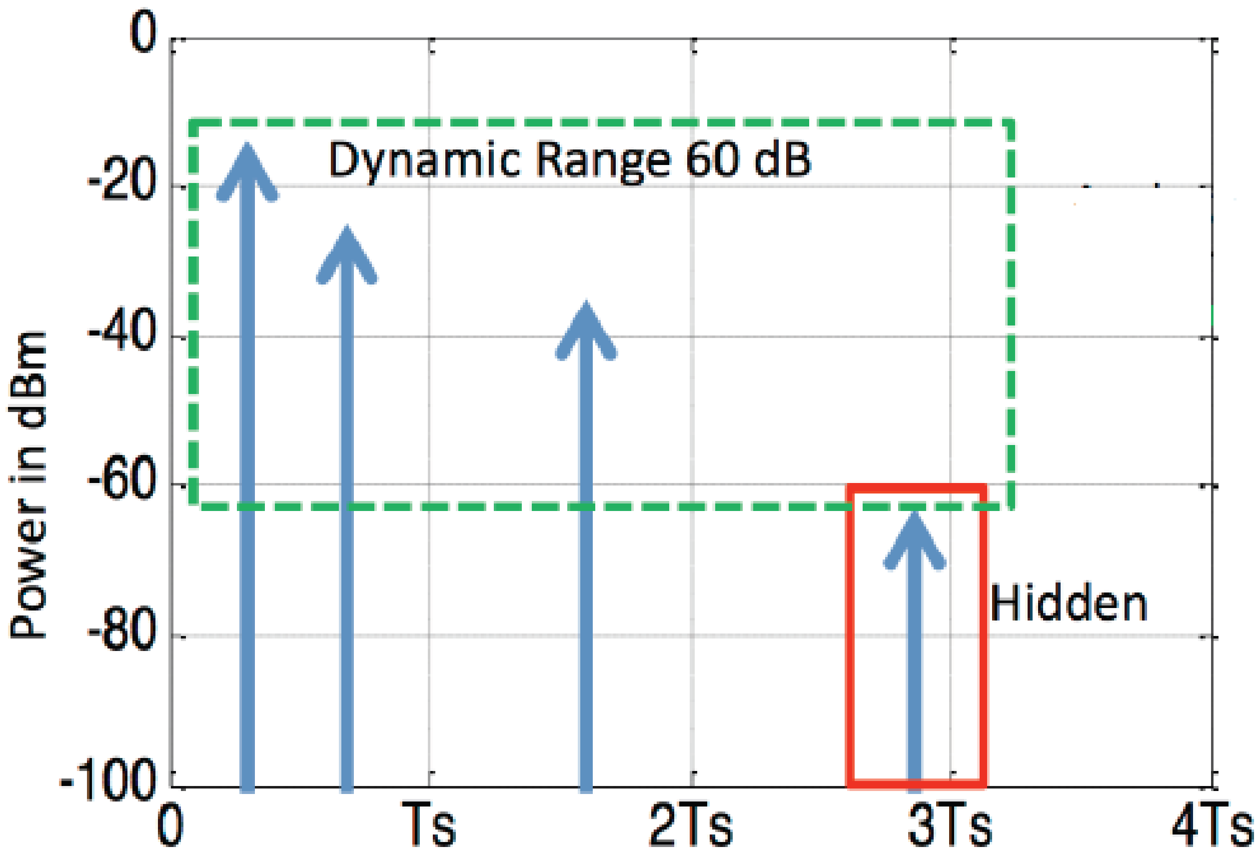
Limited sampling rate



Self-interference



Limited dynamic range



Model of backscatter

$$h_m[n] = \sum_k \alpha_k e^{i(\nu_k + \gamma_{mk})} \operatorname{sinc}(B(nT_s - (\tau_k + \frac{\gamma_{mk}}{2\pi f_c})))$$

- $\alpha_k e^{i\nu_k}$: complex attenuation for the *k*th reflection
- $\gamma_{mk} = \frac{2\pi}{\lambda}(m-1)d\sin\theta_k$: added phase shift for *k*th reflection at *m*th antenna, relative to the first receiver
- f_c : carrier frequency
- λ : wavelength
- d : distance between two consecutive antennas

Estimation of the parameters

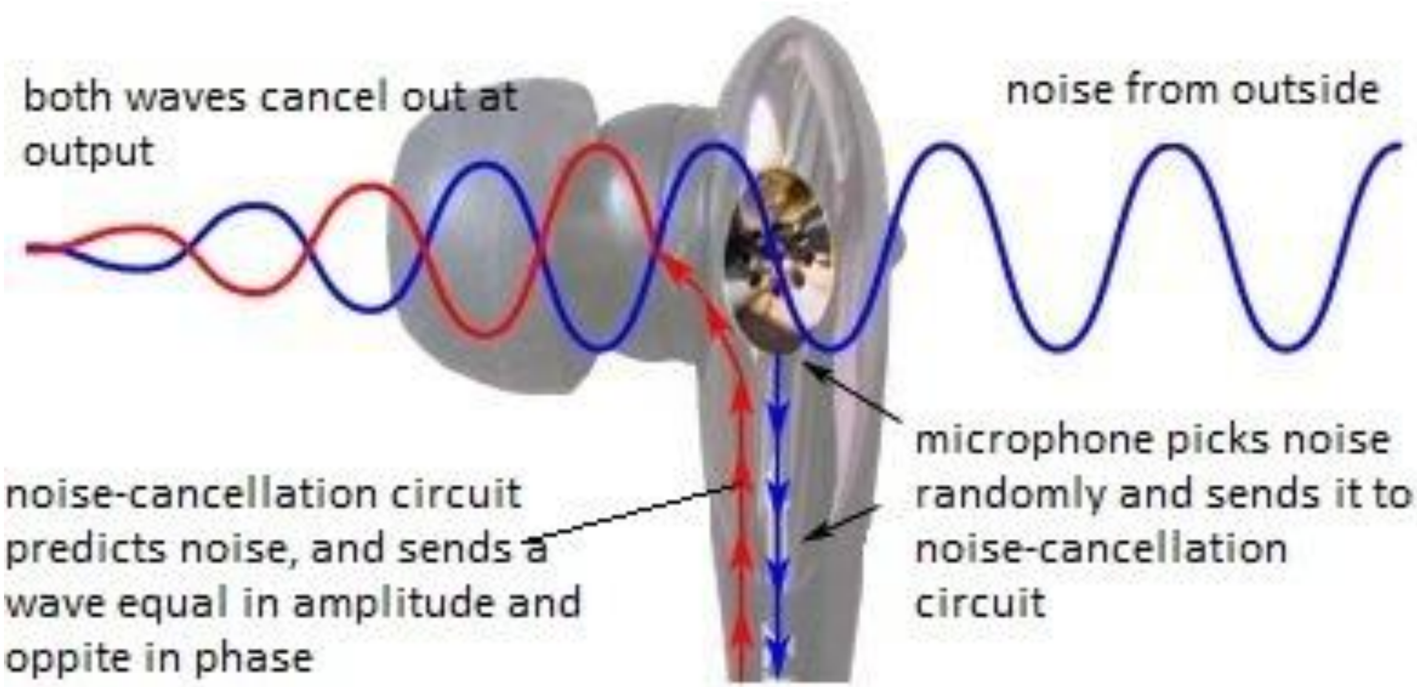
- Estimation of the linear channel ➡ $\tilde{h}_m[n]$

- Estimation of the parameters of the constituent backscatter by solving the following optimization problem

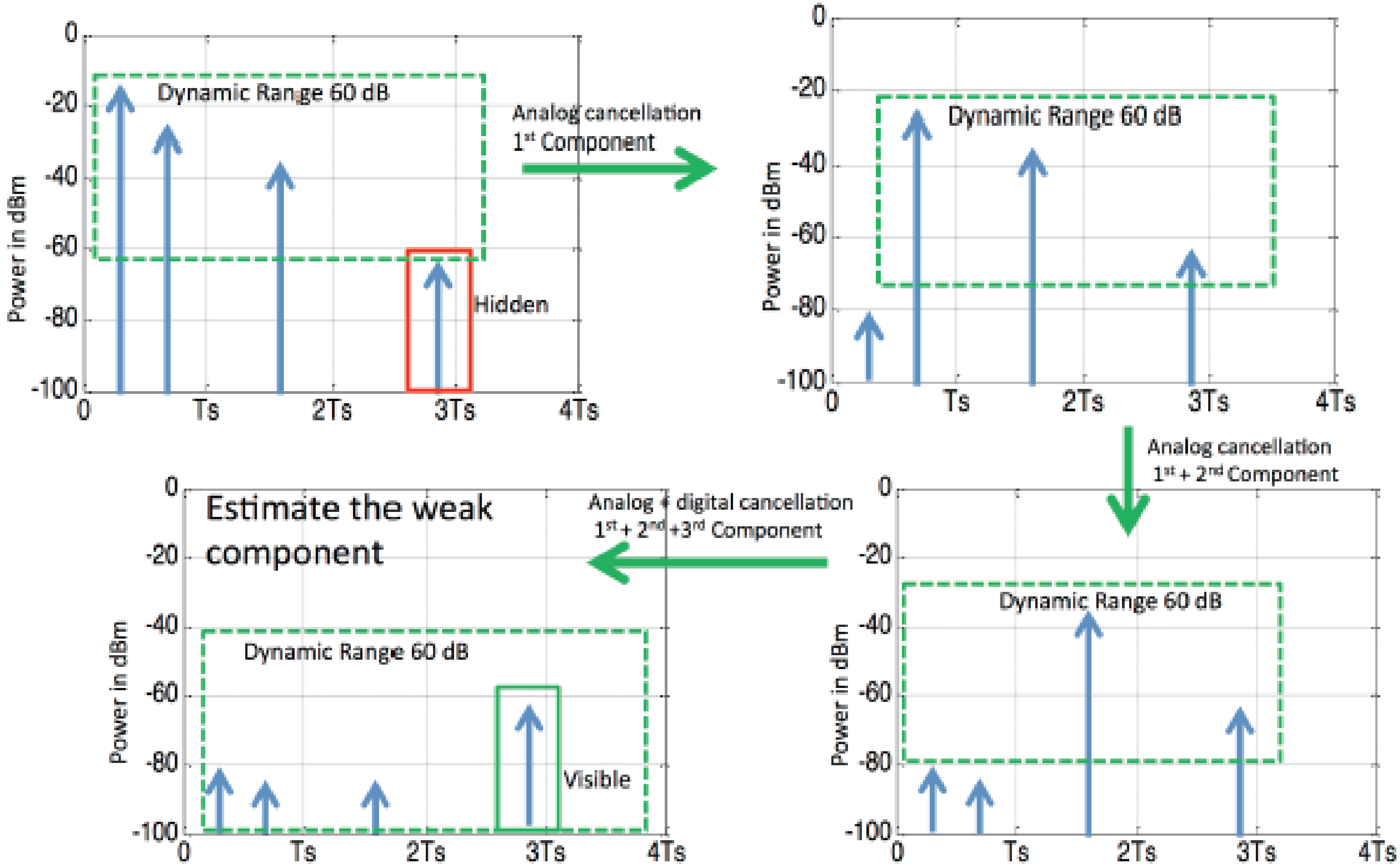
  minimize $\sum_m \sum_n \|h_m[n] - \tilde{h}_m[n]\|^2$

  where
  $$\tau_k \geq 0, \alpha_k \leq 1,$$
  $$\theta_k \in [\tfrac{-\pi}{2}, \tfrac{\pi}{2}], \nu_k \in [0, 2\pi],$$
  $$k = \{1, \ldots, L\}, n = \{-N, \ldots, N\},$$
  $$m = \{1, \ldots, M\}$$

Signal cancellation



Formal algorithm

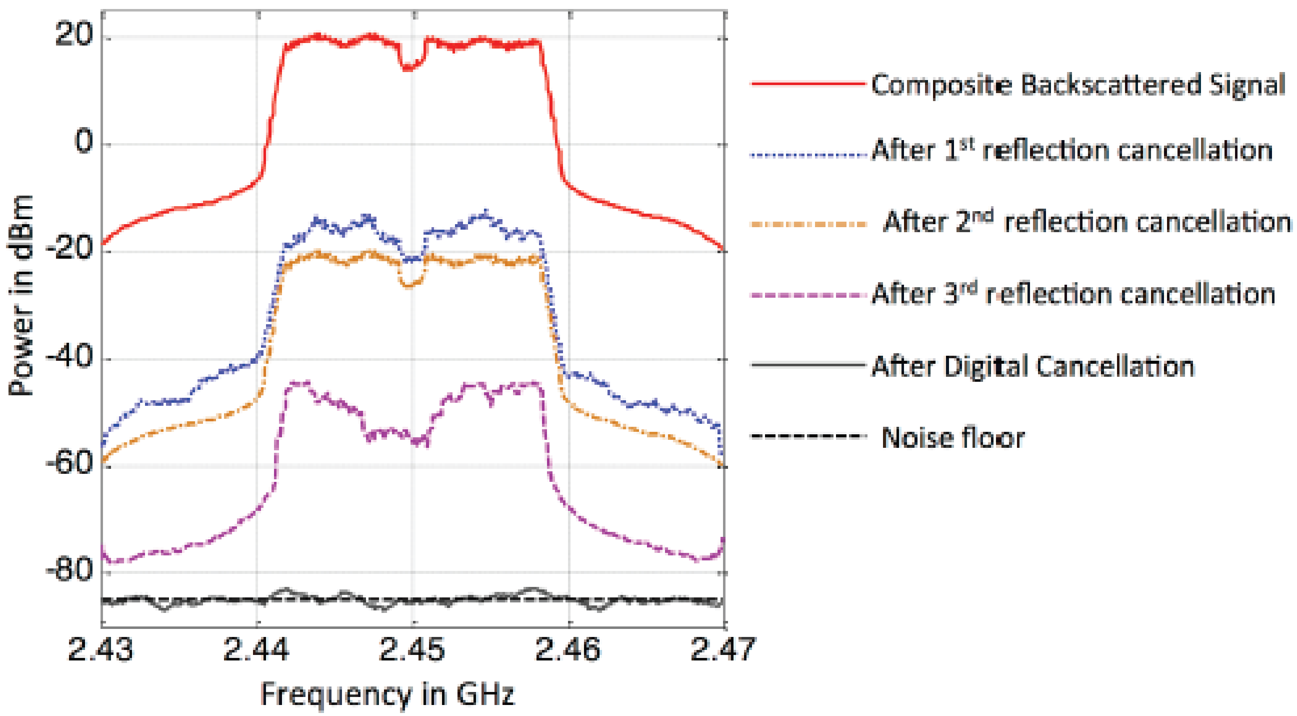


First evaluations

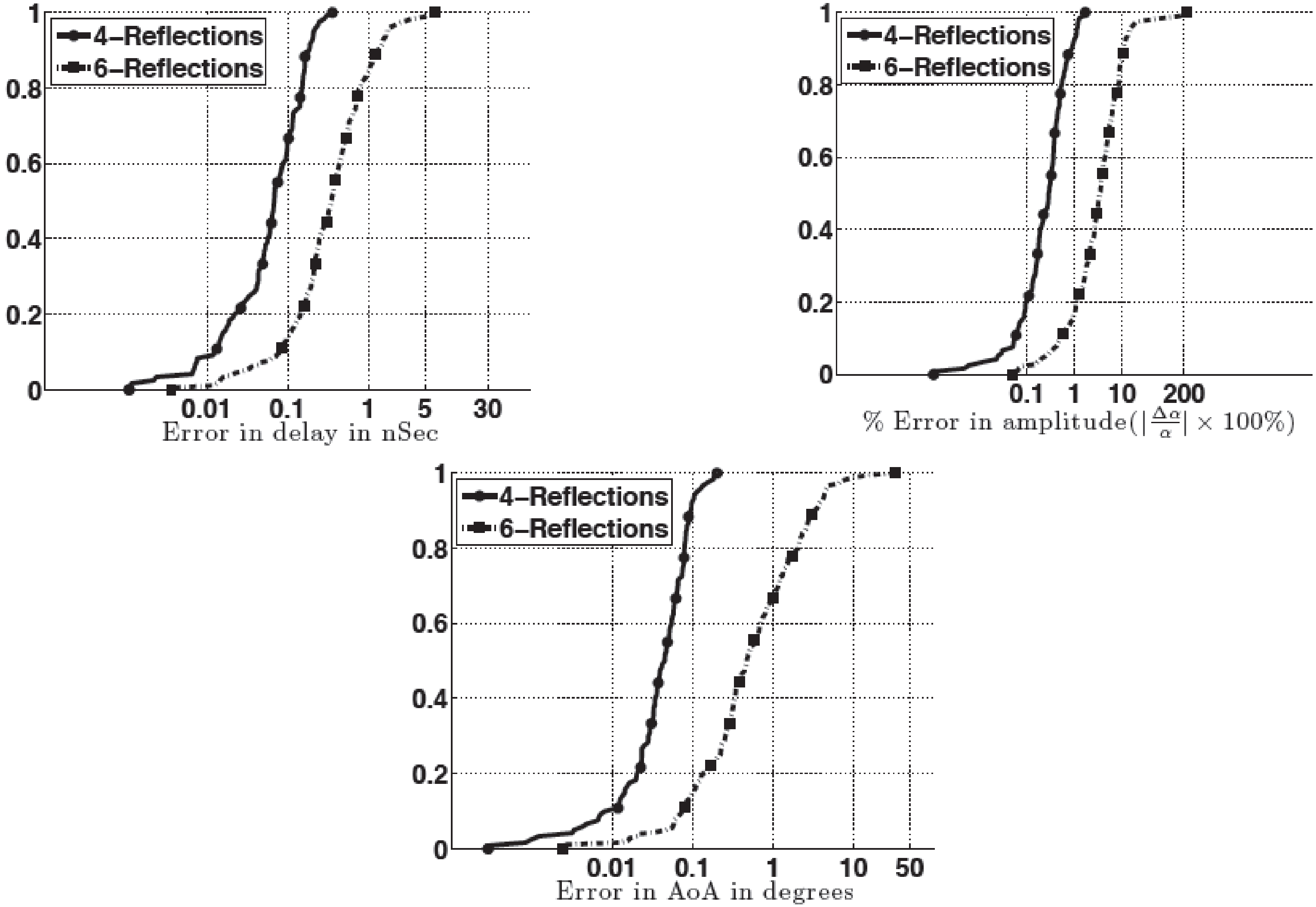
- Checking the possibility of progressive cancellation by using an emulated backscatter setup

- Checking the accuracy of the parameters estimation algorithm via MatLab simulations

Progressive cancellation results



Parameter estimation accuracy



Conclusions

- Basic building blocks for transforming a smartphone into a scanning device

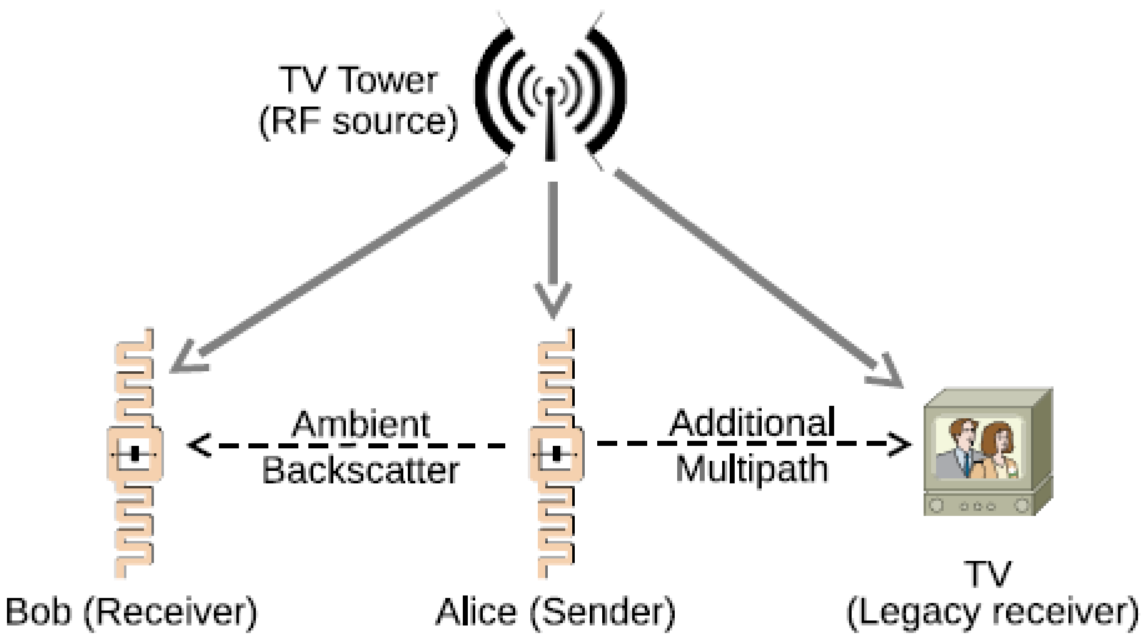
- Changes in the hardware are needed

- First evaluation of the solutions for the main challenges gave good results

- More in depth evaluations are needed

Ambient Backscatter

- Idea: enable communication among devices by using only **ambient RF signals** as only source of power



RF signals

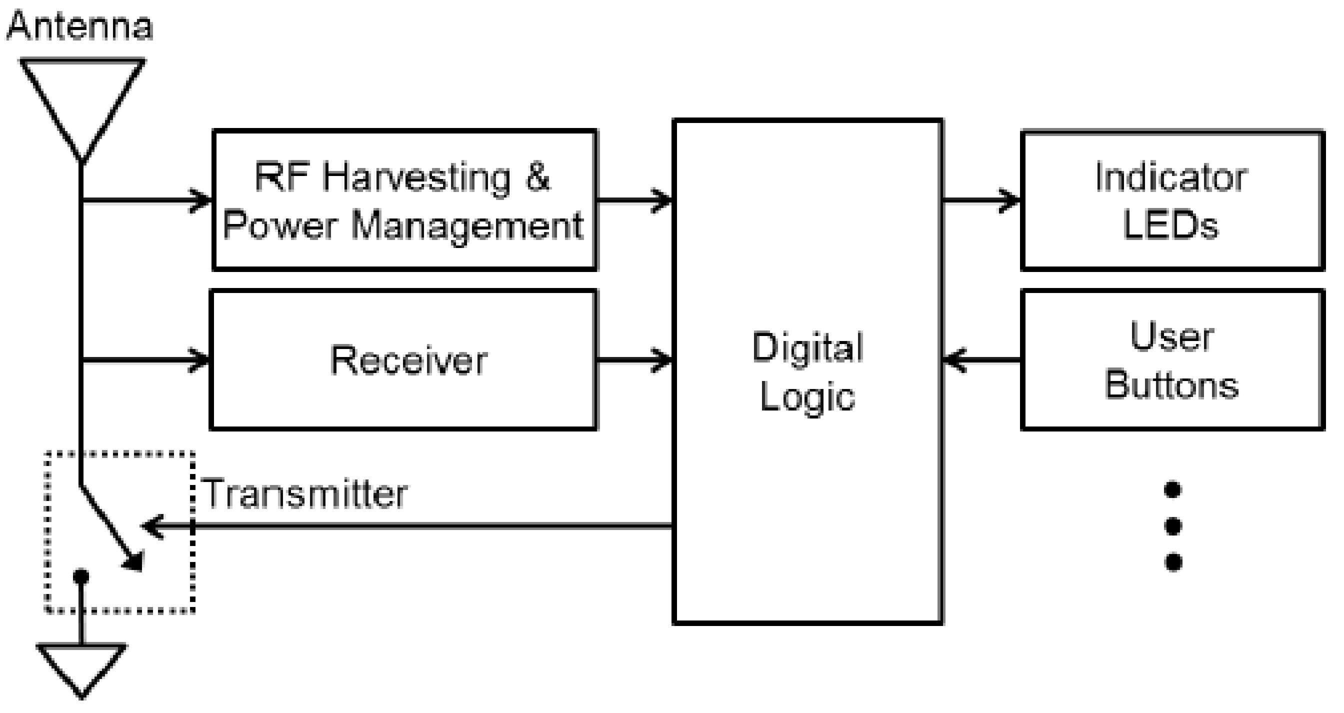
- It includes: TV, radio and cellular transmissions
- TV signals in particular have these characteristics:
  - Carry up to 1 MW power of Effective Radiated Power
  - Serve locations 100 mi away from the source (flat terrain), 45 mi (denser terrain)
  - Excellent coverage
  - Broadcast signals 24/7
  - Amplitude changes at a very fast rate
  - Synchronization symbols to compute multipath channel characteristics

Designing an Ambient Backscatter

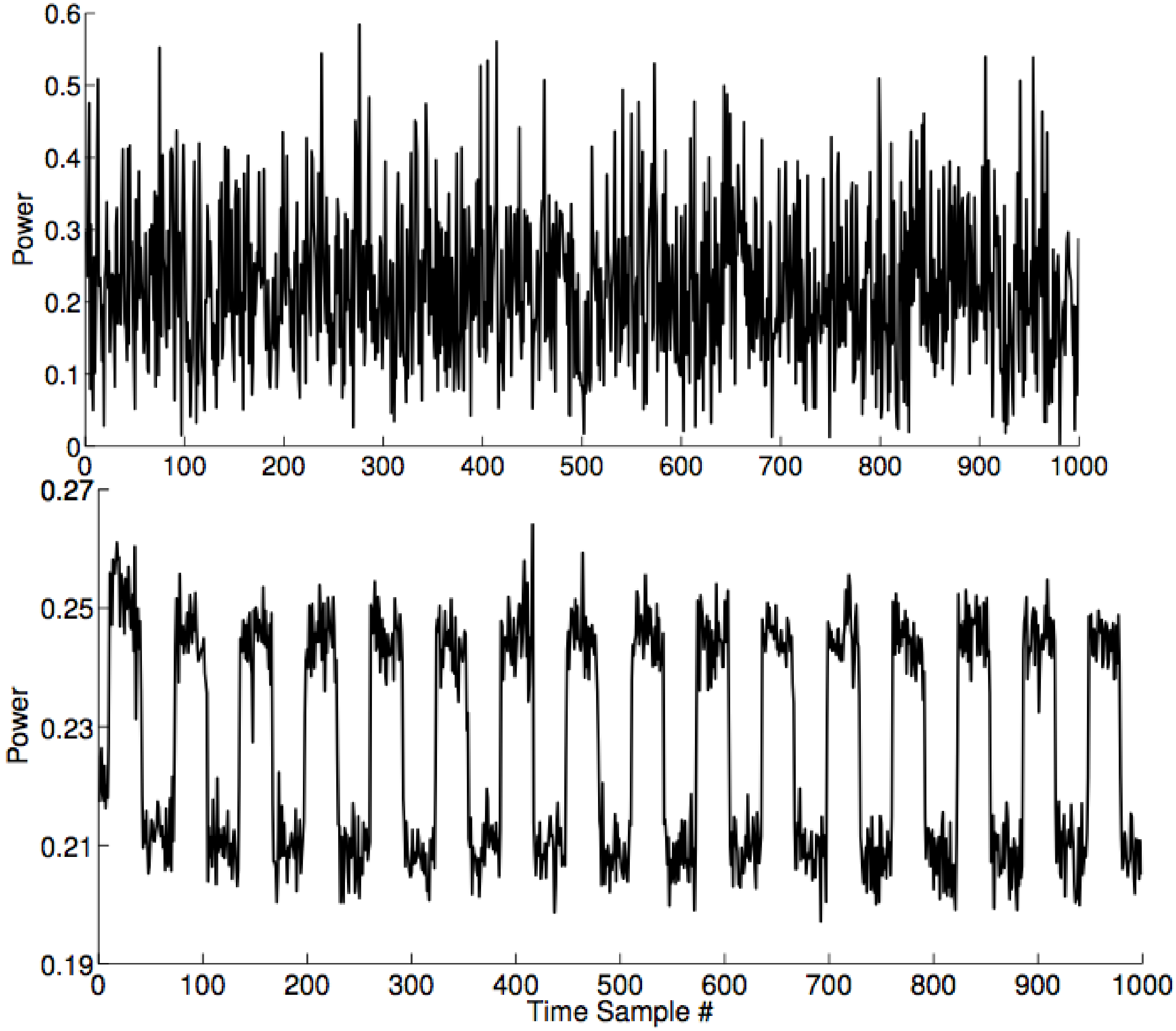
- Three main challenges:
  - Mechanism to extract the backscattered information carried by the RF signals
  - Low power infrastructure
  - Channel arbitration and bit error detection

- It differs from traditional backscatter technologies because:
  - They relies on power hungry components

Ambient Backscatter design



Extracting the backscattered signal



Formal extracting technique

- Averaging the instantaneous power in the N receiver samples:

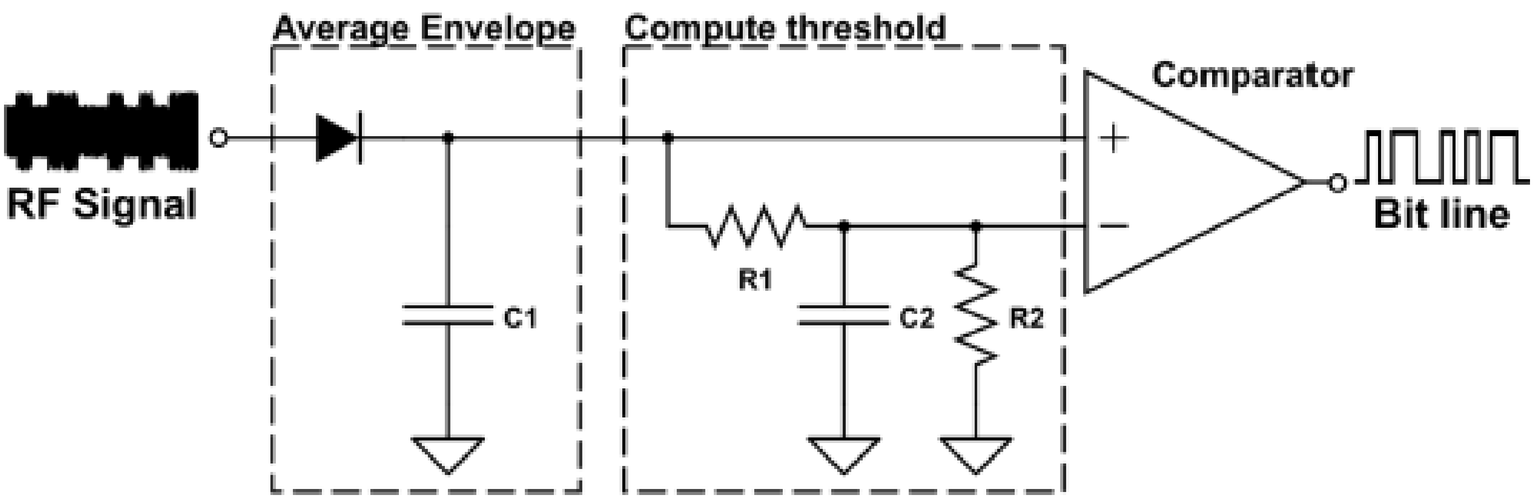
$$\frac{1}{N}\sum_{n}^{N}\left|y\left[n\right]\right|^{2}=\frac{1}{N}\sum_{n}^{N}\left|x\left[n\right]+\alpha Bx\left[n\right]+w\left[n\right]\right|^{2}$$

- B is either '0' or '1', *w[n]* is uncorrelated with *x[n]*:

$$\frac{\left|1+\alpha B\right|^{2}}{N}\sum_{n}^{N}\left|x\left[n\right]\right|^{2}$$

- We have two power levels $|1+\alpha|^2 P$ and P

Receiver circuit



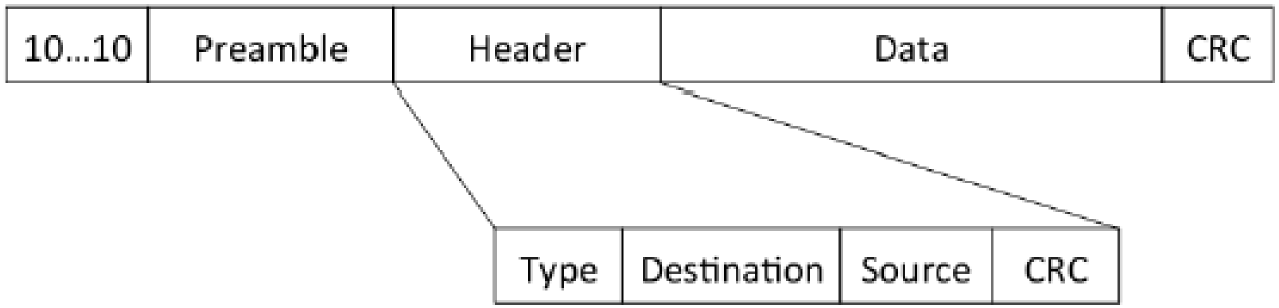
- RC circuit for the averaging stage (it acts a low-pass filter)
- Comparator which has a threshold ($\frac{V_0+V_1}{2}$) as input of the – pin and it detects the two levels of power

Physical and Link layer structure

- Three main challenges:
  - Mechanism to extract the backscattered information carried by the RF signals ✓
  - Low power infrastructure ✓
  - Channel arbitration and bit error detection

- No presence of a centralized controller
  - A new packet format
  - Link layers techniques

Packet format



- 10…10: sequence of '1' and '0' used to awake the logical unit
- Preamble: used to detect the packet
- Type: which can be data/ACK

Link Layer

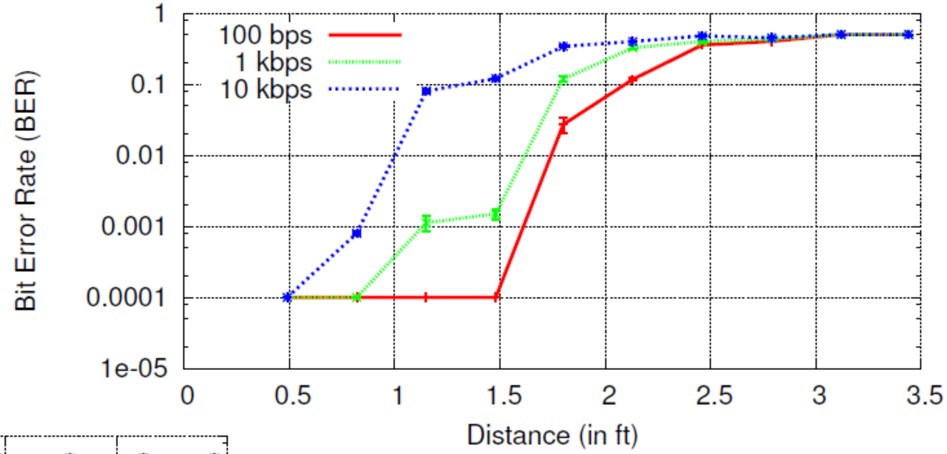
- The detection of bit errors is done using CRC

- No centralized authority to arbitrate the channel
  - Devices perform carrier sense by overhearing the channel
  - In absence of a transmitter you have a constant bit, so:

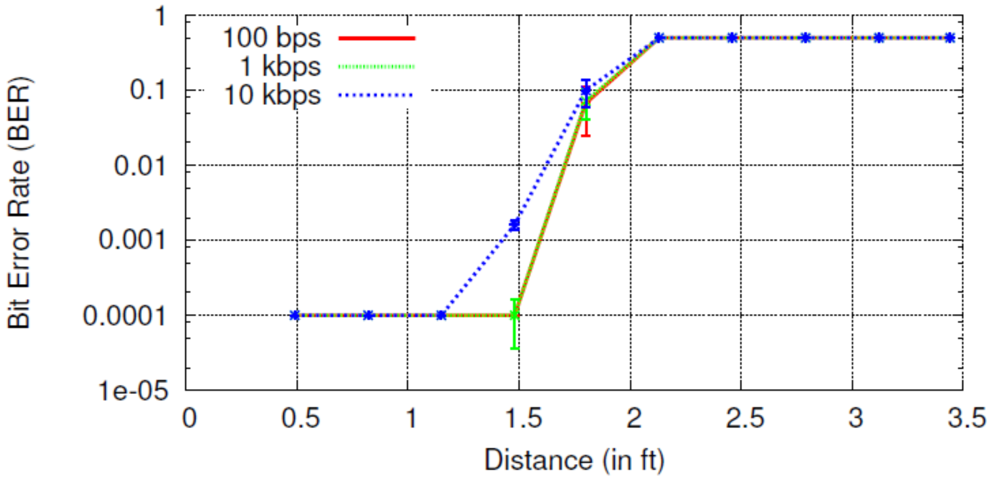
$$D = 1 - \frac{|\#ones - \#zeros|}{\#ones + \#zeros}$$

  - In presence of a transmission D is close to 1
  - In absence of a transmission D is close to 0
- RTS-CTS can be used to avoid Hidden Terminal problem

BER at different locations (Far vs Near)

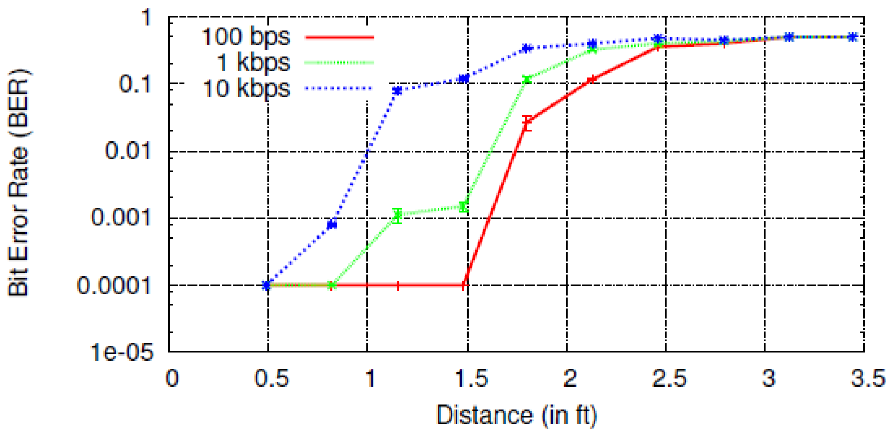


(a) Location 1: Indoor and Near

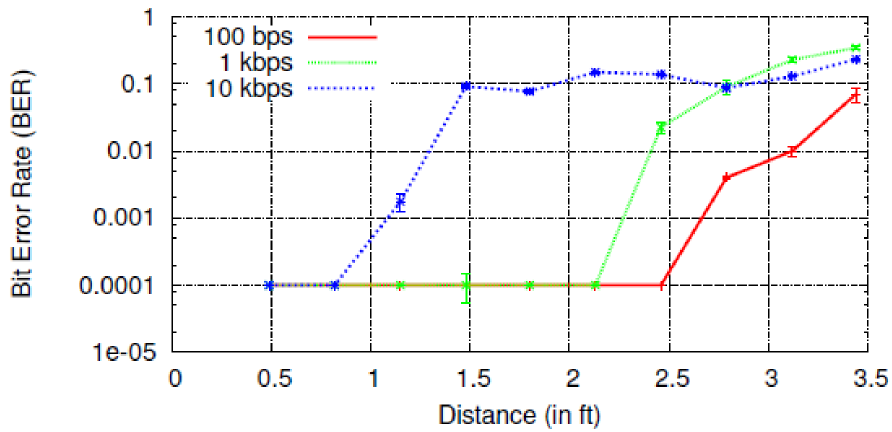


(c) Location 2: Indoor and Far

BER at different locations (Indoor vs Outdoor)

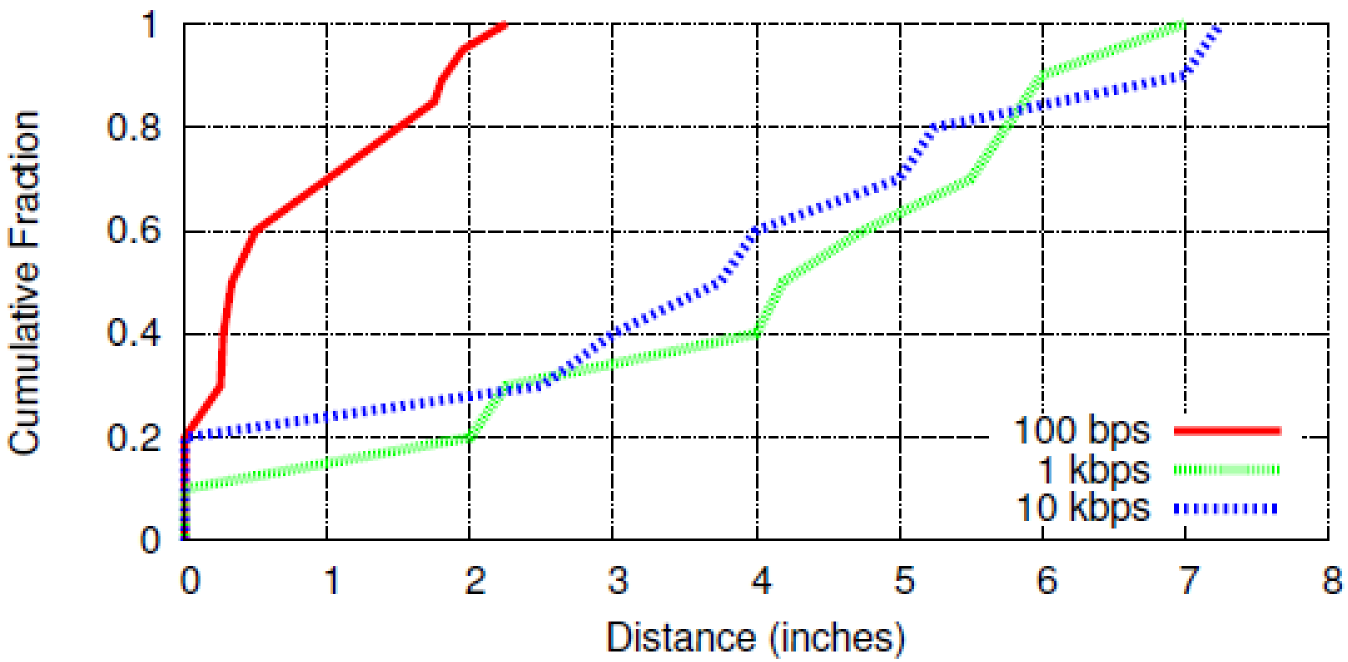


(a) Location 1: Indoor and Near

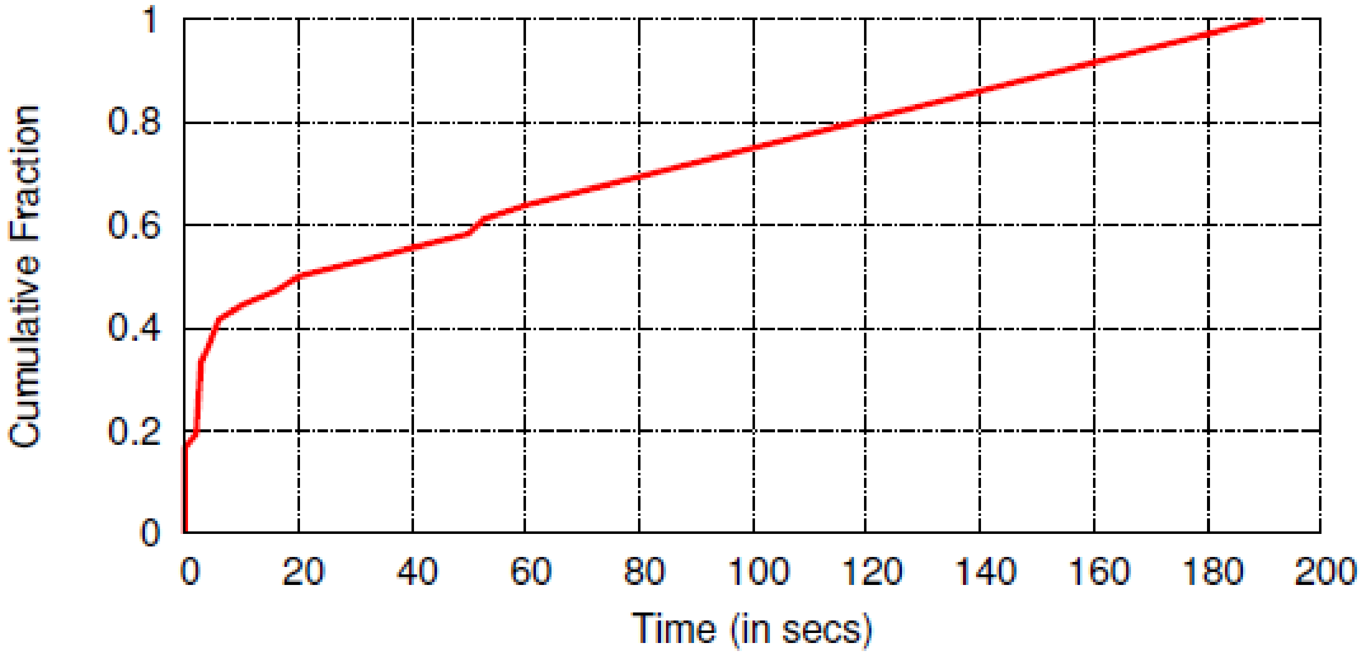


(b) Location 3: Outdoor and Near

Interference with TV



Real world application into a Grocery Store



Conclusions

- They implemented a prototype of a power free communication using TV signals
- The results were impressive
- It is a first step into a direction of battery free communication

References

- Dinesh Bharadia, Kiran Raj Joshi, Sachin Katti: “Full Duplex Backscatter”

- Vincent Liu, Aaron Parks, Vamsi Talla, Shyamnath Gollakota, David Wetherall, Joshoua R. Smith: “Ambient Backscatter: Wireless Communication Out of Thin Air”

Q&A