New Communication Paradigms for Very Large Scale Sensor networks:

Virtual Radar Imaging and Distributed Beamforming

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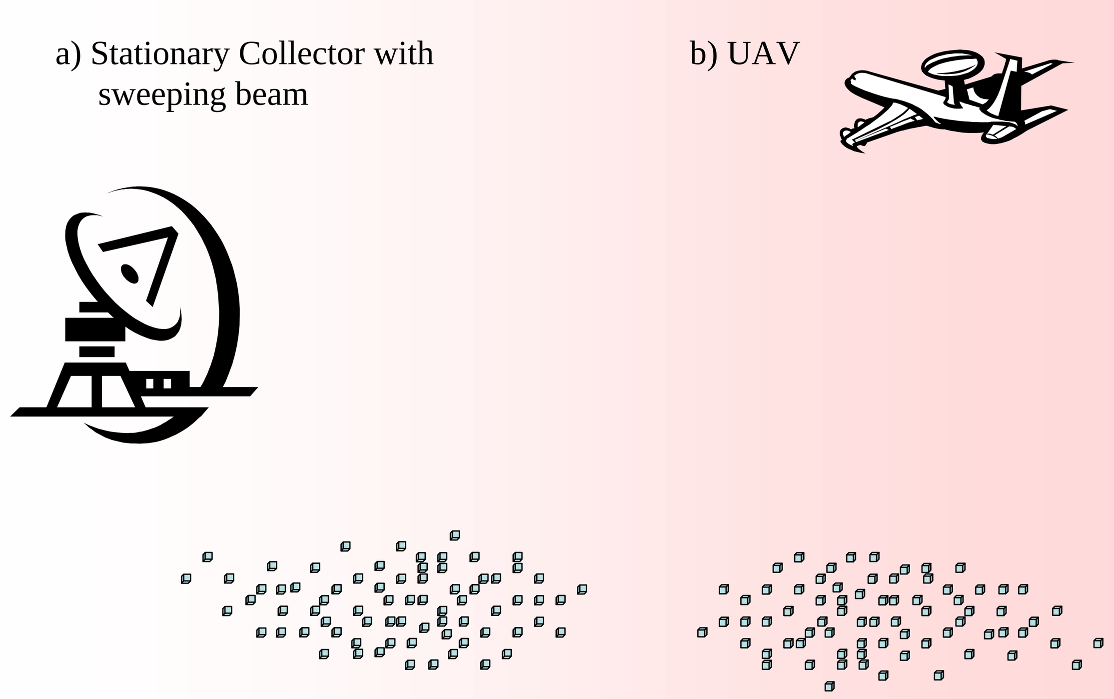
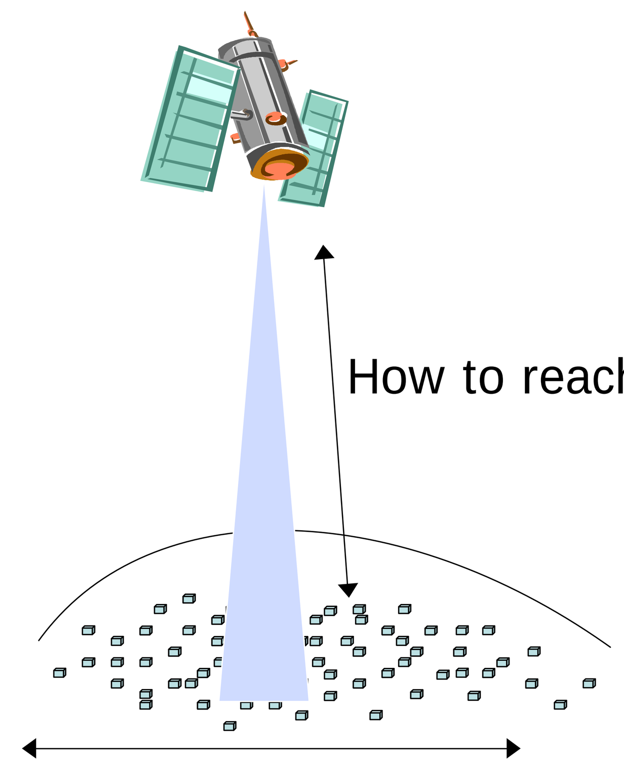
Why Imaging Sensor Nets ???

- **Simplicity** – bare-minimum functionality and protocols
- **Cost** – simplicity ➔ lower cost per sensor
- **Localization** – obtained at no additional cost
- **Scalability** – 'pixel' functionality invariant of scale
- **Applicability** – Collector far removed from sensors



Large Scale Sensor networks



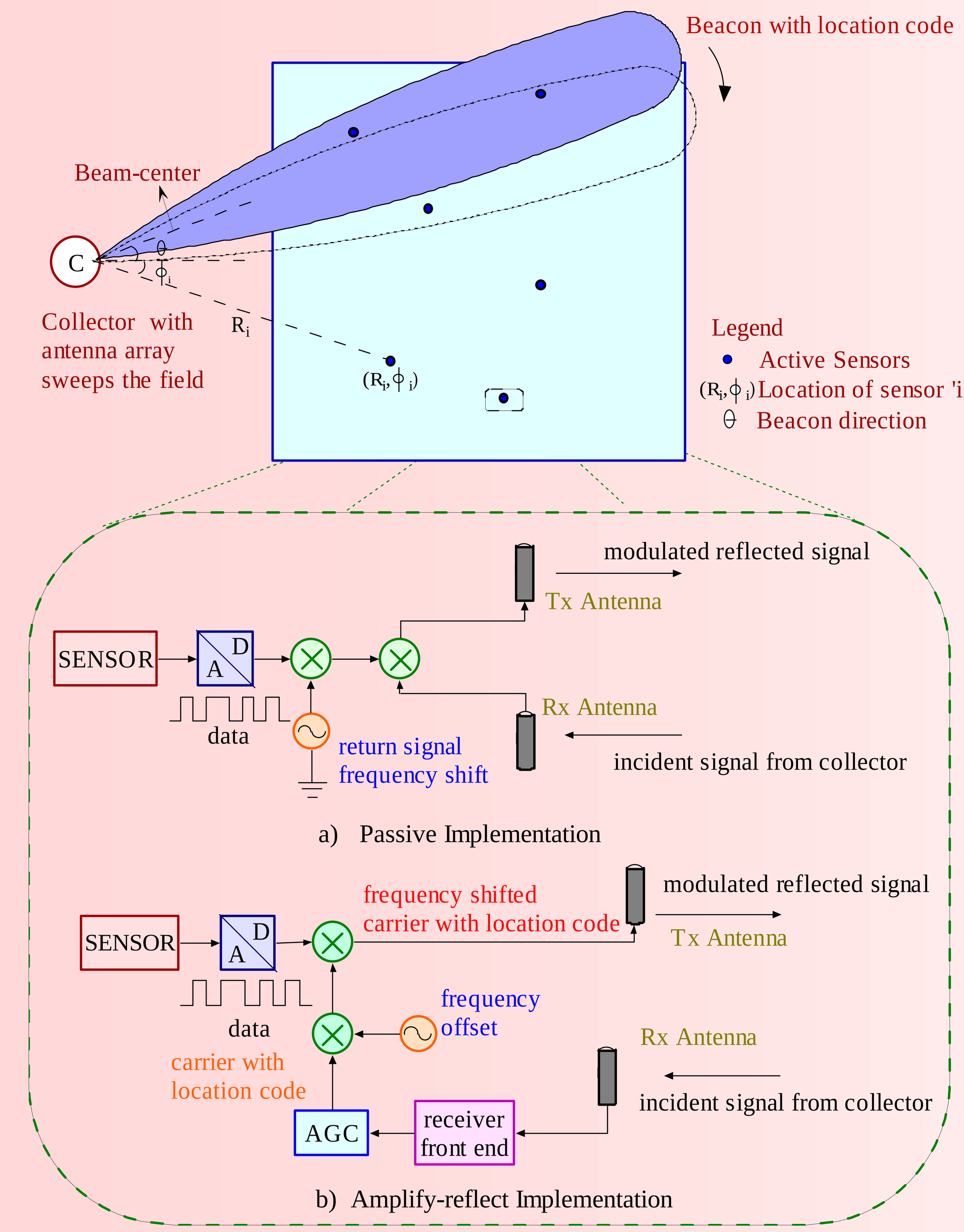
Imaging Sensor net

- Interpret sensors as 'pixels'
- Radar Imaging Techniques

Distributed Beamforming

- sensors form virtual antenna array
- adjust Tx phase to beamform

Imaging Sensor Nets: Towards a Prototype



Key Features

- Dumb sensors act as 'pixels'
- Electronically reflect and modulate collector's beacon
- Collector "images" sensor locations and demodulates data

Implementation Considerations

- Spatial Resolution ➔ High Carrier Frequency
- Ultra-simple sensor functionality – low-cost ASIC
- Collector – Software/DSP

Link Budget Analysis

$P_{transmit}$ = 80 microwatt $G_{Transmit}$=0dB $G_{Receive}$=25dB

$f_{carrier}$=1 GHz , Bandwidth of s(t) = 15 MHz

Max. range = 2200m, P_{rec}/P_{tran} = -75dB => P_r = 2.4 pW

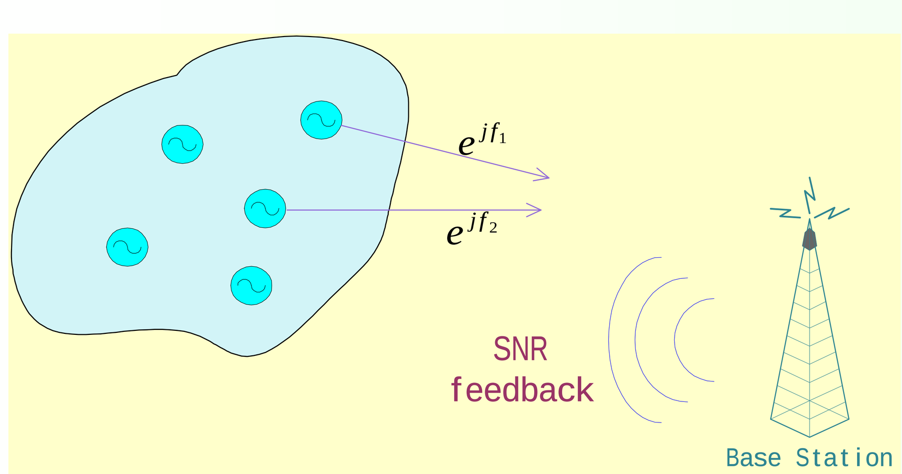
Rx NF = 3dB ***SNR$_{out}$*** = 11dB

Design SNR = 3dB/sensor/snapshot

Energy consumed per sensor per flyby = 4nJ

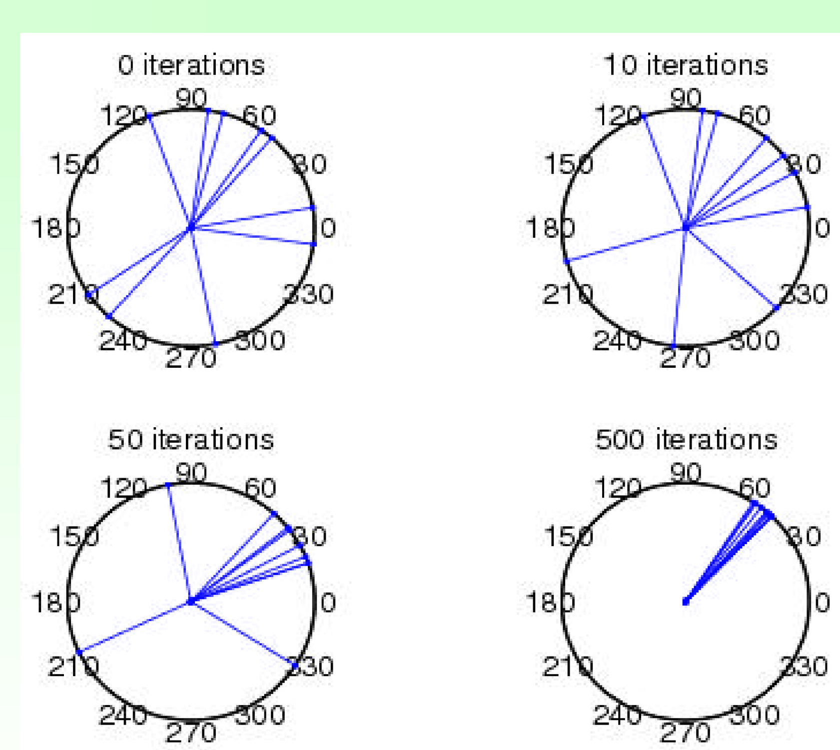
There is 7 dB margin to work with !

Distributed Beamforming with SNR feedback

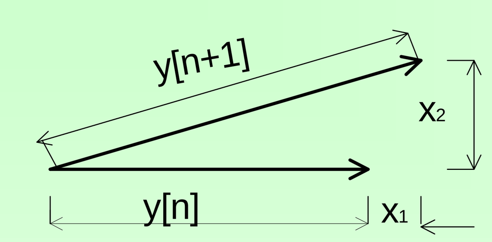


Distributed Algorithm

1. Sensors start with arbitrary phase
2. Sensors add random phase perturbation, transmit
3. Receiver broadcasts SNR feedback
   IF SNR has increased
   Sensors make perturbation permanent
   OTHERWISE
   Perturbation is discarded
4. Sensors repeat 2-3 until convergence



Analytical Model for convergence



- y[n] = received signal strength
- Φ_i is phase is sensor i
- δ_i is random phase perturbation
  - $\Phi_i \leftarrow \Phi_i + \delta_i$
- ? y[n] = y[n+1]-y[n], if >0
  = 0, otherwise
- let $\delta_i = \pm\delta$

$$y[n+1] = \left|\sum_i e^{j(f_i + d_i)}\right|$$

$$\Delta y = \left| y\cos d - \sum_i \sin f_i \sin d_i + j\sum_i \cos f_i \sin d_i \right| - y$$

$$= \left| y\cos d - x_1 + jx_2 \right| - y$$

- x1 and x2 are Gaussian by CLT
- variances s_1, s_2 are related as:

$$s_1^2 + s_2^2 = N\sin^2 d$$

All we need is an estimate of s_1 as a function of y

assuming uniformly distributed Φ_i works well!!!