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Cognitive Sub-Nyquist Collocated MIMO Radar Prototype

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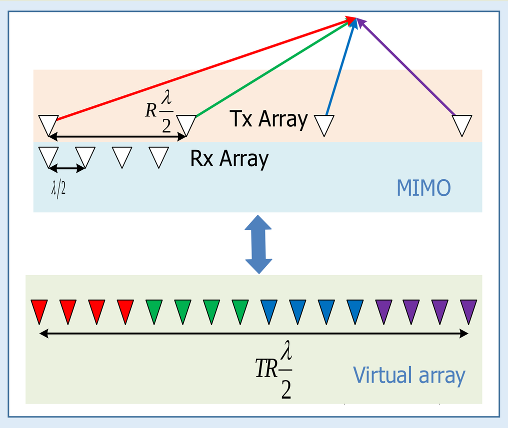
Main Contributions

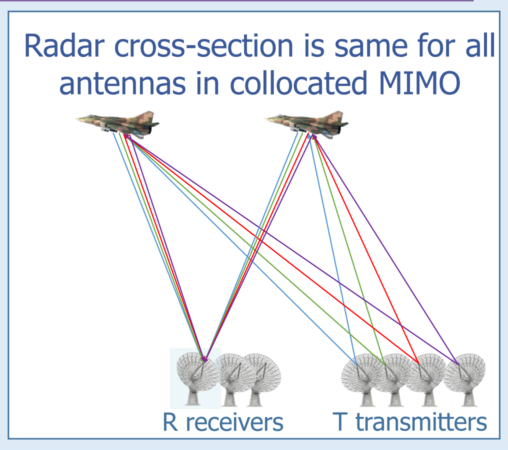
- Prototype realizes both spatial and temporal sub-Nyquist sampling in a MIMO radar without loss of angular and range resolution
- Sub-Nyquist 4x5 MIMO array shows same detection performance as Nyquist 8x10 ULA
- Cognitive transmission is employed to further enhance SNR for sub-Nyquist arrays

Conventional Collocated MIMO

MIMO array with fewer elements has same spatial resolution as a virtual array with more elements



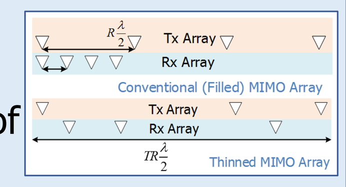
MIMO transmits orthogonal waveforms and processes linear combination of echoes received due to each waveform



Sub-Nyquist MIMO

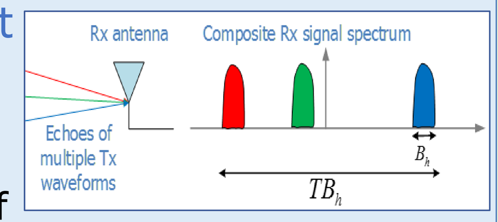
Spatial Sub-Nyquist

- Less antenna elements (randomly thinned arrays)
- Same angular resolution as of virtual array



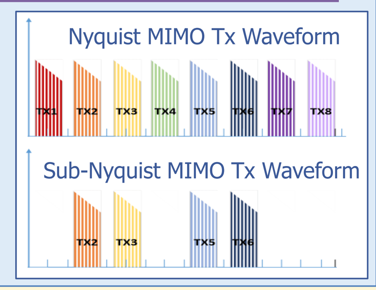
Temporal Sub-Nyquist

- Reduced sampling rate at each Rx
- Same range resolution as that of Nyquist bandwidth TB_h



Cognitive Transmission

- Entire power is focused in only few narrow subbands
- High SNR at receiver



Signal Model and Recovery

- Received signal for P pulses at the qth antenna after demodulation:

Total number of Targets; Doppler Shift; Target time delay; Element location factor; Target Azimuth

$$x_q(t)=\sum_{p=0}^{P-1}\sum_{m=0}^{M-1}\sum_{l=1}^{L}\alpha_l h_m(t-\tau_l-p\tau)e^{j2\pi\beta_{m,q}\vartheta_l}e^{j2\pi f_l^D p\tau}$$

- Fourier coefficients of the mth transmitter channel at the qth receiver:

Operating frequency; Target reflectivity

$$y^p_{m,q}[k]=\sum_{l=1}^{L}\alpha_l e^{j2\pi\beta_{m,q}\vartheta_l}e^{-j\frac{2\pi}{\tau}k\tau_l}e^{-j2\pi f_m\tau_l}e^{j2\pi f_l^D p\tau}$$

- Doppler focusing for a specific frequency ν

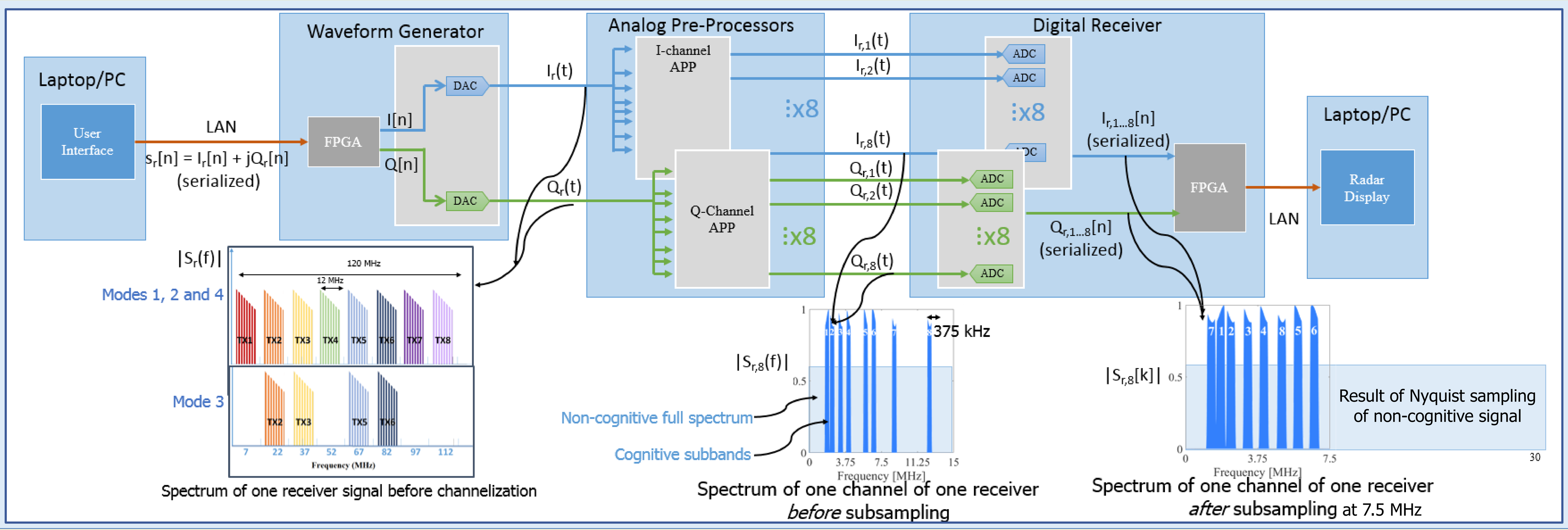
$$\Phi^{\nu}_{m,q}[k]=\sum_{l=1}^{L}\alpha_l e^{j2\pi\beta_{m,q}\vartheta_l}e^{-j\frac{2\pi}{\tau}(k+f_m\tau)\tau_l}\times\begin{cases}P & |f_l^D-\nu|<1/2P\tau\\ 0 & else\end{cases}$$

- Recover azimuth, delay and Doppler using simultaneous sparse 3D OMP with focusing

Technical Specifications

	Nyquist (Mode 1)	Sub-Nyquist (Mode 3)	Reduction
BW per Tx (incl. guard-bands)	15 MHz	3 MHz	80%
BW per Tx (excl. guard-bands)	12 MHz	3 MHz	75%
Temporal sampling rate	30 MHz	7.5 MHz	75%
Spatial sampling	8x10	4x5	50%
# Tx/Rx channels	80	20	25%

Overview of Hardware Architecture



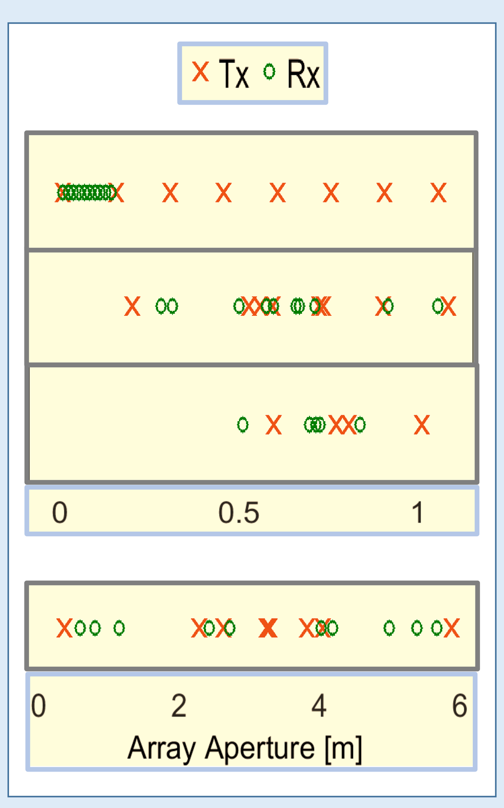
Array Modes

Mode 1: 8x10 Filled uniform array

Mode 2: 8x10 Filled random array

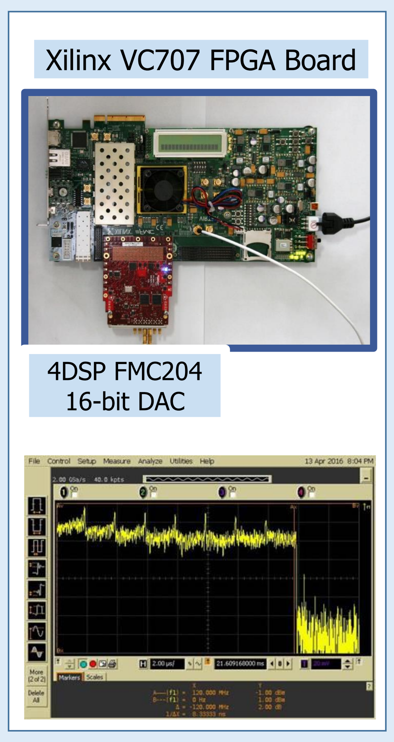
Mode 3: 4x5 Thinned random array (~Virtual 8x10 ULA) Spatial sub-Nyquist

Mode 4: 8x10 Thinned random array (~Virtual 20x20 ULA)



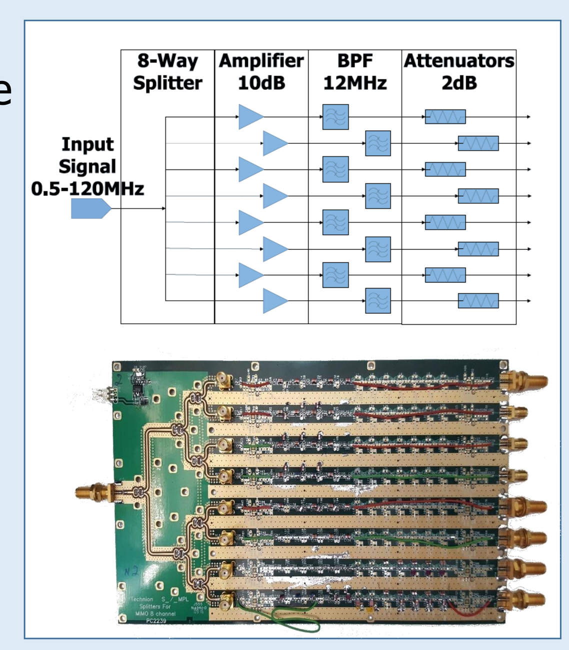
Waveform Generator

- Total BW, 8 Tx: 120 MHz
 3 MHz guard-bands
- Eight 375 kHz cognitive slices per Tx
- Cognitive BW, 1 Tx:
 3 MHz (= 8 x 375 kHz)
- BW reduction, 1 Tx (excl. guard-bands): 75% (3 of 12 Mhz)



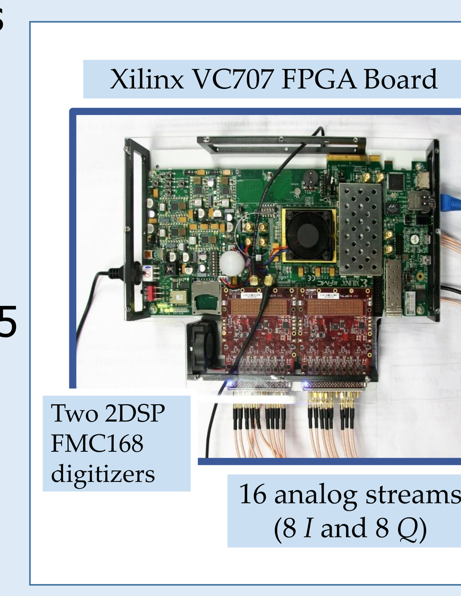
Analog Pre-Processor (APP)

- APP filters the receiver data into eight channels
- Dual back-to-back APPs in a single chassis
- BPFs have ~30 dB stopband attenuation to mitigate subsampling noise

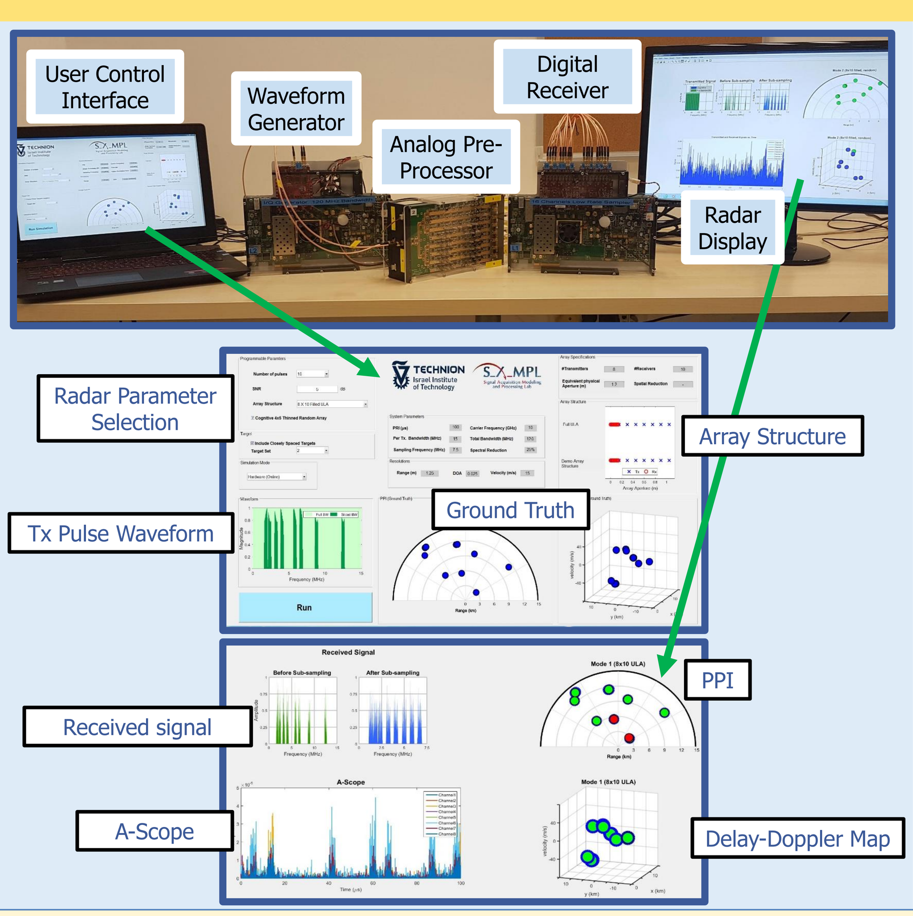


Digital Receiver

- Two 16-bit eight-channel digitizers for I and Q streams
- Sub-Nyquist sampling rate: 7.5 MHz/channel
- Signal BW with guard-bands: 30 MHz/channel

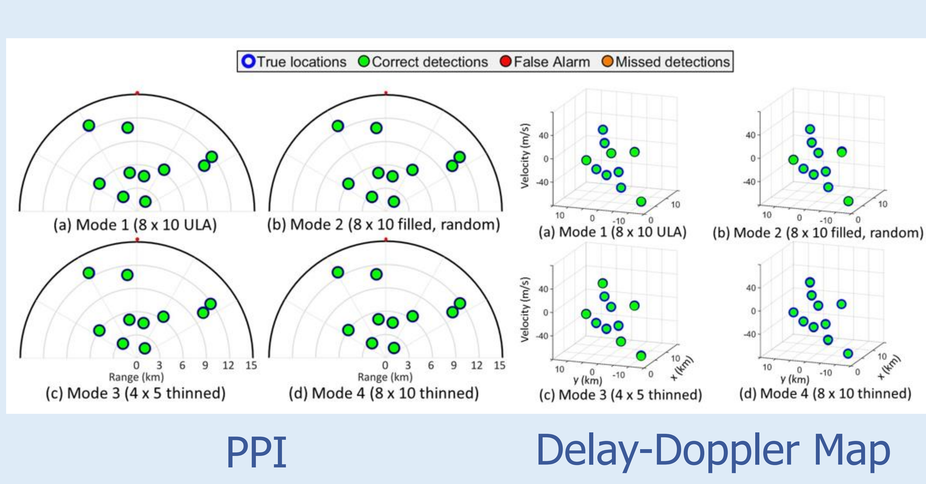


User Interface \ Radar Display



Sample Measurements Results

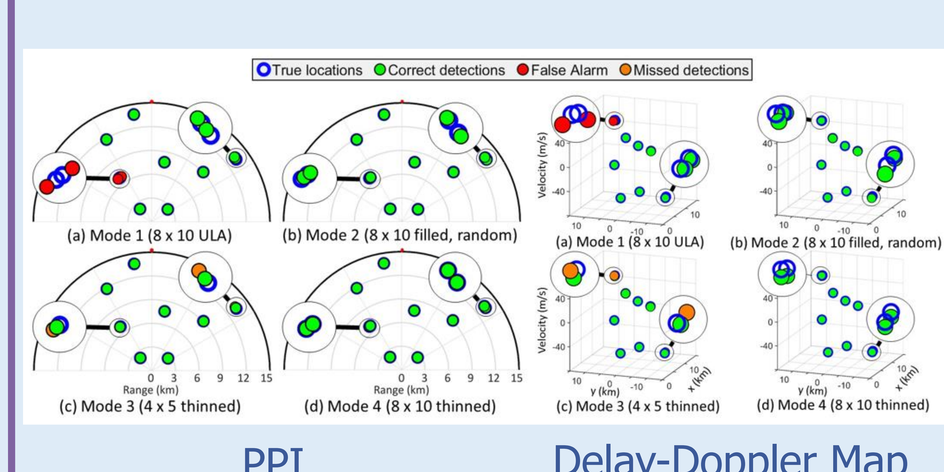
Randomly Placed Targets



10 Targets | Min. angular spacing: 0.025 | SNR = −15 dB

Mode 3 (sub-Nyquist) detection performance is same as that of Mode 1 (Nyquist)

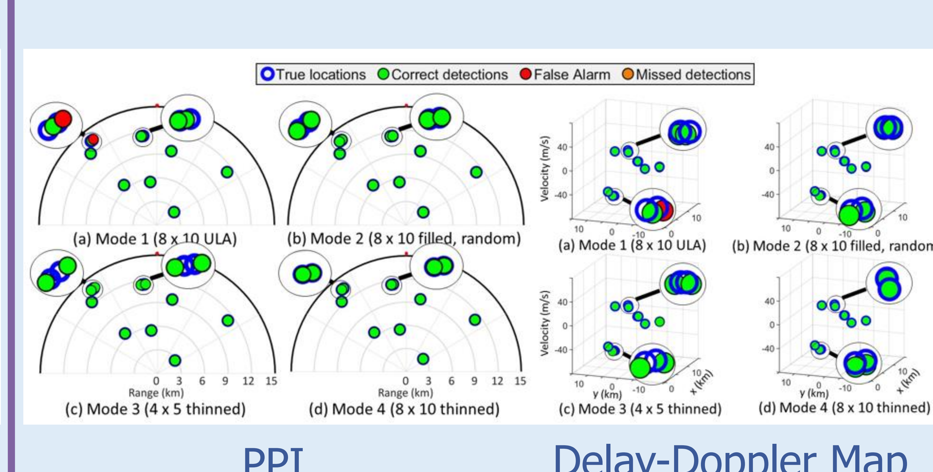
Closely Placed Targets



10 Targets | Min. angular spacing: 0.02 | SNR = −15 dB

Mode 4 (sub-Nyquist 8x10) has higher angular resolution then all other modes

Cognitive Sub-Nyquist Mode



10 Targets | Min. angular spacing: 0.02 | SNR = −15 dB

Cognitive mode 3 (sub-Nyquist 4x5) performs better than Nyquist in low SNR