

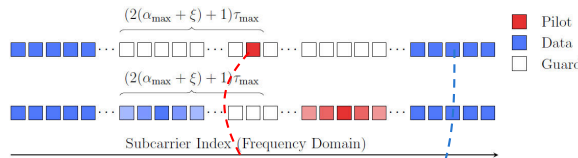
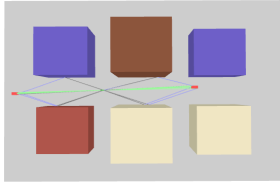
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Motivation

Why vehicular ISAC? 6G vehicular networks demand integrated sensing and communication (ISAC) from shared hardware and spectrum to meet strict latency and efficiency goals.

Why AFDM for vehicular ISAC? Affine Frequency Division Multiplexing (AFDM) employs **chirp-modulated subcarriers** that are robust to high Doppler shifts. This enables enhanced multipath separability, benefiting both communication diversity and sensing estimation.

Key takeaways: AFDM-based sensing attains comparable accuracy or superior accuracy to OFDM at lower computational cost.



System model

Monostatic ISAC at urban intersection

Propagation modeled with Sionna [1] ray-tracing engine at 26 GHz.

Simulation configuration

Parameter	Value
Carrier frequency, f_c	26 GHz
Numerology, i	{0, 1, 2, 3}
Subcarrier spacing, Δf	$15 \cdot 2^i$ kHz
Number of subcarriers, N	$1024 \cdot 2^{3-i}$
Total bandwidth, B	122.88 MHz
Total signal duration, T	7.09 ms
CPP length, L_{CPP}	$64 \cdot 2^{3-i}$
Maximum integer delay, ℓ_{max}	60
Total symbols per observation, N_s	$100 \cdot 2^i$

AFDM waveform & on-grid sensing

Key modulation structure

Time-domain transmit signal [2]:

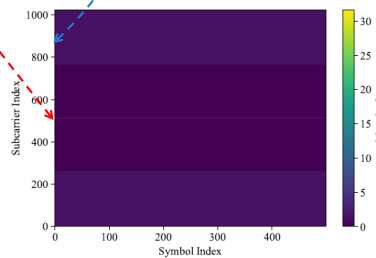
$$s[n] = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} x[m] e^{j2\pi(c_1 n^2 + \frac{m}{N} n + c_2 n^2)}, n = 0, 1, \dots, N-1.$$

Chirp parameters design for full diversity: $c_1 = \frac{2(\alpha_{max} + \xi) + 1}{2N}$, $c_2 = \frac{1}{2\pi N}$,

where α_{max} is max integer Doppler shift (normalized to Δf); ξ is inter-path interference margin. Setting $c_1 = c_2 = 0$ recovers OFDM.

Single-pilot on-grid sensing

- One pilot + guard intervals < full subcarrier grid \rightarrow lower sensing bandwidth overhead.
- Chirp structure separates delays into distinct bins \rightarrow direct per-delay Doppler estimation via 1D FFT.
- Doppler estimates reused for equalization \rightarrow sensing and communication share one processing pass.
- Sparse pilot spacing $T_s \leq 1/(2f_{d,max})$ prevents Doppler aliasing while improving spectral efficiency.



Algorithm 1 Single Pilot-Aided On-Grid Sensing

Require: Received signal $r[n]$; DAFT parameters c_1, c_2 ; delay bin $p_{\ell_i} = N/2 - 2Nc_1\ell_i$; guard half-window $W = \alpha_{max} + \xi$; estimator $\in \{LS, MMSE\}$; MRC flag.

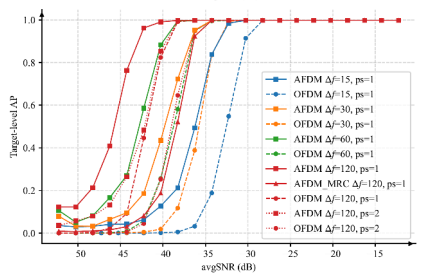
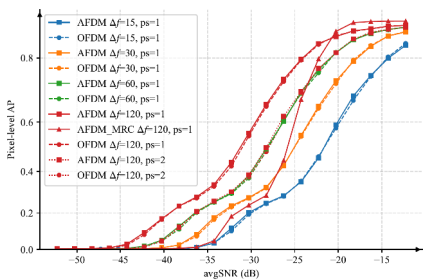
Ensure: Reconstructed DD map $\mathcal{M}(\tau, \nu)$.

AFDM demodulation: Apply DAFT to $r[n]$ to obtain $y[m]$.
if estimator = MMSE **then**
 Estimate per-bin noise power $\hat{\sigma}_m^2$ along the time.
for each delay index ℓ_i **do**
 Define local bin range $\mathcal{B}_{\ell_i} = \{p_{\ell_i} - W, \dots, p_{\ell_i} + W\}$.
for each snapshot $t = 1, \dots, T$ **do**
 Collect pilot observations $y_{\ell_i,t} = [y_t(m)]_{m \in \mathcal{B}_{\ell_i}}$.
 Estimate $\hat{h}[m]$ using selected estimator (Eq. 12).
if MRC = on **then**
 Apply MRC (Eq. 14) to obtain $\hat{h}_{\ell_i,t}$.
else
 Select bin with maximum peak.
 Apply slow-time Fourier transform to $\{\hat{h}_{\ell_i,t}\}_{t=1}^T$ to obtain $\hat{h}_{\ell_i}(\nu)$.
 Insert $\hat{h}_{\ell_i}(\nu)$ into $\mathcal{M}(\tau_{\ell_i}, \nu)$ at τ_{ℓ_i} .
return $\mathcal{M}(\tau, \nu)$

Results

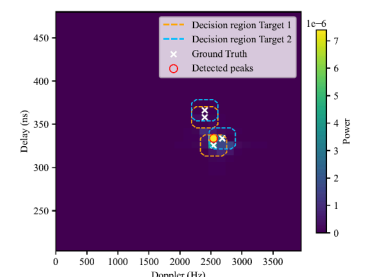
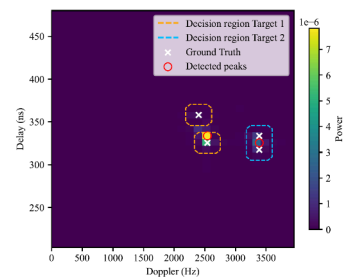
Single-target detection performance vs. SNR

All metrics (pixel-level AP, target-level AP) increase monotonically with SNR across numerologies.



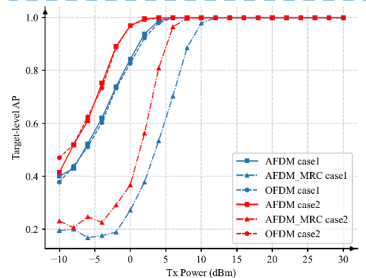
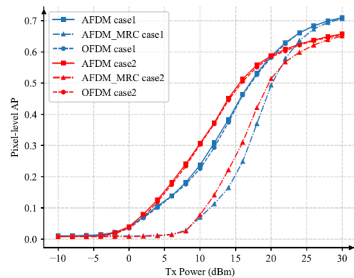
- AFDM + MRC edges above OFDM at high SNR via coherent combining.
- Halving Δf costs ~3 dB — sensing resources scale with bandwidth.
- AFDM consistently leads in target-level AP \rightarrow extended detection range.
- Sparser pilots reduce sensing budget \rightarrow lower detection performance.

Two-targets well-separated vs. closely-spaced cases



Case 1 ($\Delta v = 5$ m/s): both waveforms resolve targets cleanly.

Case 2 ($\Delta v = 1$ m/s): overlapping DD responses degrade pixel-level AP.



Target-level AP rises in case 2: merged peaks boost detection, but resolution is lost.

Future work

- Multi-target tracking for complex scenarios.
- Off-grid estimation (super-resolution methods) to push beyond bin-level Doppler resolution.