PERFORMANCE TRADE-OFF IN AN ADAPTIVE IEEE 802.11AD WAVEFORM DESIGN FOR A JOINT AUTOMOTIVE RADAR AND COMMUNICATION SYSTEM

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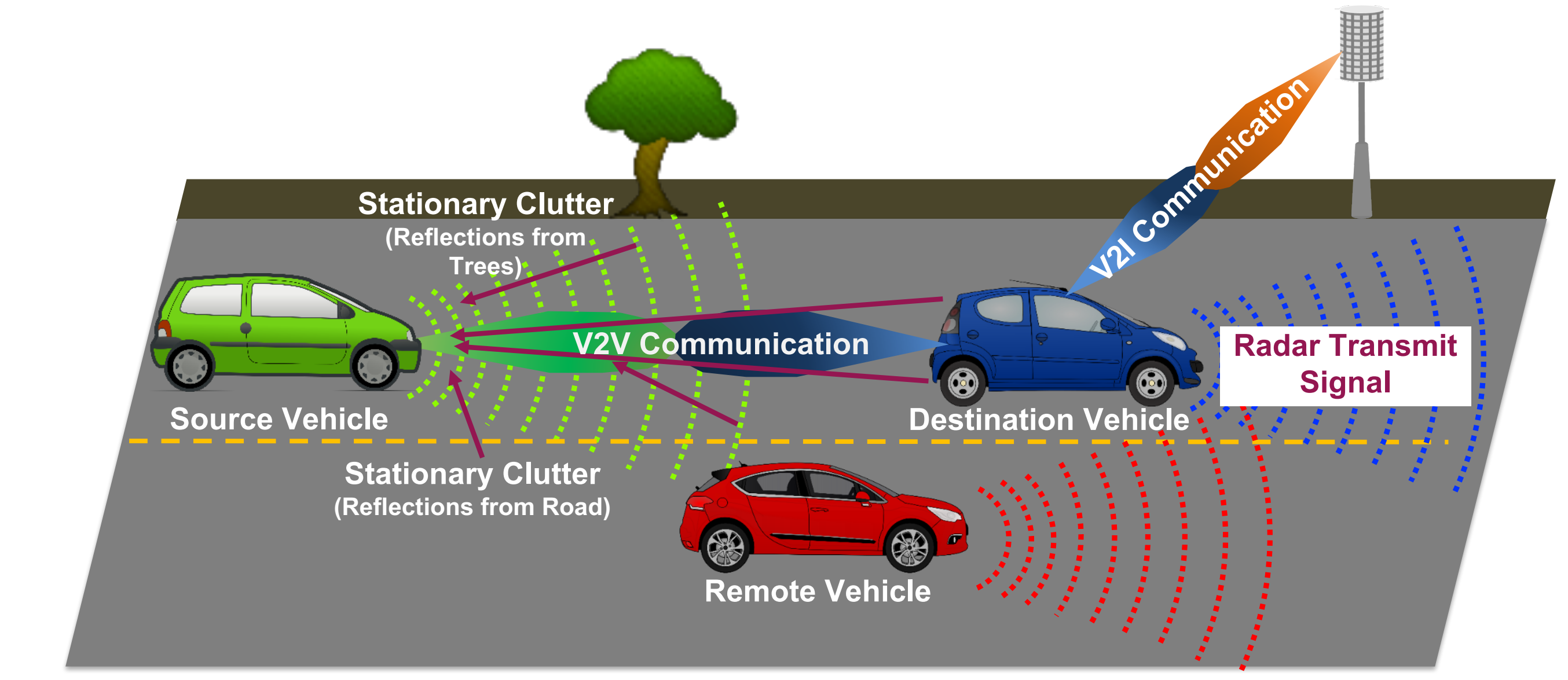
I. INTRODUCTION

A joint V2X-radar and communication system allows hardware/spectrum reuse [1]



MmWave WLAN has a larger bandwidth as compared to sub-6 GHz frequencies

Better range and velocity accuracy/resolution and a Gbps data rate than DSRC [2]

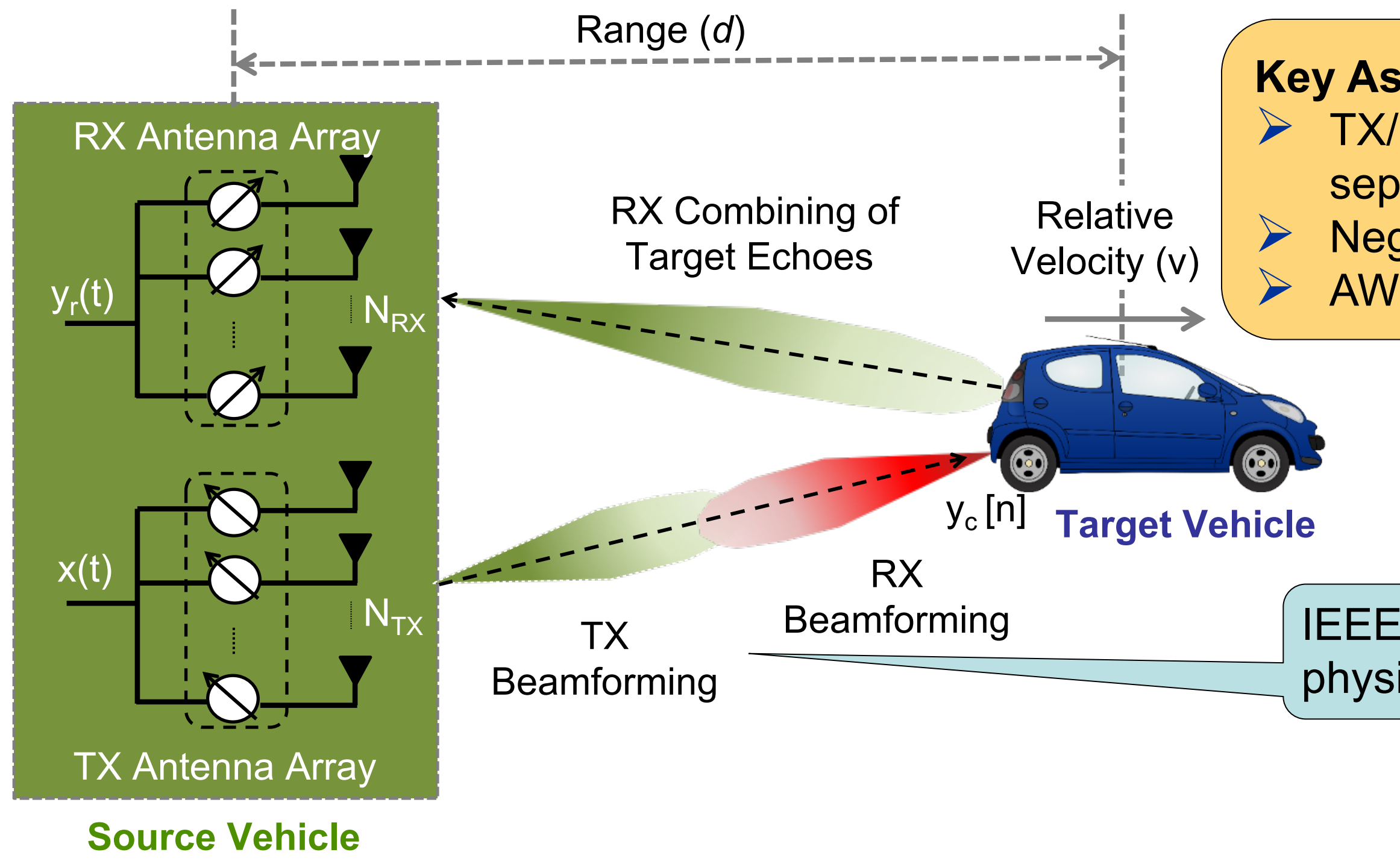
Smart IEEE 802.11ad Frame:

IEEE 802.11ad automotive radar performance limited by the preamble structure [3,4]

Our Contributions:

- Proposed an adaptive preamble design for adapting to different vehicle scenarios
- Investigated a trade-off between radar and communication using MMSE metric

II. SYSTEM MODEL



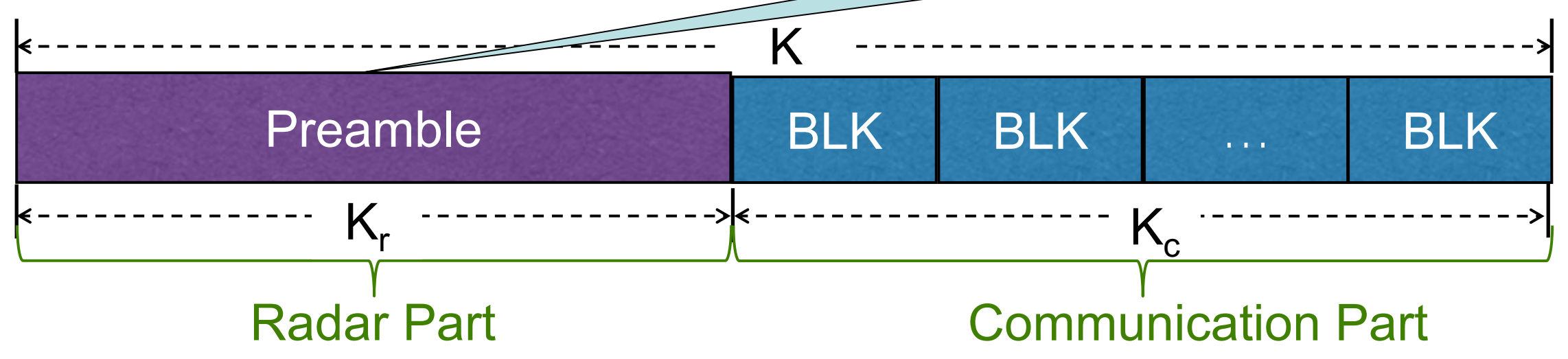
Key Assumptions:

- TX/RX antennas are closely separated
- Negligible self-interference
- AWGN noise

IEEE 802.11ad single carrier physical layer frame

Smart IEE 802.11ad Frame:

Adapt preamble duration



Optimize fraction of communication symbols

$$\alpha = \frac{K_c}{K}$$

Communication Signal Model:

Received signal at target vehicle:

$$y_c[n] = \sqrt{\mathcal{E}_s G_c}\, s[n] + w_c[n]$$

Transmit symbol
AWGN noise
Transmit symbol energy
Communication channel gain

Radar Signal Model:

Received signal at source vehicle:

$$y_r(t) = \sqrt{\mathcal{E}_s G_r}\, x(t - 2d/c) e^{j4\pi v t/\lambda} + w_r(t)$$

Carrier wavelength
AWGN noise
Radar channel gain
Speed of light

III. SMART IEEE 802.11AD WAVEFORM DESIGN

Performance Metric

Communication Metric:

Max. Spectral Efficiency:

$$r_{\text{eff}} = \alpha \log_2 (1 + \text{SNR}_c)$$

Communication SNR

Radar Metric:

Range CRB:

$$\text{CRB}_d = \frac{c^2}{32\pi^2 B_{\text{rms}}^2 (1-\alpha) K \text{SNR}_r}$$

Radar SNR
RMS Bandwidth
No. of Radar Symbols

Velocity CRB:

$$\text{CRB}_v = \frac{6\lambda^2}{16\pi^2 (1-\alpha)^3 K^3 T_s^2 \text{SNR}_r}$$

Joint Communication and Radar Metric:

Effective Communication MMSE:

$$\text{MMSE}_{\text{eff}} = 2^{-r_{\text{eff}}} = \frac{1}{(1+\text{SNR}_c)^{\alpha}}$$

Comparison to prior work:

- Radar estimation rate metric [5] is not drawn from a countable distribution.
- MMSE_{eff} metric is analogous to distortion metric in rate distortion theory.
  - Eliminates deriving estimation rates for several radar parameters.

Waveform Design Optimization

Weightings

$$\underset{\alpha}{\text{minimize}} \quad \omega_d \log(\text{CRB}_d) + \omega_v \log(\text{CRB}_v) - \omega_c \log(\text{MMSE}_{\text{eff}})$$
$$\text{subject to } \; 0 \le \alpha \le 1$$

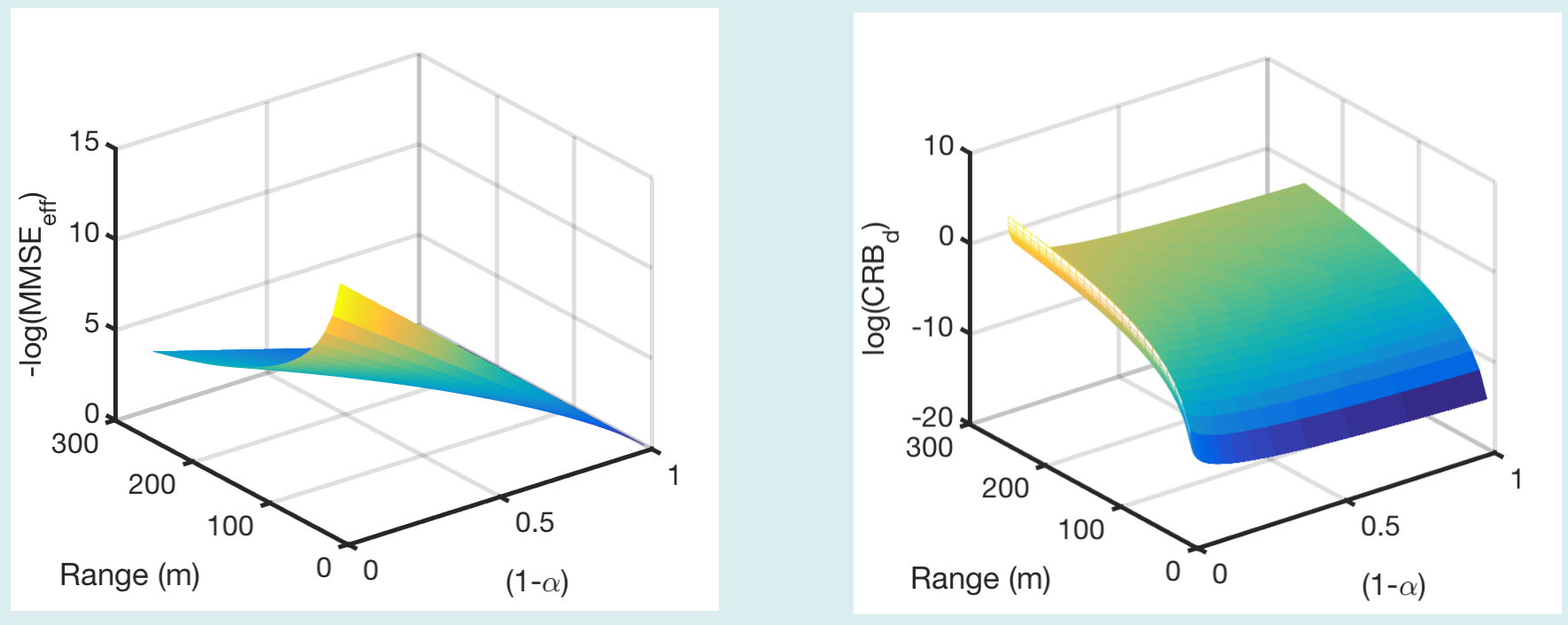
MMSE proportional fairness between radar and communication is ensured

Weighting factors satisfy the condition:

$$\frac{\omega_d + 3\omega_v}{\omega_c} > r$$

IV. NUMERICAL RESULTS

Trade-off between radar and communication

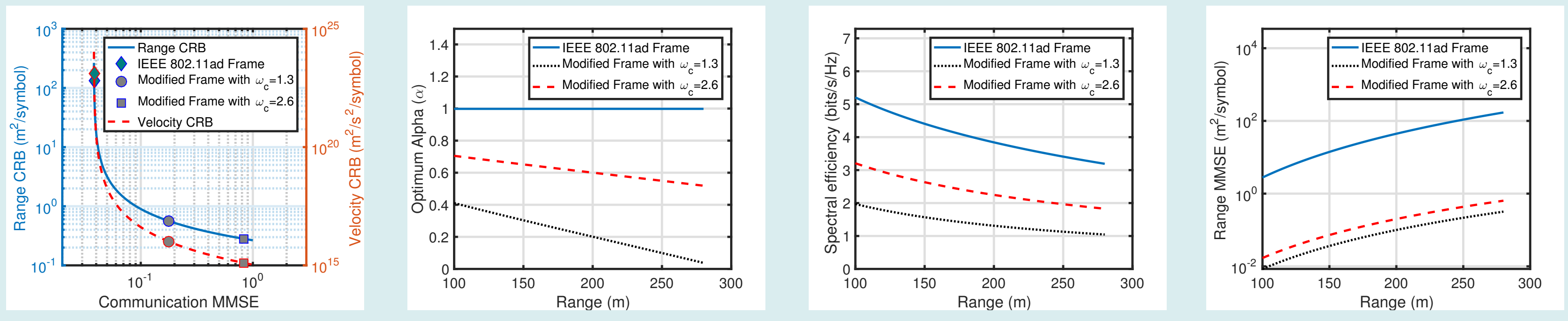


(a) Spectral efficiency decreases with d and (1- α)

(b) Range CRB decreases drastically for α close to 1

Range/velocity CRB bounds degrades more rapidly than the communication spectral efficiency

Adaptive preamble design by varying communication weighting for d up to 280 m



(a) Trade-off for different weightings at d = 270 m

(b) Optimized α decreases with d

(c) Spectral efficiency decreases with d

(d) Range CRB increases with d

At d = 270 m, CRB_d improves by 20 dB, while decreasing r_{eff} by 1.4 bits/s/Hz as compared to IEEE 802.11ad frame

Notable observations:

- With increase in d, optimum α decreases due to more rapid degradation in range CRB, and trade-off gets more tightened.
- Achieved Gbps communication data rate and decimeter-level range MSE per symbol simultaneously for a max. d = 280 m.

V. CONCLUSIONS AND FUTURE WORK

Conclusions

- Designed an adaptive preamble design that permits a trade-off between:
  - Radar parameters' estimation accuracy
  - Communication data rate
- Proposed an effective communication MMSE metric based on rate distortion theory.
- Achieved centimeter-level range MSE and Gbps data rates simultaneously up to 280 m.

Future Work

- Leverage compressed sensing techniques in the adaptive preamble to relax the trade-off.
- Extension to a large number of interesting TDD frameworks for joint radar and communication.

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