Multicarrier Phase Modulated Continuous Waveform for Automotive Joint Radar-Communications System

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Objective and Methodology

(a) A key motivation behind unified radar and communications system design is to address the problem of spectrum shortage

(b) Unified radar and communications waveform enables reuse of hardware,

(c) Need to estimate radar parameters (range, angles of arrival, Doppler shifts) and communications symbols

(d) Coupling between the quantities impacts estimation quality

(e) Novel waveform based on multicarrier phase modulated continuous waveform (MC-PMCW) allowing for separation of parameters into different domains

System Model

- 'Tx' is the transmitter and 'Rx' is the receiver vehicles
- 'T1' and 'T2' stands for the two target vehicles
- $R_q^{(1)}$ and $R_q^{(2)}$ are transmit-target and target-receiver ranges of qth target, respectively
- The $\theta^{(t)}$ is angle of departure, $\theta_1^{(r)}$ and $\theta_2^{(r)}$ are angles of arrival

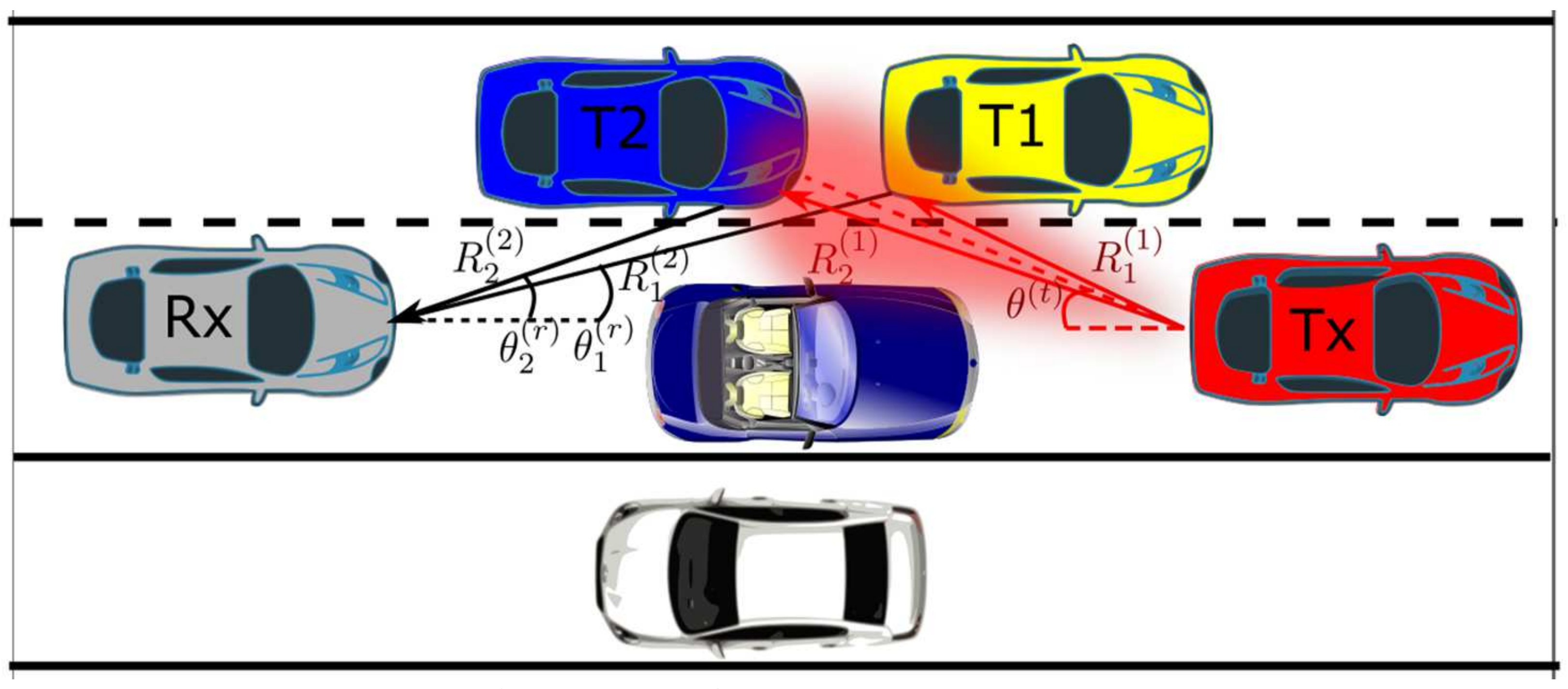

Figure 1. Vehicle configuration for joint radar-communications system

Proposed MC-PMCW transmit signal

$$x_{i,n}(t) = \sum_{m=0}^{M-1} a_{n,m}\left[\sum_{l=0}^{L-1} e^{j\phi_l} s(t - lt_c - mt_b)\right] e^{j2\pi(f_c+f_n)t}$$
$$\times e^{jk\sin(\theta^{(t)})(i-1)\frac{\lambda}{2}},\ \ i \in [1, N_t], n \in [1, N_c]$$

Received signal

$$z_{p,n}(t) = \sum_{q=1}^{Q}\sum_{i=1}^{N_t}\sum_{m=0}^{M-1}\sum_{l=0}^{L-1} \acute{d}_q a_{n,m} \acute{h}_{p,n,q}(t) e^{jk\sin(\theta^{(t)})(i-1)\frac{\lambda}{2}}$$
$$\times e^{j\phi_l} s(t - lt_c - mt_b - \tau_q) + \eta_p(t),$$

where

$$\acute{h}_{p,n,q}(t) = e^{j2\pi(f_c+f_n)(t-\tau_q-\frac{\Delta v_q}{c}t)} e^{jk\sin(\theta_q^{(r)})(p-1)\frac{\lambda}{2}}$$

Receiver Processing

How parameters manifest in the received signal:

- a) Range appears in carriers dimension and in delay i.e., fast-time (through $s(t - lt_c - mt_b - \tau_q)$).
- b) Communications symbols $a_{n,m}$, appear in frequency domain (through the index n) and in slow-time (through the index m).
- c) Doppler shifts come into slow-time.
- d) Angles of arrival only appears in spatial domain.

Key receiver steps:

Step 1: We estimate range from fast-time motivated by the fact that it is not coupled with other parameters.

Step 2: Employ the range estimates for recovering range from data symbols in frequency domain followed by detecting the data symbols.

Step 3: We can distinguish the data symbols from Doppler shifts in slow-time to estimate Doppler shifts.

Step 4: We estimate Doppler and angles of arrival from slow-time and spatial domains, respectively.

Waveform type	Resolution
PMCW-JRC	• $\Delta f_D = \frac{1}{t_{\mathrm{CPI}}} = \frac{1}{M_p tb} = 4\text{ MHz}\frac{1}{10\text{ k}} = 400\text{ Hz}$
	• $\Delta R = \frac{c}{B} = 75\text{ mm}$
	• $\Delta\theta = \frac{\pi}{\mathrm{N_r}} = \frac{\pi}{10}$
OFDMA-JRC	• $\Delta f_D = \frac{1}{t_{\mathrm{CPI}}} = 400\text{ Hz}$
	• $\Delta R = \frac{c}{B_u} = \frac{c}{N_{sub}\Delta f} = \frac{300\text{ M}}{800\text{ M}} \approx 37\text{ cm}$
	• $\Delta\theta = \frac{\pi}{\mathrm{N_r}} = \frac{\pi}{10}$
Proposed waveform	• $\Delta f_D = \frac{1}{t_{\mathrm{CPI}}} = 400\text{ Hz}$
	• $\Delta R_1 = \frac{c}{B} = 75\text{ cm}$
	• $\Delta R_2 = \frac{\Delta R_1}{Nc} = 75\text{ mm}$
	• $\Delta\theta = \frac{\pi}{\mathrm{N_r}} = \frac{\pi}{10}$

Table 1. Characteristics of proposed JRC waveforms

- t_{CPI} is time of coherent processing interval
- c is speed of the light
- t_b represents time of sending one block of code in PMCW/ MC-PMCW (t_b=4 μs) and OFDM symbol time in OFDMA JRC (t_b=0.1 ms)
- N_r =10 is number of receive antennas
- N_u =5 is the number of users
- B=4 GHz denotes total available bandwidth
- $B_u = B/N_u$ stands for user bandwidth
- N_c =10 is the number of carriers in MC-PMCW
- N_{sub}=8 K are the number of sub-carriers in OFDMA

Simulation Result

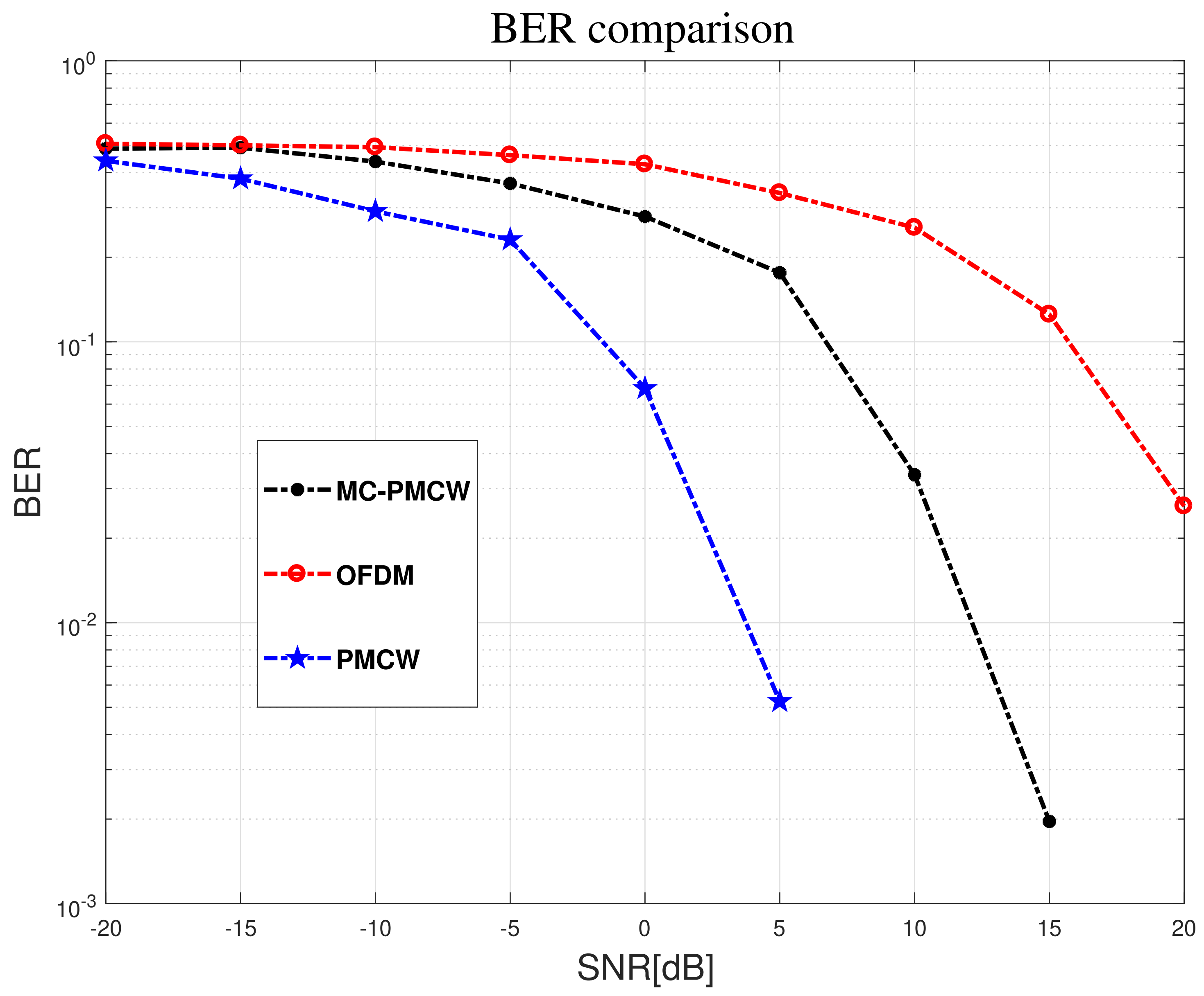

Figure 2. Uncoded BER performance of three JRC waveforms: proposed, OFDMA [2] and PMCW [1]

SNR = 5 dB				
JRC paradigm	R	f_D	θ	Throughput
PMCW-JRC	0.1009	73.9	2.4116	20 kb/s
OFDMA-JRC	0.57	309.8	2.13	340 kb/s
MC-PMCW-JRC	0.1881	65	2.0111	370 kb/s

SNR = 25 dB				
JRC paradigm	R	f_D	θ	Throughput
PMCW-JRC	0.0075	53	0.1246	20 kb/s
OFDMA-JRC	0.30	189.1	0.1231	400 kb/s
MC-PMCW-JRC	0.0099	55	0.1441	400 kb/s

Table 2. MSE of radar parameter estimates and communications throughput of three JRC paradigms, R = 10 m, f_D= 2 k, θ = 50 deg.

Conclusion

- Alternative waveform for JRC overcoming the major challenge of lack of degrees of freedom in OFDMA and PMCW
- Embeds radar and communications parameters in different domains enabling low complexity estimation
- Applicable for emerging automotive JRC

References

[1] S. H. Dokhanchi, M. R. Bhavani Shankar, Y. A. Nijsure, T. Stifter, S. Sedighi and B. Ottersten, "Joint Automotive Radar-Communications Waveform Design", presented at *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC),* Montreal, QC, Canada, October 2017.

[2] S. H. Dokhanchi, M. R. Bhavani Shankar, T. Stifter, and B. Ottersten, "OFDM-based Automotive Joint Radar-Communication System", accepted to be presented at *IEEE Radar Conference (RadarConf)*, Oklahoma, OK, 2018.

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