Performance and Complexity Comparison of Carrier Phase Estimation Algorithms for DP-64-QAM Optical Signals

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Abstract - A detailed simulative and experimental analysis of different CPE schemes for 64-QAM systems is presented. The best compromise between linewidth tolerance and complexity is achieved using a recently proposed multi-stage architecture, based on a modification of the standard V&V algorithm.

The performance of various CPE algorithms is compared:

- QPSK Partitioned V&V
- V&V+CT+MLE
- V&V+CT+2MLE
- Modified V&V (V&V*)
- V&V*+CT+MLE
- V&V*+CT+2MLE
- BPS
- BPS + MLE
- S-DD-PLL
- S-DD-PLL+ MLE
- DA–MLE

Simulation model

Received noisy samples:

$$y_k = x_k e^{j\theta_k} + \eta_k$$

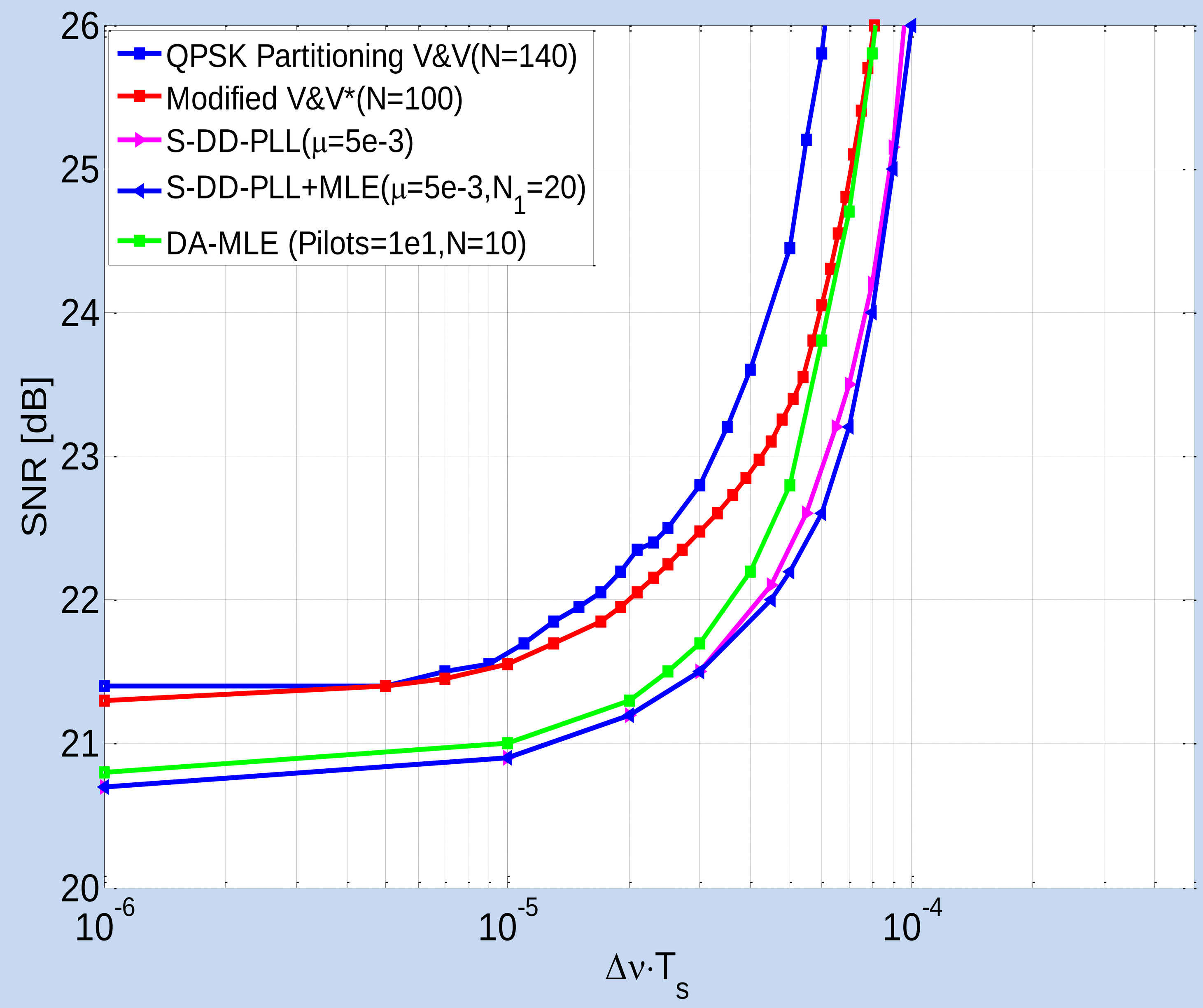
Phase noise:

$$\theta_k = \sum_{i=-\infty}^{k} \nu_i$$

$$\sigma_f^2 = 2\pi\Delta\nu T_s$$

- x_k is the data symbol at time k that belongs to the set ($\pm a \pm j\cdot b$), with $a,b \in \{1,3,5,7\}$.
- η_k is the AWG noise.
- θ_k is the laser phase noise, modeled as a Wiener process.
- $\Delta\nu$ is the combined laser linewidth of transmitter laser and LO.
- T_s is the symbol period.

Simulation Results



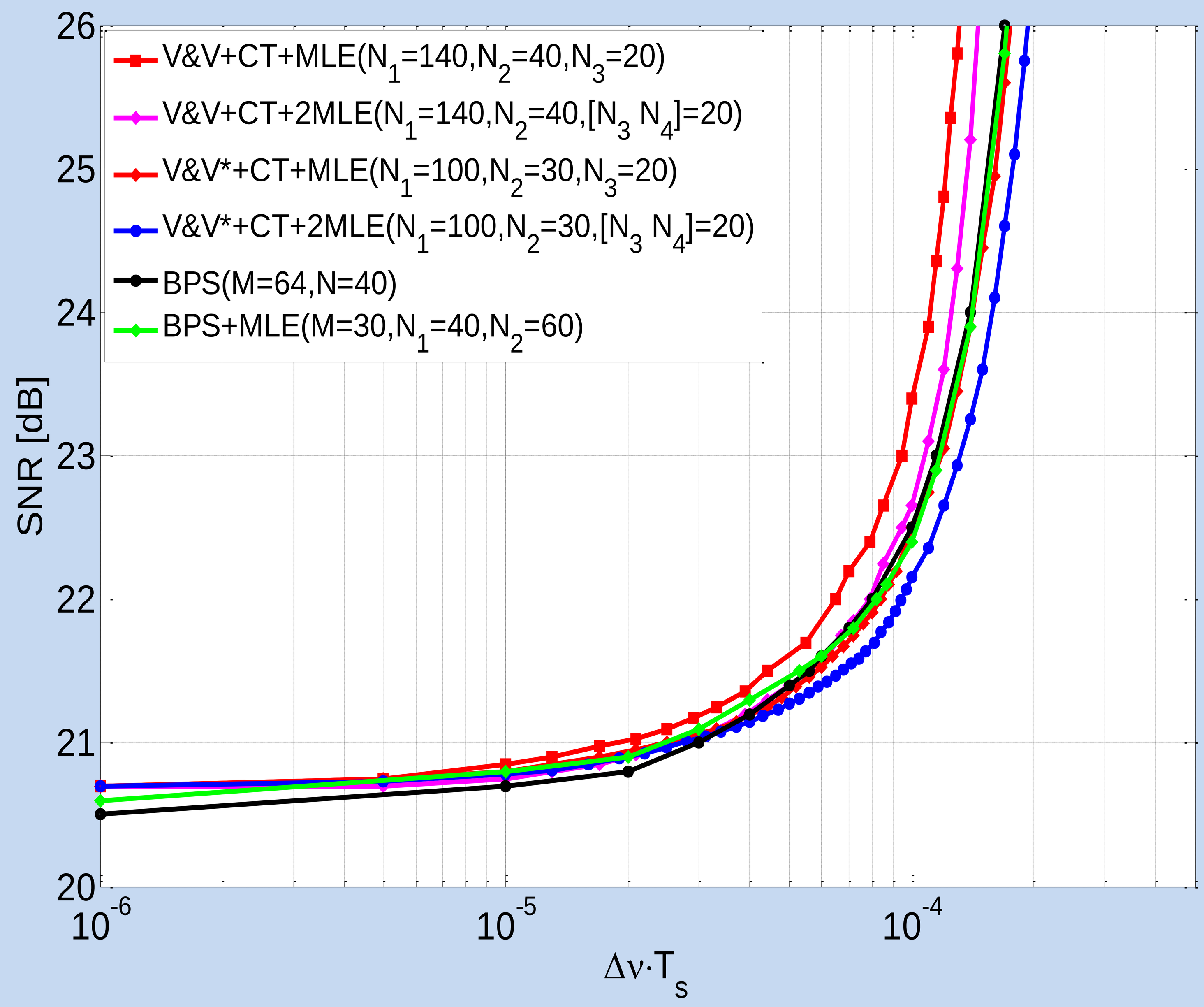


Figure. 1: SNR vs. linewidth times symbol duration ($\Delta\nu \cdot T_s$) product at BER=10^{-2} for different CPE schemes. (a) Algorithms having worst performance (b) Algorithms having best performance

Case	1	2	3	4	5	6	7	8	9	10	11
CPE	V&V	V&V*	V&V+CT+ MLE	V&V+CT+ 2MLE	V&V*+CT +MLE	V&V*+CT +2MLE	BPS	BPS+ MLE	S-DD- PLL	S-DD-PLL +MLE	DA- MLE
$\Delta\nu \cdot T_s$ @ 1dB penalty	$8.0\cdot10^{-6}$	10^{-5}	$4.5\cdot10^{-5}$	$5.6\cdot10^{-5}$	$6.0\cdot10^{-5}$	$7.1\cdot10^{-5}$	$5.7\cdot10^{-5}$	$5.4\cdot10^{-5}$	$3.0\cdot10^{-5}$	$3.0\cdot10^{-5}$	$2.5\cdot10^{-5}$
Equivalent linewidth @ 20 Gbaud	0.16 MHz	0.20 MHz	0.90 MHz	1.12 MHz	1.20 MHz	1.42 MHz	1.14 MHz	1.08 MHz	0.60 MHz	0.60 MHz	0.50 MHz

Table. 1: Laser phase noise tolerances and their equivalent linewidths at 20 Gbaud for various CPE algorithms

Experimental Setup

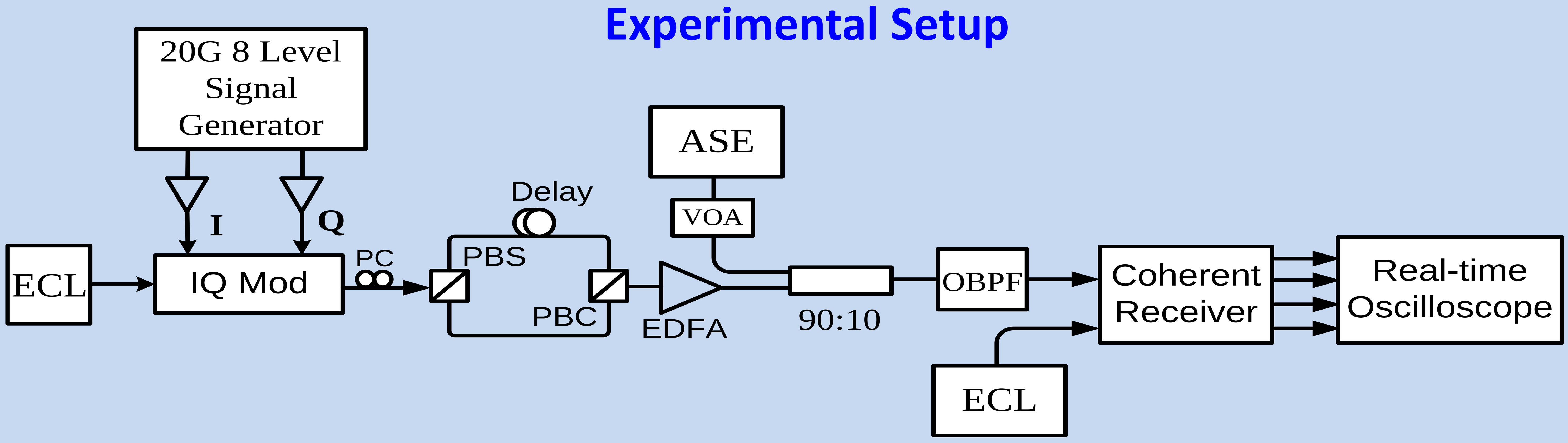


Figure. 2: Experimental setup for 240Gb/s (20Gbaud) DP-64QAM back-to-back system.

- An external cavity laser (ECL) with a linewidth of 100 kHz and wavelength 1553.32 nm is modulated by an integrated IQ modulator , whose I and Q branches are driven by two 20-Gbaud 8-level electrical signals in order to generate a 64-QAM signal QPSK Partitioned.
- The dual-polarization (DP) 64-QAM signal is generated by using a polarization multiplexing emulator.
- By loading different amounts of ASE noise, the optical-signal-to-noise-ratio (OSNR) values were varied between 25 and 37 dB.
- At the receiver side, an optical band pass filter (OBPF) with bandwidth 0.6nm is used for filtering the out-band noise.
- The received signal is coherently detected by an integrated coherent receiver with a local oscillator (ECL, with line-width 100 kHz).
- The detected signal is sampled by a 50GS/s real-time sampling scope.
- The captured data are processed offline.

Complexity analysis

CPE	Real Multipliers	Real Adders	Comparators	Look-Up Tables	Decisions
V&V	8N	3N+2	4N+2	1	N_1
V&V+CT	$8N_1+6N_2$	$3N_1+3N_2+30$	$4N_1+7$	2	N_2
V&V+CT+MLE	$8N_1+6N_2+N_3$	$3N_1+3N_2+N_3+29$	$4N_1+7$	3	$2N_3$
V&V+CT+2MLE	$8N_1+6N_2+N_3+N_4$	$3N_1+3N_2+N_3+N_4+28$	$4N_1+7$	4	N_3+2N_4
V&V*	8N	3N+2	4N+2	1	N_1
V&V* + CT	$8N_1+6N_2$	$3N_1+3N_2+30$	$4N_1+7$	2	N_2
V&V*+CT+MLE	$8N_1+6N_2+N_3$	$3N_1+3N_2+N_3+29$	$4N_1+7$	3	$2N_3$
V&V*+CT+2MLE	$8N_1+6N_2+N_3+N_4$	$3N_1+3N_2+N_3+N_4+28$	$4N_1+7$	4	N_3+2N_4
BPS	NM+2NM	2NM-M+3	M+1	0	NM+N
BPS+MLE	$N_1M+2N_1M+N_2$	$2N_1M-M+N_2+2$	M+1	1	N_1M+N_2
S-DD-PLL	2N	2N	0	0	2N
S-DD-PLL+MLE	$2N_1+N_2$	$2N_1+N_2-1$	0	1	N_1+N_2
DA-MLE	3N+1	3N-2	0	0	N+1

Table. 2: Computational complexity for various CPE algorithms

Experimental Results

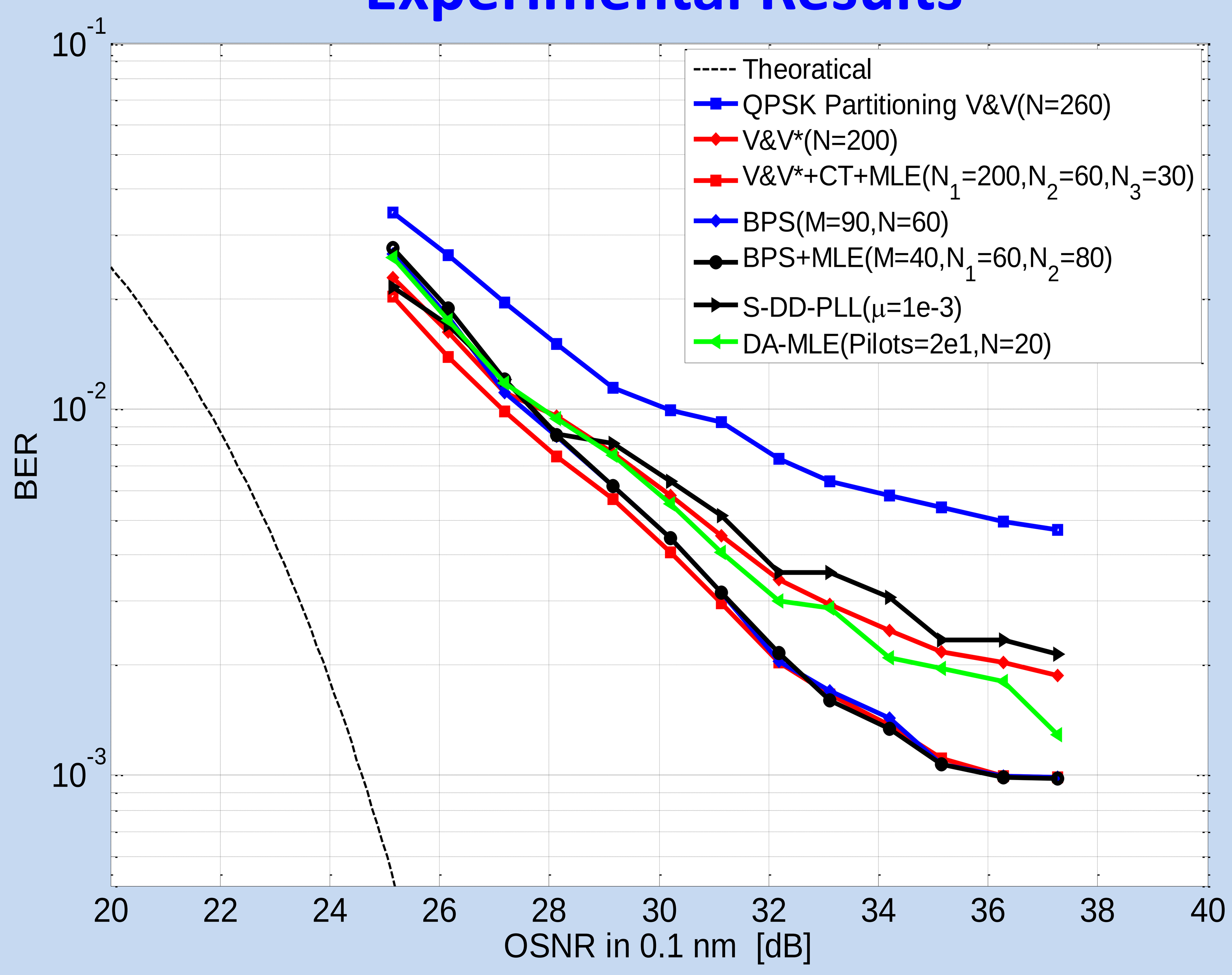


Figure. 2: BER vs OSNR performance (back to back) for different CPE algorithms.

Conclusions

A detailed simulative and experimental analysis of different CPE schemes for 64-QAM systems is presented. The recently proposed multi-stage algorithm achieves the best performance for 64-QAM systems with reduced complexity with respect to the BPS algorithm.

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