

# OFDM mmWave Channel Estimation with OMP

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This is a simple simulation of millimeter wave (mmWave) channel estimation in wideband assisted by OFDM with orthogonal matching pursuit (OMP) algorithm. The main idea of OFDM mmWave channel estimation is the shared angle of arrival (AoA) and angle of departure (AoD). However, in wideband mmWave MIMO systems, the beam squint effect cannot be neglected. For simplicity, this effect is not considered in this simulation. The number in the bracket after OMP is the number of carriers used to estimate the AoA and AoD (i.e. non-zero elements in the beam domain). The R suffix means re-estimating the carriers used to estimate the AoA and AoD using least square (LS) after the support is calculated.

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## 1 System Settings

The simulation adopts the geometric channel model for millimeter wave (mmWave).

Name	Antenna Number	Beam Number	Grid Number
Transmitter	$8 \times 1$	$2 \times 1$	$8 \times 1$
Receiver	$16 \times 1$	$4 \times 1$	$16 \times 1$

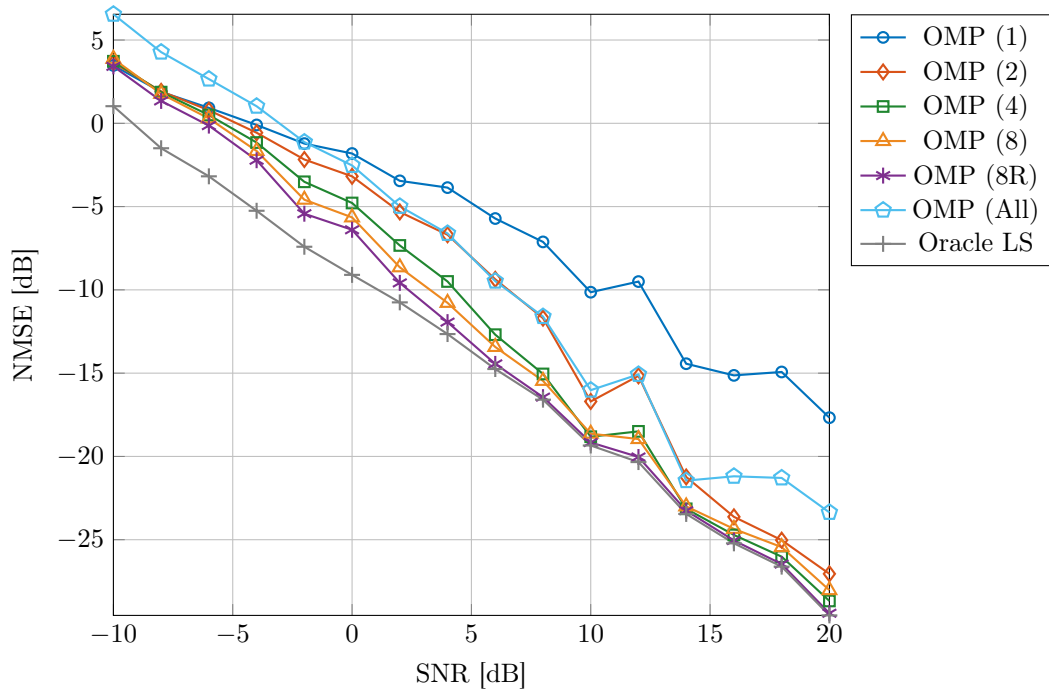
- Channel Sparsity: 6;
- Off Grid Effect: false;
- Bandwidth: Wideband;
- Carriers: 64.



## 2 Simulation Results

### 2.1 NMSE v.s. SNR (Pilot: 16)

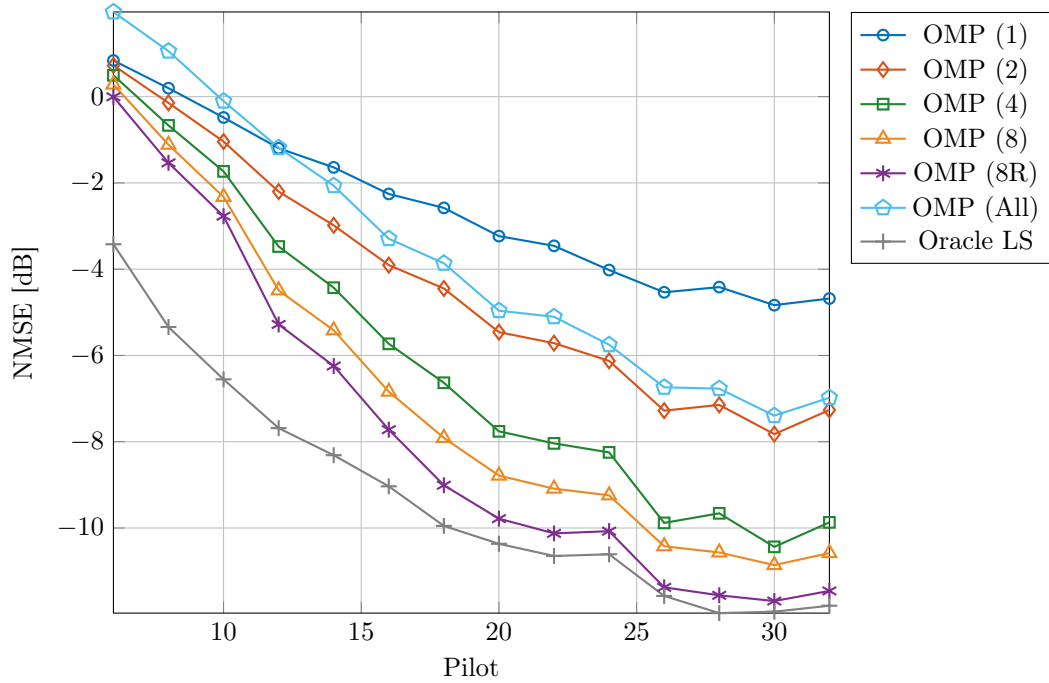
SNR [dB]	OMP (1)	OMP (2)	OMP (4)	OMP (8)	OMP (8R)	OMP (All)	Oracle LS
-10	3.47	3.63	3.72	3.87	3.42	6.55	1.03
-8	1.88	1.92	1.87	1.77	1.34	4.27	-1.50
-6	0.93	0.79	0.50	0.29	-0.14	2.66	-3.18
-4	-0.10	-0.57	-1.15	-1.66	-2.22	1.02	-5.25
-2	-1.22	-2.17	-3.51	-4.59	-5.43	-1.13	-7.41
0	-1.81	-3.18	-4.78	-5.65	-6.39	-2.53	-9.10
2	-3.45	-5.32	-7.33	-8.65	-9.58	-4.99	-10.75
4	-3.86	-6.69	-9.50	-10.78	-11.94	-6.61	-12.65
6	-5.72	-9.37	-12.69	-13.43	-14.44	-9.48	-14.75
8	-7.12	-11.70	-15.05	-15.46	-16.44	-11.60	-16.59
10	-10.14	-16.70	-18.82	-18.63	-19.16	-16.02	-19.34
12	-9.50	-15.16	-18.50	-18.96	-20.03	-15.08	-20.34
14	-14.43	-21.23	-23.15	-23.00	-23.26	-21.45	-23.45
16	-15.13	-23.63	-24.71	-24.35	-25.05	-21.19	-25.22
18	-14.93	-25.03	-26.02	-25.45	-26.46	-21.29	-26.62
20	-17.67	-27.05	-28.68	-28.03	-29.41	-23.36	-29.54



Simulated with 500 Monte Carlo tests.

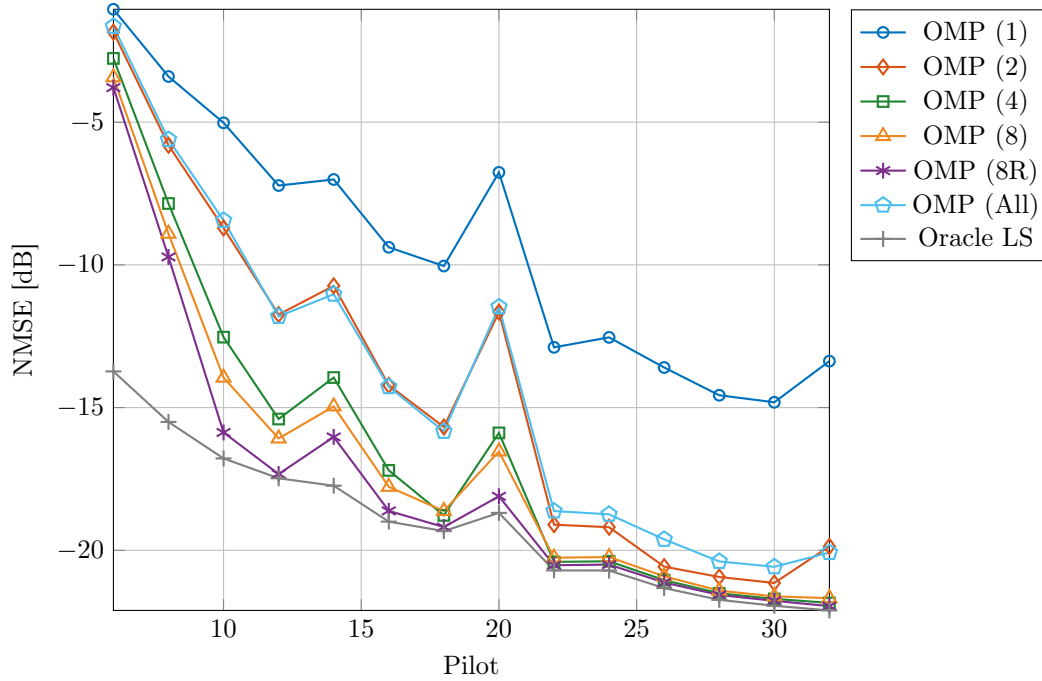
## 2.2 NMSE v.s. Pilot (SNR: 0 dB)

Pilot	OMP (1)	OMP (2)	OMP (4)	OMP (8)	OMP (8R)	OMP (All)	Oracle LS
6	0.84	0.72	0.50	0.28	0.00	1.96	-3.42
8	0.20	-0.14	-0.67	-1.11	-1.53	1.06	-5.34
10	-0.48	-1.04	-1.73	-2.32	-2.77	-0.10	-6.55
12	-1.19	-2.20	-3.47	-4.49	-5.28	-1.18	-7.68
14	-1.64	-2.98	-4.43	-5.42	-6.24	-2.06	-8.31
16	-2.26	-3.91	-5.73	-6.84	-7.72	-3.29	-9.03
18	-2.58	-4.45	-6.63	-7.91	-9.01	-3.86	-9.95
20	-3.23	-5.46	-7.76	-8.79	-9.78	-4.96	-10.37
22	-3.46	-5.71	-8.04	-9.09	-10.12	-5.10	-10.65
24	-4.02	-6.12	-8.25	-9.24	-10.07	-5.75	-10.61
26	-4.54	-7.28	-9.88	-10.42	-11.38	-6.74	-11.57
28	-4.41	-7.15	-9.66	-10.57	-11.56	-6.77	-11.97
30	-4.83	-7.82	-10.44	-10.86	-11.69	-7.39	-11.94
32	-4.68	-7.26	-9.87	-10.58	-11.46	-6.98	-11.80



### 2.3 NMSE v.s. Pilot (SNR: 10 dB)

Pilot	OMP (1)	OMP (2)	OMP (4)	OMP (8)	OMP (8R)	OMP (All)	Oracle LS
6	-1.05	-1.85	-2.77	-3.43	-3.79	-1.65	-13.73
8	-3.40	-5.81	-7.85	-8.91	-9.72	-5.61	-15.50
10	-5.02	-8.71	-12.53	-13.95	-15.87	-8.44	-16.78
12	-7.22	-11.74	-15.40	-16.08	-17.33	-11.81	-17.48
14	-7.01	-10.73	-13.95	-14.96	-16.03	-11.03	-17.74
16	-9.38	-14.22	-17.20	-17.78	-18.62	-14.27	-19.00
18	-10.04	-15.68	-18.78	-18.62	-19.19	-15.83	-19.33
20	-6.76	-11.65	-15.89	-16.54	-18.11	-11.47	-18.69
22	-12.89	-19.10	-20.41	-20.26	-20.52	-18.62	-20.70
24	-12.54	-19.19	-20.38	-20.24	-20.50	-18.74	-20.71
26	-13.59	-20.57	-21.04	-20.91	-21.13	-19.62	-21.32
28	-14.57	-20.93	-21.51	-21.41	-21.56	-20.39	-21.73
30	-14.81	-21.14	-21.70	-21.61	-21.77	-20.58	-21.94
32	-13.37	-19.86	-21.84	-21.68	-21.95	-20.08	-22.11



## 3 Simulation Configuration

### 3.1 Configuration File

Listing 1: MIMO\_wideband.sim

```

1 # MIMO_wideband.sim
2 # Wideband (OFDM) mmWave Channel Estimation with OMP
3 # Author: Wuqiong Zhao
4 # Date: 2022-09-26
5
6 version: 0.1.0 # the targeted mmCEsim version
7 meta: # document meta data
8   title: OFDM mmWave Channel Estimation with OMP
9   description:
10    This is a simple simulation of millimeter wave (mmWave)
11    channel estimation in wideband assisted by OFDM
12    with orthogonal matching pursuit (OMP) algorithm.
13    The main idea of OFDM mmWave channel estimation
14    is the shared angle of arrival (AoA) and angle of departure
15    (AoD). However, in wideband mmWave MIMO systems,
16    the beam squint effect cannot be neglected. For simplicity,
17    this effect is not considered in this simulation.
18    The number in the bracket after OMP is the number of
19    carriers used to estimate the AoA and AoD (i.e. non-zero
20    elements in the beam domain). The R suffix means
21    re-estimating the carriers used to estimate the AoA
22    and AoD using least square (LS)
23    after the support is calculated.
24   author: Wuqiong Zhao
25   email: contact@mmcesim.org
26   website: https://mmcesim.org
27   license: MIT
28   date: "2022-09-16"
29   comments: This is an uplink channel.
30 physics:
31   frequency: wide # assume narrow band
32   carriers: 64
33   off_grid: false # do not consider off-grid problem
34 nodes:
35   - id: BS # this should be unique
36     role: receiver
37     num: 1 # this is the default value
38     size: [16, 1] # ULA with size 16*1
39     beam: [4, 1]
40     grid: same # the same as physics size
41     beamforming:
42       variable: "W"
43       scheme: random
44   - id: UE # user
45     role: transmitter
46     num: 1 # a single-user model
47     size: 8 # ULA with size 8
48     beam: 2
49     grid: 8
50     beamforming:
51       variable: "F"
52       scheme: random
53 channels:
54   - id: H
55     from: BS
56     to: UE # 'from -> to' specifies the channel direction
57     sparsity: 6
58     gains:

```

```

59     mode: normal
60     mean: 0
61     variance: 1
62 sounding:
63     variables:
64         received: "Y" # received signal vector
65         noise: "noise" # received noise vector
66         channel: "H_cascaded" # the cascaded channel (actually the same as 'H' for
        ↪ simple MIMO)
67 macro:
68     - name: OFDM_ANGLE_EST_NUM
69       value: 4
70       in_alg: true
71     - name: OFDM_RE_ESTIMATE
72       value: false
73       in_alg: true
74     - name: SPARSITY_EST
75       value: 6
76       in_alg: true
77 preamble: |
78     COMMENT Here starts the preamble.
79 estimation: |
80     VNt::m = NEW `DICTIONARY.T`
81     VNr::m = NEW `DICTIONARY.R`
82     lambda_hat = INIT `GRID.*`
83     H_hat = INIT `SIZE.R` `SIZE.T` `CARRIERS_NUM`
84     Q = INIT `MEASUREMENT` `GRID.*`
85     i::u0 = LOOP 0 `PILOT`/`BEAM.T`
86     F_t::m = NEW F_{:, :, i}
87     W_t::m = NEW W_{:, :, i}
88     Q_{i*`BEAM.*`:(i+1)*`BEAM.*`-1, :} = \kron(F_t^T, W_t^H) @ \kron(VNt^*, VNr) #
        ↪ the sensing matrix
89 END
90 BRANCH
91 angle_est = INIT `GRID.R`*`GRID.T` dtype=f
92 k::u0 = LOOP 0 `OFDM_ANGLE_EST_NUM`
93     none_zero::u1 = NEW \find(\abs(VNr^H@H_cascaded_{:, :, k}@VNt)>0.1)
94     lambda_hat = ESTIMATE Q Y_{:, k} none_zero
95     angle_est = angle_est + \pow(\abs(lambda_hat), 2)
96     IF !`OFDM_RE_ESTIMATE`
97         H_hat_{:, :, k} = VNr @ \reshape(lambda_hat, `GRID.R`, `GRID.T`) @ VNt^H
98     END
99 END
100 ranking::u1 = NEW \sort_index(-angle_est)
101 support::u1 = NEW ranking_{0:`SPARSITY_EST`-1}
102 index_start::u0 = NEW 0
103 IF !`OFDM_RE_ESTIMATE`
104     index_start = `OFDM_ANGLE_EST_NUM`
105 END
106 k::u0 = LOOP index_start `CARRIERS_NUM`
107     lambda_hat = CALL LS_support Q Y_{:, k} support
108     H_hat_{:, :, k} = VNr @ \reshape(lambda_hat, `GRID.R`, `GRID.T`) @ VNt^H
109 END
110 RECOVER H_hat
111 MERGE
112 conclusion: |
113     PRINT ">>>t" `JOB_CNT`+1 '/' `JOB_NUM` '\n'
114 simulation:
115     backend: cpp # cpp (default) | matlab | octave | py
116     metric: [NMSE] # used for compare
117     jobs:
118         - name: "NMSE v.s. SNR (Pilot: 16)"
119           test_num: 500
120           SNR: [-10:2:20]

```

```

121 SNR_mode: dB # dB (default) | linear
122 pilot: 16
123 # pilot_mode: percent # num (default) | percent
124 algorithms: # compare different languages
125 - alg: OMP
126   max_iter: 6
127   macro:
128     - name: OFDM_ANGLE_EST_NUM
129       value: 1
130     label: OMP (1) # used in report
131 - alg: OMP
132   max_iter: 6
133   macro:
134     - name: OFDM_ANGLE_EST_NUM
135       value: 2
136     label: OMP (2) # used in report
137 - alg: OMP
138   max_iter: 6
139   macro:
140     - name: OFDM_ANGLE_EST_NUM
141       value: 4
142     label: OMP (4) # used in report
143 - alg: OMP
144   max_iter: 6
145   macro:
146     - name: OFDM_ANGLE_EST_NUM
147       value: 8
148     label: OMP (8) # used in report
149 - alg: OMP
150   max_iter: 6
151   macro:
152     - name: OFDM_ANGLE_EST_NUM
153       value: 8
154     - name: OFDM_RE_ESTIMATE
155       value: true
156     label: OMP (8R) # used in report
157 - alg: OMP
158   max_iter: 6
159   macro:
160     - name: OFDM_ANGLE_EST_NUM
161       value: 64
162     label: OMP (All) # used in report
163 - alg: Oracle_LS
164   label: Oracle LS
165   macro:
166     - name: OFDM_ANGLE_EST_NUM
167       value: 64
168 - name: "NMSE v.s. Pilot (SNR: 0 dB)"
169   test_num: 500
170   SNR: 0
171   pilot: [6:2:32]
172   # pilot_mode: percent # num (default) | percent
173   algorithms: # compare different languages
174   - alg: OMP
175     max_iter: 6
176     macro:
177       - name: OFDM_ANGLE_EST_NUM
178         value: 1
179       label: OMP (1) # used in report
180 - alg: OMP
181   max_iter: 6
182   macro:
183     - name: OFDM_ANGLE_EST_NUM
184       value: 2

```

```

185     label: OMP (2) # used in report
186 -   alg: OMP
187     max_iter: 6
188     macro:
189       - name: OFDM_ANGLE_EST_NUM
190         value: 4
191     label: OMP (4) # used in report
192 -   alg: OMP
193     max_iter: 6
194     macro:
195       - name: OFDM_ANGLE_EST_NUM
196         value: 8
197     label: OMP (8) # used in report
198 -   alg: OMP
199     max_iter: 6
200     macro:
201       - name: OFDM_ANGLE_EST_NUM
202         value: 8
203       - name: OFDM_RE_ESTIMATE
204         value: true
205     label: OMP (8R) # used in report
206 -   alg: OMP
207     max_iter: 6
208     macro:
209       - name: OFDM_ANGLE_EST_NUM
210         value: 64
211     label: OMP (A11) # used in report
212 -   alg: Oracle_LS
213     label: Oracle LS
214     macro:
215       - name: OFDM_ANGLE_EST_NUM
216         value: 64
217 - name: "NMSE v.s. Pilot (SNR: 10 dB)"
218   test_num: 500
219   SNR: 10
220   pilot: [6:2:32]
221   # pilot_mode: percent # num (default) | percent
222   algorithms: # compare different languages
223 -   alg: OMP
224     max_iter: 6
225     macro:
226       - name: OFDM_ANGLE_EST_NUM
227         value: 1
228     label: OMP (1) # used in report
229 -   alg: OMP
230     max_iter: 6
231     macro:
232       - name: OFDM_ANGLE_EST_NUM
233         value: 2
234     label: OMP (2) # used in report
235 -   alg: OMP
236     max_iter: 6
237     macro:
238       - name: OFDM_ANGLE_EST_NUM
239         value: 4
240     label: OMP (4) # used in report
241 -   alg: OMP
242     max_iter: 6
243     macro:
244       - name: OFDM_ANGLE_EST_NUM
245         value: 8
246     label: OMP (8) # used in report
247 -   alg: OMP
248     max_iter: 6

```



```

249     macro:
250         - name: OFDM_ANGLE_EST_NUM
251           value: 8
252         - name: OFDM_RE_ESTIMATE
253           value: true
254         label: OMP (8R) # used in report
255     - alg: OMP
256       max_iter: 6
257       macro:
258         - name: OFDM_ANGLE_EST_NUM
259           value: 64
260         label: OMP (All) # used in report
261     - alg: Oracle_LS
262       label: Oracle LS
263       macro:
264         - name: OFDM_ANGLE_EST_NUM
265           value: 64
266 report:
267     name: OFDM_mmWave_CE_OMP_Simulation
268     format: [pdf, latex] # both compiled PDF and tex files
269     plot: true # plot data
270     table: false # do not print table
271     latex:
272       command: pdflatex # command to compile the report
273       UTF8: false # no need for UTF8 support with this setting

```

## 3.2 Algorithms

Listing 2: OMP.alg

```

1  #! Function: OMP
2  #! Description: Orthogonal matching pursuit compressed sensing.
3  #! Author: Wuqiong Zhao
4  #! Date: 2022-09-16
5  #! Version: 0.1.0
6
7  # Input:
8  #   - Q: Sensing matrix
9  #   - y: Received signal
10 #   - L: Sparsity
11 # Output:
12 #   - h: The estimated sparse signal
13 h::v = FUNCTION OMP Q::m y::v L::u0
14 COMMENT Start of OMP algorithm!
15 h = \zeros(\size(Q, 1)) # initialize as zeros
16 Q_H::m = NEW Q^H # the conjugate transpose of Q
17 r = NEW y # residual
18 r_last::v = NEW r * 2 # the residual in last iteration
19 support = INIT \length(y) dtype=u # over-length support array
20 term = INIT $\size(Q_H, 0)$ dtype=f # float number array
21 j::u0 = NEW 0
22 a::v = INIT
23 FOR "" $j != \length(y)$ $j = j + 1$
24     term = \abs(Q_H @ r)
25     index::u0 = NEW \index_max(term)
26     IF j && \ismember(index, support_{0:j-1})
27         BREAK # end of the LOOP
28     END
29     support_{j} = index
30     columns::m = NEW Q_{:, support_{0:j}}
31     a = \solve(columns, y)
32     r = y - columns @ a
33     IF \sum(\abs(r - r_last)) / \sum(\abs(r_last)) < 0.0001 || j + 1 >= L

```

```

34     j = j + 1
35     BREAK # accurate enough to end iteration
36 ELSE
37     r_last = r
38 END
39 END
40 # prepare for the final return
41 h_{support_{0:j-1}} = a
42 END

```

Listing 3: Oracle\_LS.alg

```

1  #! Function: Oracle_LS
2  #! Description: Oracle LS compressed sensing.
3  #! Author: Wuqiong Zhao
4  #! Date: 2022-09-18
5  #! Version: 0.1.0
6
7  # Input:
8  #   - Q: Sensing matrix
9  #   - y: Received signal
10 #   - indices: Indices of non-zero elements
11 # Output:
12 #   - h: The estimated sparse signal
13 h::v = FUNCTION Oracle_LS Q::m y::v indices::u1
14     h = \zeros(\size(Q,1))
15     h_{indices} = \pinv(Q_{:, indices}) @ y
16 END

```

## 4 mmCEsim Information

This report is auto generated by mmCEsim. The application **mmCEsim** is a powerful tool to simulate millimeter wave (mmWave) channel estimation (CE) for both experts and learners.

mmCEsim is *open source*! The software can be freely used and distributed under the MIT license.

- Official Website: <https://mmcesim.org>
- Documentation: <https://mmcesim.org/doc>
- Tutorial: <https://mmcesim.org/tutorial>
- Examples: <https://mmcesim.org/example>
- Web Application: <https://app.mmcesim.org>
- Blog: <https://blog.mmcesim.org>
- Publications: <https://pub.mmcesim.org>
- GitHub Organization: <https://github.com/mmcesim>
- Twitter: <https://twitter.com/mmcesim>
- VS Code Extension: <https://marketplace.visualstudio.com/items?itemName=mmcesim.mmcesim>