Thinned array vs. phased arrays for adaptive pattern nulling

L. Poli, P. Rocca, M. Salucci, A. Massa

Abstract

A comparison between thinned array and phased array for pattern nulling is proposed in this report. The RF switch control or the phase shifter control are realized by indirectly maximizing the SINR to locate deep nulls along the directions-of-arrival (DoAs) of the interferences such to enable the use of these antenna systems for point-to-point communications or radar applications. A time-varying scenarios where single and multiple interfering signals impinge on the array from different angular directions is considered.

TEST CASE 17 - Thinned vs. Phased Array - 32 Elements - Time-Varying Scenario

Goal

Maximization of the SINR using genetic algorithms (GA) to determine the optimal thinned array configuration, considering a time-varying scenario.

Test Case Description

- Number of Elements $N = 32$
- Elements Spacing: $d = 0.5\lambda$
- Phase Shifters number of bits: $B = 4$
- Max Gain Pattern Direction : $\theta^d = 90°$, $\phi^d = 90°$
- Desired Signal Power: $0\,dB$
- Interference Power: $30\,dB$
- Noise Power: $-30\,dB$
- Timesteps: $T = 900$
- Number of Interferences: $N_t^I \in [1-5];\ \ t = 1, ..., T$
- Interference Direction Of Arrival: $\theta_j^i = 90°$, $\phi_j^i \in [0° - 180°];\ \ j = 1, ..., N_t^I$

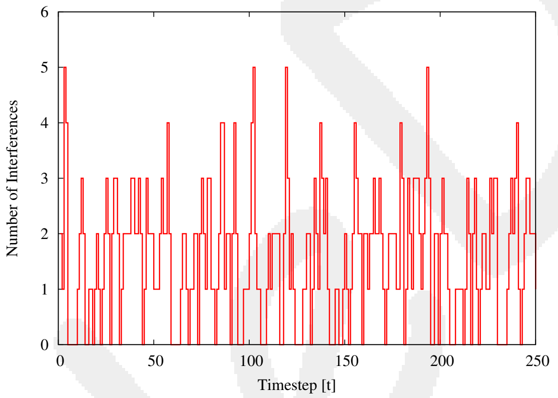

Fig.229 - Number of Interferences

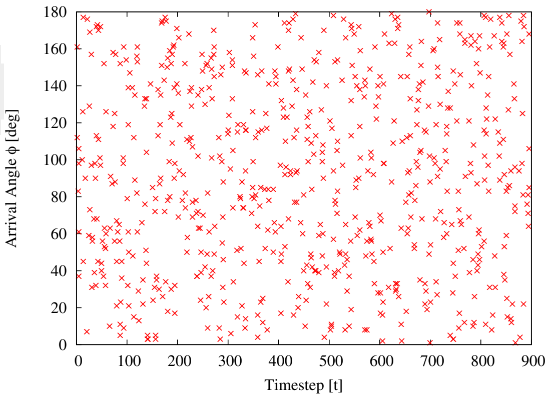

Fig.230 - Arrival Angle

Optimization Approach: GA

- Number of Variables: $X = 16$ $(\varphi_n = -\varphi_{N+1-n},\ n = 1, ..., N/2)$
- Population: 16
- Crossover Probability: 0.9
- Mutation Probability: 0.01
- Number of Generations: 200

- Phases Optimization Range: $\varphi_n \in [0 - 90]$
- Directivity Unconstrained Case: $D \in [0 - 32]$ (linear scale)
- Directivity Constrained Case: $D = 19 \pm 0.1\%$ (linear scale)

GA - Phased Array - 32 Elements - Time-Varying Scenario

	$av\{SINR\,[dB]\}$	$var\{SINR\,[dB]\}$	$min\{SINR\,[dB]\}$	$max\{SINR\,[dB]\}$
$Phased,\,Unconstrained\,case$	33.78	232.82	-30.00	45.05
$Phased,\,Constrained\,case$	18.94	426.79	-30.49	42.79
$Thinned,\,Unconstrained\,case$	16.66	393.26	-30.01	45.05
$Thinned,\,Constrained\,case,\,\eta = 0.60$	10.93	437.06	-30.03	42.79

Tab.51 - Statistical analysis of the signal-to-noise-plus-interference-ration expressed in dB values $SINR\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

	$av\{D\,[dB]\}$	$var\{D\,[dB]\}$	$min\{D\,[dB]\}$	$max\{D\,[dB]\}$
$Phased,\,Unconstrained\,case$	12.87	2.23	6.73	15.05
$Phased,\,Constrained\,case$	12.79	6.43×10^{-6}	12.78	12.79
$Thinned,\,Unconstrained\,case$	13.32	1.79	6.02	15.05
$Thinned,\,Constrained\,case,\,\eta = 0.60$	12.79	0	12.79	12.79

Tab.52 - Statistical analysis of the directivity $D\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

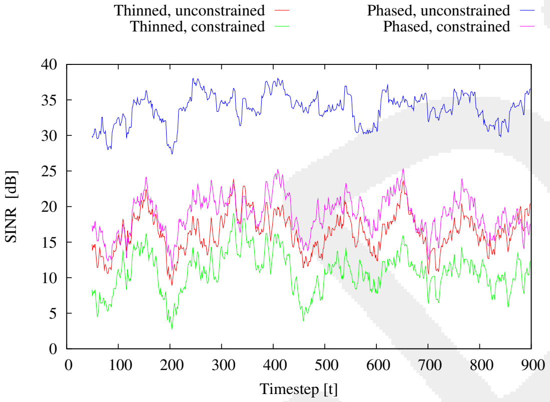

Fig.231 - SINR average comparison

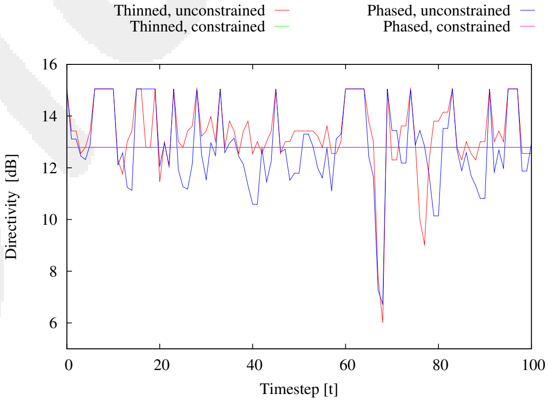

Fig.232 - Directivity comparison

Observations:

- Fig.231 riporta l'andamento medio del $SINR$ in dB mediato sui 50 timesteps precedenti;
- Il caso Thinned Constrained con $\eta = 0.60$ comporta l'imposizione di un constraint sulla direttività, che rimane sempre fissa al valore $D = 19$ ($12.79\,dB$).
- Le prestazioni dei phased arrays rispetto ai thinned arrays in termini di $SINR$ medio sono in questo caso notevolmente superiori, soprattutto utilizzando $4 - 8\,bit$ phase shifters;

TEST CASE 18 - Thinned vs. Phased Array - 64 Elements - Time-Varying Scenario

Goal

Maximization of the SINR using genetic algorithms (GA) to determine the optimal thinned array configuration, considering a time-varying scenario.

Test Case Description

- Number of Elements $N = 64$
- Elements Spacing: $d = 0.5\lambda$
- Phase Shifters number of bits: $B = 4$
- Max Gain Pattern Direction : $\theta^d = 90°$, $\phi^d = 90°$
- Desired Signal Power: $0\,dB$
- Interference Power: $30\,dB$
- Noise Power: $-30\,dB$
- Timesteps: $T = 900$
- Number of Interferences: $N_t^I \in [1-5]$; $t = 1, ..., T$
- Interference Direction Of Arrival: $\theta_j^i = 90°$, $\phi_j^i \in [0° - 180°]$; $j = 1, ..., N_t^I$

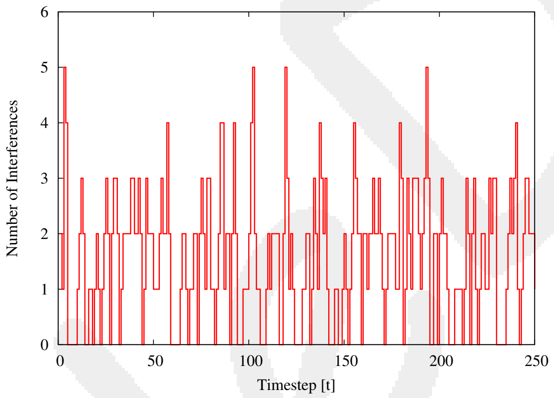

Fig.233 - Number of Interferences

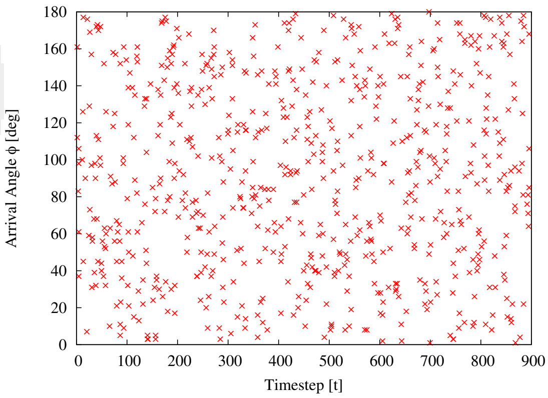

Fig.234 - Arrival Angle

Optimization Approach: GA

- Number of Variables: $X = 32$ ($\varphi_n = -\varphi_{N+1-n}$, $n = 1, ..., N/2,$)
- Population: 32
- Crossover Probability: 0.9
- Mutation Probability: 0.01
- Number of Generations: 200

- Phases Optimization Range: $\varphi_n \in [0 - 90]$
- Directivity Unconstrained Case: $D \in [0 - 64]$ (linear scale)
- Directivity Constrained Case: $D = 38 \pm 0.1\%$ (linear scale)

GA - Phased Array - 64 Elements - Time-Varying Scenario

	$av\{SINR\,[dB]\}$	$var\{SINR\,[dB]\}$	$min\{SINR\,[dB]\}$	$max\{SINR\,[dB]\}$
$Phased,\ Unconstrained\, case$	38.24	192.87	-30.00	48.06
$Phased,\ Constrained\, case$	35.16	227.47	-30.00	45.80
$Thinned,\ Unconstrained\, case$	26.80	308.50	-30.00	48.06
$Thinned,\ Constrained\, case,\ \eta = 0.60$	22.52	337.94	-30.00	45.80

Tab.53 - Statistical analysis of the signal-to-noise-plus-interference-ration expressed in dB values $SINR\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

	$av\{D\,[dB]\}$	$var\{D\,[dB]\}$	$min\{D\,[dB]\}$	$max\{D\,[dB]\}$
$Phased,\ Unconstrained\, case$	16.55	9.87×10^{-1}	13.72	18.06
$Phased,\ Constrained\, case$	15.80	7.70×10^{-6}	15.79	15.80
$Thinned,\ Unconstrained\, case$	16.62	1.10	10.79	18.06
$Thinned,\ Constrained\, case,\ \eta = 0.60$	15.80	0	15.80	15.80

Tab.54 - Statistical analysis of the directivity $D\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

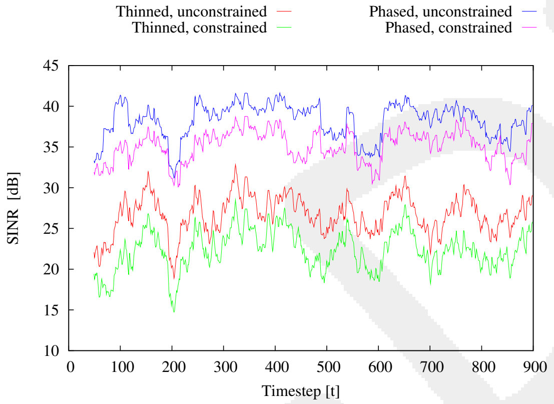

Fig.235 - SINR average comparison

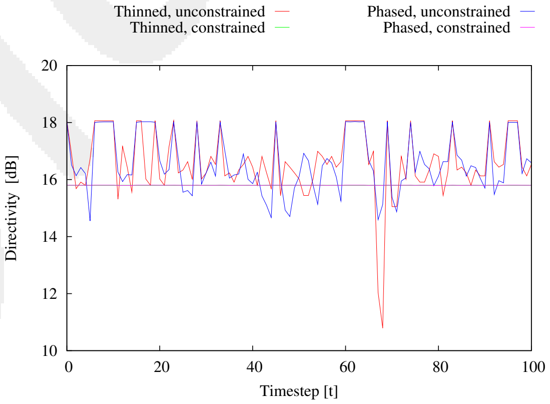

Fig.236 - Directivity comparison

Observations:

- Fig.235 riporta l'andamento medio del $SINR$ in dB mediato sui 50 timesteps precedenti;
- Il caso Thinned Constrained con $\eta = 0.60$ comporta l'imposizione di un constraint sulla direttività, che rimane sempre fissa al valore $D = 38$ ($15.80\,dB$).
- Le prestazioni dei phased arrays rispetto ai thinned arrays in termini di $SINR$ medio sono anche in questo caso superiori, tuttavia la differenza di prestazioni è più contenuta; è possibile osservare inoltre in Fig.236 una marcata escursione nei valori di direttività per le antenne phased;

TEST CASE 19 - Thinned vs. Phased Array - 128 Elements - Time-Varying Scenario

Goal

Maximization of the SINR using genetic algorithms (GA) to determine the optimal phased array configuration, considering a time-varying scenario.

Test Case Description

- Number of Elements $N = 128$
- Elements Spacing: $d = 0.5\lambda$
- Phase Shifters number of bits: $B = 4$
- Max Gain Pattern Direction : $\theta^d = 90°$, $\phi^d = 90°$
- Desired Signal Power: $0\,dB$
- Interference Power: $30\,dB$
- Noise Power: $-30\,dB$
- Timesteps: $T = 900$
- Number of Interferences: $N_t^I \in [1-5]$; $t = 1, ..., T$
- Interference Direction Of Arrival: $\theta_j^i = 90°$, $\phi_j^i \in [0° - 180°]$; $j = 1, ..., N_t^I$

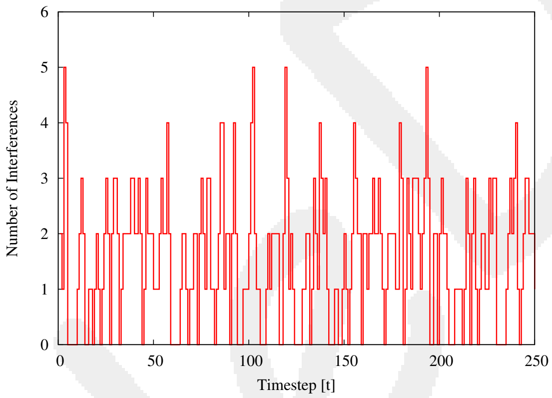

Fig.237 - Number of Interferences

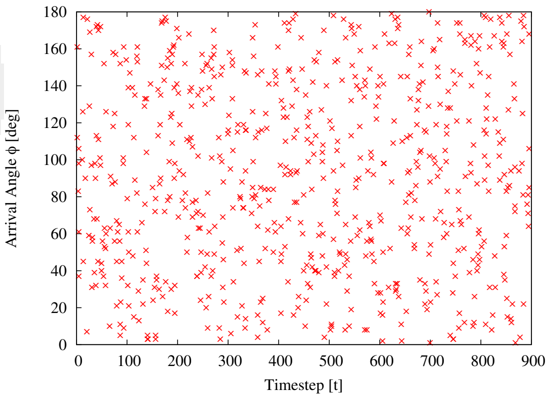

Fig.238 - Arrival Angle

Optimization Approach: GA

- Number of Variables: $X = 64$ ($\varphi_n = -\varphi_{N+1-n}$, $n = 1, ..., N/2,$)
- Population: 64
- Crossover Probability: 0.9
- Mutation Probability: 0.01
- Number of Generations: 200

- Phases Optimization Range: $\varphi_n \in [0-70]$
- Directivity Unconstrained Case: $D \in [0-128]$ (linear scale)
- Directivity Constrained Case: $D = 76 \pm 0.1\%$ (linear scale)

GA - minPwr Approach - 128 Elements - Time-Varying Scenario

	$av\{SINR\,[dB]\}$	$var\{SINR\,[dB]\}$	$min\{SINR\,[dB]\}$	$max\{SINR\,[dB]\}$
$Phased,\ Unconstrained\,case$	43.19	164.11	-30.00	51.07
$Phased,\ Constrained\,case$	45.18	120.20	-30.00	48.81
$Thinned,\ Unconstrained\,case$	29.73	322.26	-30.00	51.07
$Thinned,\ Constrained\,case,\ \eta = 0.60$	31.63	270.89	-30.00	48.81

Tab.55 - Statistical analysis of the signal-to-noise-plus-interference-ration expressed in dB values $SINR\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

	$av\{D\,[dB]\}$	$var\{D\,[dB]\}$	$min\{D\,[dB]\}$	$max\{D\,[dB]\}$
$Phased,\ Unconstrained\,case$	19.59	1.08	17.15	21.07
$Phased,\ Constrained\,case$	18.81	6.57×10^{-6}	18.80	18.81
$Thinned,\ Unconstrained\,case$	19.33	1.21	13.22	21.07
$Thinned,\ Constrained\,case,\ \eta = 0.60$	18.81	0	18.81	18.81

Tab.56 - Statistical analysis of the directivity $D\,[dB]$: average $av\{\cdot\}$, variance $var\{\cdot\}$, minimum $min\{\cdot\}$ and maximum $max\{\cdot\}$.

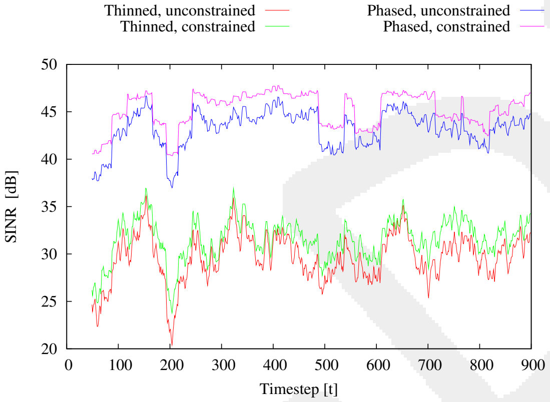

Fig.239 - SINR average comparison

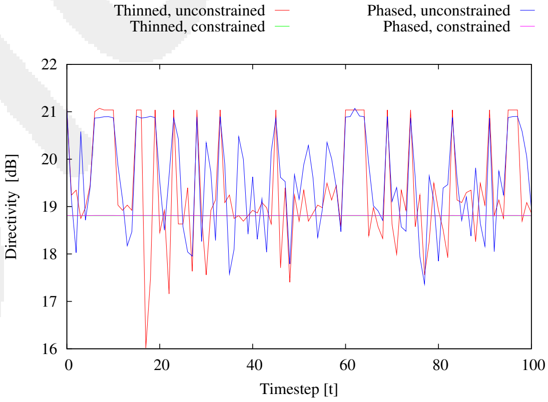

Fig.240 - Directivity comparison

Observations:

- Fig.239 riporta l'andamento medio del $SINR$ in dB mediato sui 50 timesteps precedenti;
- Il caso Thinned Constrained con $\eta = 0.60$ comporta l'imposizione di un constraint sulla direttività, che rimane sempre fissa al valore $D = 76$ ($18.81\,dB$).
- Le prestazioni dei phased arrays rispetto ai thinned arrays in termini di $SINR$ medio sono in questo caso molto contenute; è possibile osservare inoltre in Fig.240 una marcata escursione nei valori di direttività per le antenne phased;
- Per la sintesi di thinned arrays è possibile inoltre, se necessario, inizializzare opportunamente la popolazione in modo che sia composta da individui caratterizzati da un numero predefinito di bit attivi, al fine di ridurre il tempo impiegato dall'algoritmo genetico per trovare la specifica soluzione richiesta e velocizzare quindi la sintesi stessa; nella sintesi di phased arrays non esiste invece una relazione tra numero di bit attivi e direttività del pattern sintetizzato.

References

[1] P. Rocca, M. Benedetti, M. Donelli, D. Franceschini, and A. Massa, "Evolutionary optimization as applied to inverse problems," Inverse Problems - 25 th Year Special Issue of Inverse Problems, Invited Topical Review, vol. 25, pp. 1-41, Dec. 2009.

[2] P. Rocca, G. Oliveri, and A. Massa, "Differential Evolution as applied to electromagnetics," IEEE Antennas Propag. Mag., vol. 53, no. 1, pp. 38-49, Feb. 2011.

[3] P. Rocca, L. Poli, G. Oliveri, and A. Massa, "Adaptive nulling in time-varying scenarios through time-modulated linear arrays," IEEE Antennas Wireless Propag. Lett., vol. 11, pp. 101-104, 2012.

[4] M. Benedetti, G. Oliveri, P. Rocca, and A. Massa, "A fully-adaptive smart antenna prototype: ideal model and experimental validation in complex interference scenarios," Progress in Electromagnetic Research, PIER 96, pp. 173-191, 2009.

[5] M. Benedetti, R. Azaro, and A. Massa, "Memory enhanced PSO-based optimization approach for smart antennas control in complex interference scenarios," IEEE Trans. Antennas Propag., vol. 56, no. 7, pp. 1939-1947, Jul. 2008.

[6] M. Benedetti, R. Azaro, and A. Massa, "Experimental validation of a fully-adaptive smart antenna prototype," Electronics Letters, vol. 44, no. 11, pp. 661-662, May 2008.

[7] R. Azaro, L. Ioriatti, M. Martinelli, M. Benedetti, and A. Massa, "An experimental realization of a fully-adaptive smart antenna," Microwave Opt. Technol. Lett., vol. 50, no. 6, pp. 1715-1716, Jun. 2008.

[8] M. Donelli, R. Azaro, L. Fimognari, and A. Massa, "A planar electronically reconfigurable Wi-Fi band antenna based on a parasitic microstrip structure," IEEE Antennas Wireless Propag. Lett., vol. 6, pp. 623-626, 2007.

[9] M. Benedetti, R. Azaro, D. Franceschini, and A. Massa, "PSO-based real-time control of planar uniform circular arrays," IEEE Antennas Wireless Propag. Lett., vol. 5, pp. 545-548, 2006.

[10] F. Viani, L. Lizzi, M. Donelli, D. Pregnolato, G. Oliveri, and A. Massa, "Exploitation of smart antennas in wireless sensor networks," Journal of Electromagnetic Waves and Applications, vol. 24, no. 5/6, pp. 993-1003, 2010.

[11] L. Poli, P. Rocca, M. Salucci, and A. Massa, "Reconfigurable thinning for the adaptive control of linear arrays," IEEE Transactions on Antennas and Propagation, vol. 61, no. 10, pp. 5068-5077, October 2013.

[12] P. Rocca, R. L. Haupt, and A. Massa, "Interference suppression in uniform linear array through a dynamic thinning strategy," IEEE Trans. Antennas Propag., vol. 59, no. 12, pp. 4525-4533, Dec. 2011.

[13] G. Oliveri and A. Massa, "GA-Enhanced ADS-based approach for array thinning," IET Microwaves, Antennas & Propagation, vol. 5, no. 3, pp. 305-315, 2011.