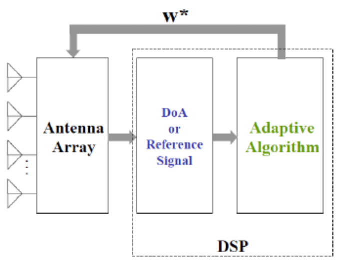
Smart Antenna and Signal Processing

Agenda

- What is Smart Antenna
- Why are Smart Antenna Systems important
- Impact of Antenna Array Characteristics on :
  1. Mobile Ad-hoc Networks Throughput
  2. Communication Channel BER
- Summary

What is a Smart Antenna ?

Typical Smart Antenna System



Areas of SAS

Why are Smart Antenna Systems important ?

Why are Smart Antenna Systems important ?

- SA integrate radio intelligence (DSP) with array antenna technology to :

  Enhance communication system performance, including :

  - Capacity (in urban area)
  - Range (in rural areas)

  Improve link quality for transmission and reception, by :

  - Multi-path management
  - Mitigation of fading

The previous are accomplished by:

- *Beam steering:*

  Placing beam maxima toward Signals Of Interest (SOI).

2. *Null steering:*

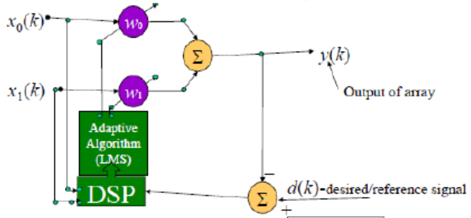
   Placing beam minima, ideally nulls, toward interfering signals;
   Signal Not Of Interest (SNOI).

3. *Spatially separate signals:*

   Allowing different users to share the same spectral and infrastructure resources (SDMA)

Beam-forming Linear Array

Least Mean Square (LMS) Temporal Algorithm



Based on the Weiner's solution: $\boxed{\mathbf{w}^{opt} = \mathbf{R}^{-1}\mathbf{P}}$

$$\mathbf{w}_{k+1} = \mathbf{w}_k + 2\mu\mathbf{x}_k\left(d_k - \mathbf{x}_k^T\mathbf{w}_k\right) \quad \text{where} \quad 0 < \mu < \frac{1}{\lambda_{max}}$$

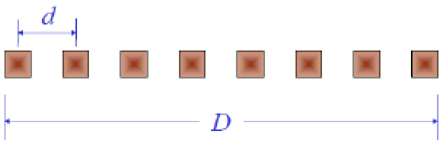
R $\Rightarrow$ auto-correlation matrix of input signal $\mathbf{x}_k$

P $\Rightarrow$ cross-correlation matrix between input signal $\mathbf{x}_k$ and desired signal d_k

λ_{max} $\Rightarrow$ largest eigenvalue of the auto-correlation matrix **R**

μ $\Rightarrow$ convergence factor/step-size parameter; determines convergence rate

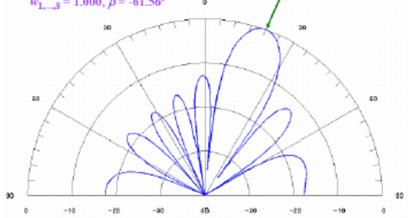
Linear Array Configuration



Beam-forming Linear Array Example

Type: *Array Factor*
Algorithm: LMS
Iterations: 55
Geometry: 8 linear array, $d = 0.5\lambda$
SOI 20°
Results: $w_{1,\ldots,8} = 1.000$, $\beta = -61.56°$

SOI



Weights and Phases Comparison

	Uniform (classical)		LMS ($i = 55$)	
Element	w	β (deg)	w	β (deg)
1	1.0000	0.00	1.0000	0.00
2	1.0000	-61.56	1.0000	-61.56
3	1.0000	-123.12	1.0000	-123.13
4	1.0000	-184.69	1.0000	-184.69
5	1.0000	-246.25	1.0000	-246.25
6	1.0000	-307.82	1.0000	-307.82
7	1.0000	-369.38	1.0000	-369.38
8	1.0000	-430.95	1.0000	-430.95

Linear Array

$N = 8$

$d = 0.5\lambda$

SOI = 20°

Antenna Geometries for Simulations

Weights and Phases Comparison

	LMS ($i = 81$)	
Element	w	β (deg)
1	1.0000	-11.62
2	0.8982	-57.05
3	1.1384	-109.98
4	1.3760	-178.77
5	1.3760	-252.21
6	1.1384	-321.01
7	0.8982	-373.94
8	1.0000	-419.37

Linear Array

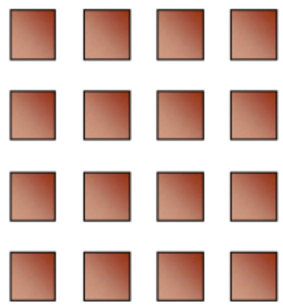
$N = 8$

$d = 0.5\lambda$

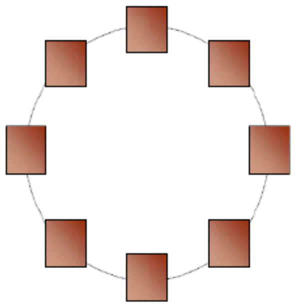
SOI = 20°

SNOI = 45°

Planar Array



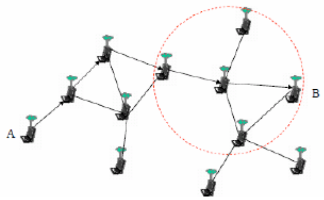
Circular Array



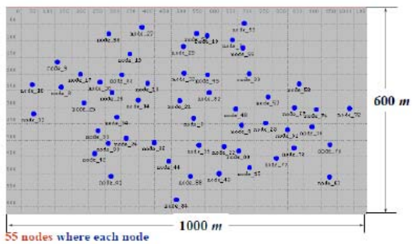
Mobile Ad-hoc Networks

Mobile Ad-hoc Networks (MANETs)

- Nodes move randomly, no fixed network infrastructure
  - Future wireless networks may not be planned and may evolve in an *ad-hoc* fashion
- Data packets are transferred in single hops



Network Model



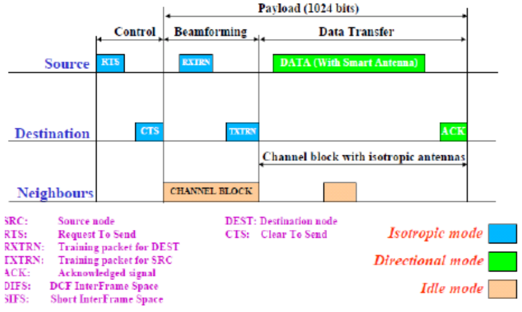
- Ø 55 nodes where each node
  - Ø models traffic as a Poisson distribution
  - Ø mobility is modeled by changing position at random every two packets
- Ø OPNET Modeler/Radio Tool is used to simulate the network

Channel Access in MANETs

Network traffic and access is controlled by adopting a protocol. The protocol chosen for the simulations is the:

Medium Access Control (MAC)

The MAC Protocol
(Based on IEEE 802.11 Standard for WLANs)



Simulation Parameters for MAC

Packet lengths used:

DIFS	0.023 L	Control Packets
SIFS	0.004 L	
RTS	0.011 L	
CTS	0.011 L	
ACK	0.011 L	
TXTRN	Variable	Beamforming Packets
RXTRN	Variable	
DATA	L	Payload (Data)

Network Through-put Simulations

Network Though-put Simulations

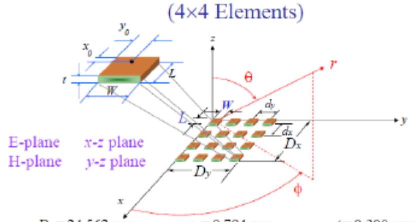
- Array Size (4×4 vs. 8×8)
- Array Distribution (Uniform vs. Tschebyscheff)
- Adaptive vs. Nonadaptive Array
- Beamforming Training Time

Network Through-put Simulations

- Array Size (4×4 vs. 8×8)
- Array Distribution (Uniform vs. Tschebyscheff)

Planar Array Configuration

(4×4 Elements)



$D_x = 24.562\ mm$ $x_0 = 0.794\ mm$ $t = 0.300\ mm$

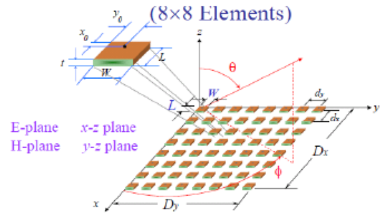
$D_y = 24.747\ mm$ $y_0 = 1.164\ mm$ $\varepsilon_r = 11.7$, Si

$d_x = 7.500\ mm$ $W = 2.247\ mm$ $\tan\delta = 0.04$

$d_y = 7.500\ mm$ $L = 2.062\ mm$ $f = 20\ GHz$

Planar Array Configuration

(8×8 Elements)



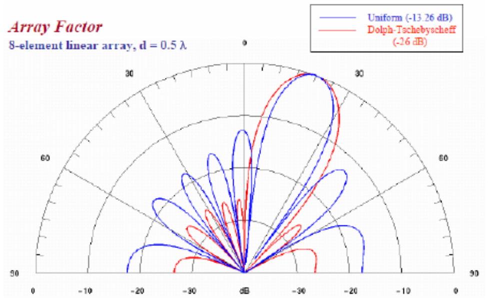
$D_x = 54.747\ mm$ $x_0 = 0.794\ mm$ $t = 0.300\ mm$

$D_y = 54.562\ mm$ $y_0 = 1.164\ mm$ $\varepsilon_r = 11.7$, Si

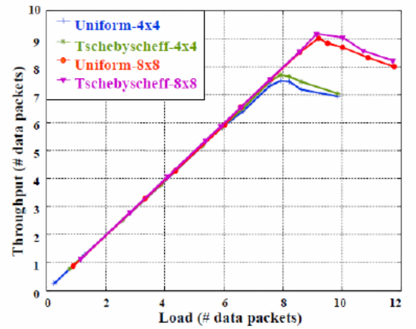
$d_x = 7.500\ mm$ $W = 2.247\ mm$ $\sigma = 0.04$

$d_y = 7.500\ mm$ $L = 2.062\ mm$ $f = 20\ GHz$

Array Design



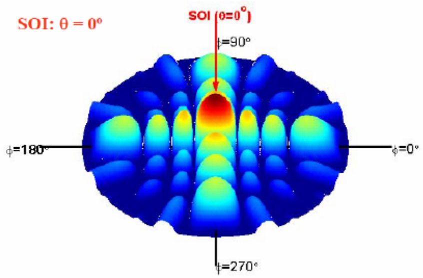
Through-put for Different Antenna Patterns



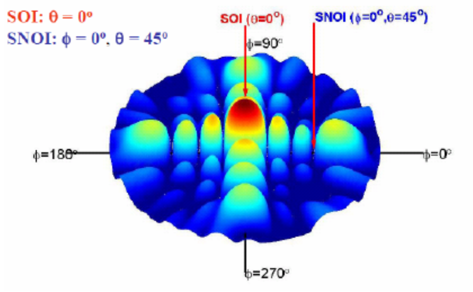
Network Through-put Simulations

- Adaptive vs. Non-adaptive Array

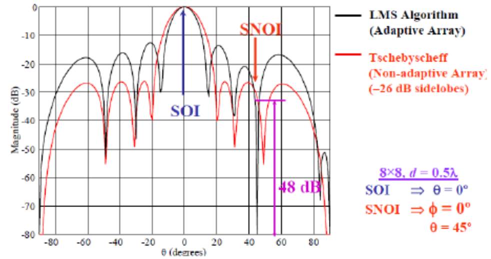
Non-adaptive Pattern



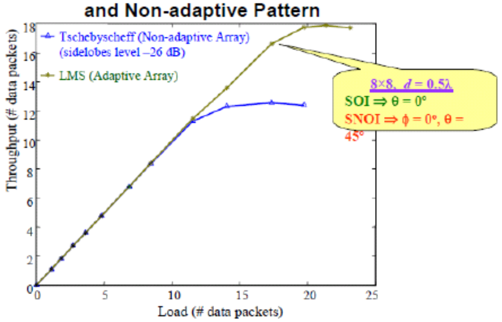
Adaptive Pattern



LMS Algorithm (Adaptive Pattern) vs.
Tschebyscheff (Non-adaptive Pattern)



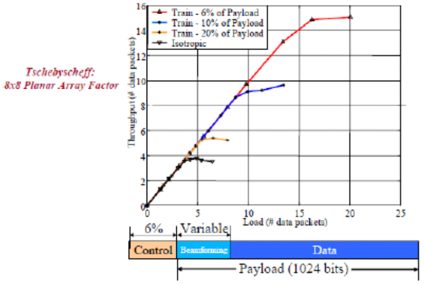
Through-put for adaptive Pattern and Non-adaptive Pattern



Network Throughput Simulations

Beam-forming Training Time

Through-put
for Different Training/Beam-forming Periods



Summary

Based on the Network Simulations, MANETs employing smart antennas can achieve higher capacity, as measured by *throughput*, by the using the following antenna array designs guidelines:

- Larger planar arrays (in this project: 8 x 8 vs. 4 x 4)
- Lower sidelobes (in this project: -26 dB vs. -13.26 dB)
- Fully adaptive array with deep nulls/minima towards the SNOIs
- Short beamforming training times

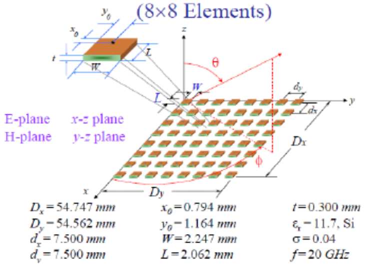
Communication System BER

Binary Phase Shift Keying (BPSK)
vs.
Trellis Coded Modulation (TCM)
vs.
Multipath/Fading

Signals Corrupted with
Additive White Gaussian Noise Channel (AWGN)

Binary Phase Shift Keying (BPSK) over AWGN

Planar Array Configuration

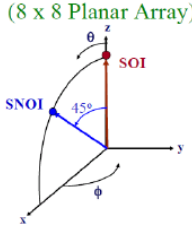


Signal used for Antenna Pattern Adaptation

	SOI		SNOI	
	ϕ_o	θ_o	ϕ_o	θ_o
Case 1*	0^o	0^o	0^o	45^o
Case 2	45^o	30^o	45^o	60^o

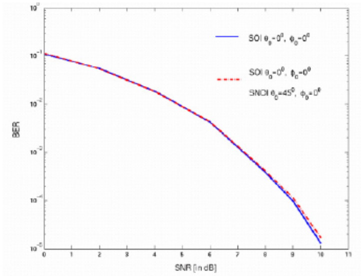
Case I
SOI: $\phi = 0°$, $\theta = 0°$
SNOI: $\phi = 0°$, $\theta = 45°$

(8 x 8 Planar Array)



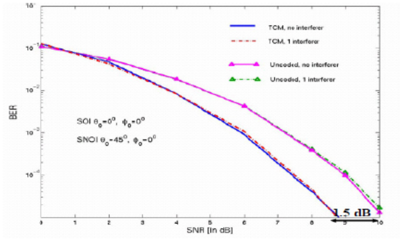
Workshop: Reconfigurable and Smart Antennas IMS 2007-

BER over Binary/Uncoded AWGN Channel (using 60 symbols for training sequence)



Trellis Code
QPSK Modulation
over AWGN Channel

BER over AWGN Channel
(Uncoded/Binary vs. Trellis Code Mod.)

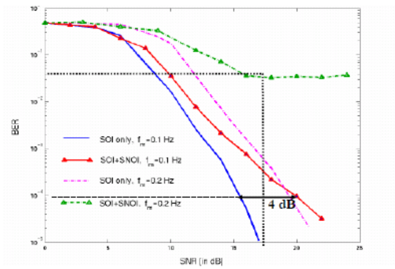


Rayleigh Fading Channel

- *BER* over Rayleigh fading channel with Doppler spreads of $f_m = 0.1$ Hz ($f_m T = 0.001$) and $f_m = 0.2$ Hz ($f_m T = 0.002$)
- The length of the training symbol is 60 symbols and is transmitted periodically every data sequence of length 940 symbols.

(Symbol duration: $T = 10$ ms)

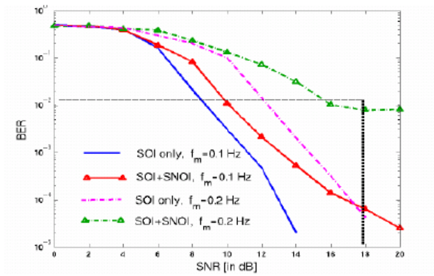
Rayleigh Fading-Binary/Uncoded Channel



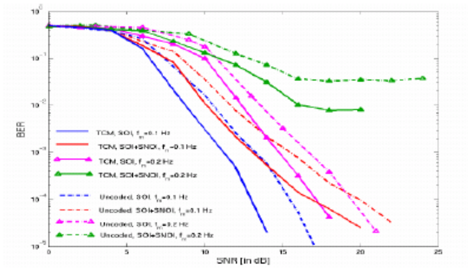
- BER for trellis coded QPSK modulation over Rayleigh fading channel with Doppler spreads of $f_m = 0.1$ Hz ($f_m T$=0.001) and $f_m = 0.2$ Hz ($f_m T = 0.002$) for both cases.
- The length of the training symbol is 60 symbols and is transmitted periodically every data sequence of length 940 symbols.

(Symbol duration: $T = 10$ ms)

Rayleigh Fading Coded Channel (TCM)

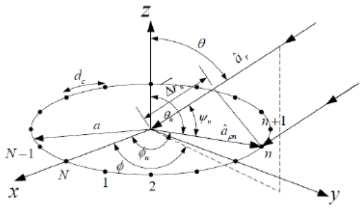


BER over Rayleigh Fading Channel (Binary/Uncoded vs. TCM)



Uniform Circular Arrays (UCAs)

Uniform Circular Array



Communication System BER

Binary Phase Shift Keying (BPSK)

vs.

Trellis Coded Modulation (TCM)

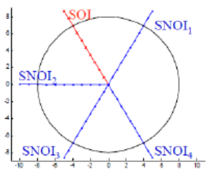
Signals Corrupted with

Additive White Gaussian Noise Channel (AWGN)

Simulation Environment of UCA

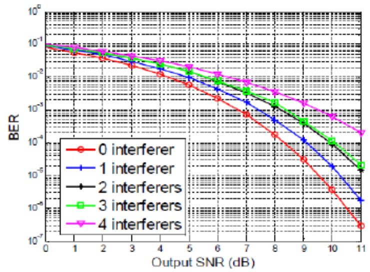
Equal power signals in the same azimuth plane with AWGN

$N = 8,\ d_c = \lambda/2,\ a = 2\lambda/\pi$

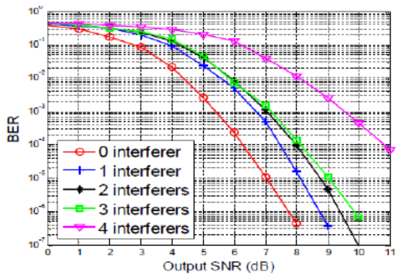


SOI	θ=90°	ϕ=120°
$SNOI_1$	θ=90°	ϕ=60°
$SNOI_2$	θ=90°	ϕ=180°
$SNOI_3$	θ=90°	ϕ=240°
$SNOI_4$	θ=90°	ϕ=300°

Binary Phase Shift Keying



Trellis Code Modulation



Trellis Code Modulation (TCM)

Well Separated SNOIs

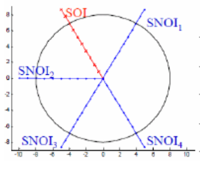
vs.

Random SNOIs

Simulation Environment of UCA

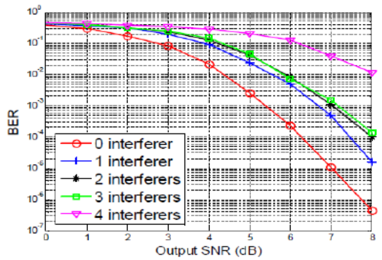
Equal power signals in the same azimuth plane with AWGN

$N = 8,\ d_c = \lambda/2,\ a = 2\lambda/\pi$

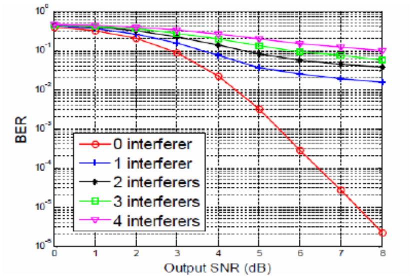


SOI	$\theta=90^\circ$	$\phi=120^\circ$
SNOI$_1$	$\theta=90^\circ$	$\phi=60^\circ$
SNOI$_2$	$\theta=90^\circ$	$\phi=180^\circ$
SNOI$_3$	$\theta=90^\circ$	$\phi=240^\circ$
SNOI$_4$	$\theta=90^\circ$	$\phi=300^\circ$

Well-separated Signals



Random SNOIs (5000 simulations)



Conclusion

By incorporating appropriate adaptive antenna array designs, and digital signal processing and communication algorithms,

Smart Antenna Systems (SAS) can:

- Increase network capacity/*throughput*
- Decrease Communication channel *Bit-Error-Rate* (*BER*)