

## Smart Antenna and Signal Processing

2012/07/17

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## 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

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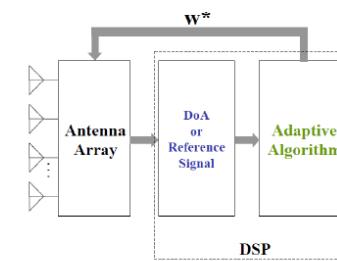
What is  
a Smart Antenna ?

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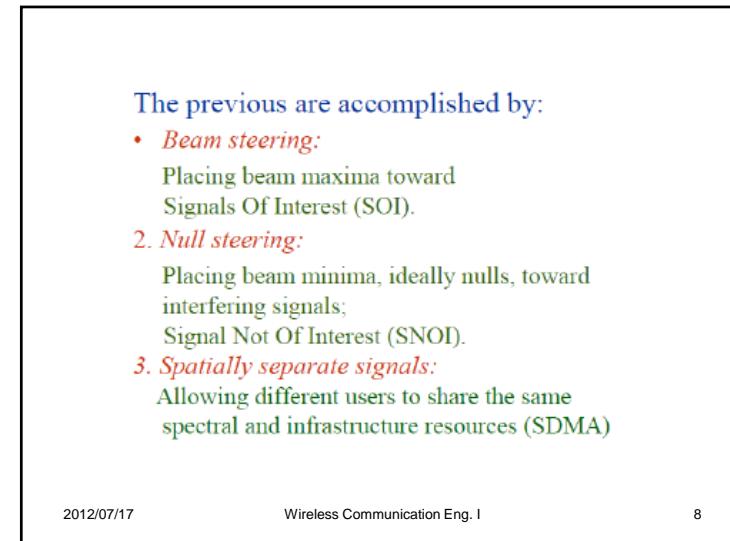
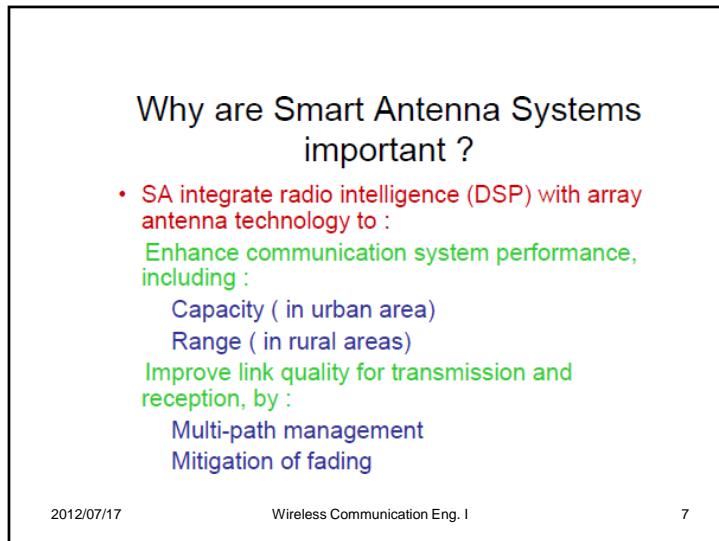
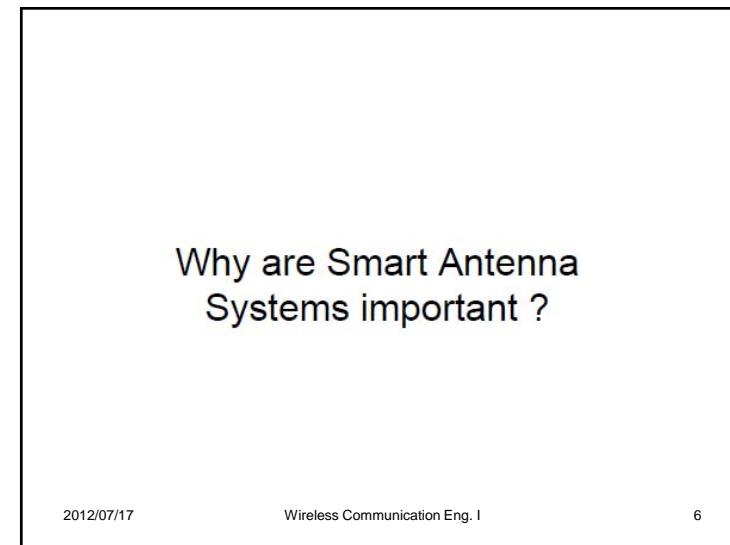
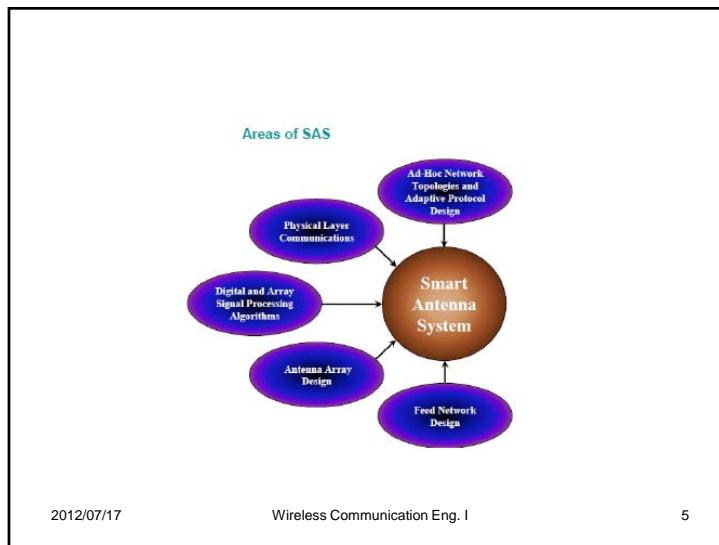
Typical Smart Antenna System



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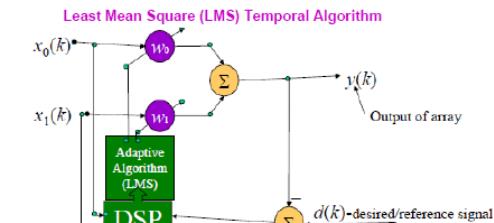


## Beam-forming Linear Array

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Based on the Weiner's solution:

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

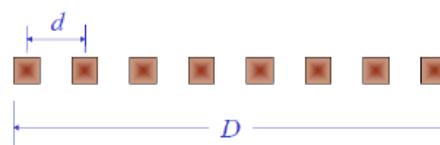
$\mathbf{R}$   $\Rightarrow$  auto-correlation matrix of input signal  $\mathbf{x}_k$   
 $\mathbf{P}$   $\Rightarrow$  cross-correlation matrix between input signal  $\mathbf{x}_k$  and desired signal  $\mathbf{d}_k$   
 $\lambda_{\max}$   $\Rightarrow$  largest eigenvalue of the auto-correlation matrix  $\mathbf{R}$   
 $\mu$   $\Rightarrow$  convergence factor/step-size parameter, determines convergence rate

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## Linear Array Configuration



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## Beam-forming Linear Array Example

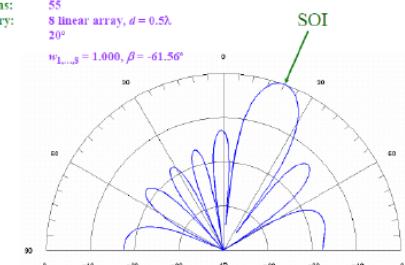
### Array Factor

Type: LMS

Iterations: 55

Geometry: 8 linear array,  $d = 0.5\lambda$ 

SOI: 20°

Results:  $w_{L=8} = 1.000, \beta = -61.56^\circ$ 

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**Weights and Phases Comparison**

Element	Uniform (classical)		LMS ( $i = 55$ )	
	$w$	$\beta$ (deg)	$w$	$\beta$ (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**  
 $N = 8$   
 $d = 0.5\lambda$   
 $SOI = 20^\circ$

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**Antenna Geometries for Simulations**

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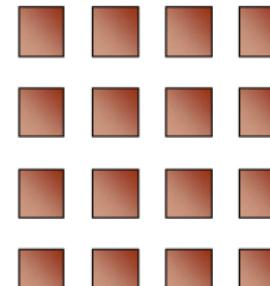
**Weights and Phases Comparison**

Element	LMS ( $i = 81$ )	
	$w$	$\beta$ (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

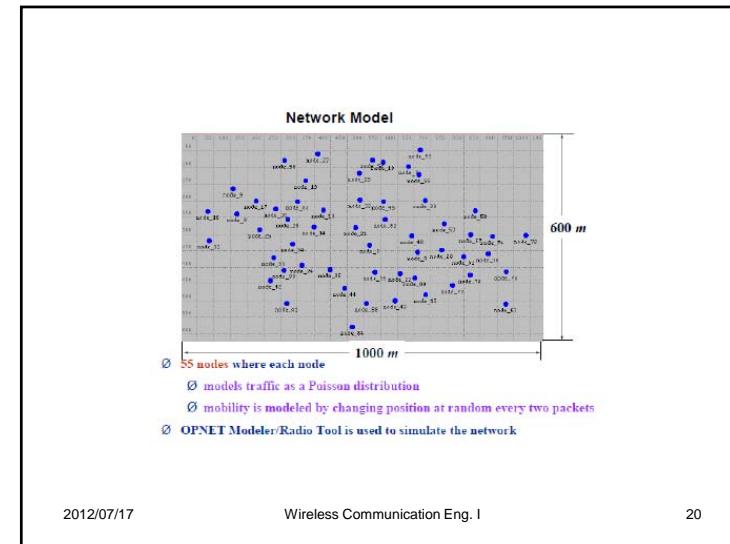
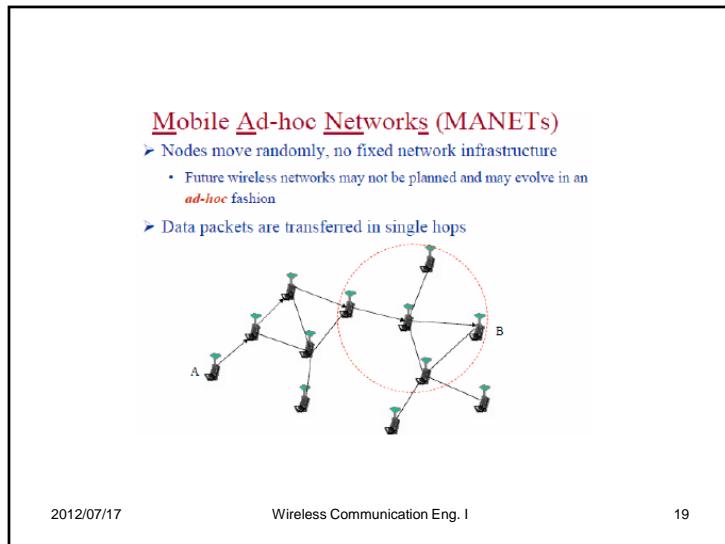
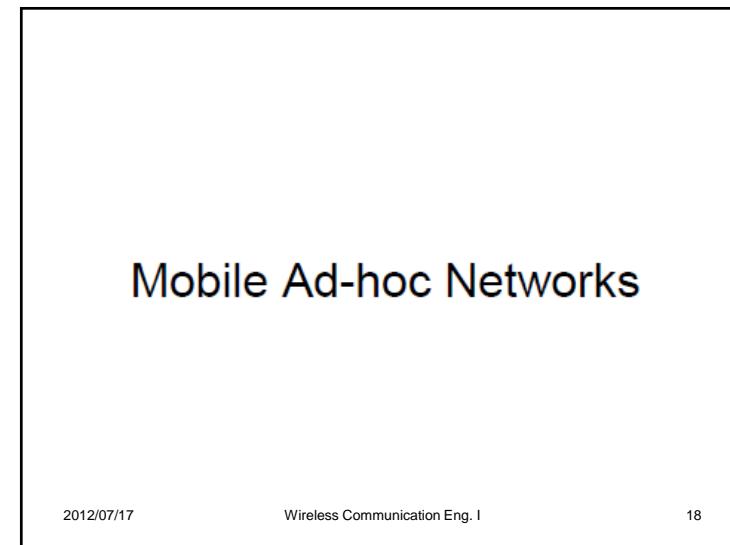
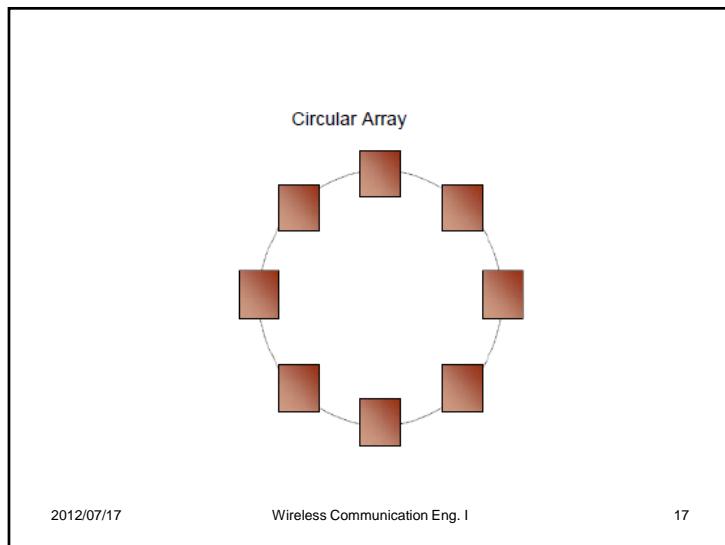
**Linear Array**  
 $N = 8$   
 $d = 0.5\lambda$   
 $SOI = 20^\circ$   
 $SNOI = 45^\circ$

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**Planar Array**



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### Channel Access in MANETs

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

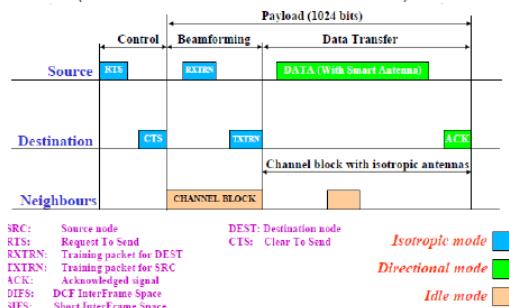
### Medium Access Control (MAC)

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



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### Simulation Parameters for MAC

Packet lengths used:

DIFS	0.023 L
SIFS	0.004 L
RTS	0.011 L
CTS	0.011 L
ACK	0.011 L
TXTRN	Variable
RXTRN	Variable
DATA	L

Control Packets

Beamforming Packets

Payload (Data)



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### Network Through-put Simulations

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### Network Through-put Simulations

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

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### Network Through-put Simulations

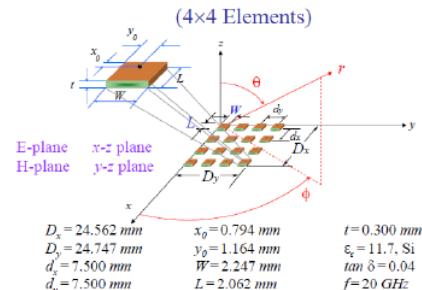
- ∅ Array Size (4×4 vs. 8×8)
- ∅ Array Distribution (Uniform vs. Tschebyscheff)

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### Planar Array Configuration

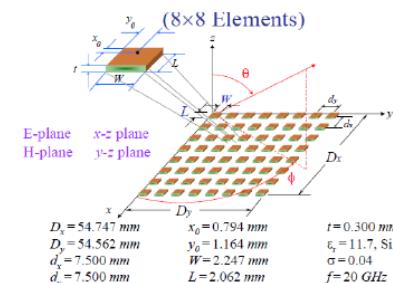


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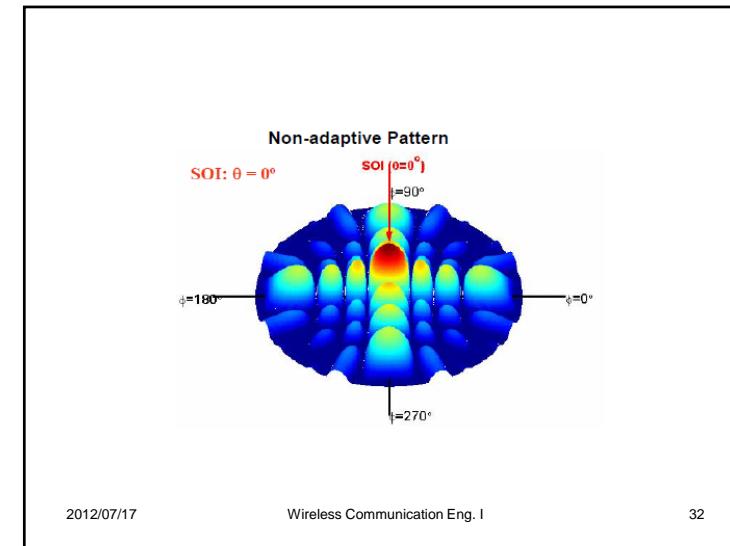
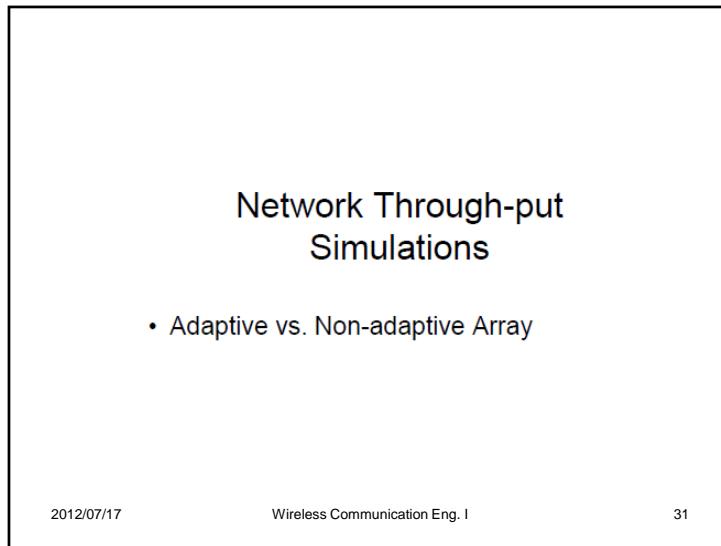
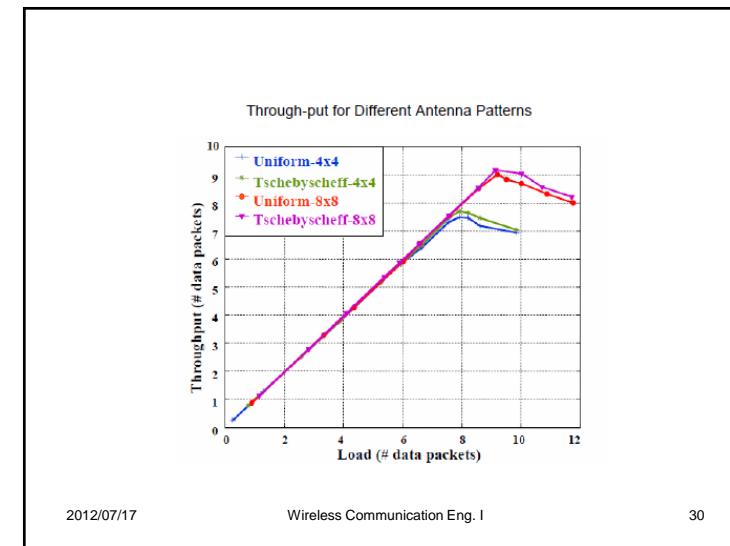
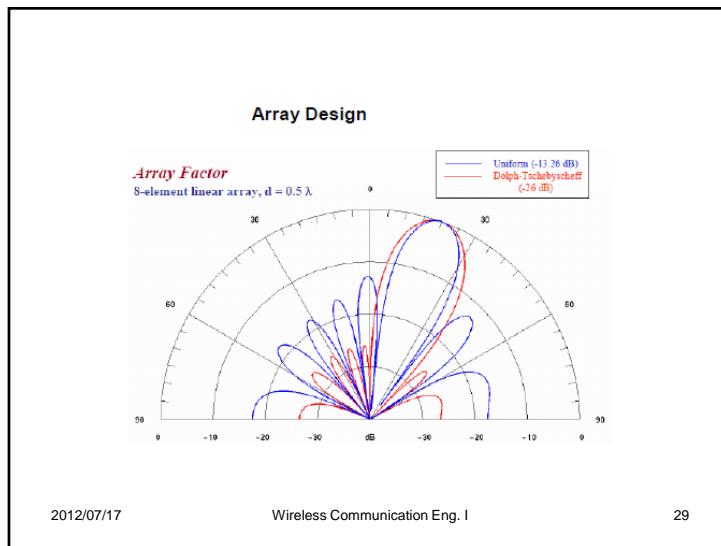
### Planar Array Configuration

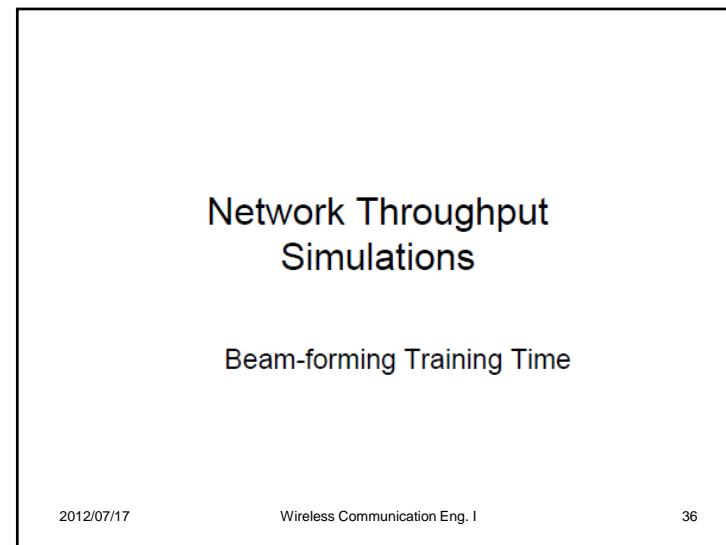
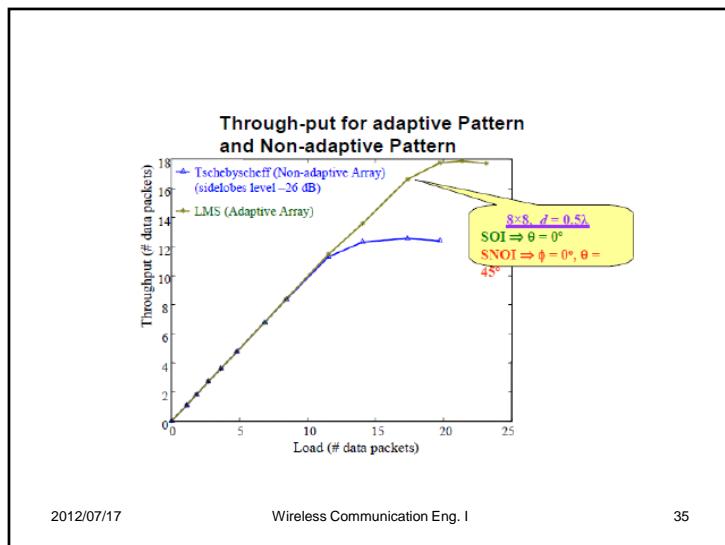
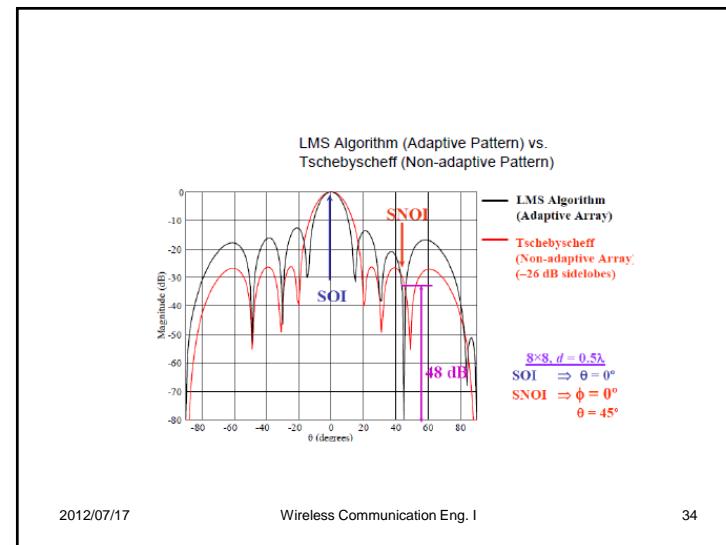
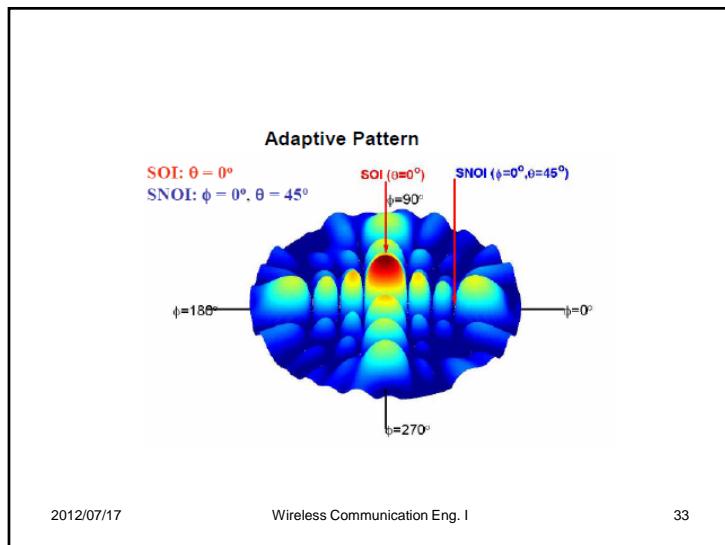


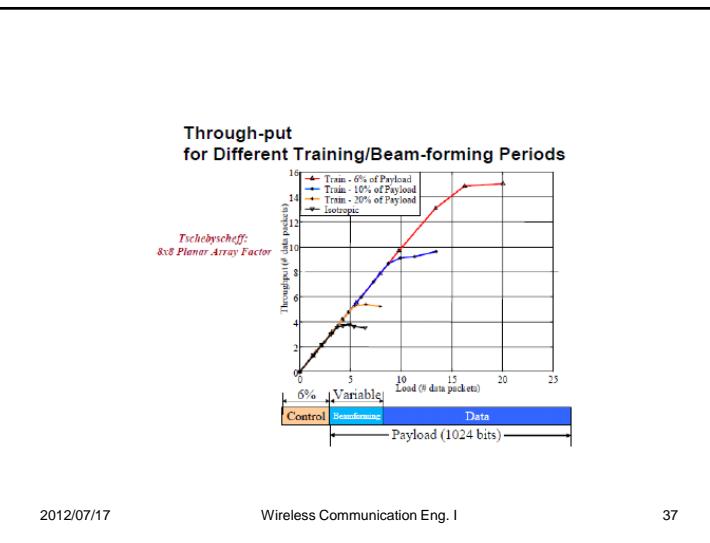
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### Summary

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

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

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### Communication System BER

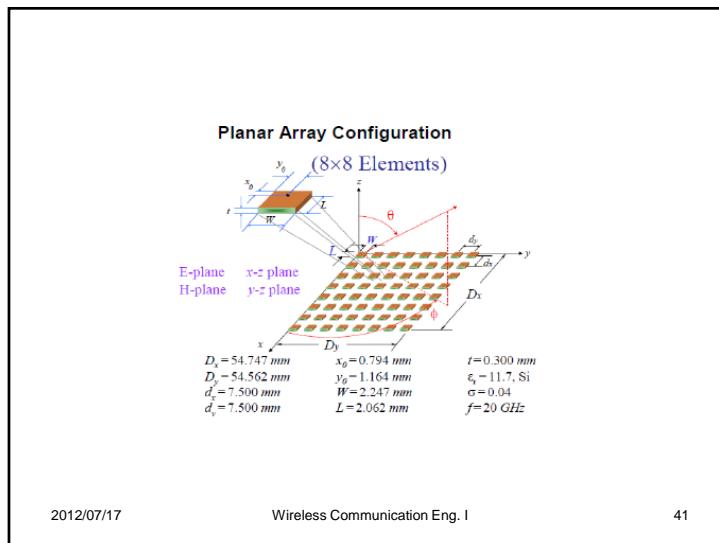
Binary Phase Shift Keying (BPSK)  
vs.  
Trellis Coded Modulation (TCM)  
vs.  
Multipath/Fading

Signals Corrupted with  
Additive White Gaussian Noise Channel (AWGN)

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### Binary Phase Shift Keying (BPSK ) over AWGN

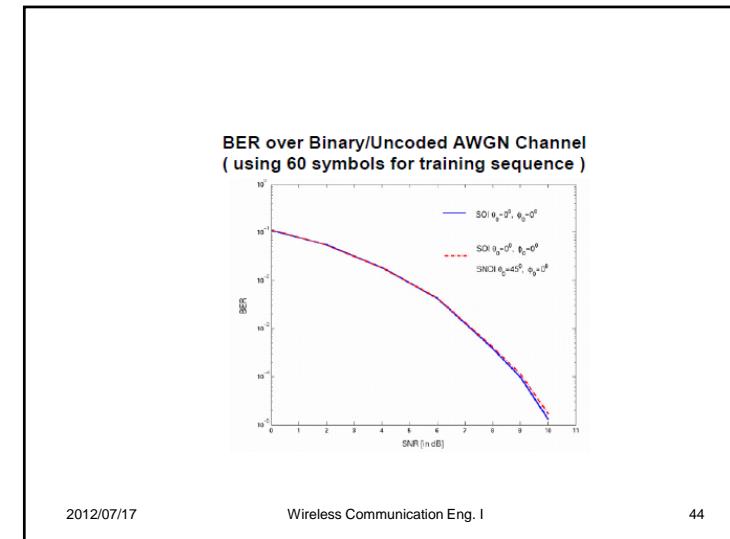
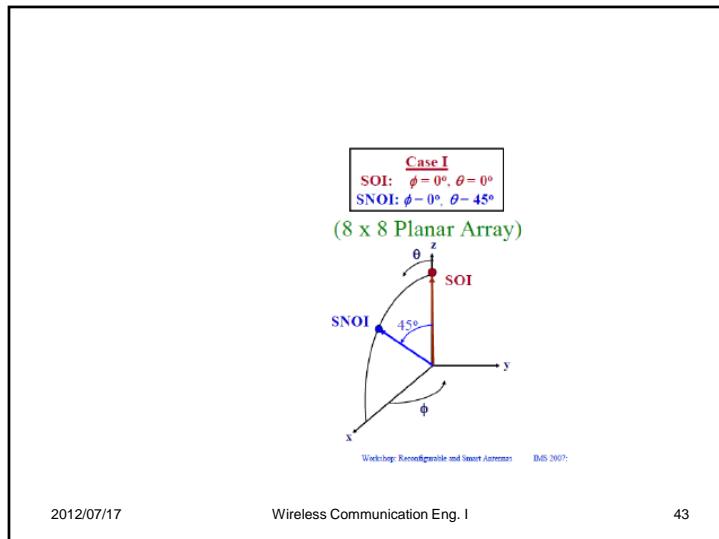
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**Signal used for Antenna Pattern Adaptation**

	SOI		SNOI	
	$\phi_o$	$\theta_o$	$\phi_o$	$\theta_o$
Case 1*	0°	0°	0°	45°
Case 2	45°	30°	45°	60°

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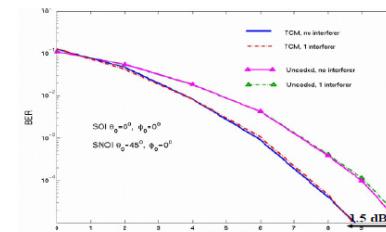
## Trellis Code QPSK Modulation over AWGN Channel

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



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## 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.

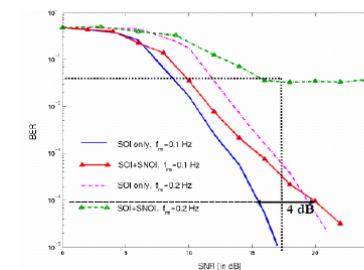
(Symbol duration:  $T = 10$  ms)

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Rayleigh Fading-Binary/Uncoded Channel



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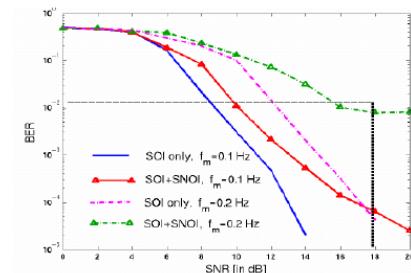
- BER for trellis coded QPSK modulation over Rayleigh fading channel with Doppler spreads of  $f_m = 0.1$  Hz ( $f_m T = 0.001$ ) and  $f_m = 0.2$  Hz ( $f_m T = 0.002$ ) for both cases.
  - The length of the training symbol is 60 symbols and is transmitted periodically every data sequence of length 940 symbols.
- (Symbol duration:  $T = 10$  ms)

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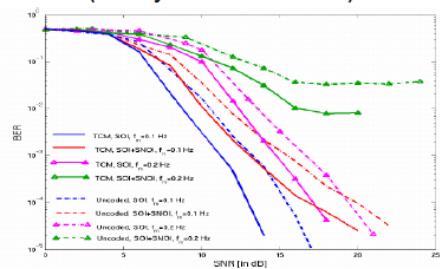
Rayleigh Fading Coded Channel (TCM )



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

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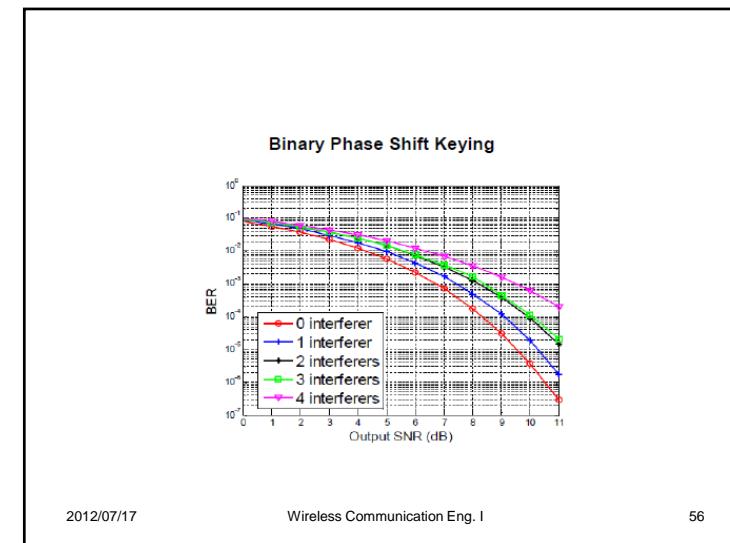
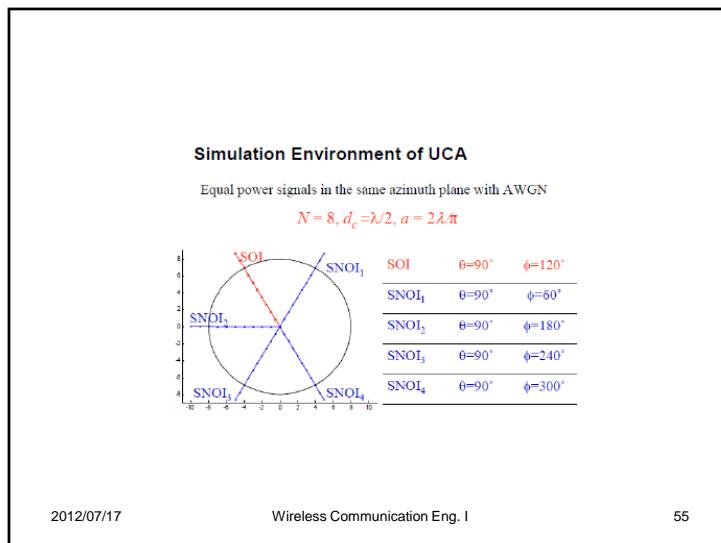
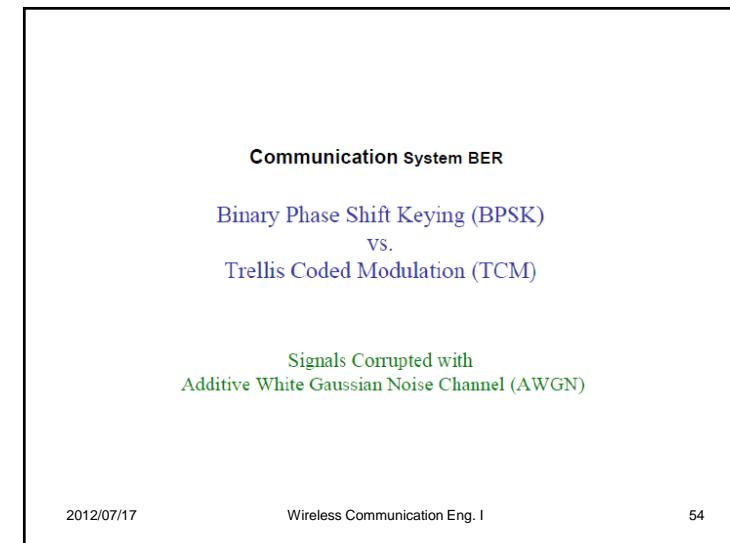
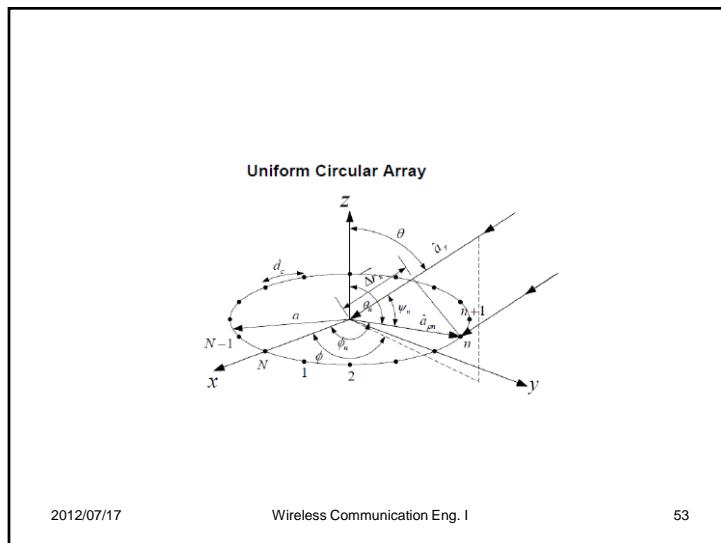
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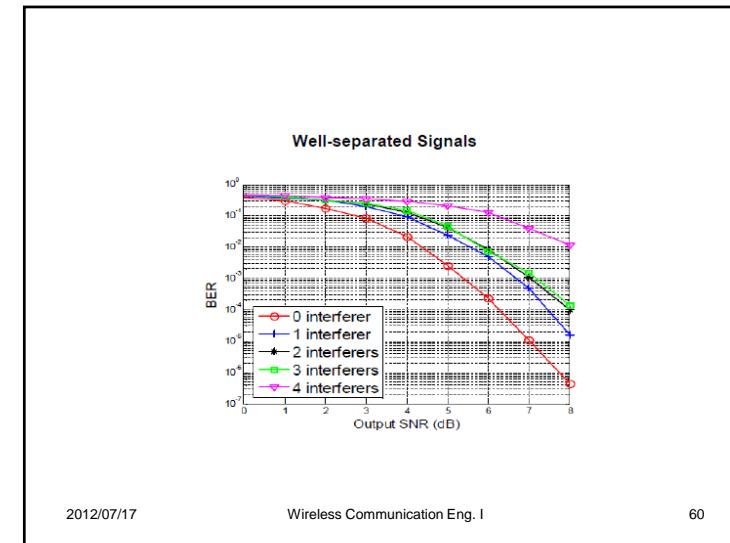
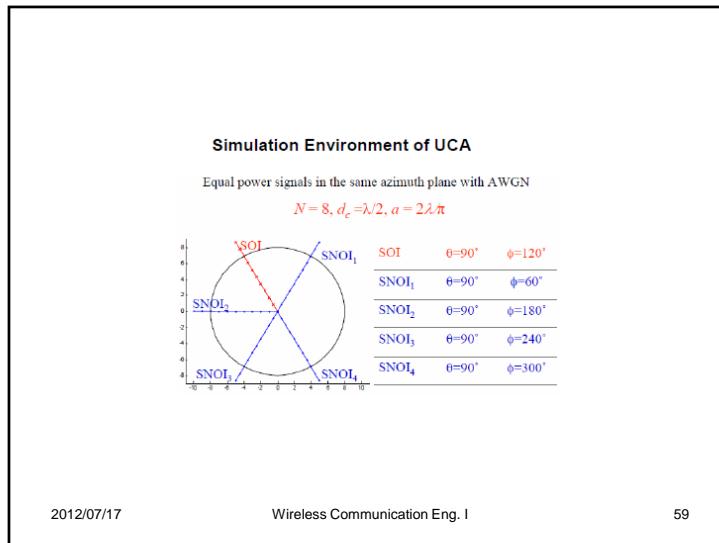
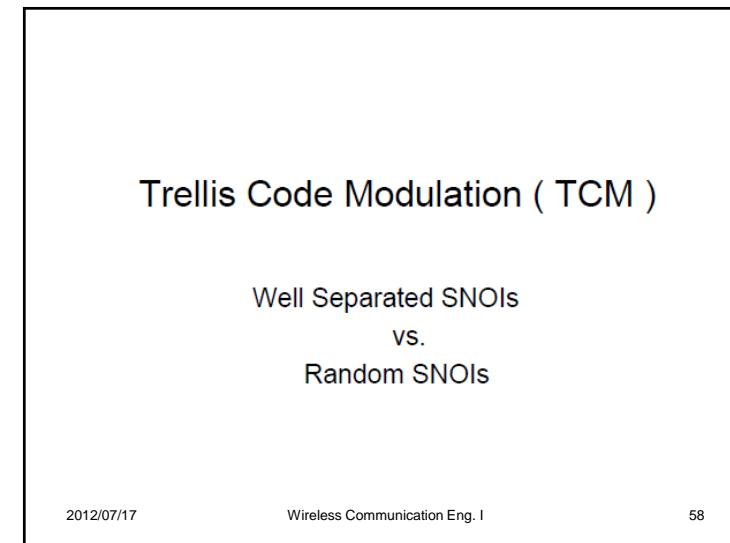
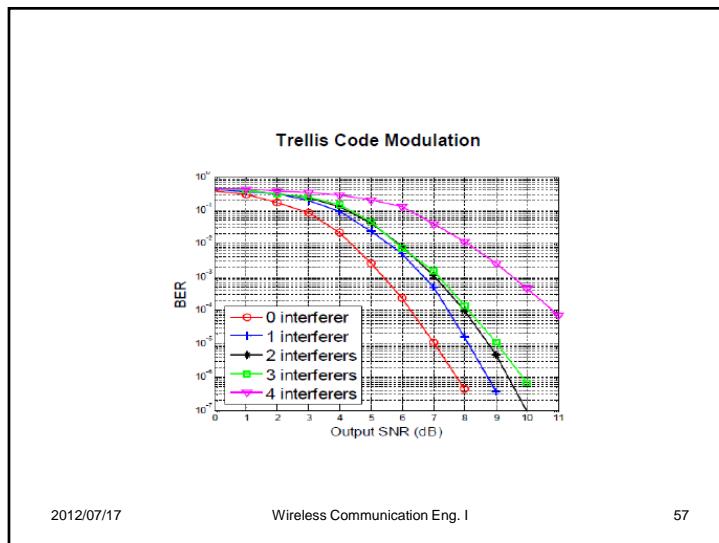
## Uniform Circular Arrays ( UCAs )

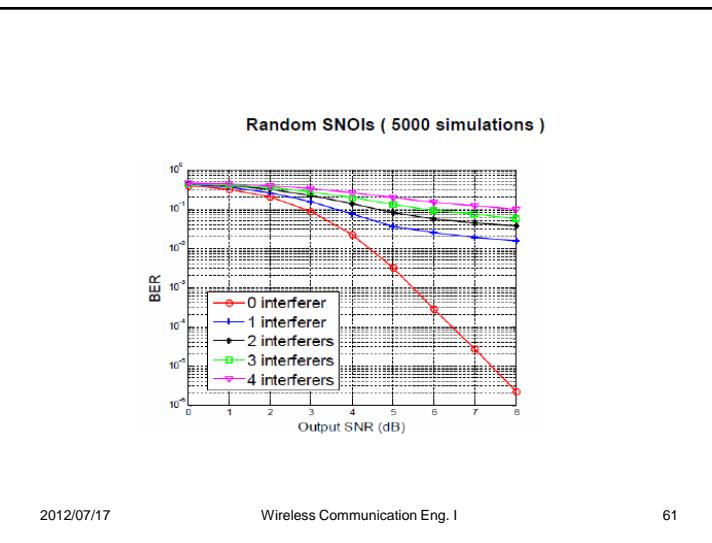
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**Conclusion**

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)*

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