Very High Spectral Efficiencies For Wireless Communications

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Outline

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- Need for Spectral Efficiency
- BLAST Technical Approach
- BLAST Capacity
- Indoor Experimental Result
- Outdoor Environment/Application
- VSNR
- Outdoor Data Collection
- Summary and Conclusions
- References

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Need

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- Growing Need for Wireless Capacity
  - More Uses and Applications
  - Each Application has More Users
  - Higher Data Rate Applications
    - Multimedia: Maps, Images, Video, etc
- Bandwidth is Limited
  - Finite Amount Provided by Nature
  - Limited Propagation Distances at Higher Frequencies
- Only Solution is Higher Spectral Efficiency:
  - More *bits/sec per Hz*

BLAST (Bell Labs Layered Space Time): Applying Processing Power for Greater Capacity

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- Currently, wireless systems operate at low spectral efficiency because imperfect channels cause signal variations
- Using multiple transmit/receive antennas permits sampling the propagation channel many ways, potentially yielding multiple parallel data channels
- Extensive signal processing on arrays can improve effective capacity by **10-100 times** by exploiting propagation channel differences

BLAST: Uses Multipath Environment to Increase System Capacity

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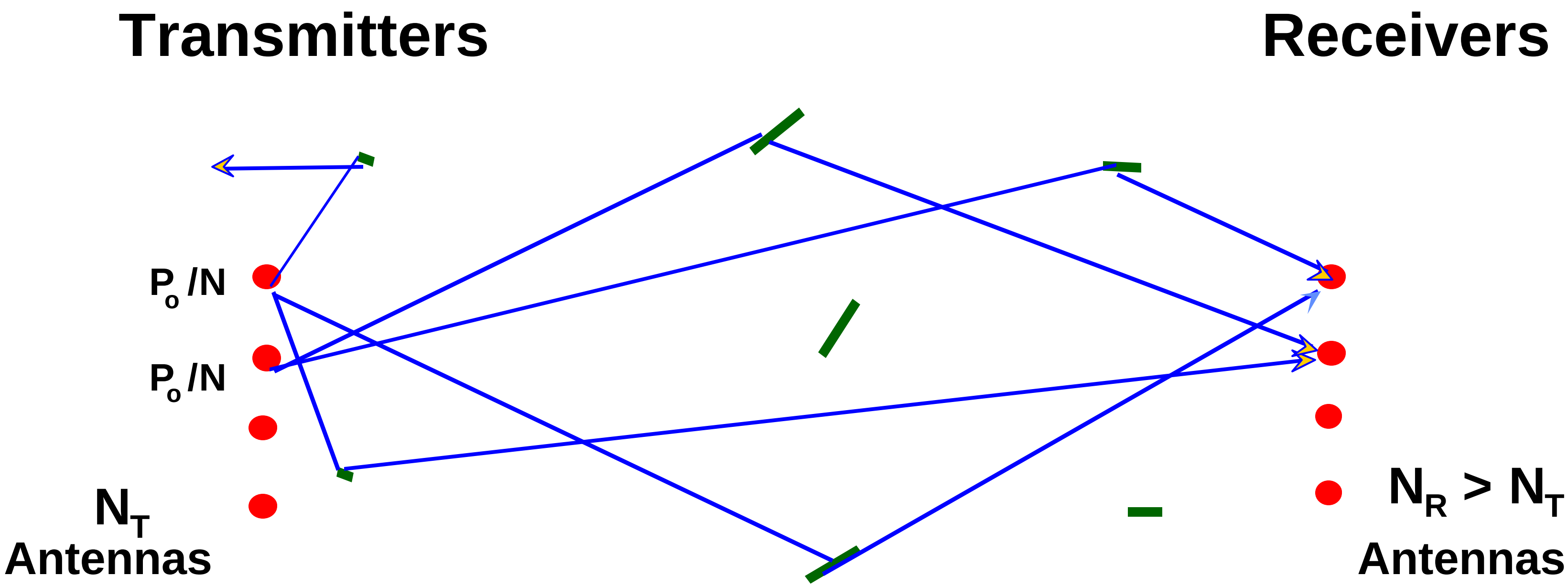

Scattering decorrelates multipath signals
Multiple, independent parallel channels
Complementary to narrow beamforming systems

BLAST: Multiple Transmit and Receive Antenna System

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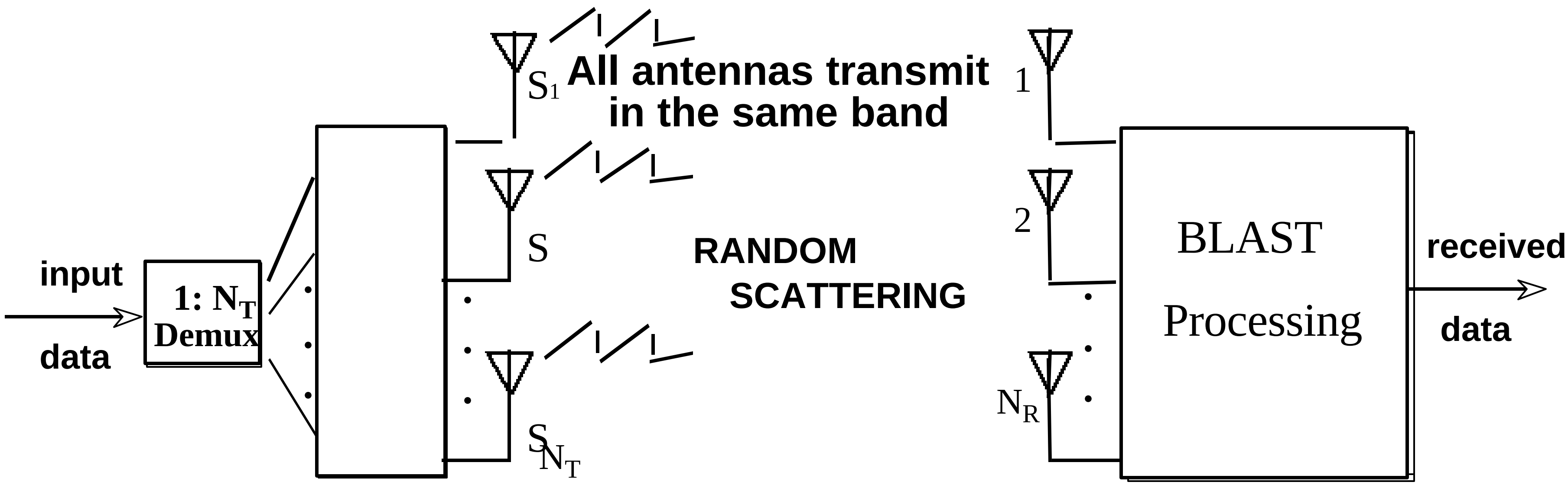

Total Power is constant (P/N_T), bit rate constant on each channel R_b
(The N_T-fold self-interference is a minor degradation.)

$$RATE \approx N_T x\, R_b$$

CAPACITY INCREASES LINEARLY WITH N_T.

BLAST Capacity

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Size of Transmit Array	n_T	Number of antenna elements in Transmit Array
Size of Receive Array	n_R	Number of antenna elements in Receive Array
Channel Matrix	$\boldsymbol{T}$	The voltage, T_{km} received at the kth element in the receive array due to a unit current in the mth element in the transmit array
Normalized Channel Matrix	$\boldsymbol{H}$	In order to incorporate the absolute attenuation into a signal-noise-ratio term a new matrix is defined as $\boldsymbol{H} = B\boldsymbol{T}$, where B is chosen so that the average of $\lvert H_{km}\rvert^2$ over all the matrix elements is unity
Noise Level	N_0	The noise on each receive element is assumed to be additive iid (independent identically distributed) gaussian noise of power N_0
Signal-to-Noise Ratio	ρ	With a signal of power, P_T, transmitted from each element, one at a time, the signal to noise ratio averaged over all k-m combinations of signal paths is: $\rho = \frac{P_T}{N_0 \lvert B\rvert^2}$ where $\lvert B\rvert^2 = \frac{n_T \cdot n_R}{\sum_{\text{All}\,k,m} \lvert T_{km}\rvert^2}$.
Capacity	C	The capacity in bps / Hz is $C = log_2 \{ det [I + (\rho / n_T) * \boldsymbol{H}\boldsymbol{H}'] \}$

Key Points and Basic Assumptions

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- Number of Receivers N_R > Number of Transmitters N_T
- Individual transmitter powers scaled by $1/N_T$
    - Total radiated power remains constant,
      independent of the number of transmitters, N_T
- Transmitted substreams are independent
    - BLAST is *not* transmit diversity
- Transmitters operate co-channel symbol-synchronized
- Burst mode operation:
    - Channel estimated during each burst via a training sequence
- Propagation environment:
    - Flat fading over symbol bandwidth
    - Stationary over burst duration

Receiver Signal Processing Overview

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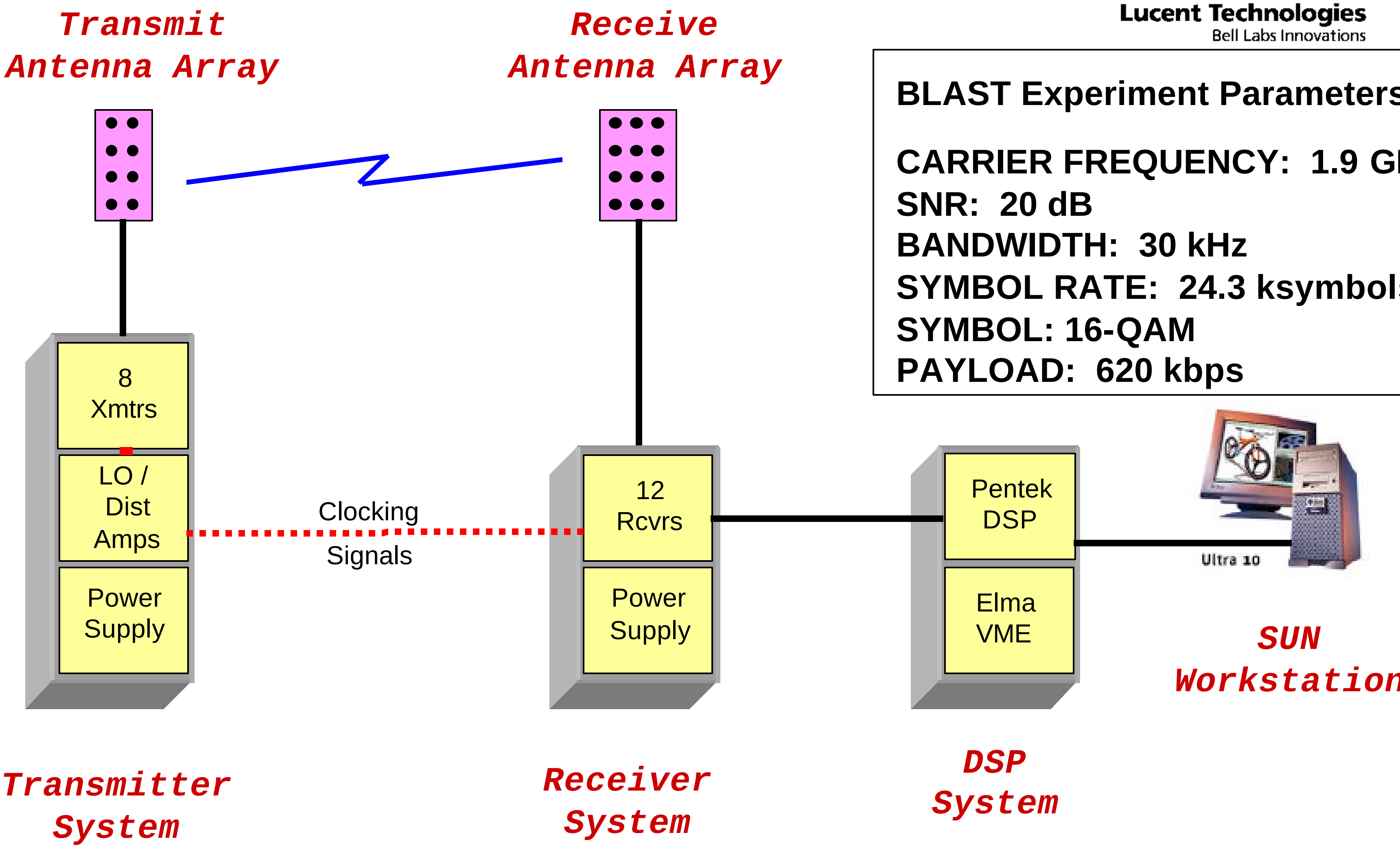
- In the real world sub-channels interfere with each other so must operate on all receivers simultaneously to extract each sub-channel

- Basic Idea: treat each sub-channel as “desired” signal, rest as “interferers” and use Adaptive Antenna Array - like techniques to detect each (i.e., linear combinatorial nulling)

- As with Adaptive Antenna Array processing, the degree of correlation between “desired” and “interferer’ vectors determines noise enhancement, hence ultimate performance. Rich Scattering $\Longrightarrow$ low correlation

- BLAST detection exploits sub -channel synchronism, permitting symbol cancellation and ordering as well as linear combinatorial nulling to be used
    - Leads to high performance esp. at higher SNRs



BLAST Experiment Parameters

CARRIER FREQUENCY: 1.9 GHz
SNR: 20 dB
BANDWIDTH: 30 kHz
SYMBOL RATE: 24.3 ksymbols/sec
SYMBOL: 16-QAM
PAYLOAD: 620 kbps

INDOOR BLAST EXPERIMENT (Reference 3)

DARPA NGI Objectives

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- Demonstrate high spectral efficiency in outdoor environment using BLAST by:
  - Understanding impact of outdoor multipath environment on BLAST
  - Developing approaches for outdoor implementation of BLAST
- Develop approach to show how BLAST can be scaled up to gigabit/sec rates

DARPA NGI Program Approach

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- Perform propagation measurements in outdoor environments to assess suitability of BLAST for Fixed wireless applications
  - City, Suburbs, Open terrain
  - Suitable Geometries, Distances, Antenna Heights, Frequencies
- Extend concept to wide bands via multi-channel techniques, e.g. Orthogonal Frequency Division Multiplexing (OFDM)
  - Show scalability to gigabit/sec data rates
- Define, prototype and demonstrate BLAST in outdoor environment

Outdoor Application of BLAST

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- Need High Capacity Links Outdoors (Over 1 km in Range)
- BLAST Depends on Multipath Propagation to Work
- Outdoor Multipath Propagation is Very Different from Indoors
  - More Discrete
  - Anisotropic (different correlation in x, y, z)
  - Wider Dynamic Range in Partitioning Intensity
  - Longer Path Differences, Time Spread
  - Potentially Different Dynamics
  - Different Correlation Bandwidth (Flat Fading)
- Need to Understand Environment, Geometry and BLAST to Achieve Outdoor Spectral Efficiency

BLAST in the Near Field

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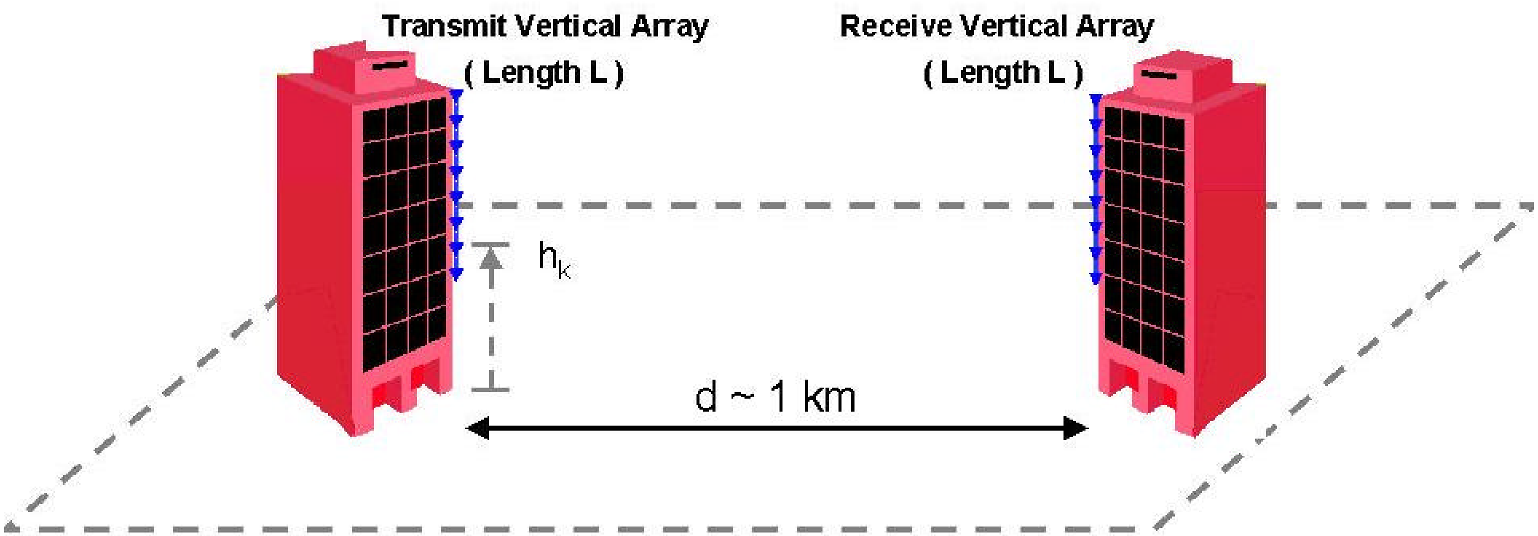

Sample Calculation at 28 GHz

d = Link Distance	= 1 km
L = Array length	= 6.4 meters
$\boldsymbol{m}$ = Curvature parameter $= 2L^2/(\lambda d)$	~ 8
n_T = Number of Transmit Array Antennas	= 16
n_R = Number of Receive Array Antennas	= 16

Height above the ground plane of the bottom of each array = 14.4 meters

(about a 4-th story building level).

Near Field BLAST Capacity

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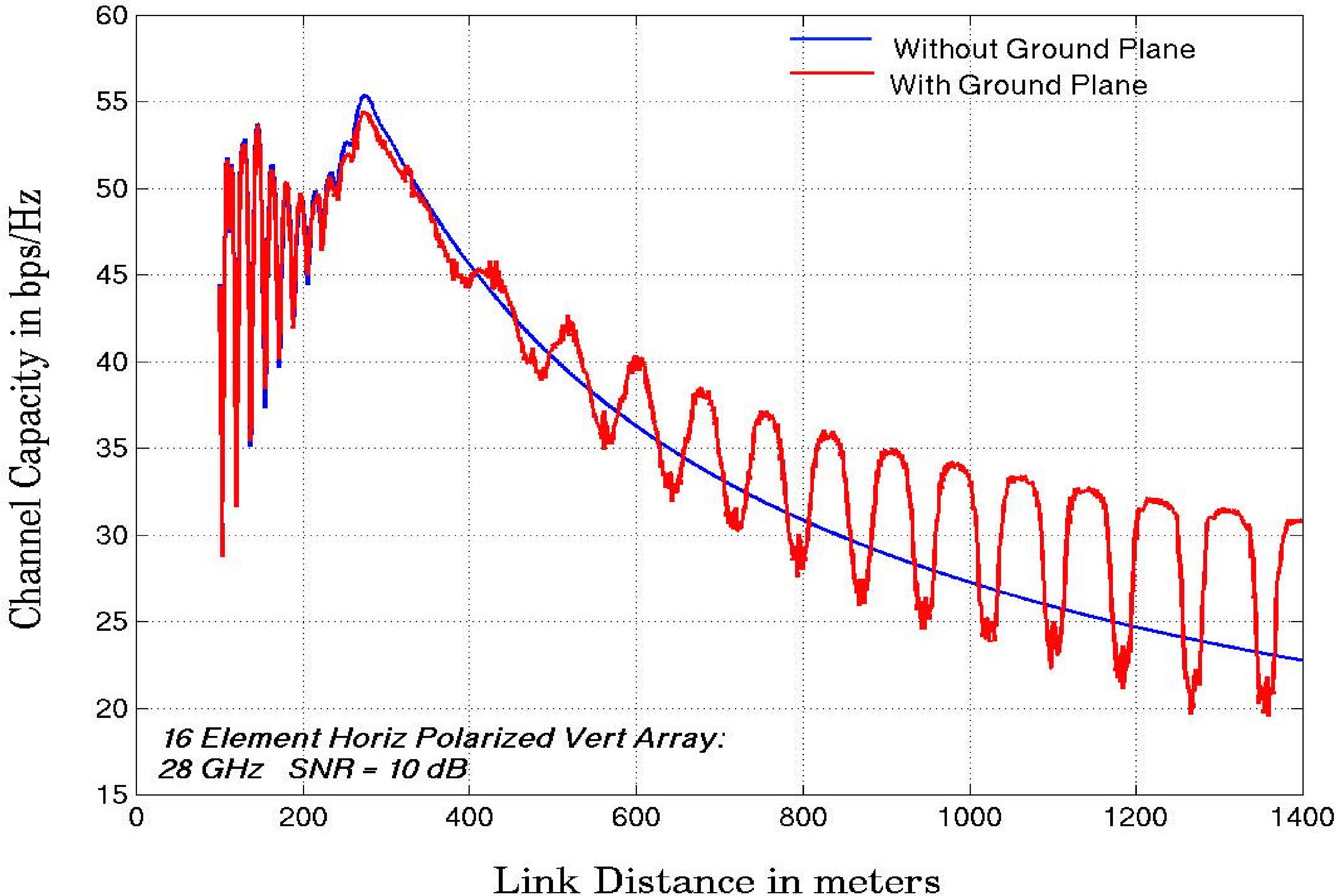

Vector Space Narrowband Radiometer (VSNR)

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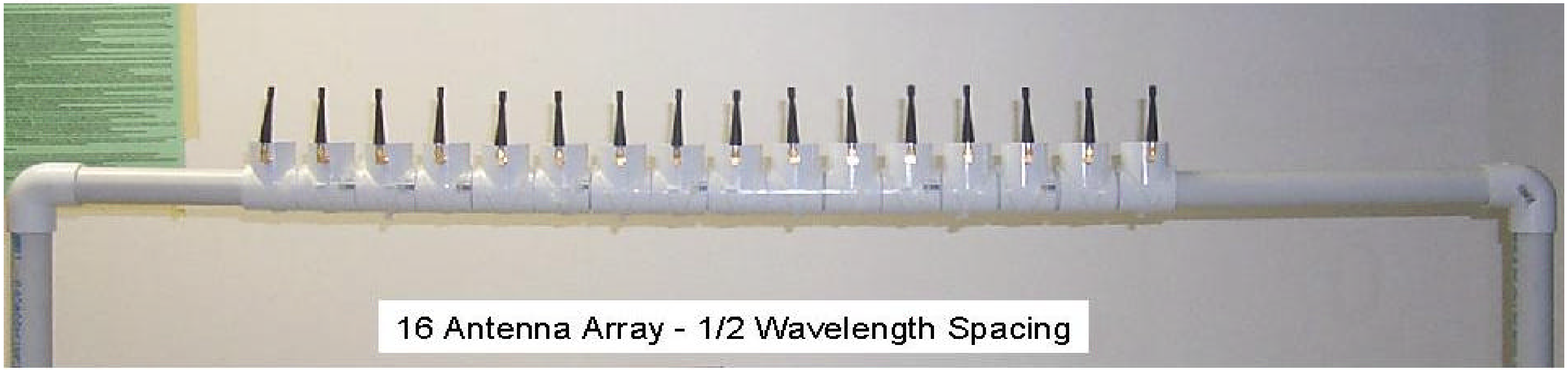
- Designed by Peter Wolniansky of Bell Labs
- 16 Transmit Elements (each with different tone)
- 16 Receive Elements
- Simultaneous Acquisition of 16 channels (I&Q)
- Data Monitoring
- Quick Look Analysis
- Beamforming
- Primarily 2.4-2.5 GHz
- Can Use Other Freqs.
- GPS Synchronized
- Field Portable

VSNR Antenna Array



- Flexible Antenna Array
  - Element Spacings from 1/2 to 4 wavelengths (16 elements)
  - Vertical or Horizontal Polarization
  - Two Horizontal and Vertical Orientation
  - Modular with Respect to Antenna Elements

Summary and Conclusions

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- Very High Spectral Efficiency Wireless Communications are Needed
- BLAST can Provide Very High Spectral Efficiency
- Need to to Understand Environment, Geometry and BLAST to Achieve Outdoor Spectral Efficiency
- New Area of Research Requiring New Measurement Systems, Analysis Approaches and Probably Yielding New Results
- Data Collection and Analysis to Support Outdoor Application of BLAST will be Soon Underway

References

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