Channel Measurements and Characterization for High Bandwidth Mobile Network MIMO links

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MNM project overview

- **Demonstrate** an adaptive ad hoc mobile network with very high spectral efficiencies using wide bandwidth (up to 25 MHz) MIMO links in a mixed open/forested environment
- **Location:** Naval Air Development Center, Lakehurst, NJ
- Demonstration using 20 SUVs equipped with 10 antennas
- SUV driven in 2 counter rotating rings over an area roughly 2 km by 4 km

MNM project goals

- 3 demonstration modes:
  - **1 MHz bandwidth**, 1 Mbps, using spectral spreading of 5, resulting in required physical layer spectral efficiency of 5 bits/sec/Hz
  - **10 MHz bandwidth**, 10 Mbps, spectral spreading of 5, resulting in required physical layer spectral efficiency of 5 bits/sec/Hz
  - **25 MHz**, 600 Mbps, required spectral efficiency of 24 bits/sec/Hz

Lucent approach

- Deploy **8×10 MIMO** terminals
- Use DSSS for 1 MHz and 10 MHz, using correlators, followed by a VBLAST “virtual antenna” processor. QPSK
- Use **OFDM** with 15 kHz frequency bins. Use VBLAST per frequency bin. Up to 64 QAM
- Permitted transmit power is **5 Watts** average power/antenna for a total radiated power of 40 Watts from each terminal

Objectives/Challenges

Key issues in channel characterization

- **Path loss** and **ambient noise** determine SNR, interference levels, and achievable rates
- **Frequency selectivity** impacts wideband system performance, determines spectral width of each OFDM sub channel, length of the cyclic prefix, number of rake fingers
- **Spatial richness** determines the number of spatial degrees of freedom supported by the channel, optimum antenna placement.
- **Temporal channel variation** impacts the frequency at which the channel needs to be measured and channel estimation methods
- Develop **simplified MIMO channel models**

Technical approach

- **Frequency selectivity**: Measure wideband 1×1 channels to get power delay profile, delay spread.
- **Spatial richness**: Collect narrowband 8 × 10 H-matrices to compute capacities, effective degrees of freedom, correlations, effective antenna spacing and arrangements.
- Combine spatial and delay profile measurements to construct a **wideband MIMO channel model**
- **Path loss** and **ambient noise** measurements to assess SNR and interference levels
- **Temporal variability** measurements collected while stationary to get channel coherence times

Spatial channel characterization

- **Measure** narrowband H-matrices while moving the receiver in the vicinity of a way point.
- Compute transmitter and receiver antenna **correlations** as a function of antenna separation and disposition (perpendicular and parallel to the vehicle).
- Determine optimal antenna **separation** and **disposition**.
- Determine number of effective transmit antennas
- Compare capacities of synthetically generated H-matrices to the capacities of measured H-matrices as a test for keyholes:
  – Is there capacity pinching somewhere else in the channel that cannot be remedied through proper antenna placement ?

Aspects of research interest

- First measurement campaign to determine wideband MIMO channel properties for
  - **Low antenna heights** (both antennas at ~ 2 meters)
  - **New environments**: Forested and open field areas with large obstructions
  - **New applications:** ad hoc networks with low access point antennas, tactical communications
  - No recognized models exist for path loss, let alone MIMO channel properties !

Technical approach

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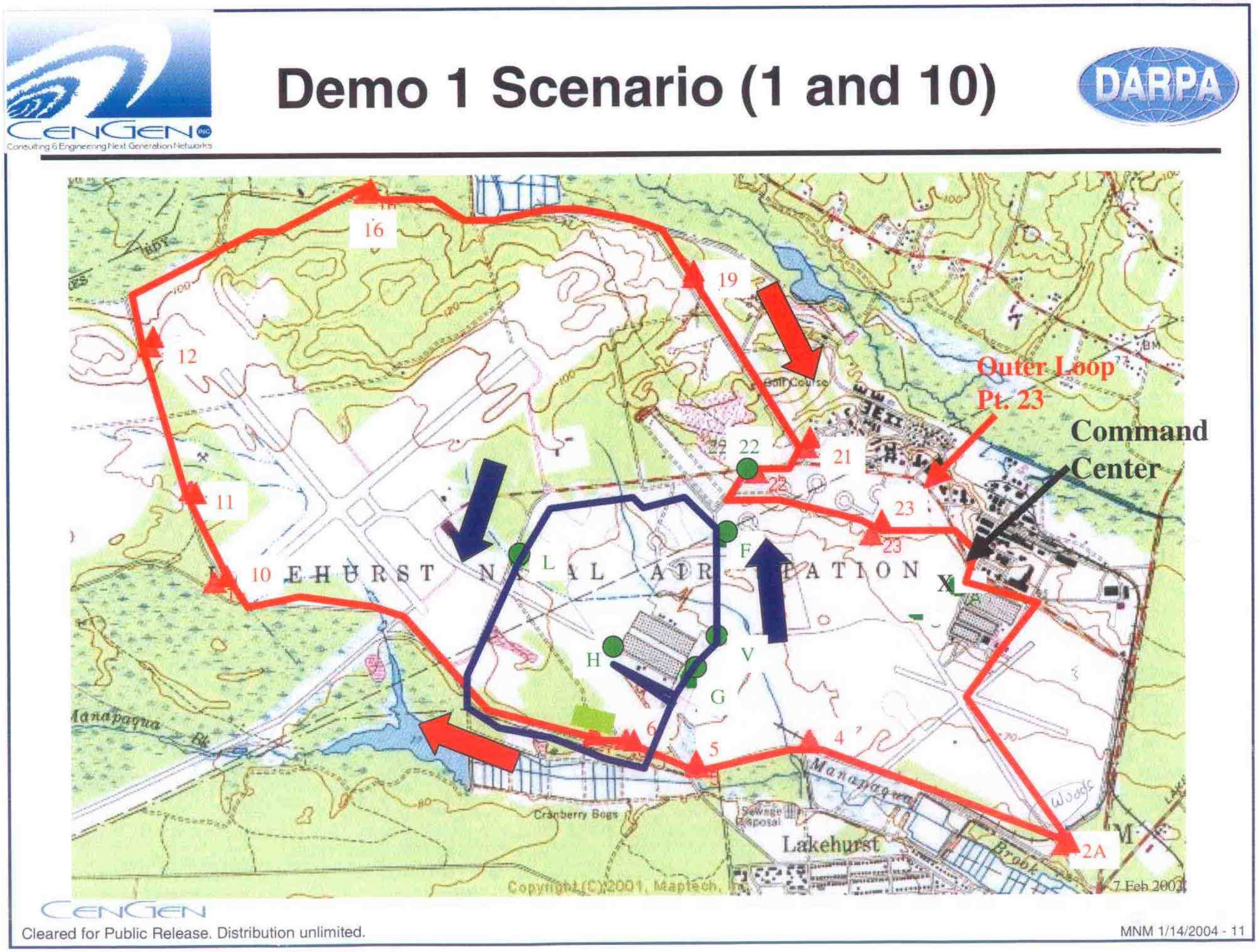
Lakehurst site



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Channel sounding equipment

- Measurements collected at **2.5 GHz**
- **Wideband** sounder, 6 W of transmit power over 6 MHz bandwidth.
- **Narrowband 8×10 H**-matrix measurements
  - Narrowband 8-antenna transmitter, emitting a 1 Watt CW signal from each antenna.
  - Narrowband 10-antenna receiver, with ten dedicated I/Q receiver chains, minimum integration window of 1.5 ms.
  - 6 dBi azimuthally omnidirectional antennas

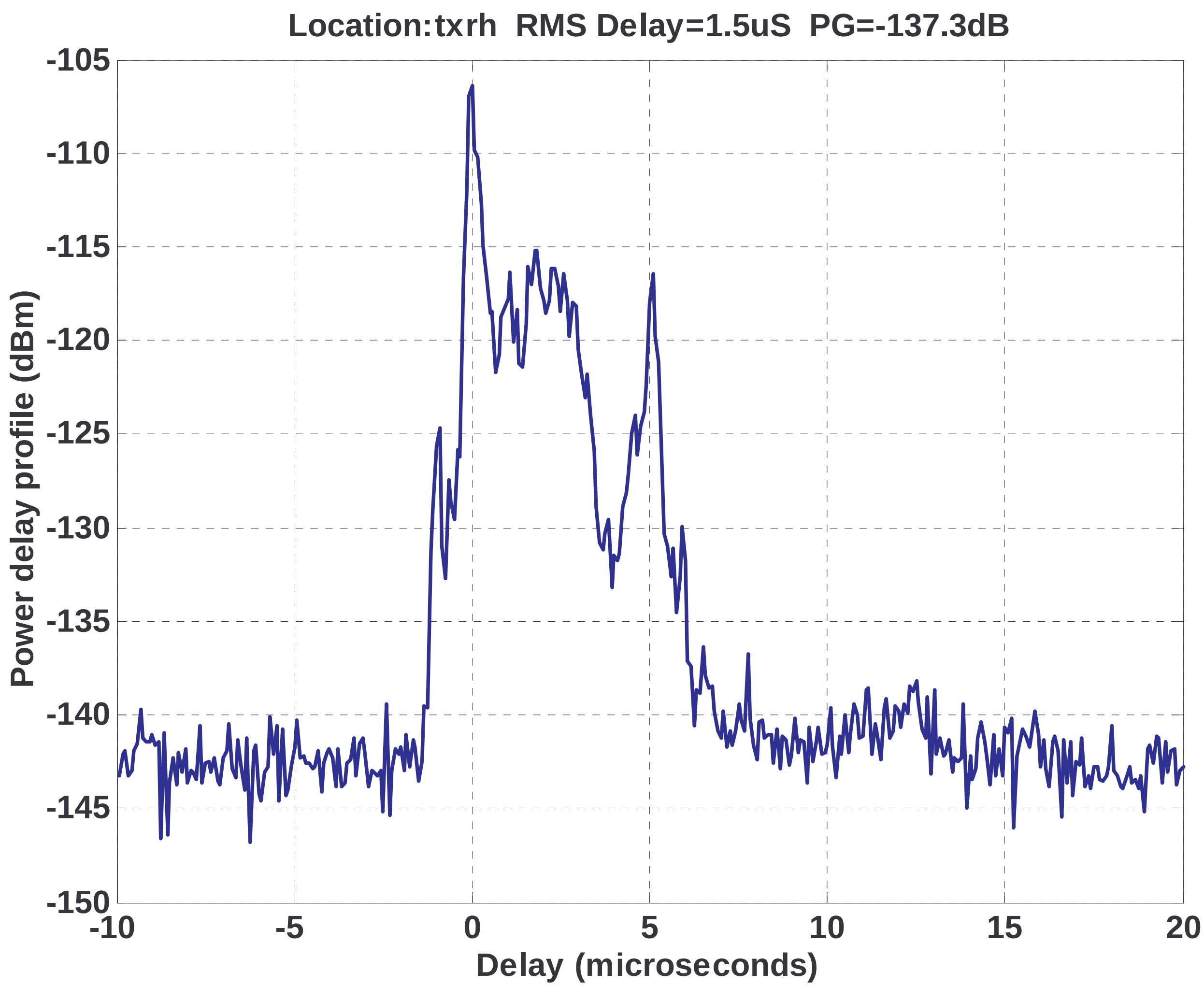
Narrowband MIMO Calibration

- VSNR up and running with all 16 receivers and 16 transmitters
- 16 by 16 Keyhole test on bench top using external frequency references (as opposed to Nova sources).
- C_{meas}=10.66 bps/Hz at 20 dB SNR.

  C_{theor}=log2(1+100*16)=10.64 bps/Hz at 20 dB SNR.
- Temporal stability (important for calibrated phased array measurements): assessed using a keyhole connection.
- Phase of received signals relative to 1st receiver used as a reference: difference between min and max phase deviations across receivers is 1.1 degree overnight.
- Transmitter phase changed randomly overnight. (DDS sources not synced)
- Short term stability: No measurable phase difference (to 5 decimal places) on any channel after 10 minutes.

Power delay profile (low delay)

Power delay profile (high delay)



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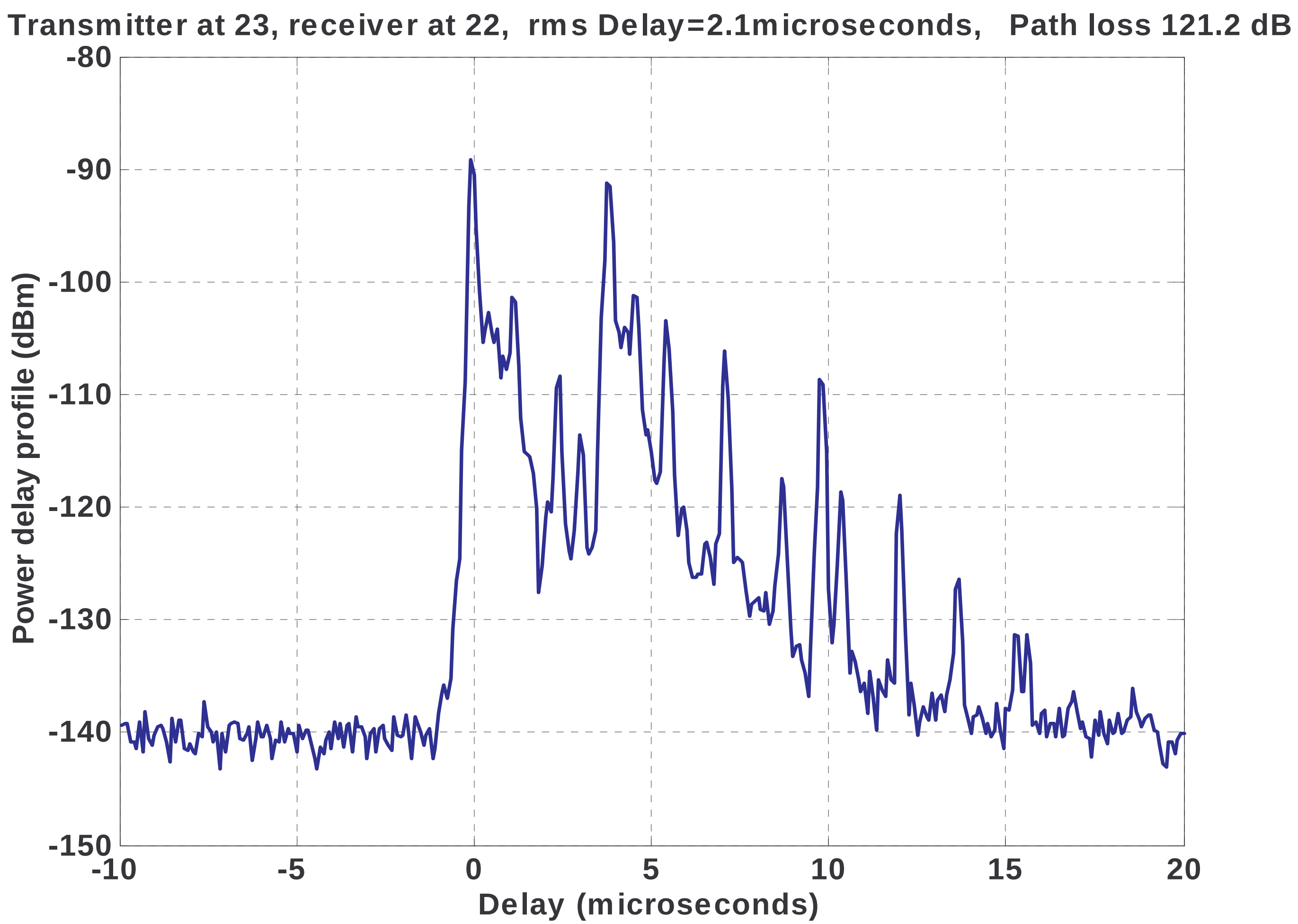
Power delay profile (very high delay)



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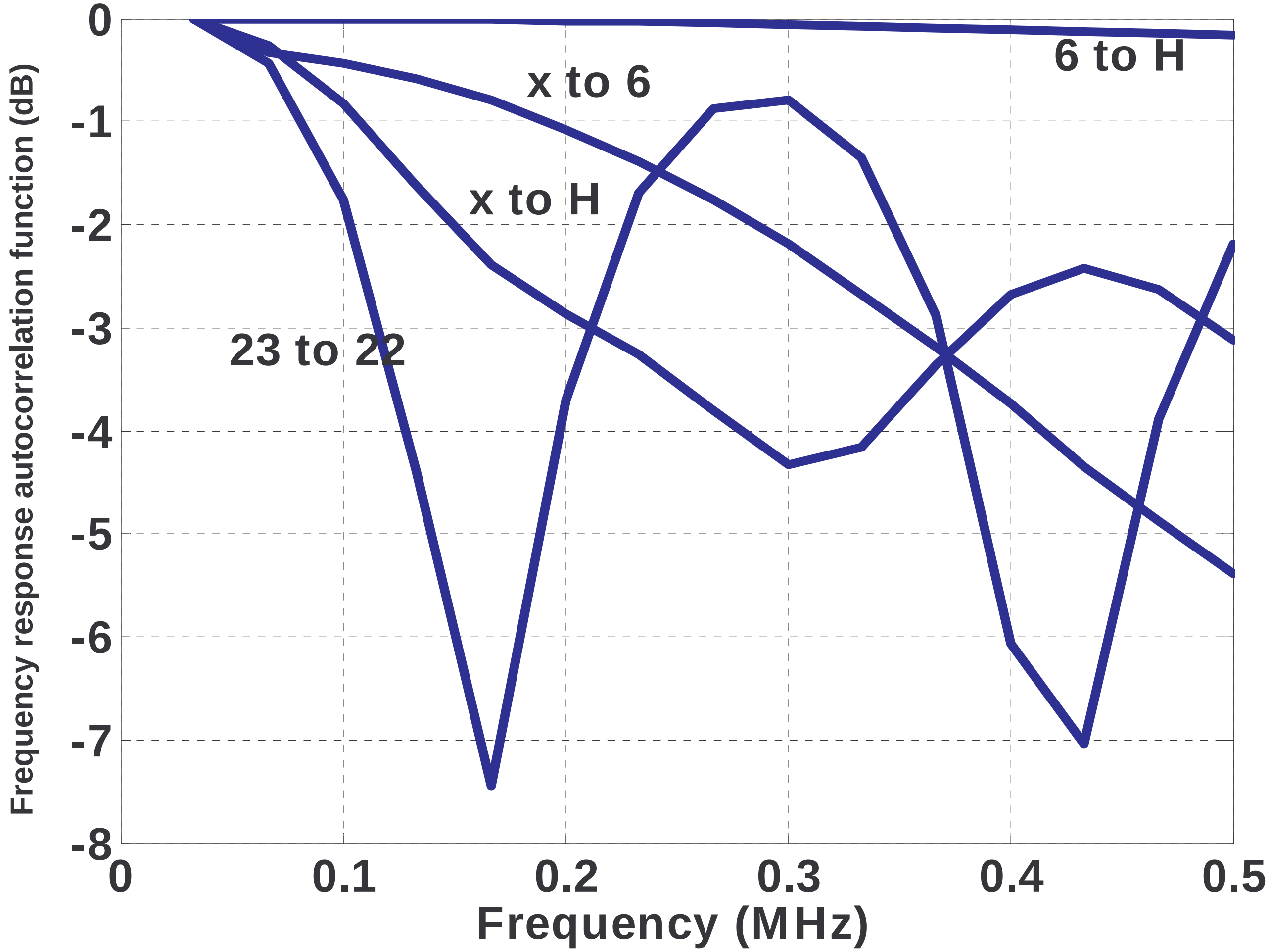
Frequency coherence



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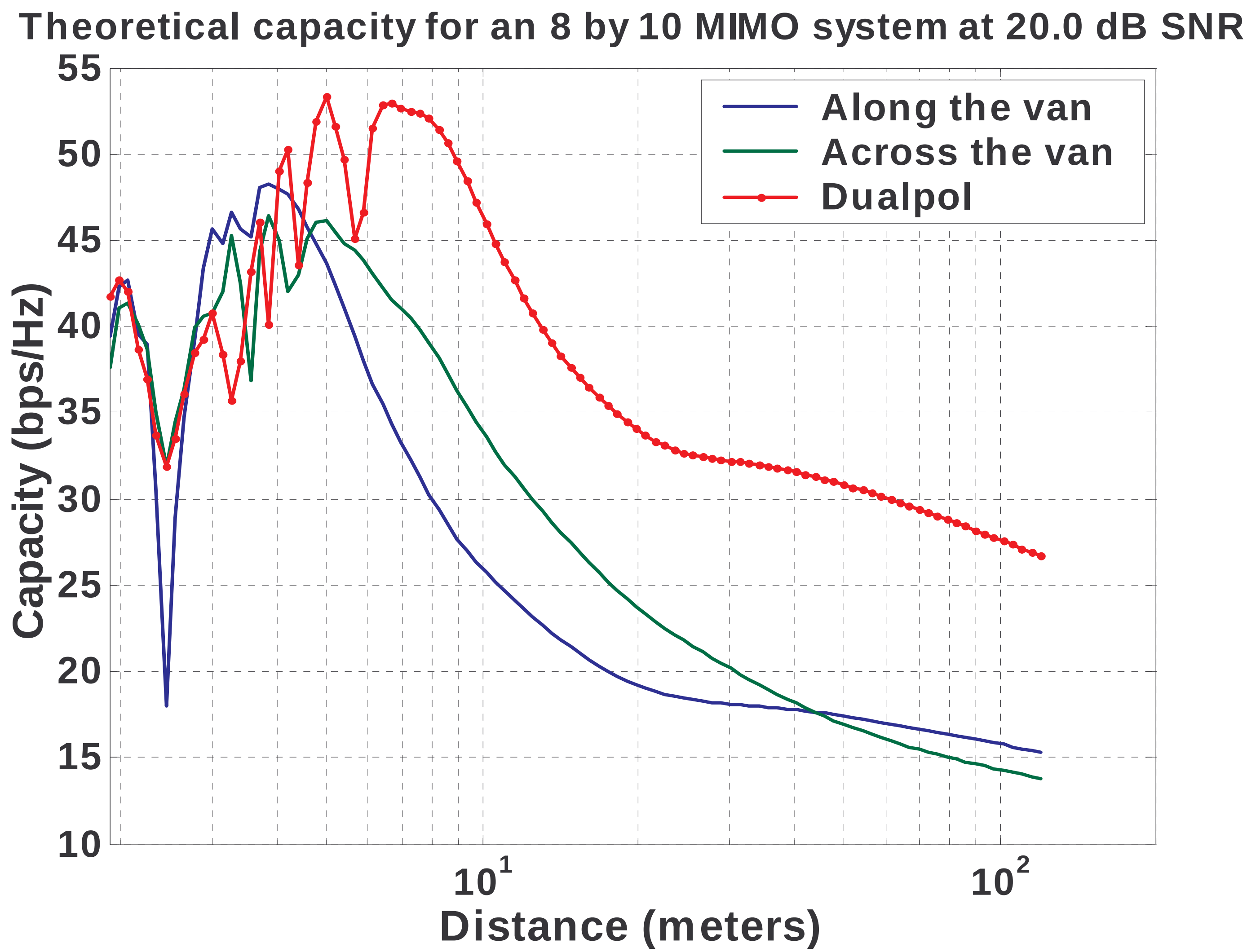
Wideband data for the inner ring

Transmitter location	Receiver location	Measured SNR(dB)	Path Gain(dB)	rms delay spread (µs)	Received power (dBm)	90% delay span (µs)	95% delay span (µs)
Parking lot	Parking lot at 10 m	79.6	-58.5	0.08	-59.5	0.3	0.3
X	F	75.4	-101.9	0.27	-62.9	0.8	0.8
X	V	66.9	-106.9	0.33	-67.9	0.9	0.9
X	G	67	-101.5	0.13	-62.5	0.3	0.3
X	H	43.5	-137.3	1.45	-98.3	5.4	5.5
X	L	46.6	-133.4	1.05	-94.4	0.9	7.1
X	6	36.8	-144.3	0.57	-105.3	1.8	1.9
H	G	57.2	-121.9	1.15	-82.9	3.4	6
H	V	53.5	-127.1	1.36	-88.1	4.5	4.7
G	V	60.1	-87.9	0.34	-48.9	0.3	0.3
G	F	59.5	-118.5	0.89	-79.5	0.7	1
V	F	57.5	-116.4	1.71	-77.4	7.1	7.2
V	L	59.4	-120.7	0.6	-81.7	1.3	1.6
F	L	58.9	-119.2	0.86	-80.2	1.4	1.5
F	6	29.1	-151.5	1.59	-112.5	6.3	6.4
L	6	35.1	-145.6	0.69	-106.6	1.6	3.2
L	H	79	-95.6	0.12	-56.6	0.2	0.2
6	H	59.1	-121.2	0.1	-82.2	0.3	0.3
6	G	61	-120.1	0.19	-81.1	0.3	0.3
6	G	61	-120.1	0.19	-81.1	0.3	0.3
21	10	40.2	-142	0.82	-103	0.3	0.6
19	10	44.8	-132.8	0.79	-93.8	0.6	0.7
Parking lot	Parking lot at 13 m	78.4	-60.6	0.07	-61.6	0.2	0.2

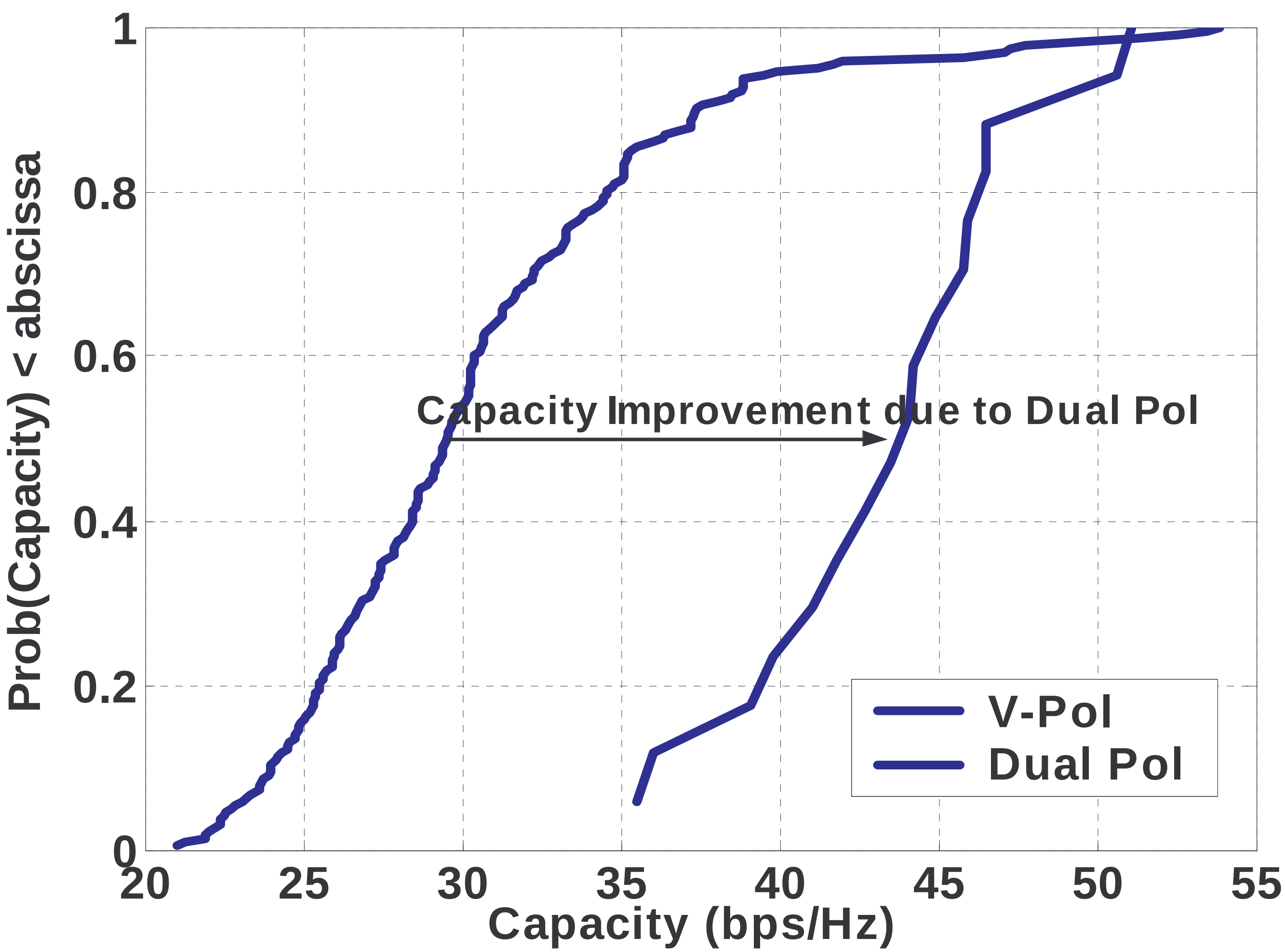
Wideband data for the outer ring

Transmitter location	Receiver location	Measured SNR(dB)	Path Gain PG(dB)	rms delay spread (µs)	Received power (dBm)	90% delay span (µs)	95% delay span (µs)
Parking lot	Parking lot at 10 m	78.1	-57.4	0.07	-58.4	0.1	0.2
4	2a	6.2	-172.9	0	-133.9	0	0
5	4	58.4	-120	0.06	-81	0.1	0.2
6	5	48	-131.6	0.32	-92.6	1.1	1.2
11	10	63.1	-114.6	0.07	-75.6	0.1	0.2
12	11	63.9	-90.7	0.08	-61.7	0.1	0.2
16	12	9.6	-170.2	0.04	-131.2	0.1	0.1
19	16	13.2	-165.9	0.08	-126.9	0.3	0.3
21	19	65.2	-102.8	0.08	-63.8	0.2	0.2
22	19	29.2	-151.9	3.53	-112.9	8.5	8.7
22	21	65.4	-100.6	0.11	-61.6	0.2	0.3
23	22	57.7	-121.2	2.11	-82.2	5.6	7.3
23	F	78	-90.6	0.17	-61.6	0.2	0.2
5	2a		<-173				
6	4	21.1	-159.6	0.1	-120.6	0.3	0.3
10	5	24.7	-157.2	0.33	-118.2	0.9	1
10	6	12.9	-160.4	0.98	-121.4	2.2	2.2
11	6		<-173				
12	10	50.5	-130.3	0.87	-91.3	0.3	0.6
16	11		<-173				
19	12	27.3	-153.7	1.57	-114.7	0.2	0.3
21	16		<-173				
F	21	47.7	-125.1	1.52	-86.1	6	6.1
23	21	63.4	-115.6	0.72	-76.6	0.3	4.3
2a	22	15.1	-166.3	0.15	-127.3	0.4	0.4
2a	F	22.4	-158.1	0.35	-119.1	1.5	1.5
2a	23	34.8	-145.3	0.35	-106.3	1	1
11	L	33.5	-146	1.12	-107	4.4	5.3
12	L	44.5	-136.2	0.99	-97.2	5	7.1

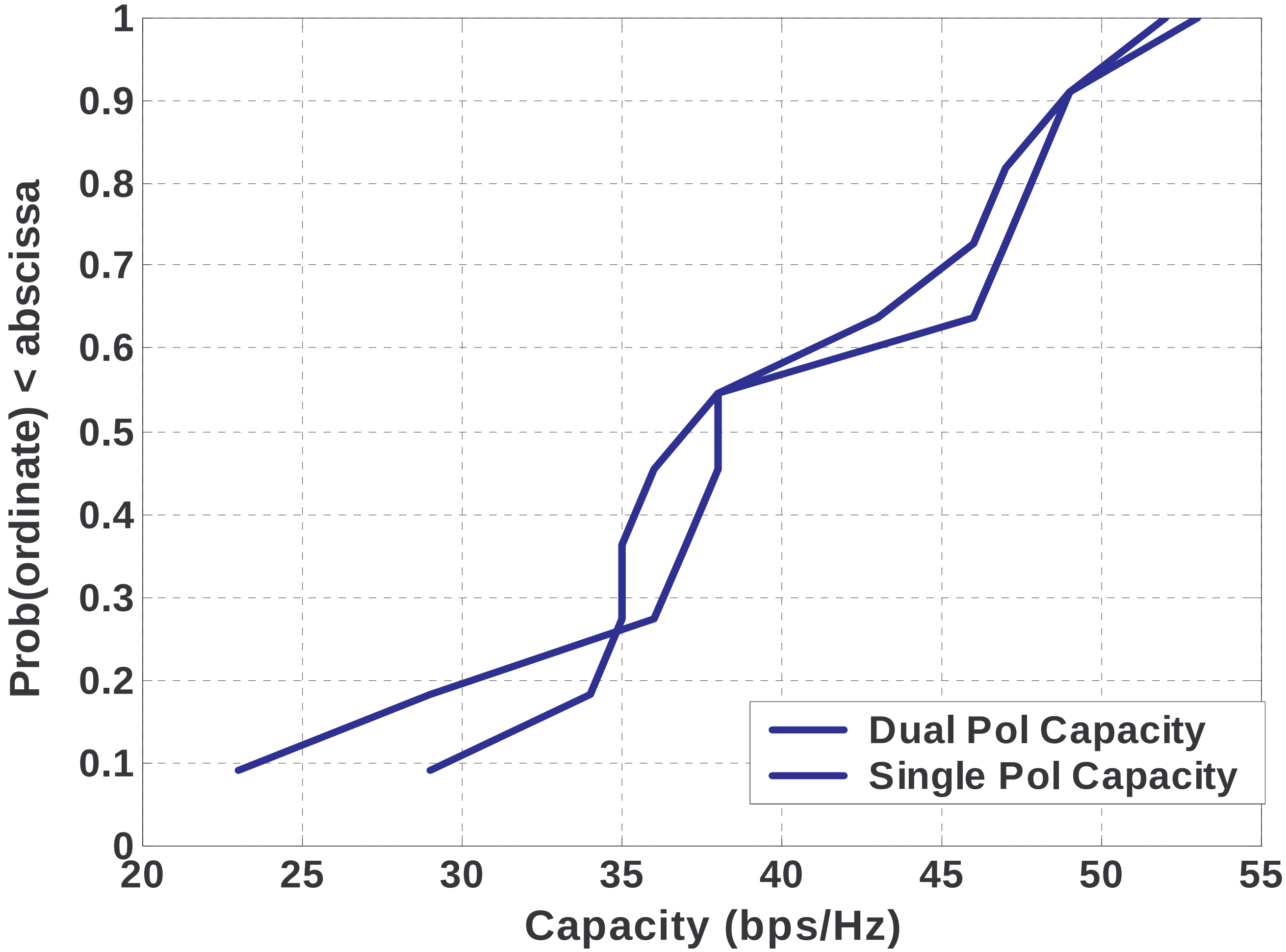
Capacity in free space



LOS 8×10 MIMO capacity at 50 m, 23 dBm



Measured 8×10 capacities for long range links at 23 dB SNR



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Summary

- **Extensive MIMO measurements** in rural wooded/open areas conducted using **ground level** platforms.
- Median rms delay spread of about 0.3 μsec, 90% of delays below 1.5 μsec.
- Median 8×10 MIMO capacities at 23 dB SNR found to be generally high:
  - **Long range links median capacity** of **37 bps/Hz** (65 % of corresponding Rayleigh *iid* capacity)
  - **LOS links median capacity** of **44 bps/Hz** (77 % of corresponding Rayleigh *iid* capacity)
- Use of **dual polarization** has been found to increase capacity in LOS links by over 50%.