MIMO Capacity for UWB Channel in Rectangular Metal Cavity

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Outline

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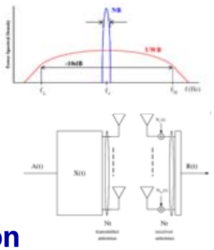
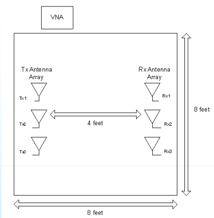


Introduction

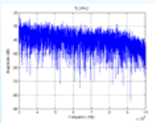
- Confined Metal Environment:
  - intra-ship
  - intra-vehicle
  - intra-engine
  - manufacturing plant
  - assembly line
  - nuclear plant

- The channel characteristics in such an environment are different from those in the traditional wireless communication environments.
- UWB technique is a competitive technology for wireless communication in confined metal environment.
- MIMO is an important breakthrough in the scientific research on wireless communication.

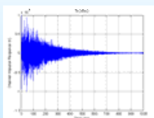
Channel Sounding



Parameter	Value
Frequency Band	3 GHz-10 GHz
Bandwidth	7 GHz
Number of Tones	7001
Transmission Power	10 dBm
Frequency Step	1 MHz
Antenna Polarization	vertical
Averaging Number	128
Antenna Height	1.35 m



Channel Transfer Function



Channel Impulse Response

Capacity Calculation

- Spectrum Shaping Schemes
  - Water Filling
  - Time Reversal
  - Channel Inverse
  - Constant PSD

- Spectrum Efficiency

$$\frac{C}{W}=\frac{1}{W}\int_{f_0}^{f_1}\log_2\det\left(\mathbf{I}_{N_r}(f)+\frac{\mathbf{H}(f)\mathbf{R_S}(f)\mathbf{H}^H(f)}{N_0}\right)df$$

Transmitted Power

$$P=\int_{f_0}^{f_1}\mathrm{tr}\left[\mathbf{R_S}(f)\right]df$$

TX SNR

$$\rho=\frac{P}{N_0 W}$$

Water Filling

$$\frac{C}{W}=\frac{1}{W}\int_{f_0}^{f_1}\log_2\det\left(\mathbf{I}_{N_r}(f)+\frac{\mathbf{H}(f)\mathbf{R_S}(f)\mathbf{H}^H(f)}{N_0}\right)df=\frac{1}{W}\sum_{i=1}^{N_t}\int_{f_0}^{f_1}\left(\log_2\left(\frac{\mu}{\lambda_i(f)}\right)\right)^+df$$

Time Reversal $\mathbf{X}(f)=\alpha\mathbf{H}^H(f)$

$$\frac{C}{W}=\frac{1}{W}\int_{f_0}^{f_1}\log_2\det\left(\mathbf{I}_{N_r}(f)+\frac{\mathbf{H}(f)\mathbf{R_S}(f)\mathbf{H}^H(f)}{N_0}\right)df=\frac{1}{W}\int_{f_0}^{f_1}\log_2\det\left(\mathbf{I}_{N_r}(f)+\frac{\rho W\mathbf{H}(f)\mathbf{H}^H(f)\mathbf{H}(f)\mathbf{H}^H(f)}{\int_{f_0}^{f_1}\sum_{i=1}^{N_r}\sum_{j=1}^{N_t}|H_{ij}(f)|^2df}\right)df$$

Channel Inverse $\mathbf{X}(f)=\alpha\mathbf{H}^H(f)\left[\mathbf{H}(f)\mathbf{H}^H(f)\right]^{-1}$

$$\frac{C}{W}=\frac{1}{W}\int_{f_0}^{f_1}\log_2\det\left(\mathbf{I}_{N_r}(f)+\frac{\mathbf{H}(f)\mathbf{R_S}(f)\mathbf{H}^H(f)}{N_0}\right)df=N_r\log_2\left(1+\frac{\rho W}{\int_{f_0}^{f_1}\mathrm{tr}\left[\left[\mathbf{H}(f)\mathbf{H}^H(f)\right]^{-1}\right]df}\right)$$

Constant PSD $\mathbf{R_S}(f)=\frac{P}{WN_t}\mathbf{I}(f)$

$$\frac{C}{W}=\frac{1}{W}\int_{f_0}^{f_1}\log_2\det\left(\mathbf{I}_{N_r}(f)+\frac{\mathbf{H}(f)\mathbf{R_S}(f)\mathbf{H}^H(f)}{N_0}\right)df=\frac{1}{W}\int_{f_0}^{f_1}\log_2\det\left(\mathbf{I}_{N_r}(f)+\frac{\rho\mathbf{H}(f)\mathbf{H}^H(f)}{N_t}\right)df$$

Capacity Bound

Water Filling Asymptotic Behavior

The lower bound of spectrum efficiency when the transmitted power is sufficiently large

$$\frac{C}{W}\approx N_t\left(\log_2\left(\frac{\rho}{N_t}\right)-\bar{\lambda}_{\log}\right)$$

The upper bound of spectrum efficiency when the transmitted power is sufficient small.

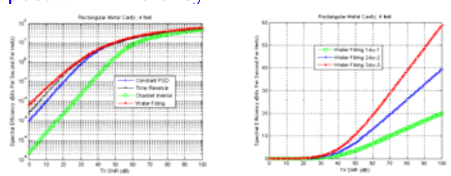
$$\frac{C}{W}\approx\frac{\rho}{\lambda_{\max}\ln 2}$$

Jensen's Inequality Bound

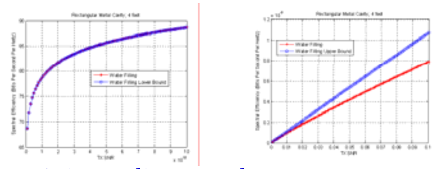
$$\frac{C}{W}=\frac{1}{W}\int_{f_0}^{f_1}\log_2\det\left(\mathbf{I}_{N_r}(f)+\frac{\mathbf{H}(f)\mathbf{R_S}(f)\mathbf{H}^H(f)}{N_0}\right)df\le\log_2\det\left(\mathbf{I}_{N_r}(f)+\frac{\int_{f_0}^{f_1}\mathbf{H}(f)\mathbf{R_S}(f)\mathbf{H}^H(f)df}{WN_0}\right)$$

Numerical Results

- Spectrum Efficiency



- Bounds of Water Filling



- Jensen's inequality Bound Error

Tx SNR	Time Reversal	Channel Inverse	Constant PSD
20	0.0325	0	0.0034
40	0.0610	0	0.0066
60	0.0867	0	0.0099
80	0.1101	0	0.0130
100	0.1318	0	0.0161

Conclusion

- The channel characteristics in confined metal environment make wireless communication challenging.
- UWB technique plus MIMO is a competitive candidate for wireless communication in rectangular metal cavity among possible technologies, because it can fully employ radio resources not only in frequency domain but also in space domain.

Slide 1

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