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Channel capacity of two-antenna BLAST architecture

S.L. Loyka

The BLAST architecture has been recently proposed as an extremely efficient tool for wireless communications in rich multipath environments. However, the channel capacity of the BLAST architecture strongly depends on the correlation between individual channels. The author reports an explicit closed-form expression of the channel capacity of a two-antenna BLAST architecture as a function of the channel correlation.

Introduction: The Bell Labs layered space-time (BLAST) architecture, which uses multiple antennas at both the transmitter and receiver, has been recently proposed as an extremely efficient tool for wireless communications in rich multipath environments [1 – 4]. Typical values of channel capacity of this architecture may be as high as 10–100 times those for traditional architectures. The BLAST channel capacity in the case of independent (uncorrelated) Rayleigh faded paths between antennas has been extensively investigated [1, 3]. In the general case of $n \times n$ channels and when the transmitted signal vector is composed of statistically independent equal power components each with a Gaussian distribution, the channel capacity is given by the following [3]:

$$C = \log_2 \det\left(\mathbf{I} + \frac{\rho}{n}\mathbf{H}\cdot\mathbf{H}^+\right) \quad \text{bit/s/Hz} \qquad (1)$$

where n is the number of transmit/receive antennas, ρ is the signal-to-noise ratio, **I** is an $n \times n$ identity matrix, **H** is the normalised channel matrix (for our consideration, we do not need a non-normalised channel matrix so we shall not consider it), and $^+$ represents the transpose conjugate. In the case of n independent identical channels **H** = **I** and

$$C = n \cdot \log_2\left(1 + \frac{\rho}{n}\right) \qquad (2)$$

For large n, this channel capacity is substantially higher than that of a traditional 1 × 1 channel (with the same total radiated power). However, the practical value of the BLAST channel capacity strongly depends on the correlation between paths (individual channels) [3] and may be substantially smaller in the case of highly-correlated channels. In this Letter, we consider a two-antenna BLAST architecture with correlated paths and report an explicit closed-form expression for the channel capacity as a function of the channel correlation.

Two-antenna BLAST architecture: We now consider the case of a two-antenna architecture with correlated channels:

$$\mathbf{Y} = \mathbf{H}\cdot\mathbf{X} \qquad (3)$$

where $\mathbf{X} = (x_1\ x_2)^T$ and $\mathbf{Y} = (y_1\ y_2)^T$ are the transmitted and received signal vectors, respectively, and T means transpose. Two antennas are used both at the transmitter and at the receiver. Since **H** is normalised,

$$\sum_{i,j=1}^{2} |h_{ij}|^2 = 2 \qquad (4)$$

Y and **X** are also normalised (h_{ij} denotes components of **H**). Since transmitted signals are uncorrelated, the correlation coefficient of received signals is

$$r = \frac{\langle y_1 \cdot y_2^* \rangle}{\sqrt{\langle y_1 \cdot y_1^* \rangle \langle y_2 \cdot y_2^* \rangle}} = \frac{h_{11}h_{21}^* + h_{12}h_{22}^*}{\sqrt{(|h_{11}|^2+|h_{12}|^2)(|h_{22}|^2+|h_{21}|^2)}} \qquad (5)$$

where ⟨ ⟩ denotes the time average, and * denotes the complex conjugate. The cause of correlation of the received signals is the correlation of the channels. Thus, r is also the correlation coefficient of individual channels (note that it depends on the channel matrix only).

For simplicity, we consider further the case of equal received powers (the case of unequal received powers can be considered in a similar way):

$$P_r = P_{r,1} = P_{r,2} = \langle y_1 \cdot y_1^* \rangle = \langle y_2 \cdot y_2^* \rangle \qquad (6)$$

In this case, eqn. 5 reduces to

$$r = h_{11}h_{21}^* + h_{12}h_{22}^* \qquad (7)$$

Using eqns. 1, 4 and 7, and after some mathematical development, we obtain

$$C = \log_2\left(1 + \rho + (1 - |r|^2)\left(\frac{\rho}{2}\right)^2\right) \qquad (8)$$

This expression gives the explicit dependence of the channel capacity on the channel correlation. Note that when $r = 0$ (independent channels), this equation reduces to eqn. 2 for $n = 2$, and when $r = 1$ (completely correlated channels), eqn. 8 reduces to the classical Shannon formula.

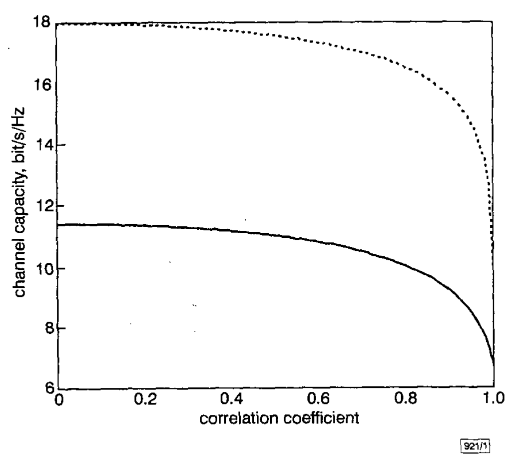

Fig. 1 *2 × 2 BLAST channel capacity against absolute value of correlation coefficient*

——— ρ = 20dB
– – – – ρ = 30dB

Fig. 1 shows the BLAST channel capacity against the channels' correlation coefficient for ρ = 20dB and ρ = 30dB. As we can observe from this Figure, the channel capacity decreases substantially for $|r| > 0.6 - 0.8$.

When the received signals have different powers, eqn. 8 can be generalised to

$$C = \log_2\left(1 + \rho + 4\beta(1-\beta)(1-|r|^2)\left(\frac{\rho}{2}\right)^2\right) \quad (9)$$

where

$$\beta = \frac{P_{r,1}}{P_{r,1} + P_{r,2}} \quad (10)$$

Using eqns. 9 and 10, we find that the maximum channel capacity is achieved for equal received powers ($\beta = 1/2$). Note that eqn. 9 reduces to eqn. 8 for $\beta = 1/2$, and to the classical Shannon formula for $\beta = 1$ or 0.

We should note that the considerations given above are general enough to take into account spatial path properties (multipath, etc.) and antenna characteristics as long as the channels are linear.

Conclusion: The equations given above enable us to analyse the dependence of the two-antenna BLAST architecture channel capacity on the channel correlation in a simple and general way, and to calculate the channel capacity using all the results about the spatial channel correlation obtained earlier (see, for example, [5, 6]). We state in conclusion two hypotheses regarding the $n \times n$ channel (with arbitrary n): (i) Its channel capacity is determined by a generalised form of eqn. 9:

$$C = \log_2\left(\sum_{i=0}^{n} a_i \left(\frac{\rho}{n}\right)^i\right) \quad (11)$$

where a_i are determined by the channels' correlation coefficients and by the relative channel powers; (ii) Maximum channel capacity is achieved for equal channel powers.

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Co-channel interference in high capacity fixed wireless loops (FWL)

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The importance of the incident power density pattern (IPDP) for future fixed wireless loop (FWL) systems is discussed. Also an investigation into some of the important S/I implications of the IPDP for proper system capacity simulations is presented

The increased demand for fast internet and other data services has resulted in severe bandwidth requirements for future fixed wireless loop (FWL) systems. These requirements could be met through very efficient reuse of the allocated bandwidth. Such a reuse could possibly be achieved via the use, at the base station, of highly directive (5–10°) scanning beams [1] in conjunction with fixed directive (15–25°) subscriber antenna beams. At each base station, multiple and non-overlapping scanning beams, with low sidelobes, simultaneously operating at the same frequency band can increase the frequency reuse many-fold. Such beams could help to reduce delay spread and co-channel interference. Scattering, diffraction, and multiple reflections of transmission from subscribers in actual environments could result in a wide angular spectrum of power incident on the base station, referred to as the incident power density pattern (IPDP). We discuss the IPDP and some of its important S/I implications for proper system capacity simulations.

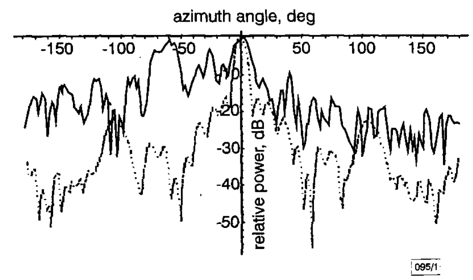

Fig. 1 *Azimuth radiation patterns of 8° dish antenna at 2.475GHz*

——— Measured dish antenna pattern on Red Bank to Crawford Hill, NJ 10.4km path
·········· Measured free-space dish antenna pattern

In Fig. 1 we compare the measured radiation patterns of an 8° dish in free space as well as in a 10.4km path. The sharp difference between the patterns strongly indicates that multiple narrow beams may strongly interfere with one another over a broad azimuth angular interval.

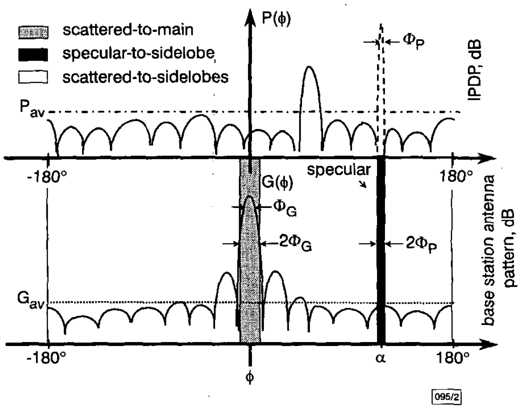

Fig. 2 *Base antenna radiation pattern $G(\phi)$ and incident power density pattern $P(\phi)$ against azimuth angle ϕ*

Free space antenna pattern and incident power density pattern (IPDP): Consider a narrow beam base station antenna pointing at $\phi = 0°$ in the azimuth direction. The free space radiation pattern of this antenna $G(\phi)$ has a 3dB beamwidth Φ_G and an average sidelobe level G_{av}. A subscriber, located at $\phi = \alpha$, is radiating to the base station antenna (uplink). The radiation incident on the base station is composed of specular rays, reflected rays, scattered and diffracted rays. The specular rays are typically associated with a narrow angular sector around the line-of-sight path. The reflected rays are caused by large structures that are not in the line-of-sight path. Vegetation and small structures cause the scattered and diffracted rays. For convenience, we shall refer to the total power of the reflected, diffracted and scattered rays as the scattered power. We designate the power density angular distribution, incident on the base station, as the incident power density pattern (IPDP) $P(\phi)$. In some environments power could be incident on the base station from practically every direction. The