Recovering handset MIMO capacity with polarization-agile antennas

David G. Landon*(1) and Cynthia Furse (2)
(1) L-3 Communications, Salt Lake City, USA
(2) University of Utah, Salt Lake City, USA

Introduction

Multiple Input Multiple Output (MIMO) communication systems rely on significant variation between multiple signal paths to create independent channels for communication. Transceiver signal strength to or from a portable handset is subject to large variations due to the "essentially random orientation" typical of their use [1] and the resultant polarization mismatch between the handset antenna and the impinging wavefronts. This work synthesizes an inexpensive solution to recover a significant fraction of these average capacity losses. Marrying the idea of antenna subset selection [2] and polarization agile antennas [3], one arrives at a polarization-selectable approach of great value both to MIMO systems and to single-input single-output (SISO) systems. This work demonstrates that the typical assumption of a receiver with fixed orientation is very inaccurate for predicting the capacity of handheld MIMO wireless devices. It corrects the standard MIMO normalization with the more appropriate reference array normalization for antenna comparisons. It demonstrates significant recovery of the capacity and diversity losses from parallel array element designs through switchable polarization-agile elements.

Recovering capacity

Two transmit and two receive antennas are placed in the planar Rayleigh-distributed simulated multipath environment described in [1]. The detected power (computed in simulation) of a "traditional model," consisting of a pair of perfectly polarization-aligned dipoles, is used to normalize each candidate array [4]. The transmit antennas are widely spaced (10-λ) to guarantee decorrelated fading. The receive antennas are spaced by $\lambda/2$ and each antenna is actually a polarization-agile design such as those depicted in Fig 1. Fig 1a is a "2-spoke", dual-fed patch design, Fig 1b is a "4-spoke" patch design depicting a straightforward extension to the design given in [3], and Fig 1c is a "4-spoke" dipole design, where the term "spoke" refers to the number of individually selectable polarization orientations.

The transmit elements have a fixed orientation, generating vertical-polarized energy. The receive array is aligned in "traditional model" simulations. In other "rotated" models, the receive array is oriented randomly as is typical of the way handsets are held. Received signals are measured at each antenna in each receive array in the same 30,000 simulated environments as detailed in [1]. For each measurement, a simple flat-fading model relating channel outputs, y, and inputs,

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x, as $y = Hx$ is assumed. Channel capacity for a 2x2 MIMO system is computed in this work via waterfilling [5] from the channel matrix, H. A best matrix, in the maximum capacity sense, is selected in each measurement by computing the capacity in an exhaustive search over each possible combination of one active spoke per polarization-agile antenna. A simpler technique based on activating the spokes with the strongest received signal strength was discarded for its inability to achieve maximum capacities over the ensemble of simulated measurements.

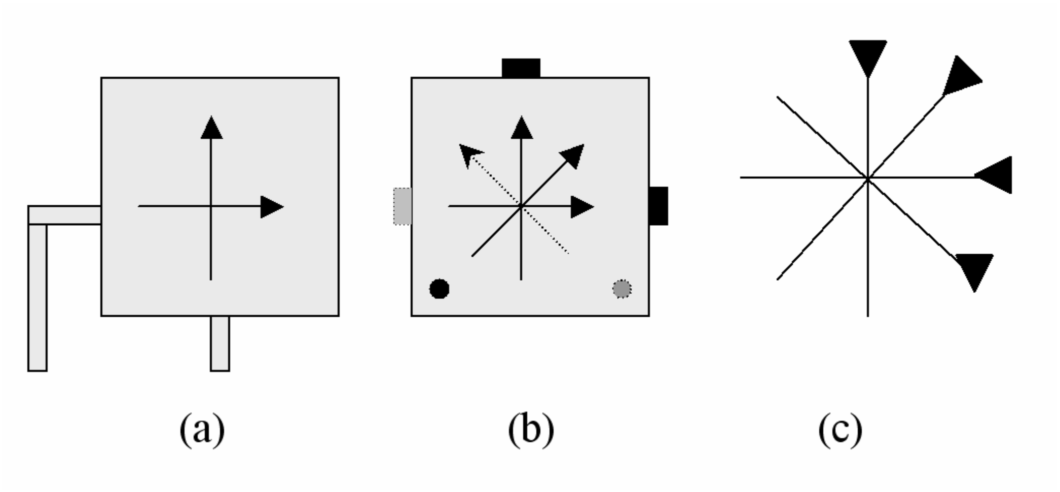

Figure 1 Polarization agile antennas: (a) a dual-fed patch, (b) an extension (gray elements) on the design from [3] in which filled rectangles are PIN diodes, feeds are at bottom corners and polarization modes are given as arrows, and (c) four rotated dipoles.

Polarization-agile designs such as those depicted in Fig 1 recover capacity losses not typically modeled in MIMO systems. The traditional configuration of two parallel dipoles demonstrates these losses well. The polarization-aligned "traditional model" supports a capacity of $C_E = 2\ \log_2(1+\text{SNR}) = 2\ \log_2(1+20\text{dB}) = 13.3$ bits/use, a value that drops to just 8.8 bits/use when subject to random orientation in "traditional model rotated" (see Fig 2, marker A). Patch antenna versions, "traditional patches" and "traditional patches rotated" represent a pair of coplanar patch antennas respectively polarization-aligned and unaligned with corresponding capacities of 12.4 bits/use and 8.4 bits/use. The reduced capacity of the "traditional patch" is mostly accounted for by the reduced planar directivity of the patch antenna. For the same impinging power, the patch detects 1 dB less power and offers a capacity of $2\ \log_2(1+\text{SNR}) = 2\ \log_2(1+(20\text{-}1)\text{dB}) = 12.7$ dB. This loss is not apparent for a standard normalization to detected power, leading to an incorrect suggestion that average capacities would agree to within 0.1 bit/use. This underscores the importance of using a normalization that fairly compares candidate antenna array designs. The remaining 12.7-12.4 = 0.3 bits/use might be a consequence of the more limited number of impinging waves collected by the directive gain pattern of the patch as compared to the dipole. Due to relatively poor outage power collection, the randomly oriented pair of parallel dipoles performs abysmally. At an outage likelihood of 10% (90%-reliability), for example, patches outperform dipoles with a capacity of 5.5 bits/use as compared to just 2.2 bits/use for the "traditional model rotated." Both fall far below the 10.9 bits/use predicted by the perfectly oriented "traditional model."

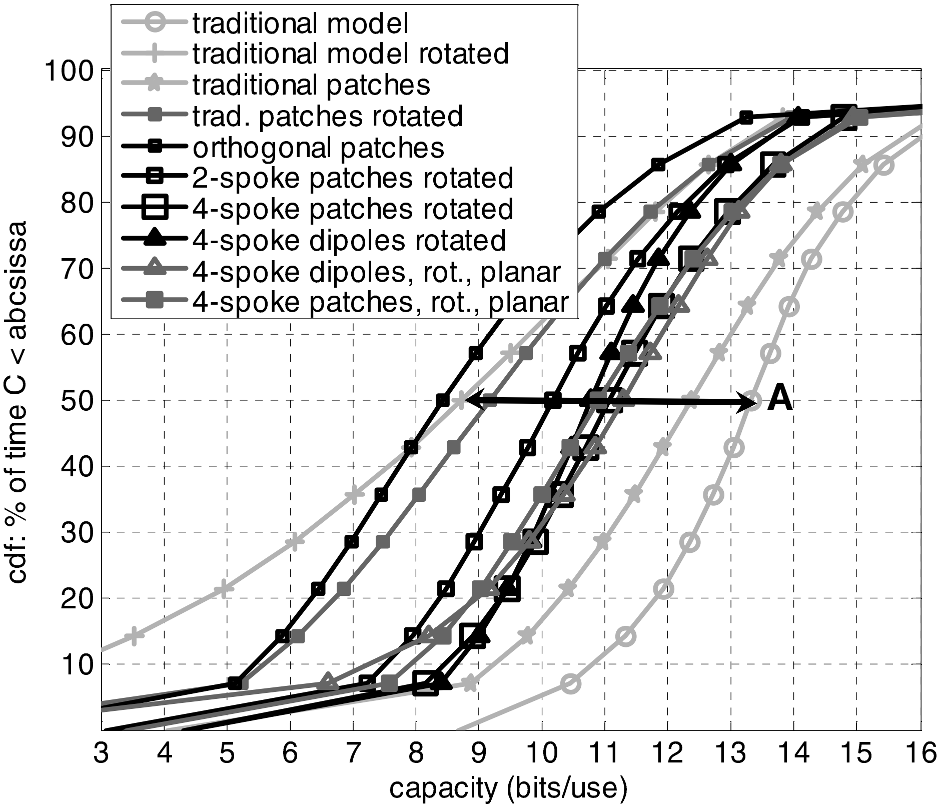

Figure 2 Cumulative distributions of capacity over switched angle-diverse array designs. The "4-spoke patches rotated" design achieves capacities higher than other designs near outage levels and within 0.2 bits/use on average with the added benefit of requiring fewer costly feed ports than the "4-spoke dipole" designs.

The curves "2-spoke" and "4-spoke patches rotated" represent the improved capacities achieved by *n*-spoke switched patch antennas based on designs depicted in Fig 1a and 1b. Using two spokes increases C_E by 1.8 bits/use. Using three spokes increases this by 0.6 bits/use (not shown in Fig 2), while increasing the count to four spokes adds another 0.3 bits/use for a total of 2.7 bits/use beyond the "traditional patches rotated." Moving from 4 spokes to 8, only adds another 0.1 bits/use (also not shown) indicating that four spokes is a point of diminishing return. This is fortuitous, as it is doubtful that a patch with more than 4 spokes could be constructed—remember that a fifth spoke spaced by 45^{o} at 180^{o} would be equivalent to one at 0^{o}. A pair of "4-spoke dipoles rotated" outperforms "4-spoke patches rotated" by 0.2 bits/use for C_E, but underperforms by more than 1 bit/use for $C_{0.1}$. From a system design perspective, dropping to 3-spokes might be a prudent choice. A pair of 3-poke patches offers 0.3 bits/use less than a pair of

4-spoke patches, but it requires just one feed port rather than two (and an associated power splitter) as depicted in Fig 1b.

Of course, the 2-spoke and 4-spoke designs described above require 3-dimensional designs using two orthogonal polarization-agile patches. As this leads to a size that may be undesirably large, the "4-spoke dipoles, rot. planar" and "4-spoke patches, rot. planar" curves are included to show the performance of purely planar versions of these designs. The "4-spoke dipoles, rot. planar" design gains 0.3 bits/use on average (C_E) but loses 1.9 bits/use for a 10% outage probability ($C_{0.1}$) relative to the 3-dimensional orthogonally placed "4-spoke dipoles, rotated" design. The significant outage penalty must be carefully weighed against the marginal average gains and the improved 3-dimensional footprint of the device. The differences between the orthogonal and planar patch designs are less significant. C_E for "4-spoke patches, rot. planar" design only beats that of the "4-spoke patches rotated" by 0.1 bits/use and $C_{0.1}$ for the planar design is only 0.7 bits/use worse, making it much more reasonable to trade the capacity losses of this planar design for its smaller size. Interestingly, if an array consists of two patches, each with a single feed, the curves "trad. patches rotated" and "orthogonal patches" suggest that the co-planar configuration is consistently preferable.

References:

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