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Link-Specific, Propagation-Based Wireless MIMO System Deployment

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Setting the Scene

Propagation is at the heart of wireless communications. It sets the ultimate limits for the transmission speed and throughput of any system built upon radio. Given the obvious attractiveness of wireless on one hand, and the complexity of the radio channel on the other, it is clear that the deployment of the novel MIMO systems must consider and exploit the radio channel in full. MIMO systems, which have *multiple antennas at each end* of the link, i.e. a number of N_R at the receive and N_T at the transmit sides, offer huge transmission capacity by attempting to do just this. Ideally, independent, orthogonal data transmission channels are set up between the individual antenna elements to maximize transmission capacity. MIMO systems can be set-up in fixed wireless access (FWA) systems, in wireless local area networks (WLANs), and on top of emerging mobile communications standards, such as the Universal Mobile Telecommunications System (UMTS).

With many users interfering with each other in limited frequency bands, another issue comes into play, well known from public mobile communications networks: *interference limitation*. The anticipated proliferation of WLANs will become a victim of its own success by eventually slowing down transmission speed considerably. In the 2.45 GHz ISM band, IEEE 802.11b will not only be subject to microwave oven interference, but to Bluetooth devices as well. It is expected that, in the near future, laptop computers will be furnished with antenna arrays, e.g. on the back of the display cover. Together with smart antenna technology at the access point (AP), MIMO systems will come quite naturally. Besides smart reception techniques, WLAN connections, being set-up in an ad-hoc fashion, will require some self-regulating mechanism to curb unwanted radiation into directions where the signal cannot be captured anyway by an intended user. Although WLAN standards according to IEEE 802.11 and to HIPERLAN/2 have in-built mechanism to shun occupied channels, techniques to minimize interference are essential for the sake of transmission speed.

As a third issue, the power consumption of high-data-rate transmission will be addressed by the topic of this paper. It would be highly desirable to save transmitter power, expensive to amplify to high levels, by transmitting into a few directions only. With adaptive antenna arrays this can be done by either exploiting directive antenna gain or by directing the available watts to a few dedicated directions.

MIMO Deployment Based on Link-Specific Measurement

The presentation will discuss measurements by various groups [1,2,3,4] demonstrating that MIMO capacity has a large local variation, depending on the position of the antenna arrays and on the environment. The immediate question that follows: *how*, then, to deploy MIMO systems to maximize capacity practically?

A comparison will show the differences between two approaches: first, to identify the channel matrix **H** for the particular transmit and receive arrays with which the measurements are made, and use that to calculate channel capacity [3]; or, second, to identify from the measurements the actual multipath components, synthesize **H** from these and then calculate capacity [5]. The former is limited by the fact that any measurement taken is a function of the antenna arrays used for measurement. So, the impact of variants of the antenna structure upon capacity cannot be assessed.
The clue to the latter is given by double-directional channel measurements, pioneered by Martin Steinbauer of Technische Universität Wien of Vienna, Austria [6]. By measuring the transfer functions or the impulse responses between each antenna element of the arrays at both ends of the radio link, and by sophisticated signal processing he was able to determine the *directions of departure (DoDs)* as well as the directions of arrival (DoAs). Common to two different forms of Steinbauer´s method is their ability to actually track a wave carrying significant power from the transmit array to the receive array via several (up to three) scattering points. They rely on the shift invariance principle of the superresolution algorithm ESPRIT [7]. To obtain an estimate of the number, strength and angles of departing and impinging waves quite some computation is necessary. As the computing power of laptop computers lies idle most of the time anyway, the evaluation procedure is not too big a burden for WLANs, not to speak of FWA where the link environment changes rather slowly if at all.

One of the surprises of evaluating double-directional measurements was that these directions may be more or less discrete, particularly when several reflections or scatterings are involved before a departing wave reached a receive antenna. This latter condition certainly can be the case in non-line-of-sight situations (NLOS). An interesting consequence of discrete DODs and DOAs is that such situations lend themselves for *deterministic* instead of *stochastic* site-specific channel modeling. Deterministic channel modeling has previously mostly been associated with ray-tracing or similar methods using databases about the propagation environment [8]. In contrast to ray tracing, the procedure favored in the present paper relies on *measurement* of an actual propagation environment. Examples of measured office environments that will be presented will clearly demonstrate that there exist at least large angular sectors, either from which no significant power was received or into which no power is transmitted that would eventually reach an intended receive antenna.

It is also interesting to distinguish between situations in which the incoming multipath huddles around a narrow angular range, or conversely, where the major multipath is widely separated. Having observed either situation in a given environment would lead straightforward to a proper selection of an optimum smart antenna algorithm for the receiver following the receive array. In the first case, one would probably opt for an exploitation of diversity, in the second case beamforming will be more appropriate.

The procedure envisaged to deploy a MIMO system in a given environment is this.
Before data transmission,
First, a *test phase* in which the transfer functions between N_T antenna elements on the transmit and N_R antenna elements on the receive sides are measured;
Then, an evaluation of the DoAs and DoDs by the double-directional procedure via one of two superresolution evaluation methods (Alternating Estimation and Beamforming, and Joint Parameter Estimation and Pairing [9]). Reference [5] gives the details to calculate MIMO capacity from these directions and the paths linking them;
Next, *antenna weights* $\mathbf{w}_T$ and $\mathbf{w}_R$ are calculated and set either to maximize link throughput or to minimize the angular transmit range to those DoDs for which corresponding DoAs exist ("valid DoDs"). Transmitting in valid DoDs only will keep *transmit power to the necessary*

minimum and will help in *keeping the system interference low*. This step requires a certain, but modest exchange of control data between mobile terminal and access point (or two or more mobile terminals);
Finally, the communication link being established, *data transfer* can commence.

Summary and Conclusions

The tools and procedures either
to optimize link capacity in a given environment;
to minimize interference; or
to minimize transmit power
in the deployment of MIMO systems will be explained and discussed. A key enabler is the identification and tracking of individual multipath components, a result of the so-called double-directional measurement method. The determination of DoAs and DoDs is largely independent of the arrays used for the preparatory measurement. A convenient side result will be guidelines where to exploit beamforming and where diversity in a given smart antenna installation. Discussion will also include techniques to operate MIMO antennas with variable data rates [10].

References

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