Over the air antenna measurement test-bed to assess and optimize WiFi performance

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***Abstract*—A typical home network environment has been built to assess and optimize WiFi antenna design for residential gateways. The measurement process is described and some examples illustrate interactions between antennas and their environment.**

I. Introduction

WiFi equipment has encountered a great success and its usage is now generalized particularly in the home network for Internet access. The first WiFi equipment followed the 802.11b standard and required only one antenna. Today with 802.11n and 802.11ac typically up to 3 or 4 antennas can be used. Some chipset vendors have already announced samples with up to 8 radio chains [1]. Advanced antenna processing like transmit beamforming tends also to be generalized.

For aesthetic reasons and also to avoid any cable disconnection risks, most of the WiFi antennas are now integrated on the printed circuit board (PCB). In practice, a WiFi MIMO antenna may be far away from the more academic dipole array antenna. Each radiating element has a particular radiation pattern depending on the used technology and on the near field obstacles on the PCB. WiFi performance assessment and optimization including antenna effects imply a lot of experimentations. Some tests can be performed using a hardware multipath channel simulator but it is then not possible to consider antennas. Antenna pattern measurement in an anechoic room does not take into account interactions with the indoor multipath propagation channel and with the signal processing made by the chipset. In this paper we present an over the air (OTA) performance testing environment and the associated measurement process.

The paper is organized as follows. The 802.11n/ac system model and notations are presented in section II. The section III details some typical interactions between MIMO antennas and the indoor propagation environment. The section IV presents the OTA testing environment and the measurement process used to assess and optimize WiFi performance.

II. 802.11n/ac System Model and Notations

A typical 802.11n/ac transmission scheme consists in the well known singular value decomposition (SVD) based transmit beamforming as defined in the 802.11n/ac standards. The MIMO channel matrix for a particular OFDM subcarrier is represented by the H matrix. H includes the multipath propagation channel as well as the transmitter (Tx) and receiver (Rx) antennas (Fig.1). For a system with NTx transmitting antennas and NRx receiving antennas, the SVD of a channel matrix H is given by

$$H = U^0 S^0 V^{0^*}. \qquad (1)$$

U^0, V^0 are respectively a NRx × NRx and NTx × NTx unitary matrix, (.)* means transpose-conjugate and S^0 is a NRx × NTx diagonal matrix with the square root s_i of eigen values of H^*H, where the singular values are arranged in decreasing order. The number of spatial streams Nss that can be used, is between 1 and rank(H). In the general case, the linear precoding matrix V applied at the transmitter side is deduced from V^0 by selected only its first Nss columns. Alternatively, for the receiver the first Nss lines of U^{0^*} are selected and applied (Fig.1). For a simpler MIMO system without transmit beamforming, V can be replaced by a constant spreading matrix, designed to spread Nss spatial streams over NTx antennas and U* is then a simple ZF or MMSE filter. For example $V = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix}$ for Nss=2 and a 4x4 MIMO.

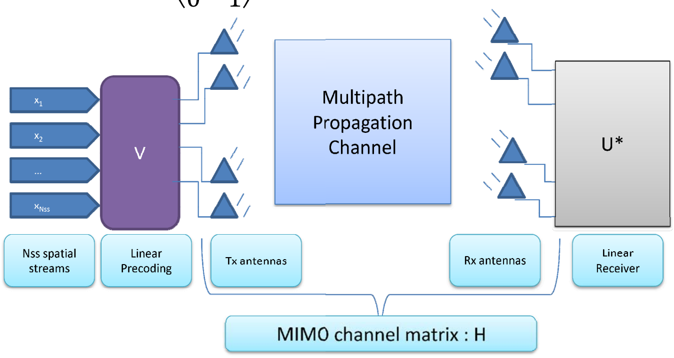

Fig. 1. Typical MIMO transmission scheme.

III. Interactions between WiFi Antennas and the Indoor Environment

A. Introduction

A WLAN deployed in the indoor environment faces a lot of interactions with its environment. Mainly, beside the near field obstacles, the antennas interact with a multipath propagation channel and the signal processing algorithms. The objective is that the whole system, including antennas and signal processing, exploits the multiple paths at their best to optimize range and throughput. Some examples detailed below illustrate interactions between multipath, antennas and WiFi performance.

B. The indoor MIMO propagation channel

The indoor channel has some spatial and temporal characteristics important to consider for system design. It presents clusters of multiple paths in a reduced number of directions at the access point (AP) side and also at the terminal side. From measurements made in an office environment with a directional and rotating antenna, we have observed 2 or 3 main clusters (Fig.2). This is far away from the Jake's model with an uniform angular distribution. The power angular spectrum is one of the key parameters for MIMO performances, as it defines the antenna correlation [2] and directly impacts rank(H) and system performance.

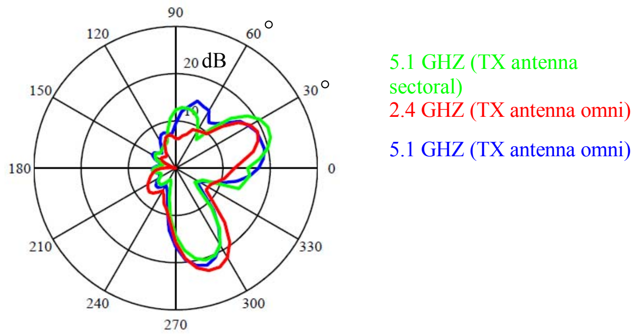

Fig. 2. Example of power angular spectrum measured in an office environment.

In the time domain, the measured power delay profile approaches a linear decay (Fig.3). This is well modeled by the IEEE TGn [3] and TGac channel models.

The indoor channel is a time varying channel even if the AP and the terminal are not moving: the environment may change (opened/closed doors, people moving) and modify the channel. For example, we measured a 10 dB loss for a people crossing the direct path at 5 GHz (Fig.4).

C. Performance variability

We performed throughput measurements [4] with a 802.11n 2x2 equipment in various home environments. Fig. 5 displays the measured UDP throughput in function of the average received power. It can be observed that throughputs are quite scattered and particularly for the higher values with two spatial streams. The received power is not the single parameter explaining WiFi MIMO performance. Parametric simulations [5,6] performed with TGn channel models [3] highlight the strong impact of the MIMO channel on performances. For example, for a typical office environment (channel model ChD) and for the same SNR, the packet error rate (PER) is much better than for the home environment (ChB) which has less and shorter multiple paths (Fig.6). A reduced PER allows the system to fall back to a higher modulation and to improve the throughput.

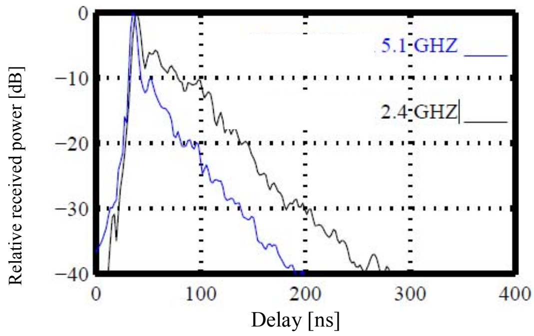

Fig. 3. Average power delay profile measured in office environment (256 MHz bandwidth).

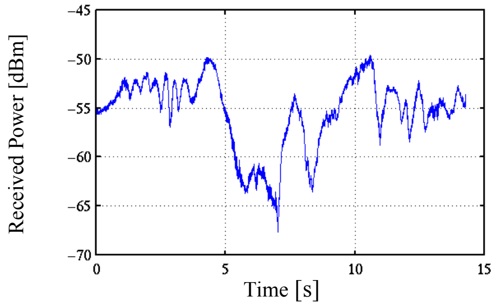

Fig. 4. Received power (narrow band) when a person crosses the direct propagation path

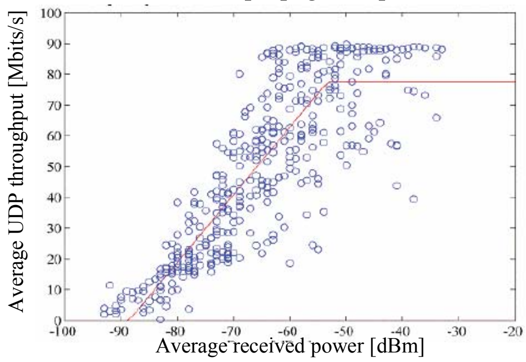

Fig. 5. Throughput (UDP downlink traffic with 1350 bytes packet) vs. average received power.

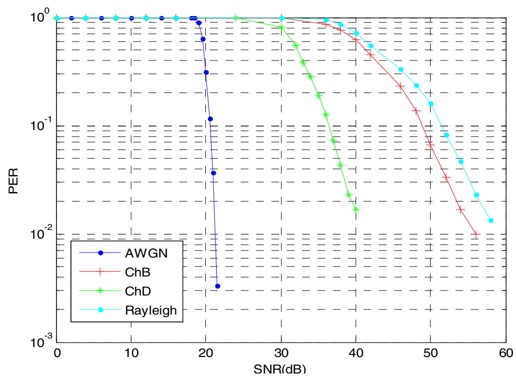

Fig. 6. Simulated PER versus SNR for reference TGn channels and 802.11n 2x2.

The power angular spectrum also strongly interacts with antennas and MIMO performance: a higher azimuth spread improves PER (Fig.7) and allows using higher modulations (MCS). When the angular spread becomes low, an increase of the antenna spacing is advantageous (Fig. 8).

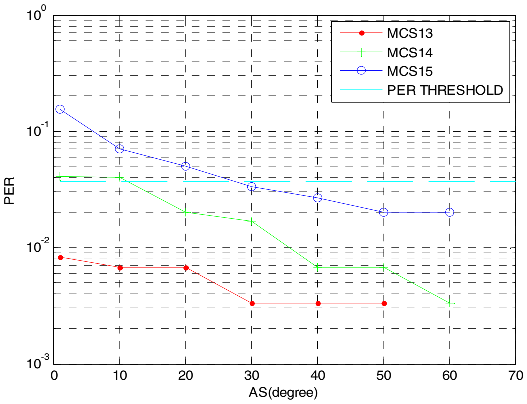

Fig. 7. PER versus Angular Spread (AS) for modulation and coding schemes MCS13, 14 and 15. TGn Channel D, with SNR= 38 dB [5].

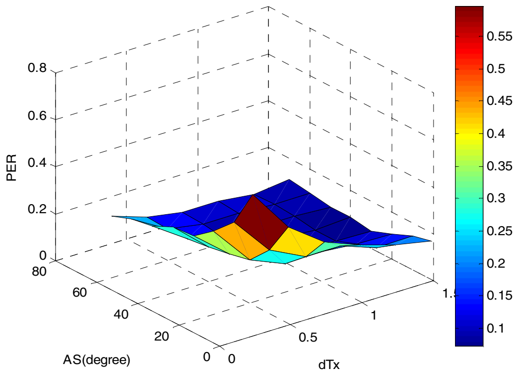

Fig. 8. PER versus Angular Spread and transmitting antennas spacing (dTx in λ) [5].

D. Antenna design requirements

A WiFi residential gateway has rather internal antennas than external dipoles. Due to near field obstacles on the PCB or on the casing, each antenna element has an irregular and particular radiation pattern (Fig.9). The whole MIMO antenna pattern needs to be as omni as possible to get an omni coverage and also for practical reasons: the gateway can be laid in any possible orientation. Complementary element antenna patterns could be an intuitive solution: for example, for a 3x3 MIMO, three 120° sectors. However, to benefit from the higher throughputs with multiple spatial streams this is not recommended: the indoor MIMO channel is clustered and some sectors could be inefficient and lead to a rank deficient channel matrix H. A better solution is to design each antenna element to approach an omni pattern.

A sufficient antenna spacing is also needed, to have diversity and a full rank H matrix, even if the angular spread is low. The antenna element correlation calculated as in [7] is an indicator for the design that approaches only the signal correlation when the multipath directions are uniformly distributed. The transmit and receive correlation, depend also on the H matrix [2] and on the multipath angles [8,9]. OTA measurements are needed to assess performance with real MIMO channels.

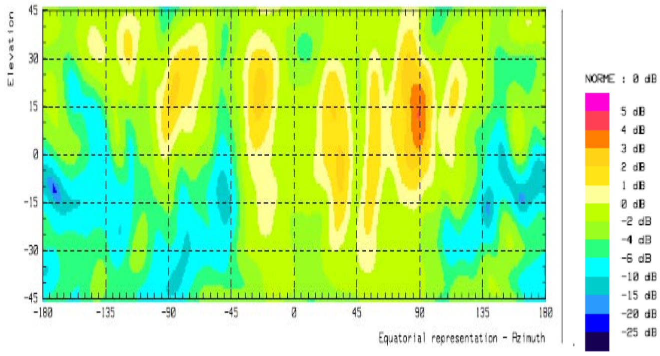

Fig. 9. 3D antenna pattern vs. azimuth and elevation for a 5 GHz internal stamp antenna (measured by Or. Labs La Turbie)

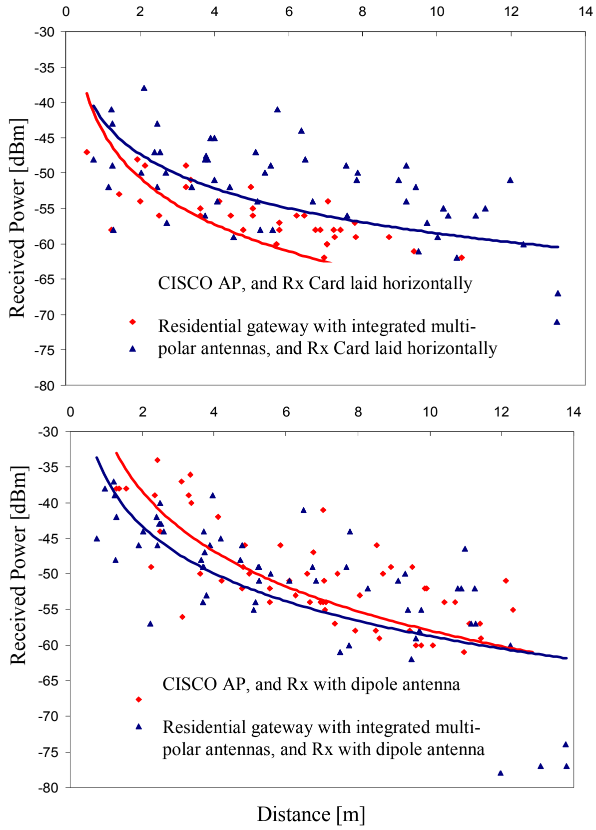

Fig. 10. Impact of the Tx and Rx antenna polarization on the path loss in an indoor residential environment.

E. Interaction with the receiving device

The antenna polarization at the Tx and Rx side is another important characteristic for the system range. For Tx and Rx at the same floor, 2.4GHz measurements made in our home environment (§IV) reveal the lowest path losses between vertically polarized omni directional dipole antennas (Fig.10).

WiFi gateways may be led horizontally or vertically and the associated devices may have a random orientation. It is recommended to have a multi polarized MIMO antenna to keep nearly the same range independently of antenna orientation (Fig.10).

IV. OTA TESTING IN THE HOME ENVIRONMENT

A. Typical home environment

Considering the previous results, the antenna system and the multipath characteristics can not be omitted to assess WiFi performances. We have also chosen to build a residential environment, based on a survey of the typical room surfaces and building materials in France. The floor plan is representative of a middle sized apartment of 12x8 m² with 3 rooms, a small kitchen, a corridor and a living room (Fig.11). In order to have stable and time reproducible measurements, the apartment is located in an interference free environment concerning the 2.4 and 5 GHz WiFi frequency bands.

Fig. 11. Living room and corridor of the apartment.

B. Measurement process

The residential gateway or WiFi AP under test is laid on a rotating arm in the azimuth plane (Fig.12). The measurement process consists in defining some reference Rx points and to collect for each point and for each AP azimuth the received power and the measured downlink average throughput. The spatial averaging is performed by a slow rotation of the Rx device during the measurement (Fig.12). An instantaneous measure would not be representative: the received power may be in a fading hole for one AP azimuth and no more for another one. Fig.13 displays an example of average measurements for a 2x2 MIMO and illustrates a probably bad design of the MIMO antenna. At short range, where high throughputs are expected, the measured values are too scattered in function of the AP azimuth.

V. CONCLUSION

We have given some examples to illustrate interactions of WiFi MIMO antennas with the indoor multipath channel. In particular integrated antenna design for optimized WiFi performances is a complex task that needs over the air measurements. For this, a typical residential environment was built. The next challenges concern antenna design and WiFi performance optimization for beamforming and particularly for 802.11ac MU-MIMO. Antenna decorrelation is needed to transmit multiple spatial streams, but correlation is needed to have the best beamforming gains.

Fig. 12. Rotating arm at the Tx side (1) and at the Rx side (2).

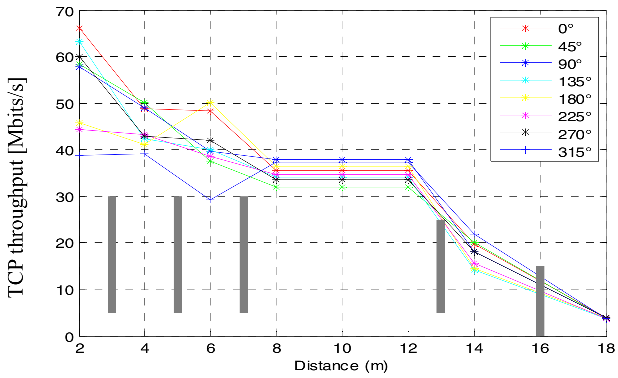

Fig.13. Example of throughput measurement (TCP) for a 2x2 MIMO in function of the AP azimuth and the receiver location

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