Testbedding MIMO HSDPA and WiMAX

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***Abstract*—Modern wireless communication systems employ MIMO and feedback—two properties that make it especially difficult to *measure* the performance of such systems with reasonable effort in actual outdoor scenarios.**

In this paper, we will present a time, cost, and manpower efficient measurement approach to evaluate the throughput achieved by such systems. Summer/winter, large distance outdoor-to-indoor/outdoor, urban/alpine measurements have been carried out to successfully test this approach. Exemplarily, we report on the throughput gains (over TX power and base-station-antenna-rotation) of standard compliant 2x2 MIMO HSDPA and IEEE 802.16-2004 WiMAX when, for example, employing improved channel coding methods.

I. Motivation

Modern wireless communication systems rely on complex algorithms to squeeze out the last bit of performance from a radio link. They do so by exploiting the characteristics of a channel in an ingenious way. In the end—although sometimes a good benchmark—it is not the BER or the theoretically achievable capacity that counts, but the throughput actually achieved by the system under investigation.

Determining the throughput performance of ingenious transmission schemes, on the other hand, is a different story. To do so, usually, the communication system is simulated in e.g. MATLAB and the channel is replaced with sounded coefficients and/or a channel model—that is, in essence, a simplified numerical replica of reality. But what effects should be considered in such a model? What about quantization effects, power amplifier non-linearities, mutual antenna coupling, and phase noise? And, most important, are there *yet unknown* and maybe critical influences on the performance?

The alternative extreme is to build the entire system, or at least a prototype, to determine its performance under real-world conditions. Unfortunately, this approach has some severe drawbacks too; namely, it requires a lot of time, money, and manpower, in addition to having little flexibility (E.g. how to quickly try out a new channel coding scheme?). Hence, the usability of prototypes in "university-style" research is very limited.

Between those two extremes lies "testbedding". The essence of testbedding is not to make any assumptions on the channel at all (including DA/AD converters, mixers, amplifiers, antennas, etc.) but simplifying the wireless communication system at some other point, e.g. real-time capability or equipment-size/mobility.

During the past five years, we have tried many different measurement approaches including channel sounding and real-time implementation to determine the mean throughput of communication systems under real-world conditions [1, 2]. We have found that—especially for our case of academic research which has limited financial resources—the testbedding approach presented in this paper is very attractive due to its excellent trade-off between effectiveness and efficiency.

This paper will first report on our testbed before demonstrating the power of our approach by presenting exemplary measurement results.

II. Our Measurement Approach

Compared to pure simulations, measurements usually require an often underestimated amount of money, manpower, and time. Therefore, we try to minimize our research expenses by simplifying our measurements compared to "commercial systems" in the following way:

- We only analyze the physical layer of radio communication systems.
- We only employ one TX and one RX unit with a maximum of four antennas each (16 each by switching). Therefore, we can only consider the up-/downlink scenario from a single base station to a single user. By measuring in an unused band we can later on choose between having no interference at all (noise is only thermal) or adding interference from other previously made measurements with different TX locations in the digital domain (assuming that the receiver is linear).
- We only consider such scenarios on a block-by-block basis in real-time.
- We do not put constraints on the size of our TX and the RX unit. Currently, they are as big as a small table.
- We use more sophisticated radio frequency hardware than a cheap commercial product would. We do so for three reasons. At first, to carry out the very precise measurements required by some experiments. Second, to be prepared to meet the specifications of future communication systems. Third, to easily evaluate the throughput-impact of some commercial part by comparing it to our "reference" (e.g. the impact of a cheap, noisy oscillator).
- We implement all necessary algorithms in MATLAB/C in floating point. In addition to being "feasible", this gives us all the flexibility needed to quickly change the code if new ideas come up that want to be tried out (e.g. LDPC instead of turbo channel coding as in the example shown later).
- We measure systems employing feedback only in static scenarios in order to have enough time for calculating the

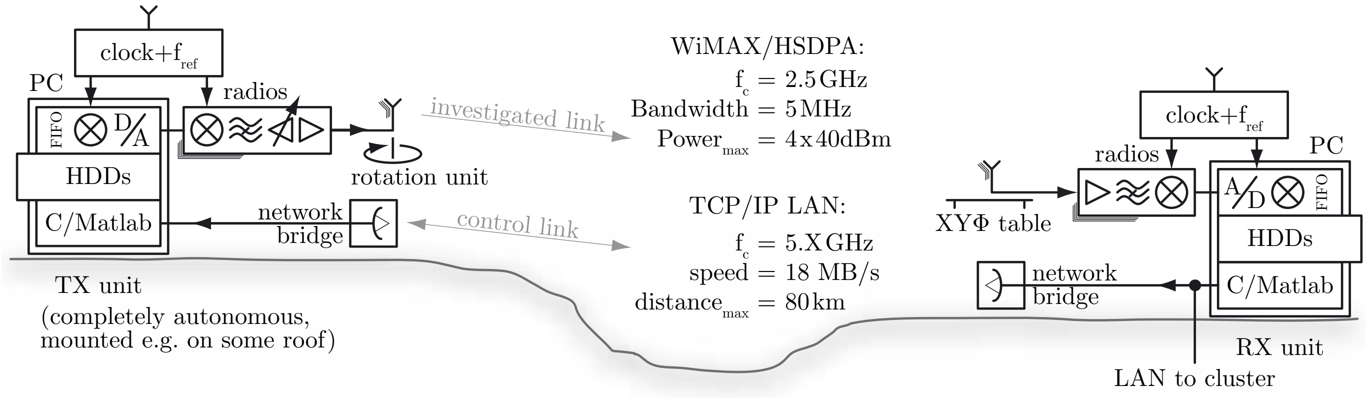

Fig. 1. Measurement set-up.

feedback and, as a result, the required new transmit signal.

- We (optionally) employ external synchronization in frequency and time. This gives us the choice to measure with no, a constant, or a randomly selected frequency offset [3].

A. Transmitting a Block of Data

Figure 1 shows the basic measurement set up used for all our measurements. Prior to a measurement, the following steps are carried out (the numbers in the brackets are typical times to carry out the steps):

- The TX and RX unit are set up. *(1 day)*
- All required transmit-data-blocks are pre-generated in MATLAB and then stored on parallel solid state hard-disks for instantaneous access (in the form of 14 bit complex baseband data samples). *(2 hours)*
- The rubidium+GPS stabilized "clocks" of the TX and RX unit are reset to 0 with a relative accuracy of ±20 ns. The required handshaking is carried out via the control radio-link so that there is no need for a cable connection. To meet the accuracy required by typical measurements, this procedure takes less than half an hour from a cold start. *(30 min)*

The transmission of an HSDPA block then works in the following way (see also Figure 3):

- At first, the RX unit (the master) requests the transmission of a "previous-block" via the control link. (HSDPA requires the receiver to feed back information calculated from the previously received block in order to transmit a channel adapted signal.) *(3 ms)*
- The transmitter then copies the selected block (that is, pre-generated transmit data samples) from the solid state hard disks to the FIFOs of the transmit hardware. *(9 ms)*
- Next, via the control link, the TX unit tells the RX unit the exact time the transmission will take place—that is, current time plus 4 ms. (The delay of the control link is typically less than 4 ms.) Another 4 ms are required for the handshaking between PC and external synchronization hardware. *(8 ms)*
- Consequently, at exactly the same time, the transmission of a data block is triggered by the TX and the RX hardware.
- In real-time, the transmit data samples are interpolated to 200 MSamples/s, digitally upconverted to 70 MHz, converted to the analog domain (14 bit), analog upconverted to 2.5 GHz, attenuated (digitally adjustable), amplified, and then transmitted. At the receiver, exactly the reverse procedure takes place so that at the end, the already downsampled received complex baseband data samples are stored in the internal memory of the RX unit (not on the hard disks). *(5 ms)*
- These received samples are now immediately evaluated in MATLAB up to the point where the feedback is calculated, and not further. For the case of HSDPA this means that only synchronization, channel estimation, and feedback calculation is carried out. *(26 ms times RX-antenna-count)*
- Now, the RX unit requests the transmission of the actual channel-adapted data block via the control link (its index is determined by the feedback information calculated from the previous data block). In addition, the RX unit also requests the transmission of the two possible HSDPA retransmis-

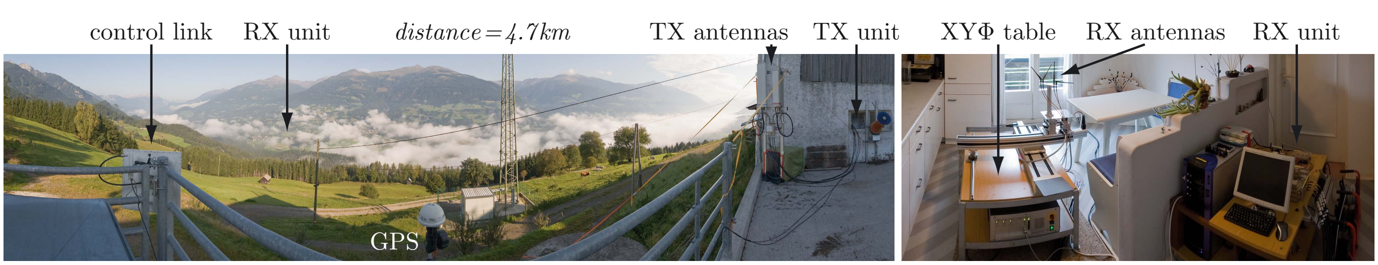

Fig. 2. Panoramic view of the alpine scenario measured (use PDF to zoom).

sions, even if it may turn out later on (after the evaluation of the data block) that this is not necessary. *(3 ms)*

- Transmission now takes place in real-time (as described above). *(57 ms)*
- At last, all four received blocks are stored on RAID hard disks for later/immediate off-line evaluation in a cluster. *(10 ms)*

In the case of WiMAX, things are simpler because there are just seven possible feedback values, and therefore transmit blocks (in contrast to a few thousand for MIMO HSDPA). As shown in the right of Figure 3, we just transmit all possible blocks one after the other without calculating any feedback information. As an advantage of this method, we can later on still try different methods for calculating the feedback and their impact on the throughput. In addition, we can also evaluate all possible combinations of one, two, three, and four receive antennas later on off-line from the same set of recorded data. The same holds true for e.g. trying different receiver types. In HSDPA, such investigations are only possible if the feedback (that has already been used to select the correct transmit data block) is unaltered by the investigation.

Note that both methods require the channel to stay constant during the transmission of four/seven data blocks (95 ms/37 ms). Later off-line testing showed that this is the case—that is, no significant impact on the average throughput caused by non quasi static channels could be observed.

B. Inferring the Mean Performance

Up to now, we have actually only transmitted a "single" HSDPA and WiMAX data block (4+7 physically). To infer the mean throughput performance of a specific scenario (as shown in Figure 5) we carry out the following steps:

- We repeat the procedure above for all different schemes under investigation *(the curves in Figure 5)*.
- We repeat all above for different transmit power levels *(the x-axis in Figure 5)*. To do so, we attenuate the transmit signal prior to the power amplifier. (For the rotation measurements we measure at a fixed attenuation value several different TX antennna rotations.)
- We repeat all above for different receive antenna positions. They are created by moving the RX antennas using a fully automated XYΦ positioning table as shown in Figure 2. To minimize large scale fading effects we measure within an area of $3 \times 3\,\lambda$. Correlation between the different positions is minimized by a systematic sampling approach maximizing the distance between all positions measured.

Measuring all this typically takes from one hour up to a day. The evaluation of the data blocks (up to a terabyte of baseband data samples) is carried out using a self programmed PC cluster software that parallelizes the off-line evaluation of the received data on a position-by-position basis on all currently available employee-PCs of our institute *(typically 60 cores during nights)*.

- Once calculated, we collect all results from the cluster in order to e.g. average the throughput observed over the positions measured. Several tests are carried out in order to test the validity of the results, e.g. we check for measurement outliers or interference that should not exist.
- Finally, we estimate the accuracy of the measurement by means of bootstrapping methods [4]. In all throughput graphs, the dots represent the inferred mean throughputs, the vertical lines the corresponding 90% confidence interval, and the horizontal lines the corresponding 5% and 95% percentiles. Note that we did not change the RX antenna positions between measuring different schemes at different transmit power levels. This, on one hand, leads to smooth curves. On the other hand, the *relative* positions of the curves are far more accurate than the confidence intervals for the *absolute* positions might suggest.

The whole measurement and evaluation procedure is fully automatized so that we can carry out one very extensive (or several trial) measurements per day. In between and during the measurements we then adapt, bug fix, and optimize our code to instantly test it again in the real-world scenario. Doing so, we actually do not really carry out measurement campaigns in the usual way (half a year planning in advance, measuring one week, and two years or more evaluating the data), but constantly test our code in changing real-world scenarios (we regularly change the RX unit position, sometimes it snows, etc.).

III. Exemplary Measurement Result

In the following we will report on 2×2 MIMO HSDPA and 2×2 MIMO WiMAX measurements carried out in alpine and urban scenarios:

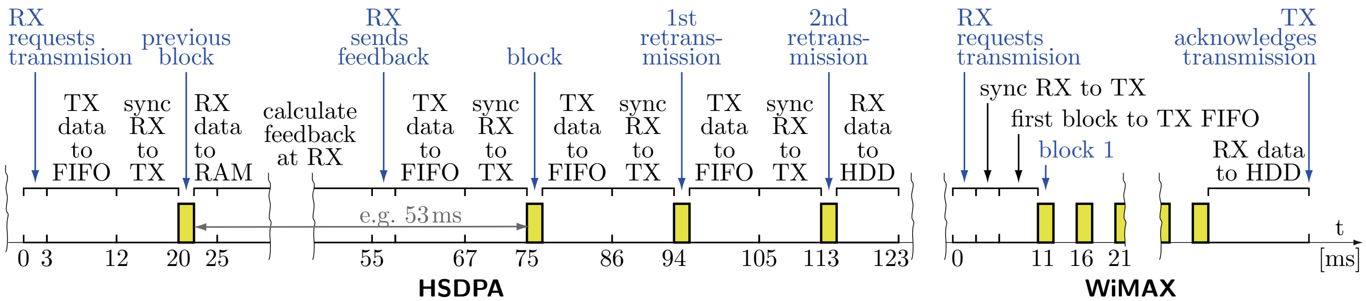

Fig. 3. Timing of the transmission of a "single" data block.

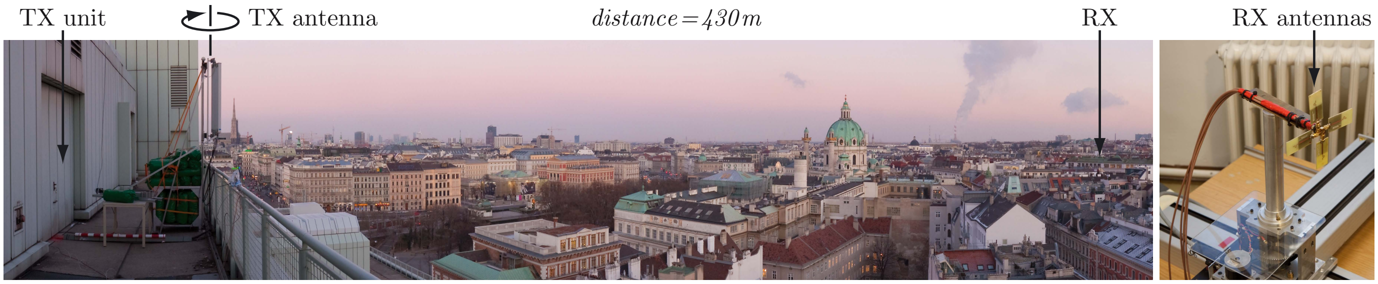

Fig. 4. Panoramic view of the urban scenario measured (use PDF to zoom).

- Alpine Scenario: The base-station antenna (Kathrein 800 10543 [5], 60° XX-Pol basestation panel antenna, ±45° polarization, down tilt 6°) is placed 5.7 km away from the RX unit which is located inside a house in a village on the other side of the "Drautal"-valley[1] as shown in Figure 2. At the RX unit we utilized standard Linksys WiFi-Router rod antennas. We investigated RX antenna positions where the TX antennas can and cannot be seen from the window of the room where the RX antennas have been placed (bedroom, kitchen, ...). We also placed the RX unit outside in the middle of a field. In all measured scenarios, the results obtained did not change significantly, apart from a variation in the average path loss.
- Urban Scenario: The base-station antennas (Kathrein 800 10543 [5], 60° XX-Pol basestation panel antenna, ±45° polarization, down tilt 6°) are placed on the roof of a big building in the center of Vienna 430 m away from the RX unit that is placed inside an office room, see Figure 4. At the RX unit we utilize two low-cost printed monopole antennas [6]. In all measurements carried out, the direct path from the TX to the RX antennas was blocked by the building the RX unit were located in.

Using the above described procedure we obtained the mean throughput-performance of the following standard conform transmission schemes (the solid lines in Figure 5):

- 2x2 MIMO HSDPA: We measured the recently standardized Dual-stream Transmit Antenna Array (D-TxAA) HSDPA [7, 8] system and compared it to its single stream variant TxAA. Performance gains of the dual stream system are especially interesting for network operators that have to decide if D-TxAA is a worthwhile investment. In both systems, adaptive precoding at the transmitter is used to increase the receive SNR. The feedback was calculated by maximizing the data throughput given by analytic expressions of the post equalization SINR [9].
- 2x2 MIMO WiMAX: We measured an IEEE 802.16-2004 [10] standard compliant MIMO WiMAX system. The standard compliant system was compared to a system employing LDPC channel coding to evaluate the potential performance gains.

[1] Detailed transmitter and receiver positions for both scenarios can be downloaded for Google Earth at http://www.nt.tuwien.ac.at/fileadmin/data/testbed/Vienna-and-Carinthia-TX-RX-GPS.kmz.

A. HSDPA: D-TxAA instead of TxAA

The HSDPA throughput results in Figure 5 show that the D-TxAA system outperforms TxAA already at transmit powers of about 25 dBm. Especially in the urban scenario, the gain of the dual stream system is significant. Compared to the "achievable throughput" [11], HSDPA looses about 6 dB in SNR in the alpine scenario and about 9 dB in the urban scenario. This is due to the larger delay spread in the urban scenario causing more post equalization interference. When rotating the transmit antennas, the received signal power and the throughput change according to the transmit antenna gain pattern (Figure 5).

B. WiMAX: LDPC instead of Turbo Coding

Since all signal processing algorithms used in our measurements are carried out in MATLAB only, it is relatively easy to investigate, for example, advanced channel coding schemes in WiMAX. Besides the standard compliant convolutional and the Turbo coding we implemented a regular LDPC code. This code has variable node degree $d_v = 3$ and has been constructed using the progressive edge growth algorithm [12]. The decoder at the receiver uses the sum-product algorithm [13].

The throughput results in Figure 5 show that in both scenarios (alpine and urban), the Turbo code outperforms the convolutional code by about 3 dB. An additional gain of about 1 dB is achieved when implementing LDPC channel coding. At low SNR, the performance of the Turbo code is worse than the convolutional code. This is because the lowest adaptive modulation and coding scheme in case of Turbo coding is 4-QAM with coderate 1/2 [10] whereas it is 2-PAM with coderate 1/2 for the other coding schemes.

IV. Conclusion

In this paper, we presented a powerful measurement approach that enables a researcher to try out new, yet unexplored modulation techniques in real-world scenarios with reasonable effort. As an example, we presented HSDPA and WiMAX measurements in an urban and an alpine scenario to exemplary demonstrate its efficiency. We see significant performance gains of D-TxAA compared to TxAA, especially in the urban scenario. In the WiMAX system, LDPC channel coding promises about 1 dB gain over Turbo channel coding. Compared to the achievable throughput, both systems—WiMAX and HSDPA—loose more than 5 dB in terms of SNR, leaving room for future improvements.

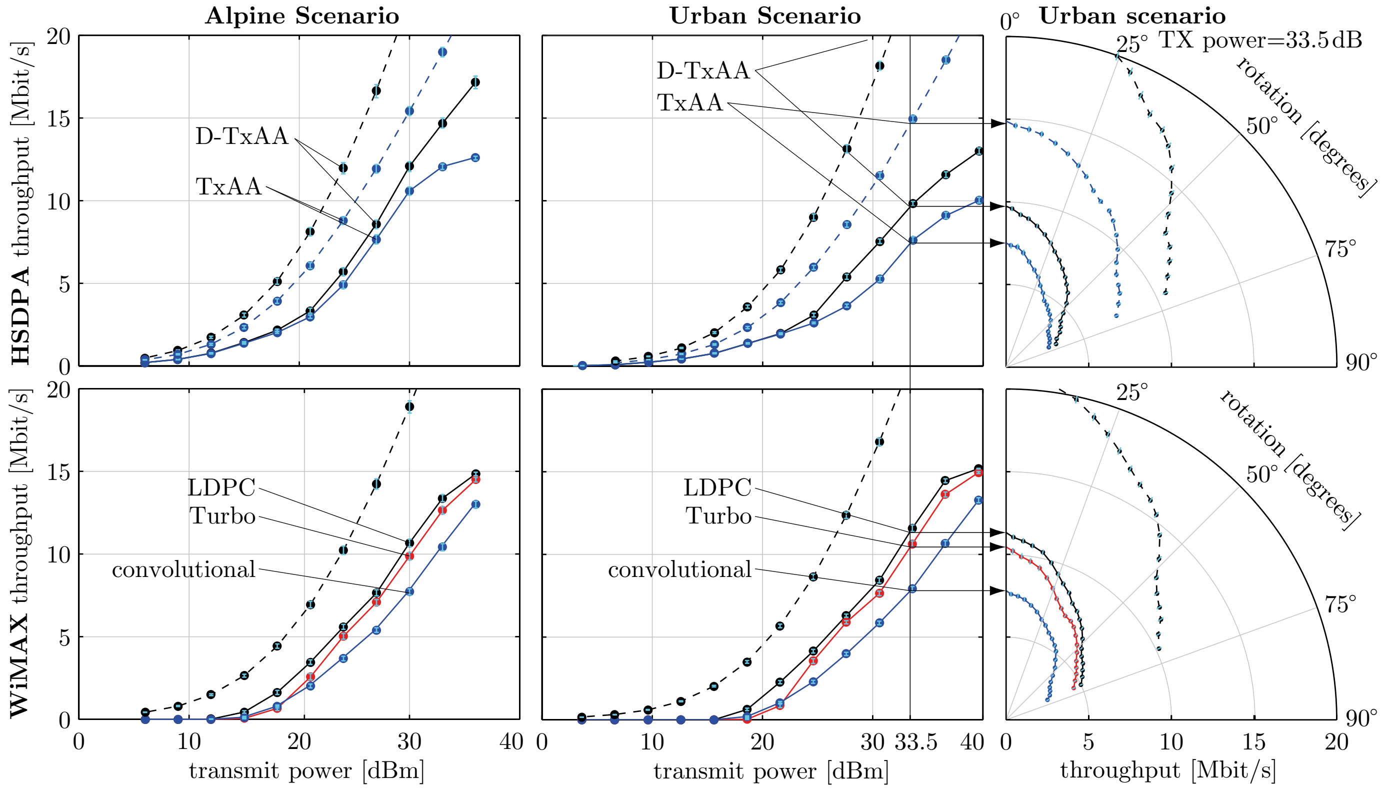

Fig. 5. Exemplary measurement results. (dashed: achievable throughput, solid: measured throughput)

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