Channel Hardening in Massive MIMO – a Measurement Based Analysis

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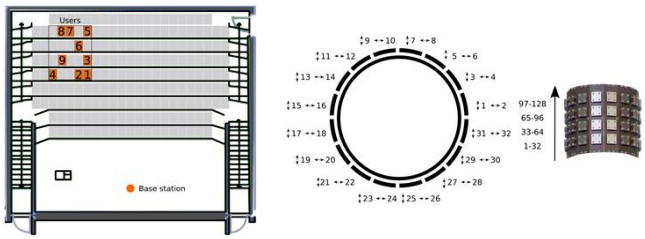
Introduction and motivation

One goal for future wireless communication systems is to support critical communications, meaning that high reliability is required. A promising technology to reach this is massive MIMO, where the base stations are deployed with a large number of antennas. Thereby spatial diversity can be exploited in order to increase reliability. This means that small-scale fading decreases and the channel behaves deterministically, which is called channel hardening. Here, channel hardening is analyzed based on measurements in an indoor auditorium.

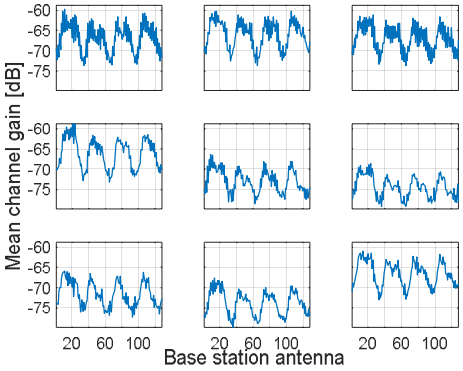
Measurement scenario and equipment

We analyze channel measurements with a 128-port cylindrical array and nine closely-spaced users in an indoor auditorium. The array consists of 64 dual-polarized patch antennas and the users have omni-directional antennas with vertical polarization. User antennas are tilted 45 degrees and are randomly moved in a small area.

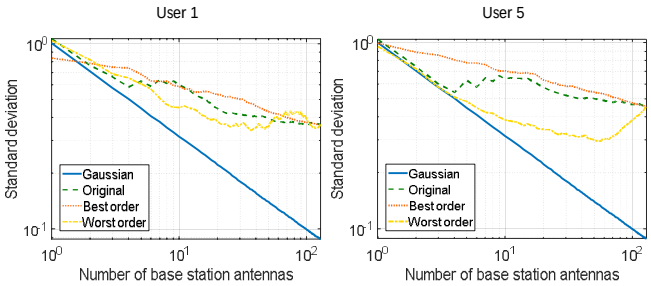


Variations of channel gain over the base station array for user 1-9

As seen, the power varies between users as well as between base station antennas.



Channel hardening, for increasing number of base station antennas, when choosing the antennas in different orders



Gaussian – complex independent identically distributed channel
Original – choosing the antennas according to the numbering in the cylindrical array
Best order – choosing the antennas with the highest mean channel gain first
Worst order – choosing the antennas with the lowest mean channel gain first

Acknowledgement
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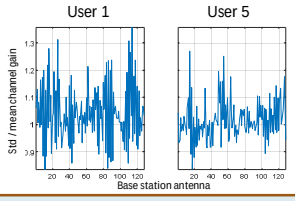
The definition of channel hardening used here

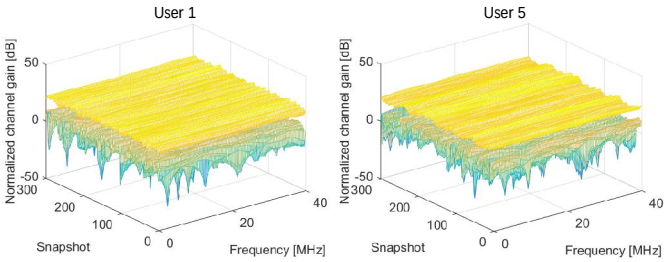
$$\frac{\mathrm{Var}\{\|\boldsymbol{h}_k\|^2\}}{(\mathrm{E}\{\|\boldsymbol{h}_k\|^2\})^2} \to 0, \qquad \text{as} \quad M \to \infty$$

Standard deviation of channel gain for each base station antenna in the array

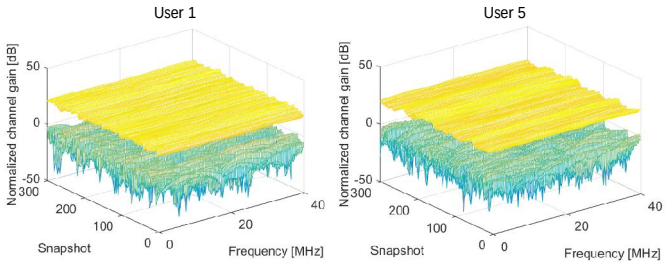
Some antennas experience larger variations.



Channel gain over frequency and time for 128 antennas vs the single strongest antenna



Channel gain over frequency and time for 128 antennas vs the single weakest antenna



Conclusions and future work

The measurements show a significant channel hardening effect in massive MIMO systems, but it is lower than theoretically expected. The result is a flatter channel in both time and frequency. Channel hardening, when increasing the number of base station antennas, is evaluated with the result that the standard deviation of channel gain decreased with 3.2-4.6 dB. The amount of channel hardening that can be expected is dependent on the base station antenna arrangement, the order in which the antennas are chosen, whether the antenna elements are in LOS or NLOS and the users' position and interaction with the environment.

Future work will include extending this analysis to further narrow down the parameters that create channel hardening in a practical scenario.