PRECODING FOR EIGHT-ANTENNA MIMO SYSTEMS

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WHITEPAPER

Introduction

The use of MIMO in wireless communication offers many benefits, such as transmit and receive diversity that come with the use of multiple antennas at transmitter and receiver respectively. With MIMO, multiple streams of data can be delivered simultaneously if multiple antennas are present at both transmit and receive side.

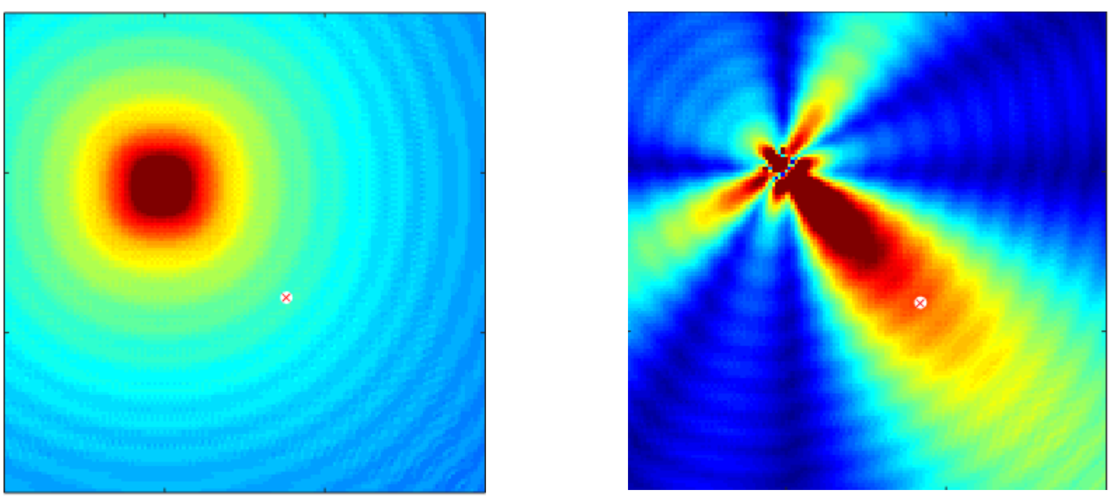
One of the most powerful improvements enabled by MIMO is the ability to use precoding to “steer” the transmitted signals. One implementation of precoding focuses the signal towards a chosen receiver, leading to better signal strength at the receiver. This is known as Beamforming. In another implementation of precoding, a single transmitter is able to simultaneously send multiple data streams to multiple receivers without mutual interference between the different streams. In this case, precoding is used to achieve the desired interference cancellation by steering parts of the signal away from an intended location. This is known as MU-MIMO (Multi-User MIMO).

This paper will discuss the use of precoding and highlight the importance of good-quality channel information to enable precoding.

Precoding

Precoding involves the individual control of the amplitudes and phases of the signals sent from the various transmit antennas. When precoding is chosen carefully, it can be used to better focus energy towards the intended receiver. This is referred to as “beamforming”.

Figure 1 shows a two-dimensional illustration of beamforming. Figure 1(a) depicts an omni-directional radiation pattern typical for systems without beamforming. The energy radiates uniformly in all directions. Figure 1(b) shows a radiation pattern that is obtained with beamforming. By modifying the phases and amplitudes of the antennas, energy can be steered towards an intended receiver (indicated by the white circle in the plot). The resulting increase in received power leads to a more reliable communication between transmitter and receiver.

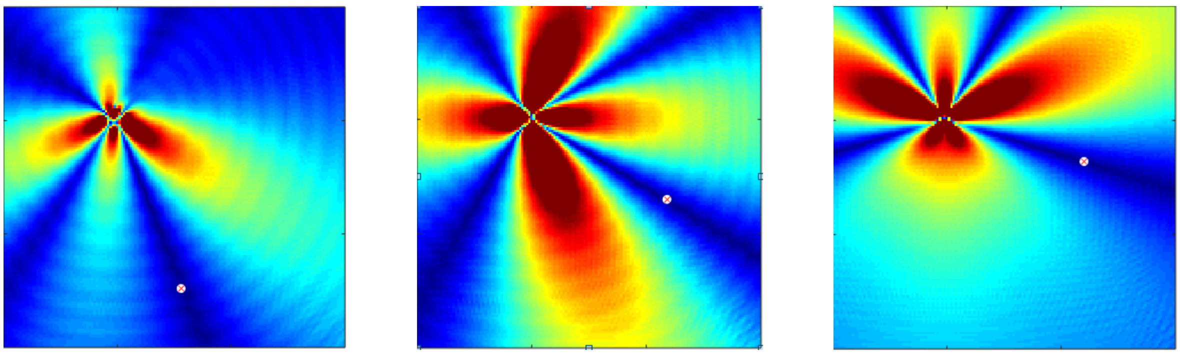


(a) (b)

Figure 1: two-dimensional illustration of Beamforming. Precoding directs the signal towards the intended receiver.

Alternatively, the precoding can be chosen such that it *cancels* the signal at a chosen location, which can be used to remove interference at a given receiver. This is referred to as Multi-User MIMO interference cancellation.

Figure 2 illustrates interference cancellation. The precoding has been chosen such that no energy is directed towards the indicated location. The absence of energy is indicated by the dark blue region. While antenna patterns may exhibit regions of low energy, precoding allows to steer these nulls in any desired direction. Figure 2(a) to Figure 2(c) show cancellation in three different chosen directions.



(a) (b) (c)

Figure 2: Illustration on interference cancellation. Precoding steers the signal away from the intended locations.

Conceptually, the MIMO channel can be considered as the equivalent of a number of independent paths, called “singular modes” in matrix theory. These “paths” don’t correspond to physical paths in space, but thinking of them as such can still be a useful analogy to understand the workings of precoding. Some of the paths between transmitter and receiver will be stronger than others (i.e. have less attenuation). Some of the paths may even result in no power being delivered to the receiver. In the case of beamforming, precoding directs the antennas (by modifying their phases and amplitudes) such that all transmit power is steered into the strongest path, resulting in the strongest possible receive signal. In the case of interference cancellation, the antennas are instead configured to steer the power into a path that yields no output power, resulting in the nulling of the signal at the desired location.

Both beamforming and interference cancellation benefit from higher number of transmit antennas. The more antennas, the more fine-grained the tuning can be and the better the resulting effect will be (be it boosting or cancelling the signal at the receiver).

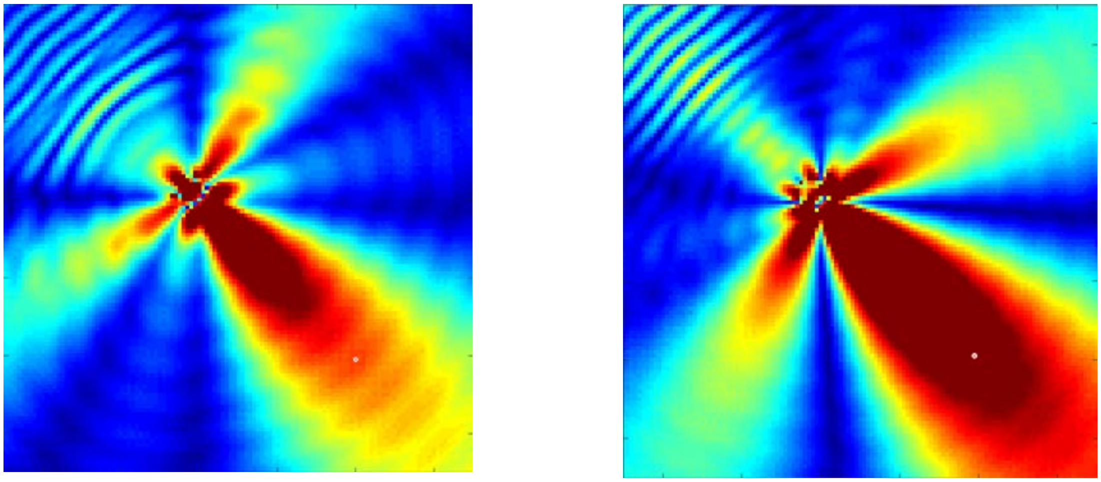
8-Stream Channel Sounding

To achieve the desired effect at a specific location requires information about the channel between the transmitter and the intended receiver. In the 802.11 standard, a protocol is established for this channel information (channel state information or CSI) to be explicitly fed back from the receiver (“Beamformee”) to the transmitter (“Beamformer”) in response to a training frame that is sent by the transmitter. The transmission of the training frame and its subsequent response are called “sounding”.

To get the best possible results, ideally, the Beamformer should send a training frame that has a number of streams identical to the number of transmit antennas. This allows the transmitter to get a full understanding of the channel and provides the correct number of degrees of freedom to control each of the antennas individually. In Wi-Fi, the number of streams in the training signal is additionally constrained by the number of streams the Beamformee can process. This number could be lower than the number of antennas at the transmitter as is the case for many of the existing devices in the field. The Beamformer can still sound the channel with a lower number of streams, but in that case, it no longer has sufficient information to control each of the antennas individually. This will constrain the amount of steering that can be achieved with precoding.

Consider the case of a transmitter with eight antennas doing beamforming. With eight-stream feedback from client devices, the transmitter can derive a precoding such that all its eight antennas can be deployed to steer the transmit power into the strongest path towards the receiver. On the other hand, if the transmitter only has access to four streams, the transmitter can no longer distinguish the best path that could be achieved with eight antennas. As a result, the resulting signal will travel from transmitter to receiver over a combination of paths, some of which are suboptimal. Compared to steering based on the eight-stream feedback, part of the energy is wasted in the propagation over lower-quality paths. The net result is a reduction in beamforming gain.

The difference between four- and eight-antenna beamforming is illustrated in Figure 3. The darker the color, the higher the energy at a given location. Figure 3(a) shows beamforming using four antennas. The energy is clearly directed towards the target receiver. With eight antennas however (as illustrated in Figure 3(b)), more energy is delivered at the same location, resulting in better performance.

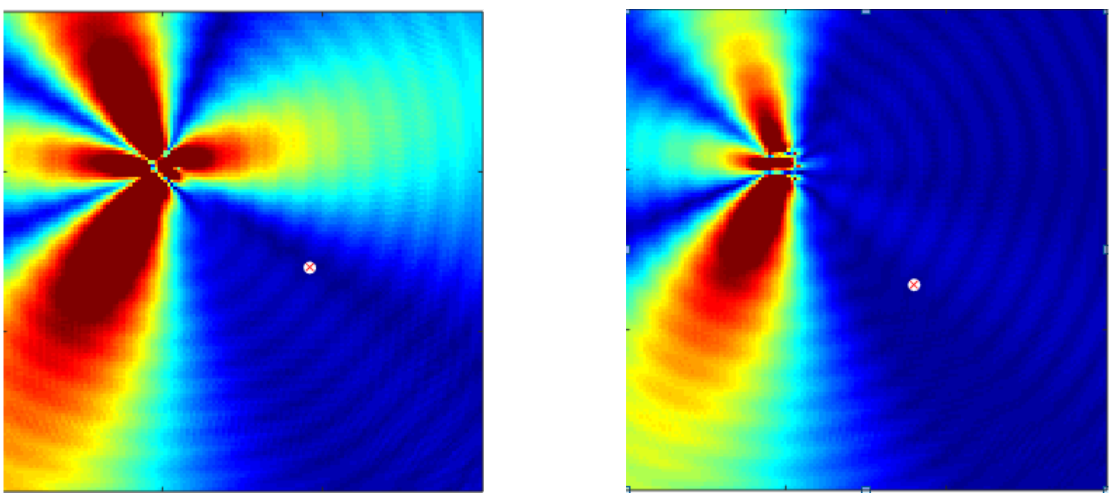


(a) (b)

Figure 3: Illustration of BF gain with four antennas vs. eight antennas

A similar effect exists for MU-MIMO and in general in interference cancellation. More antennas make it possible to steer energy away from a chosen location, leading to interference cancellation at that location.

Figure 4 illustrates the difference between interference cancellation with four (Figure 4(a)) and eight (Figure 4(b)) antennas. With eight antennas, signal can be steered away more effectively, creating a larger area where no signal is received (indicated by the dark blue color).



(a) (b)

Figure 4: Illustration of signal cancellation

Quantenna ESP

While a high-end 8-antenna AP works best with 8-stream feedback, it can be constrained by limitations at the Beamformee side. In fact, a lot of deployed client devices only provide 4-stream feedback regardless of the capabilities of the AP. Some may even support only 3-stream feedback.

Quantenna has developed an ESP (Enhanced System Performance) that can achieve near 8SS level of performance despite clients' limitation in providing full channel feedback. The requires special techniques to gather 8SS-equivalent channel information and suitable post-processing of the channel information in a manner entirely transparent to the beamformee. The result is enhanced system performance closer to what would have been provided by 8-stream feedback.

Figure 5 compares the measured beamforming performance of the three different types of channel feedback: 4-stream feedback, 8-stream feedback and ESP. For reference, the performance without beamforming is shown as well. The transmitter is an 8-antenna AP. As predicted by theory, 8-stream feedback allows for more accurate steering of the antennas, resulting in better performance relative the 4-stream feedback. Figure 5 also shows the results for ESP, when connected to the same client device that provides 4-stream feedback. The performance of ESP clearly outperforms "regular" 4-stream feedback and brings it close to the performance enjoyed by devices that provide 8-stream feedback.

This means that with ESP the performance enhancements of an 8-antenna AP are now also available to client devices that were not initially optimized for operation with 8-stream feedback and 8-antenna devices.

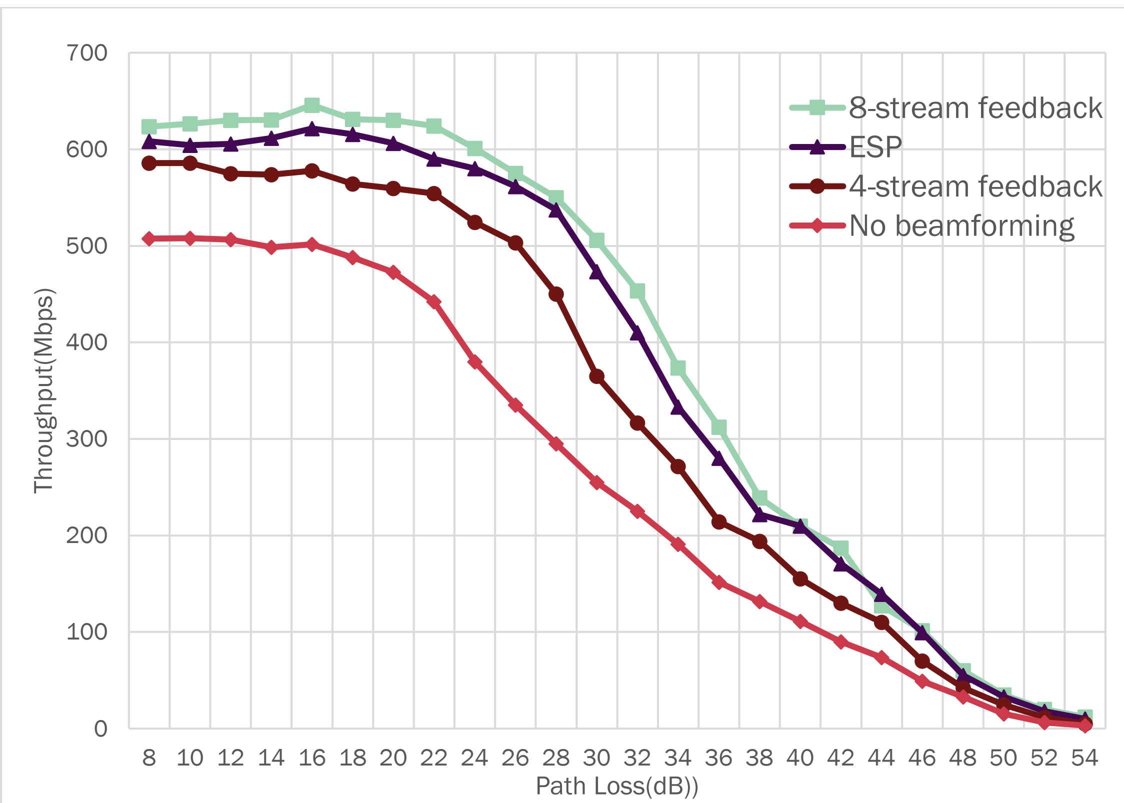


Figure 5: Comparison of Beamforming results for different types of channel feedback

Conclusion

This paper describes the fundamentals of precoding and channel sounding. A transmitter with multiple antennas can precode its transmission to achieve either beamforming or interference cancellation. The effectiveness of the precoding depends on both the number of transmit antennas on the access point and the dimension of the channel feedback from the client. Optimal results are obtained when the dimension of the channel feedback matches the number of transmit antennas.

Quantenna's ESP enhances performance of client devices that don't provide full support for an 8-antenna AP. This extends the benefits of 8-antenna APs to a whole class of legacy devices in a transparent and interoperable way.

About Quantenna

Quantenna (Nasdaq: QTNA) is the global leader and innovator of high performance Wi-Fi solutions. Founded in 2006, Quantenna has demonstrated its leadership in Wi-Fi technologies with many industry firsts in the market. Quantenna continues to innovate with the mission to perfect Wi-Fi by establishing benchmarks for speed, range, efficiency and reliability. Quantenna takes a multidimensional approach, from silicon, system to software for Wi-Fi networks and provides solutions for OEMs and service providers worldwide. For more information, visit www.quantenna.com.