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WHITE PAPER

# Transmit Smart with Transmit Beamforming

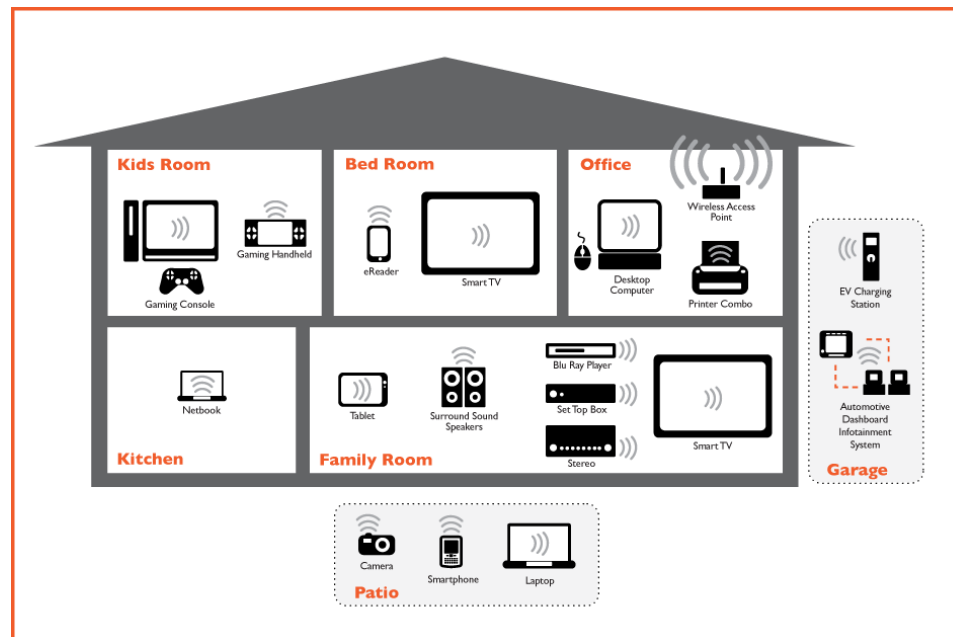
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## Introduction

One of the challenges often faced with Wi-Fi is limited range and rate. Today's "connected home" likely has multiple stories and walls with several devices connecting to the home's WLAN – from computers and printers, to phones and TVs, to tablets and gaming consoles. And not all spots in the home can provide an environment for good connectivity. For example, in a typical home, neither the access point (AP) or the TV has much flexibility in position. Techniques to improve connectivity in such scenarios, by improving range and rate, are invaluable. Beyond home networks, even enterprise APs and hotspots can benefit from such improvements. One of the most effective and efficient techniques to boost connectivity performance is **transmit beamforming**.

Transmit beamforming avoids some of the challenges associated with introducing a new technology, such as a significant hardware update or lack of backward compatibility. User scenarios that benefit from transmit beamforming include whole home media distribution, streaming of rich media, displaying content from cameras and phones to TVs, sending photos to printers, and enhancing gaming experience.

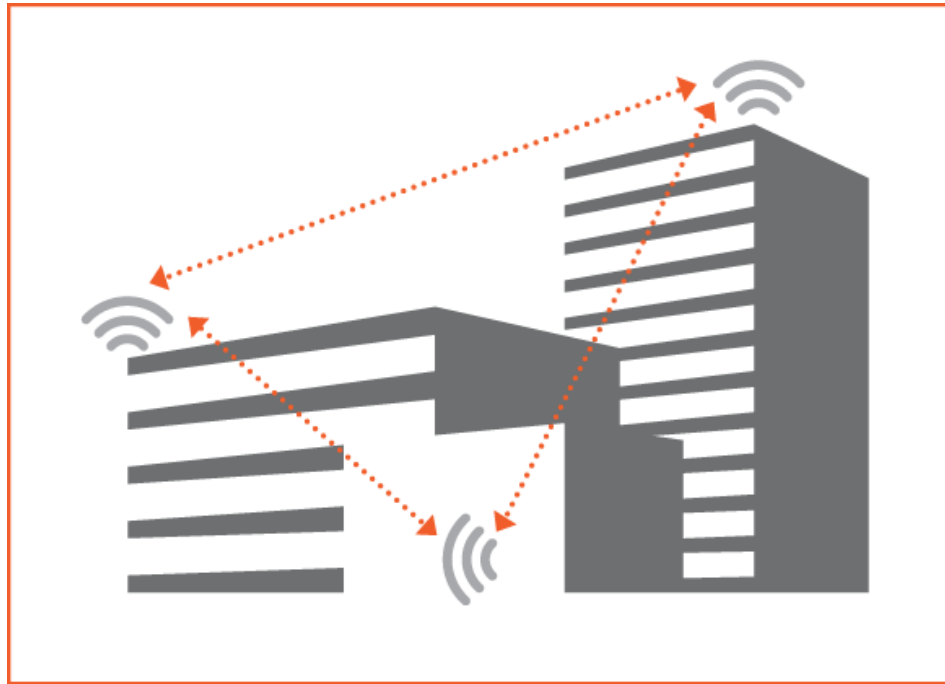


CONNECTED HOME – SHORT RANGE COVERAGE

## What is Transmit Beamforming?

Transmit beamforming (Tx BF) is a technique implemented in digital signal processing (DSP) logic to improve range and data rate for a given client, or device. In a basic system (single stream), Tx BF works on the principle that signals sent on separate antennas can be coordinated to combine constructively at the receive antenna. Specifically, the phases of the transmit signals are manipulated to improve directivity. Tx BF is specified in the IEEE 802.11n specification and takes advantage of the multiple transmit antennas available in a multiple input, multiple output (MIMO) system. Efficient steering of individual streams in such a system provides overall gain. This can be achieved through knowledge of the channel between the transmitter and receiver. Thus, it can be viewed as a form of transmit diversity with a known channel.

In a typical 802.11 system, an AP beamforms to the client and provides increased gain at the client. This leads to higher data rates and reduced number of retries, which in turn can increase the overall capacity of the system and lead to more efficient use of the spectrum. The gain improvement can be up to 12dB, and range improvement can be up to twice that of a system without beamforming—in the case of a 4 transmit antenna system beamforming to a 1 receive antenna system. Also, Tx BF provides maximum benefit in an asymmetrical system, where the number of transmit antennas is different from the number of receive antennas.



**BUSINESS PARK - LONG RANGE COVERAGE**

## Implementation

Implementation of Tx BF requires a system with two or more antennas at the transmitter—the basic case being a two Tx system transmitting a single stream. Tx BF is implemented at the baseband level on each subcarrier of the OFDM system; therefore, it is a per packet-based implementation.

Implementation involves computation of the steering matrix (transmitter weights applied to the transmitted signal) used to steer the signal for a specific client. The weights, in turn, are derived from knowledge of channel, also known as Channel State Information (CSI). Actual implementation varies from chip vendor to chip vendor. The end that applies the steering matrix to transmitted signal is called the beamformer (BFer), and the other end, which the BFer is steering toward, is called the beamformee (BFee).

In general, beamforming does not require the BFee to be aware of beamforming occurring at the BFer. In this case, the BFee cannot and does not provide any feedback to help improve directivity. Assuming the channel is reciprocal (i.e., identical in uplink and downlink directions), the BFer then estimates the channel at its end based on receive signals. It uses these estimates to generate the steering matrix used to steer the outgoing signals.

While it is not the 802.11n standards-based implementation, the primary advantage of this method is that beamforming can be done regardless of the BFee being an 802.11n or a legacy device, since the

process is completely transparent to the client. Also, it does not add a feedback overhead in the system. Thus, the overall gain achieved can be significant.

## Implicit vs. Explicit Beamforming

The 802.11n standard defines two types of implementation of Tx BF: implicit feedback and explicit feedback.

The standard also defines a process called “sounding” of the channel by which the Channel State Information (CSI) is determined. A sounding packet is also defined for this purpose. However, since Tx BF as a technology does not need BFee feedback, sounding packets are an optional feature in the standard, not requiring the BFee to be able to process an NDP or a packet with a staggered preamble, which is the case in legacy systems.

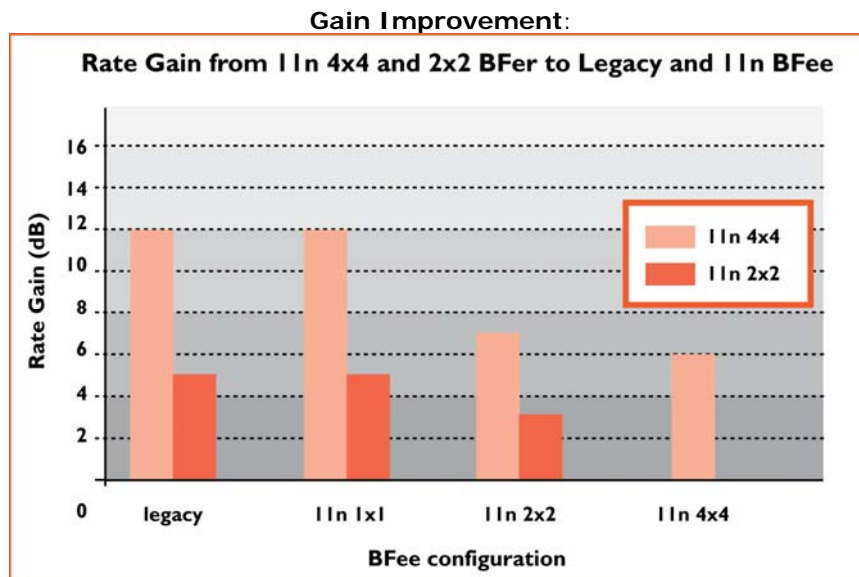
### Implicit feedback:

Implicit feedback Tx BF is based on the assumption that the channel between the BFer and BFee is reciprocal (i.e., identical in uplink and downlink directions). The BFer transmits a training request (TRQ), which is a standard packet in 802.11, and expects to receive a sounding packet in response. Upon receiving the sounding packet, the BFer estimates the receive channel and computes the steering matrix that it will use to steer subsequent transmissions to this BFee in the transmit direction. This method, however, requires computation of correction matrices in order to eliminate any mismatch between the uplink and the downlink channels; in other words, it requires calibration to maintain the reciprocity of the channel.

### Explicit feedback:

In explicit beamforming, the BFee estimates the channel upon transmission of a sounding packet by the BFer. Depending on the implementation, the BFee responds with raw channel estimates or computes the steering matrix and feeds it back to the BFer in compressed or uncompressed forms. In case raw channel estimates are transmitted, the computation of the steering matrix occurs at the BFer. This method provides very reliable steering matrices since the actual channel between the BFer and the BFee is estimated.

## How Does It Perform?



**Range Improvement:**

From BFer	To BFer	Range Improvement
11n 4x4	legacy	1x to 2x
11n 4x4	11n 1x1	2x to 3x
11n 4x5	11n 2x2	1.9x
11n 4x6	11n 4x4	1.6x
11n 2x2	legacy	1x to 1.7x
11n 2x3	11n 1x1	1.7x
11n 2x4	11n 2x2	1.1x to 1.5x

Tx BF provides up to 12 dB of perceptible gain in over-the-air tests in home and enterprise environments. It also increases the rate at range of high-definition (HD) video streaming applications by about 2x their current range with the same bandwidth. Due to extended range, it is possible to run higher order modulation schemes at cell edges than before, thus increasing the overall capacity of the system.

## Limitations

Standards based beamforming adds a feedback overhead in the system. Also, since CSI is changing from time to time, especially with motion of either AP or client, the steering matrix needs frequent updating. Additionally, it operates on a per-client basis. Since broadcast signals cannot be optimized, which would include beacons, the overall maximum range of the AP cannot be increased using only beamforming. 2x2 systems get only a modest benefit from Tx BF since they only have the minimum required antennas.

However, 4x4 systems are becoming the defacto configurations in APs, thus making the 2x2 limitation non-existent. For systems that do implement 2x2 APs, it is only a marginal design change to the system with potential to provide better gain than if it were implemented without. Additionally, since most enterprise APs and hotspots already deploy MIMO systems, which are now emerging in home APs as well, it is more beneficial to implement beamforming than not. Finally, referring to the aforementioned use case scenario, where the AP and a client such as a TV are relatively fixed, per-client improvement is highly desirable.

## Conclusion

Tx BF is a major technology upgrade with minimal change to an existing system. The benefit of range and rate improvements are essential to provide a satisfactory user experience given today's rich media content-focused demands. The gains that it can provide far outweigh its limitations.

## Marvell's Commitment

Marvell is committed to providing cutting-edge technology to its customers by adopting technologies that provide the most benefits to its customers, and in turn to theirs.

In early 2011, Marvell announced that the entire family of Marvell Avastar™ 802.11n solutions will leverage Tx BF technology to dramatically improve link robustness for clients ranging from new and existing 1x1- 4x4 MIMO products to legacy devices. Specific product examples include:

- **Avastar 88W8797** Integrated 2x2 WLAN/Bluetooth/FM Single-Chip SoC--The first high-performance multiple-input multiple-output (MIMO) Wi-Fi + Bluetooth + FM combination radio

with advanced power management designed specifically for next-generation handheld products. Ideal for tablets and smartphones, the Avastar 88W8797 also allows communication with a new breed of mobile devices, including body sensors for personal health monitoring and remote controls for home automation. It is also well-suited to other products that require MIMO Wi-Fi performance such as home media servers, Blu-ray players, set-top-boxes, and digital televisions.

- **Avastar 88W8787** WLAN/Bluetooth/FM Single-Chip SoC--A highly integrated system-on-a-chip (SoC), specifically designed to support high throughput data rates for next-generation products. The Avastar family of wireless devices delivers best-in-class single-function and multi-function radios for the entire spectrum of always-on consumer electronics devices, including WLAN/Bluetooth/FM enabled cellular handsets, portable audio/video devices and accessories, personal navigation devices, personal digital assistants, gaming platforms.
- **Avastar 88W8782** WLAN Single-Chip SoC --A highly integrated wireless local area network (WLAN) system-on-chip (SoC) specifically designed to support high throughput data rates for next-generation WLAN products. The Avastar family includes single-function and multi-function radios that establish new industry benchmarks for power consumption, wireless performance, solution footprint and advanced features. The Avastar 88W8782 is designed to support IEEE 802.11a/g/b and 802.11n payload data rates. The device provides the combined functions of DSSS and OFDM baseband modulation, MAC, CPU, memory, host interfaces, and direct-conversion WLAN RF radio on a single integrated chip, for imaging platforms, gaming platforms, CE devices, cell phones, eReaders, and more.
- **Avastar 88W8766** Integrated WLAN/Bluetooth Single-Chip SoC--Another highly integrated wireless local area network (WLAN) system-on-chip (SoC), specifically designed to support high throughput data rates for next generation WLAN products. This device is designed to support IEEE 802.11a/g/b and 802.11n payload data rates. The device also supports Bluetooth 4.0+High Speed (HS) and Bluetooth Low Energy (BLE). The device provides the combined functions of DSSS and OFDM baseband modulation, MAC, CPU, memory, host interfaces, and direct-conversion WLAN RF radio with integrated 2.4 GHz PA and T/R switch on a single chip, for laptops/notebooks, imaging platforms, gaming platforms, and CE devices.
- **Avastar 88W8764** Integrated 4x4 MAC/Baseband/RF MIMO SoC--A highly integrated 4x4 wireless local area network (WLAN) system-on-chip (SoC), specifically designed to support high throughput data rates for next generation WLAN products. The device is designed to support IEEE 802.11n/a/g/b payload data rates. The Avastar 88W8764 provides the combined functions of DSSS, OFDM, and MIMO baseband modulation, MAC, on-chip CPU, memory, host interfaces, and direct-conversion WLAN RF radio on a single integrated chip. The device supports 802.11n beamformer and beamformee functionality, enabling a simplified, integrated solution, for PCs, wireless gateways/routers/access points, wireless client cards/bridges, and wireless home A/V systems.

By incorporating Marvell's Tx BF technology, the award-winning Avastar products deliver significant range and throughput performance. The Tx BF technology does not require special antennae or any other cost increase of the wireless subsystem and provides greater than 10dB of perceivable gain in over-the-air tests in home and enterprise environments. This gain translates to an increased throughput of 2x depending on the environment. Beamforming outperforms other DSP techniques for range extension like LDPC by at least 6 times.

Leveraging its leadership in design, connectivity and performance in its portfolio of Tx BF compatible products, Marvell is becoming the "flag bearer" for this technology. For more information on Marvell products, visit [www.marvell.com](http://www.marvell.com).

## About the Author

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Bhama Vemuru is a member of the technical marketing team of Marvell's Connectivity Business Unit. She has more than eight years of experience working with various wireless technologies. Most recently, she was a Senior Wireless Systems Engineer in Marvell Research & Development, and she previously worked in CDMA and ATM technologies at Wipro India. Bhama is a graduate of Osmania University in India and holds a Masters degree in Electrical Engineering from UCLA. In her current role, Bhama has technical marketing, program and product management responsibilities for leading Marvell customers.

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