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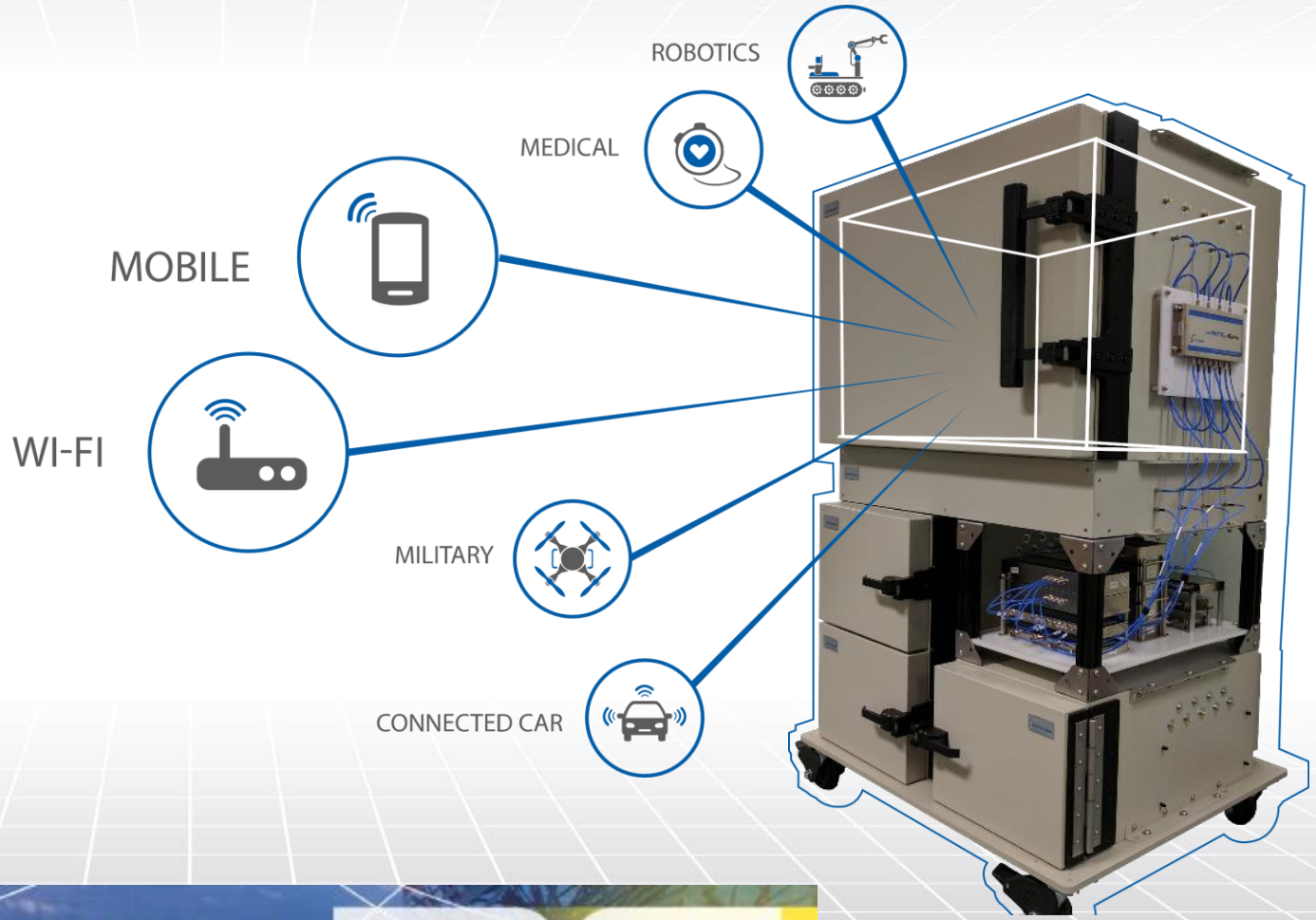
Wireless personal testbeds

The importance and the challenge of Over The Air testing in current and future wireless technologies

April 2018



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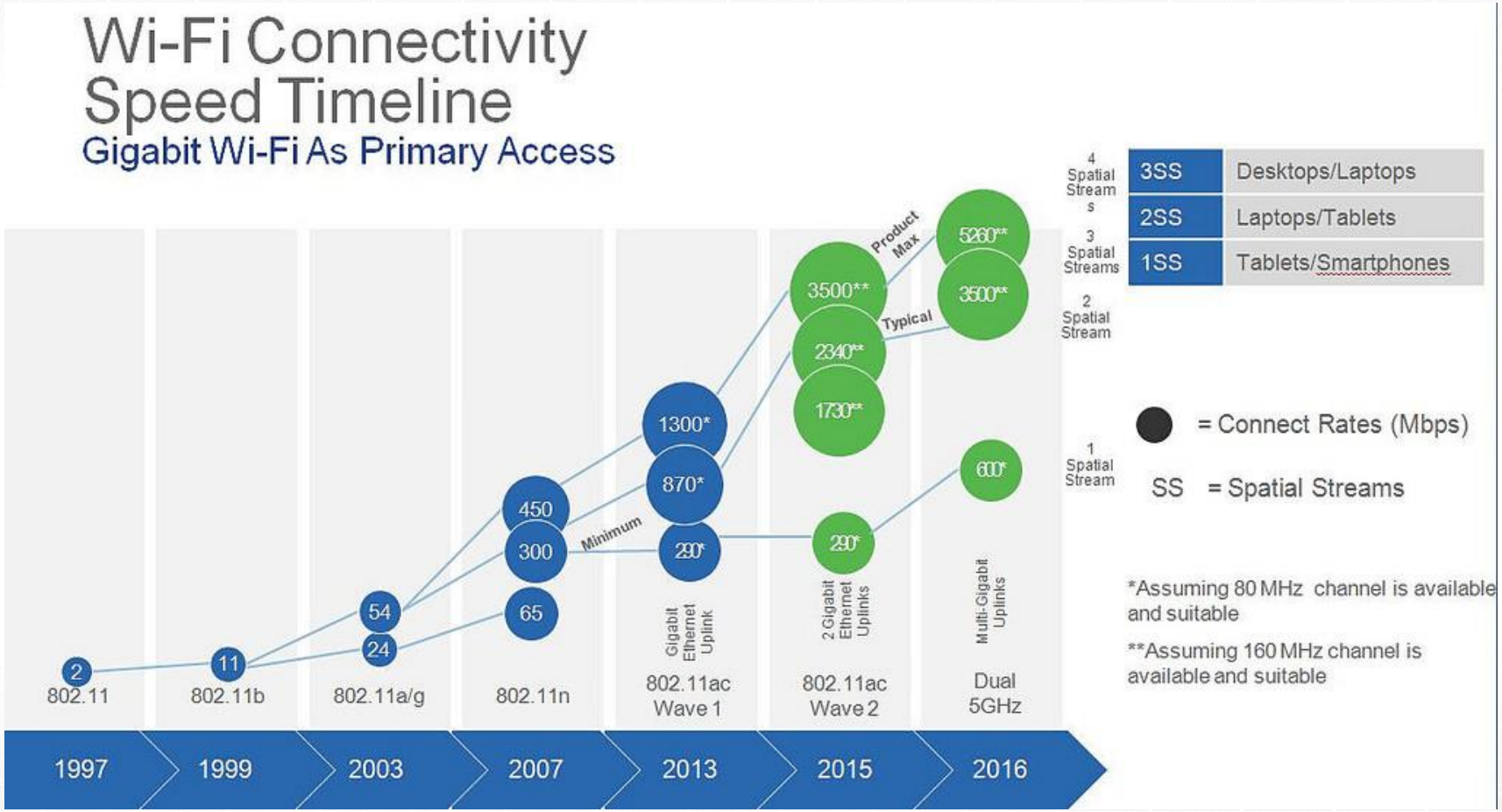
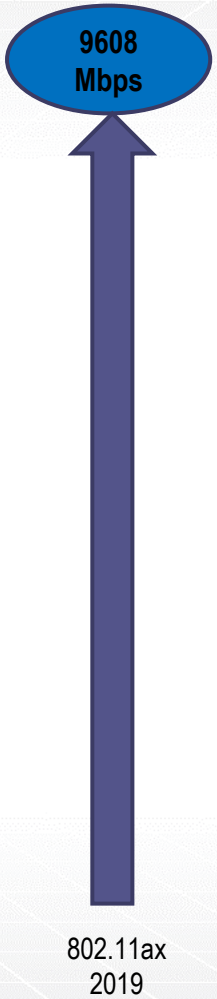
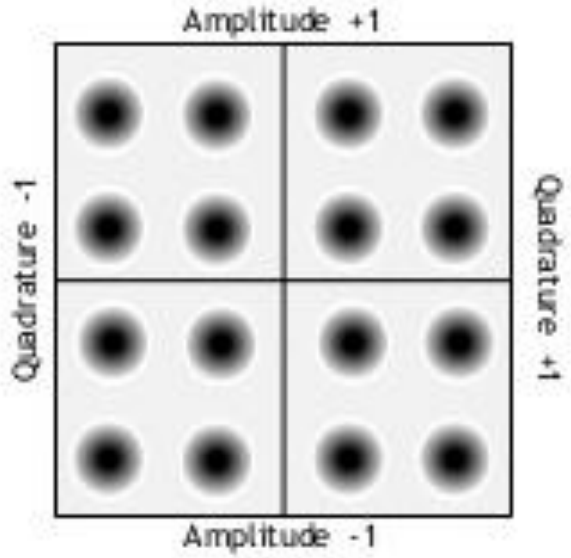


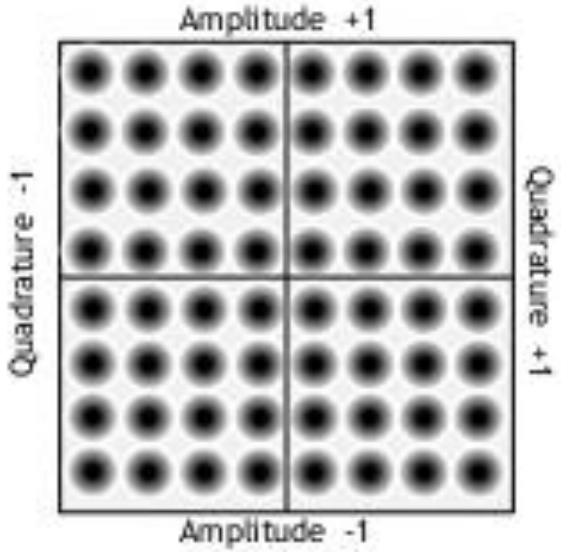


What enables these high data rate?



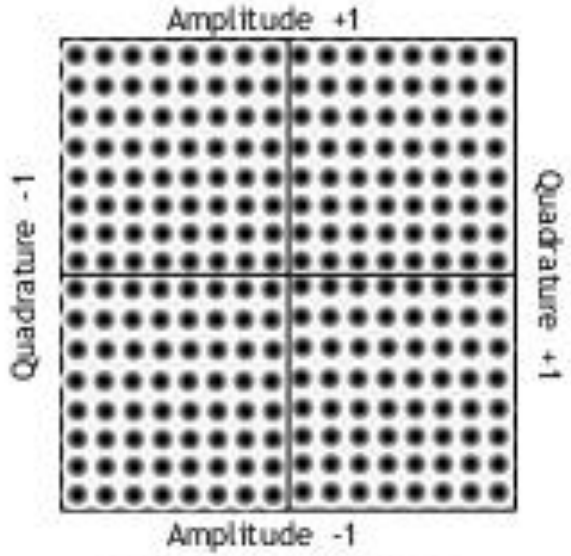
16-QAM constellation

4 bits/symbol



64-QAM constellation

6 bits/symbol



256-QAM constellation

8 bits/symbol

Adding more modulations gets you part of the way there…

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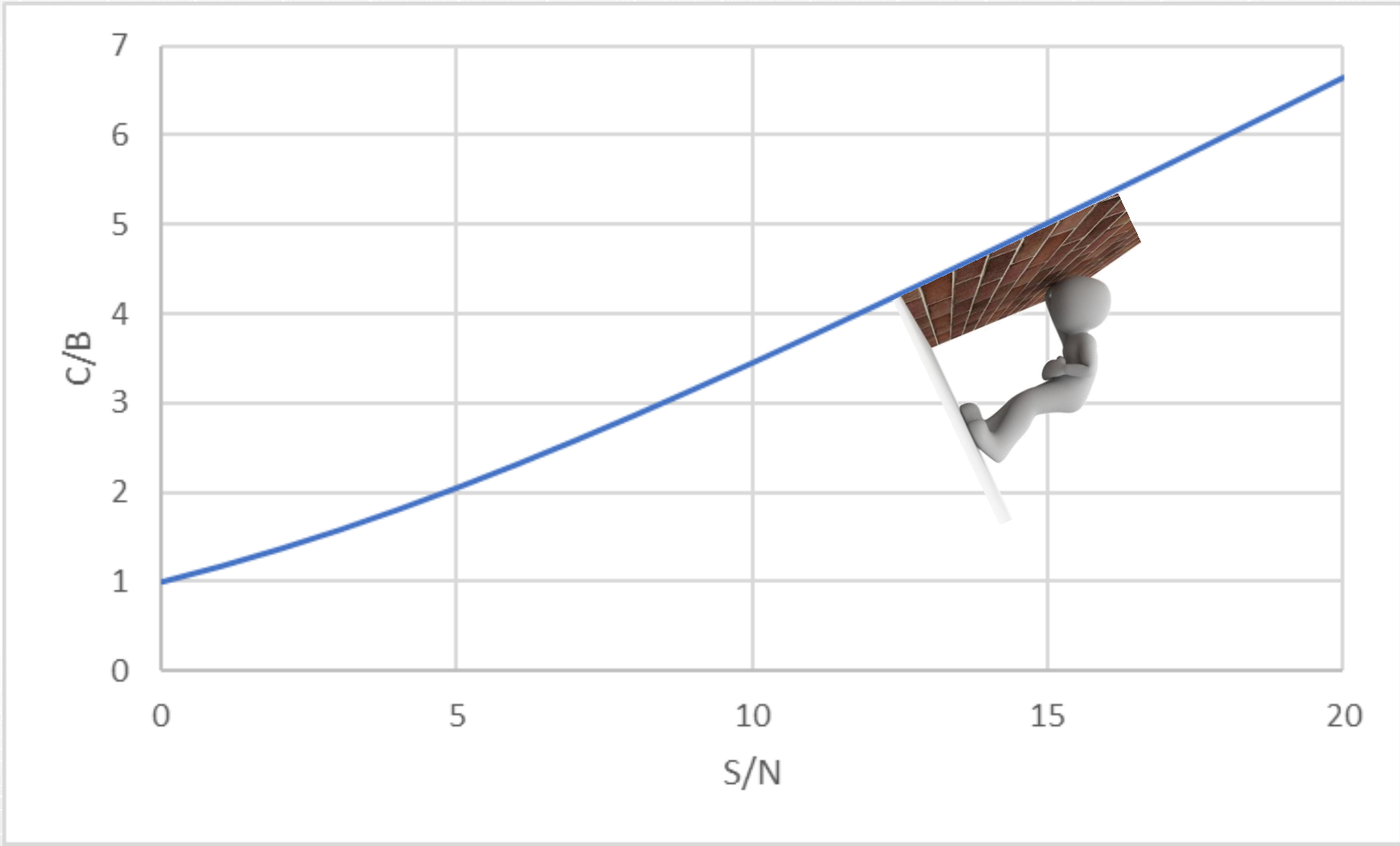
But you eventually run up against the Shannon Limit



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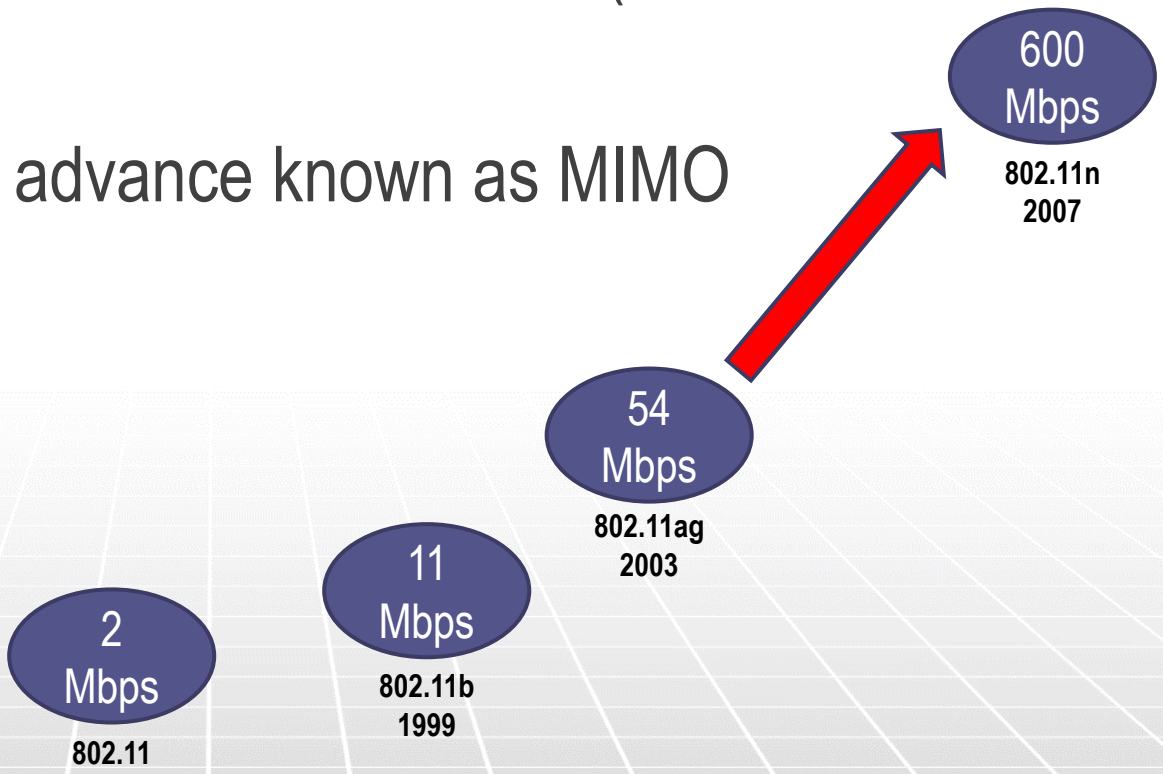
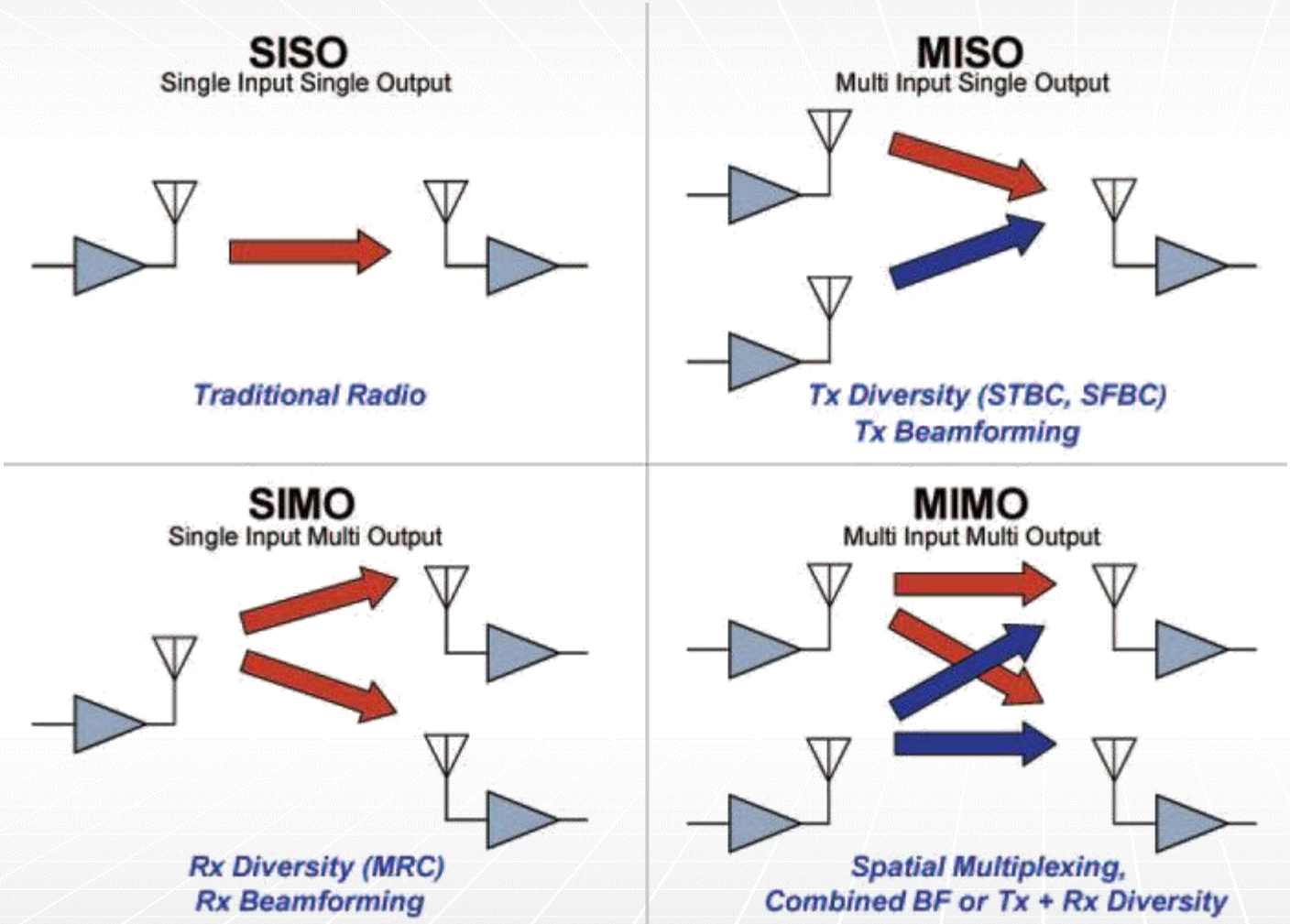
MIMO and beamforming to the rescue

- From 802.11g to 802.11n, Wi-Fi experienced an order of magnitude increase in data rates
  - From 54 Mbps to 600 Mbps
- Some of this was enabled by increased bandwidth (20 MHz to 40 MHz channels.)
- Most of it was enabled by the advance known as MIMO

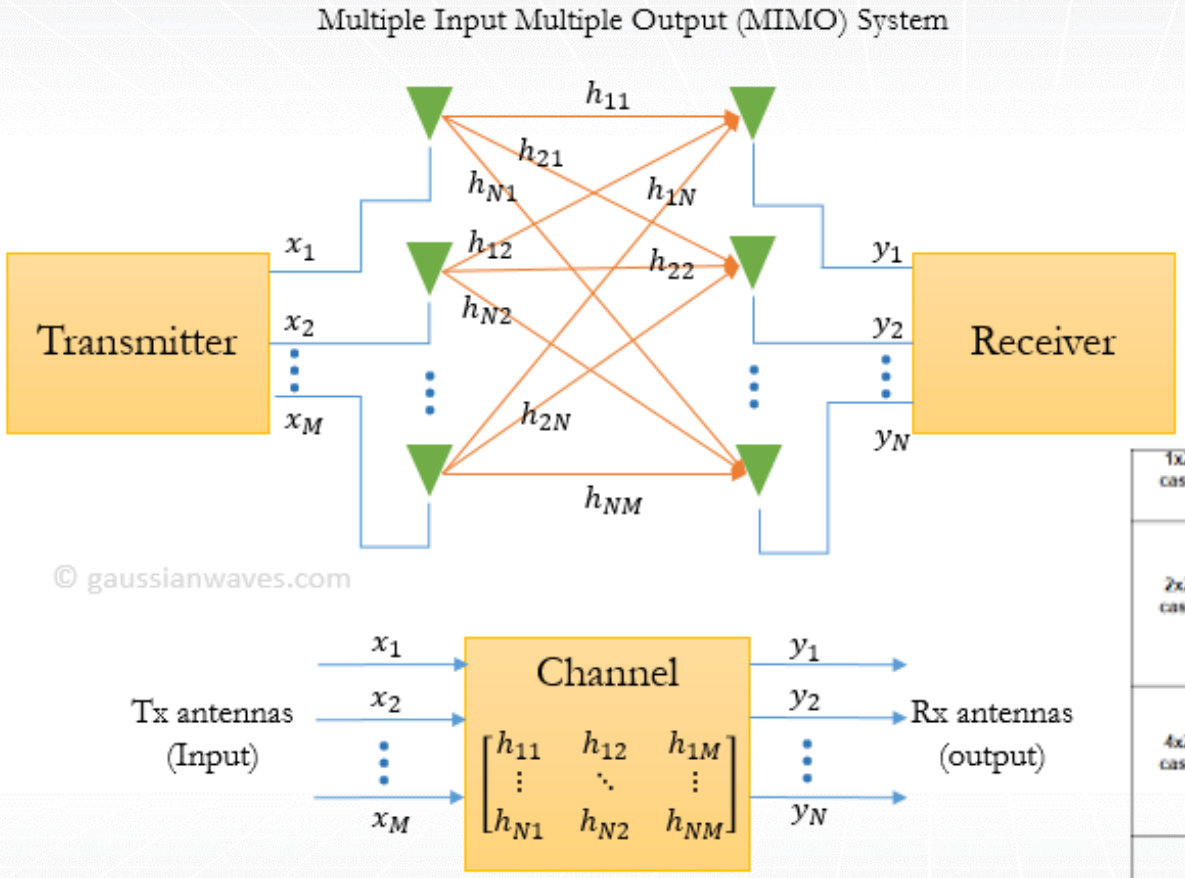


Quick refresher on MIMO



- In a MIMO system, multiple streams of information are sent, and received, using the same spectrum
- The signals are all mixed up at the receiver, and they need to be unmixed
- Notice that every transmit antenna has a channel to every receive antenna
- MIMO complexity grows as the product of the number of antennas

MIMO complexity grows with the number of streams

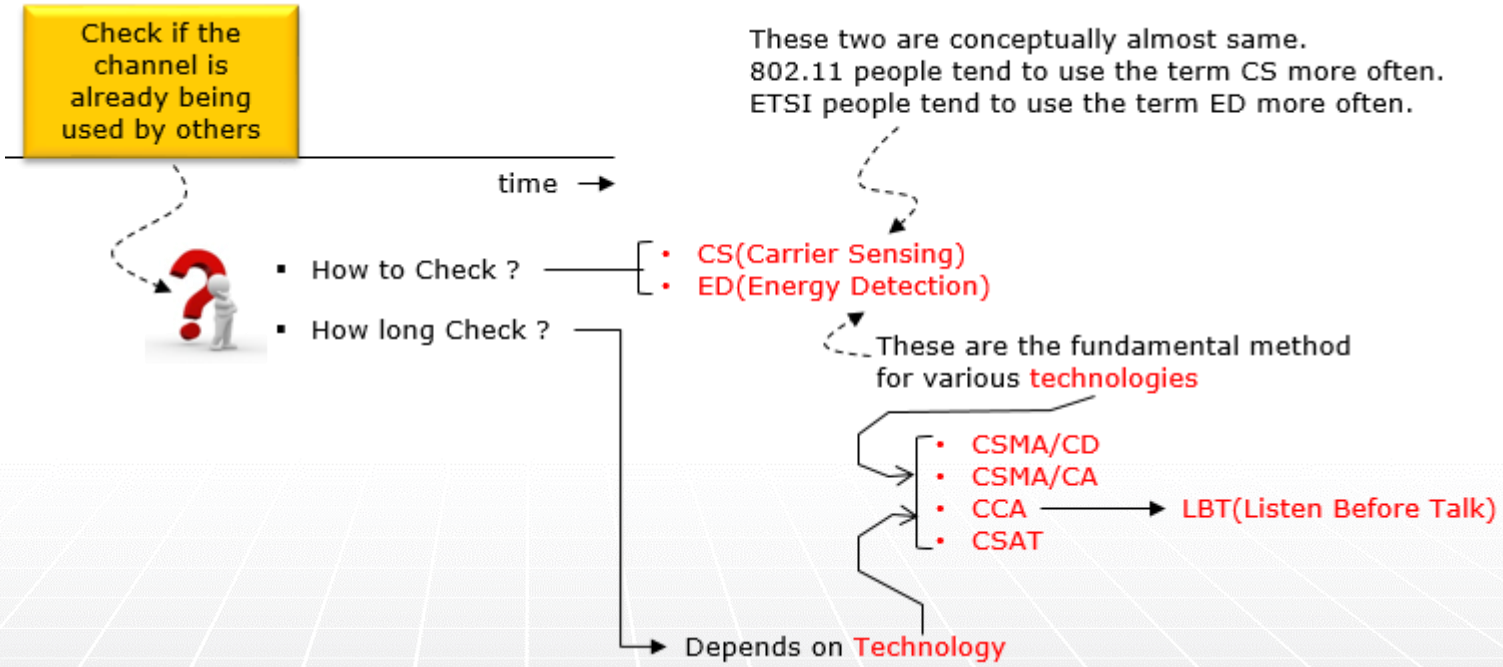


- But when it works in the ideal case, you can increase your throughput (nearly) linearly with the number of streams

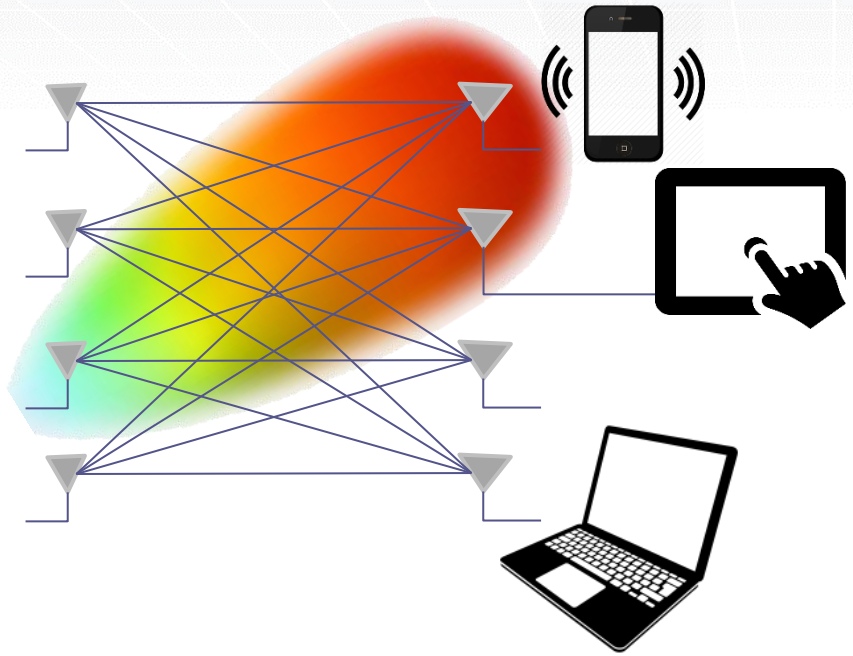
1x2 case	$R_{rx1} = R_{rx} = \begin{bmatrix} 1 & \beta \\ \beta^* & 1 \end{bmatrix}$
2x2 case	$R_{rx2} = R_{tx2} \otimes R_{rx} = \begin{bmatrix} 1 & \alpha \\ \alpha^* & 1 \end{bmatrix} \otimes \begin{bmatrix} 1 & \beta \\ \beta^* & 1 \end{bmatrix} = \begin{bmatrix} 1 & \beta & \alpha & \alpha\beta \\ \beta^* & 1 & \alpha\beta^* & \alpha \\ \alpha^* & \alpha^*\beta & 1 & \beta \\ \alpha^*\beta^* & \alpha^* & \beta^* & 1 \end{bmatrix}$
4x2 case	$R_{rx4} = R_{tx4} \otimes R_{rx} = \begin{bmatrix} 1 & \alpha^{1/3} & \alpha^{2/3} & \alpha \\ \alpha^{1/3} & 1 & \alpha & \alpha^{2/3} \\ \alpha^{2/3} & \alpha & 1 & \alpha^{1/3} \\ \alpha & \alpha^{2/3} & \alpha^{1/3} & 1 \end{bmatrix} \otimes \begin{bmatrix} 1 & \beta \\ \beta^* & 1 \end{bmatrix}$
4x4 case	$R_{rx4} = R_{tx4} \otimes R_{rx} = \begin{bmatrix} 1 & \alpha^{1/3} & \alpha^{2/3} & \alpha \\ \alpha^{1/3} & 1 & \alpha & \alpha^{2/3} \\ \alpha^{2/3} & \alpha & 1 & \alpha^{1/3} \\ \alpha & \alpha^{2/3} & \alpha^{1/3} & 1 \end{bmatrix} \otimes \begin{bmatrix} 1 & \beta^{1/3} & \beta^{2/3} & \beta \\ \beta^{1/3*} & 1 & \beta^{1/3} & \beta^{2/3} \\ \beta^{2/3*} & \beta^{1/3*} & 1 & \beta^{1/3} \\ \beta^* & \beta^{2/3*} & \beta^{1/3*} & 1 \end{bmatrix}$

MIMO enables more than just higher data rates

In “traditional” Wi-Fi, an AP could only talk to one device at a time. All other devices had to wait their turn.

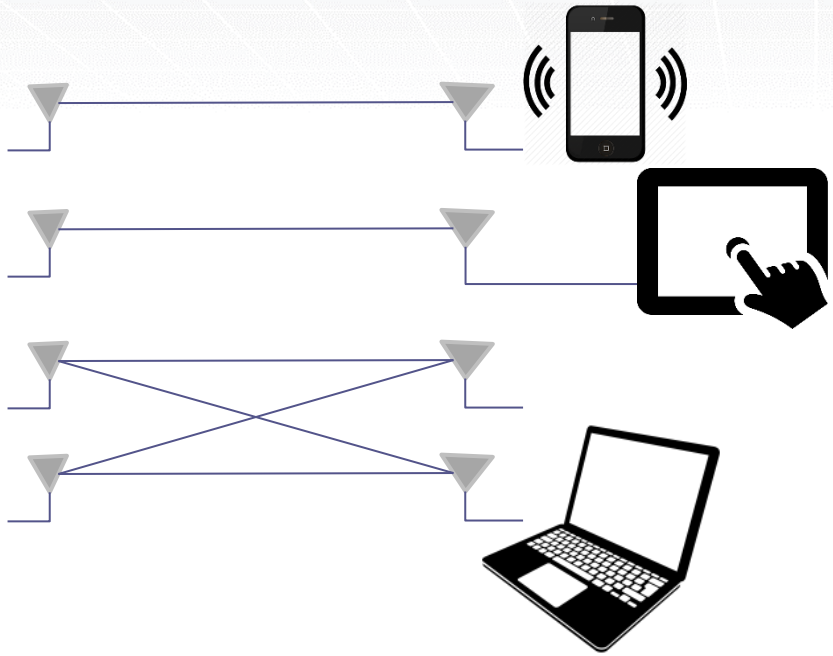


Single user MIMO behaves as does “classic” Wi-Fi



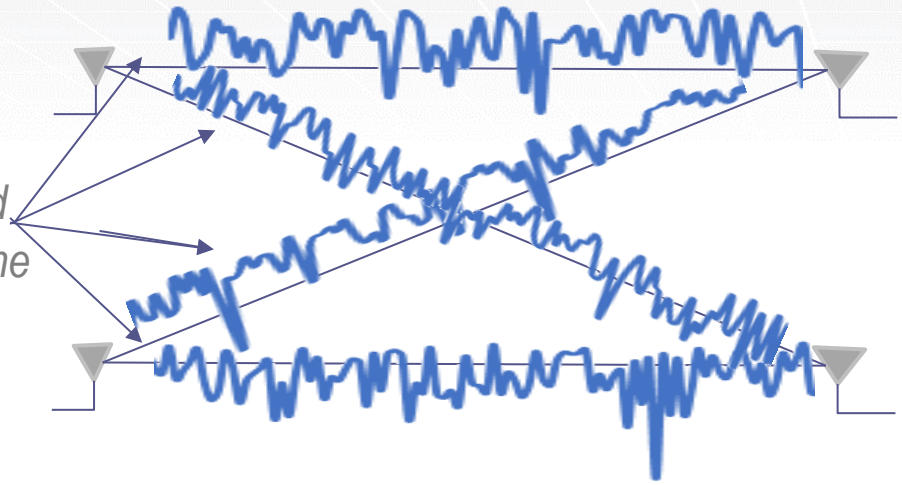
- MIMO streams could only be directed to one device at a time
  - Tx/Rx combinations are used to enhance either throughput or range, or a combination

Multi user MIMO lets Wi-Fi overcome the “one-at-a time” limit



- Multi-user (“MU”) MIMO lets an AP use its MIMO streams at the same time…
- …but use them for different users
- Dramatically increase the capacity of 802.11
  - Eliminates the “only one user at a time (per channel)” limitation of Wi-Fi

MIMO as compared to beamforming

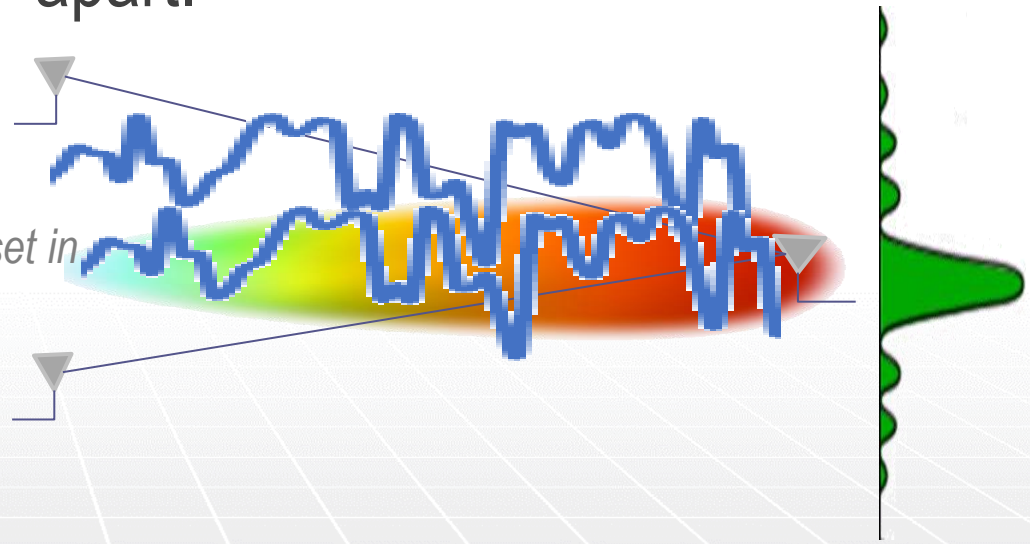


Highly uncorrelated signals, in the ideal case.

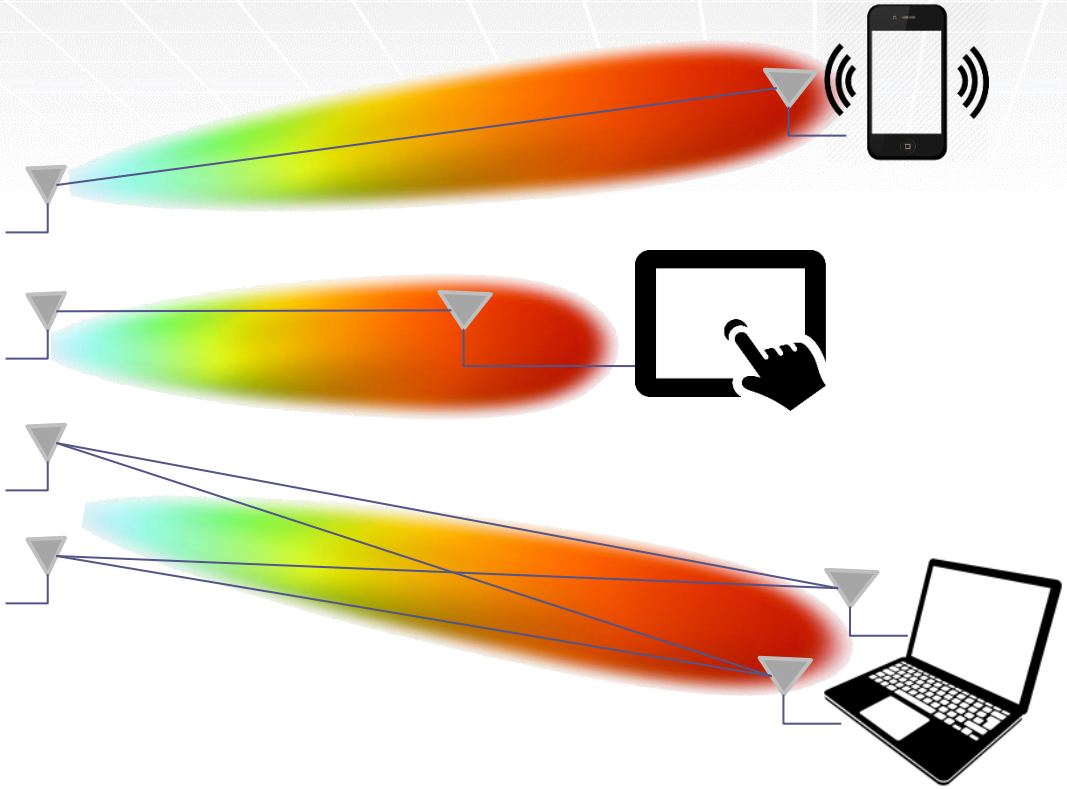
- **MIMO:** Treats “space” as another dimension for separating data. (Like frequency or time.)
  - The more different the signals are, the easier they are to tell apart.

- **Beamforming:** Uses phase to steer a signal to a specific direction in space.
  - Creates peaks and nulls based on the phase offset.

Highly correlated signals, offset in phase.



Multi-user MIMO uses beamforming

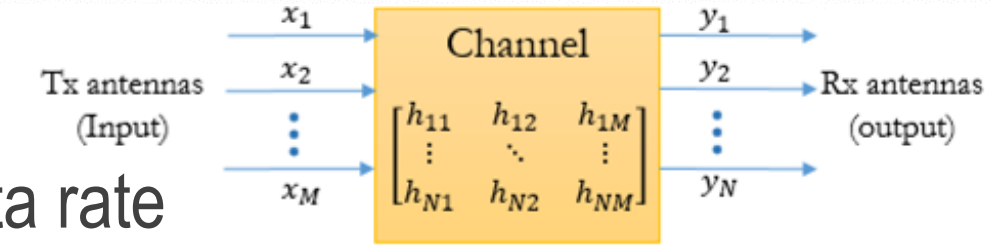


- "To keep the three transmissions separate, the AP uses beamforming to focus each of the transmissions toward its respective receiver. For this type of scenario to work, it is necessary that the receivers are located in different enough directions that focused transmissions avoid interfering with each other."

802.11ac, A Survival Guide, Matthew S. Gast, O'Reilly Publication

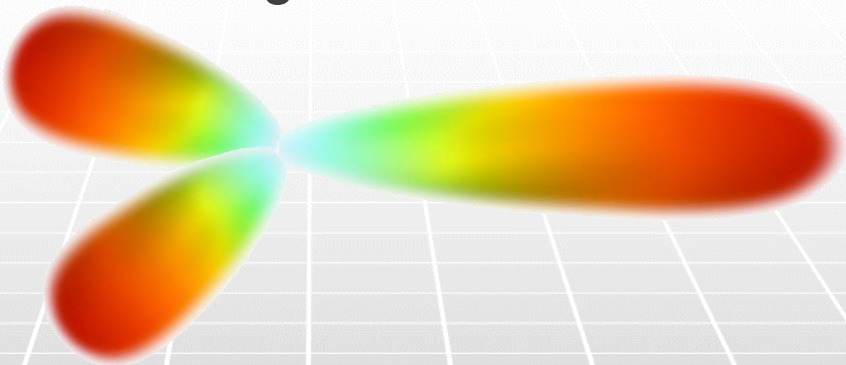
The importance of the RF domain

- Many of the advances in 802.11 performance have come from advances in the RF domain
- MIMO
  - Increases in data rate



- Beamforming
  - Increases in range

- MU-MIMO
  - Coupling MIMO with beamforming to enable increases in efficiency



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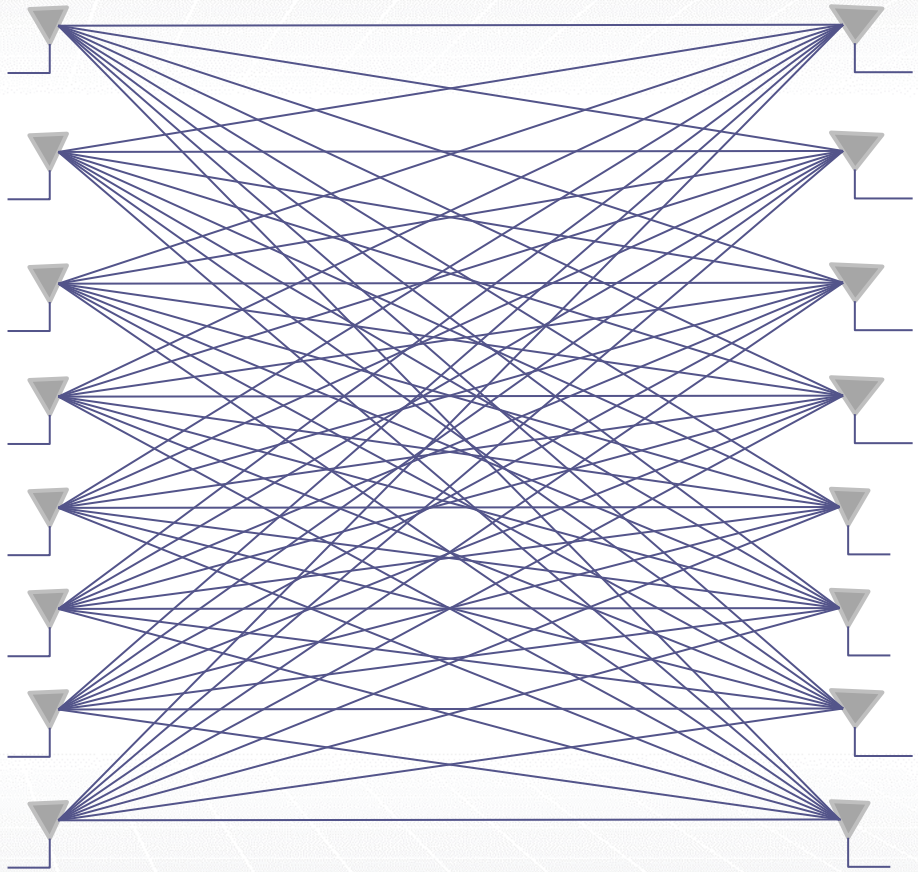
Conducted testing of MIMO systems is *hard*, and *expensive*

- "Typically, wireless channels are commonly emulated using time-varying Finite Impulse Response (FIR) filters…In fact, it is not uncommon in literature to present systems that reach a MIMO order of 8x8 and higher…To support these emerging trends and provide accurate characterization of the system performance over an ever increasing set of possible channel configurations, it is imperative to design new emulation platforms that are highly scalable and computationally efficient in terms of the array size. ***This reality places FIR based approaches at a disadvantage since the complexity of the platform scales poorly with an increase in the MIMO array size.***"



Design and Implementation of a Scalable Channel Emulator for Wideband MIMO Systems.
Hamid Eslami, Student Member IEEE, Sang V. Tran, Ahmed M. Eltawil, Member IEEE

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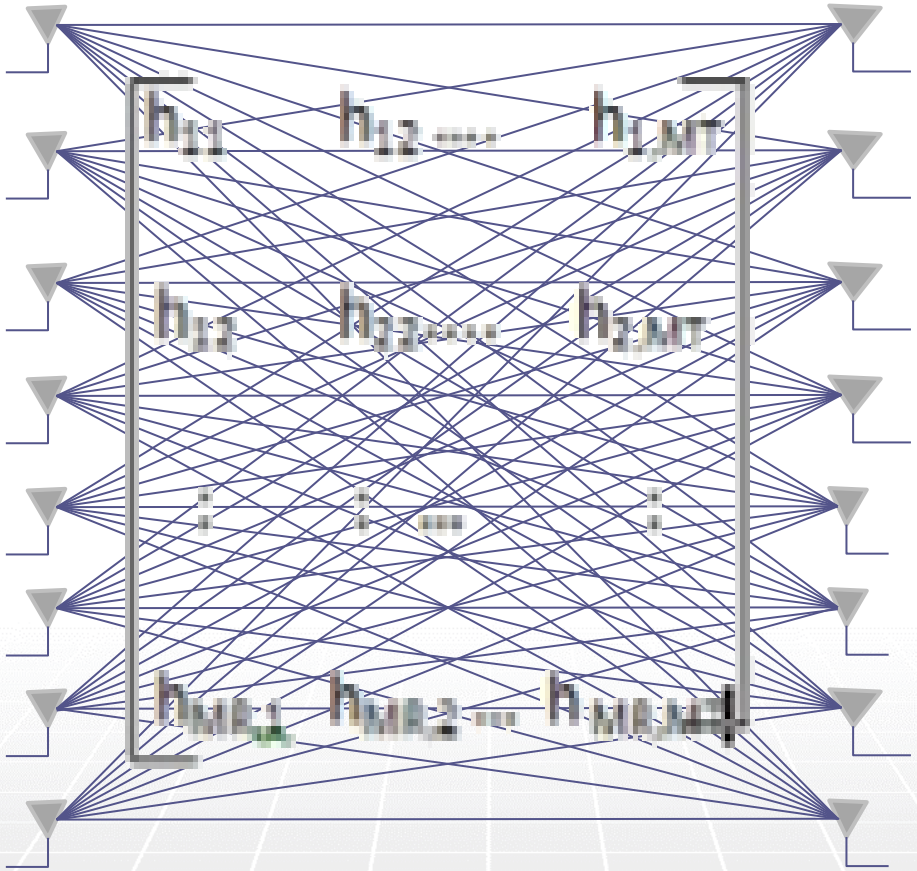
Because you have enable *all* of the possible connections

- Cabling antennas to each other only gives the diagonal terms of the correlation matrix



- Any terms off the diagonal require a large number of additional connections

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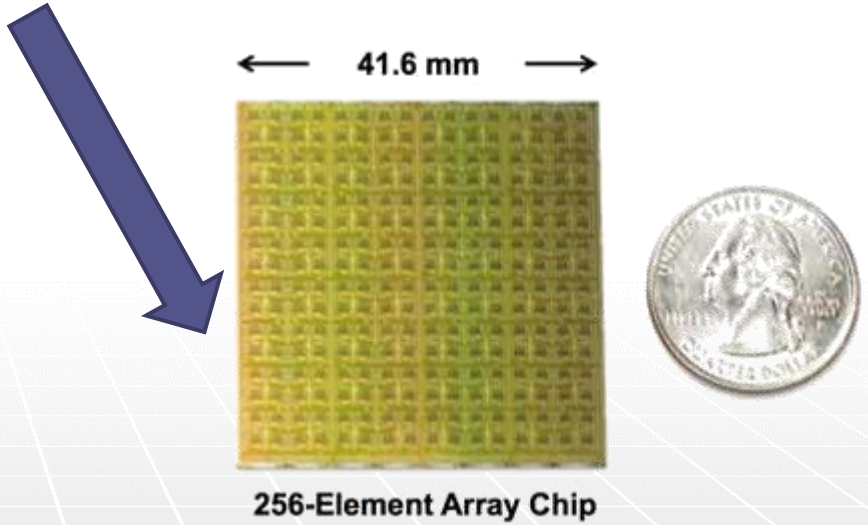
And MIMO scaling won't stop with 8 streams

- 802.11ax enables 8 streams of MIMO
- Wireless technologies are moving towards Massive MIMO, with 10s or 100s of streams
- The only way these devices can be tested is using OTA techniques



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All of which means that *over-the-air (OTA) testing is the only way*

- Highly integrated devices, with transceiver systems directly integrated with the antenna arrays
- No more connectors or probe points for conducted testing
- In addition, conducted testing becomes nearly impossible with hundreds of antenna elements
- And, the testing needs to be able to check beamforming capabilities, etc.
- THEREFORE: the vast majority of the testing for advanced Wi-Fi and 5G mmWave devices will need to be done Over The Air (OTA).

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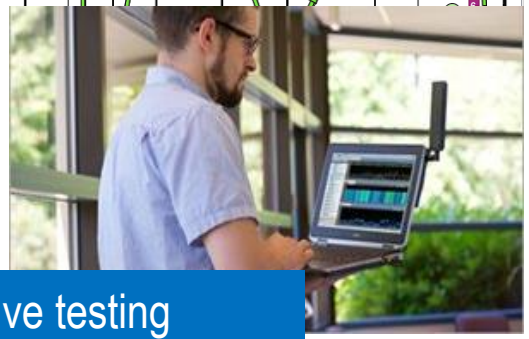
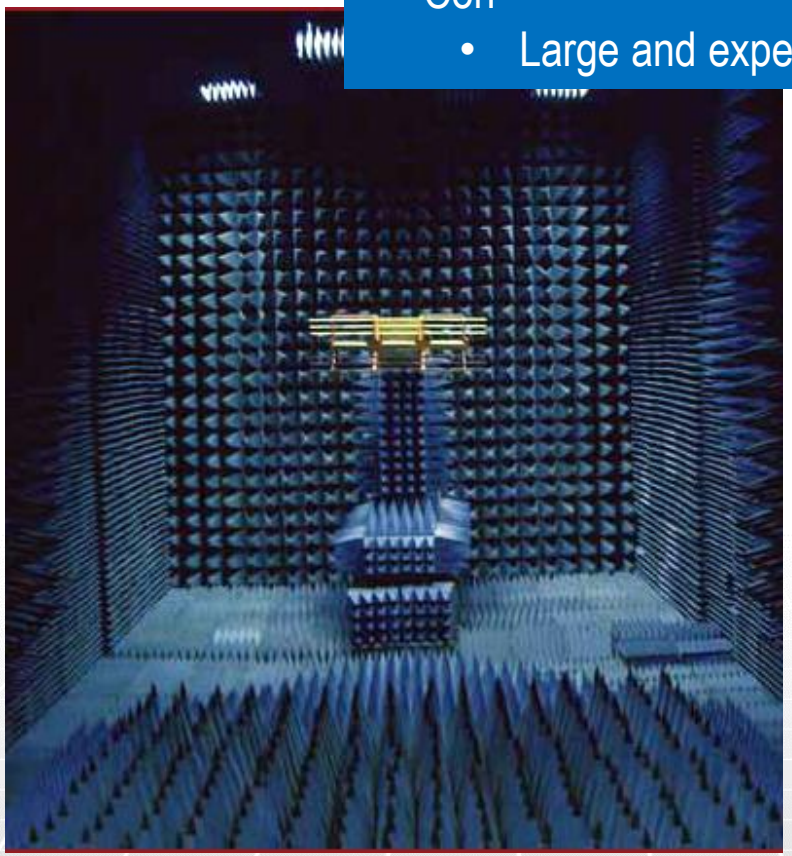
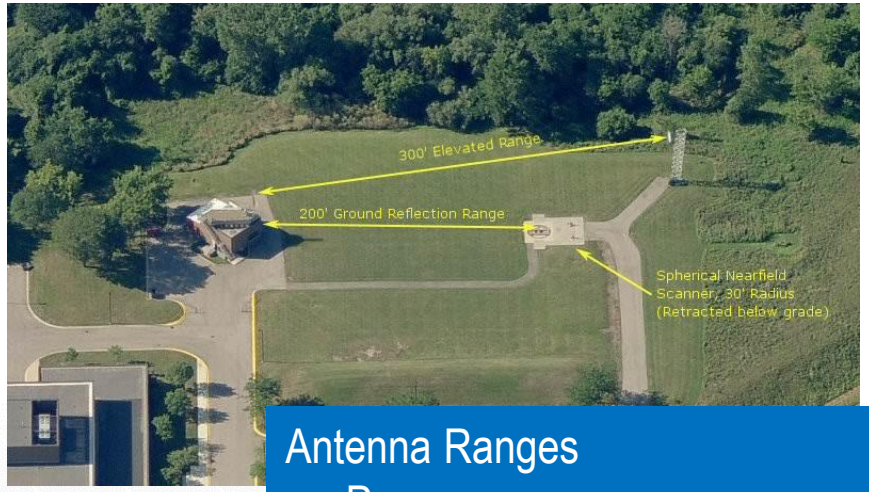
Traditional OTA Options



Walk/drive testing
- Pro
  - Real-world test
- Con
  - Interference



Anechoic Chambers
- Pro
  - Clean environment
- Con
  - Large and expensive



Antenna Ranges
- Pro
  - Large devices
- Con
  - Very expensive and hard to use

octoScope octoBox wireless testbed

- Reduce wireless test time from weeks to hours
  - Complete isolation and repeatable RF environment minimizes time-consuming open-air testing
  - Automation accelerates data collection, improves test coverage and product quality
- Demonstrate highest achievable performance
  - Ideal MIMO environment for highest possible throughput
  - Supports latest technologies, such as 160 MHz 802.11ac, 802.11ax, MU-MIMO and Beamforming
- Qualify User Experience
  - Emulate real-world challenges
  - Programmable range of condition from best MIMO environment to challenging real-life impairments

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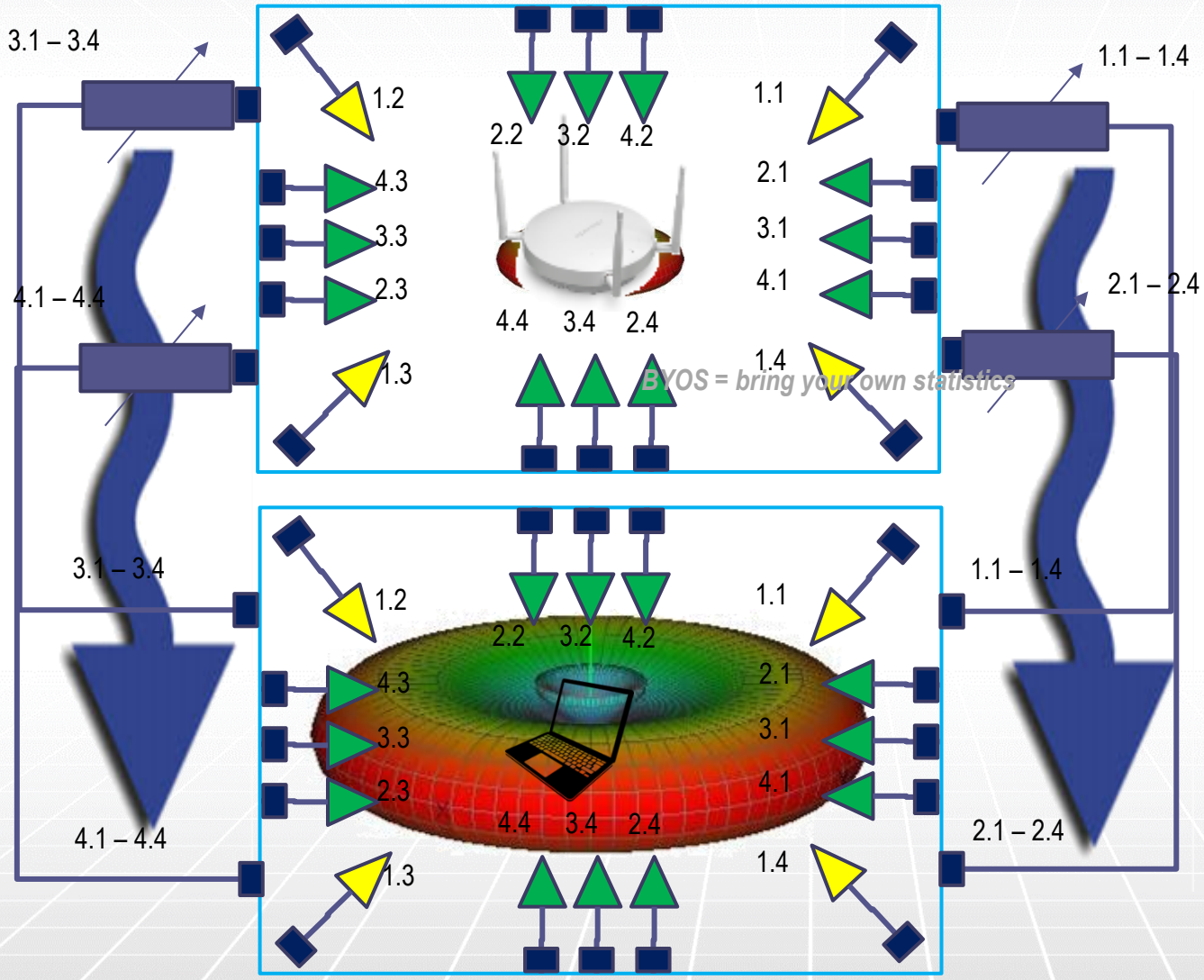
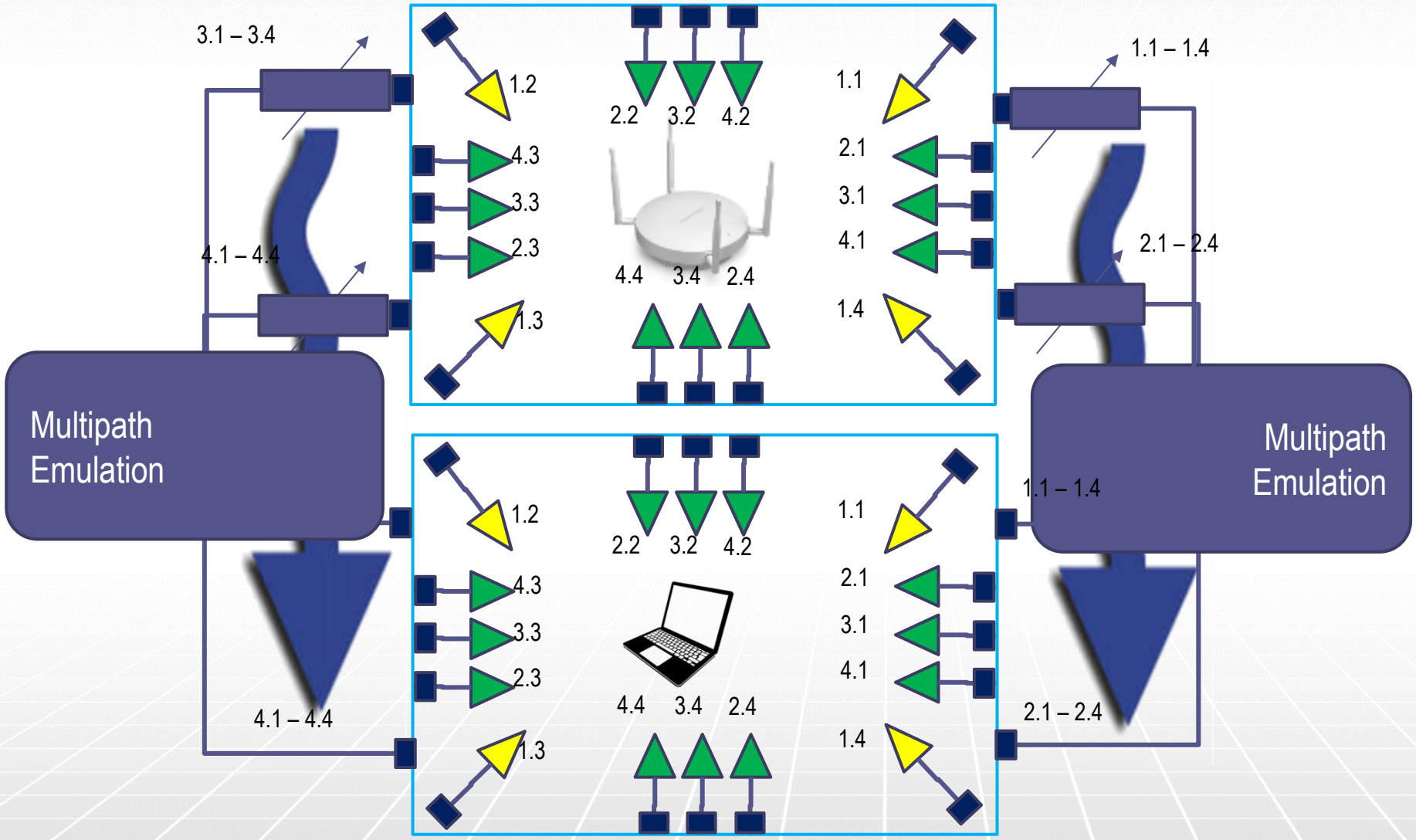
OTA testing creates the off-diagonal terms naturally



- Many paths create a rich RF environment for MIMO testing
- As higher order MIMO modes become available (e.g. 8x8) a large number of paths are needed in order to have maximum MIMO gain

octoScope Multipath emulation creates a complete MIMO channel



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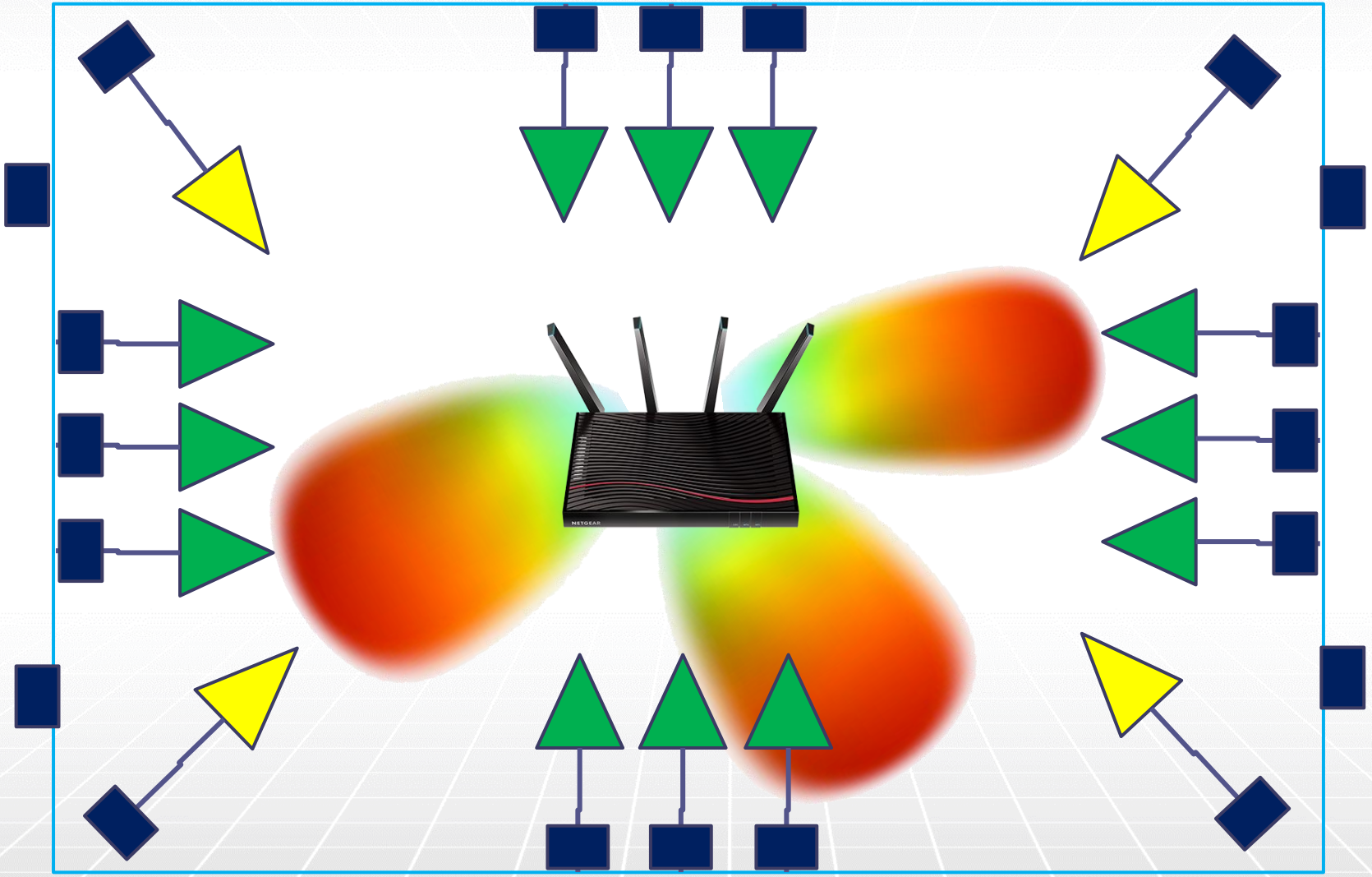
And OTA testing allows for beamforming and MU-MIMO testing



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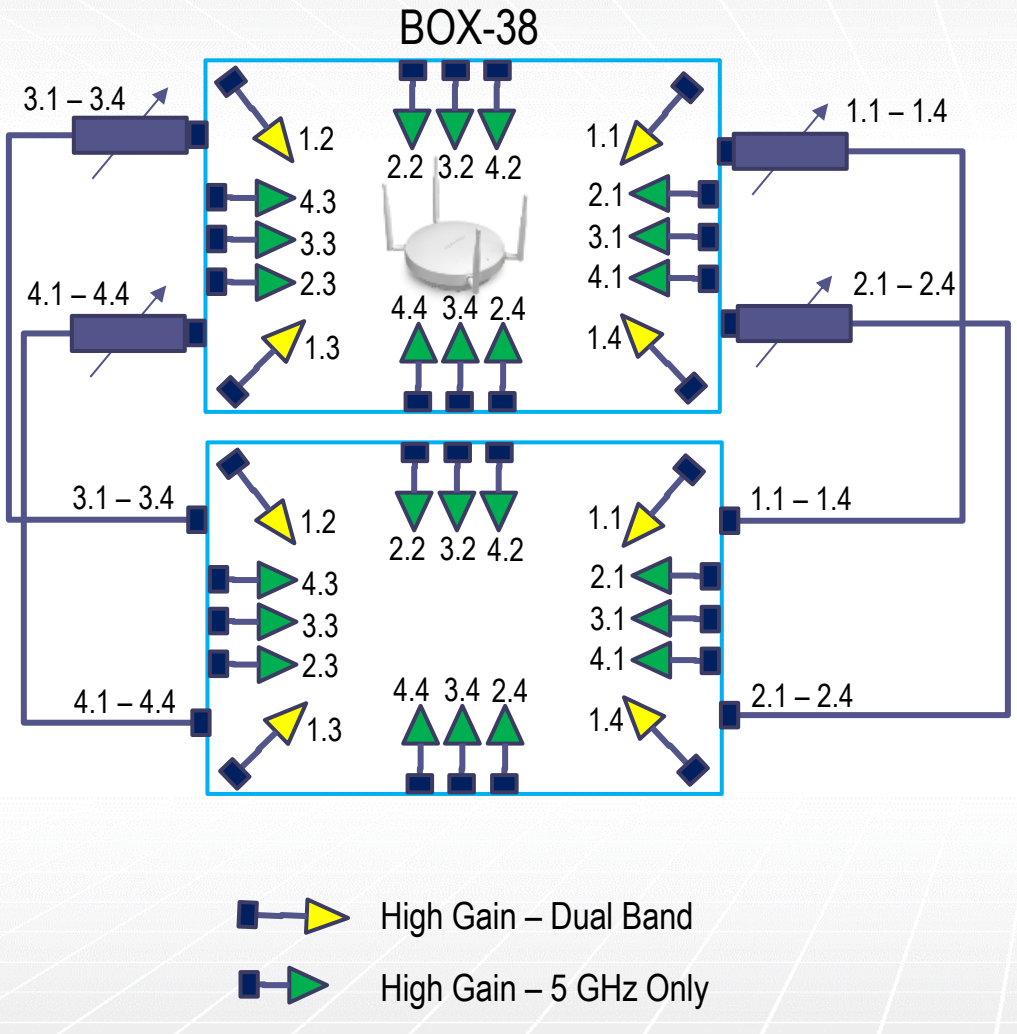
Personal testbeds for OTA



octoScope Summary

- MIMO and beamforming technologies make OTA testing absolutely essential
- Antennas are becoming more and more integrated with the transceivers, so performance testing must include the antennas
- As Wi-Fi evolves to 802.11ax, the challenges increase. 802.11ax will use 8 MIMO streams instead of the 4 MIMO streams used by 802.11ac
  - 5G technologies take this to a much higher level
- Multi-user MIMO (and OFDMA) will provide additional test challenges
- Developers, operators, and testers need simple test setup that can test complicated technologies

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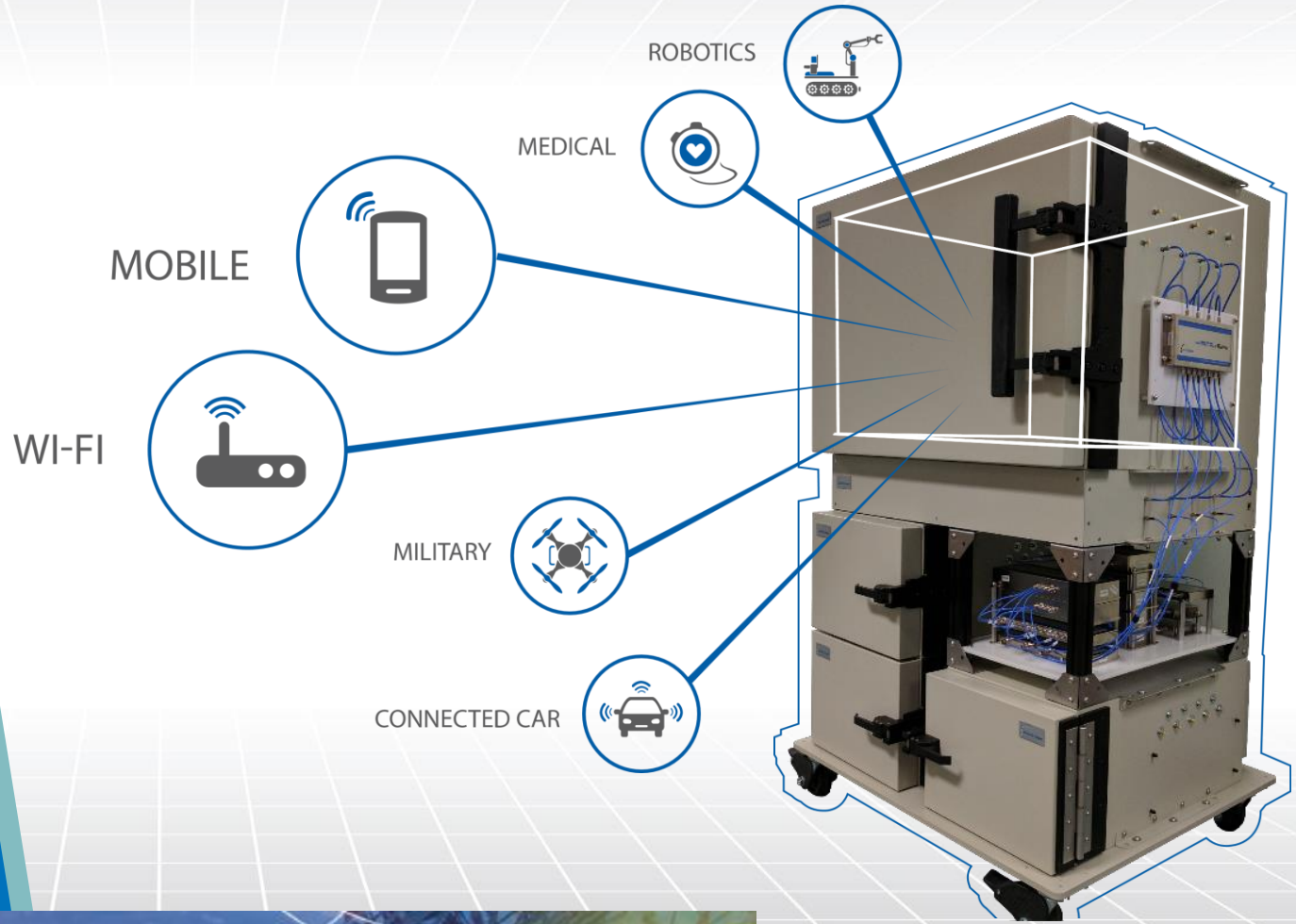

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Abstract

- **The importance and the challenge of Over The Air testing in current and future wireless technologies**.
  MIMO radios make OTA testing absolutely essential to determine the multipath effect on performance. The antennas play an elementary role in the integrated concept and the performance testing must therefore be done including the antennas. This makes OTA measurement and simulation of the RF propagation model necessary. The WiFi evolution to 802.11ax makes the challenge even bigger. 802.11ax will use 8 MIMO streams instead of the 4 MIMO streams used by 802.11ac. In addition, Multi-user and OFDMA will provide additional test challenges. This workshop examines how an ideal test environment should be configured to meet this challenge.