UC San Diego
JACOBS SCHOOL OF ENGINEERING
Electrical and Computer Engineering

WCSNG
Wireless Communications
Sensing and Networking

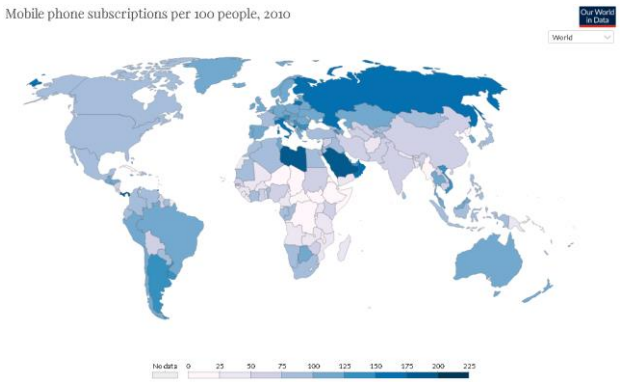
GreenMO: Enabling Virtualized, Sustainable Massive MIMO with a Single RF Chain

Agrim Gupta*, Sajjad Nassirpour, Eamon Patamasing, Manideep Dunna,

Alireza Vahid, Dinesh Bharadia

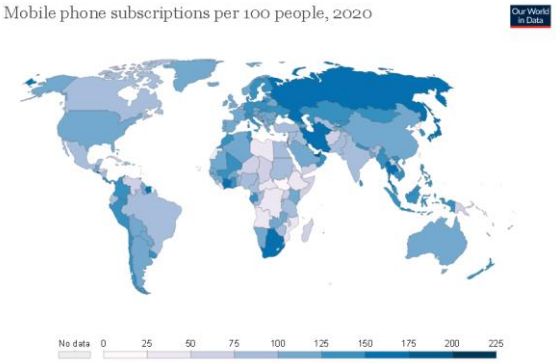
Increased carbon footprint of ICT over the years

Start of 2010s:

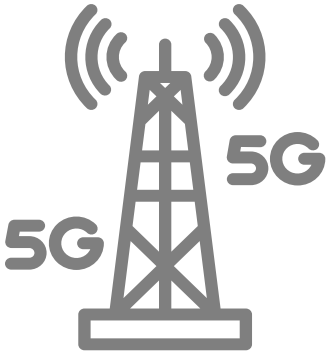


Limited penetration in upcoming markets

Start of 2020s:



Approaching ubiquitous deployments [1]



Telcos have about same carbon footprint as the “heavily scrutinized” aviation industry [2]

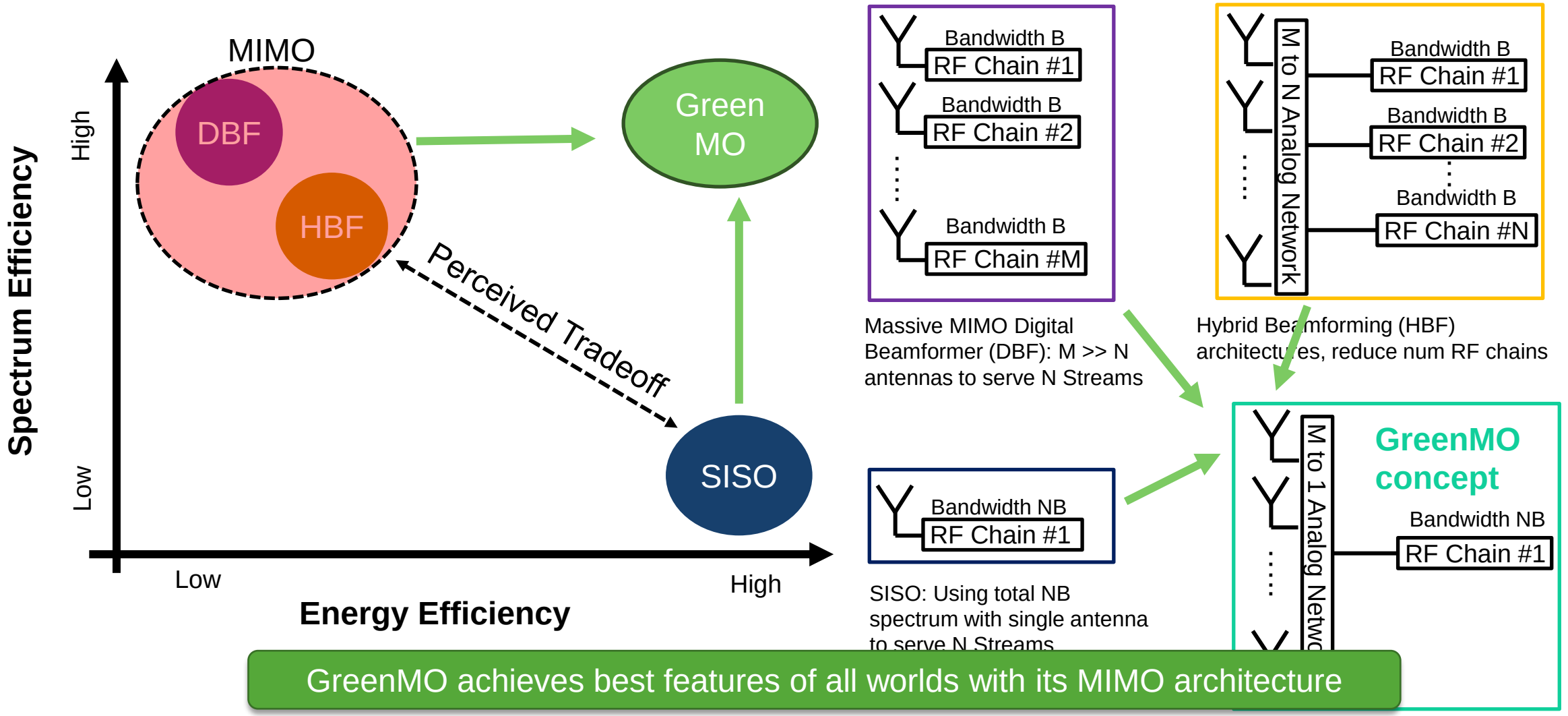
What is leading to such a high footprint? How do we support the growth of networks sustainably?

Importance of designing power-efficient base-stations in NextG

"With over 7 million BTS currently deployed around the world, base stations today consume more than 70% of the total energy used in mobile networks." [3]

[3]: *Sustainability and The Life of a Base-Station: Nokia*

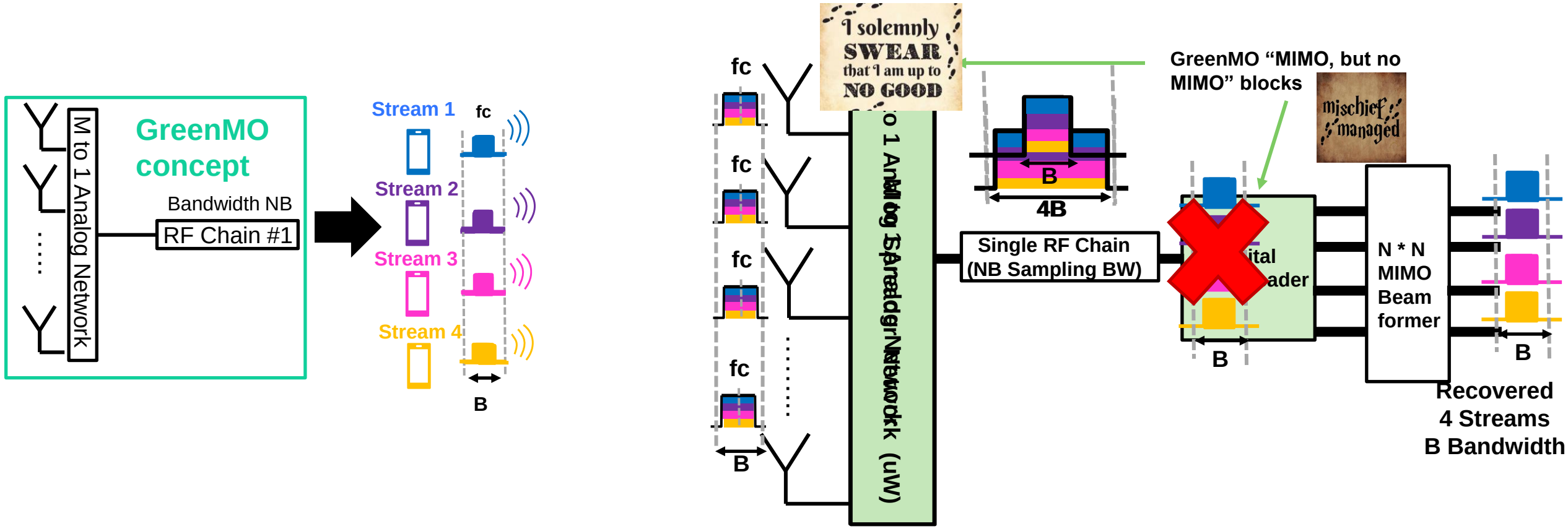
State of Today's MIMO: MIMO growth possible while keeping power at bay?



GreenMO achieves best features of all worlds with its MIMO architecture

How does GreenMO enable spectrum & energy efficiency?

Target: Allow MIMO with single high bandwidth RF chain interfaced to many antennas

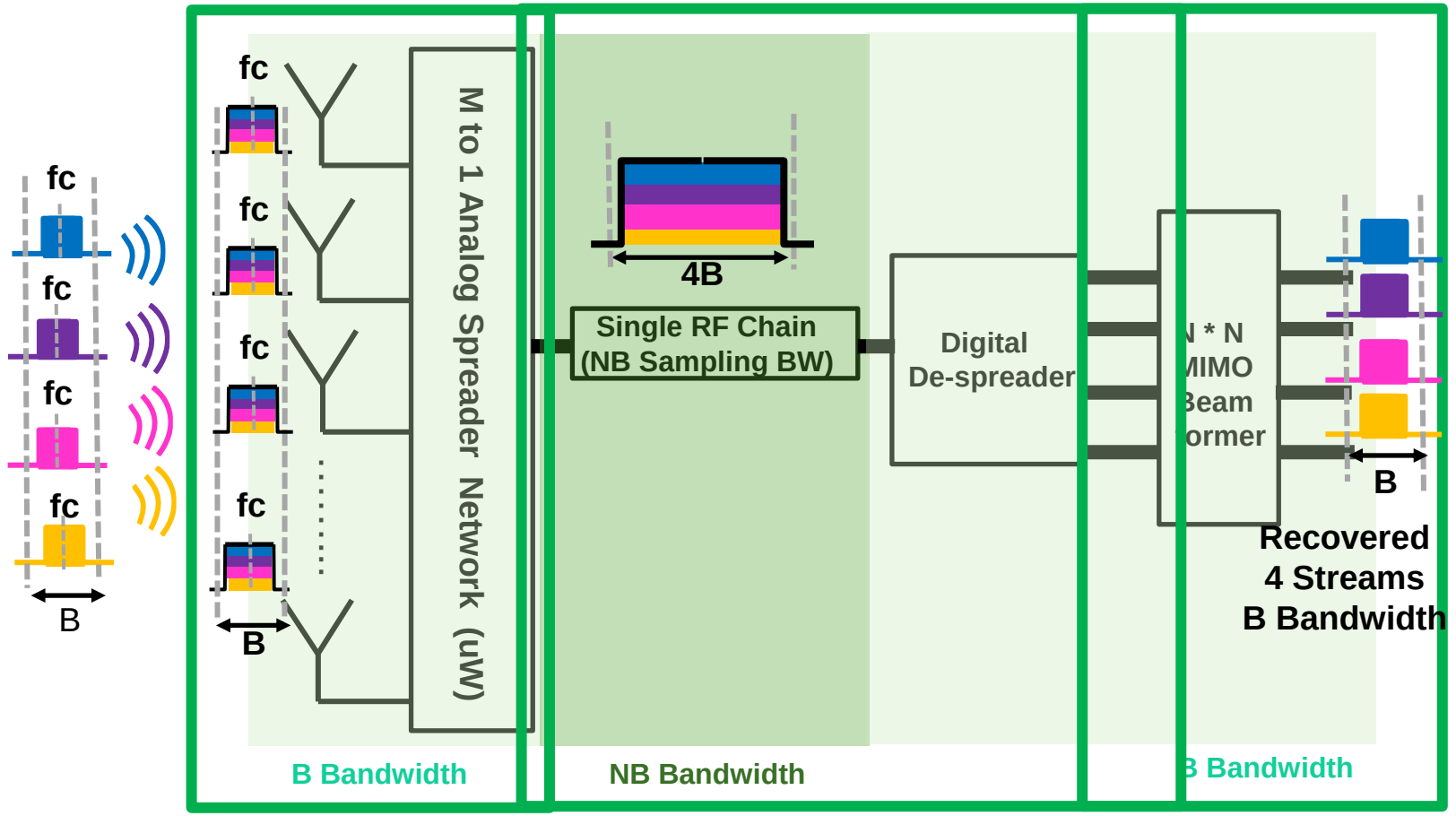


Within Radio Stackup, Spreading in analog, de-spreading in digital domain allows MIMO with single RF Chain

How does GreenMO enable spectrum & energy efficiency?

Key Idea: Use High Intermediate BW to facilitate Massive MIMO with single RF chain

1. **Ultra-low uW power Analog Network**
2. **Allows flexibility and user-proportionate digital interfacing**
3. **Enables low-complexity MIMO processing to reduce interference**

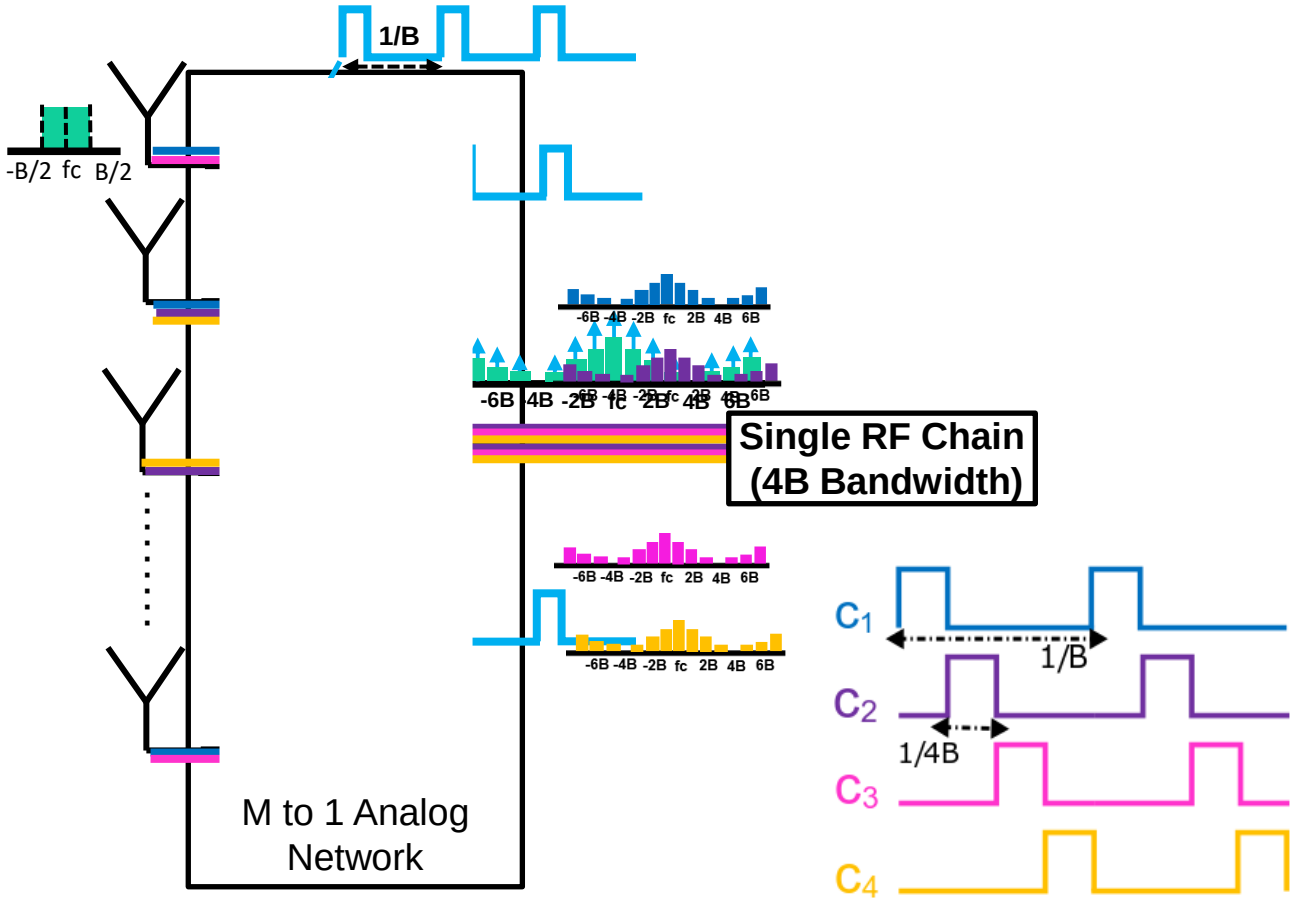


GreenMO's ultra-low power RF switch analog network for N streams

1. **RF switches with analog spreading codes: <1 dB insertion loss, ~100 uW power draw**

2. **Supply same spreading codes across multiple antennas to gain diversity**

3. **1/N duty cycle codes enable creating N different phase codes (1 per stream)**

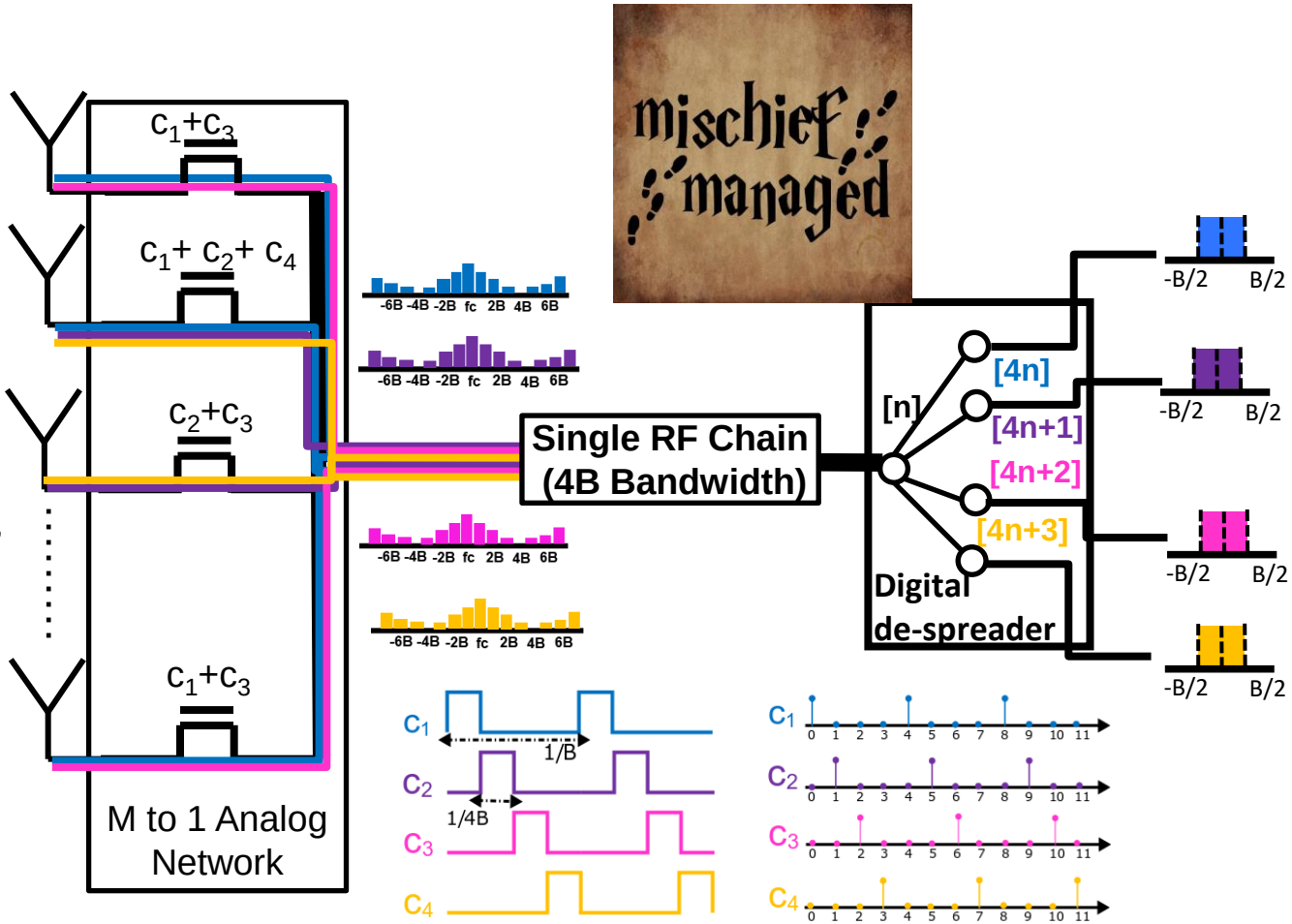


GreenMO configures the M antenna array into N sub-arrays, in form of N different spreaded bandwidth signals

Getting back to B bandwidth: Creation of virtual RF chains to sub-arrays

1. **1/N duty cycle codes sampled at NB creates orthogonalized time-samples**

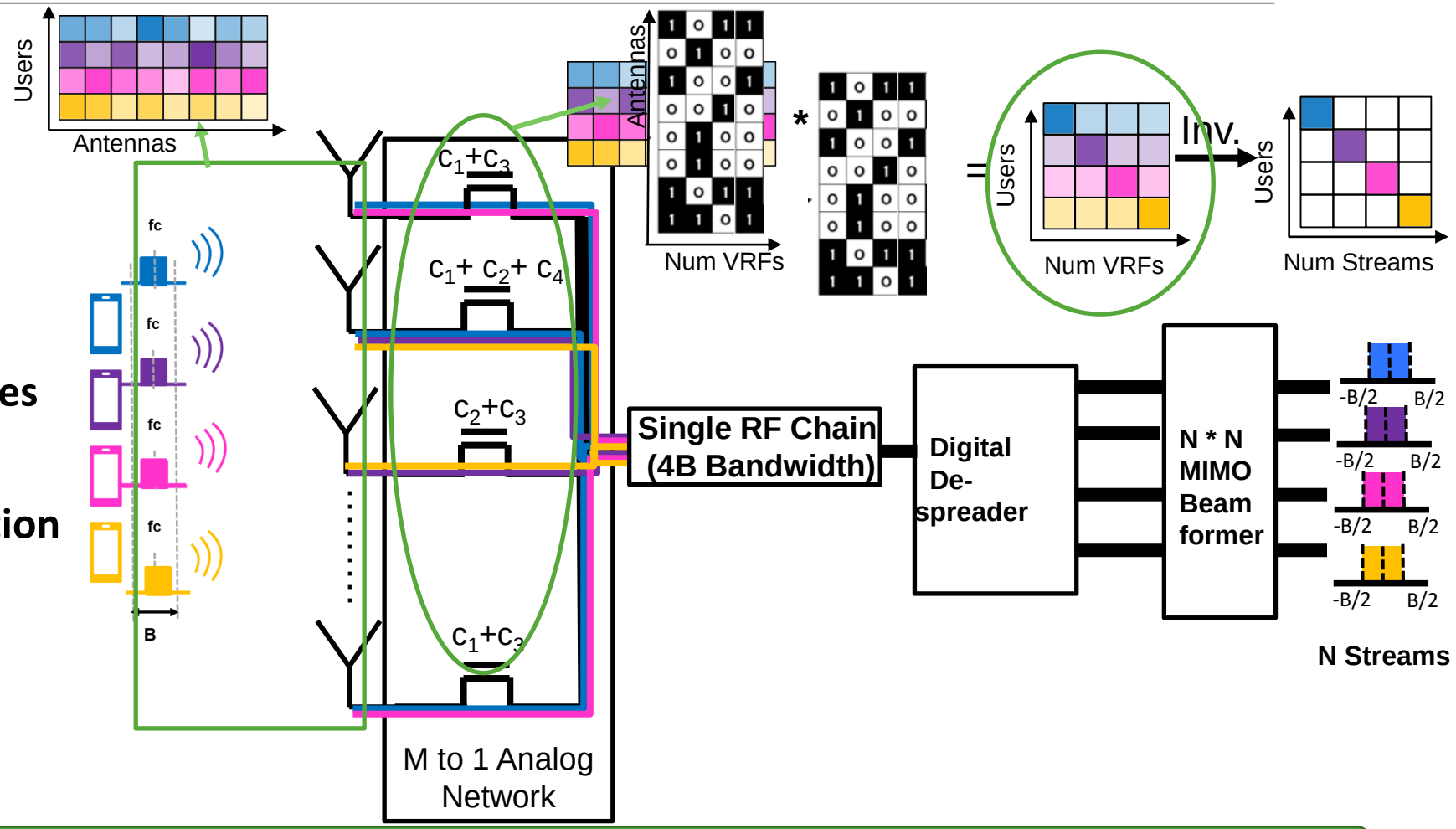
2. **Digital de-spreader splices through to downsample ↓N + create N "virtual RF chains"**



GreenMO flexibly changes number of (virtual) RF chains by controlling the sampling rate + switching duty cycle

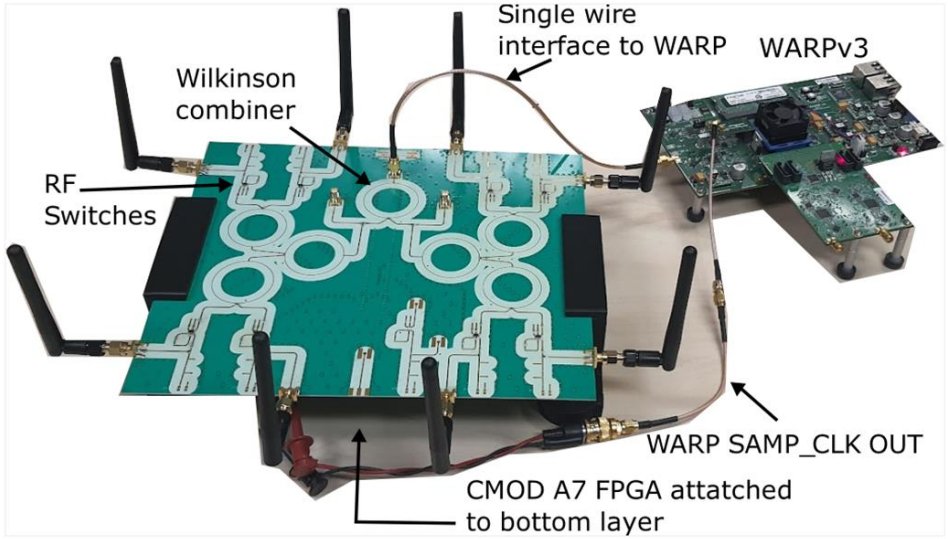
Easy-to compute MIMO Processing atop virtual RF chains

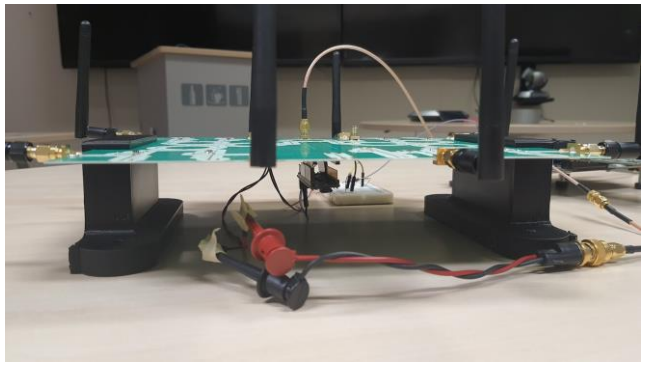
1. **A N*N equivalent channel gets created on N virtual chains**
2. **Antenna Selection leads to diagonal heavy channel matrices**
3. **Leads to interference cancellation with simple matrix inversion**

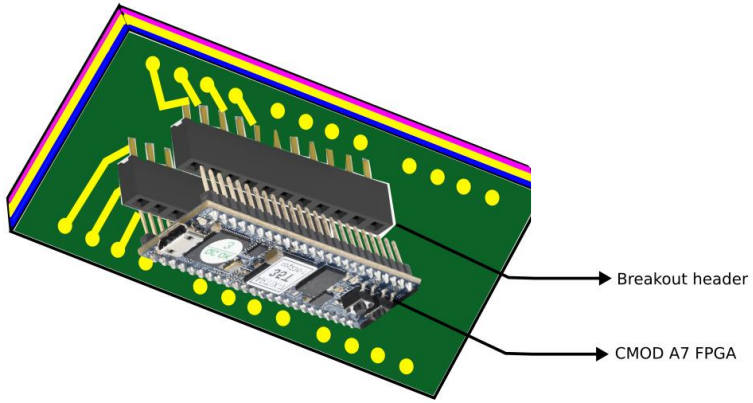


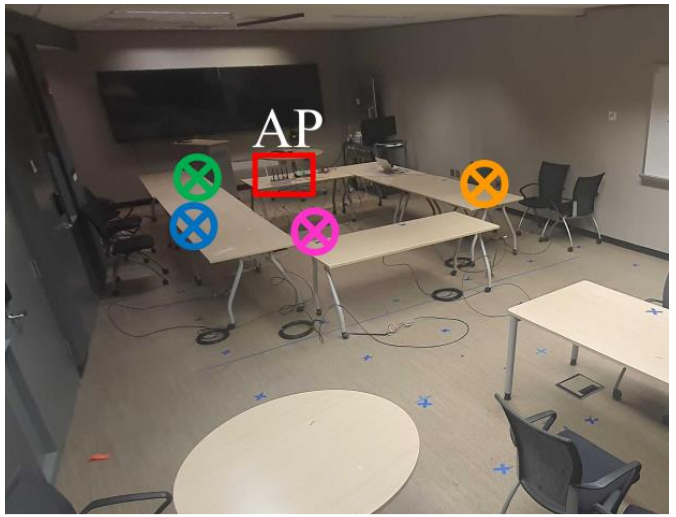
GreenMO's spreading de-spreading combined with efficient MIMO processing gets back the per-user streams

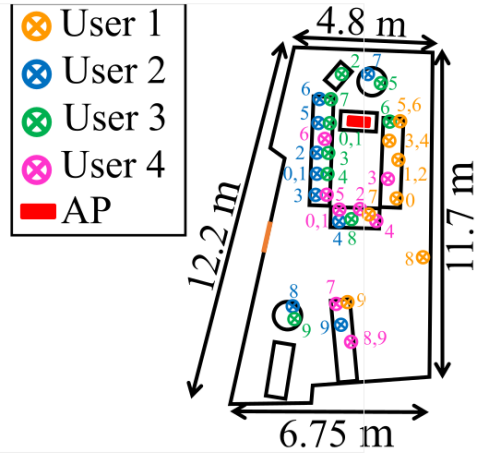
Implementing and testing GreenMO on a PCB prototype



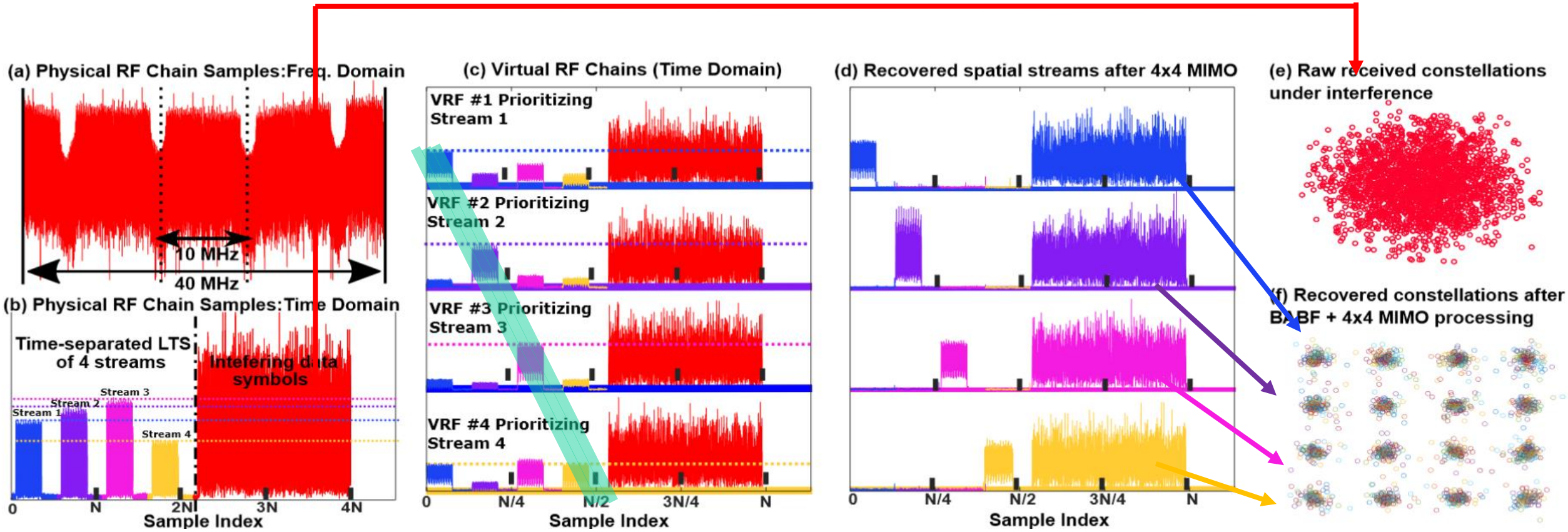




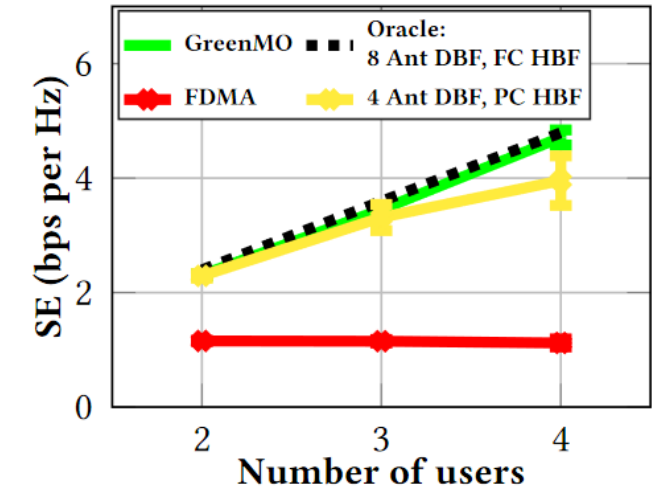


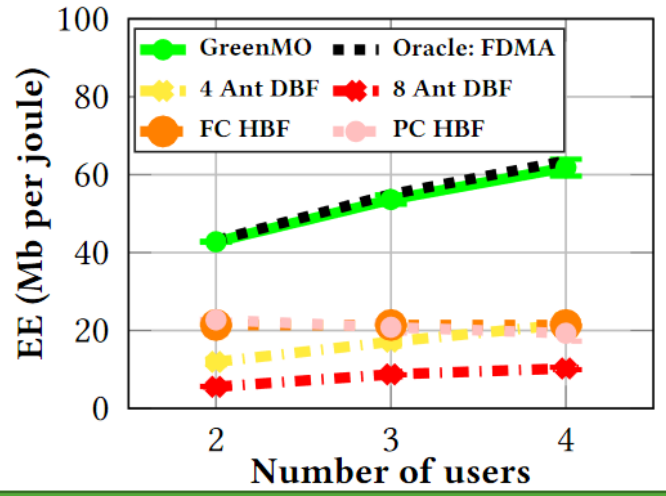


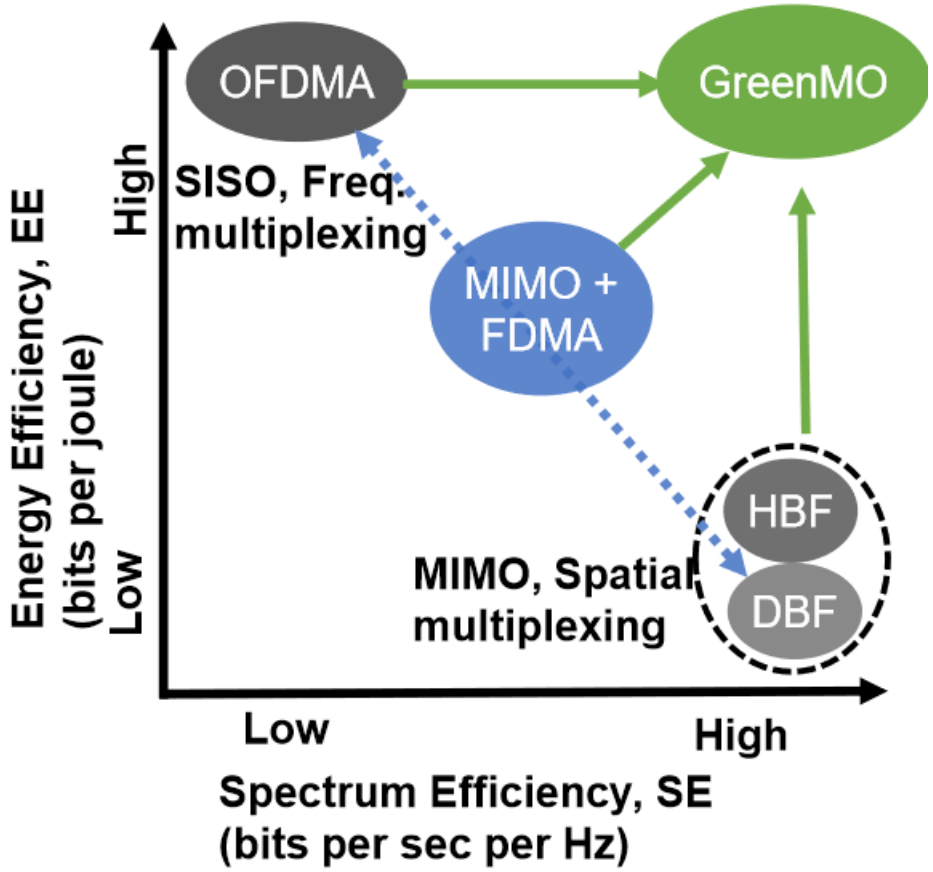
Putting it all together: Actual trace captured using the hardware



Baseline comparisons vs DBF, HBF, SISO with GreenMO for 2-4 users, 8 antennas

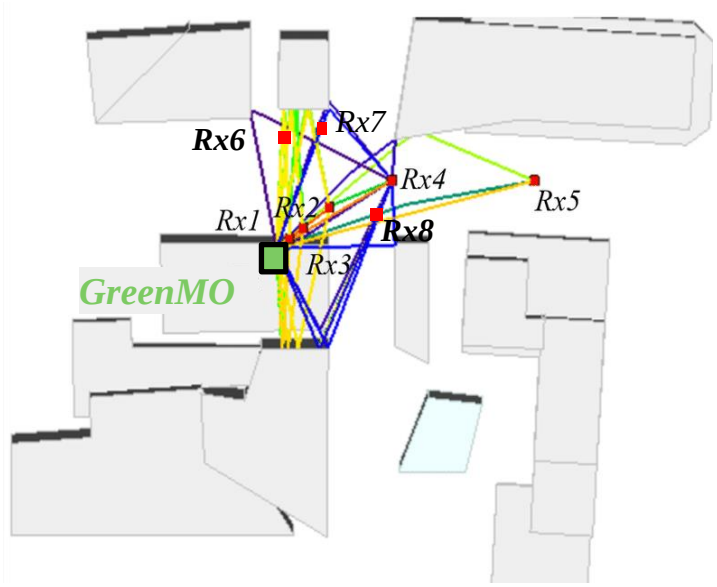


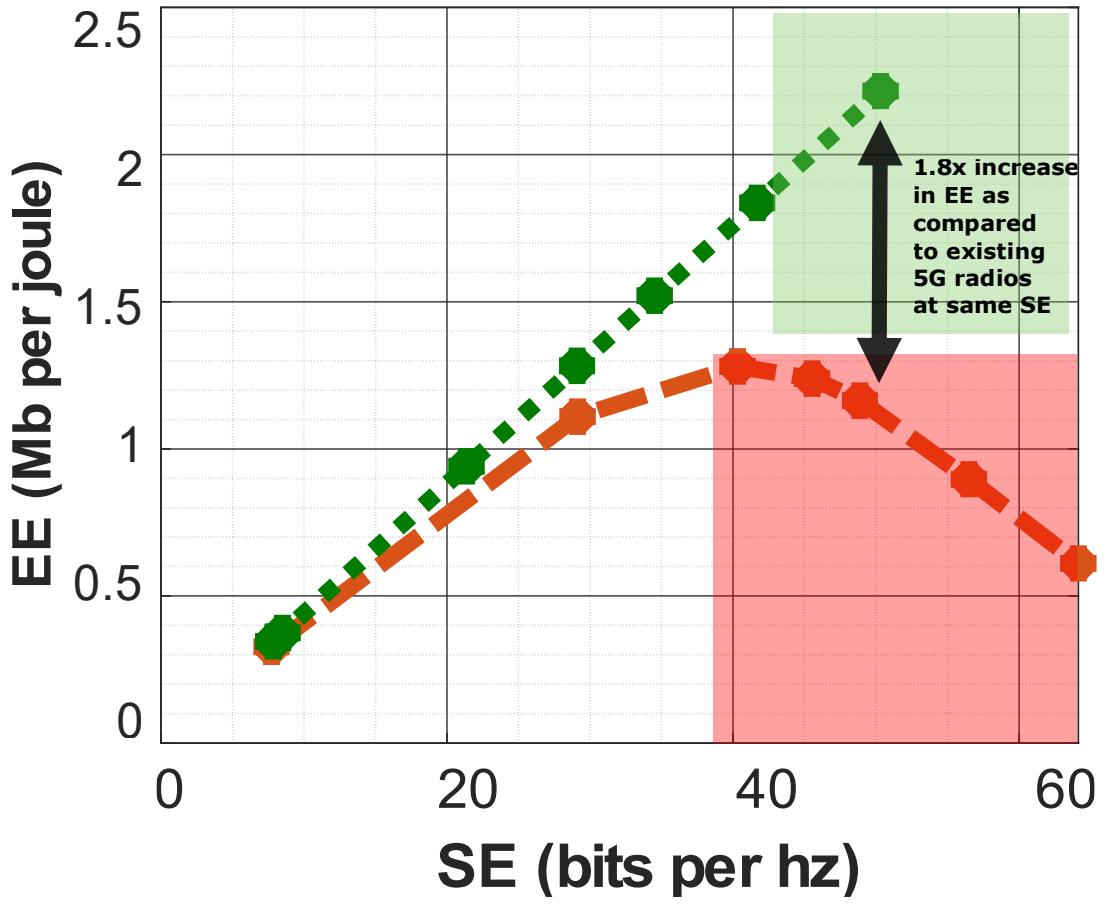


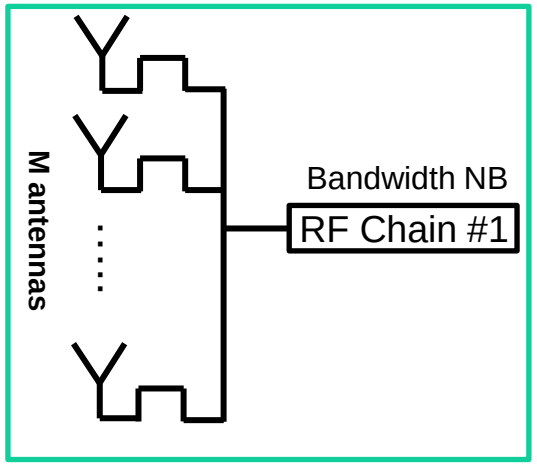


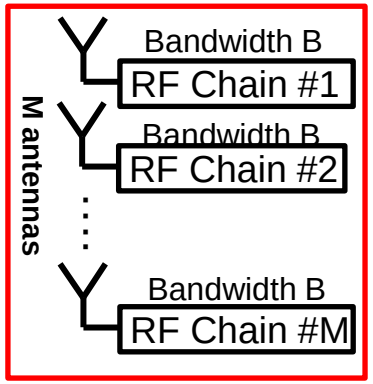
GreenMO meets both SE of mMIMO and EE of FDMA

Larger scale simulations: Comparisons with 5G TX/RX MIMO via 8 100 MHz streams



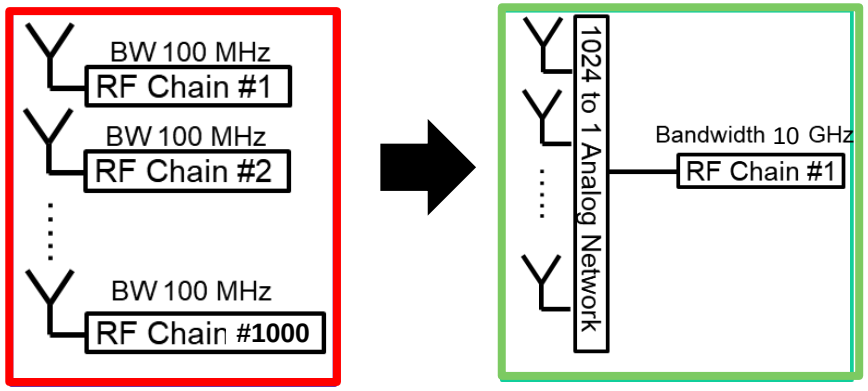




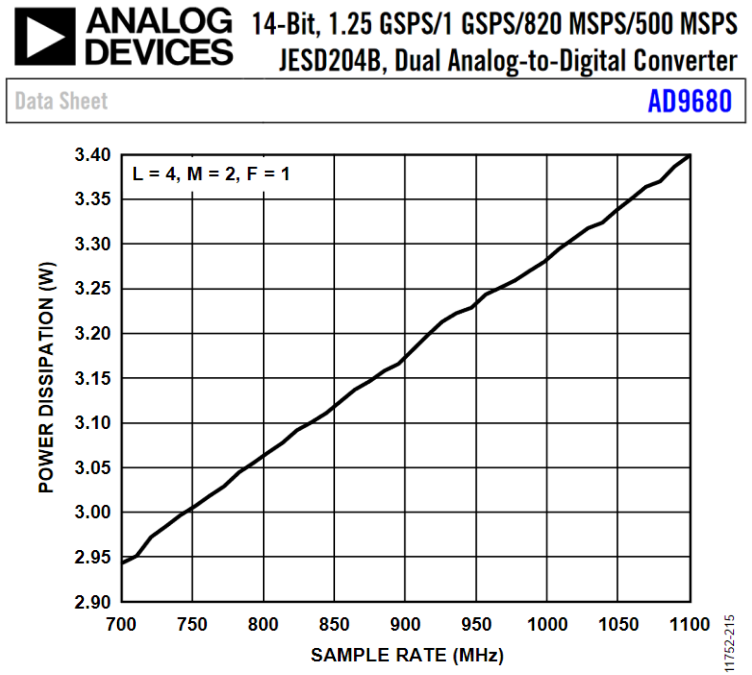


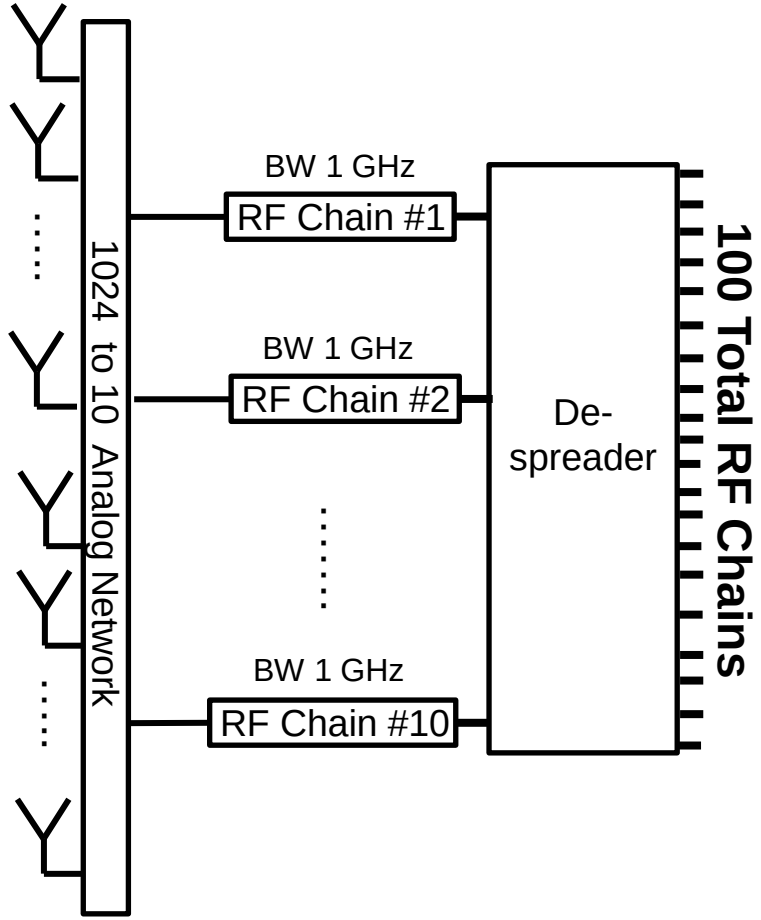
GreenMO can increase EE of Massive MIMO base-station **by 1.8 times** while meeting similar SE performance.

Extreme MIMO Next G: Can we scale even higher? 100 streams, 100 MHz each?



"Power Consumption of RF chains should be linear with sampling frequency"





GreenMO introduces optimization of physical/virtual RF chains as we build next generation Massive MIMO

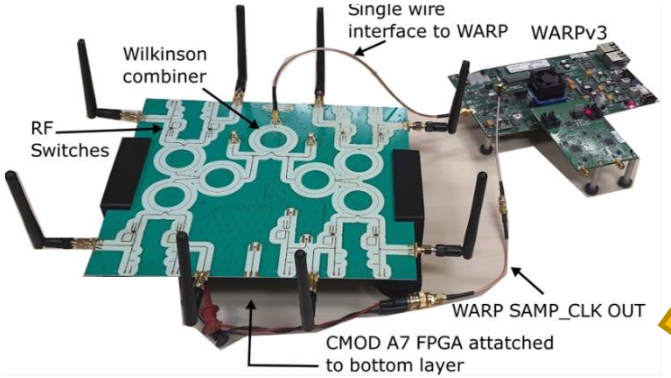
Thank you, open for questions and discussions!

More about GreenMO, Artefacts

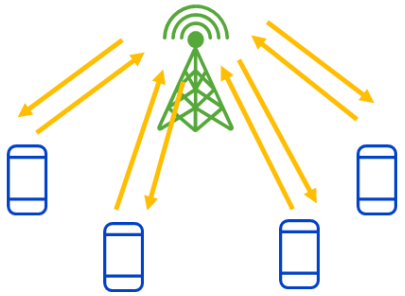
https://wcsng.ucsd.edu/sustainability

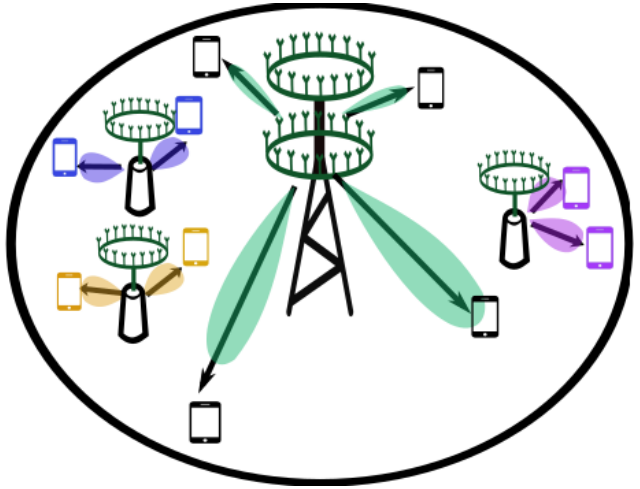
https://github.com/ucsdwcsng/GreenMO_Artefacts

Next big step with GreenMO: building a university wide testbed!



Demonstrating downlink MIMO with GreenMO





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