MASSIVE MIMO

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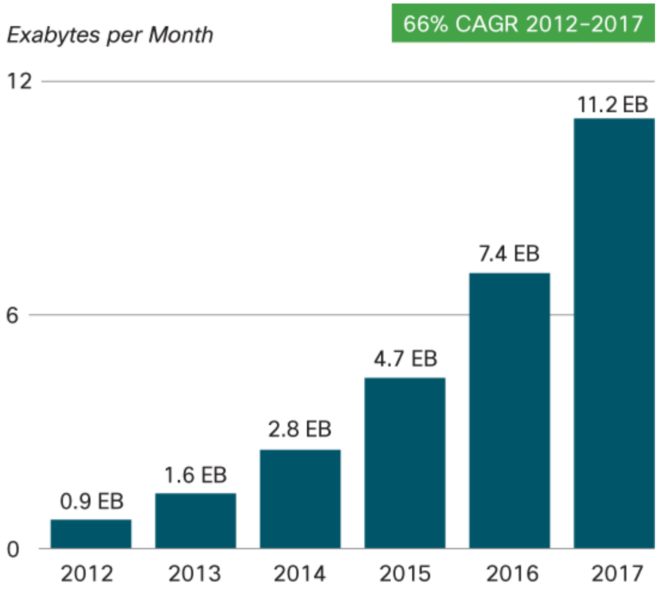
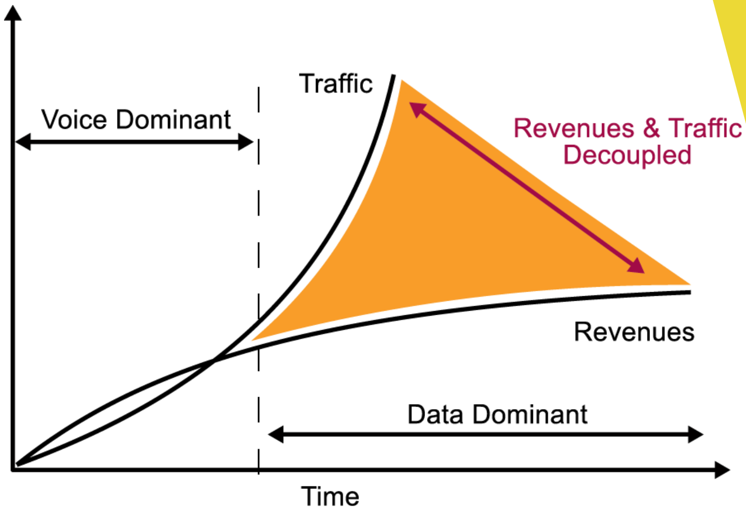
OUTLINE

- Challenge of Network Traffic Growth
- Point-to-Point MIMO
- Multi-User MIMO
- MASSIVE MIMO
    - I. Linear Pre-coding and Decoding
    - II. Channel Estimation
    - III. Measuring Channel Characteristics
    - IV. Power Control
- Performance of Massive MIMO

Challenge of Network Traffic Growth

- **Data Dominant Era**
  - – 66% annual growth of traffic
  - – How to achieve in a cost and energy efficient way?



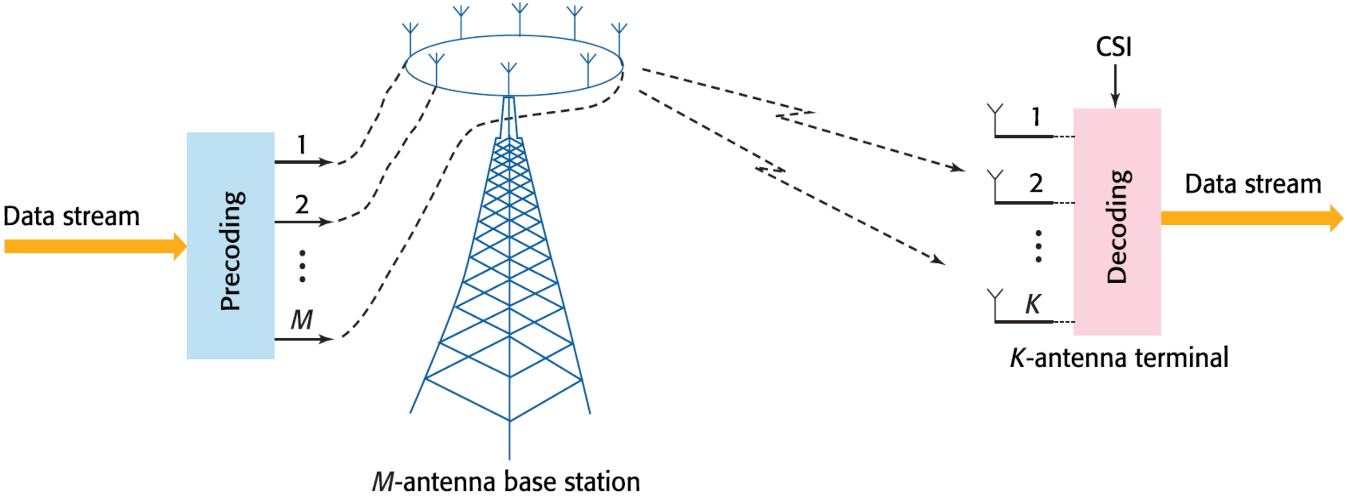


1. exploitation of spectrum that is currently unused or underutilized

2. deployment of ever more access points, each covering a commensurately smaller area

3. use of access points and/or terminals with multiple antennas

Point-to-Point MIMO



$$C \propto \min(M, K) \log_2(\rho_{\mathrm{d}}), \quad \rho_{\mathrm{d}} \gg 1$$

$$C = \log_2 \det\left(\mathbf{I}_K + \frac{\rho_{\mathrm{d}}}{M} \mathbf{G}_{\mathrm{d}}^{\mathrm{H}} \mathbf{G}_{\mathrm{d}}\right)$$
$$= \log_2 \det\left(\mathbf{I}_M + \frac{\rho_{\mathrm{d}}}{M} \mathbf{G}_{\mathrm{d}} \mathbf{G}_{\mathrm{d}}^{\mathrm{H}}\right)$$

- Pilots in downlink and uplink:

$$\tau_{\mathrm{d}} \geq M, \quad \tau_{\mathrm{u}} \geq K \Rightarrow \tau_{\mathrm{d}} + \tau_{\mathrm{u}} \geq M + K$$

- Not readily scalable beyond 8×8

Multi-User MIMO

Single K antenna user

⇩

K autonomous single-antenna users

$$C_{\text{sum up}} = \log_2 \det\left(\mathbf{I}_K + \frac{\rho_{\text{u}}}{K}\mathbf{G}_{\text{u}}^{\text{H}}\mathbf{G}_{\text{u}}\right)$$

$$C_{\text{sum down}} = \sup_{\mathbf{a}}\left\{\log_2 \det\left(\mathbf{I}_M + \rho_{\text{d}}\mathbf{G}_{\text{d}}\mathbf{D}_{\mathbf{a}}\mathbf{G}_{\text{d}}^{\text{H}}\right)\right\},$$
$$\mathbf{a} \geq \mathbf{0},\ \mathbf{1}^{\text{T}}\mathbf{a} = 1$$

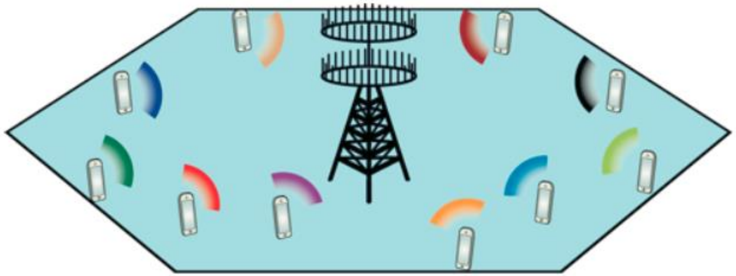
- Pilots in downlink and uplink:

$$\tau_{\text{d}} \geq M$$
$$\tau_{\text{u}} \geq K$$
$$\Rightarrow \quad \tau_{\text{d}} + \tau_{\text{u}} \geq M + K$$

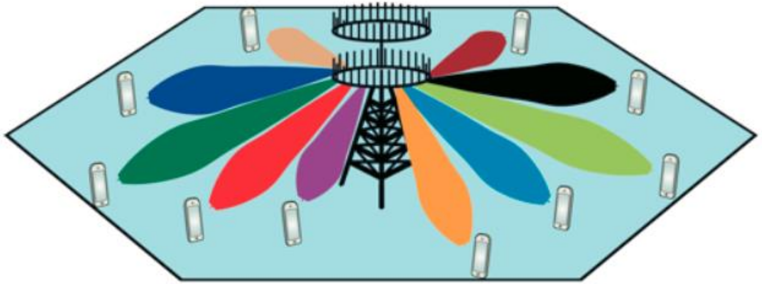
Advantages:

- ❑ Multi-User MIMO is less vulnerable to the propagation environment in comparison with Point-to-Point MIMO
- ❑ Only single-antenna terminals are required

MASSIVE MIMO



Uplink



Downlink

- Many antennas (M) at BSs
- More antennas than users (K)

New key characteristics:

● $M \gg K$: Favorable propagation
● Frequency dependence and fast fading disappear
● Scalability: Estimation overhead independent of M
● Simple linear precoding and detection
● Elegant ergodic capacity analysis

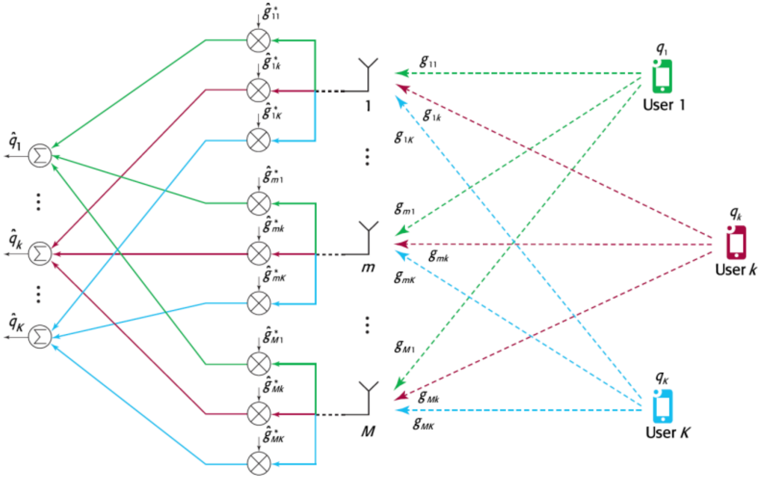
Scalability

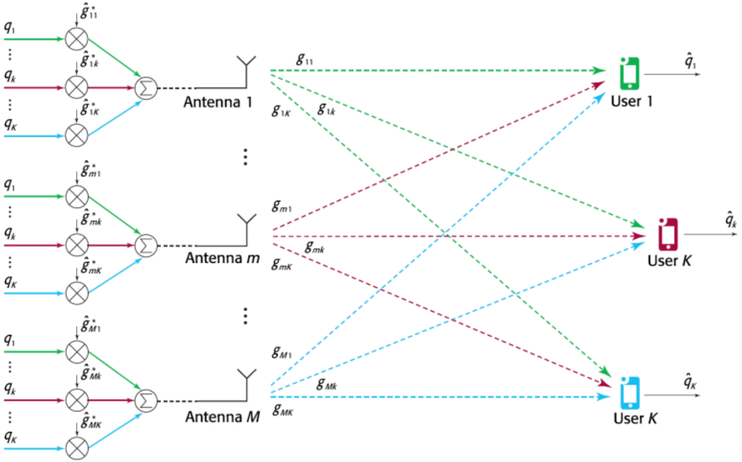
- Only the base station learns the downlink channel
- The number of base station antennas is typically increased to several times the number of users
- A simple linear precoding/decoding multiplexing is employed on the downlink/uplink

Linear Pre-coding and Decoding

- ❑ Matched filter decoding for uplink

- ❑ Conjugate beamforming for downlink





How do imperfect channel estimates affect the performance of linear pre-coding and decoding?

Advantage:

The Massive MIMO signal processing can be performed locally at each antenna!

- ❑ Under high SNR conditions, zeroforcing may perform significantly better than matched filtering and conjugate beamforming

Channel Estimation

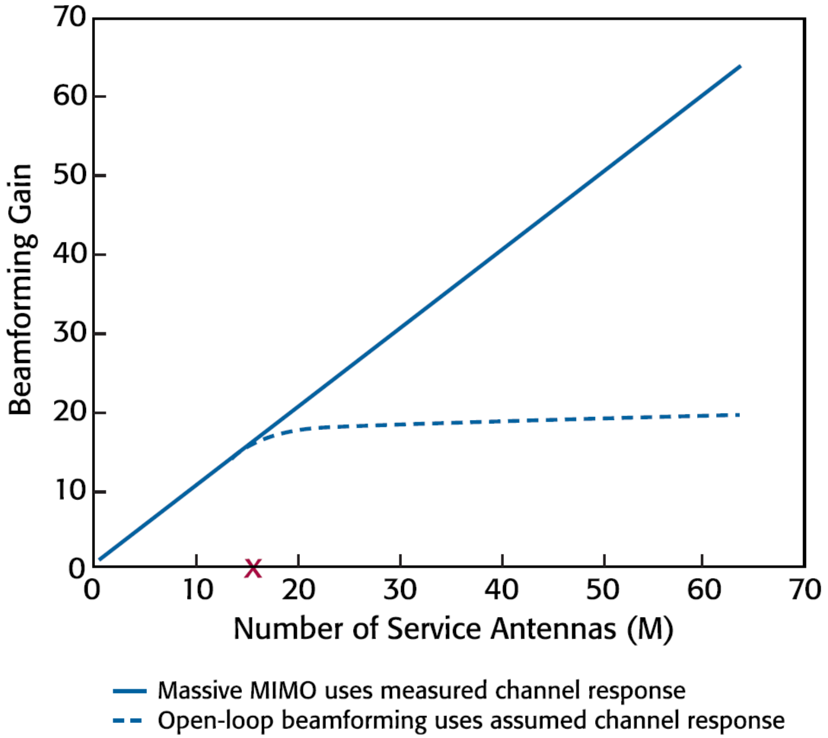
Transmitting known training signals

Estimating the frequency response

- TDD System:

- FDD System:

Measuring Channel Characteristics



Makes Massive MIMO a scalable technology!

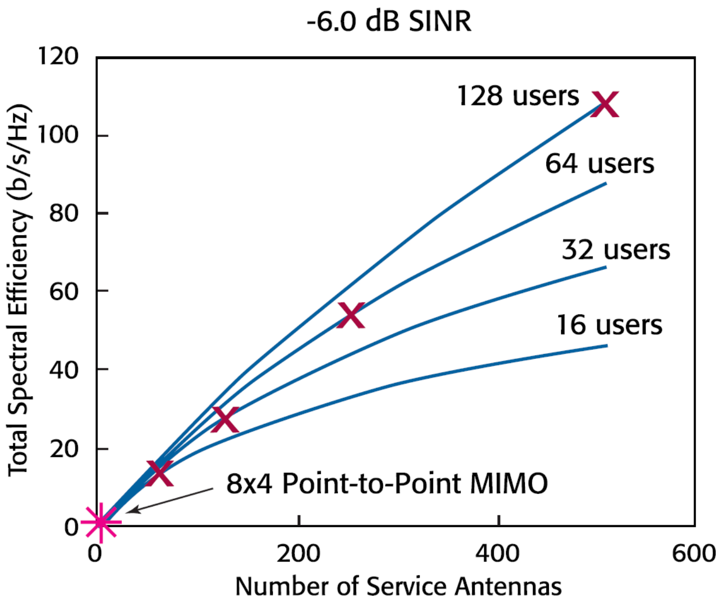
Power Control

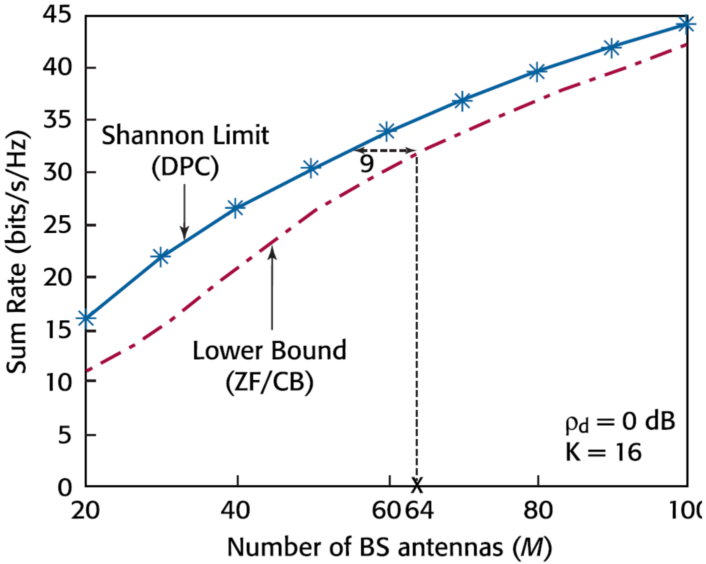
- ❑ The large number of antennas in Massive MIMO, makes the beamforming gains virtually constant over frequency.
- ❑ The power control coefficients:

I. Can be made independent of frequency.

II. Their effect on the data rate attained by an individual user may be computed without regard to the short term channel estimates obtained from the pilots.

Performance of Massive MIMO





$$C_{\text{sum cb}} > K \log_2\left(1 + \frac{M\rho_{\text{d}}}{K(1+\rho_{\text{d}})}\right)$$

$$C_{\text{sum zf}} > K \log_2\left(1 + \frac{(M-K)\rho_{\text{d}}}{K}\right)$$

Limitation: There is a finite limit to the number of users that can be served simultaneously.

THANKS!

Any questions?