Random Access Protocols for Massive MIMO

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CSI acquisition and data transmission in Crowd Scenarios

Megacities

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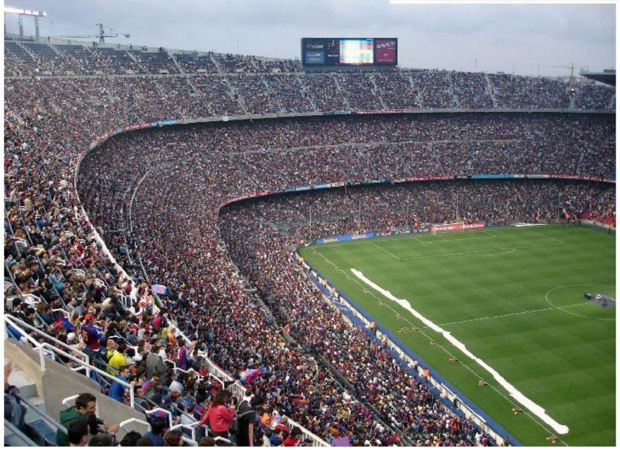
Machine type communications

http://edition.cnn.com/2013/05/02/travel/london-city-airport-internet-of-things/



Hotspots

Presentation Content

- Massive MIMO: **massive number of spatial degrees of freedom**

  Crowds: exploit **very large multiplexing gain**

- Uplink Training based on **orthogonal pilot sequences**

  Length/number of orthogonal pilots **limited**

  Pilot shortage

- One solution: **random access** to the pilots and possibly the data

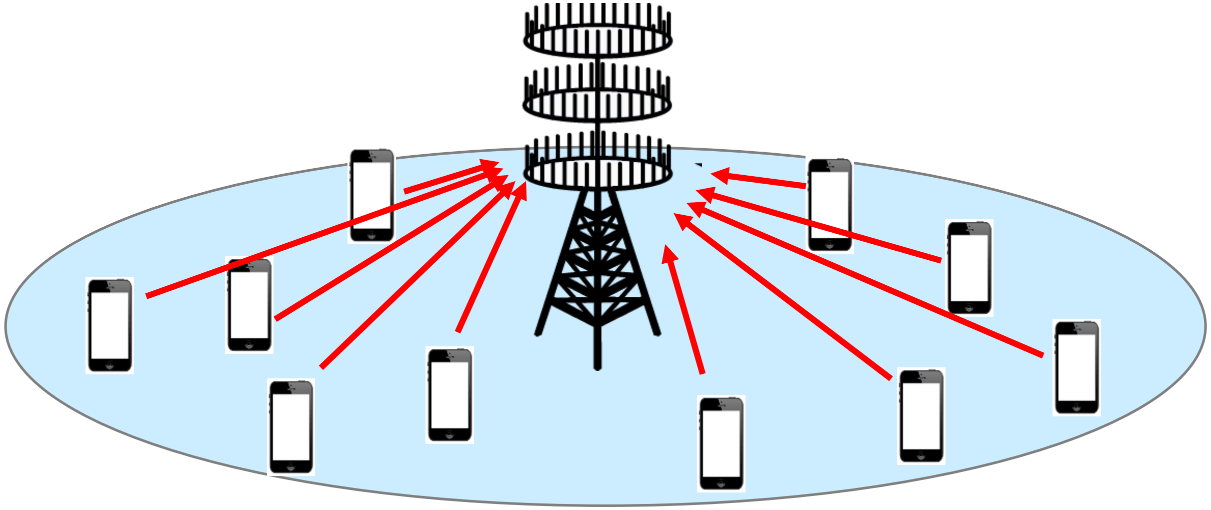
CSI Acquisition in Massive MIMO

Time-division duplexing and channel reciprocity

CSI is acquired using uplink training

Exploited for downlink transmission

Orthogonal pilots



Orthogonal Pilots are a limited resource

Number of orthogonal pilots = pilot sequence length

Pilot Sequence length limited by:

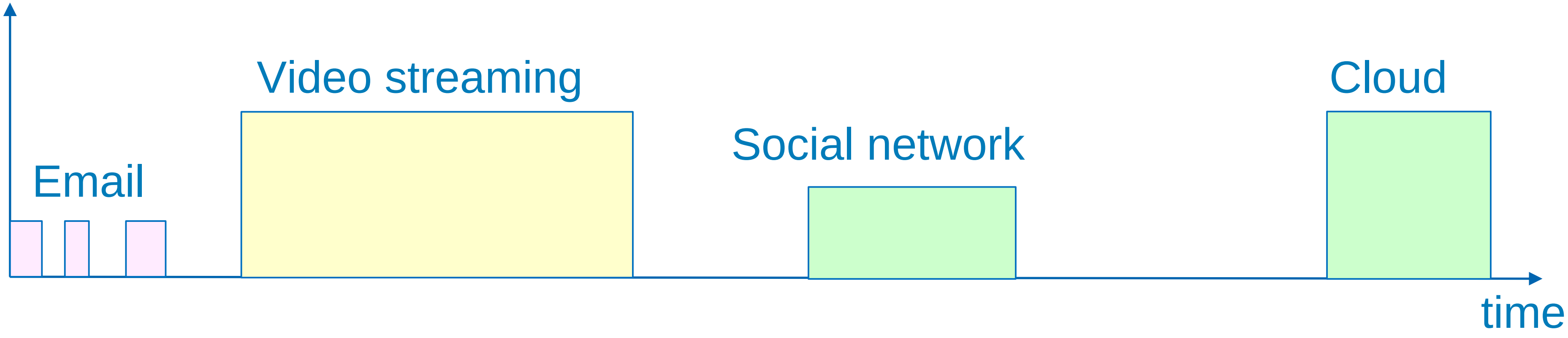
- # of pilots limited by channel coherence time
- # of pilots limited by transmit power

Pilot Shortage

Number of pilot sequences is much smaller than the number of pilot sequences

Traffic Burstiness

Non-streaming internet applications



Machine-type communications: crowd of devices transmitting sporadically

unpredictable and **intermittent** traffic

Random Pilot Access

Crowd of devices with **unpredictable** and **intermittent** traffic

Makes pilot pre-allocation very inefficient

Need for:

Scalable and efficient pilot access and data transmission protocols.

Proposed solution:

Random Access to **Pilot sequences**

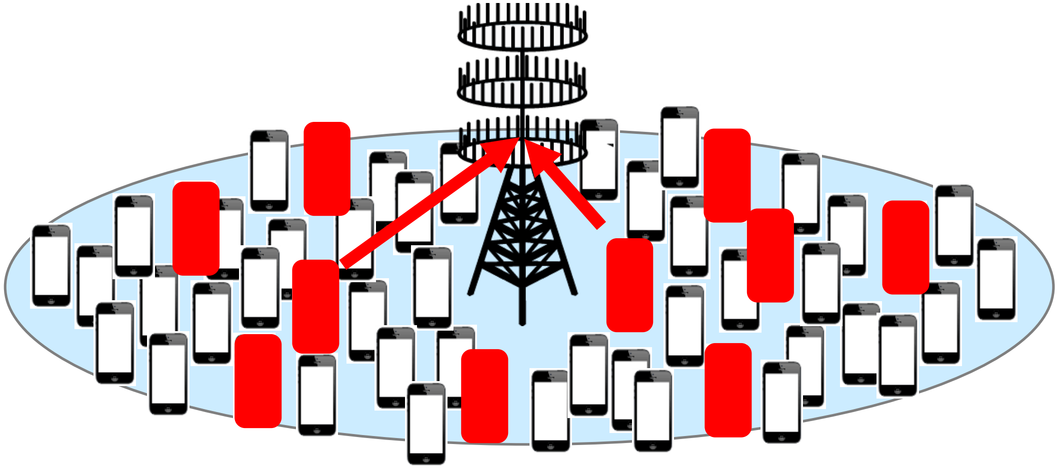
Random Access to Pilots

Total number of terminals K and τ_p orthogonal pilots available

Users select a pilot sequence uniformly at random with probability p_a

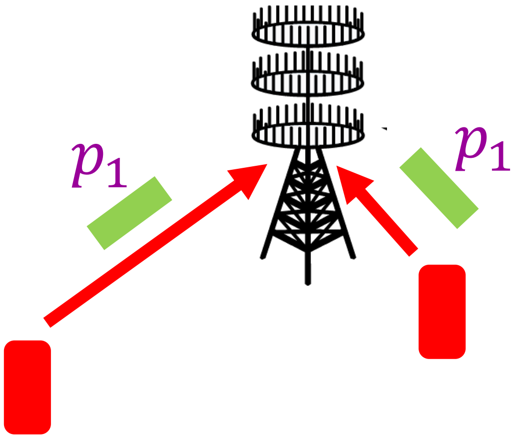
Random pilot selection ⟹ COLLISIONS

Collisions = Pilot contamination



Intra-Cell Pilot contamination

Pilot Collision



UL Pilot
transmission

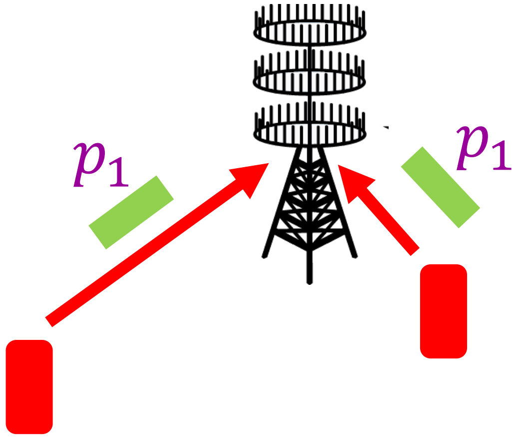
- Users with same pilot sequence**: their channel cannot be distinguished**:

$$\hat{g} = \sum_{\text{all colliders}} g_i \;+\; noise$$

- Beamforming at BS based on contaminated channel estimation: results in **inter-user interference**

Two kinds of approaches

Random Access to Pilots

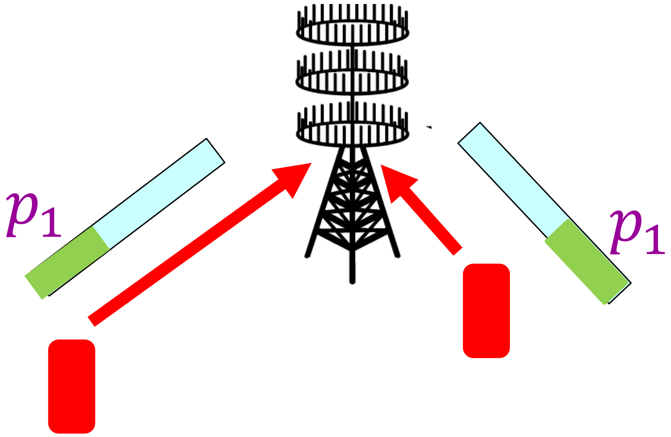


Pilot Contention resolution

Terminal sends payload when no pilot contention

Collision in the pilot domain only

Random Access to Pilots and Data



Uplink data is embarked with the pilots

Data affected by collision-induced interference

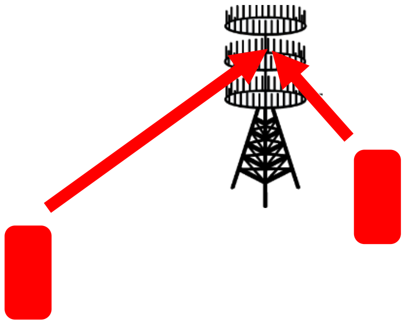
Collision in the pilot and data domain

Pilot Contamination

Suppression

Methods based on spatial separation, diversity in path loss, timing offsets

If successful, BS can decode ID of separable users which are admitted for DL/UL data transmission



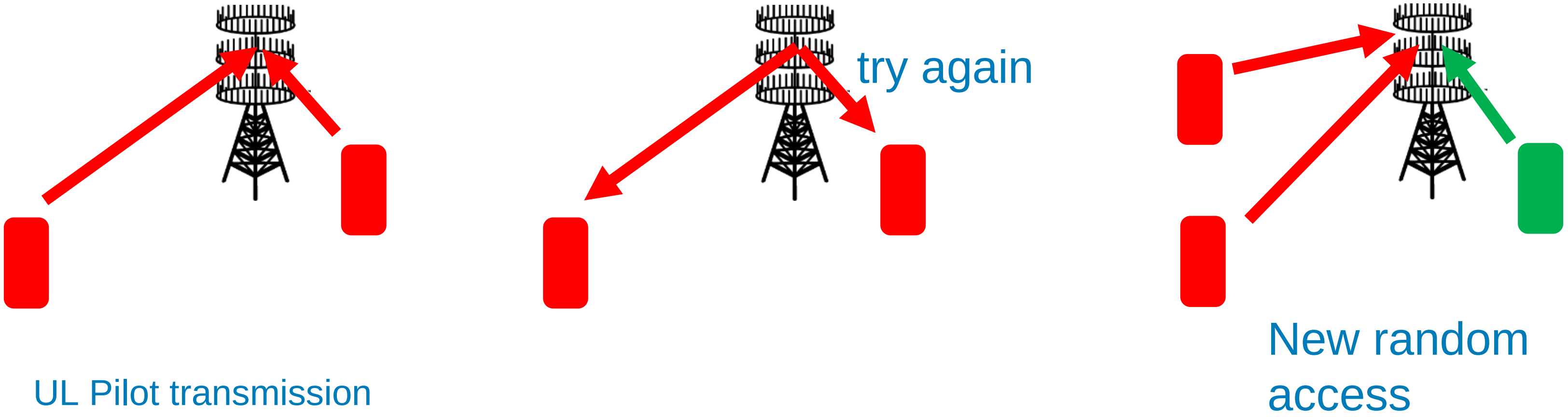
UL Pilot transmission

Pilot Contamination

Avoidance

Detection of collision at the BS

BS sends a message to colliding devices:
try again until no collision



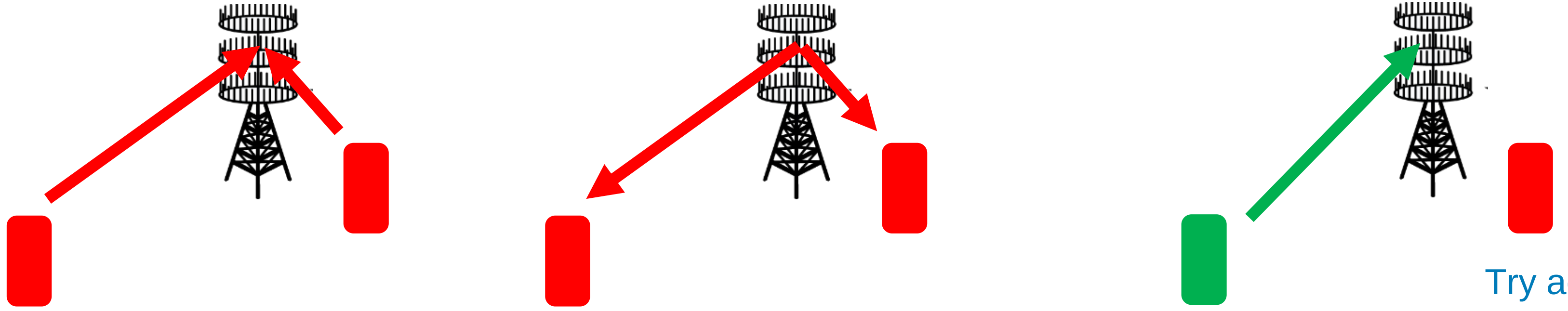
Pilot Contamination

Avoidance

Detection of collision at the device

BS sends a precoding pilot

1) Device detects collision
2) Device decides whether to retransmit the pilot sequence



Precoded pilot

UL Pilot transmission

Decision:
Retransmit UL Pilot?

No collision
(with high probability)

Try again

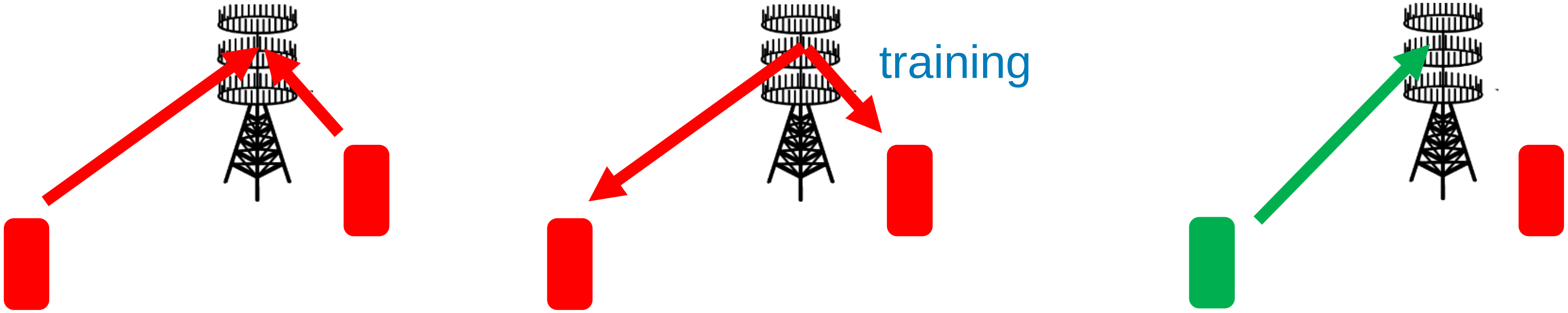
Pilot Contamination

Contaminated channel estimation

$$\hat{g} = g_1 + g_2 + noise$$

Precoding

$$w = \frac{g_1+g_2+noise}{\|g_1+g_2+noise\|}$$



⇩

$$y_1 = \frac{g_1^H+g_2^H+noise}{\|g_1+g_2+noise\|} g_1 \; + n$$

Channel hardening $E(|g_i|^2) = \beta_i$

$$y_1^2 \approx \frac{\beta_1^2}{(\beta_1+\beta_2+\sigma_n^2)} \quad \Longleftrightarrow \quad y_1^2 = \frac{\beta_1^2}{(\beta_1)}$$

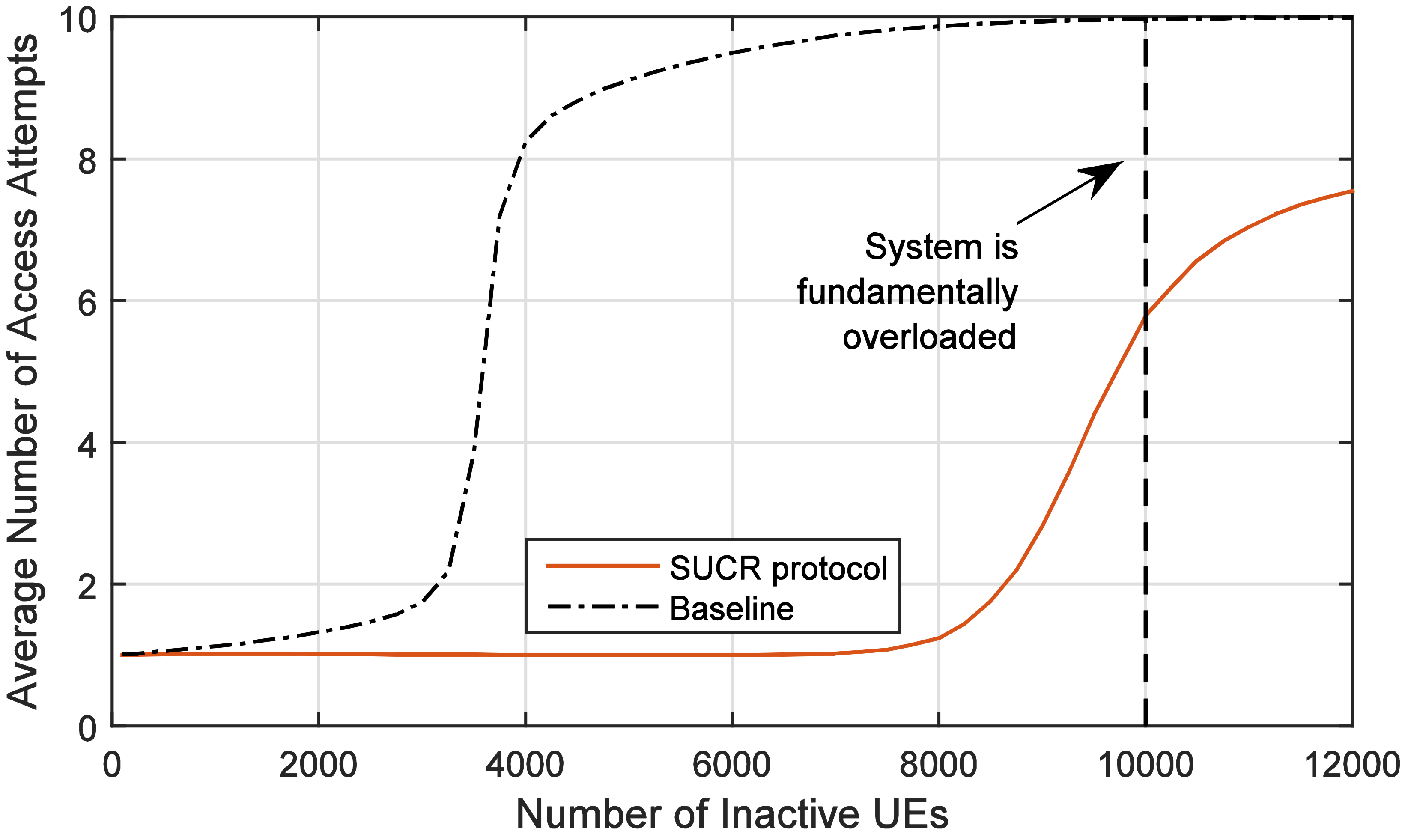
Expected

Training based Estimate of $\beta_1 + \beta_2$ from y_1^2: $\hat{\beta}_{sum}$

Compare β_1 to $\hat{\beta}_{sum}$ ⟹ **Collision detection**

Compare β_1 to $\hat{\beta}_{sum}/2$ ⟹ **STRONGER user**
Retransmit the pilot sequence

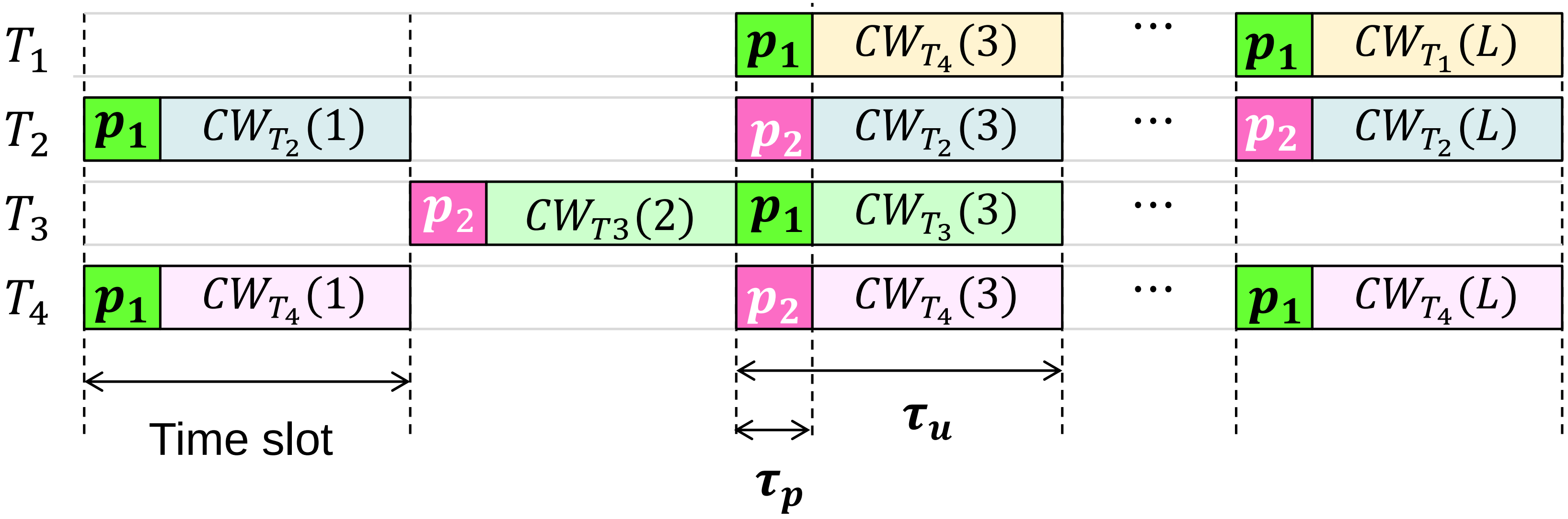
Collision resolution



System is fundamentally overloaded

Uplink Joint Pilot and Data Transmission

For delay-tolerant communications



One codeword sees an asymptotic number of:

- **channel fades (small and large scale)**
- **pilot contamination events**

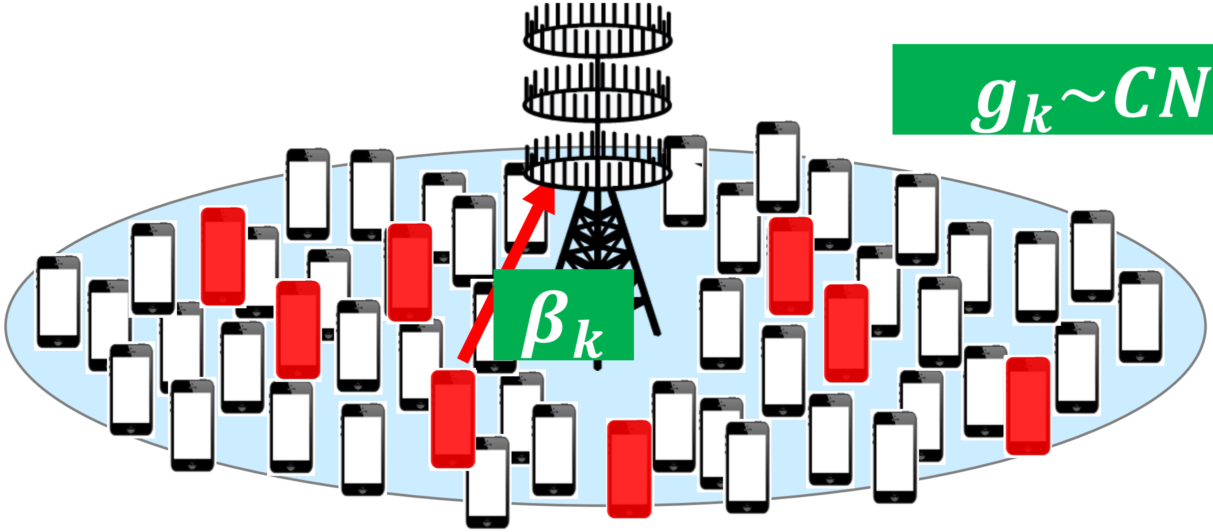
Uplink Sum Rate Bound – MRC at BS

$$\frac{\tau_u - \tau_p}{\tau_u} \; \mathrm{E}_{\mathrm{K_a, c}} \; K_a \; \mathrm{E}_{\text{Large scale fading}} \; \text{Rate user 0}\,(K_a, c_0, \text{large scale fading})$$

Number of active users

Number of contaminators to user 0

$$= \text{Sum Rate}\,(\tau_p, p_a)$$



$$g_k \sim CN(0, \beta_k I)$$

Uplink Sum Rate Bound- MRC at BS

$$\mathcal{R}_1 = \frac{\tau_u - \tau_p}{\tau_u} \sum_{K_a=1}^{K} p(K_a)\, K_a \sum_{c=0}^{K_a-1} p(c|K_a)\ \mathbb{E}_{\beta}\left[\log_2(1+\underline{\mathrm{SINR}}_1)\right]$$

Probability of having Ka active terminals out of K

Probability of having c contaminator to a given user conditioned on Ka active users

Channel energy

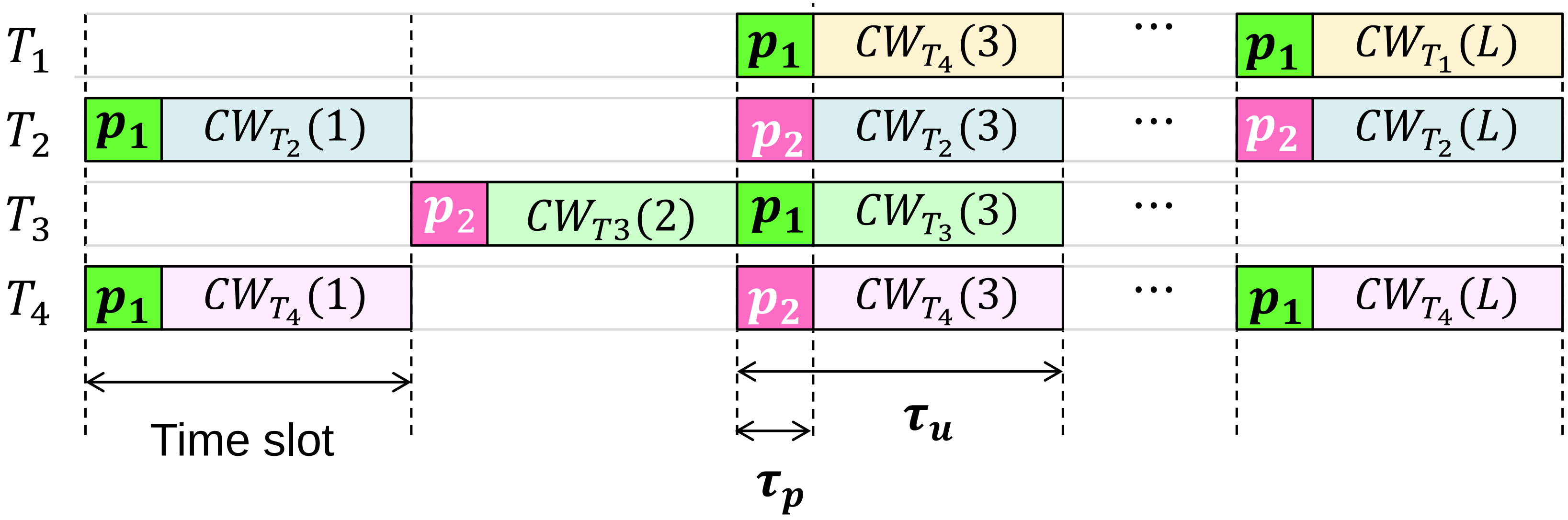
$$K_a \sim \mathrm{Binomial}(K, p_a)$$

$$c|K_a \sim \mathrm{Binomial}(K_a - 1, 1/\tau_p)$$

$$\underline{\mathrm{SINR}}_1 = \frac{\tau_p(M-1)\beta_0^2}{\tau_p(M-1)\sum_{j\in\mathcal{C}_0}\beta_j^2 + \sum_{i\in\{0,\mathcal{C}_0\}}\beta_i(1+\tau_p\sum_{j\in\mathcal{C}_i}\beta_j) + (1+\sum_{i\notin\{0,\mathcal{C}_0\}}\beta_i)(1+\tau_p\sum_{i\in\{0,\mathcal{C}_0\}}\beta_i)}$$

Optimization wrt τ_p and p_a

Heuristic Solution



$$\tau_p^o = \frac{\tau_u}{3}$$

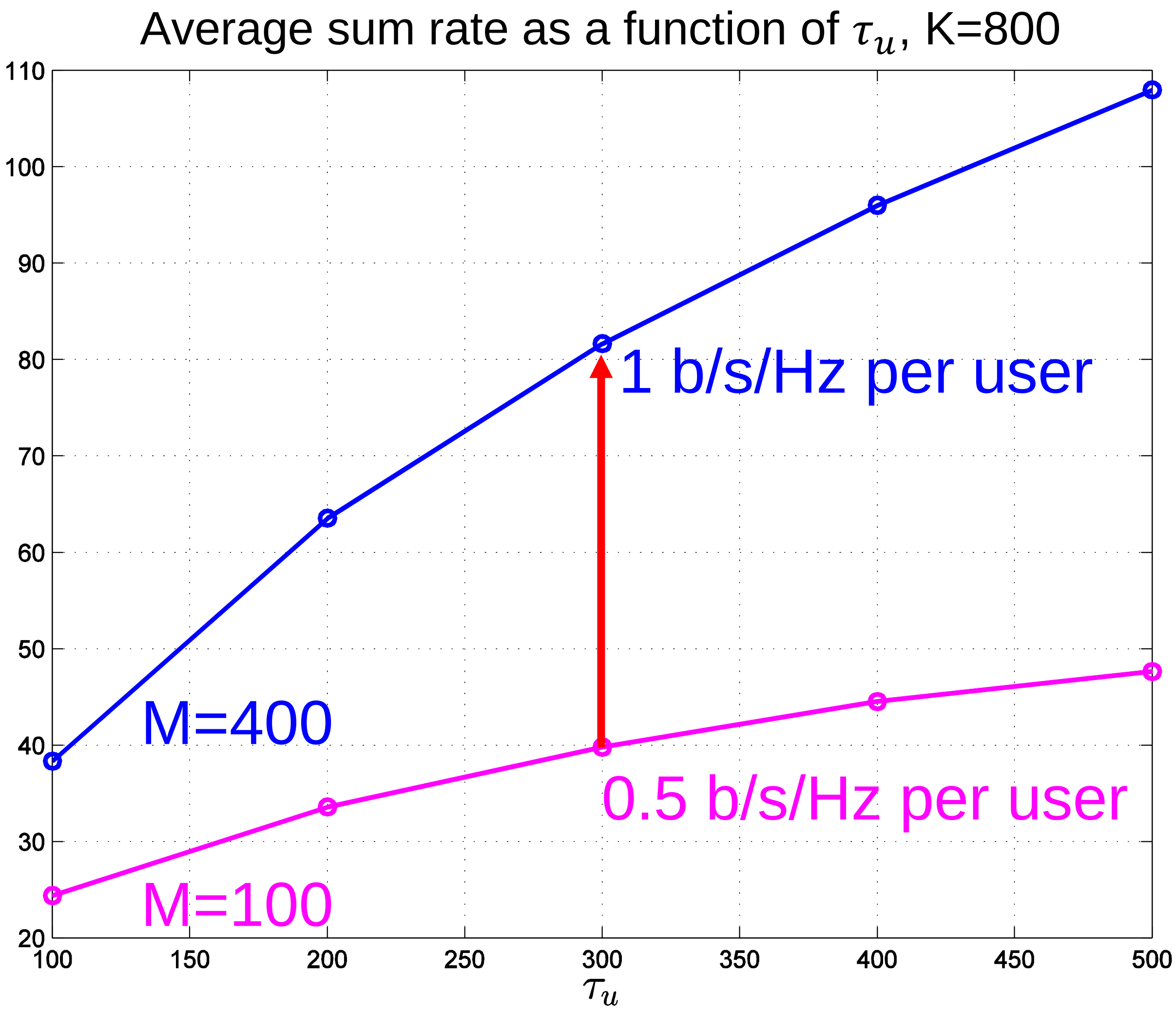
$$p_a^o\, K = a \sqrt{\tau_u\, M}$$

Depends on the channel energy variations

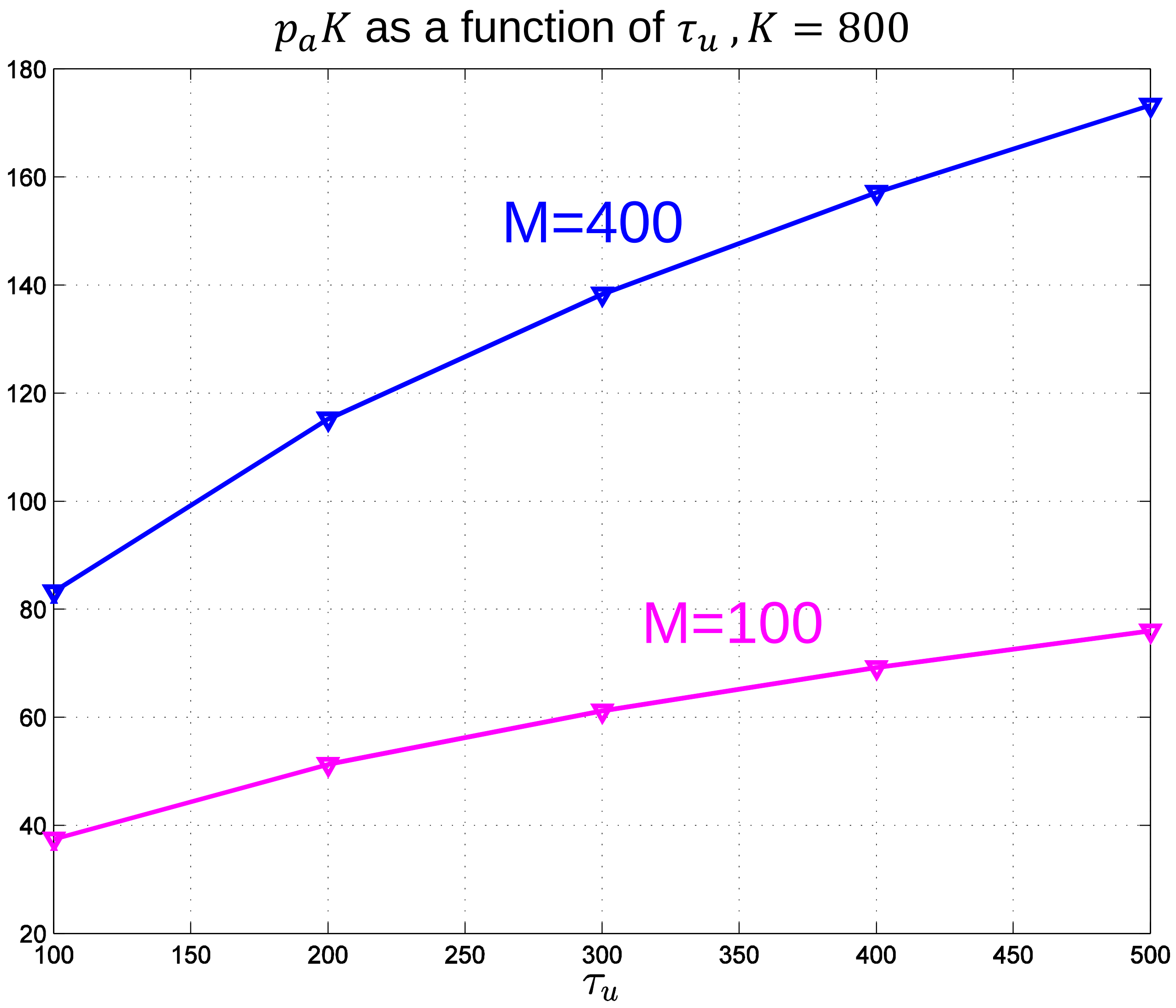
$$\text{Sum Rate} \sim \sqrt{M\, \tau_u}$$

Average Sum Rate

$\text{Rate} \sim \sqrt{M\,\tau_u}$



Average Number of Active Users



Conclusions

- **New services and scenarios in 5G**: new way to access the pilots and transmit the data
- **Massive MIMO is a fundamental enabler** for crowd MBB and mMTC
- Creation of an efficient standard for wireless networks based on massive MIMO technology will require a **complete re-design of the multiple-access layer**.