NORTHWESTERN UNIVERSITY

Communications and Networks Lab

An Adaptive Limited Feedback Scheme for MIMO-OFDMA Based on Optimal Stopping

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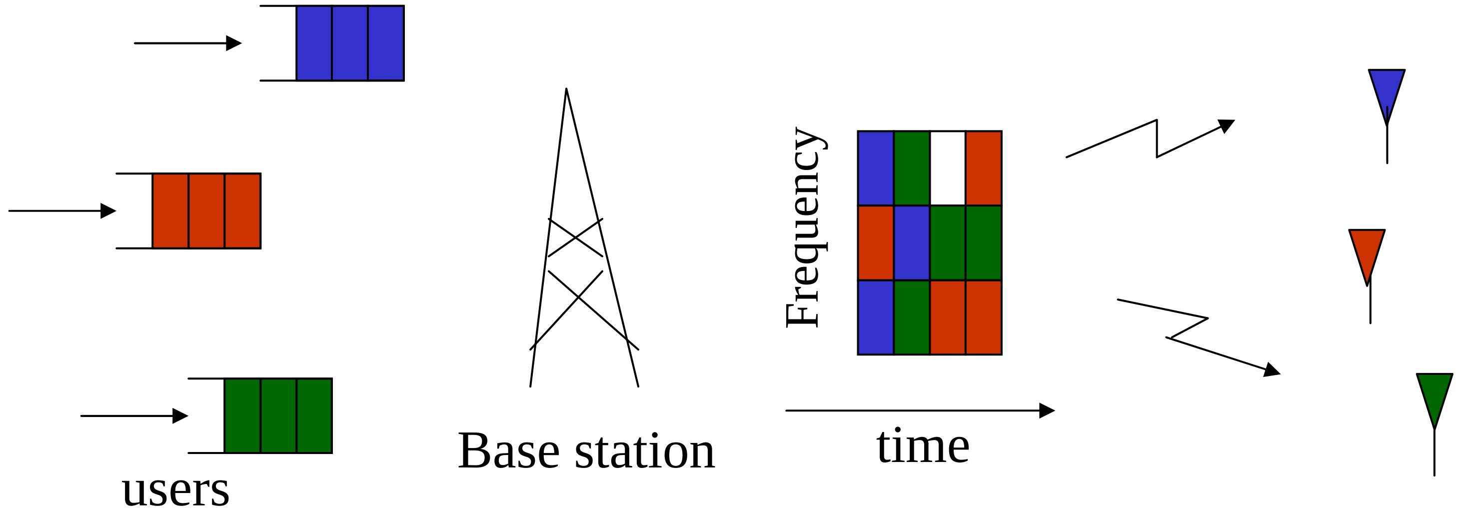
Downlink OFDMA

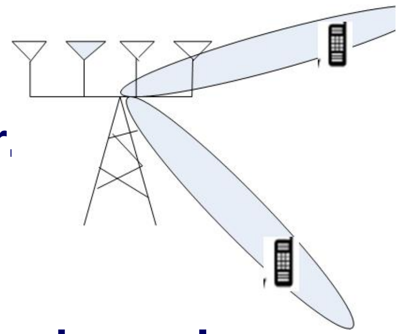


- Allocate frequency slots among users at each scheduling interval.
- Objective: maximize sum rate
  - Exploit channel state information (CSI) at Base Station (BST).

Downlink Feedback Problem

- Overhead for acquiring complete channel info. is prohibitive.
  - Full CSI at transmitter (BST) scales with number of users K and number of sub-channels N.
- How can we reduce the feedback overhead while retaining performance benefits?
  - Must balance uplink overhead with downlink performance.

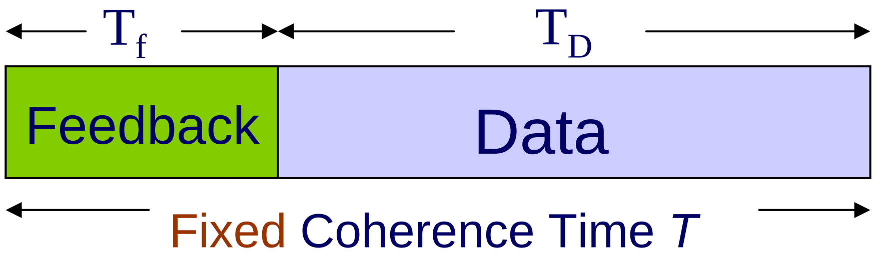
System Model For MIMO-OFDMA



- **Downlink model: K receivers, N OFDM sub-channels.**
- **M antenna at the base station. Single antenna at the receiver.**
  - **Can support up to M data streams.**
- **Every user uses the same codebook with size M.**
- **Every user calculates the worst case SINR on each beam/sub-channel**
  - **assuming M data streams will be transmitted at the same time.**

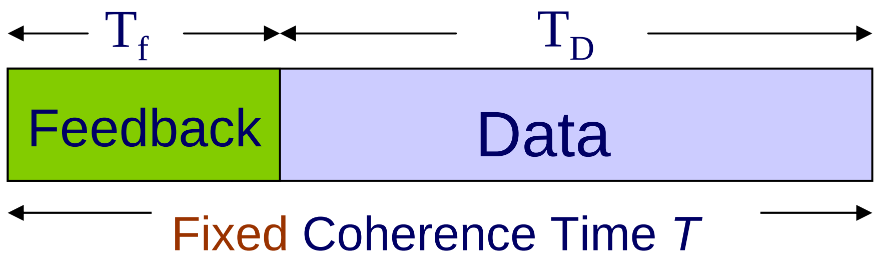
- **Complete CSI requires feeding back K ·N · log M channel coefficients per coherence time…**

Feedback Model with Fixed Coherence Time



- **Time division duplex (TDD) model**
  - **1 frame = 1 coherence time *T*.**
- **First part of frame used for feedback from users. Second part of frame for data transmissions to scheduled users.**
- **Fixed feedback rate R_F per sub-channel.**
  - **Total feedback bits per coherence time $\leq N R_F T$**
- **Objective: maximize the sum capacity taking the time for feedback into consideration.**

Feedback and Data Tradeoff



- Larger T_f benefits the resource allocation at the base station
  - Better exploit multiuser diversity and frequency diversity
- Smaller T_f implies more time for data transmission (larger T_D)
- Previously studied fixed T_f schemes for OFDMA [JSAC08]
- Here: adaptive T_f scheme for MIMO-OFDMA
  - based on feedback received within the coherence time T.
  - Optimal stopping problem.

Beam Selection

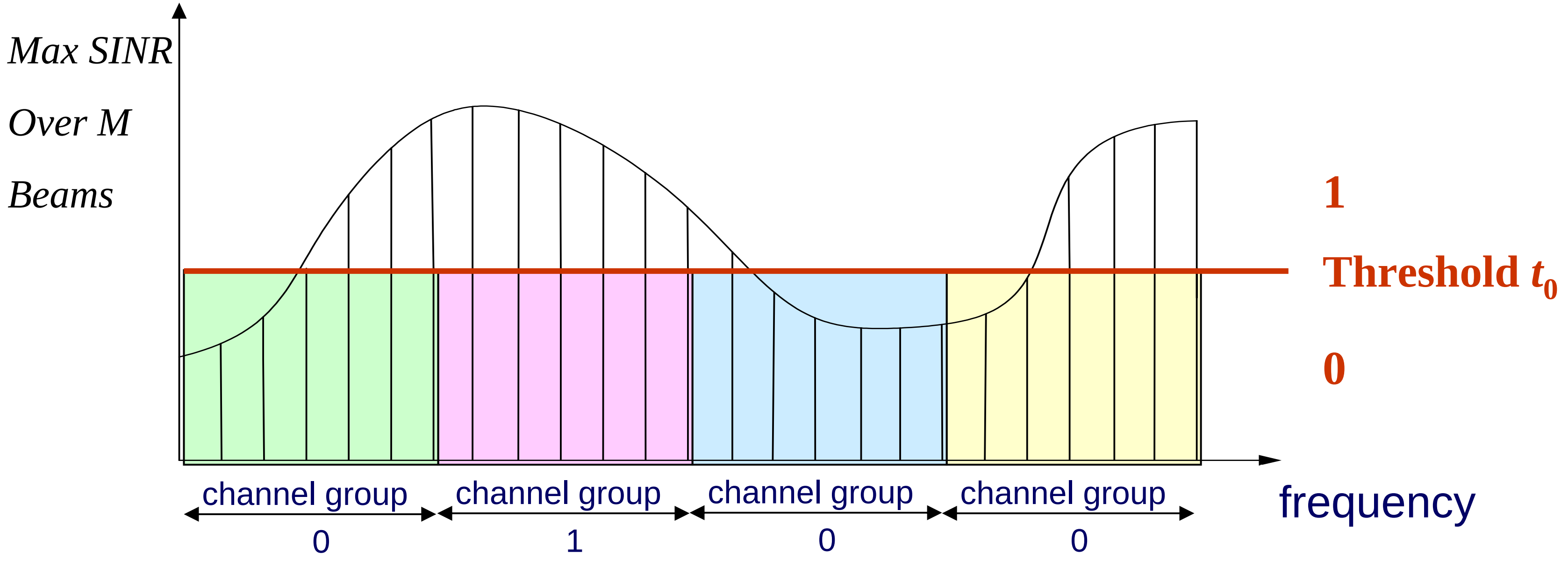
- Beams are selected from a codebook

$$\mathcal{V} = \{\mathbf{v}_1, \cdots, \mathbf{v}_M\}$$

- For each sub-channel *i*, user *k* computes [Yoo, *et. al* JSAC07]:
    - $m_{k,i} = \arg\max_n \{|\mathbf{v}_n^\dagger \mathbf{h}_k|\}$ (receiver knows $\boldsymbol{h}_k$)
    - The SINR for beam $m_{k,i}$ assuming all other M-1 beams are also active (worst-case).

- User *k* requests beam $m_{k,i}$ if the associated worst-case SINR exceeds the threshold t_0.

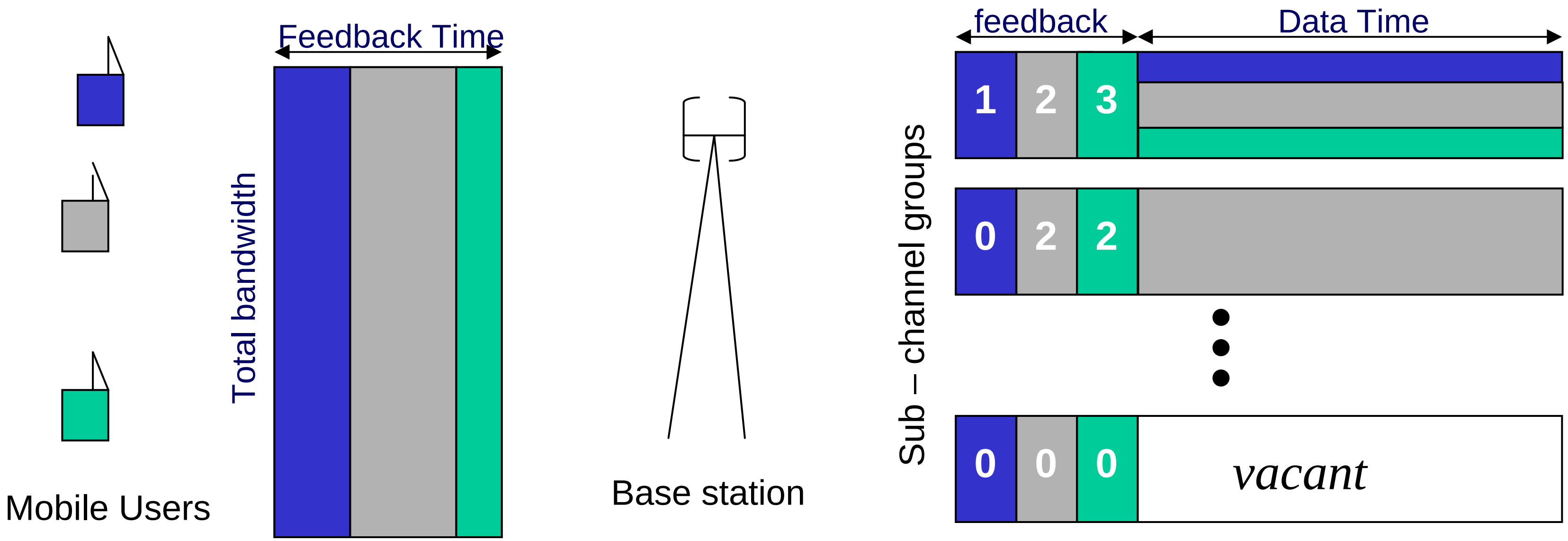
Sub-Channel Groups



- Each sub-channel group contains αN sub-channels, $0 \leqslant \alpha \leqslant 1$.

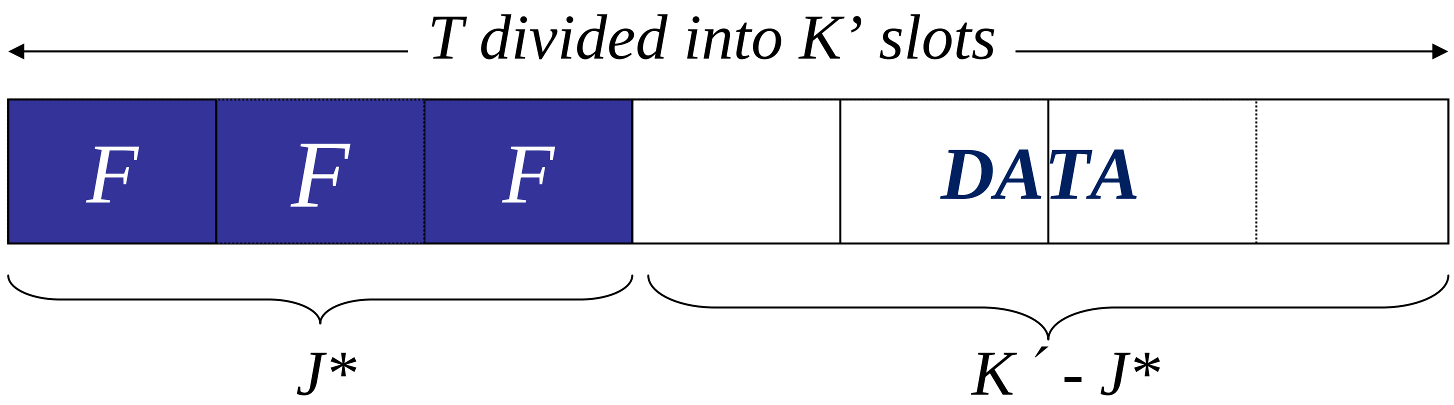
- A user requests a sub-channel group if all worst-case SINRs in that group> t_0.

Feedback Scheme



- **Users feedback compressed requests sequentially.**
- **If a beam for a sub-channel is requested by >1 user, the base station randomly assigns one of them to that sub-channel.**

Adaptive Feedback



- Coherence time *T* divided into *K'* slots.
  - At most 1 user can feedback compressed requests/slot.
- Feedback *adaptively* stops after *J** slots.

Optimal Stopping Rule

- One-step look-ahead policy (given *K'*):

  Stop at slot *n* if $R_n \geq E(R_{n+1}|s_n)$

  R_n is the rate after *n* feedback slots:

  $$(1 - \frac{n}{K'}) \sum_{i=1}^{M} (i x_{i,n}) \log(1 + t_0)$$

  $x_{i,n}$ = number of sub-channels on which *i* data streams have been requested at time *n*.

  $s_n = [x_{0,n}, \ldots, x_{M,n}]$

- From this *J** can be obtained in closed-form.

Results Outline

- Given fixed $R_F T$, the system size K and N scale with fixed ratio K/N.
  - Each user feedback slot converges to same length by law of large number

- The sum capacity is optimized over system parameters
  - Number of slots K'
  - Sub-channel group size
  - Threshold
  - Requesting probability of a sub-channel group

Scaling Properties

- Given fixed $R_F T$, the sum capacity scales linearly with N.
  - Holds for any load K/N.
  - Not true for previous (non-adaptive) policies.

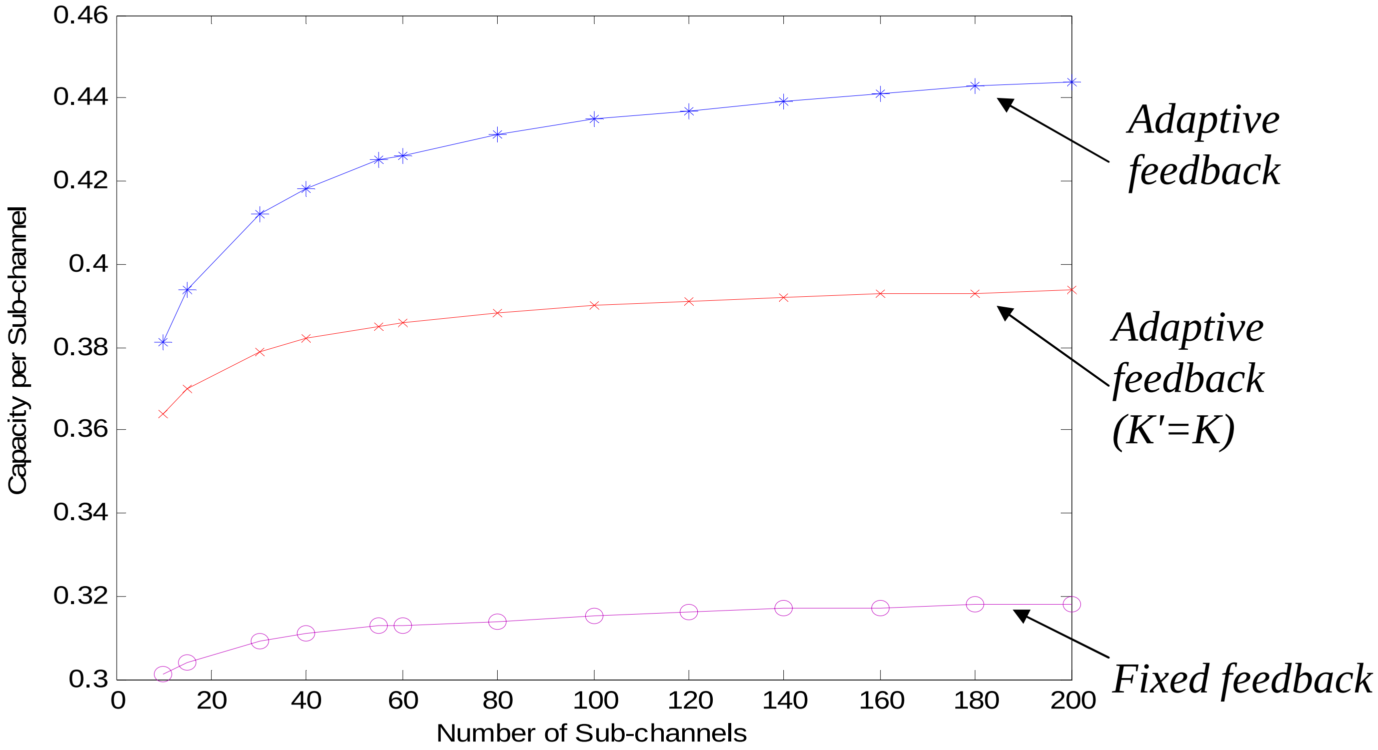
- Optimal system parameters:
  - Number of slots K' scales as $K' \log K' = O(K)$
  - Sub-channel group size scales as $O(\log K')$
  - Each user requests a finite number of sub-channel groups on average.
  - Average stopping time J^* scales as $O(K')$

Capacity vs Feedback

- If $R_F T$ increases slower than log K, then the achievable rate per sub-channel increases as M log ($R_F T/(M$-1)).

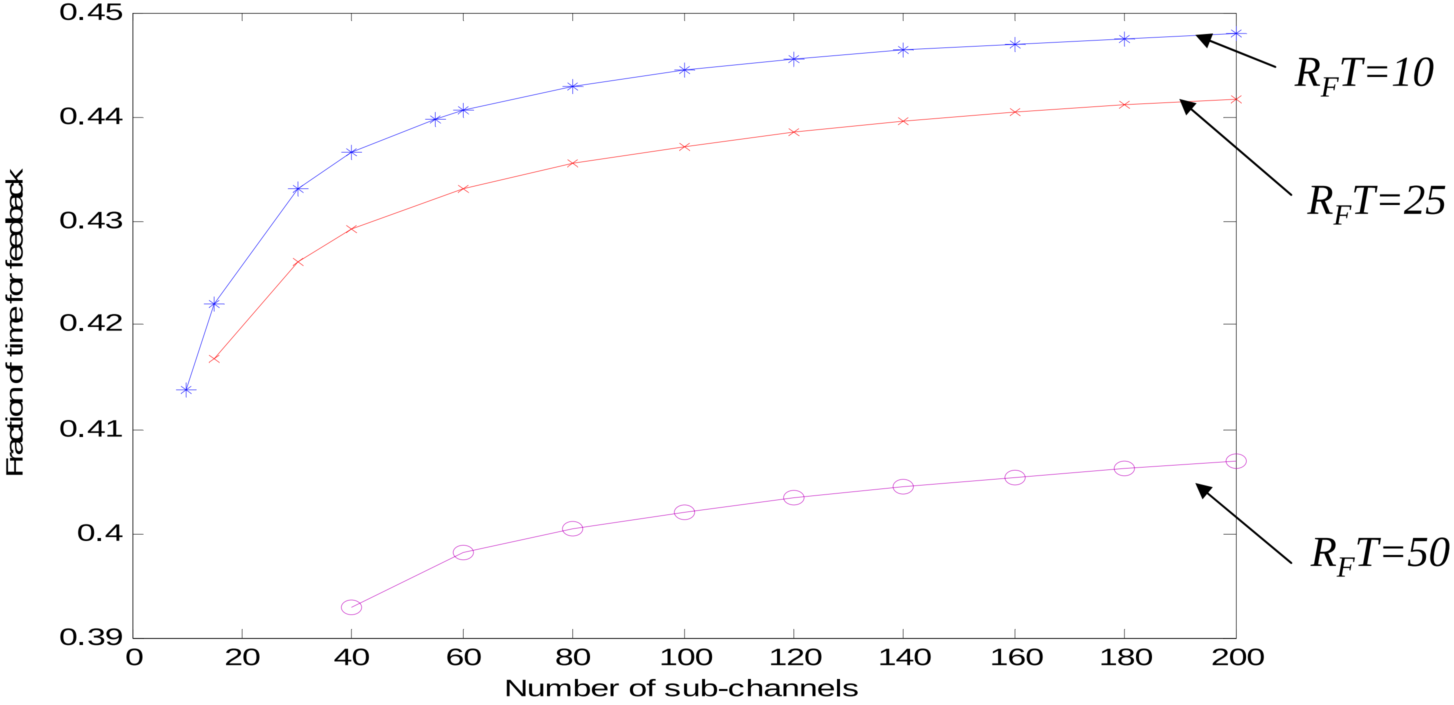
- If $R_F T$ increases faster than log K, then the achievable rate per sub-channel increases as M log log K.

Performance Comparison



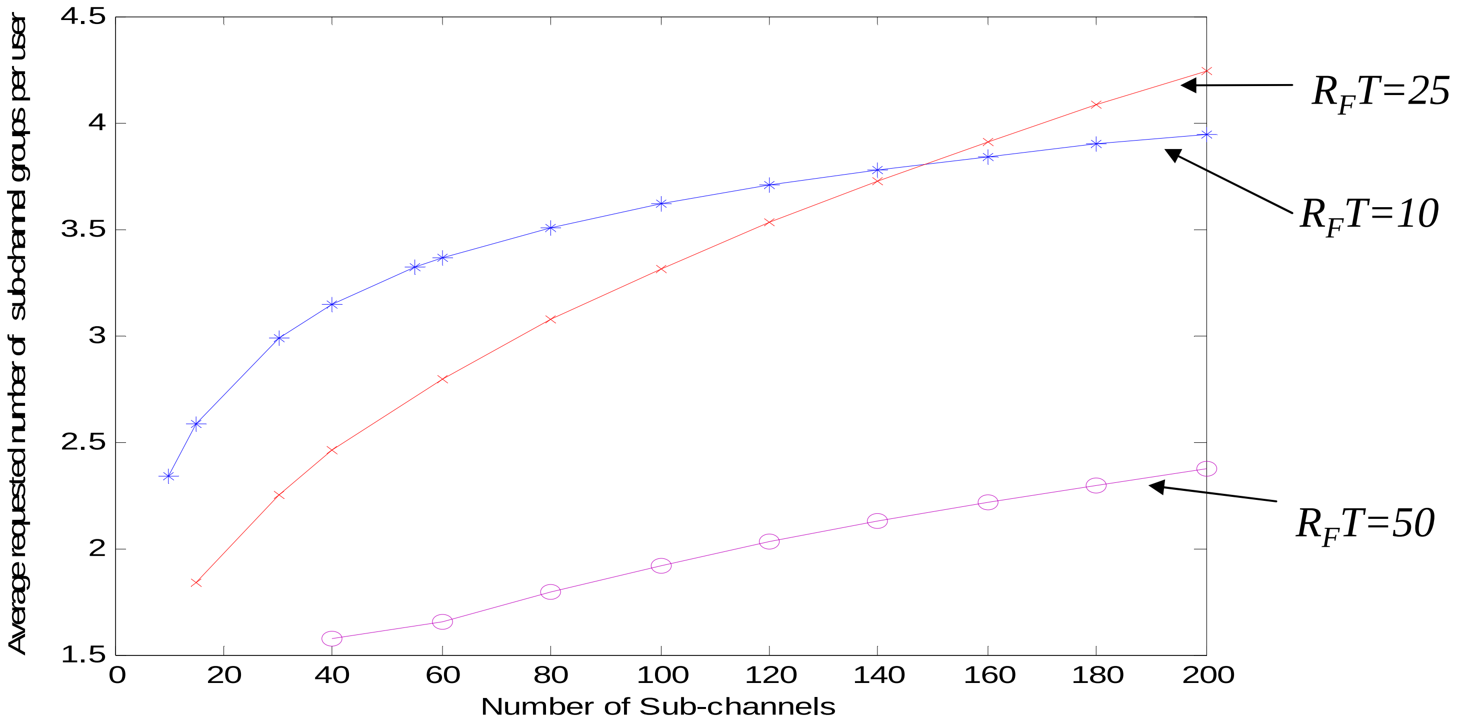
$R_F T=10, P=1.5, M=4, K/N=2$

Fraction of Time for Feedback



P=1.5, M=4, K/N=2

Requested Sub-Channel Groups/User



$P=1.5, M=4, K/N=2$

Conclusions

- Presented a scalable limited-feedback scheme for downlink MIMO-OFDMA.
  - Explicitly accounts for feedback overhead.
  - Optimal stopping provides scalability with users; improves on static feedback for all parameter ranges.
- Several assumptions can be revised in future work:
  - Larger codebook size
  - Temporally correlated channels
  - Overhead due to downlink signaling