Downlink MIMO in IEEE 802.11ac-based Infrastructure Networks

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Outline

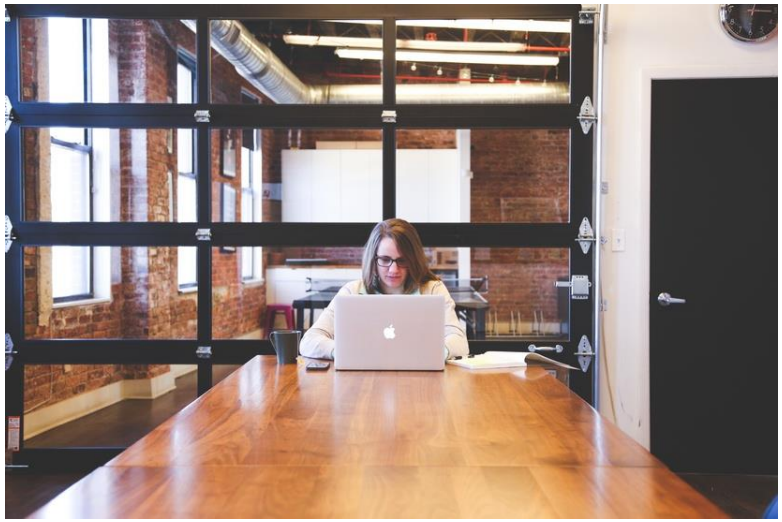
- Motivation,
- System Model,
- Problem Statement,
- Proposed Approach,
- Evaluation,
- Conclusion.

Motivation

- Clear trend towards deploying dense IEEE 802.11 wireless networks (WiFi) in **enterprise environments**,
- Wireless traffic explodes due to novel applications & appearance of WiFi enabled BYOD,
- New **802.11ac** offers very high peak data rate by
  - Using **MIMO** transmissions (up to 8 antennas)
    - Open and closed-loop approaches; latter is more efficient but requires a complex channel sounding resulting in high overhead
  - Higher order **modulation** (256-QAM),
  - Larger **bandwidth** (up to 160 MHz)
    - Channel bonding might be inappropriate as in dense AP deployment the overall network capacity may be reduced due to co-channel interference / contention.

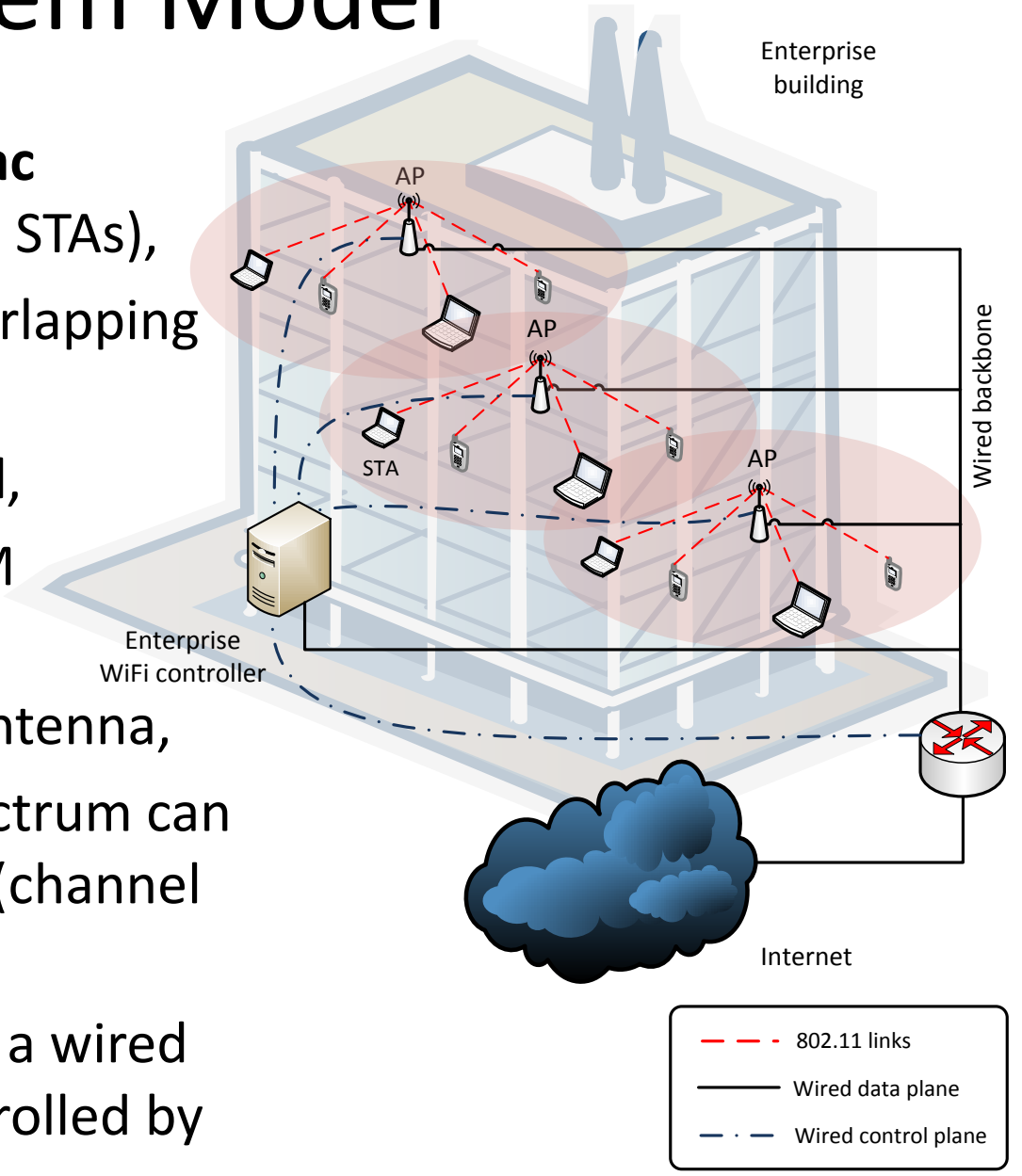
Motivation (II)

- In practice, the WiFi cells are **unequally loaded**:
  - **Lightly** loaded APs, i.e. floors, serving only a small number of active STAs/flows,
  - **Highly** loaded APs, i.e. in conference rooms, serving a large number of active STAs/flows.



System Model

- DL of **enterprise 802.11ac** network (APs plus assoc. STAs),
- **High AP density**, i.e. overlapping cells,
- AP are **unequally loaded**,
- APs are equipped with M antennas (e.g. ULA),
- STAs have just a single antenna,
- Total available radio spectrum can be used simultaneously (channel bonding).
- All APs are connected to a wired backbone & can be controlled by a centralized controller.

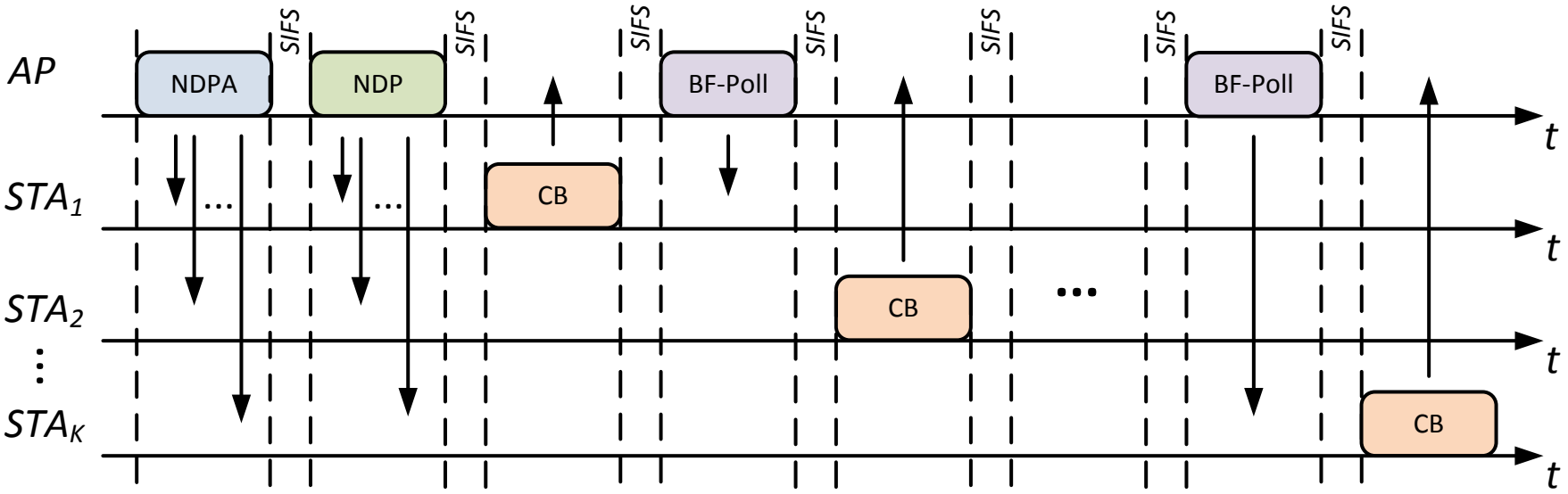


Problem Statement

- **Objective**: **maximize the average DL rate** in each cell which indicates the overall effectiveness of an AP.
- As we assume **unequal network load** our objective can be achieved by optimizing the DL throughput of highly loaded APs.
- **Idea**: lightly loaded APs use their unused degree of freedom to **perform interference nulling** towards STAs located in adjacent hotspot cells/AP => SINR gain for STAs in hotspot cells.
- **But: STAs to be nulled** must be carefully **selected** because otherwise the **channel sounding overhead** may exceed the gain from interference nulling.

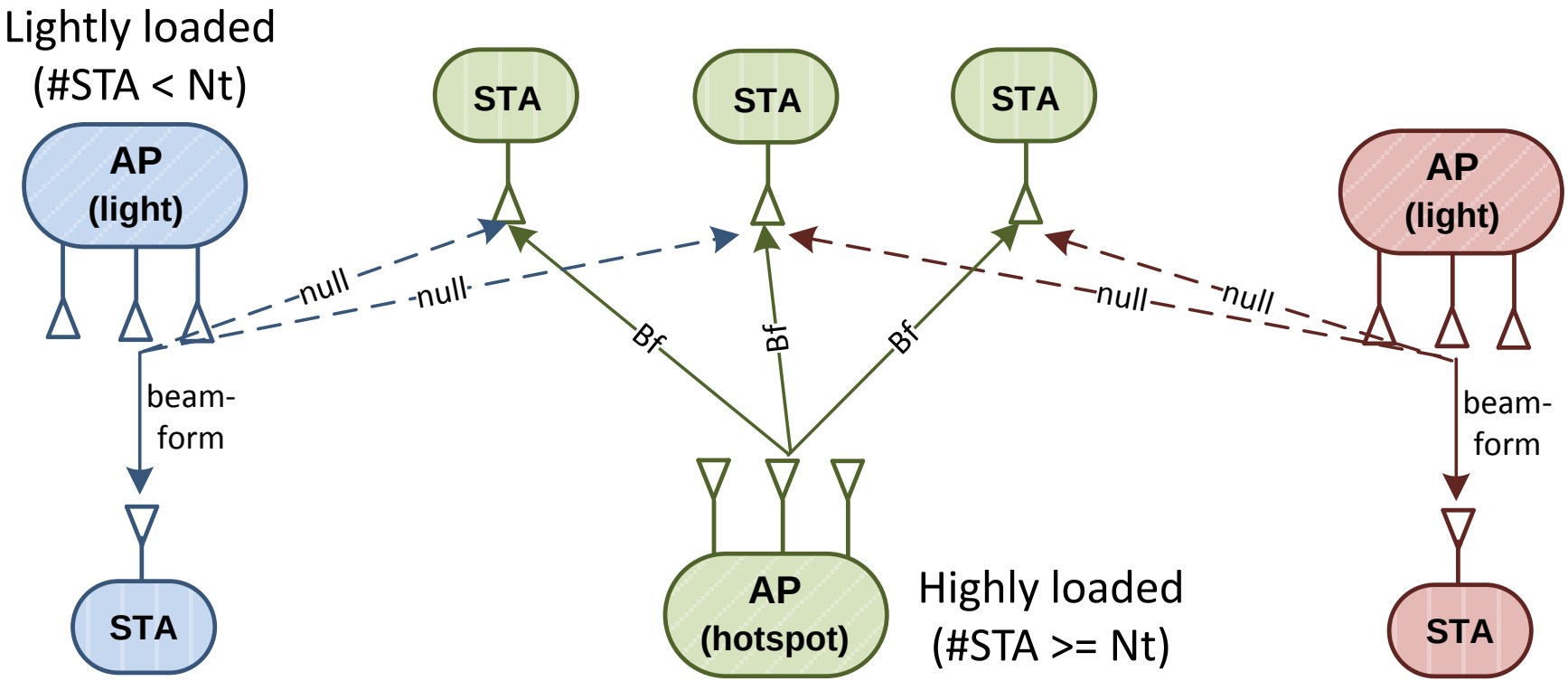
Reminder: 802.11ac Channel Sounding

- Standard way to obtain **CSI at transmitter side**,
- The transmitter (AP) sends a **sounding packet** including only preambles and receives a **Compressed Beam** (CB) frame with modified CSI from the probed receiver(s), usually STA(s).
- **Multi-user sounding**: for each additional user a BF-Poll is transmitted which is replied by a CB.



Illustrative Example

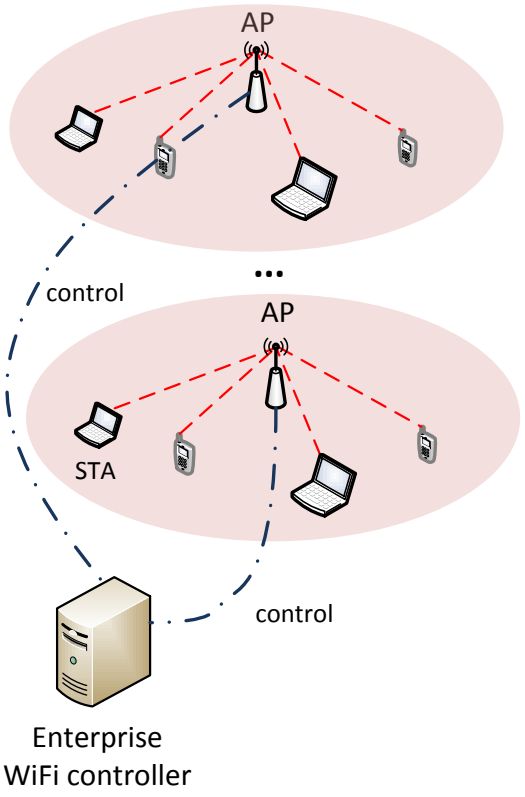
- HS AP performs MU-MIMO (SDMA) by steering **multiple beams** towards its STAs whereas adjacent APs beamform their signal to their STAs, while **nulling** interference to the nearest STAs of the HS AP.

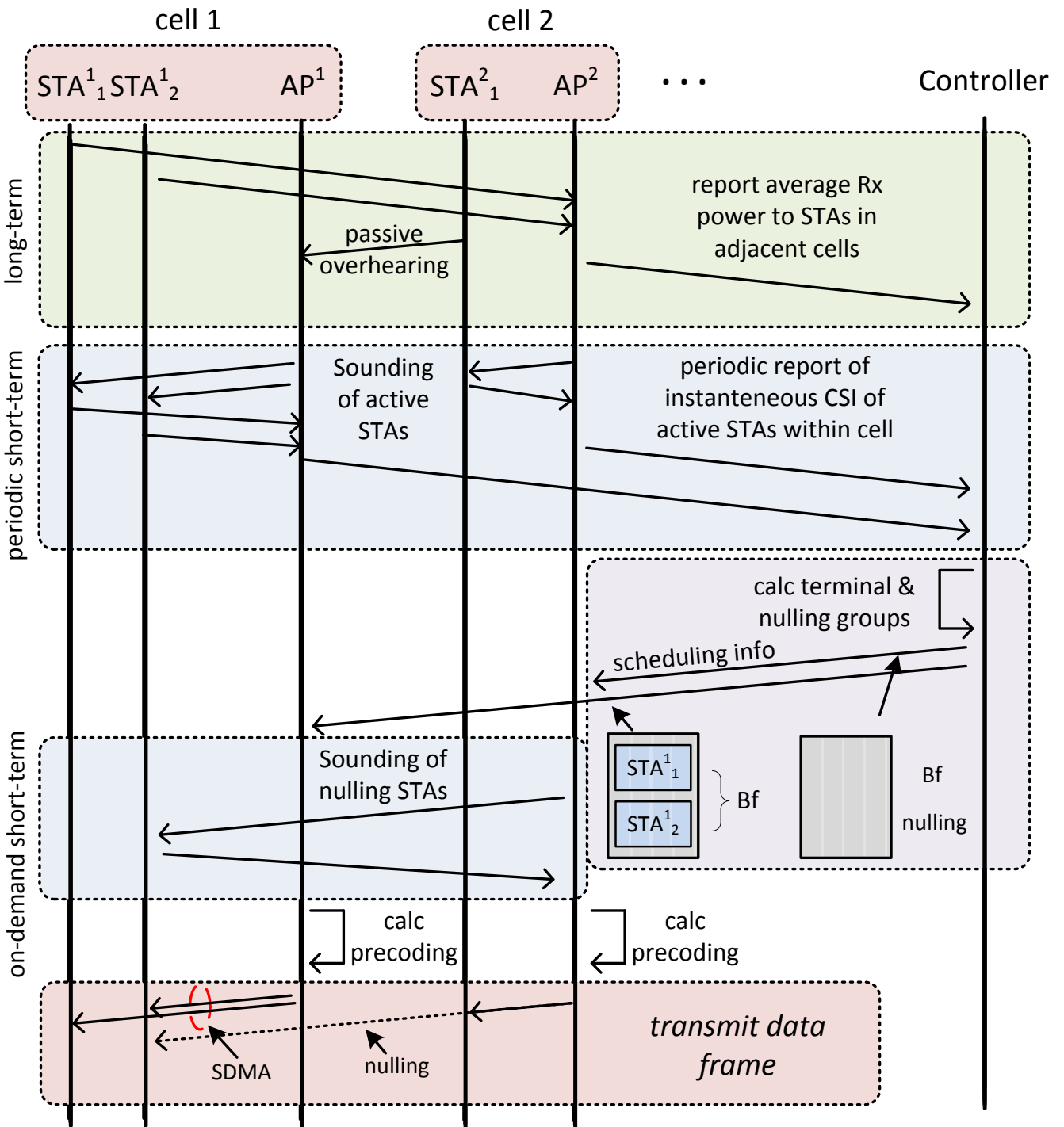


Proposed Approach

- **Frequency-reuse 1**, i.e. all APs use full spectrum,
- MAC layer - **time aligned channel access** is required for interference-nulling (global TDMA),
- Channel sounding is performed regularly to active STAs in each cell,
- Controller **algorithm groups STAs** in two sequential steps:
  - i) **SDMA grouping** - find **optimal grouping** of active STAs into spatially compatible groups:
    - Available instantaneous CSI is used for grouping
  - ii) **Null grouping** - find optimal set of STAs to be nulled by any AP in each time slot:
    - Only **average CSI** towards STAs in adjacent cells is available during grouping.
    - After grouping the instantaneous CSI towards STAs in nulling groups is estimated.
- **Reasoning**: spatial multiplexing gain from SDMA is higher than SNIR gain from nulling.

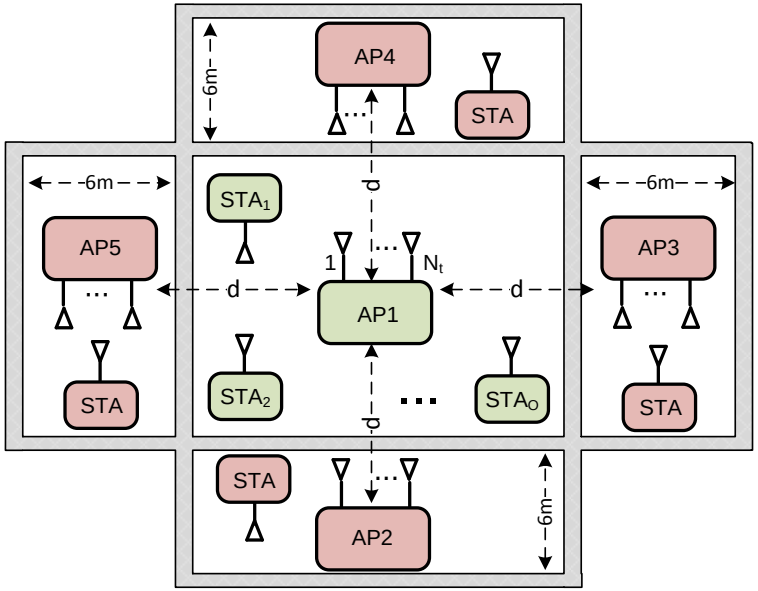
Data & Control Flow





Evaluation

- Methodology
  - System-level simulation,
  - Placement & channel model,
  - Performance metrics,
- Methods under study:
  - **Baseline (5x20 MHz)**: standard 802.11ac with dedicated 20 MHz channel for each cell,
  - **Baseline (CSMA)**: standard 802.11ac where each cell uses the full 100 MHz,
  - **Indep**: same as Baseline (CSMA) but with CSMA deactivated,
  - **Proposed**



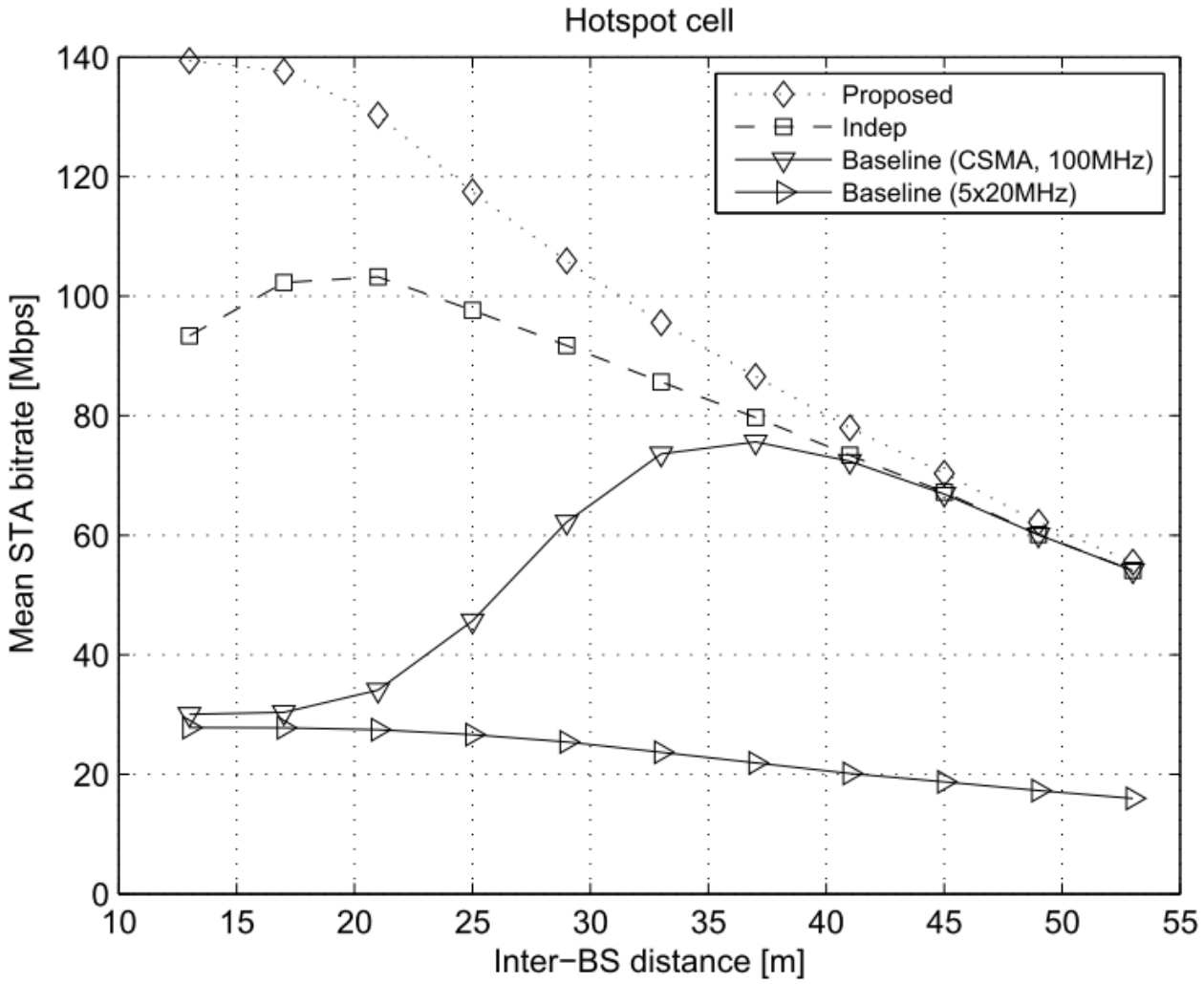
Scenario: hotspot cell in the middle surrounded by four lightly loaded cells.

Parameter	Value
System bandwidth	100 MHz & 5 × 20 MHz
PHY	IEEE 802.11ac (long preamble)
MAC	TDMA, CSMA/CA 802.11ac
Center frequency	5.32 GHz
Transmit power	10 dBm
STA noise density (dBm/Hz)	-167 dBm/Hz
STA noise figure	6 dB
Direction	Downlink
Channel sounding	explicit, 802.11ac
Pathloss model	802.16m indoor small office (A1)
MU-MIMO precoding	Zero-forcing
MU-MIMO grouping	Best-fit algorithm
Carrier sensing threshold	SINR=-3 dB (BPSK 1/2)
Inter AP distance	13-54 m
STA placement	uniform
No. of antennas at AP	4,8,12
No. of antennas at STA	1
No. of STAs in hotspot cell	20
No. of STAs in adjacent cells	1
No. of placement seeds	1000

TABLE I: Simulation Parameters.

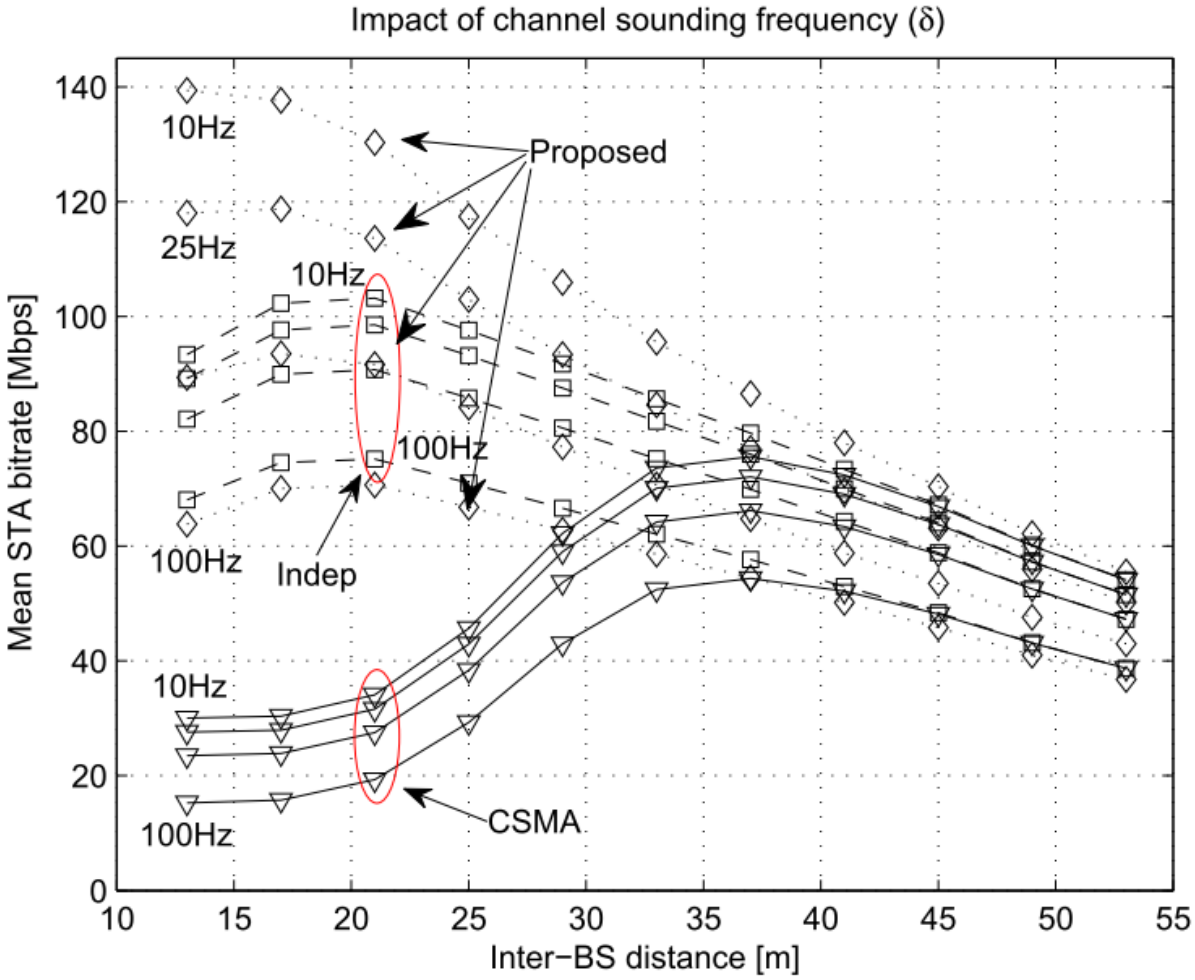
Mean STA Bitrate in Hotspot Cell

- Nt=8, δ=10 Hz (low mobility)
- Gain is especially high in very dense deployments



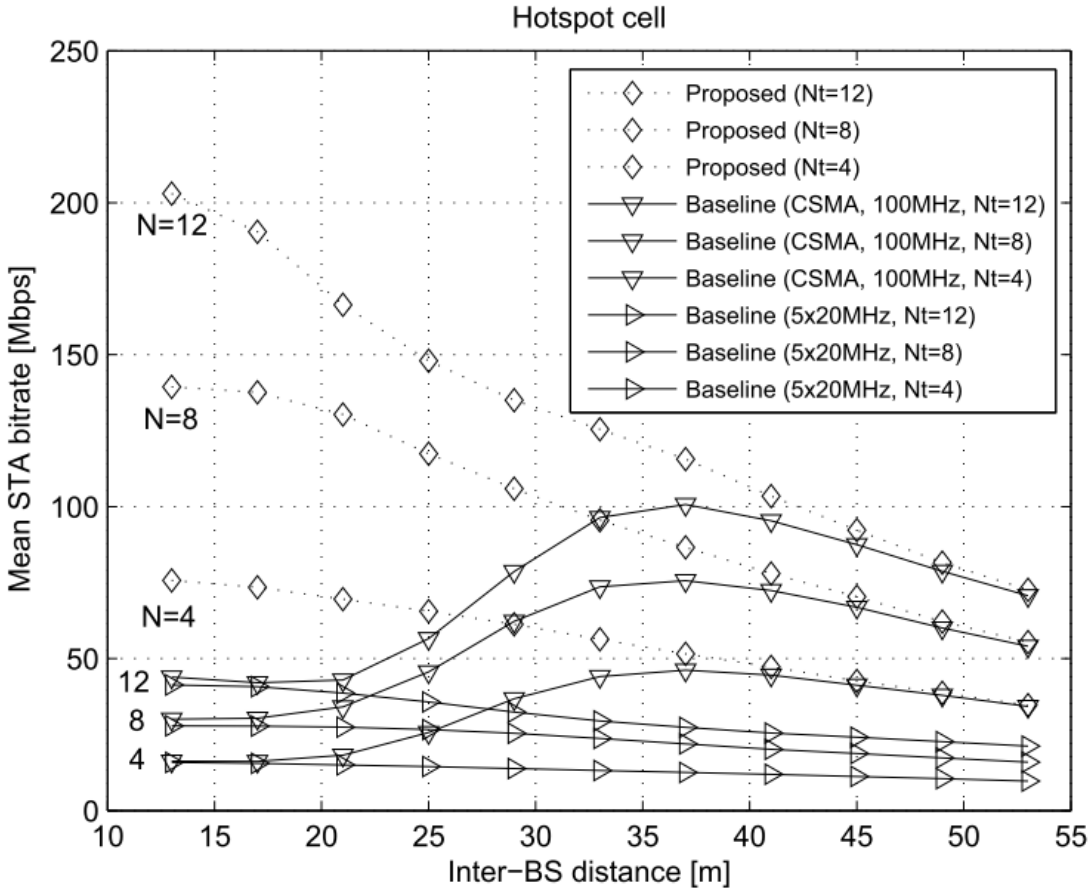
Channel Sounding Update Rate (HS Cell)

- High impact due to additional channel sounding overhead
- For δ<25 Hz the proposed scheme outperforms all other



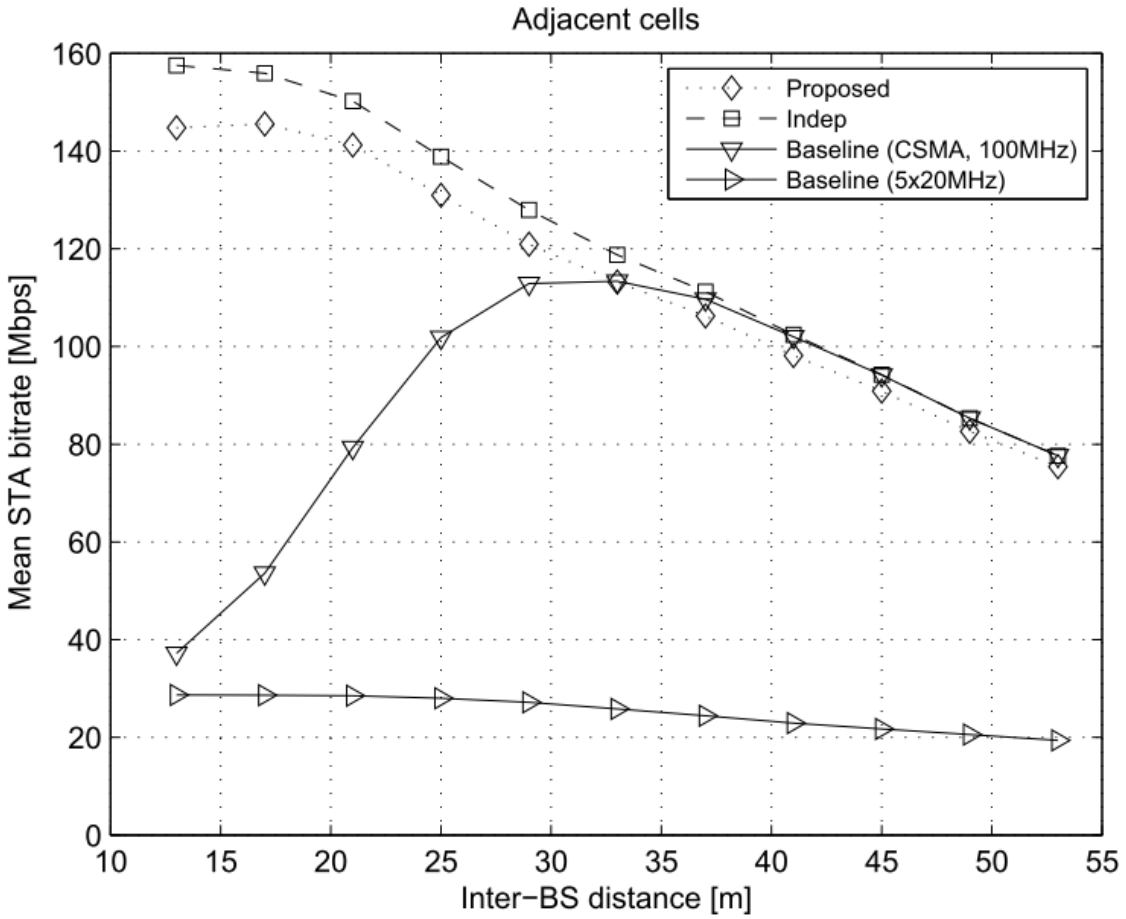
Impact of Number of Antennas (HC Cell)

- Note: in 802.11ac channel sounding overhead increases with number of antennas (Nt),
- Proposed scheme **scales** with number of antennas at AP.



Mean STA Bitrate in Lightly-loaded Adjacent Cells

- Analyze the performance degradation in adjacent cells due to nulling towards hotspot cell,
- Nt=8, δ=10 Hz



Conclusions

- A combination of two MIMO techniques, namely **MU-MIMO** and **interference nulling**, is a promising way to improve the downlink performance of **802.11ac enterprise** WiFi networks with unequal network load.
- An architecture is presented where a central controller executes an algorithm performing in two steps:
  - i) **Grouping of spatial compatible STAs** which are served by SDMA,
  - ii) **Null grouping** for interference management where the unused degree of freedom of lightly loaded APs is used to perform null steering towards STAs in highly loaded adjacent cells.
- The proposed adaptive algorithm takes the **channel sounding overhead** explicitly into account when calculating the set of STAs to be nulled.