# Early-Late Protocol for Coordinated Beam Scheduling in MmWave Cellular Networks

Ziyuan Sha[1], Zhaocheng Wang[1], Sheng Chen[2], and Lajos Hanzo[2]
[1]Department of Electronic Engineering, Tsinghua University, P.R. China
[2]School of Electronics and Computer Science, University of Southampton, U.K.

# Outline

- Background
- Idea of Time-domain Beam Schedule
- Proposed EL Protocol
- Future Visions

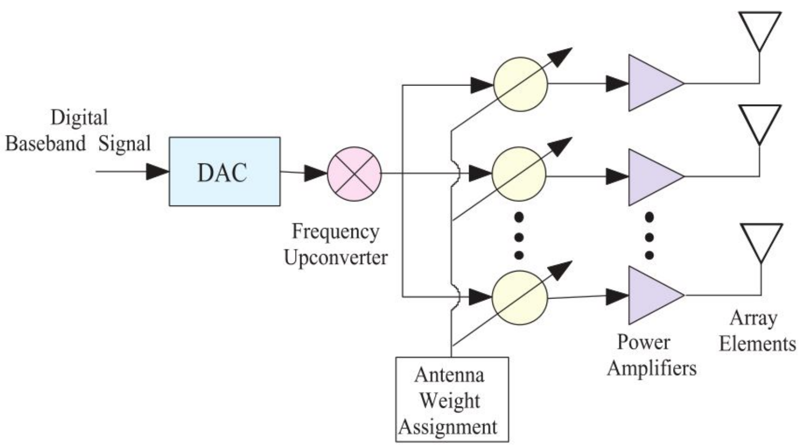
# Analog Beamforming Technique

## Large-Scale Antenna Array

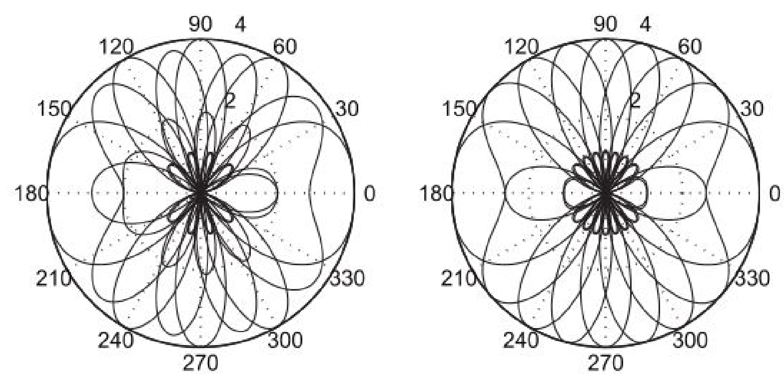
- Small wavelength facilitates large antenna array
- High beamforming gain compensates large path loss

## Analog Beamforming

- Number of RF Chains << Number of Antennas
- Use analog phase shifters to steer directional beam
- Select steering vector from codebook




**Analog Beamforming Architecture[1]**

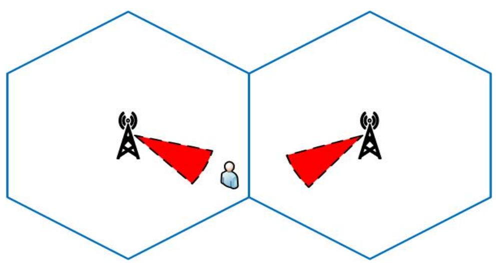



**Codebook Based Beamforming[1]**

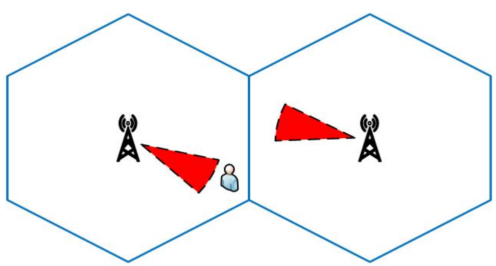

[1] S. Kutty, and D. Sen, "Beamforming for Millimeter Wave Communications: An Inclusive Survey," *IEEE Commun. Surveys Tuts.*, vol. 18, no. 6, pp. 949–973, Dec.

# Inter-cell Interference in MmWave

- **Beam-aware Inter-cell Interference (ICI)**
  - Neighbor Beam points towards user → High ICI
  - Neighbor Beam does not point towards user → Almost no ICI
- **Compare with Low-frequency LTE**
  - LTE: Wide radiation pattern, stable ICI
  - MmWave: Narrow radiation pattern, time-varying and bursty ICI

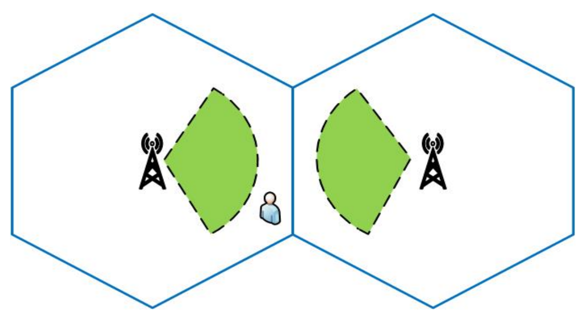


(a) High level interference



(b) Low level interference

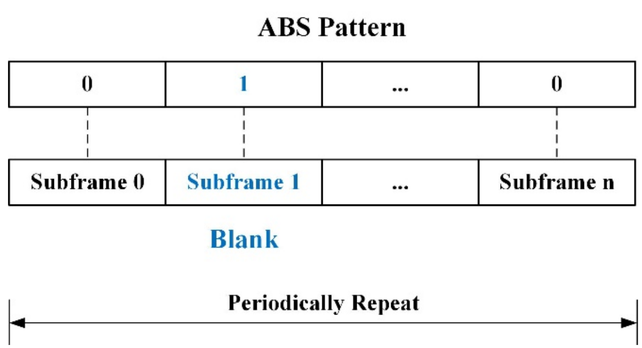
**MmWave ICI**



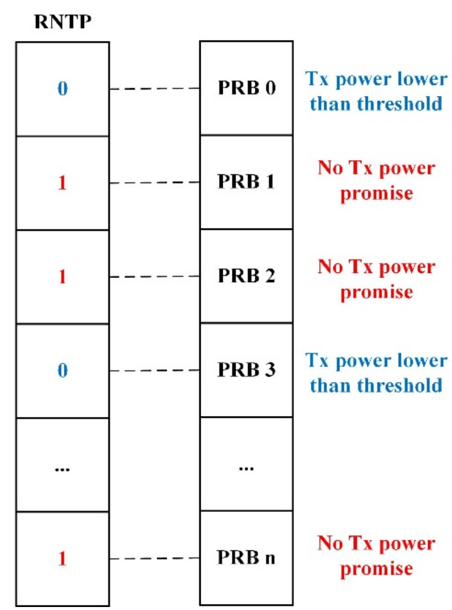
**Low-frequency ICI**

# Inter-cell Interference Coordination (ICIC)

- **Cell Coordination in Low Frequency**
  - Coordination info in LTE: ABS and RNTP
  - Almost blank subframe (ABS): mute a cell in time domain
  - Relatively Narrow Tx Power (RNTP): mute a cell in frequency domain
  - MIMO Processing Technique
- **Problem: How to exploit the narrow beam in MmWave ICIC?**




**ABS Info**



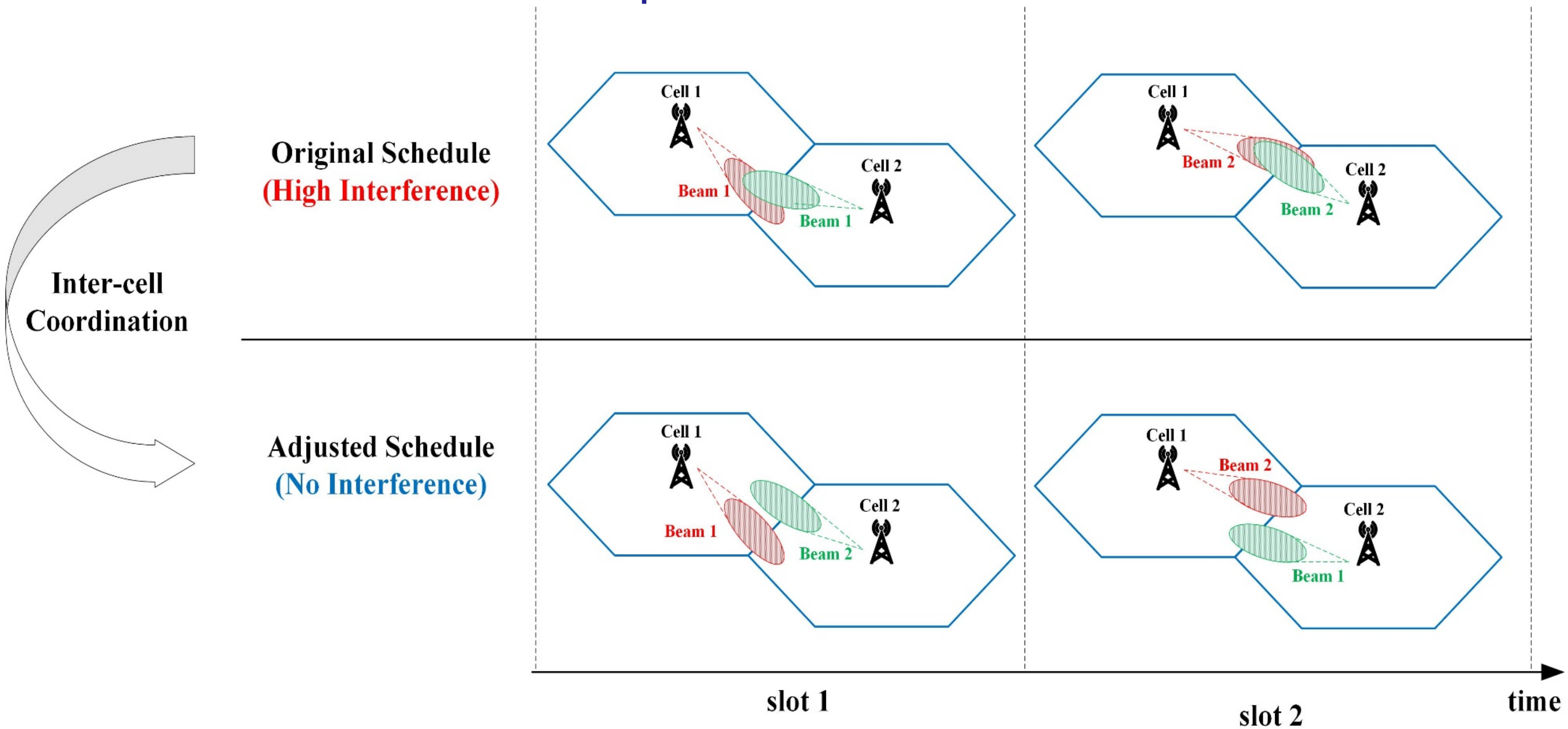

**RNTP Info**

# Outline

- Background
- Idea of Time-domain Beam Schedule
- Proposed EL Protocol
- Future Visions

# Time-domain Beam Scheduling

- **An Example of Avoiding ICI via Beam Scheduling**
  - Switch the beam sequence in cell 2



# Time-domain Beam Scheduling

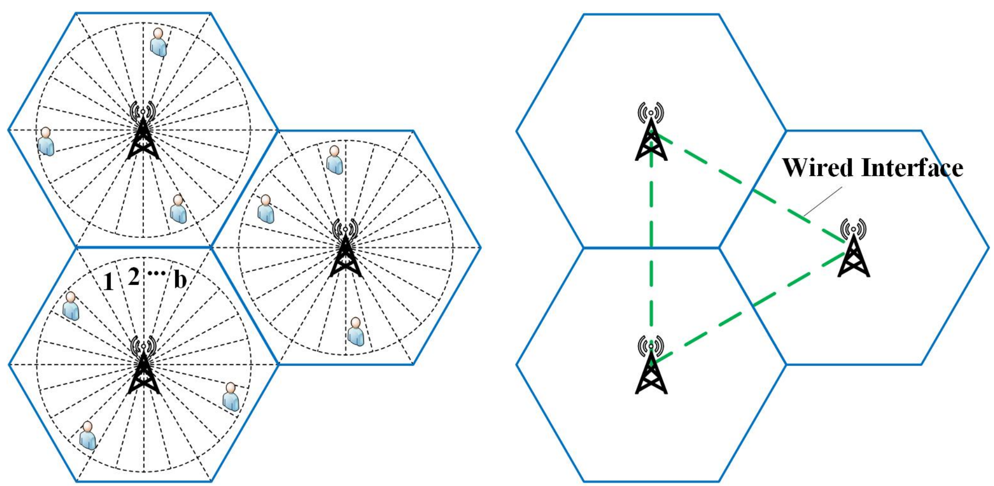
- **Inspirations**
  - ICI level can be strongly influenced by beam scheduling
  - A well-designed coordinated beam scheduling may avoid the occurr ence of ICI
- **Advantages of Mitigating ICI via Beam Scheduling**
  - Do not require precise CSI, we only need to know the beams which can not be used simultaneously
  - No muting resource loss compared with ABS and RNTP schemes
  - Pure network-side operation

# Outline

- Background
- Idea of Time-domain Beam Schedule
- Proposed EL Protocol
- Future Visions

# System Model

- **Cellular Network with $K$ Cells**
  - Each cell is covered by $B$ beams from codebook
  - Each $60^{\circ}$ sector is covered by $b = B/6$ beams
  - $N$ time slots, each cell uses one beam at one time slot
  - Each cell has $M$ users served by $M$ different beams
- **Wired Interface**
  - Adjacent cells are connected by wired interface
  - Exchanges information for cell coordination




(a) (b)

# System Model

## User Service Demand

- $m$th user in $k$th cell has service demand $d_{k,m}$
- The sum of $d_{k,m}$ of all users in cell $k$ is $N$

$$\sum_{m=1}^{M} d_{k,m} = N, k = 1,2, \cdots, K$$

- Assumption: user number $M$ is small compared with beam number $B$ and time slot number $N$

## Flat-top Beam Pattern

- Constant directional gain inside or outside beamwidth

$$G(\phi) = \begin{cases} G_{max}, & \text{if } |\phi| < \frac{\phi_b}{2} \\ G_{min}, & \text{if } |\phi| > \frac{\phi_b}{2} \end{cases}$$

where $\phi_b$ represents beamwidth

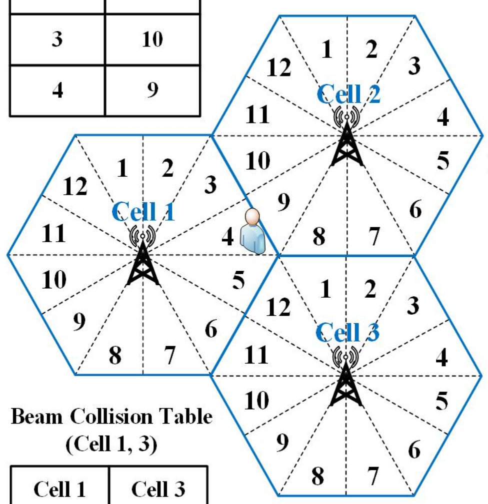
# Beam Collision Table

## ➢ Beam Collision Table

- Each row records a pair of beams with collision
- Every two neighboring cells maintain a mutual beam collision table
- Long-term valid, low maintenance overhead

Beam Collision Table
(Cell 1, 2)

| Cell 1 | Cell 2 |
|---|---|
| 3 | 10 |
| 4 | 9 |




Beam Collision Table
(Cell 2, 3)

| Cell 2 | Cell 3 |
|---|---|
| 7 | 2 |
| 8 | 1 |

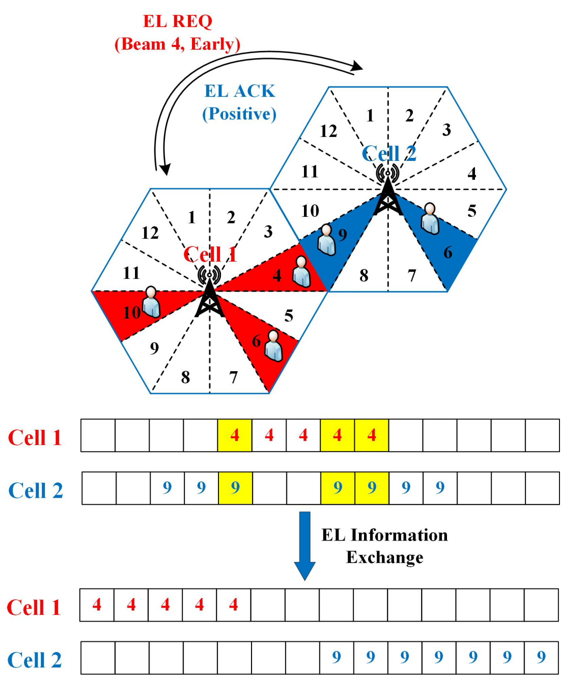
Beam Collision Table
(Cell 1, 3)

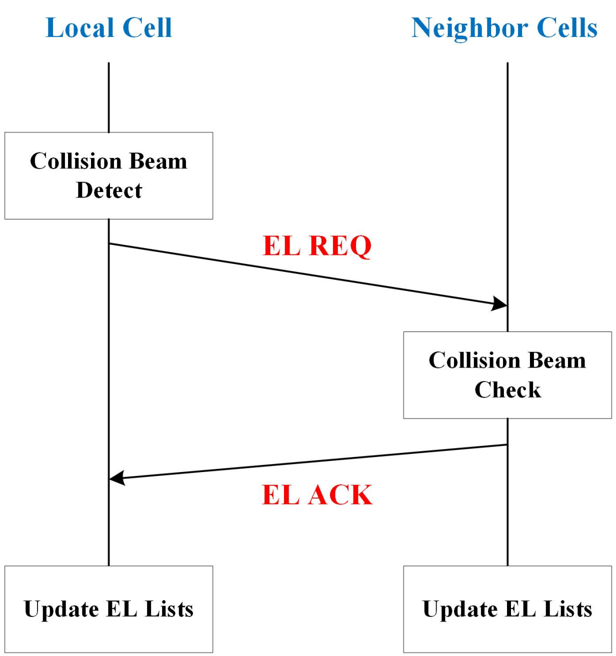
| Cell 1 | Cell 3 |
|---|---|
| 5 | 12 |
| 6 | 11 |

# Early-late Information

## Adjacent Cells Exchange Early-late (EL) Info

- Main idea: Stagger two colliding beams in time domain
- EL REQ: indicates a local beam to be scheduled at early or late time
- EL ACK: indicates whether the beam colliding with the beam indicated by EL REQ will be scheduled
- EL Lists: Early (late) list records the beams to be scheduled at early (l ate) time

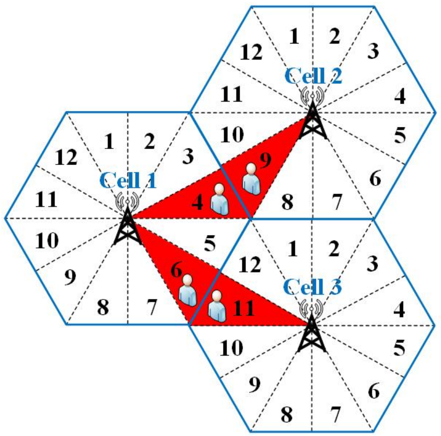


# EL Balancing Mechanism

## ➢ EL Unbalance Problem

- Do not hope an early or late list records too many beams
- Early and late lists are preferred to be balanced




| | Early List | Late List |
|---|---|---|
| Cell 1 | {4} | {6} |
| Cell 2 | {} | {9} |
| Cell 3 | {11} | {} |

(a) EL Balance (Preferred)

| | Early List | Late List |
|---|---|---|
| Cell 1 | {4,6} | {} |
| Cell 2 | {} | {9} |
| Cell 3 | {} | {11} |

(b) EL Unbalance (Not Preferred)

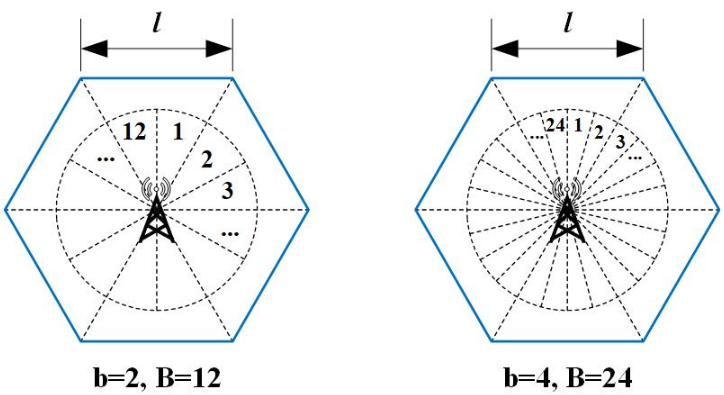
## ➢ EL Balancing Mechanism

- Each EL REQ is sent to balance current EL Lists
- EL info exchange window: Each cell randomly selects a time to st art sending EL REQ in the window

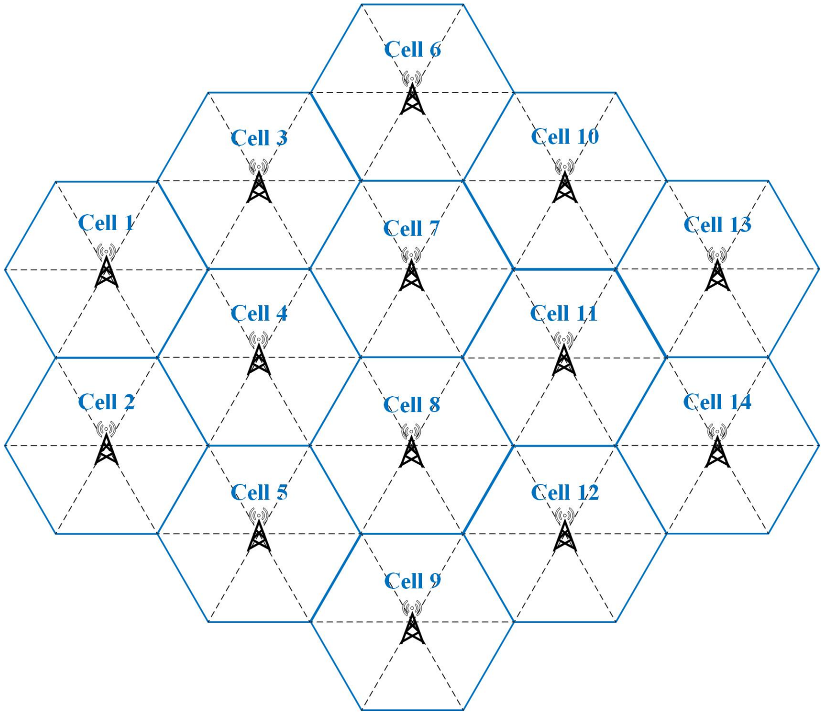
# Simulation Scenario

## Scenario: Cellular Network with $K = 14$ cells

- Regular hexagon cells
- Two beam patterns with $B = 12, 24$
- All users located at cell edge
- Randomly generated service demands



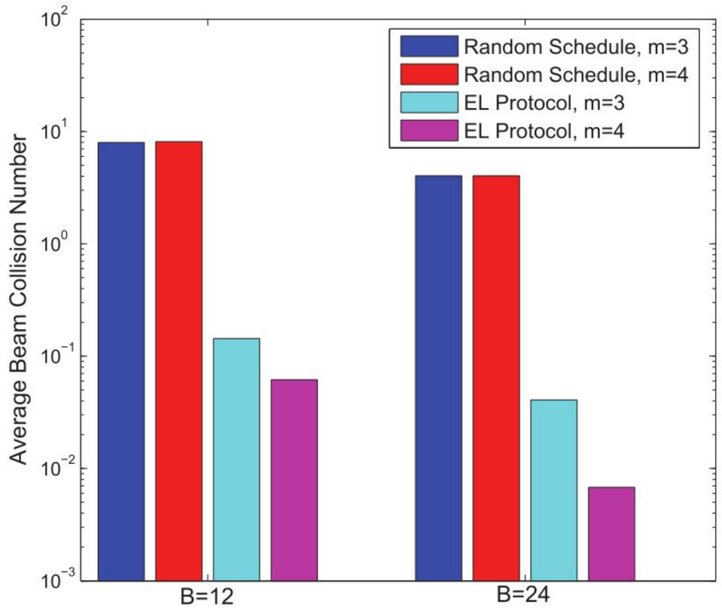

**Beam Pattern**



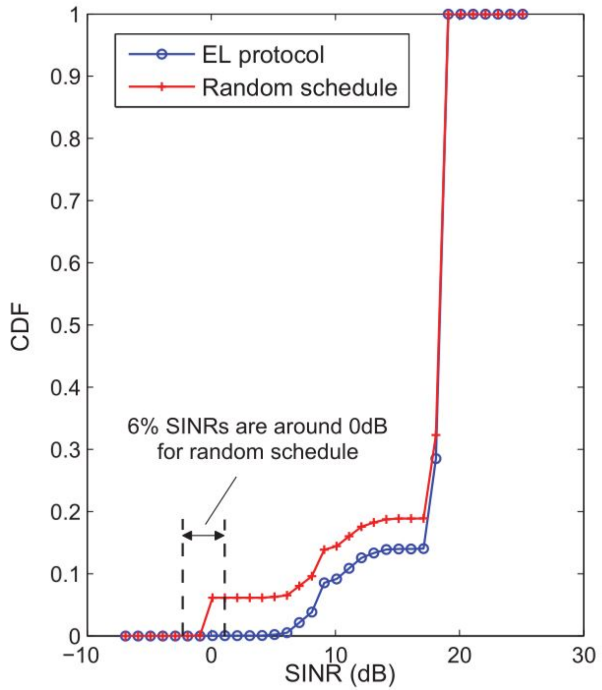

**Cellular Network**

# Simulation Results

- Numbers of Beam Collisions
- CDF of User SINR
  - EL Protocol eliminates the low SINR region (around 0dB)




**Numbers of Beam Collisions**




**CDF of User SINR**

# Outline

- Background
- Idea of Time-domain Beam Schedule
- Proposed EL Protocol
- Future Visions

# Centralized Beam Scheduling

## EL Protocol

- Distributed scheduling scheme
- Easy to implement and do not need a central scheduler
- Hard to acquire the optimal scheduling

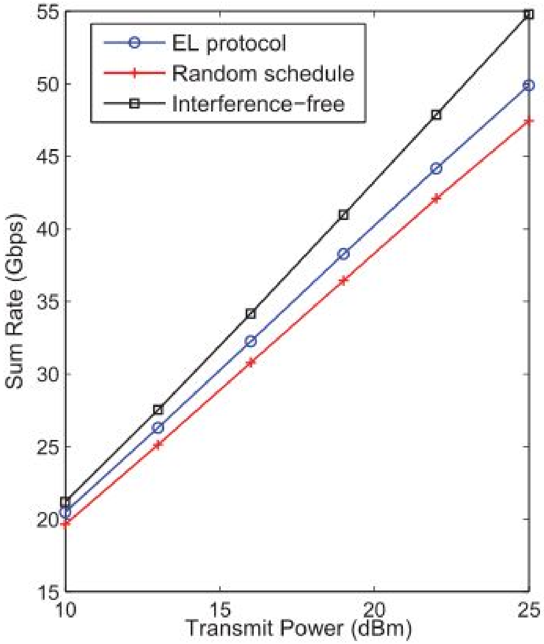
## Centralized Beam Scheduling

- Possible to acquire the global optimal scheduling, in terms of su m rate, number of collisions, etc.
- Provide more theoretic insights of time-domain beam scheduling

# Performance Upper Bound

➢ **Performance Upper Bound of Beam scheduling**

- The limit of network performance with beam scheduling
- Problem: How close can we reach to the ideal interference-free case ?




**Sum Rate Gap**

# Thank you!