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RIS-Assisted 6G Networks: Challenges and Tradeoffs in Control Standardization

Ehsan Tohidi, Max Franke, André Drummond,
Stefan Schmid, Admela Jukan, and Slawomir Stańczak

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Much research on RIS ***devices*** and physical properties, ***network-level*** studies rare. We need models for understanding ***performance*** and ***standards***. What is ***unique*** here? And implications for ***control plane***?

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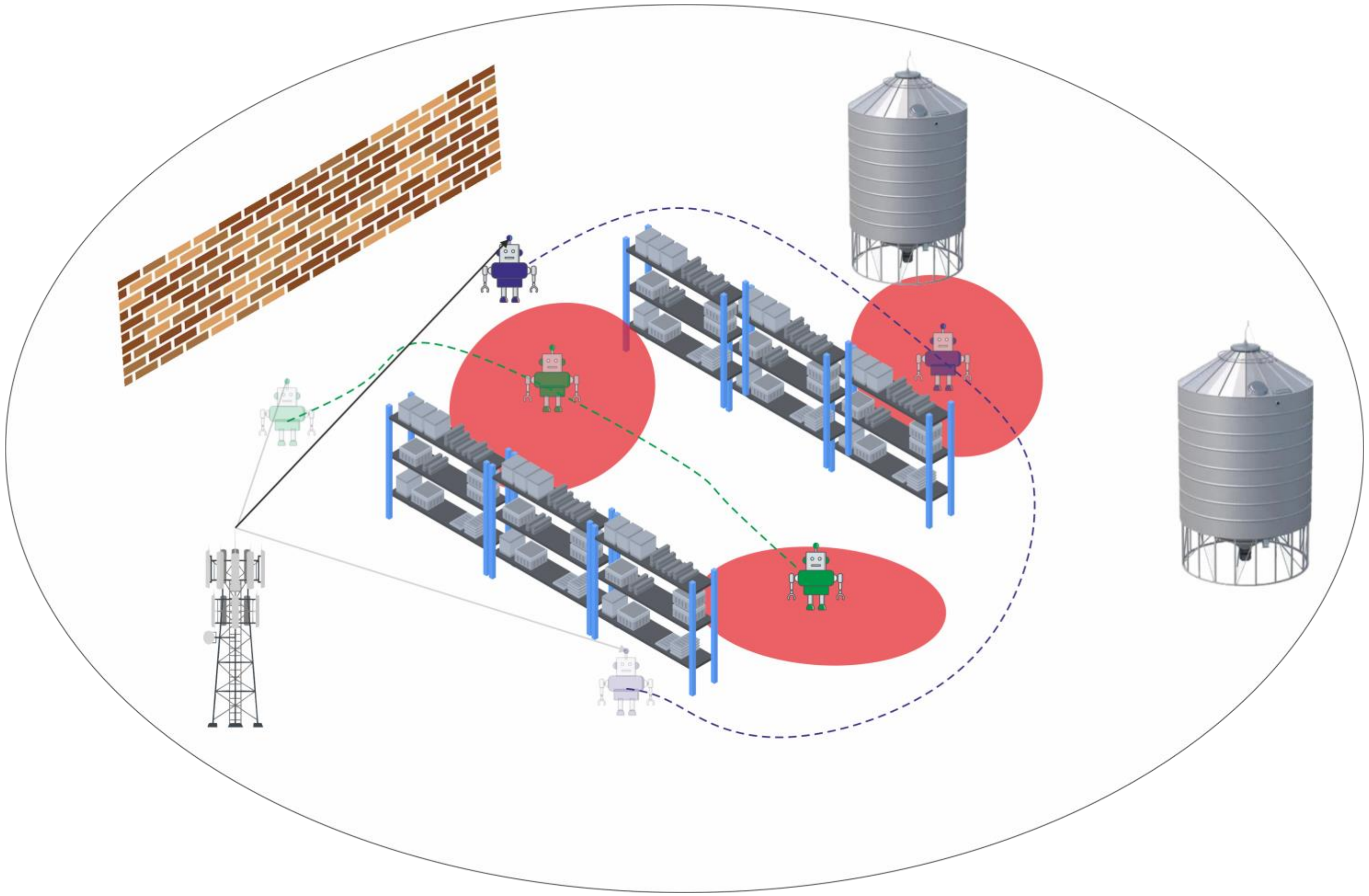
Campus Networks (e.g., Smart Factories)

Reliability Issue



E. Tohidi *et al.*, "Reliability Assurance in RIS-Assisted 6G Campus Networks," *20th International Conference on the Design of Reliable Communication Networks (DRCN)*, 2024.

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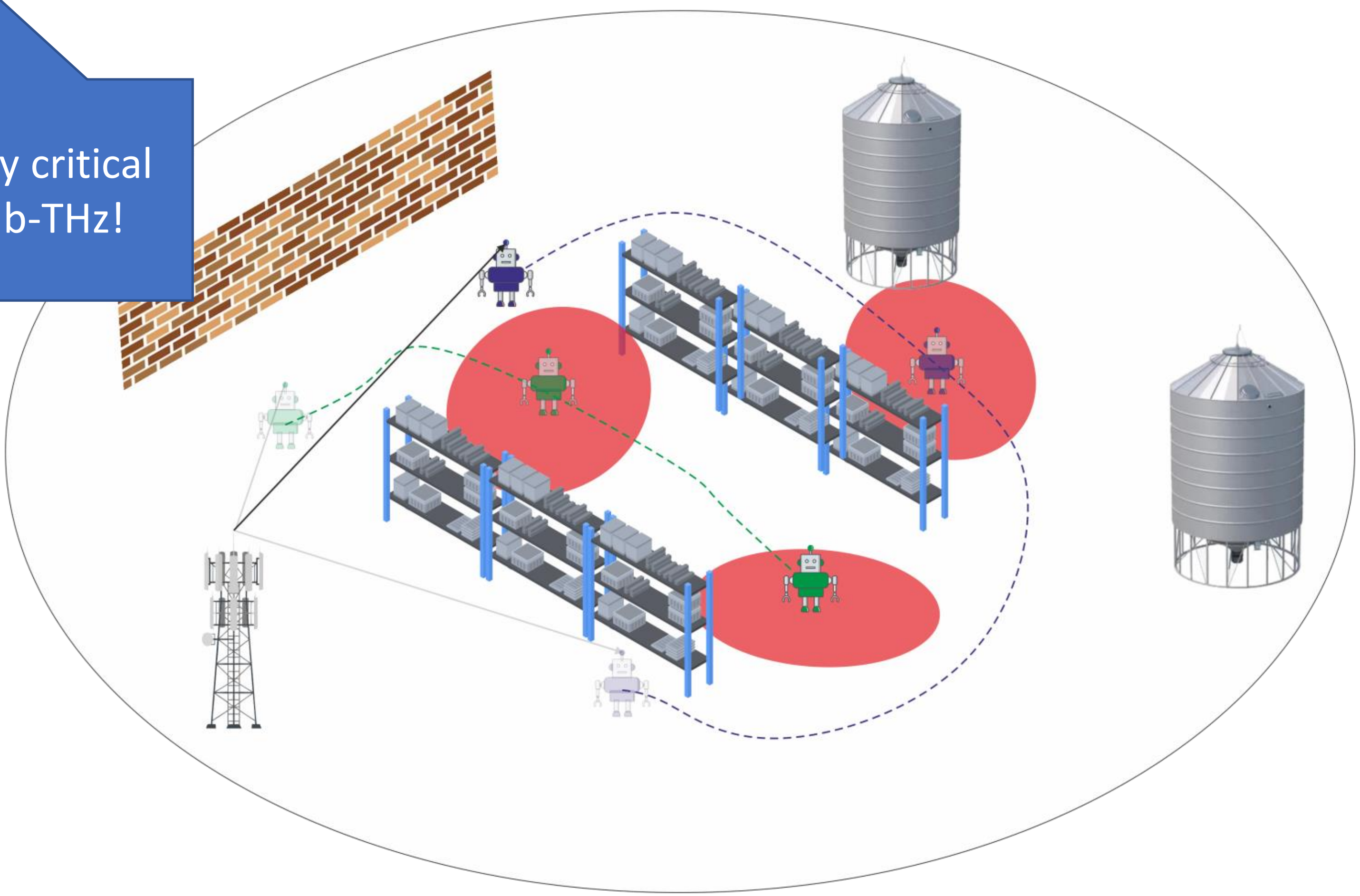
Campus Networks (e.g., Smart Factories)

Reliability Issue

LoS blocking especially critical for mmWave and sub-THz!



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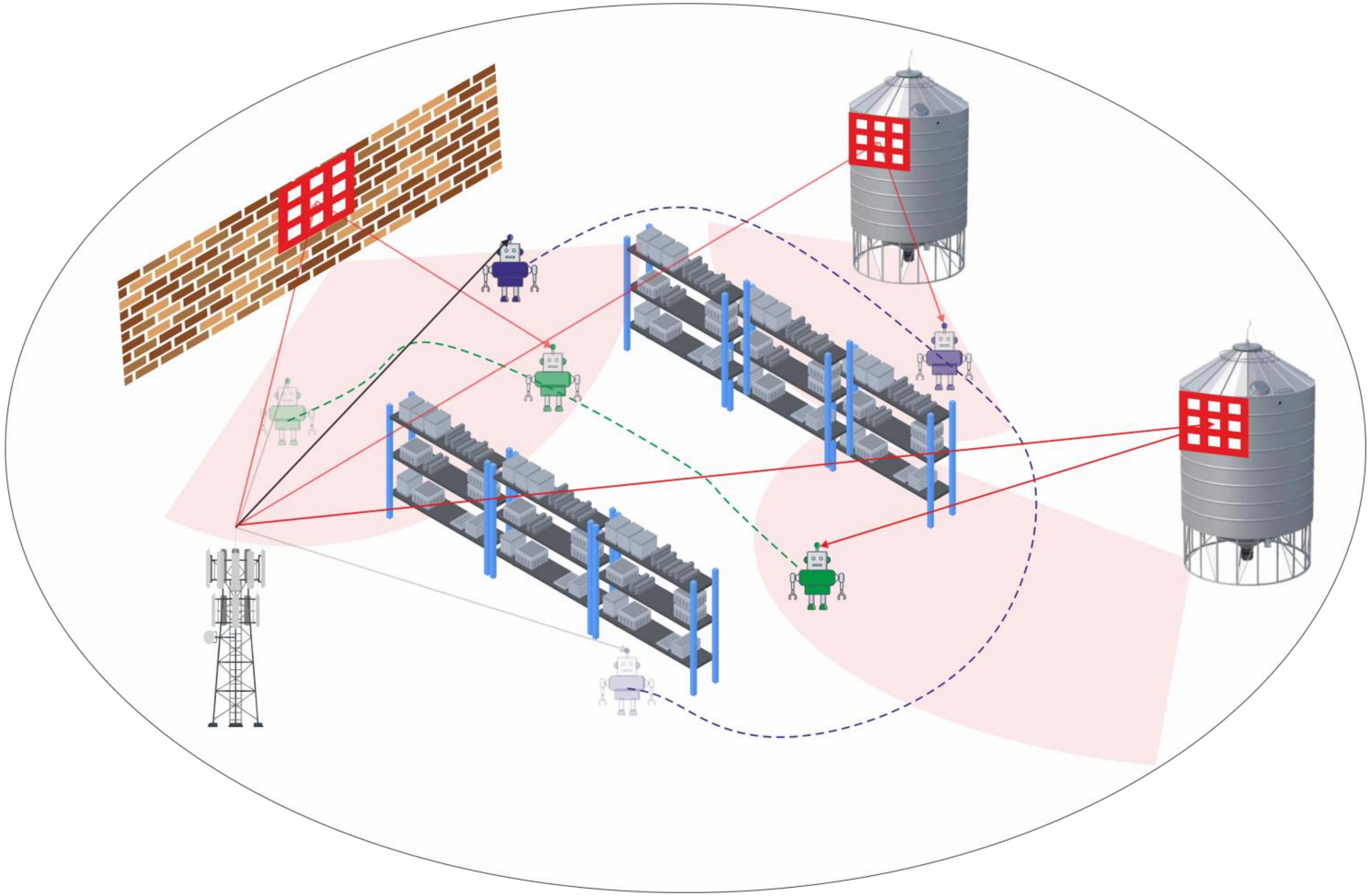
Campus Networks (e.g., Smart Factories)

Reliability Assurance: RIS



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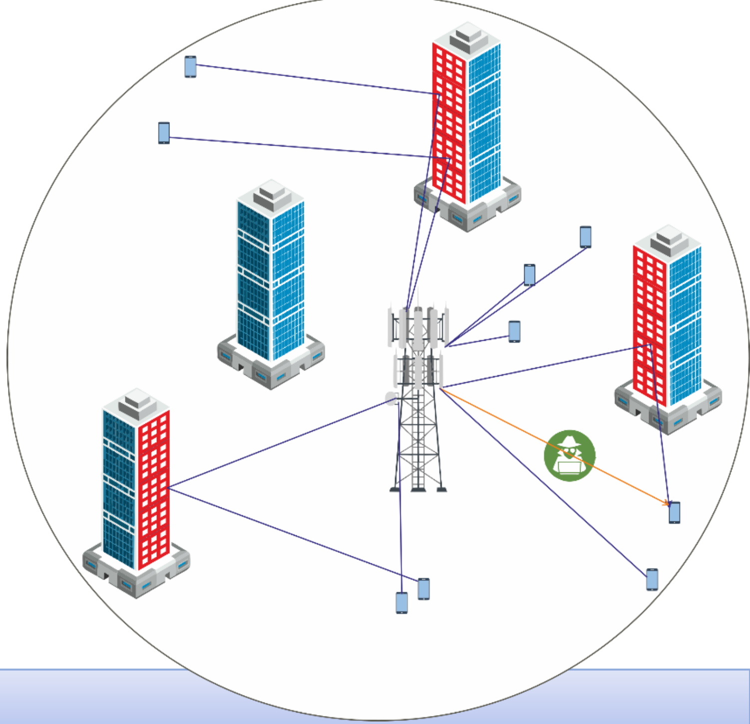

Introduction

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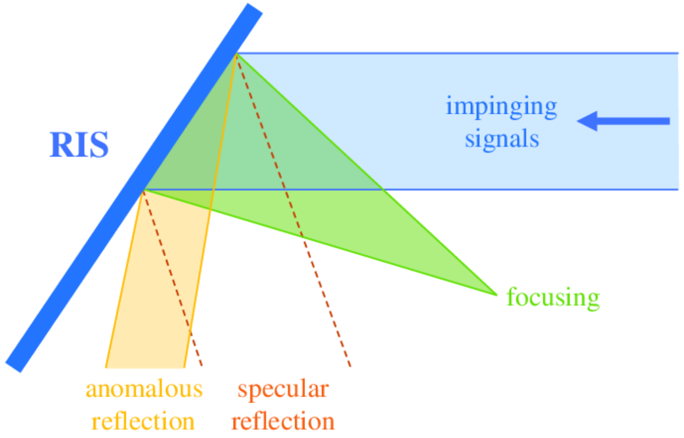
Introduction

What is a Reconfigurable Intelligent Surface?

- Reconfigurable Intelligent Surface (RIS) is a ***planar surface*** comprising a large number of passive reflecting elements, each of which is able to induce a ***controllable phase change*** to the incident signal independently
- Specular reflection to anomalous reflection



Advantages
Anomalous reflection - Reconfigurability

Disadvantage
Multiplicative fading due to cascaded channel

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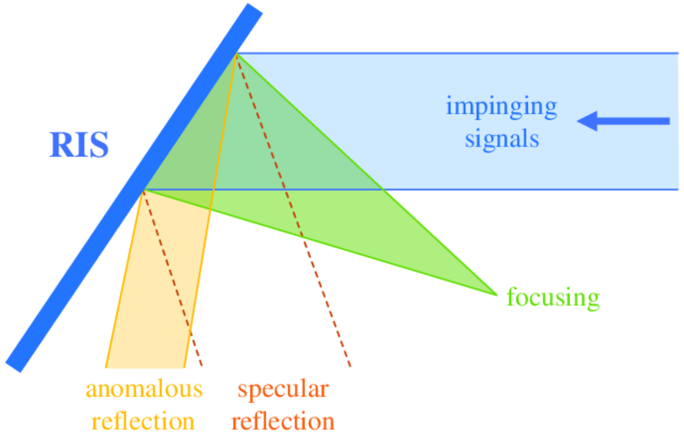

Aka „double path loss“

Advantages
Anomalous reflection - Reconfigurability

Disadvantage
Multiplicative fading due to cascaded channel

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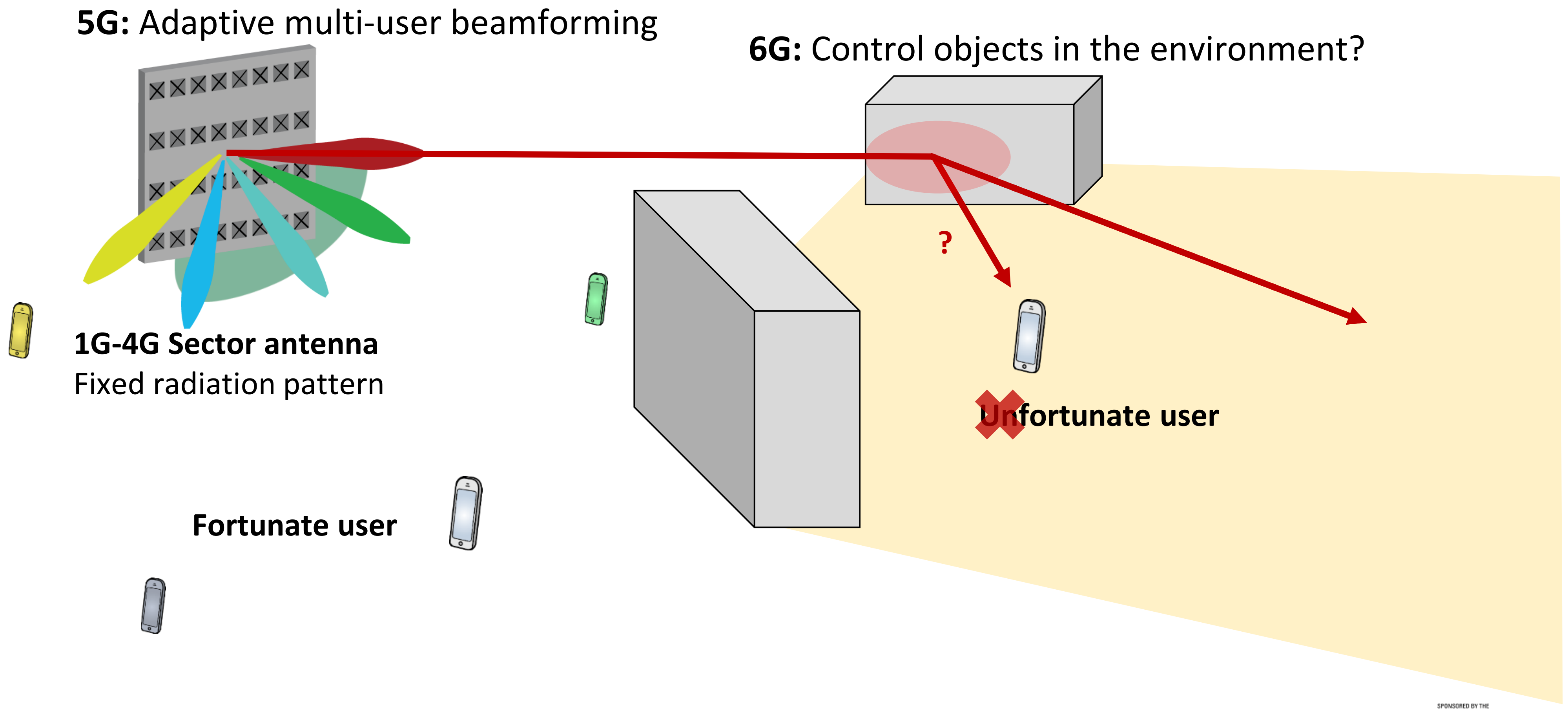
Key Technology for 6G?



credit: Emil Björnson

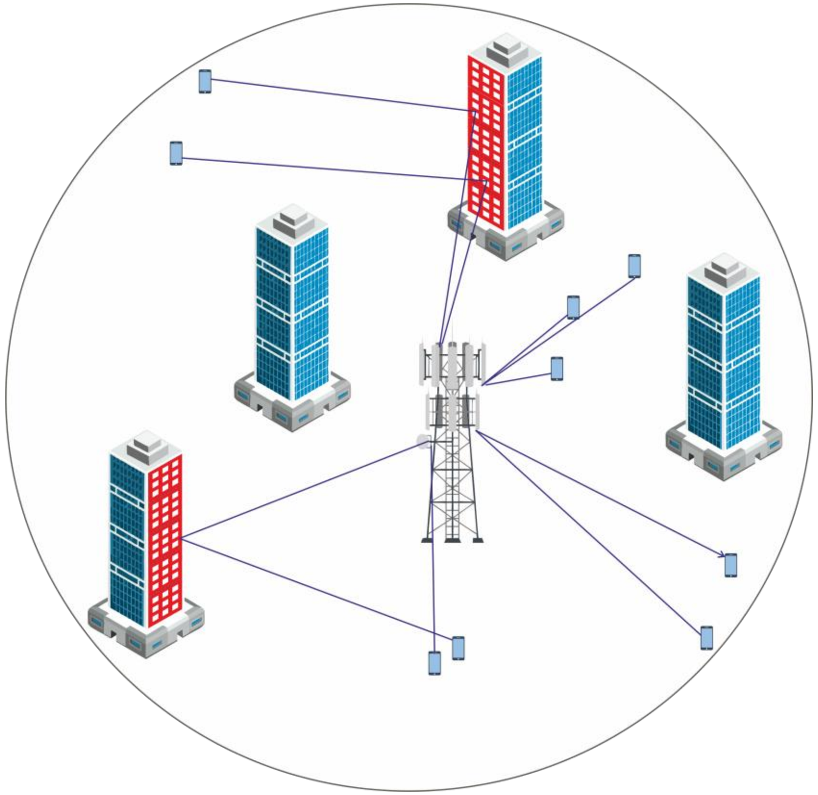
Key Technology for 6G?

credit: Emil Björnson

System Model

- RIS-assisted wireless communication system
  - BS, multiple RISs, and several UEs
- BS and RISs are static, while *UEs can be static or mobile*

Even BS-UE initial access may take time: requires alignment of directional antennas both at BS and UE (using beam sweeping, fixed codebooks).



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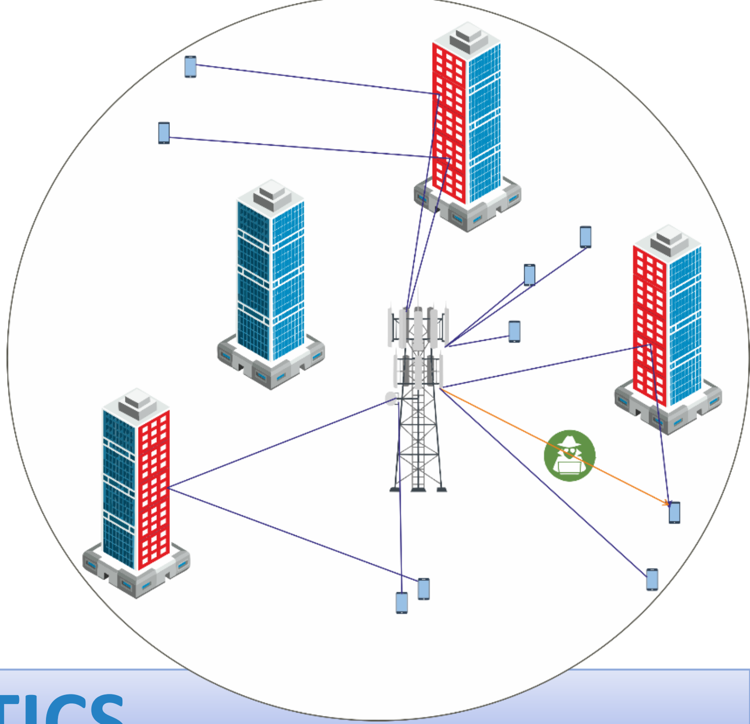

RIS-ASSISTED LINK CHARACTERISTICS

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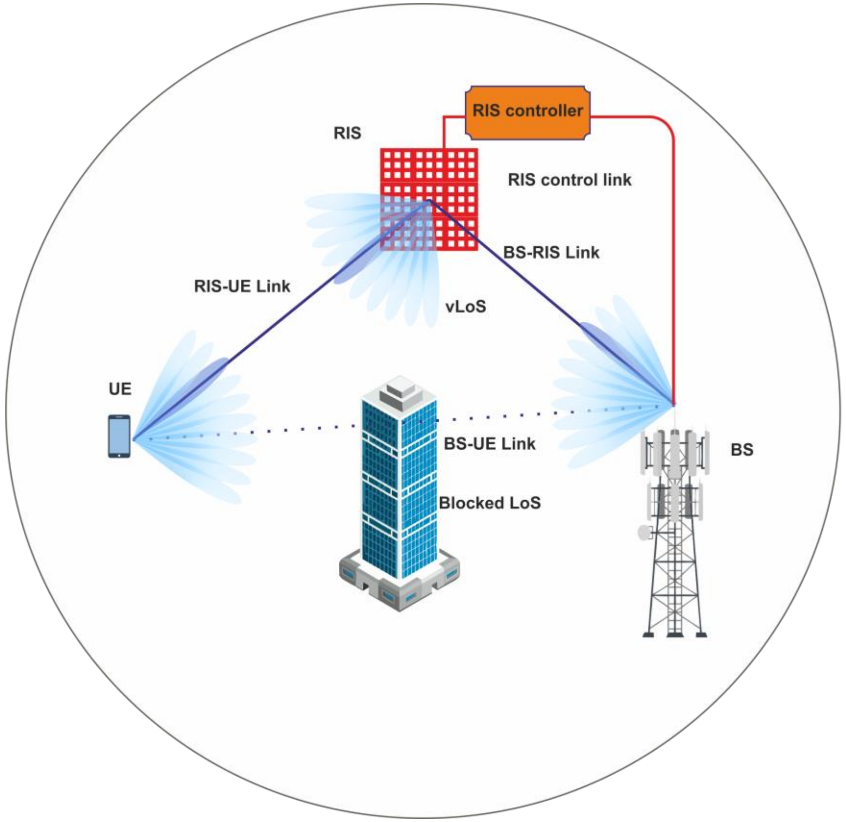
Cascaded Channel

Additional path loss

- RIS-assisted link, consists of two ***concatenated*** links—commonly referred to as a ***cascade channel***—namely the BS-RIS and RIS-UE links
- This inherent characteristic of RIS-assisted systems results in ***lower*** overall channel gains than direct links.
- Another key factor affecting the RIS-assisted channel gain is the ***RIS gain***
  - The RIS ability to capture ***incident signal energy*** and redirect it toward the intended receiver
  - ***larger RIS surfaces*** yield higher RIS gain and, consequently, higher RIS-assisted channel gain.



Cascded Channel

Additional path loss

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- This inherent characteristic of … s in ***lower*** overall channel gai…

Other factors matter, e.g., when located in near-field. Our focus here however far-field (each RIS serves one UE at a time).

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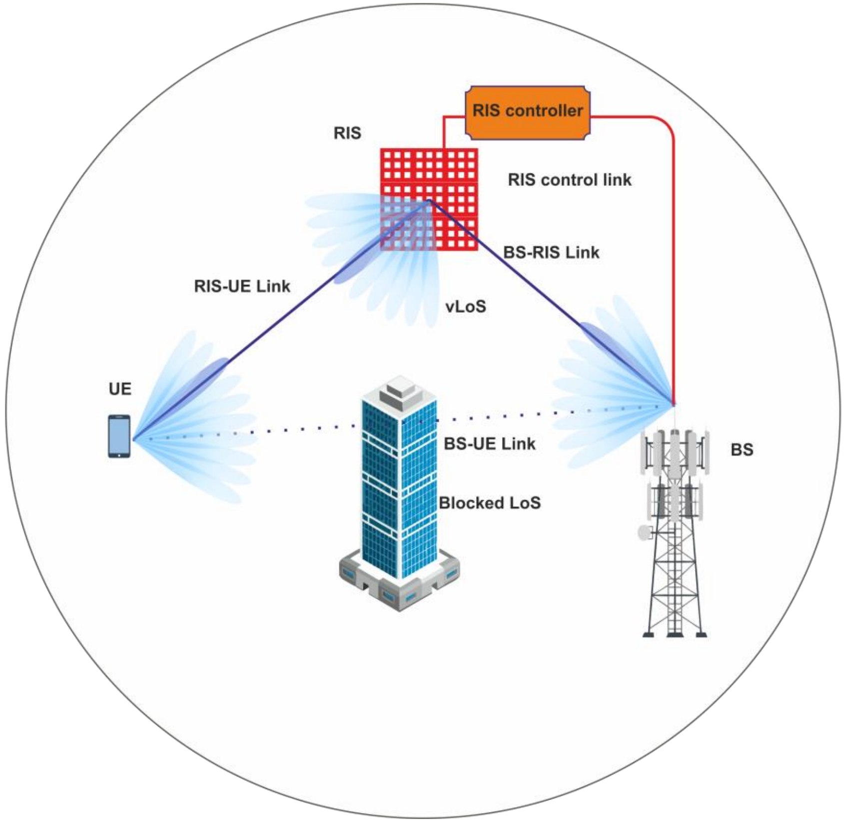

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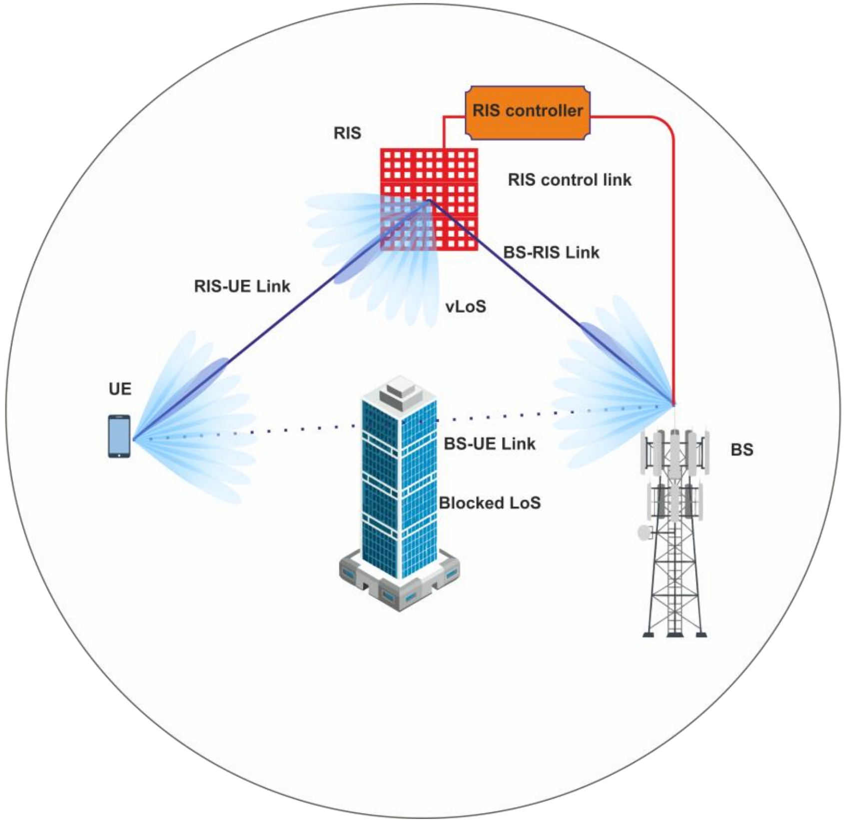
Reconfiguration Time

Critical and Non-negligible

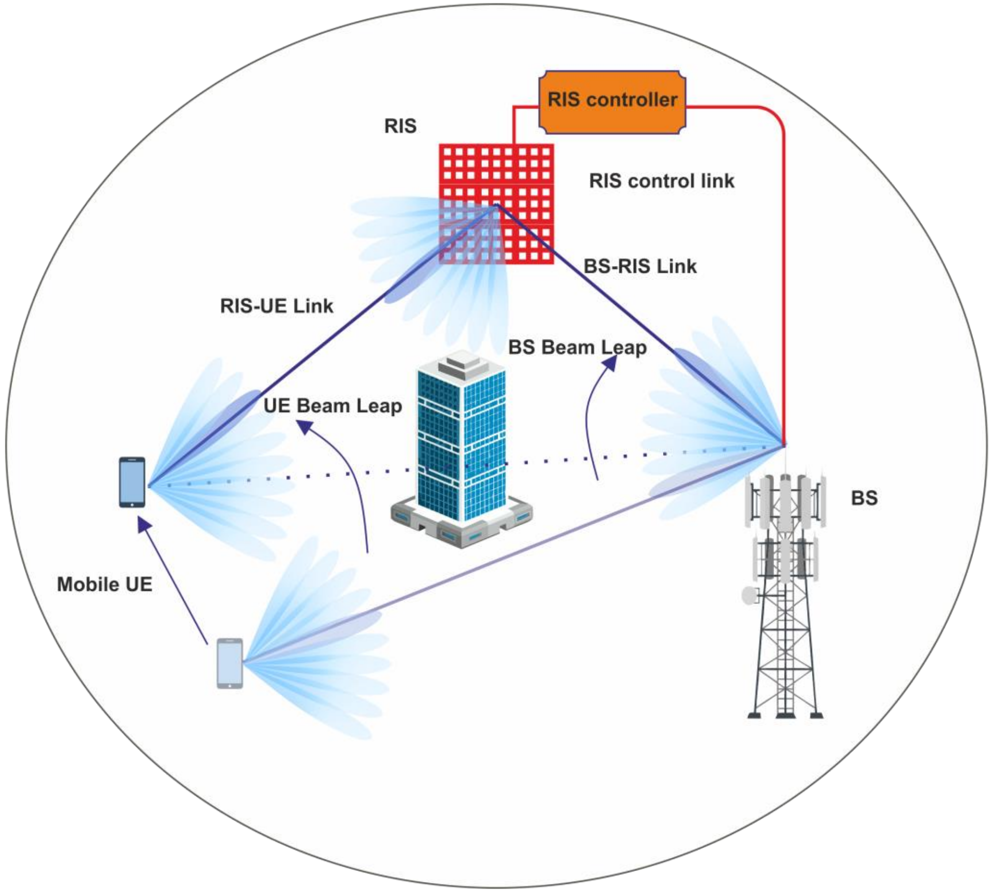
- RIS can perform ***beamforming*** by dynamically altering the ***phases*** of the reflected waves.
- Various technologies, each with its cost, energy consumption, and response time characteristics
  - *Varactor* diodes and PIN diodes, can achieve reconfiguration times in the range of a few *nanoseconds*
  - *Liquid crystals* (LC), have reconfiguration times that can extend beyond ten *milliseconds*
- LC technology offers advantages such as ***cost-effectiveness***, scalability, low energy consumption, and the ability to provide continuous phase shifting.
  - Relatively longer reconfiguration time associated with LC highlights the *importance* of carefully considering this factor in practical deployments.



Beam Leap While Tracking

Sudden shift in the required beam direction

- In a mobile UE scenario, due to the *movement* of the UE, the device currently served via a RIS-assisted link may enter a *blind spot of the RIS*
  - BS may be able to serve the UE directly if the direct linkis no longer blocked at the new location
  - the system may need to switch to another RIS that can provide coverage in the UE’s new location
- the next beam selected by the BS will likely be significantly different from the current one, as it may need to point in a completely different direction
  - Starkly contrasts *conventional tracking methods*, where beam sweeping typically occurs within neighboring beams to account for *small movements* of the UE.



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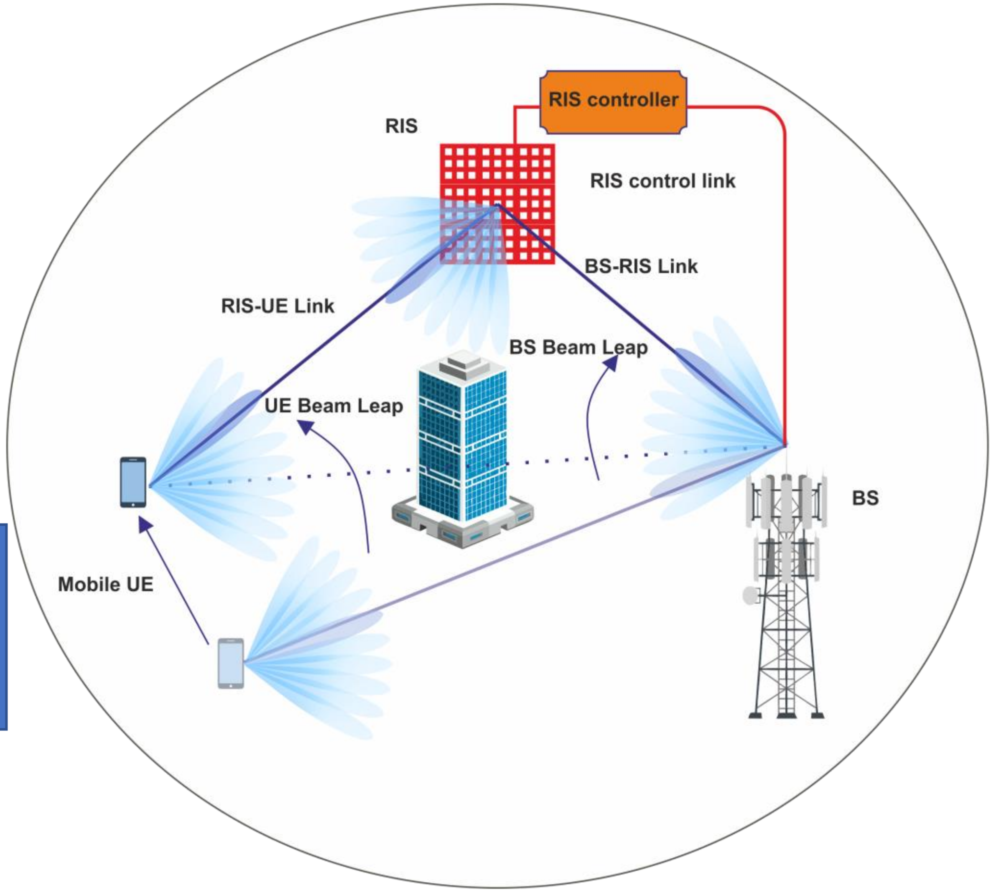
  - Starkly contrasts *conventional tracking methods*, where beam sweeping typically occurs within neighboring beams to account for *small movements* of the UE.

Another new aspect! Requires beam jump/leap procedure.



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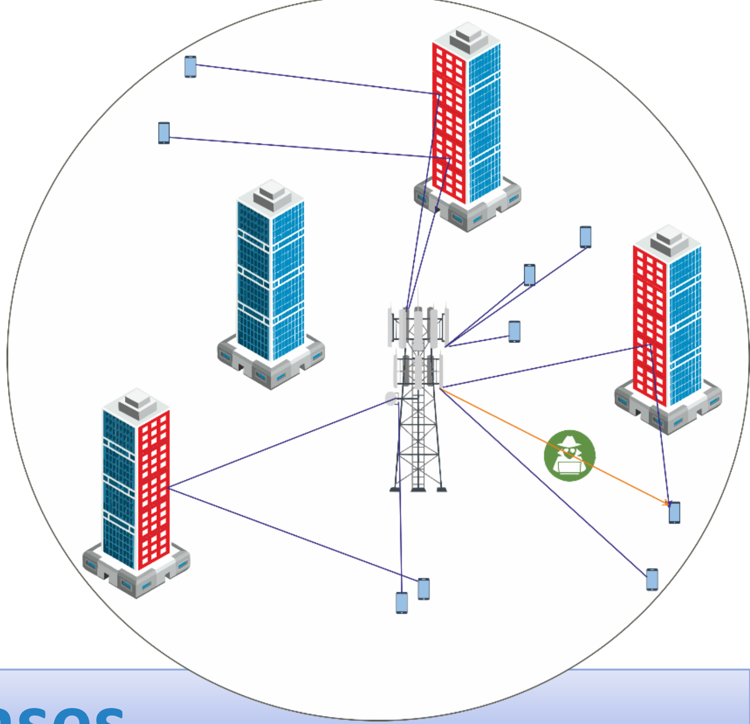

CONTROL PLANE ASPECTS: Use Cases

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Scenarios and Challenges for Control Plane

Depending on Use Case

Table I
CHALLENGES FOR THE NON-LOS USE CASES.

UE	Static	Mobile
Single	None	Tracking (RIS)
Multiple	Switching (RIS) Multiplexing (BS)	Tracking (RIS) Switching (RIS) Multiplexing (BS)

Table II
CHALLENGES FOR THE INTERMITTENT LOS USE CASES

UE	Static	Mobile
Single	Leap (BS)	Tracking (RIS/BS) Leap (BS)
Multiple	Switching (RIS/BS) Multiplexing (BS) Leap (BS)	Tracking (RIS/BS) Switching (RIS/BS) Multiplexing (BS) Leap (BS)

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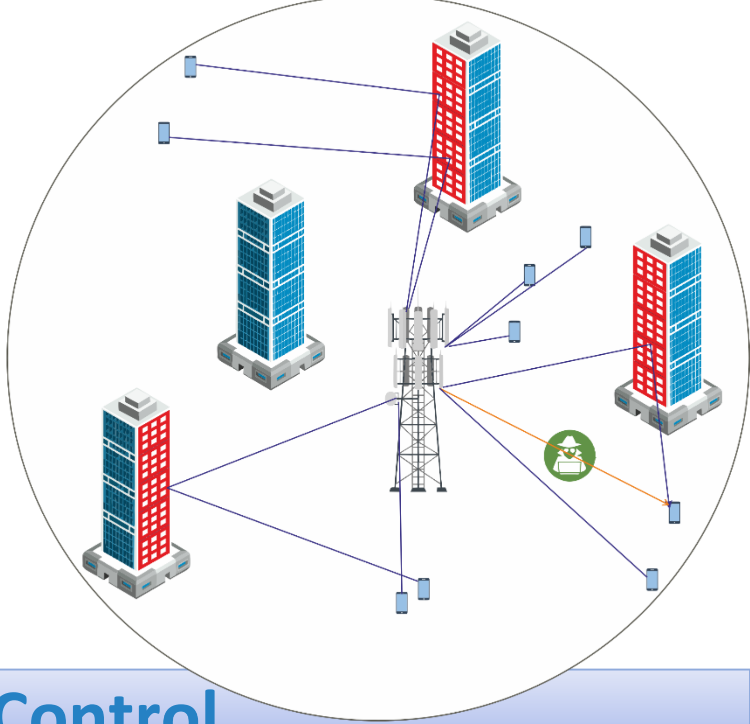
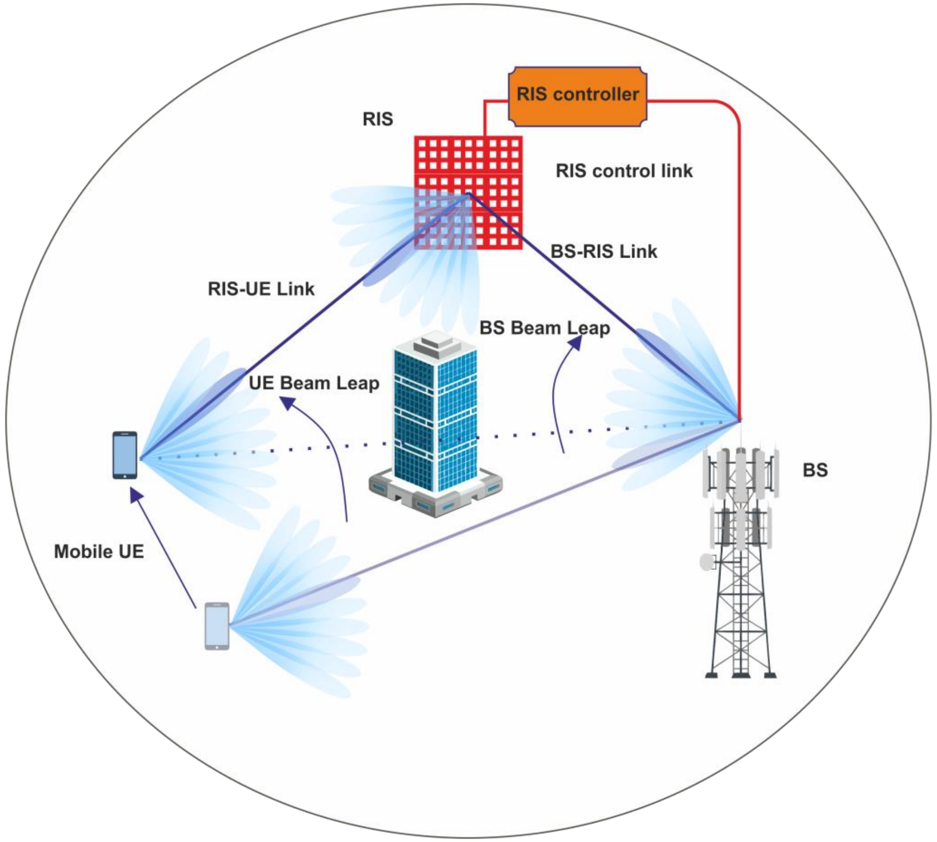


CONTROL PLANE ASPECTS: Proposed RIS Control

Proposed RIS Control

RIS-assisted Link Restoration Procedure

- Link restoration: establishing a RIS-assisted link for a UE that was initially connected directly to the BS. *Triggered* based on:
    - *Predicted ("anticipated")* based on prior information available to the BS (e.g., *radio maps* of the environment).
    - *Continuously monitor channel quality* and detect link degradation trends.
- BS triggers the ***network controller*** → initiate the link restoration
- Network controller creates a pool of *candidate RISs*
    - Resource allocation algorithm to select the RIS
- The BS and the RIS controller are informed and configured accordingly
- BS's perspective: the shift in beam direction—from the direct link toward the UE to the beam aimed at the RIS, i.e., "***beam leap***".



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Proposed RIS Control

RIS-assisted Link Restoration Procedure

Triggered by the BS.

- Link restoration: establishing a RIS-assisted link for a UE that was initially connected directly to the BS. *Triggered* based on:
  - *Predicted ("anticipated")* based on prior informatio... *radio maps* of the environment)
  - ...*ality* and detect li...

Could also require handover (new BS): not considered here.

Depending on demand, available resources, priority…

- ...*ler* → initiate the link restoration
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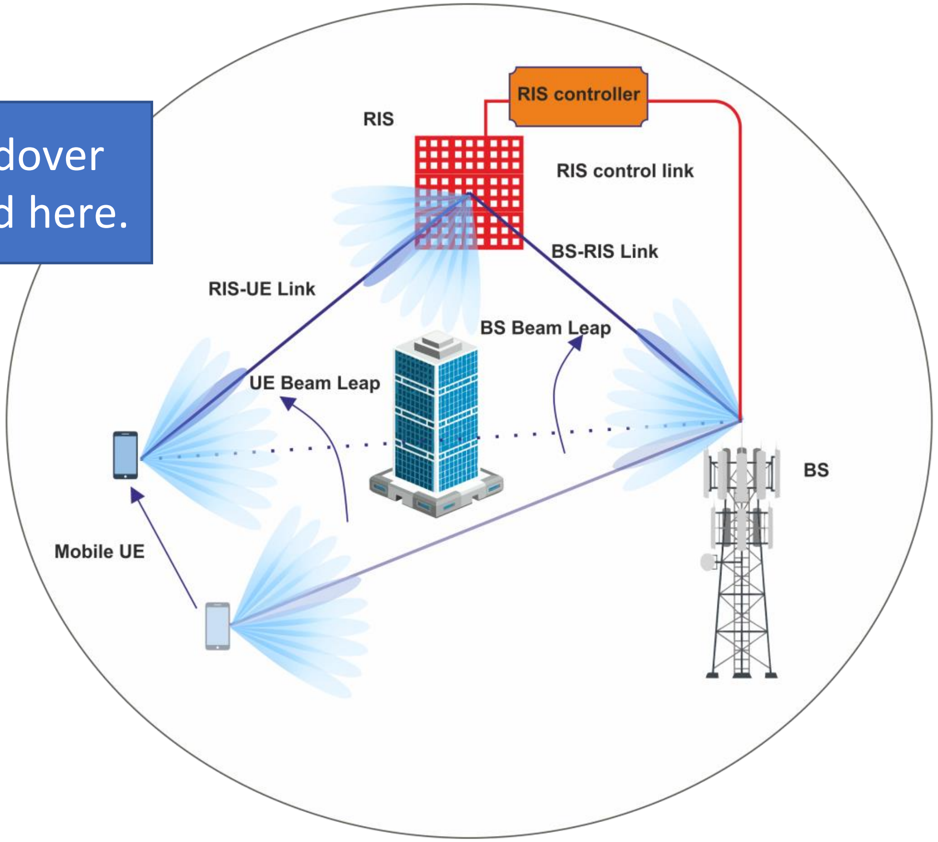
  - Resource allocation algorithm to select the RIS
- The BS and the RIS c...ller are informed and configured accordingly
- BS's perspectiv... –from the direct link toward the UE to the beam aimed at the RIS, i.e., "*beam leap*".

Accuracy depends on time elapsed since last connection, mobility speed, etc.



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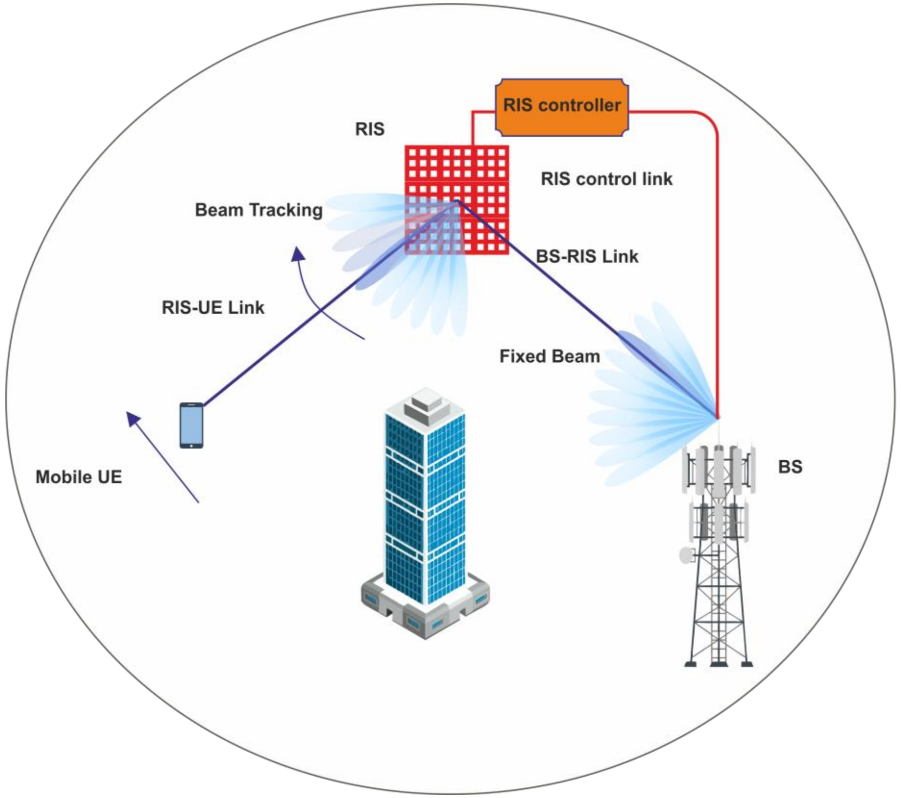
Proposed RIS Control

Beam-Tracking in RIS-assisted Link

- Connection quality degradation
- RIS controller is notified to adjust the beam
  - *Localized beam sweeping* through a few neighboring beams
  - Narrow beams of RIS → more neighboring beams (compared to conventional beam sweeping)
- *BS* keeps its beam *locked* in the optimal direction toward the RIS
  - *No beam sweeping* at the BS



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Beam-Tracking in RIS-assisted Link

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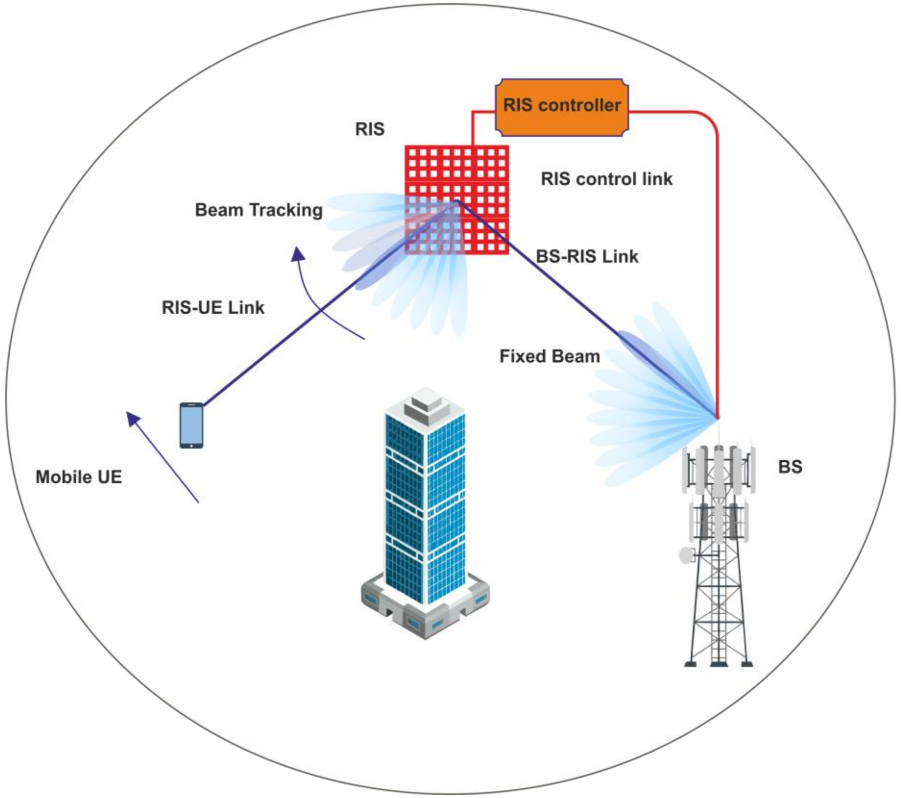
- RIS controller is … e beam
  - *Localized beam sweeping* through a few neighboring beams
  - Narrow beams of RIS → more neighboring beams (compared to conventional beam sweeping)
- *BS* keeps its beam *lock* … toward the RIS
  - *No beam sweeping* at the BS

RIS: localized sweep compared to BS!

Due to larger surface, RIS beams are narrower than BS‘ beams.

BS can lock beam: same RIS.

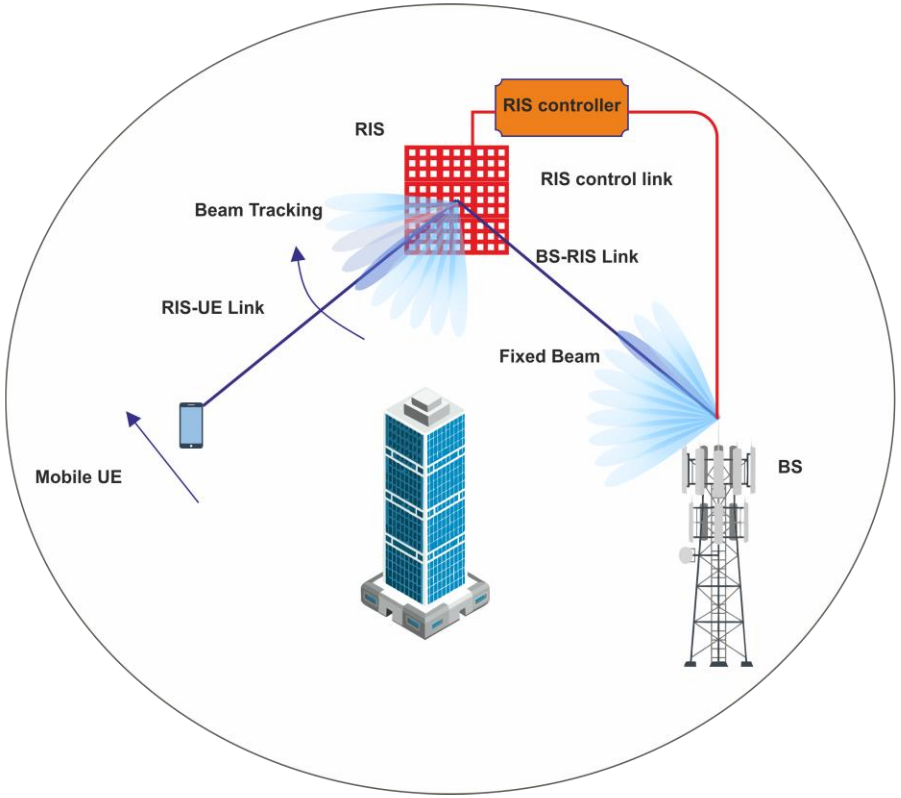


Proposed RIS Control

Try BS-Direct link

- *BS* will attempt to re-establish a *direct link* whenever possible
  - transition from the RIS-assisted link to a direct BS-UE

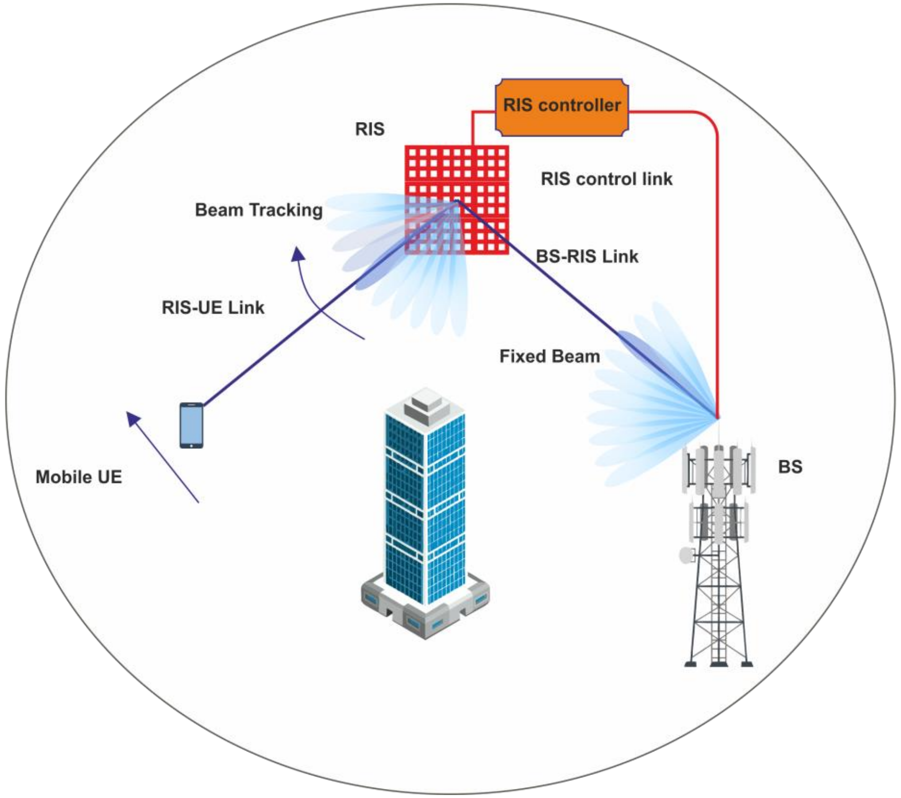
This direction is less critical than restoration: improves quality.



Proposed RIS Control

Keep Connection during Intermittent LoS Connection

- *Frequent changes* in connection status—between LoS and non-line-of-sight (nLoS)—within short time intervals complicate transitions.
- This rapid fluctuation in connection quality can lead to connection loss, as the link may not be re-established within the limited available time.
- Proposed solution: *maintain the previous connection* for a short duration until the new connection is established.



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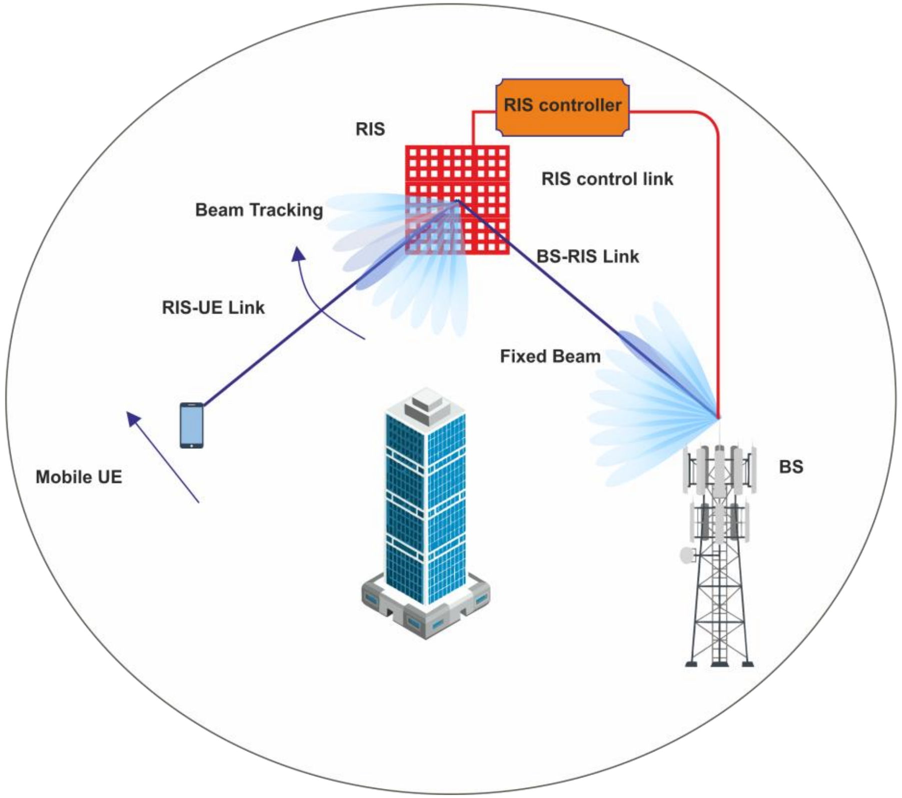
Proposed RIS Control

Link Backup – Multi connectivity

- ○ *Abrupt* channel behavior in high frequency, e.g., terahertz
- ○ *Link backup* strategy
  - *Candidate RIS reserved* for potential abrupt disconnections
  - The problem of over allocation (not scalable)
- ○ Multiconnectivity
  - Provide multiple links simultaneously
  - Seamless switch to the new link

Price: requires more resources!



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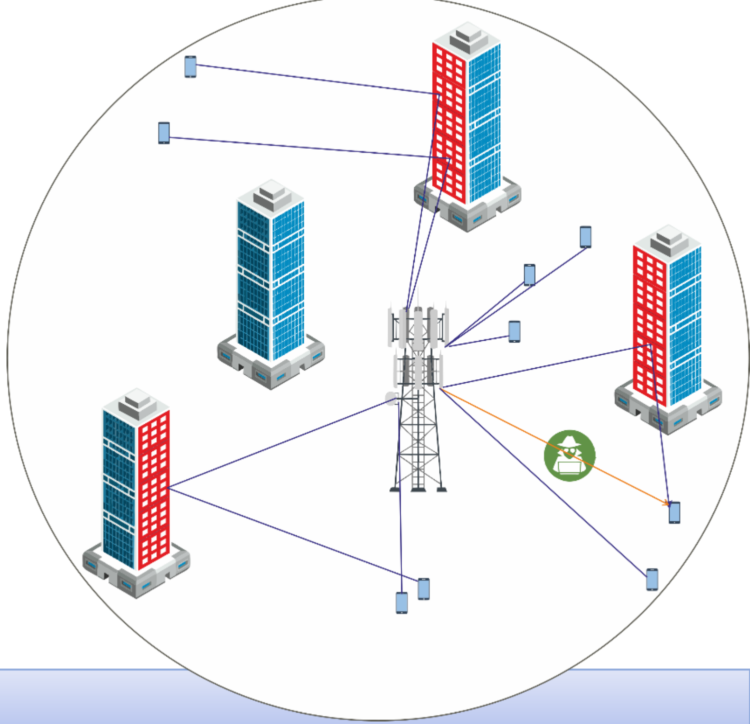

RIS-ASSISTED 6G NETWORKS

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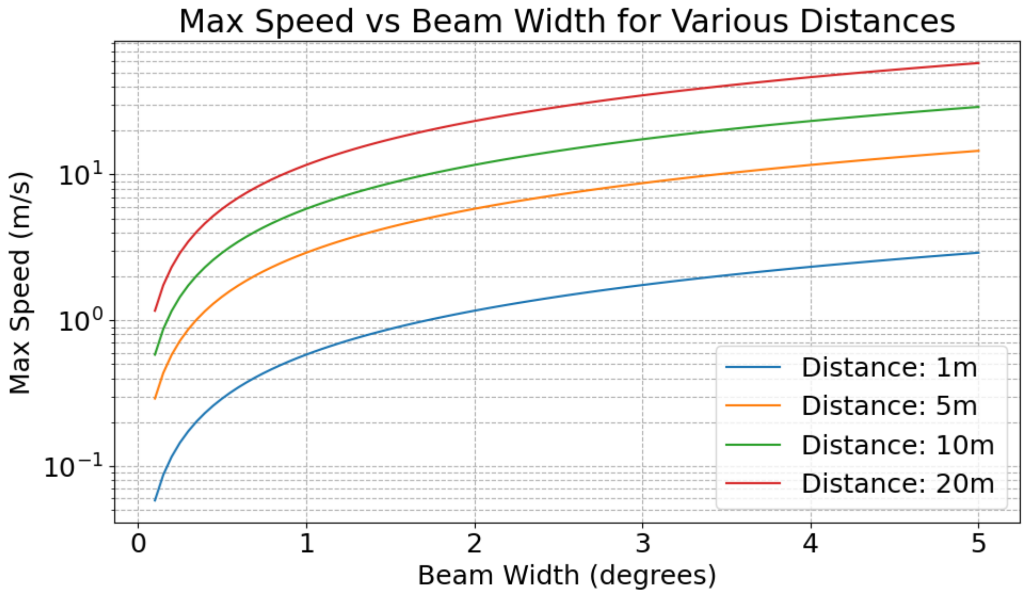
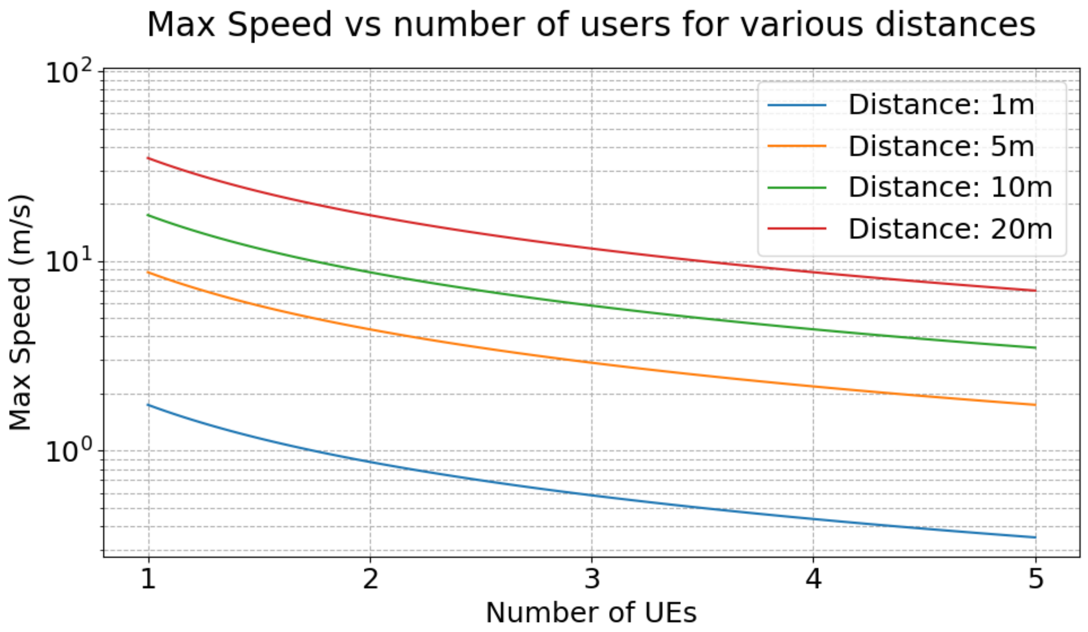
RIS-ASSISTED 6G NETWORKS

RIS in Practice

- Simplified model (optimistic): max speed an UE can move is limited by *reconfiguration time* and #UEs
- RIS reconfiguration time assumed to be 10 ms
- 5G and beyond standards in handover interruption time





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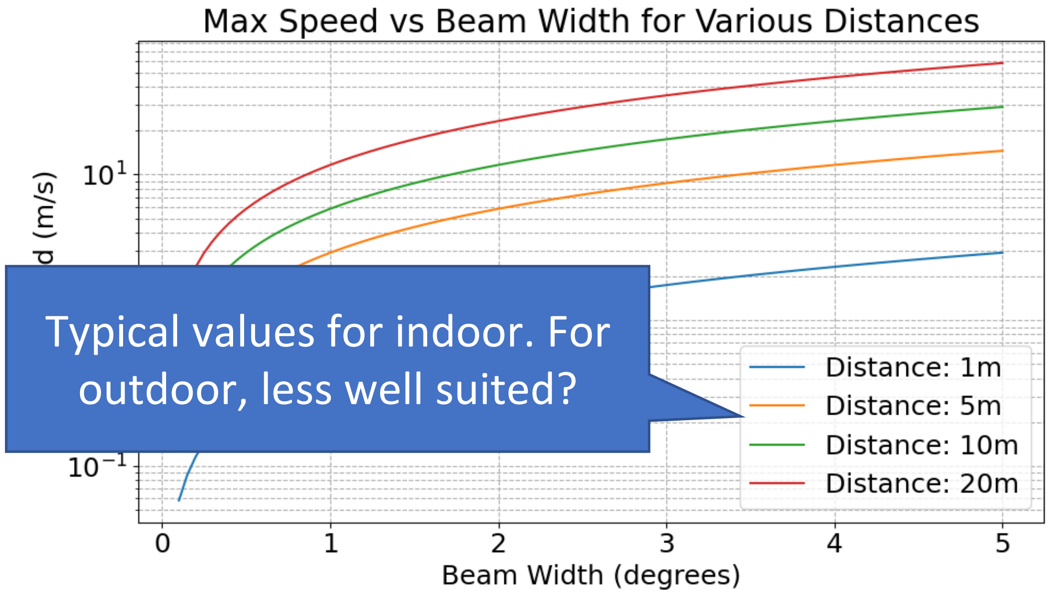
RIS-ASSISTED 6G NETWORKS

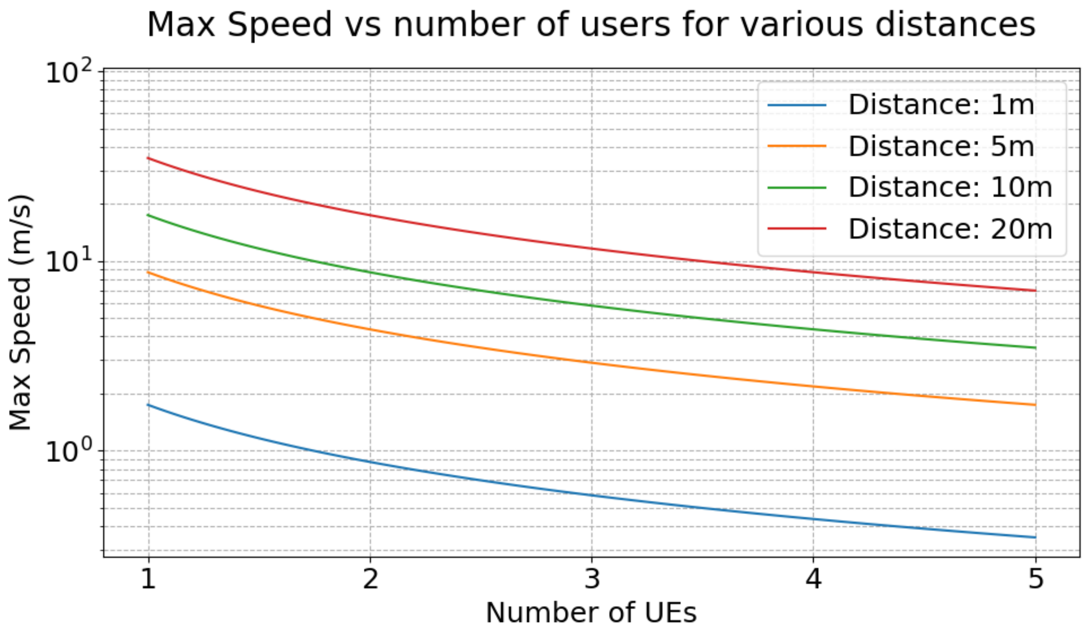
RIS in Practice

- Simplified model (optimistic): max speed an UE can move is limited by … Es
- RIS reconfiguration time assumed to be 10 ms
- 5G and beyond standards in handover interruption time

Delay due to switching between users.



Typical values for indoor. For outdoor, less well suited?



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Summary

- RIS promising but not much literature on *link level studies* yet
- Reality is complex: *call to community* to conduct more research on realistic *models* and *prototypes*
- A prerequisite for *standardization*

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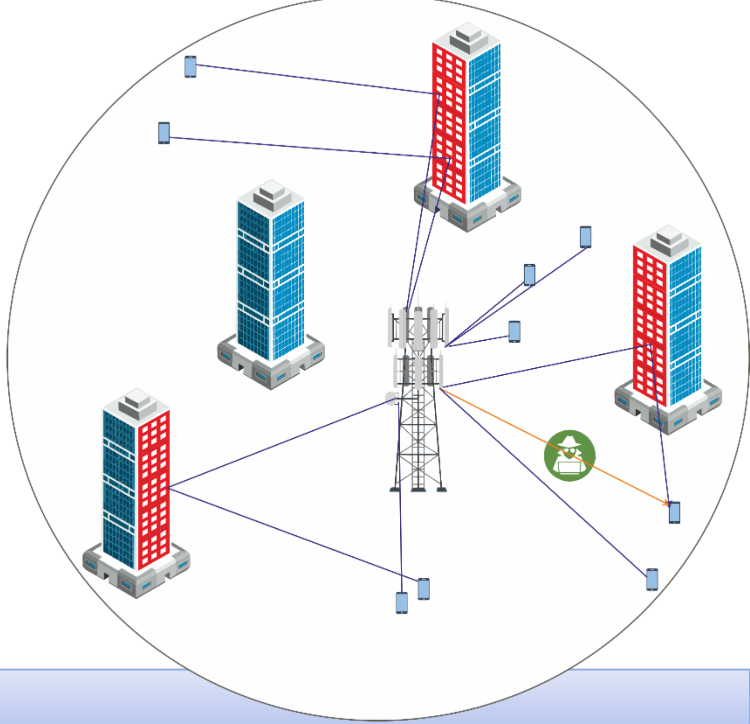

Thank you! Questions?

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