UC San Diego
JACOBS SCHOOL OF ENGINEERING
Electrical and Computer Engineering

WCSNG
Wireless Communications
Sensing and Networking

mmSubArray: Enabling Joint Satellite and Terrestrial Networks in Millimeter-wave Bands

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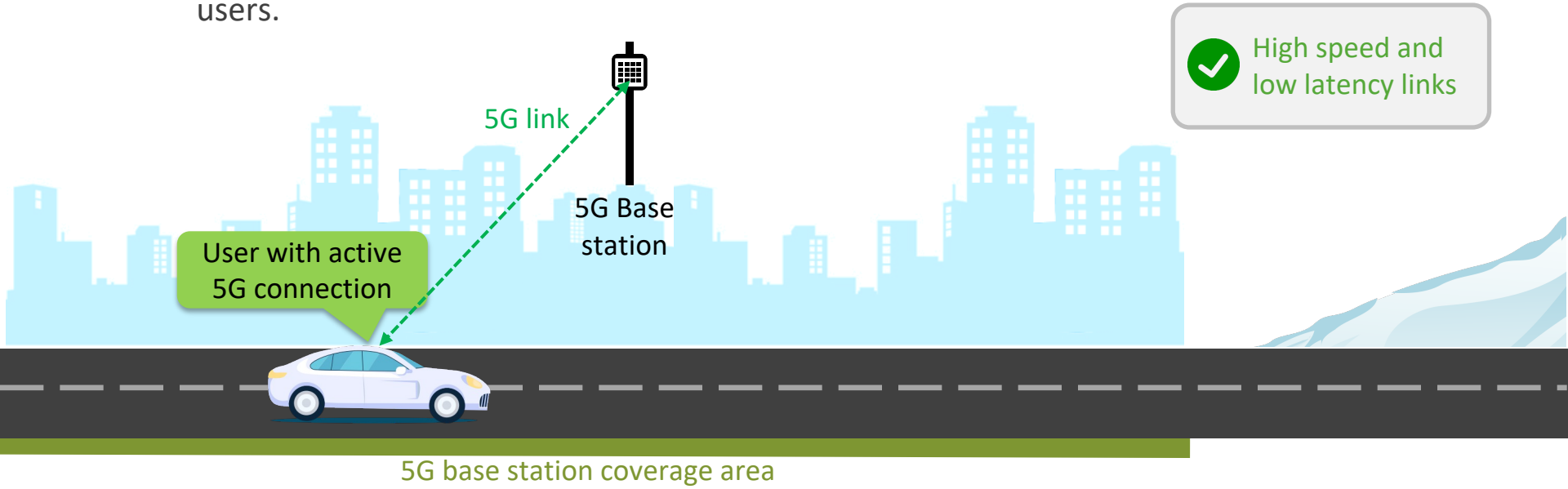
Terrestrial networks (5G)

- We have more smart phones than people in the world (>8B), highlights the importance for connectivity and accessibility.
- Terrestrial networks such 5G offers a **high speed** and **low latency link** to vast number of users.

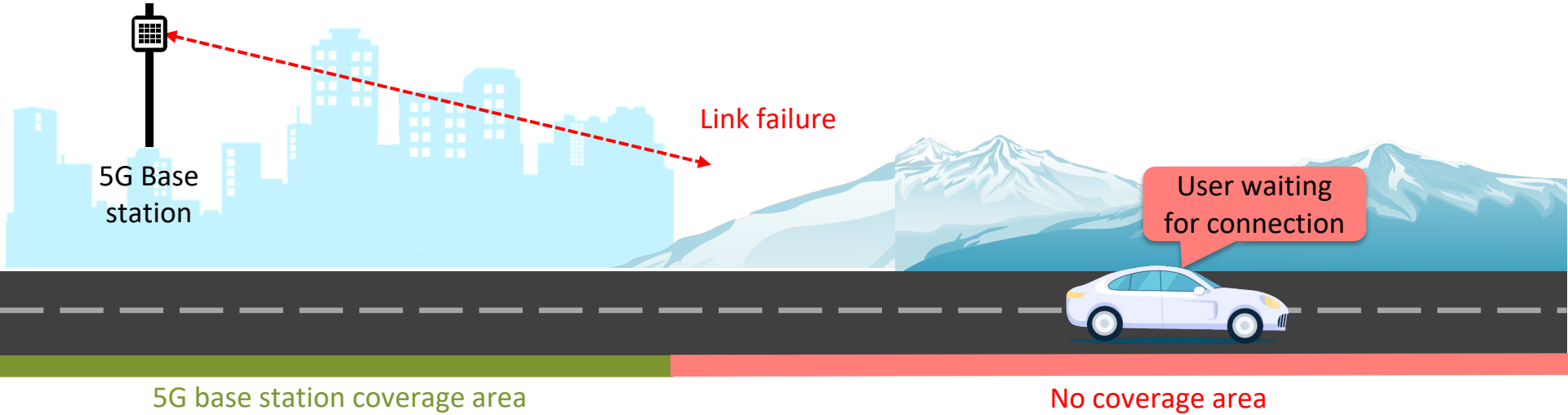


Terrestrial networks: *Coverage is limited*

Terrestrial networks' coverage is limited to few km

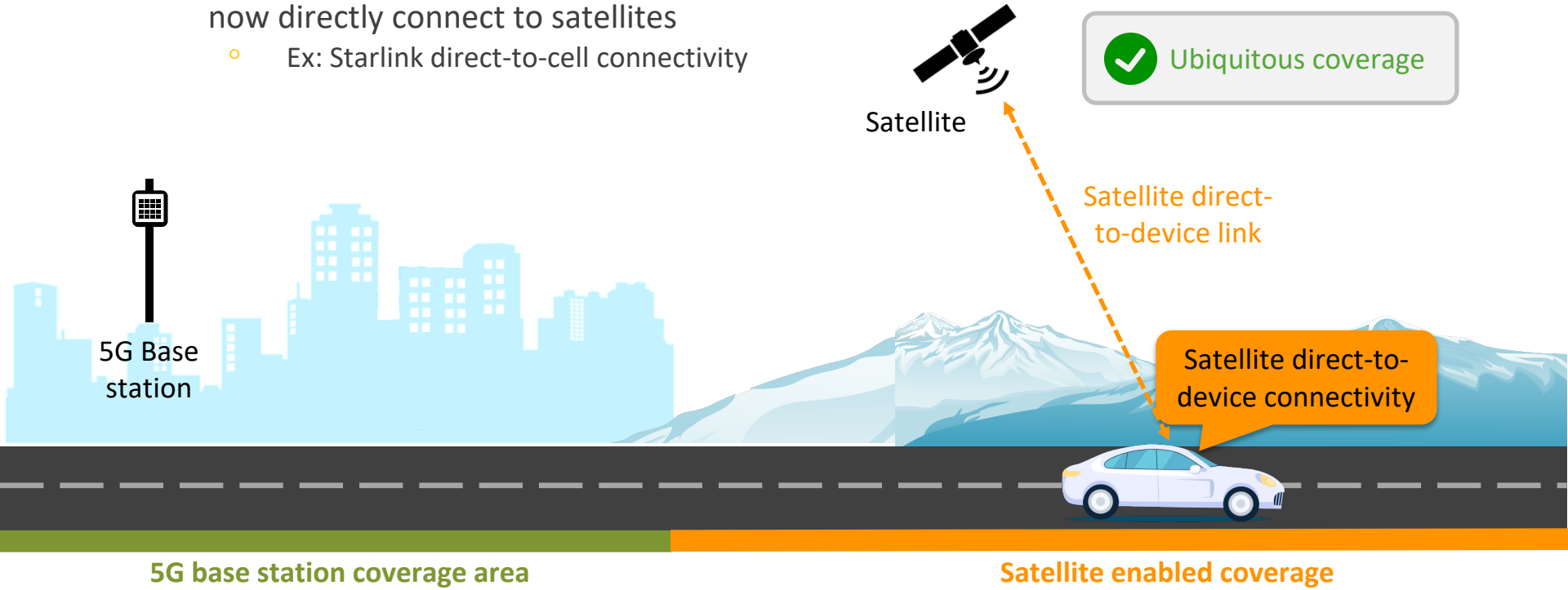
High speed and low latency links

Limited coverage



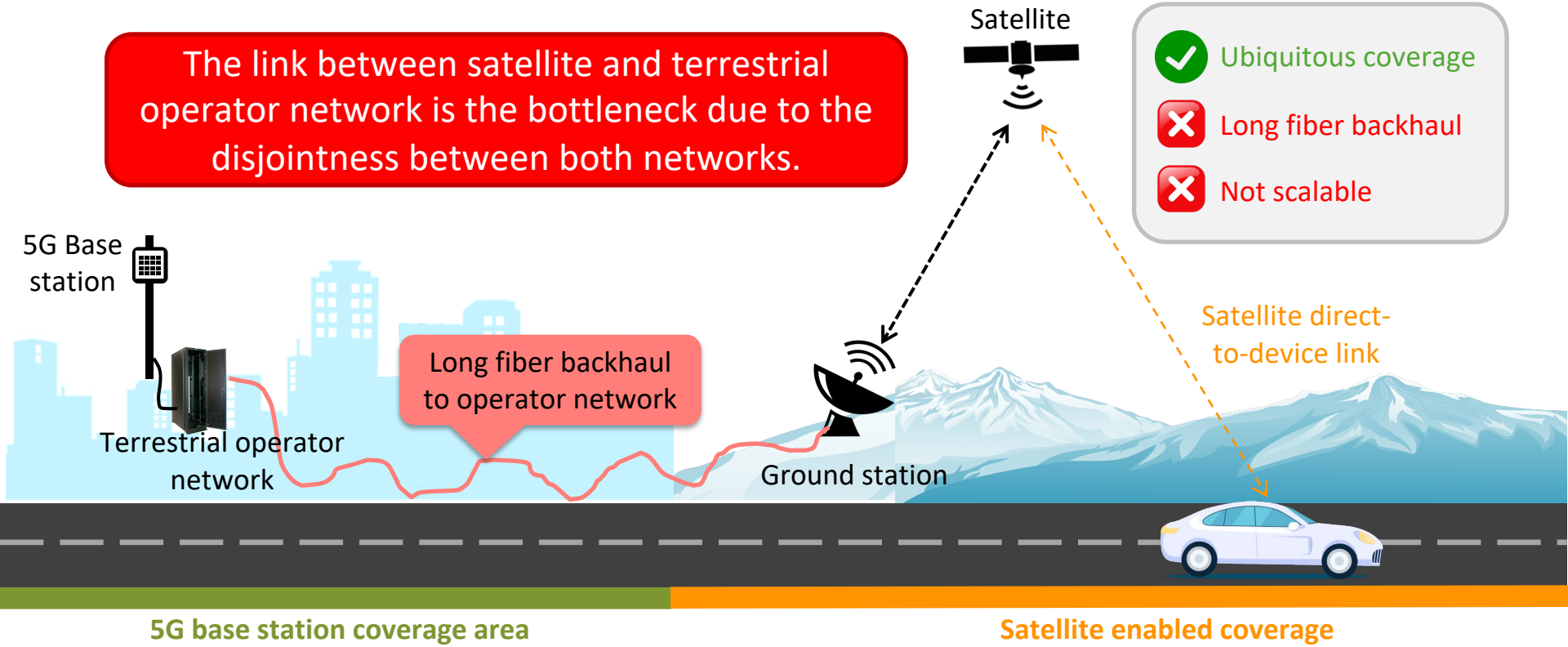
Satellite direct-to-device connectivity

- With latest advancements in smartphones and LEO satellites, terrestrial devices can now directly connect to satellites
  - Ex: Starlink direct-to-cell connectivity



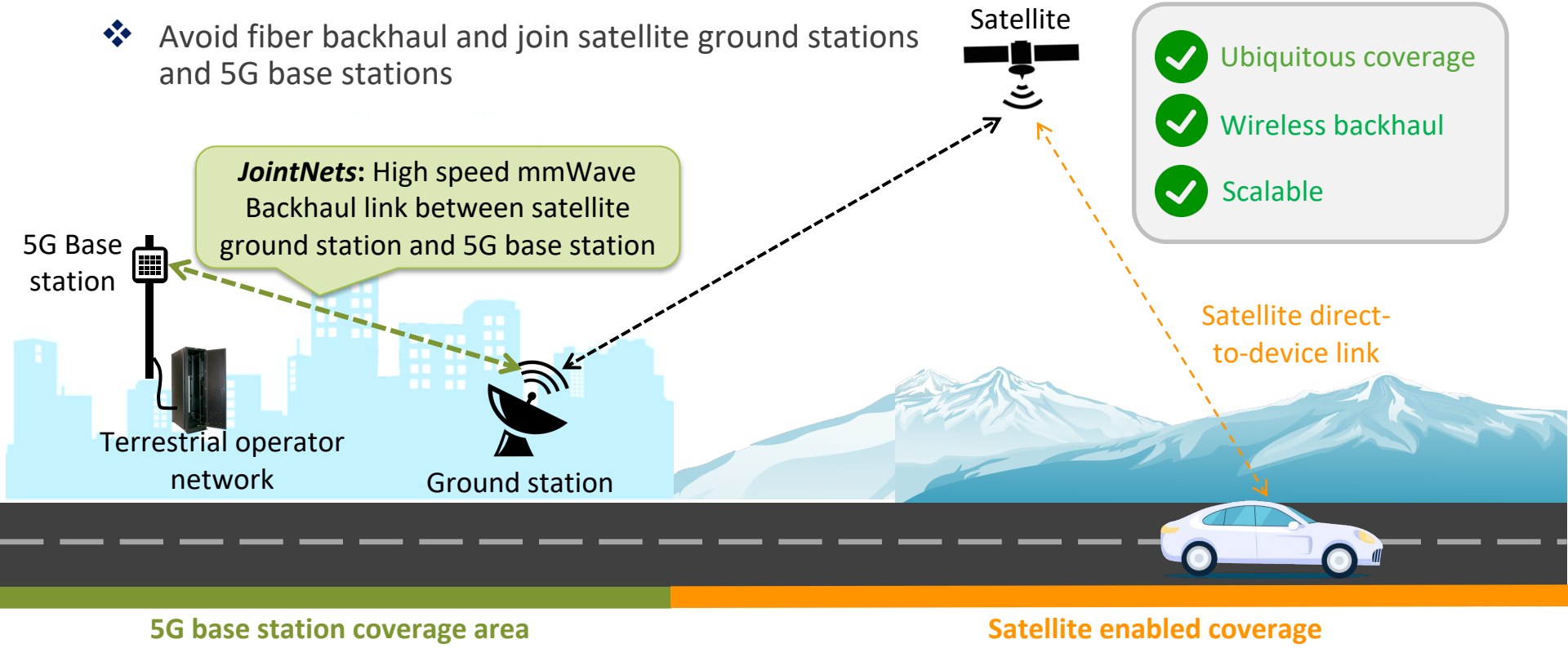
Satellite direct-to-device connectivity: *challenges*

The link between satellite and terrestrial operator network is the bottleneck due to the disjointness between both networks.



Proposed Joint satellite and terrestrial networks *(JointNets)*

- Avoid fiber backhaul and join satellite ground stations and 5G base stations



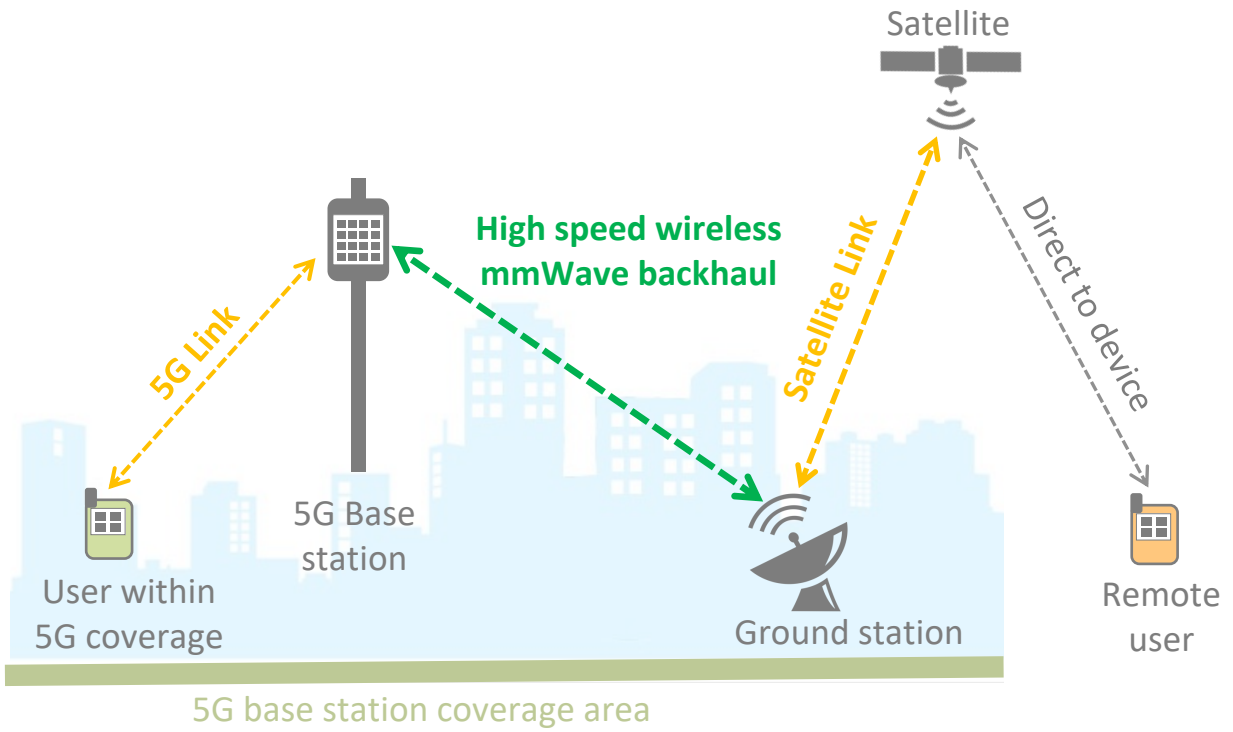
Two requirements for ***JointNets***

Enable Backhaul

Enable wireless backhaul and join satellite and terrestrial networks

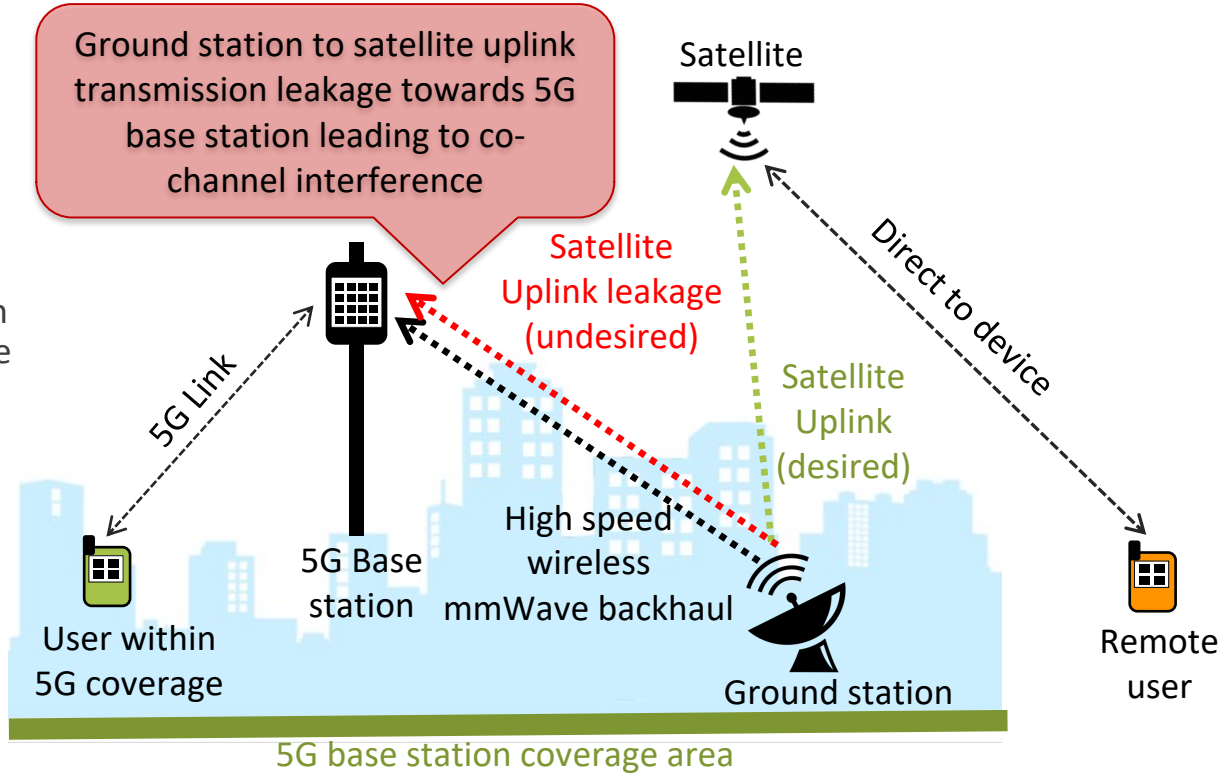
Enable coexistence

Both networks should operate without affecting each other, even when they are nearby and using the same frequency bands.



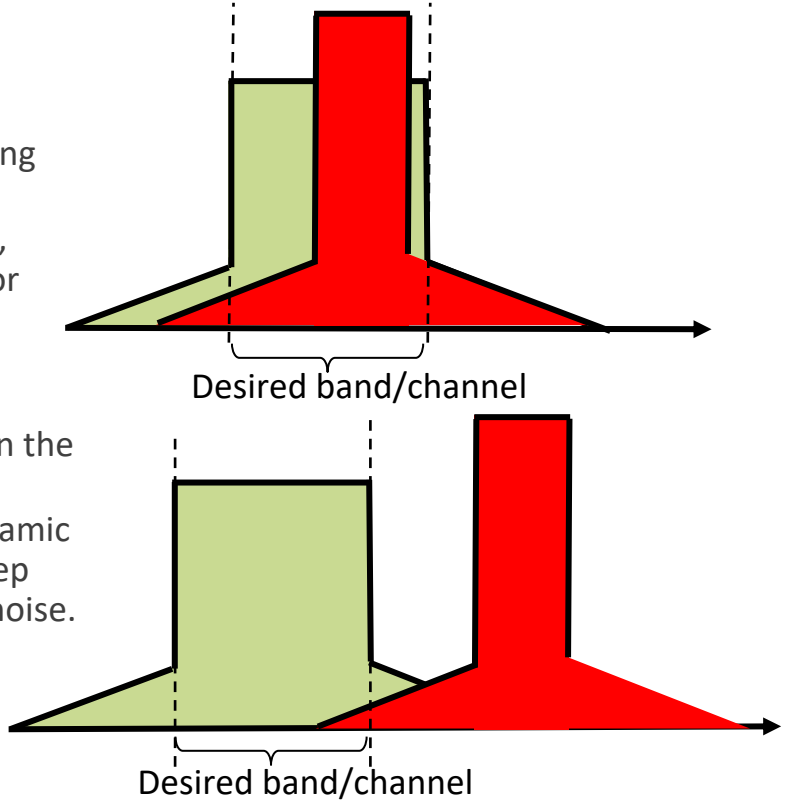
JointNets challenge: Interference

- When a satellite ground station and a 5G base station are in proximity and use overlapping frequency bands, it can lead to interference issues
- Ground stations transmit uplink signals in the 27.5-30 GHz band with **high transmit power**. Further, unlike GEO satellites, LEO satellites move rapidly, requiring frequent dish realignment and causing **sidelobe leakage.**
- These can lead to significant interference at 5G base stations, resulting in poor signal-to-noise ratio (SNR) or link failures.



Interference: *Co-channel and Adjacent channel*

- Co-channel Interference
  - When multiple sources transmit in overlapping frequency bands.
  - Interference power increases the noise floor, resulting in poor signal-to-noise ratio (SNR) or may cause link failure.
- Adjacent channel interference
  - When there is a simultaneous transmission in the adjacent channel.
  - Adjacent channel interference increases dynamic range on the receiver, there by degrading step size and leading to increase in quantization noise.



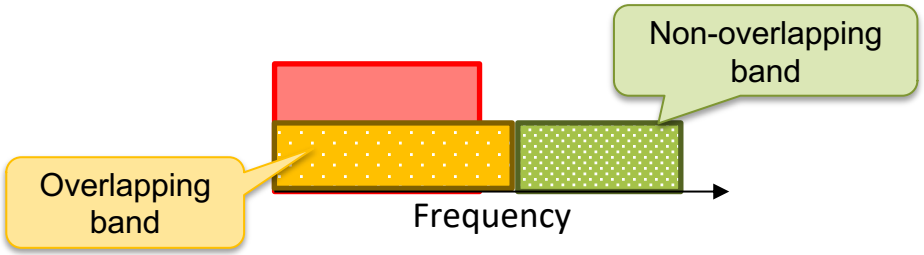
Current approaches to address interference (when ***nearby***)

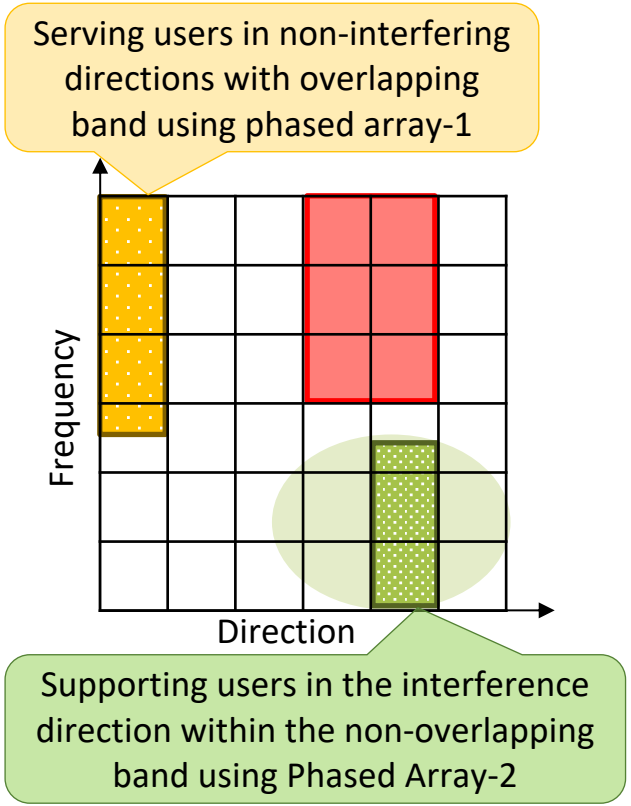
Approach	Full Spectrum Usage (Co-existence)	Coverage gaps (Coexistence)	Enabling backhaul	Comments
Frequency separation (Filtering)	✗	✓	✓	Significant wastage of spectrum (full overlap can lead to 100% wastage)
Direction Separation (Beam nulling)	✓	✗	✗	Effective spectrum usage but creates coverage gaps and cannot backhaul

How to enable **backhaul** and **coexistence**
while fully utilizing spectrum and avoiding coverage gaps?

Our approach: key insights

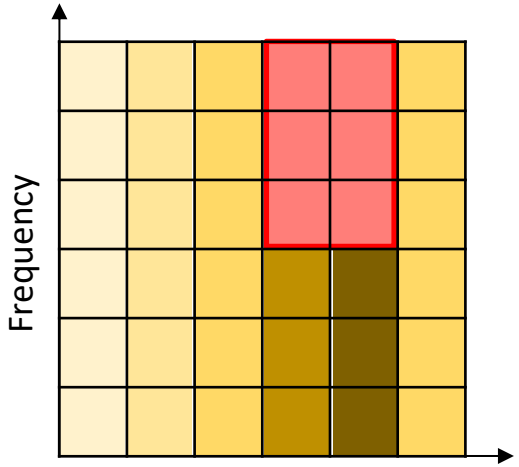
- Satellite interference is localized
  - ⟹ Satellite ground station interference only occurs in partial bandwidth
- **Key insights**
  - Divide the available bandwidth into overlapping and non−overlapping bands.
  - Beam non-overlapping bands in interference-prone or any other necessary direction
  - Beam overlapping bands into non-interfering directions.





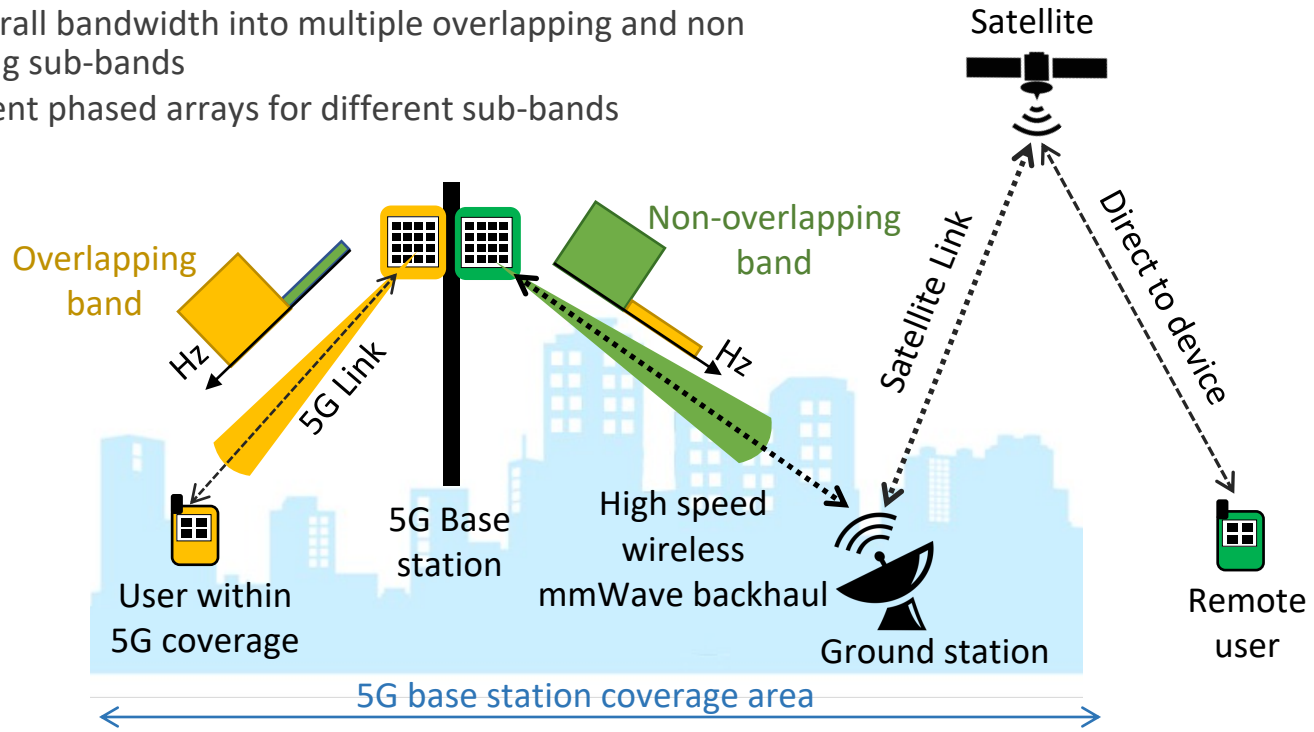
Fundamental problem with phased array

- Phased array
  - Beams full bandwidth in one direction
  - It cannot split and beam in different directions

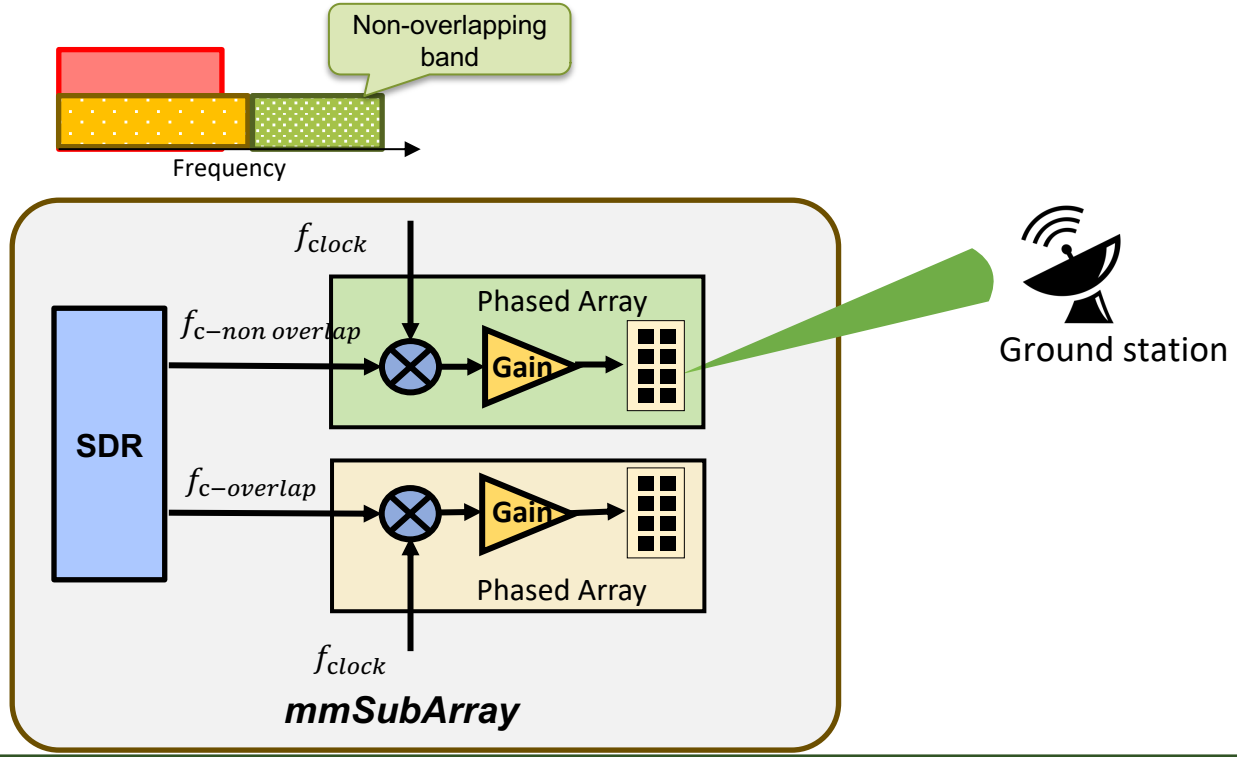


Proposed ***mmSubArray*** solution

- ***mmSubArray*** approach
  - Divide overall bandwidth into multiple overlapping and non overlapping sub-bands
  - Use different phased arrays for different sub-bands

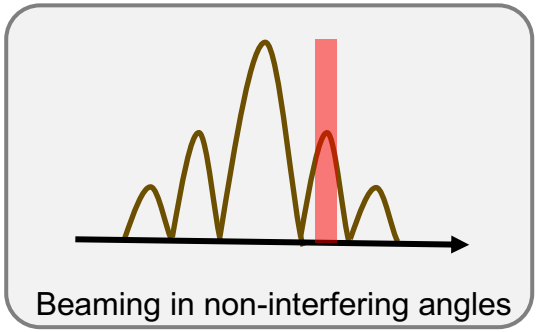


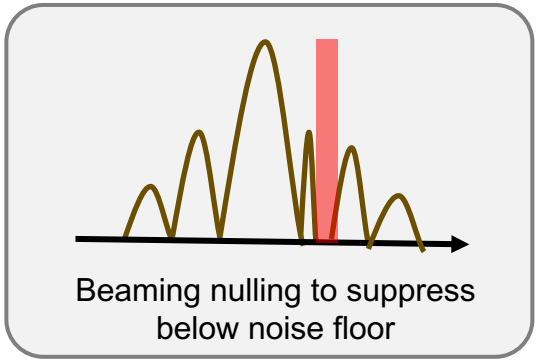
Proposed ***mmSubArray*** solution (a): *Beaming non-overlapping band to satellite ground station*

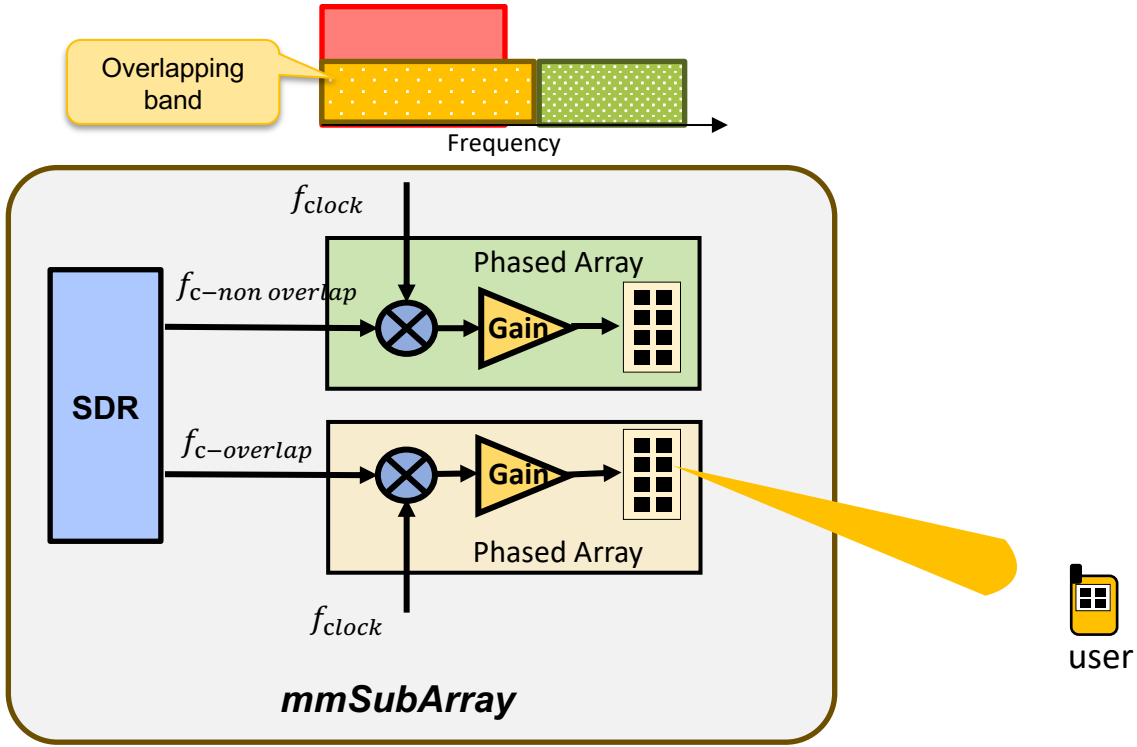


Enabling backhaul through non-overlapping band

Proposed ***mmSubArray*** solution (b): *Suppressing interference and supporting users*

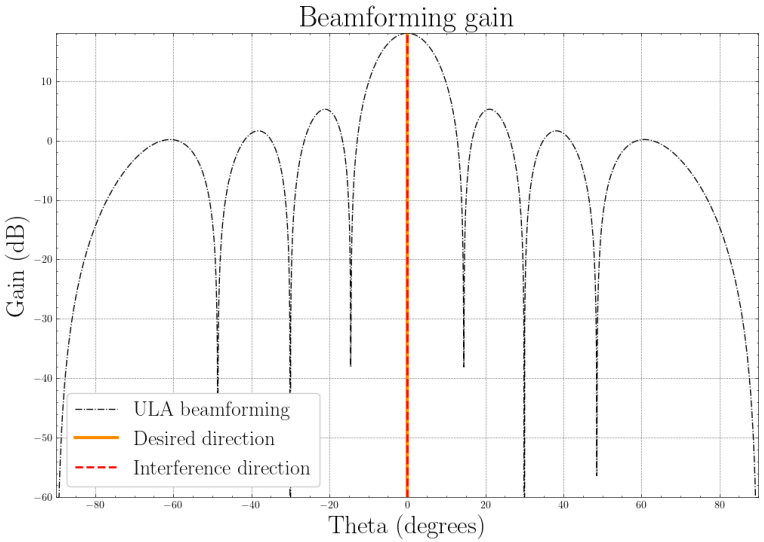


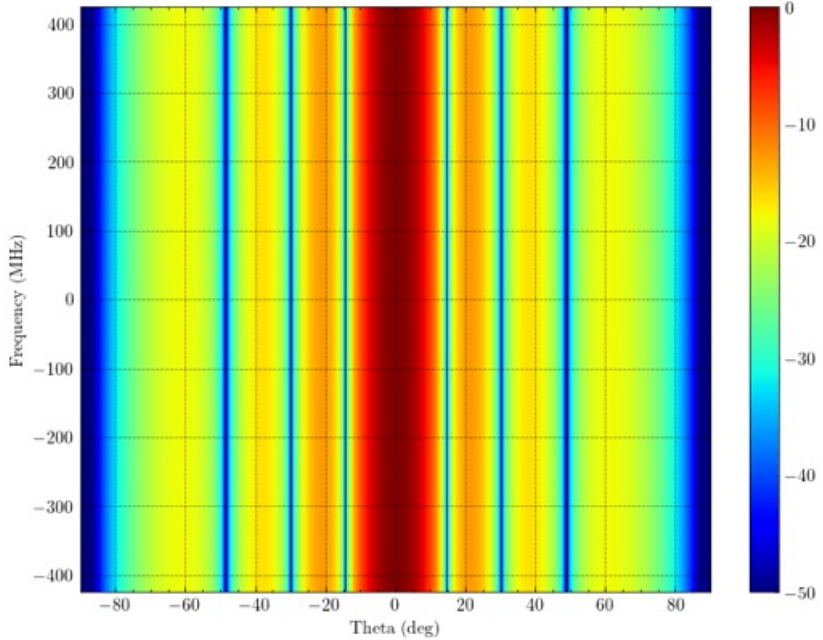




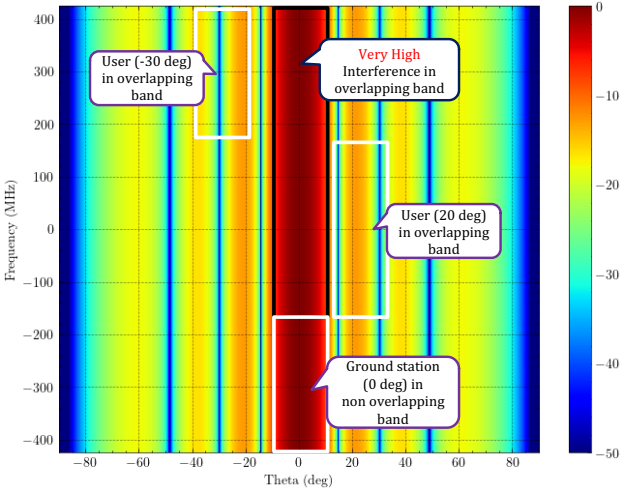
Enabling coexistence by suppressing interference and effectively supporting users in noninterfering directions

Simulator Results: *Beamforming in frequency and space*

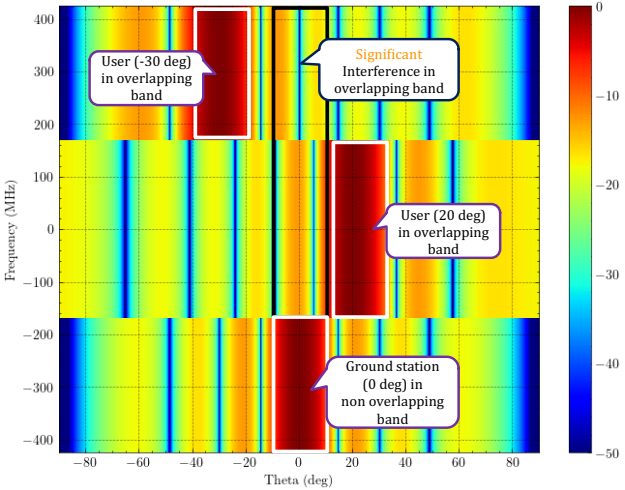




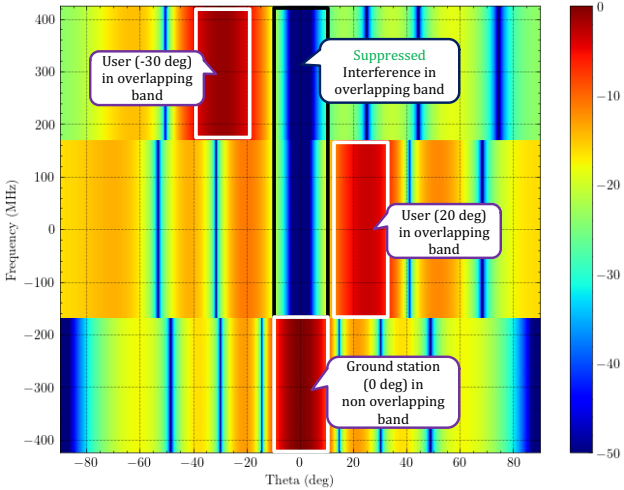
Simulator Results: *Splitting and Nulling*



Supporting user in interferer directions



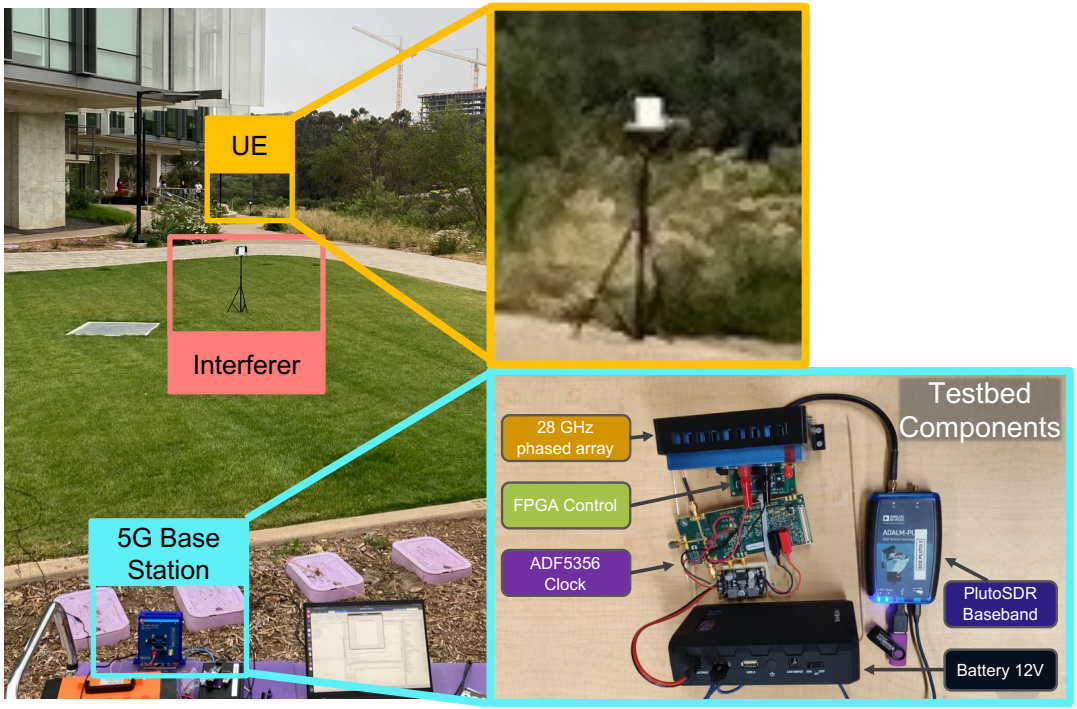
Splitting: Supporting users in non-interferer directions



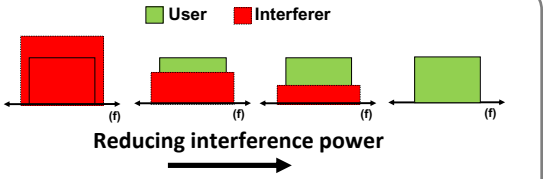
Splitting + Nulling: Supporting users in non-interferer directions with nulling

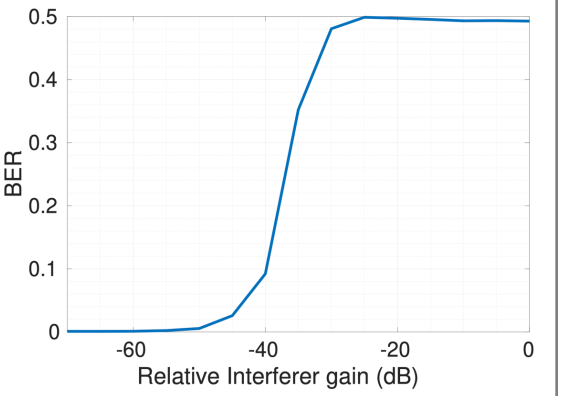
Over-the-air experiments: *Hardware Setup*

- Hardware setup with commercial phased arrays mimicking 5G user (UE), Interferer and Base station

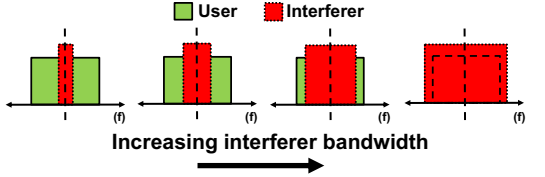


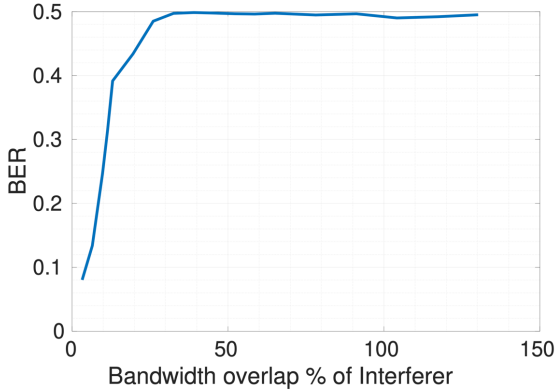
Over-the-air experiments: *Results*



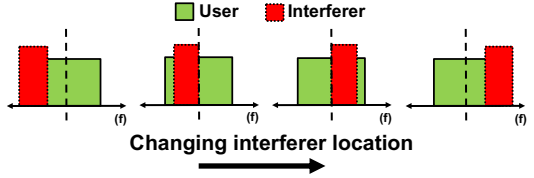


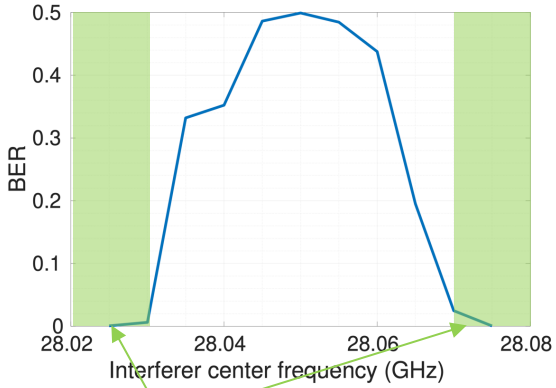
Suppressing interference below the noise floor ***enables coexistence*** in overlapping bands





Partial overlap (>25%) results in similar degradation as full bandwidth overlap



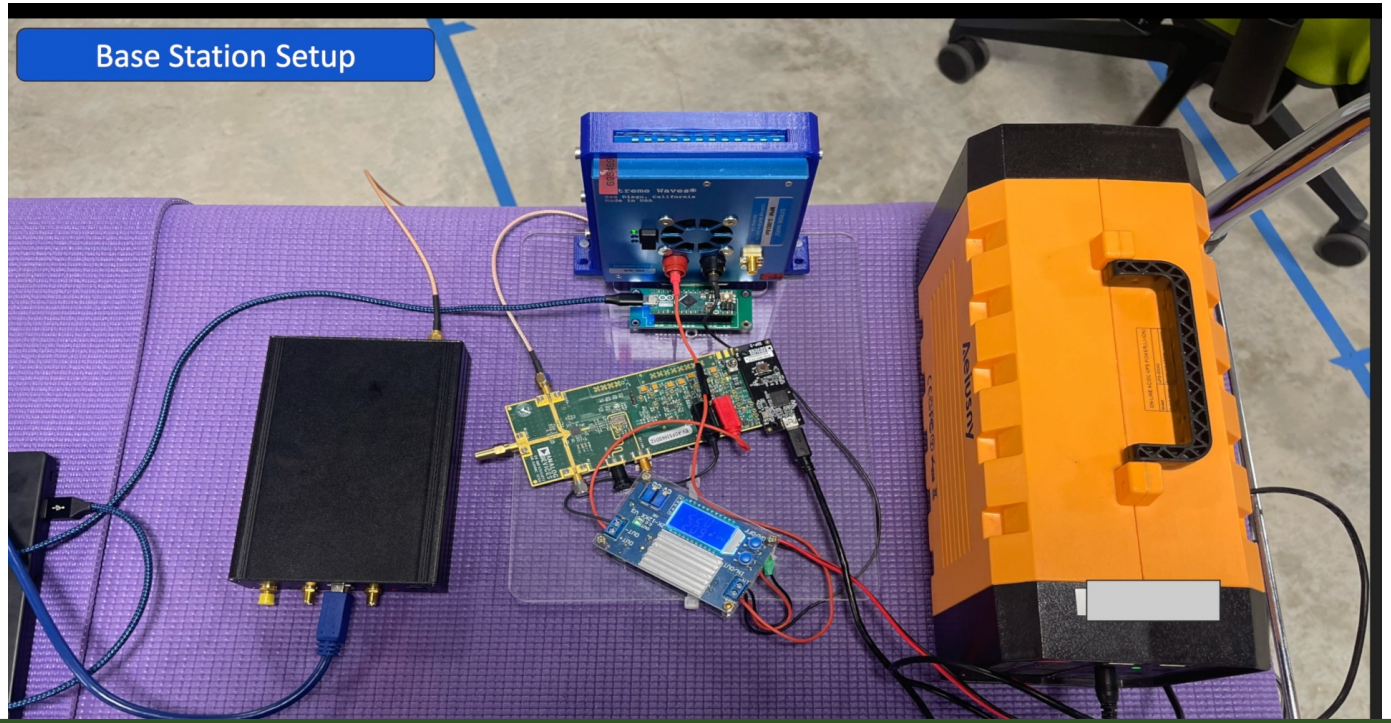


Adjacent channel Interference does not significantly affect the link performance

A non-overlapping band only experiences adjacent channel interference, which remains unaffected and helps in enabling backhaul

mmSubArray Prototype: *Demo video*

(link: https://www.youtube.com/embed/uGWcX8MJM4Y)



mmSubArray suppresses interference in overlapping bands by beaming in non-interfering directions and applying nulling

mmSubArray Enables ***JointNets***

- High speed wireless **mmWave backhaul** – *no more expensive fiber backhual.*
- Ensures **Coexistence** - suppress interference and support users effectively.
- Achieves ***high spectral efficiency*** on both networks and ***avoid coverage gaps***.

Artifacts and more details at

wcsng.ucsd.edu/mmsubarray

Questions?