

Sigcomm 2021

Two beams are better than one

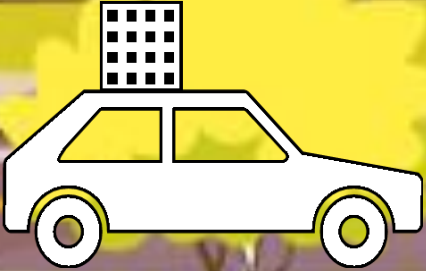
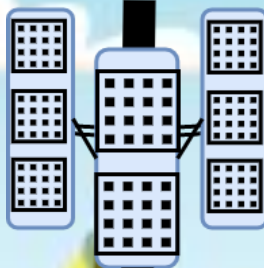
Towards Reliable and High Throughput Millimeter-wave Links



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5G Base station
(gNB)



Vehicular application



5G Access Point
(AP)

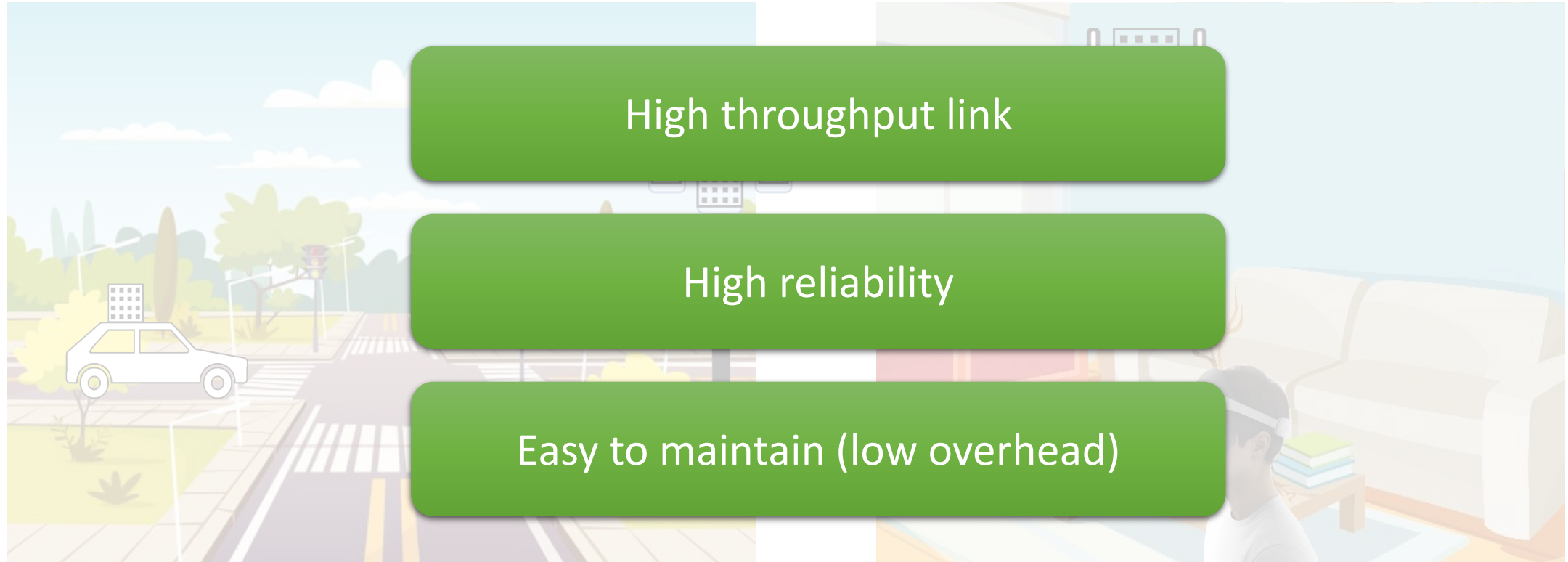


AR/VR application

Requirements for Vehicular and AR/VR applications

Vehicular

AR/VR

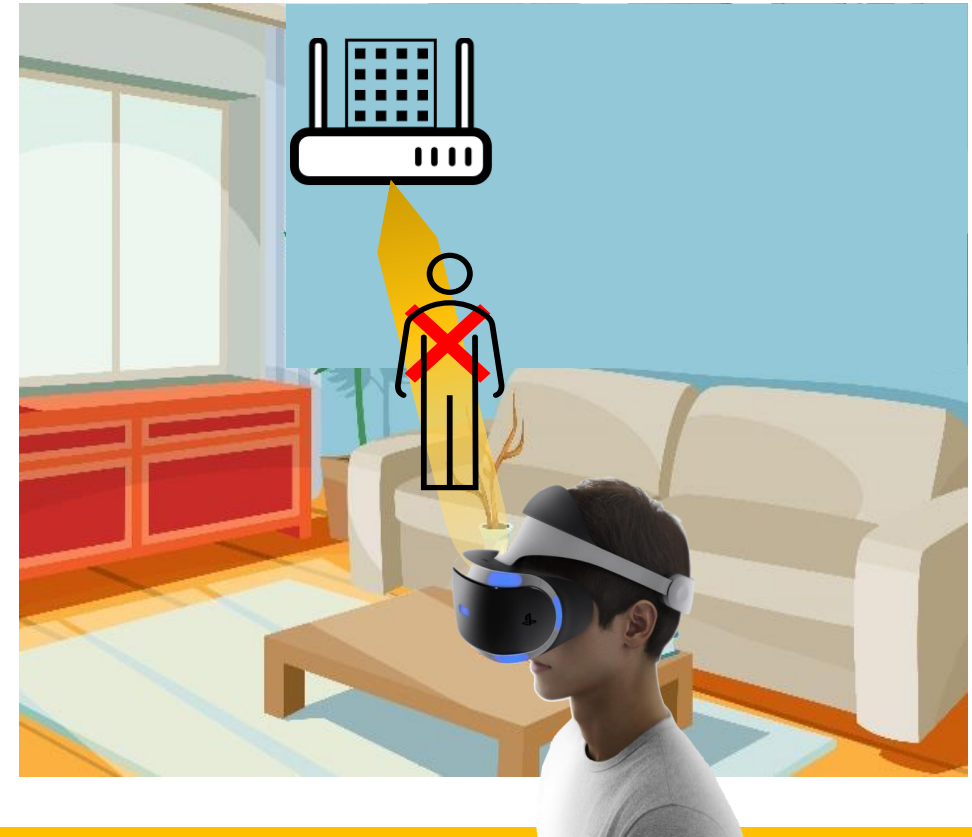


Millimeter-wave provides high throughput but lacks reliability

User mobility



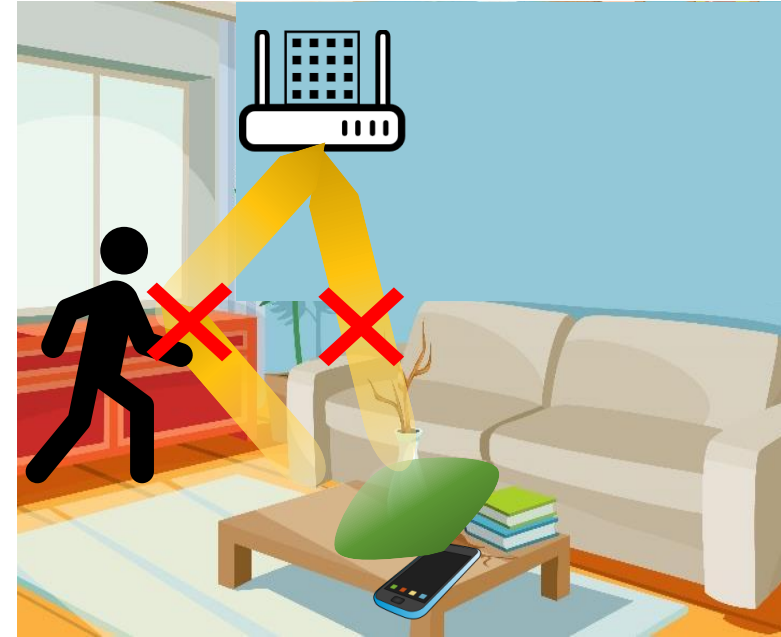
Blockage



mmReliable: Two beams are better than one!



Traditional: Single Beam

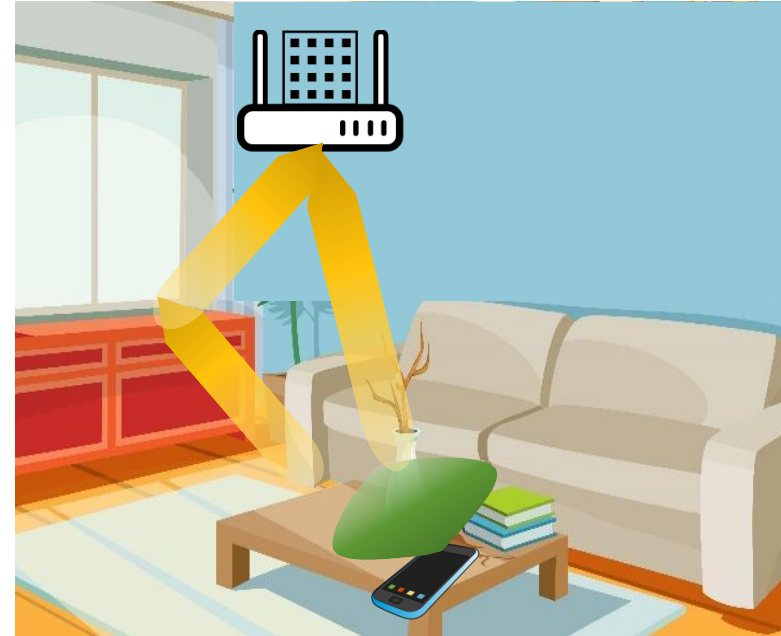


mmReliable: Multi-Beam
(multiple main lobes)

Multi-beam link avoids a single point of failure → Reliable link

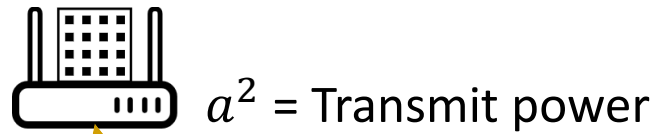
mmReliable: Towards Reliable and High Throughput Millimeter-wave Links

- ❖ High reliability
 - Corollary of using multi-beam
- ❖ High throughput
 - Creating *Constructive multi-beam*
- ❖ Easy to create
 - Standard 5G testbed
 - 5G NR compliant
- ❖ Easy to maintain
 - Proactive (not reactive) user tracking and beam maintenance



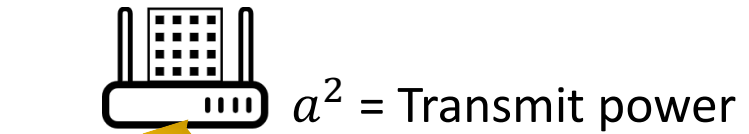
mmReliable: Multi-Beam
(multiple main lobes)

Can multi-beam provide high throughput?



Single Beam

$$\text{SNR} \propto a^2$$



Multi-Beam

$$\text{SNR} \propto (\sqrt{2}a)^2 = 2a^2$$

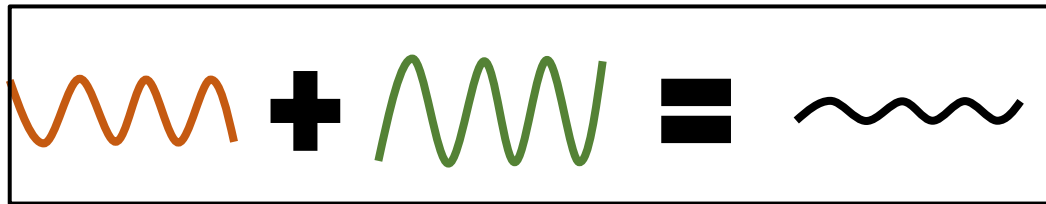
Total power is preserved:

$$\frac{a^2}{2} + \frac{a^2}{2} = a^2$$

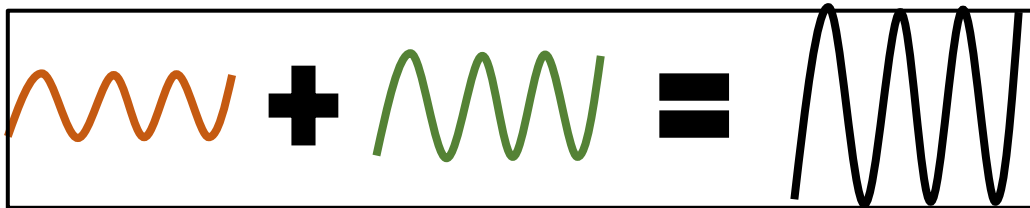
$$\frac{a}{\sqrt{2}} + \frac{a}{\sqrt{2}} = \sqrt{2}a$$

Multi-beam provides 2x SNR gain than single beam → Higher throughput

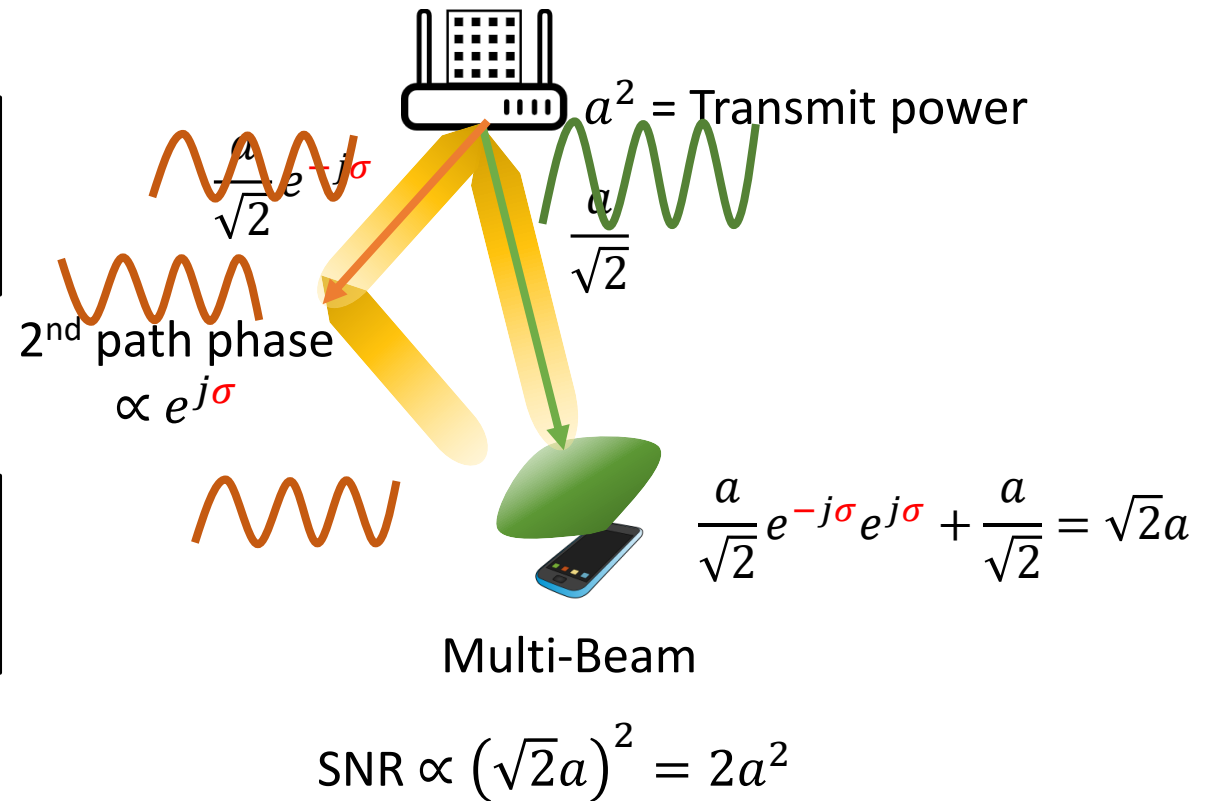
Achieving high throughput with per-beam **phase control**



Destructive Multi-Beam

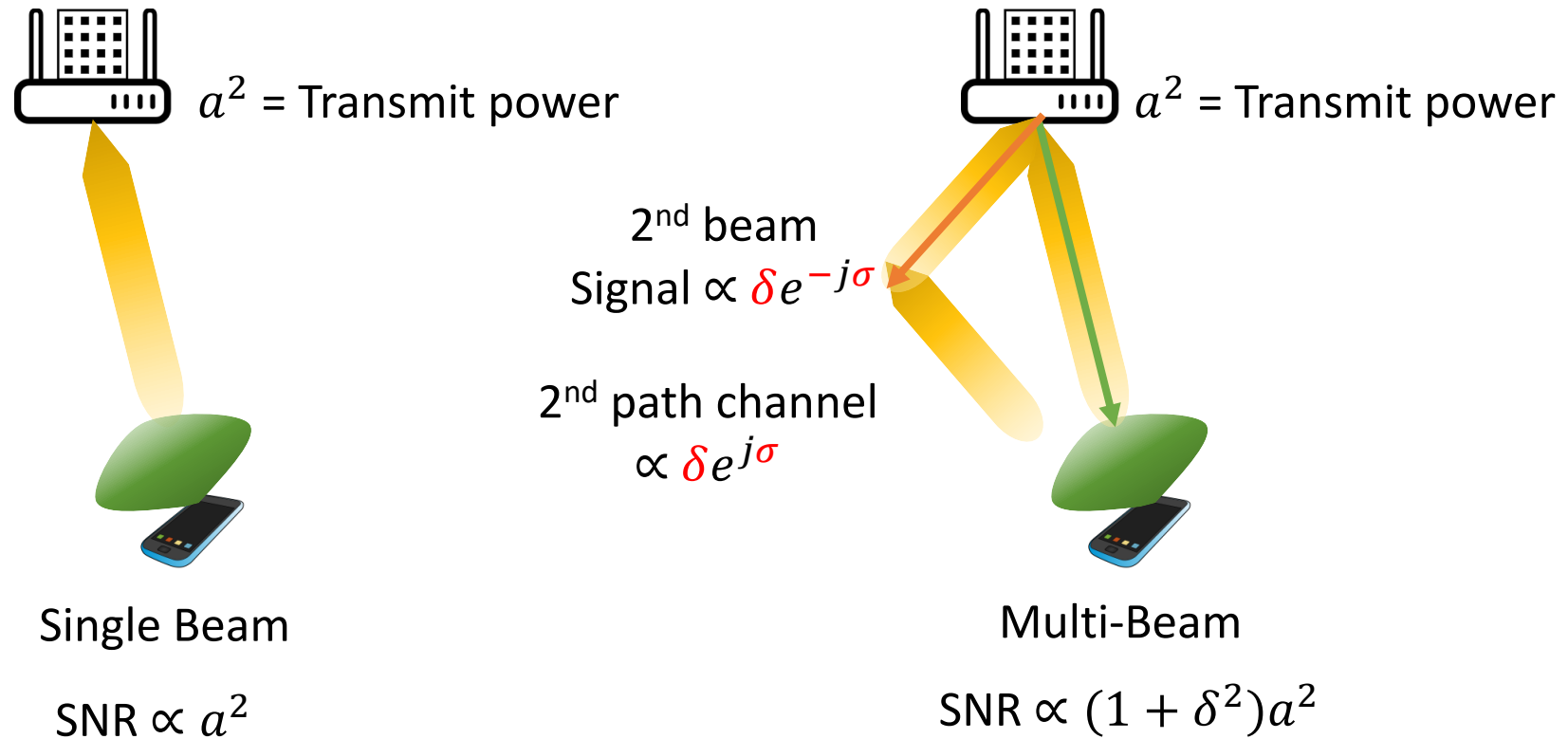


Constructive Multi-Beam



mmReliable requires **phase control** to create constructive multi-beam

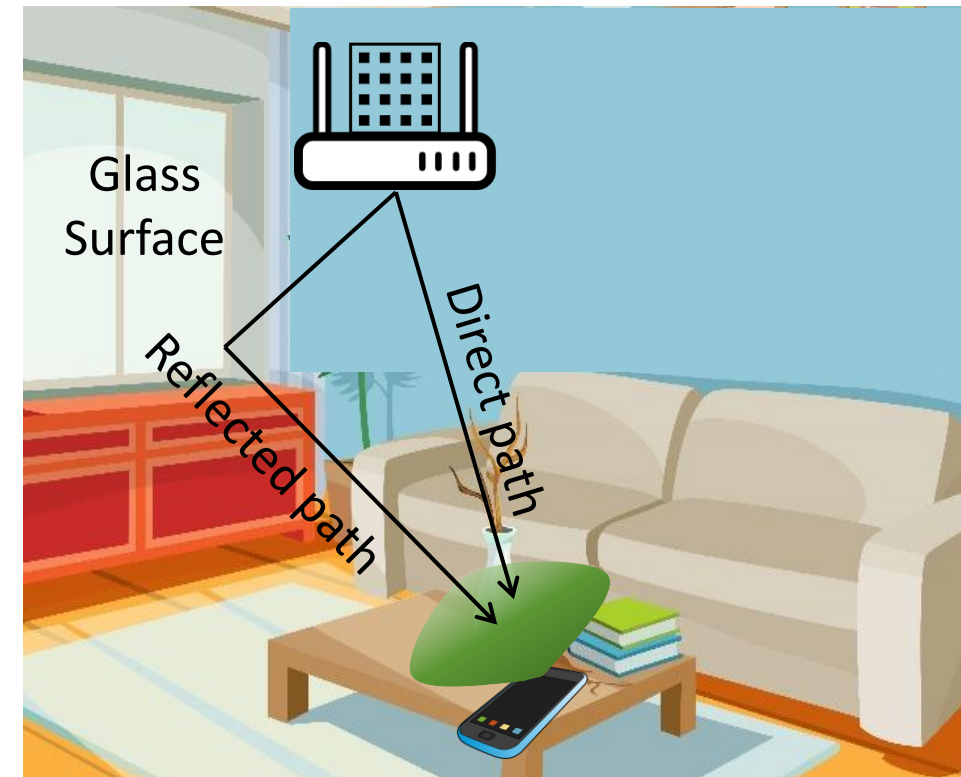
Constructive multi-beam also require per-beam **power control**



Constructive multi-beam requires both phase and power control to achieve higher SNR and higher throughput

Strong multi-path exists for mmWave

Material	Reflection loss (28 GHz)
Metal surface	1-3 dB
Glass surface	1-6 dB
Dry-wall, Concrete	5-10 dB

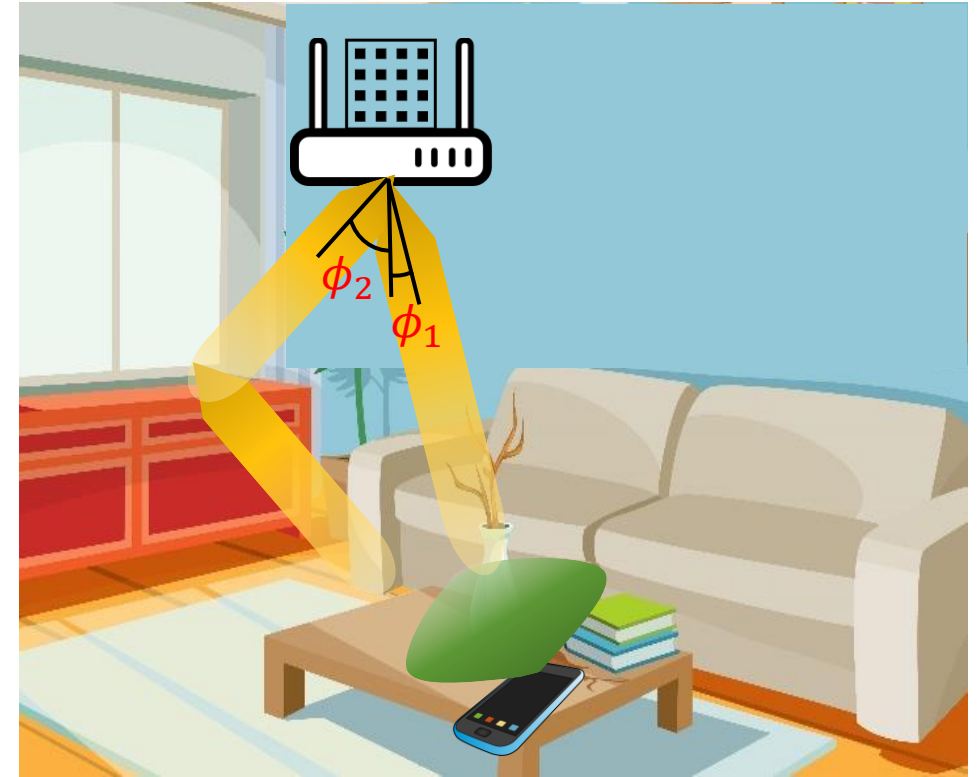
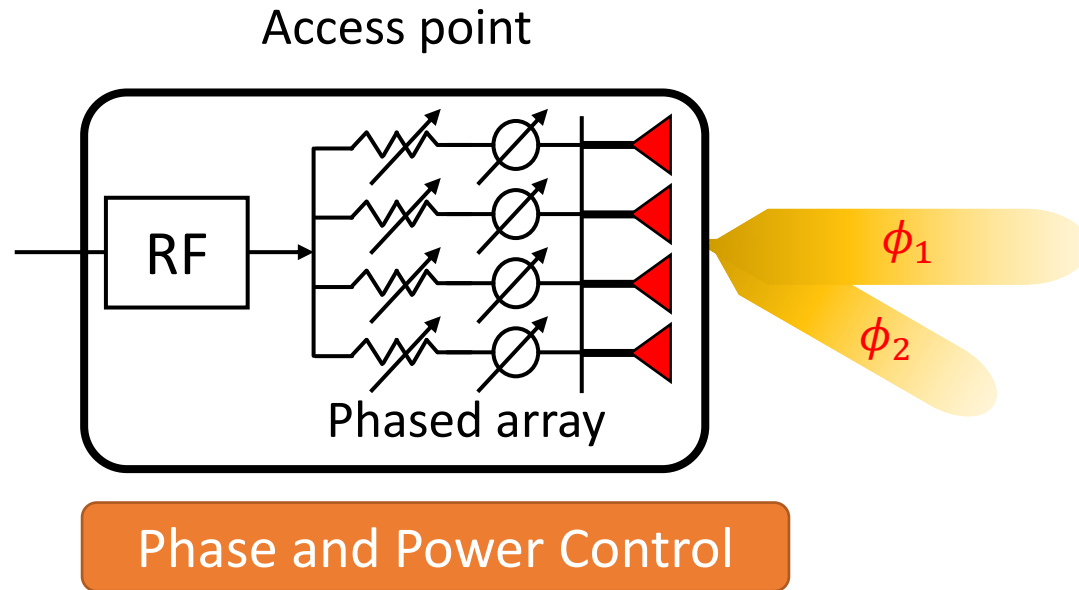


Multi-path environment

Strong reflectors leads to higher throughput using constructive multi-beam

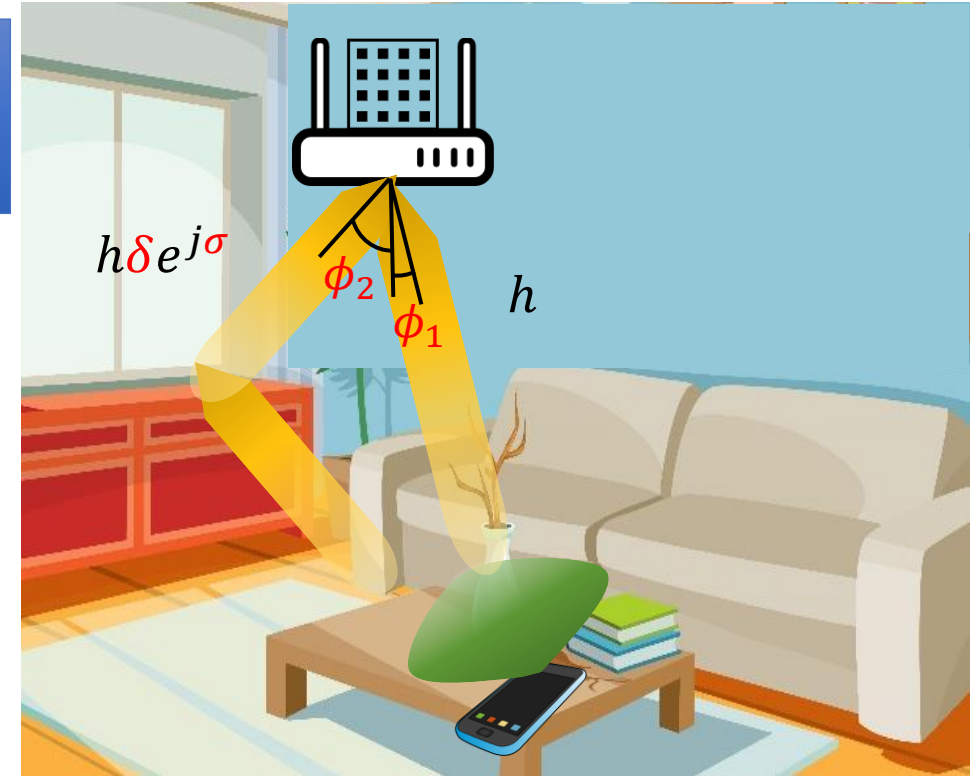
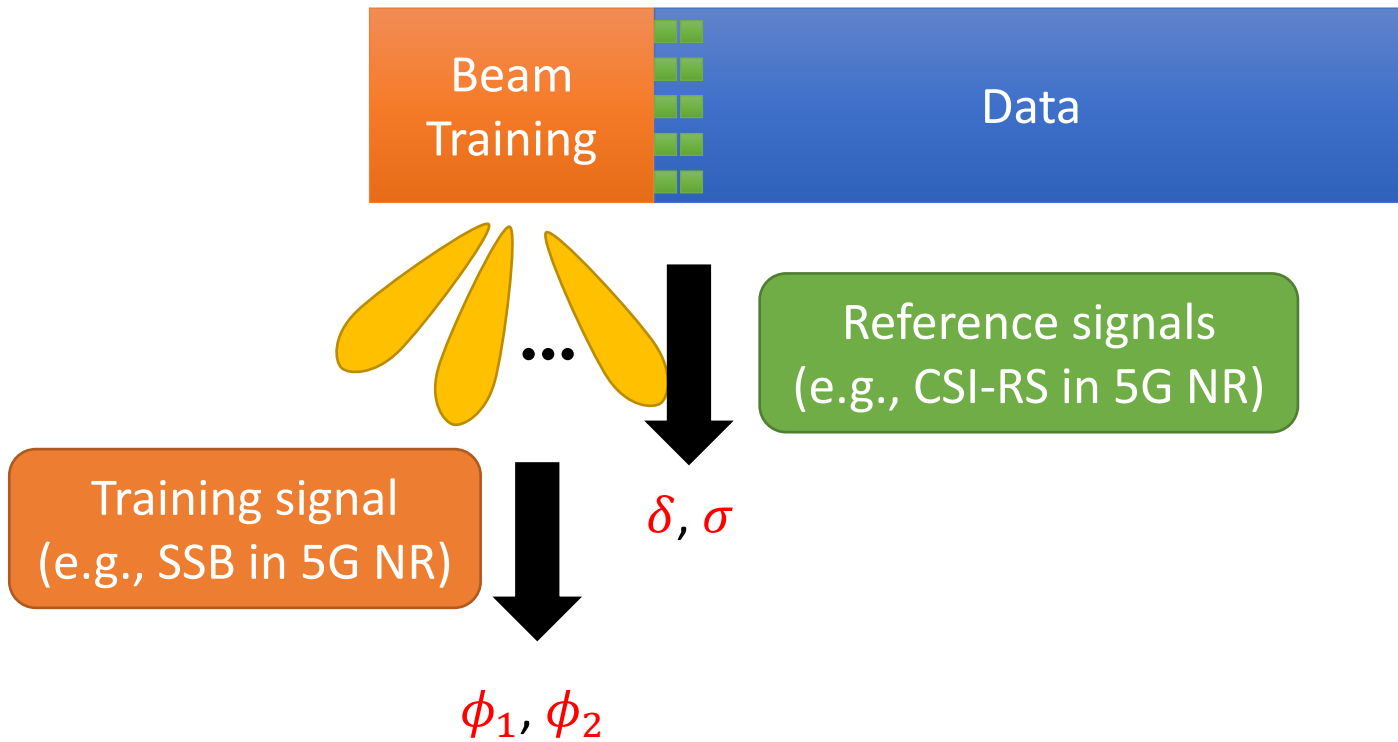
Reference: [Telecom Infra Project: Analysis of 28GHz and 60GHz Channel Measurements in an Indoor Environment](#)

Constructive Multi-beam can be created using standard mmWave phased arrays



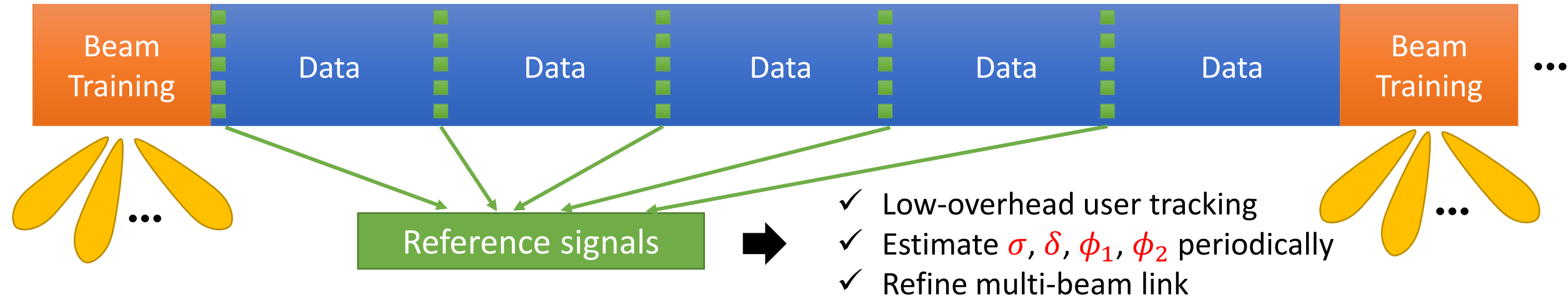
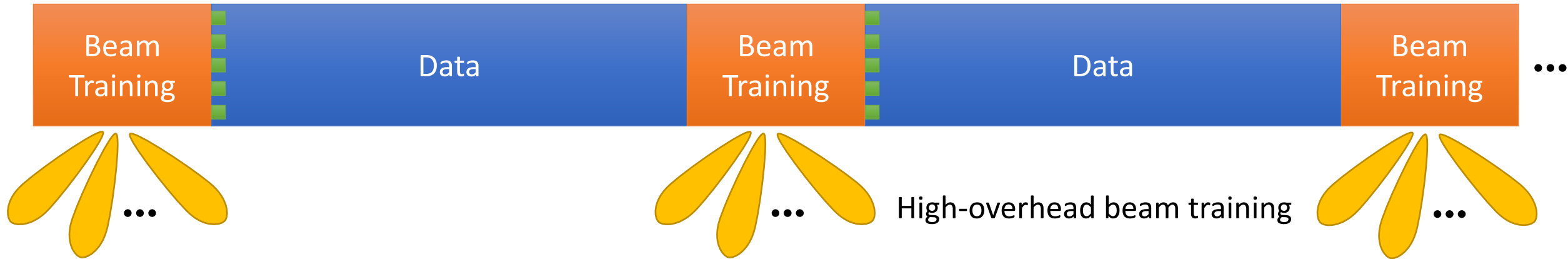
Constructive Multi-beam can be generated with COTS hardware

mmReliable is 5G NR protocol compliant

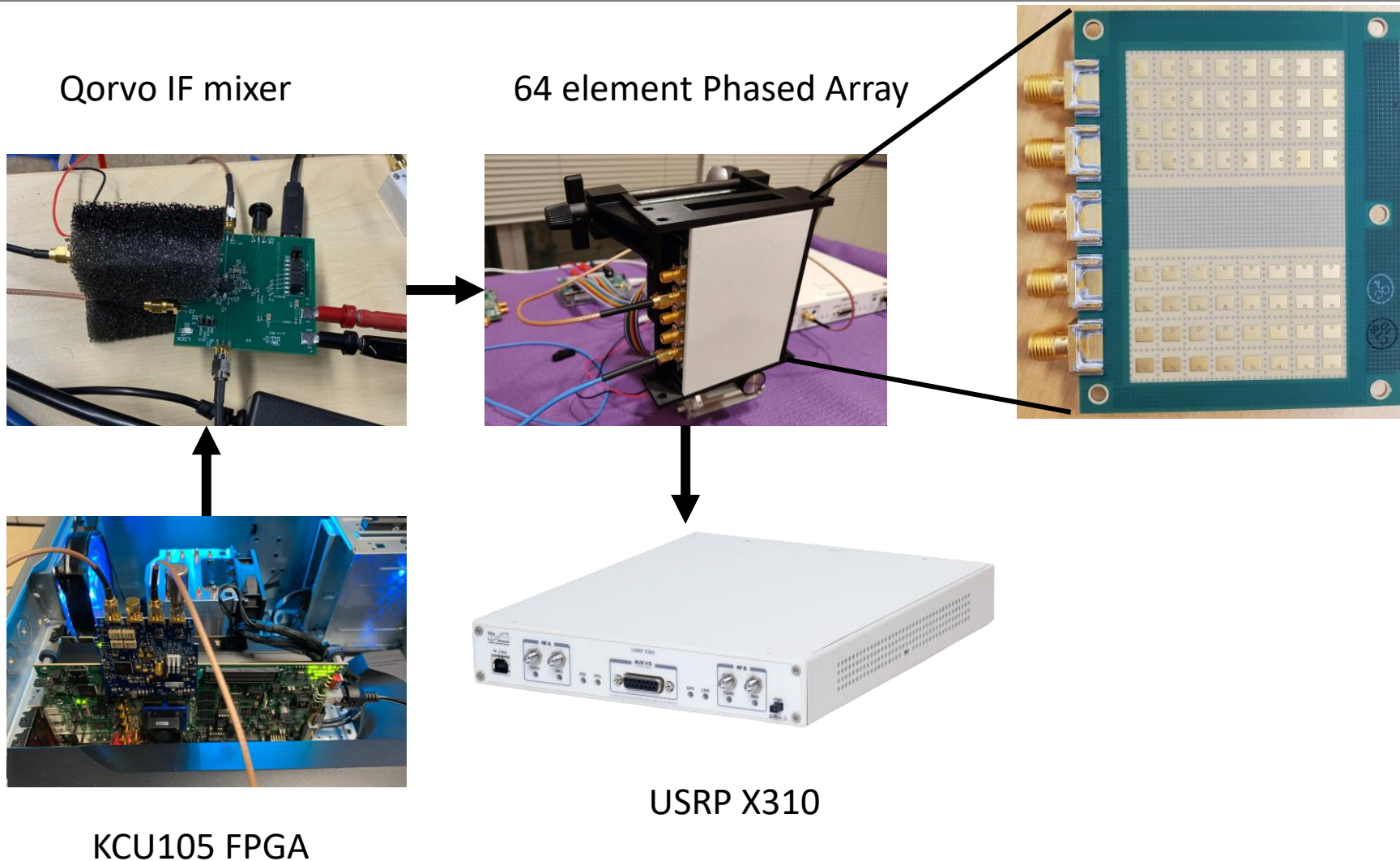


More details in our paper...

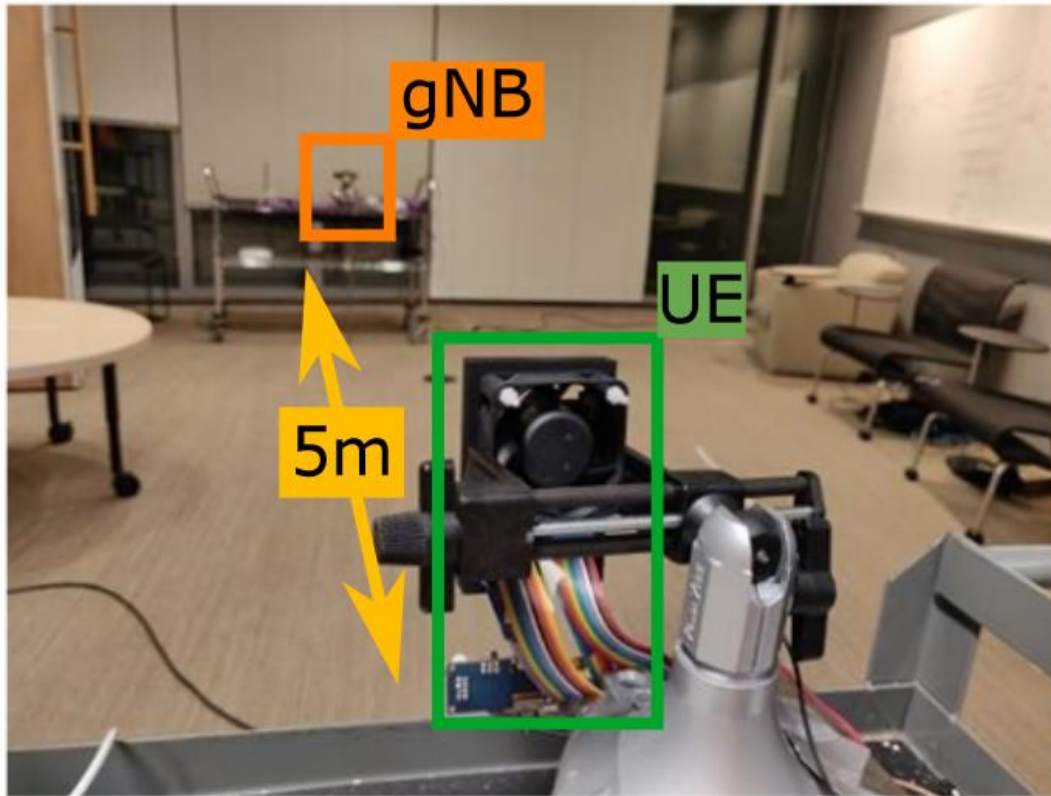
Proactively maintaining multi-beam for a **mobile** user



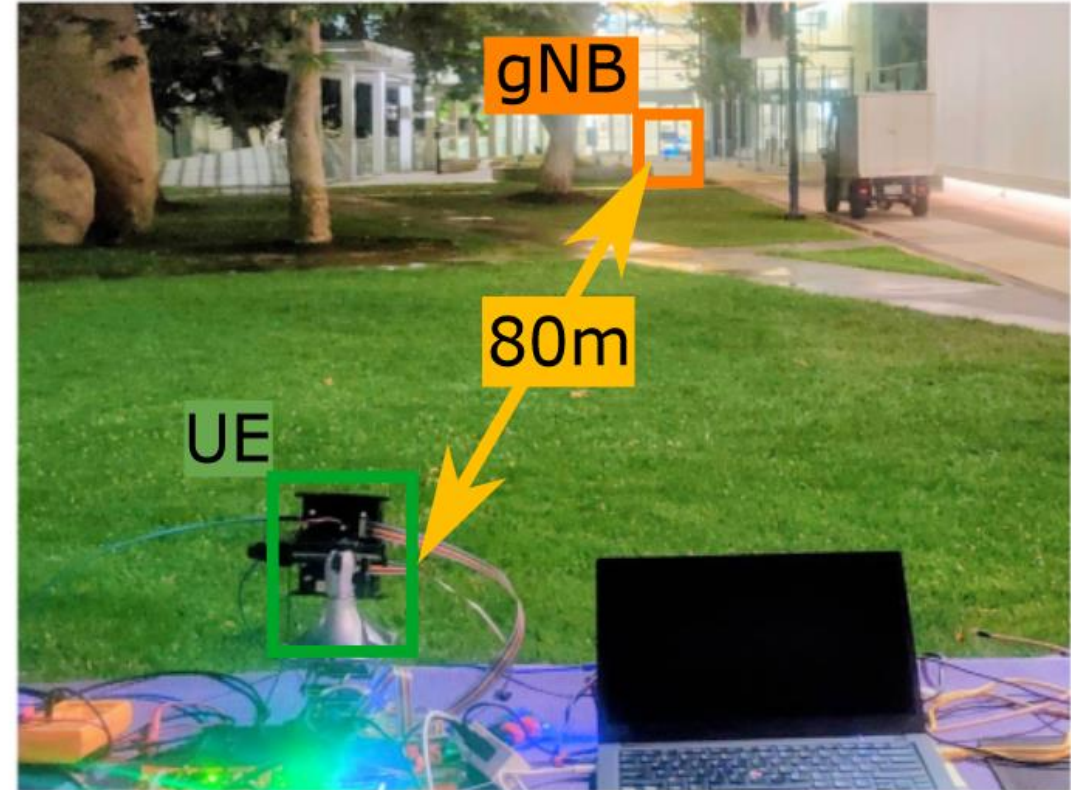
We evaluate mmReliable on 5G testbed mMobile



Indoor and outdoor evaluation of mmReliable

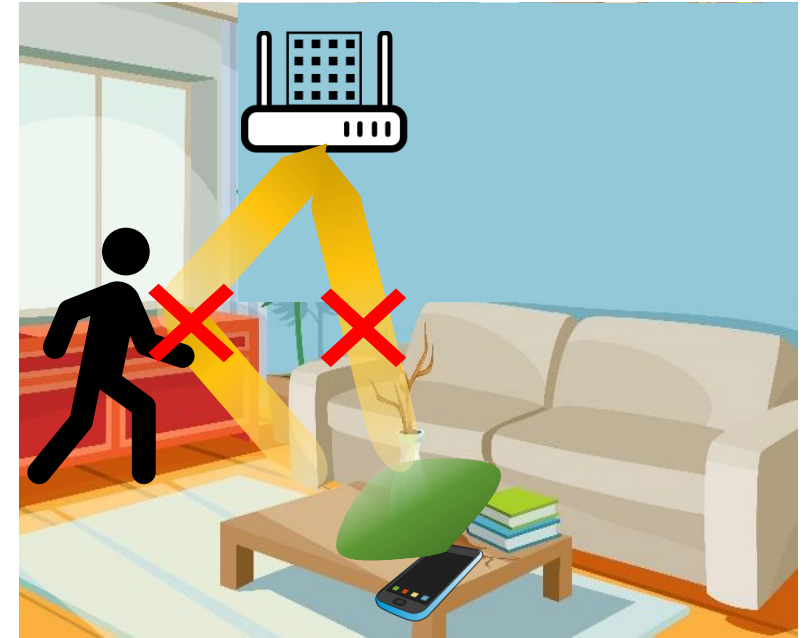
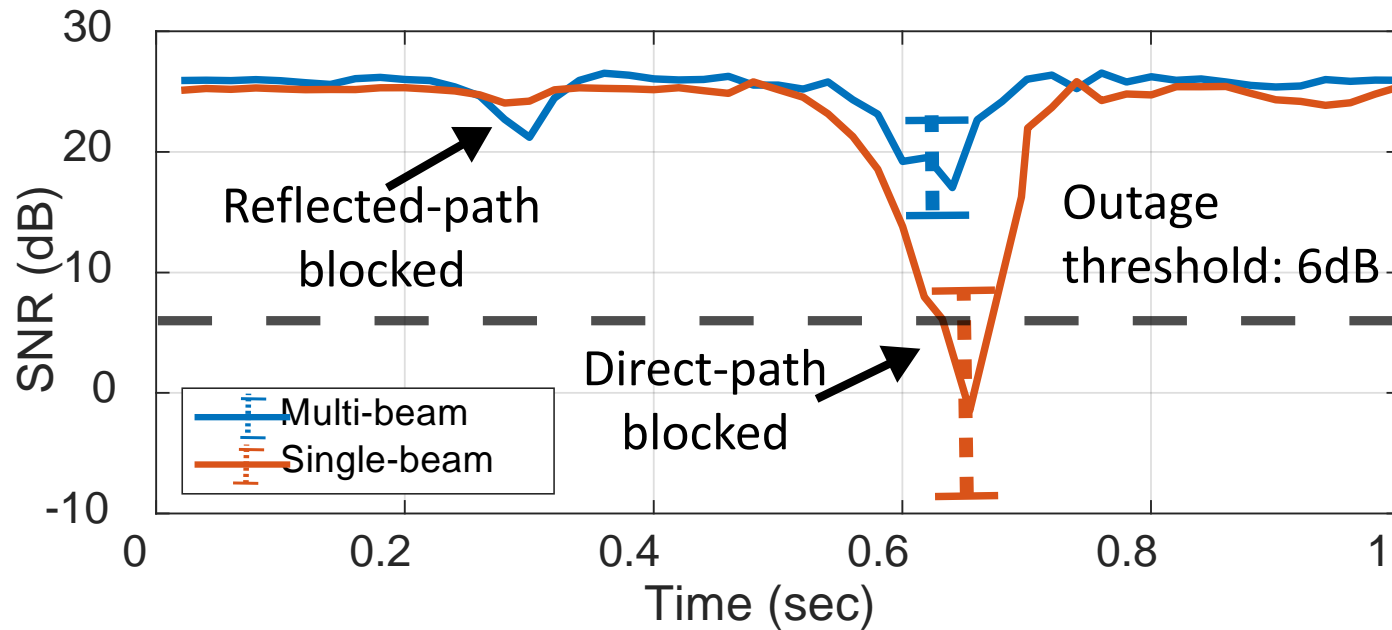


Indoor 5m link



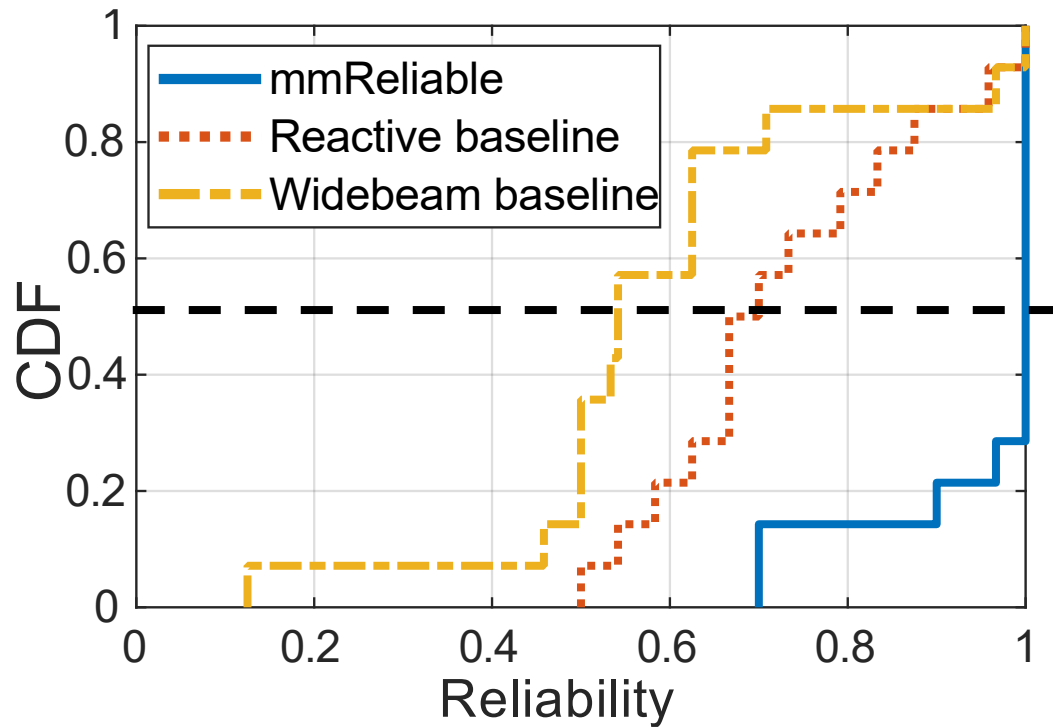
Outdoor 10m - 80m link

Multi-beams are resilient to blockage

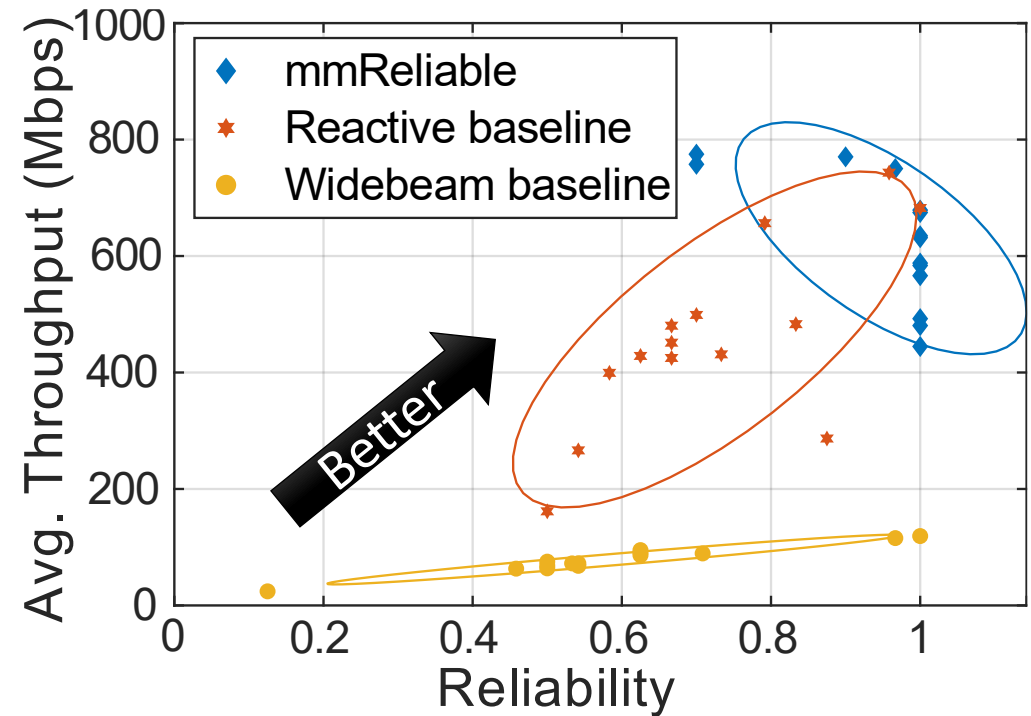


Multi-beam maintain high throughput despite occasional blockages

mmReliable provides improved throughput and reliability



Achieve **100 %** reliability (median)



While providing **1.5x** higher throughput

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Two beams are better than one

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Artifacts available

<https://wcsng.ucsd.edu/mmreliable>

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