Massive MIMO at 60 GHz vs. 2 GHz: How Many More Antennas?

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joint work with

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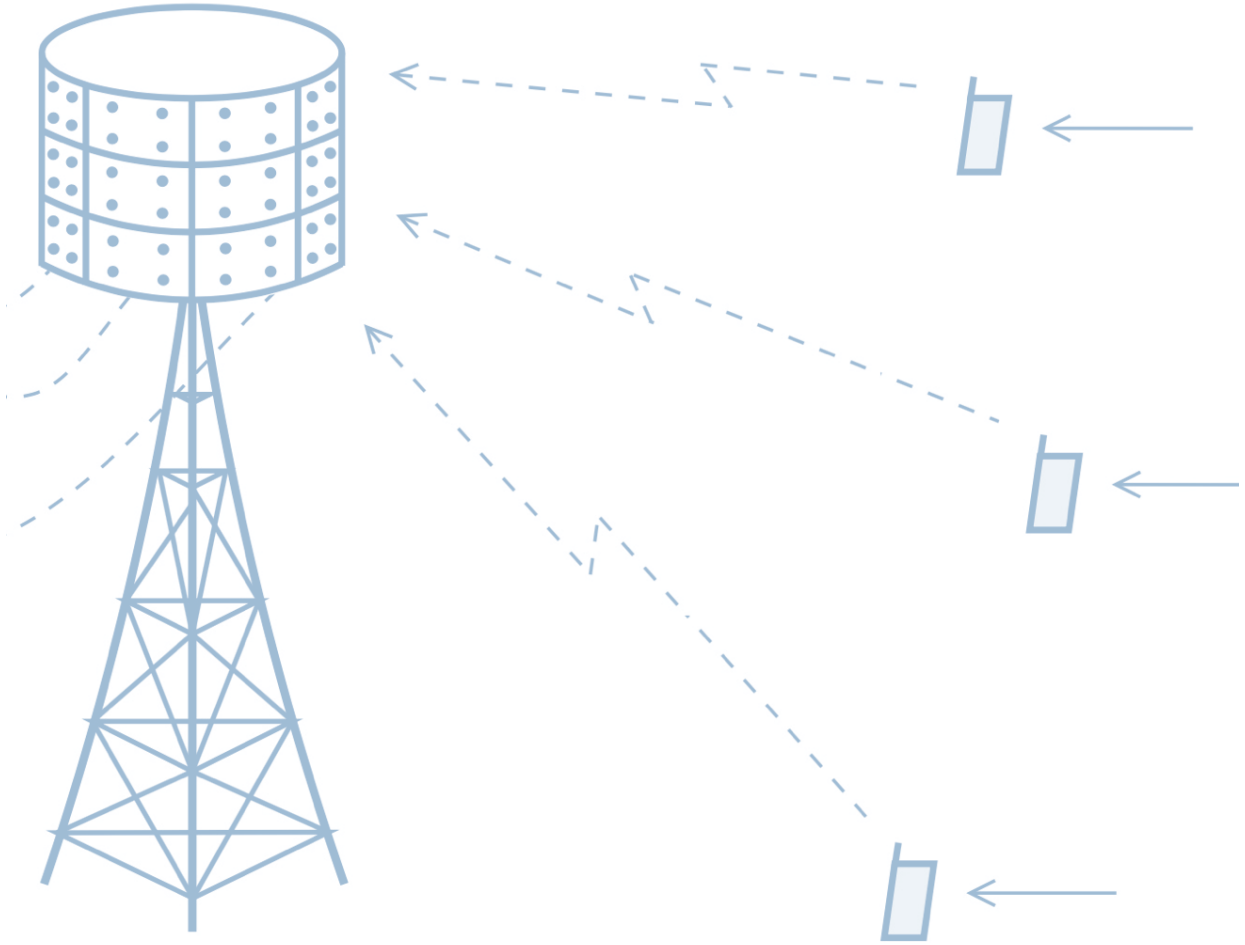
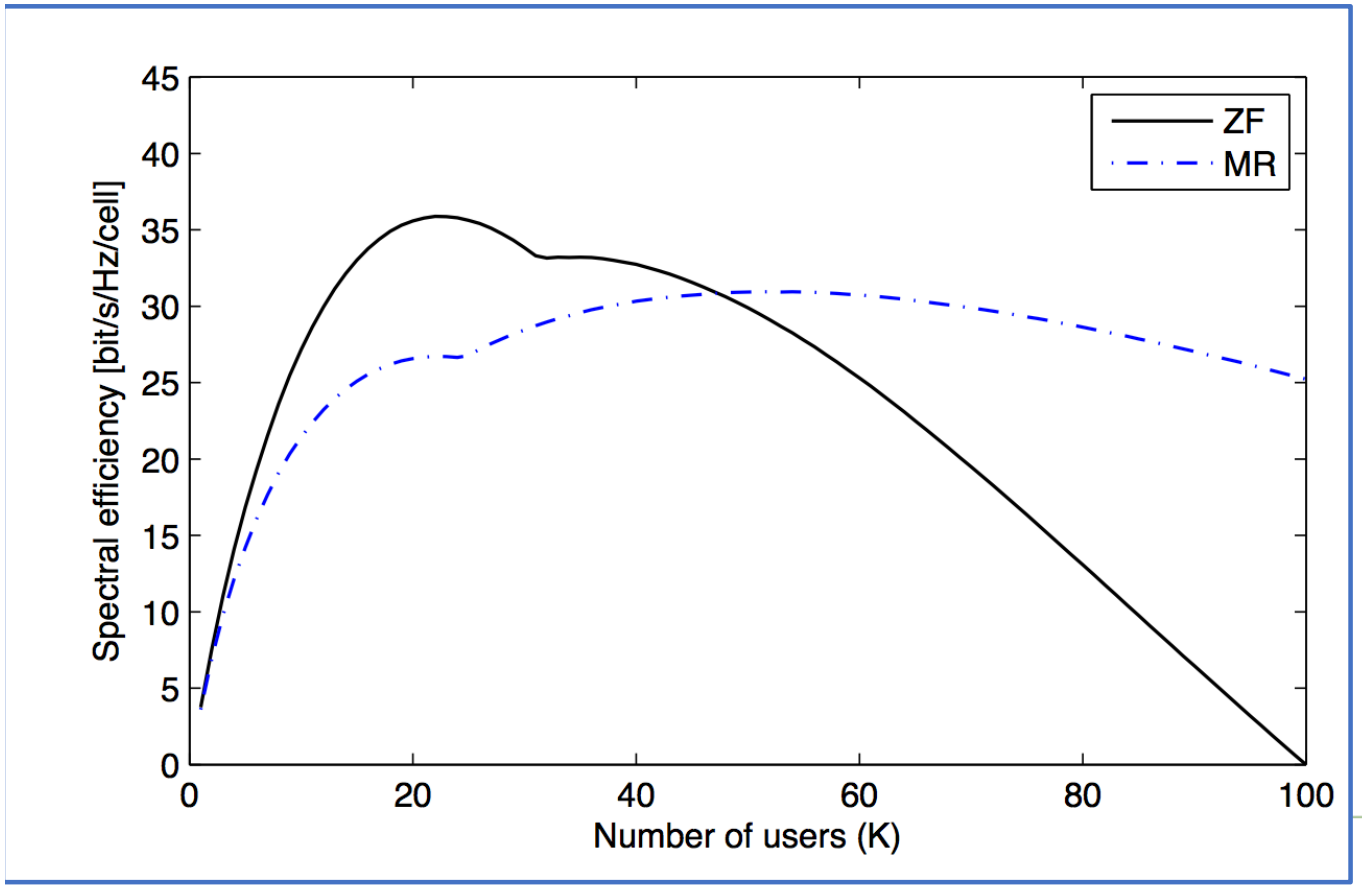
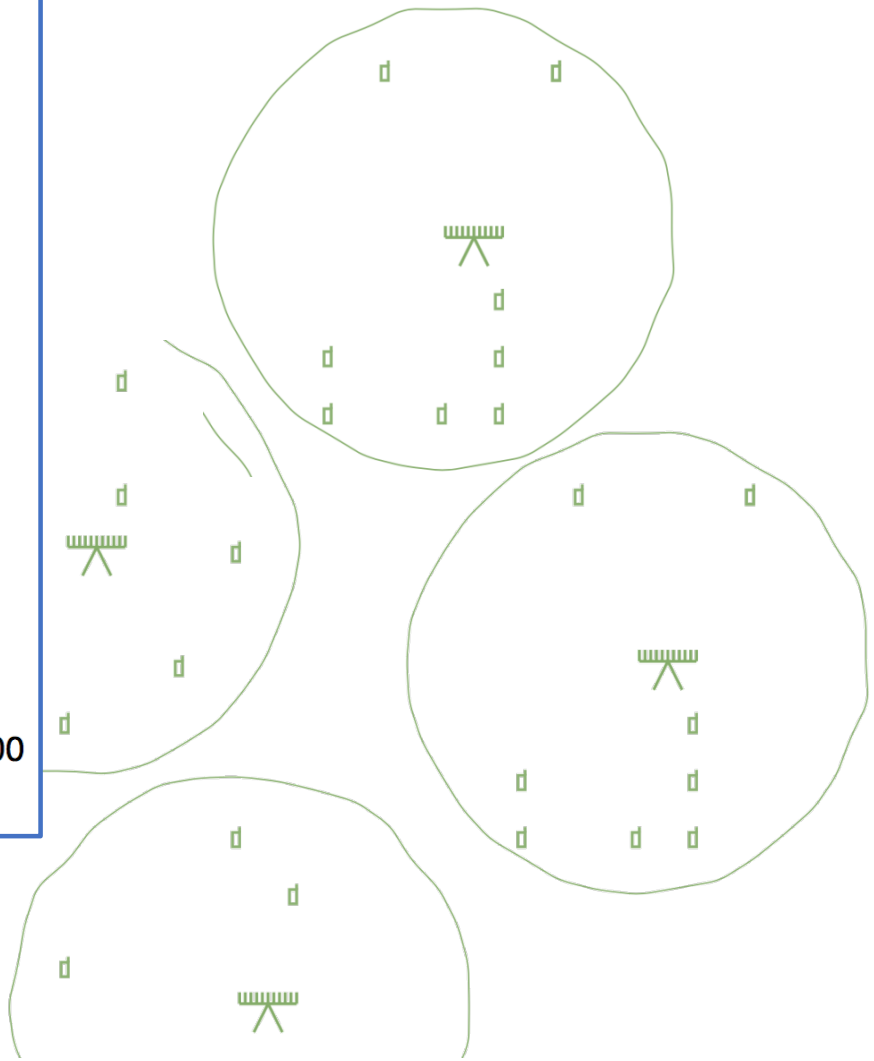


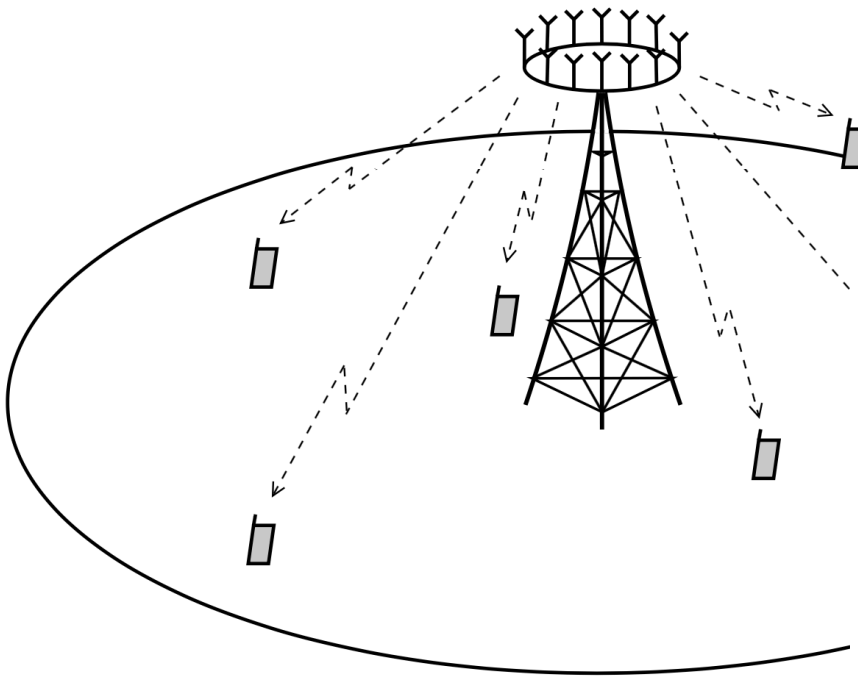
Cellular Massive MIMO in PCS bands offers uniformly high QoS



- 1 ms $\times$ 200 kHz channel coherence, 100 antennas
- Max-min fairness power control



We compared PCS (1.9 GHz) with mmWave (60 GHz) in line-of-sight



Cell radius	500 m
Mobility	negligible
No. of multiplexed terminals	18
Base station height	30 m
Terminal height	1.5 m
Propagation	free-space/line-of-sight
Antenna type	omni (0 dBi)
Power control	max-min fairness (uniform QoS)
Bandwidth	20 MHz
Downlink power	10 W
Uplink power	200 mW
Base station noise figure	9 dB
Terminal noise figure	9 dB

Simple, exact performance formulas are available in closed form...

- Zero-forcing in the downlink:

$$y_k = \sqrt{\frac{\rho\beta_k\eta_k}{\sum_{k'=1}^{K}\left[(\boldsymbol{H}^H\boldsymbol{H})^{-1}\right]_{k'k'}\cdot\eta_{k'}}}\cdot q_k + w_k$$

- SINR for kth terminal:

$$\text{SINR} = \frac{\rho\beta_k\eta_k}{\sum_{k'=1}^{K}\left[(\boldsymbol{H}^H\boldsymbol{H})^{-1}\right]_{k'k'}\cdot\eta_{k'}}$$

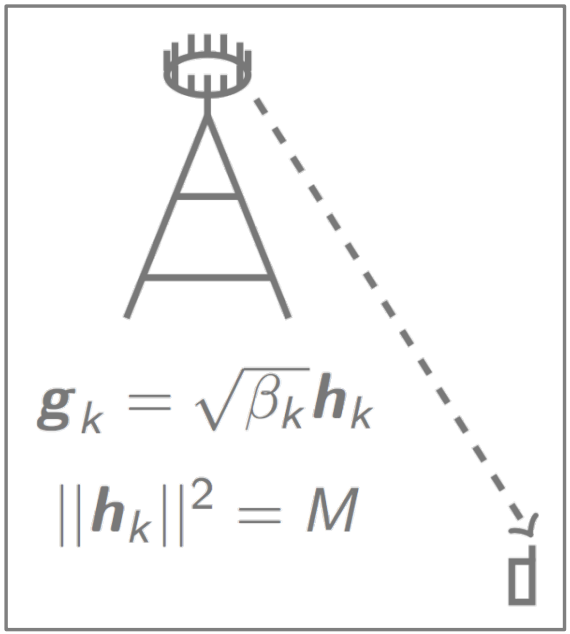
- Max-min fairness choice of η_k:

$$\eta_k = \frac{\sum_{k'=1}^{K} 1/\beta_{k'}}{\beta_k}$$

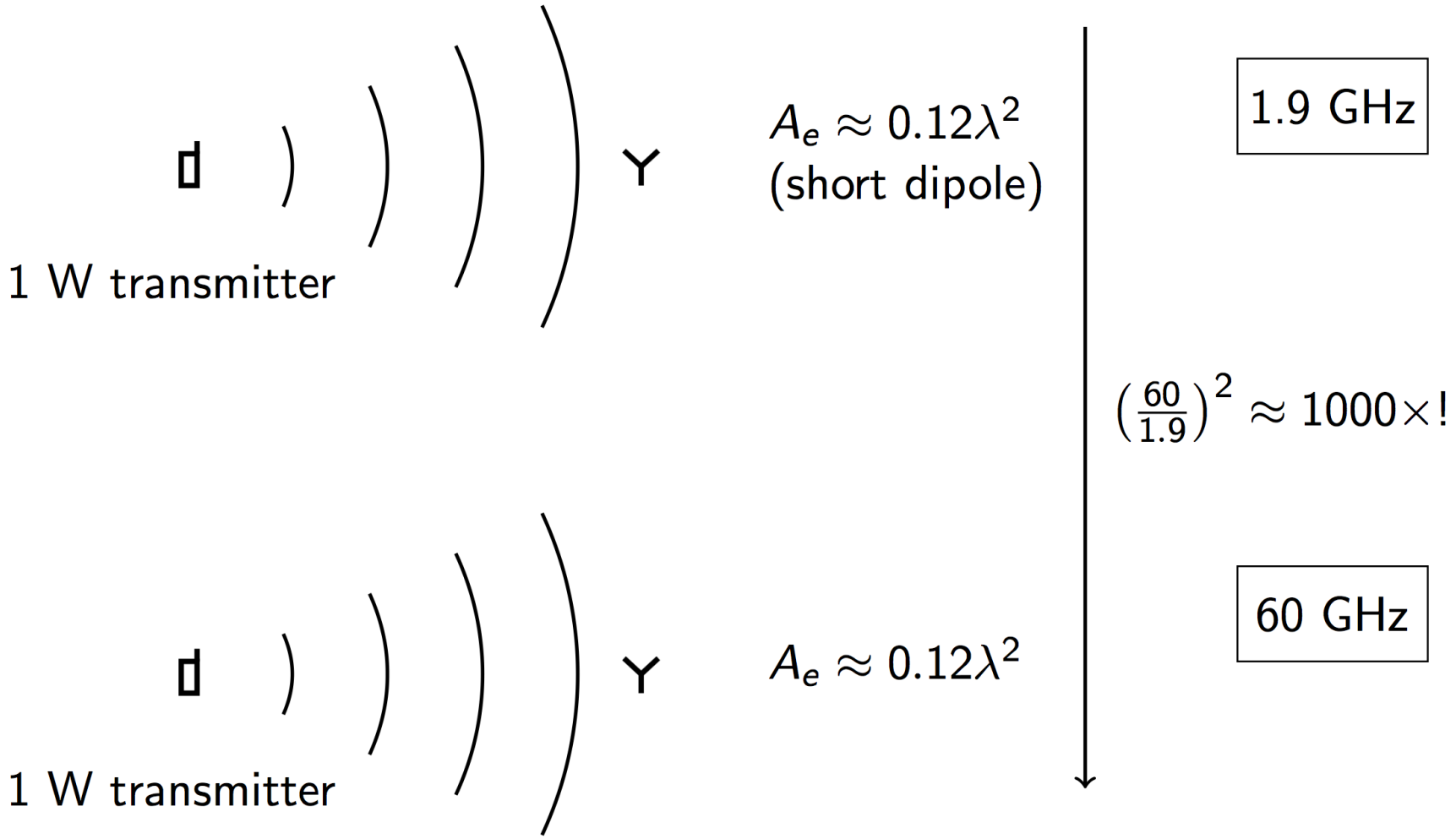
- Resulting max-min optimal SINR:

$$\overline{\text{SINR}} = \frac{\rho}{\sum_{k'=1}^{K}\left[(\boldsymbol{H}^H\boldsymbol{H})^{-1}\right]_{k'k'}/\beta_{k'}}$$

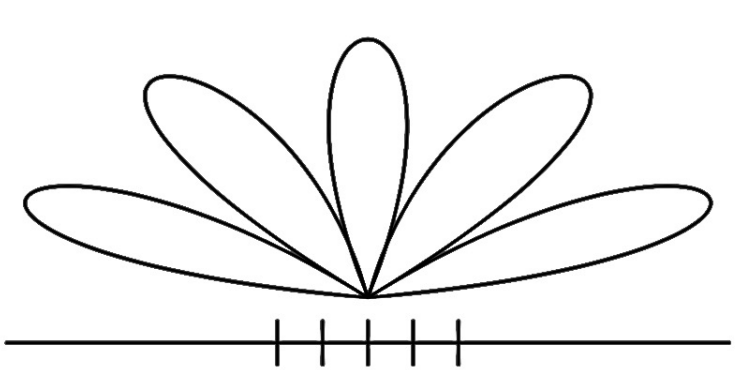
(uplink similarly)



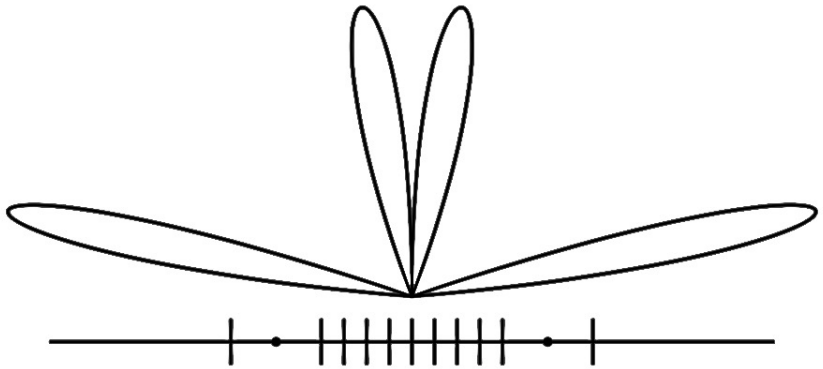
Link budget calculation: 128-antenna PCS → 128,000-antenna mmWave



But more antennas → better orthogonality → less power to invert channel



$M = 5$

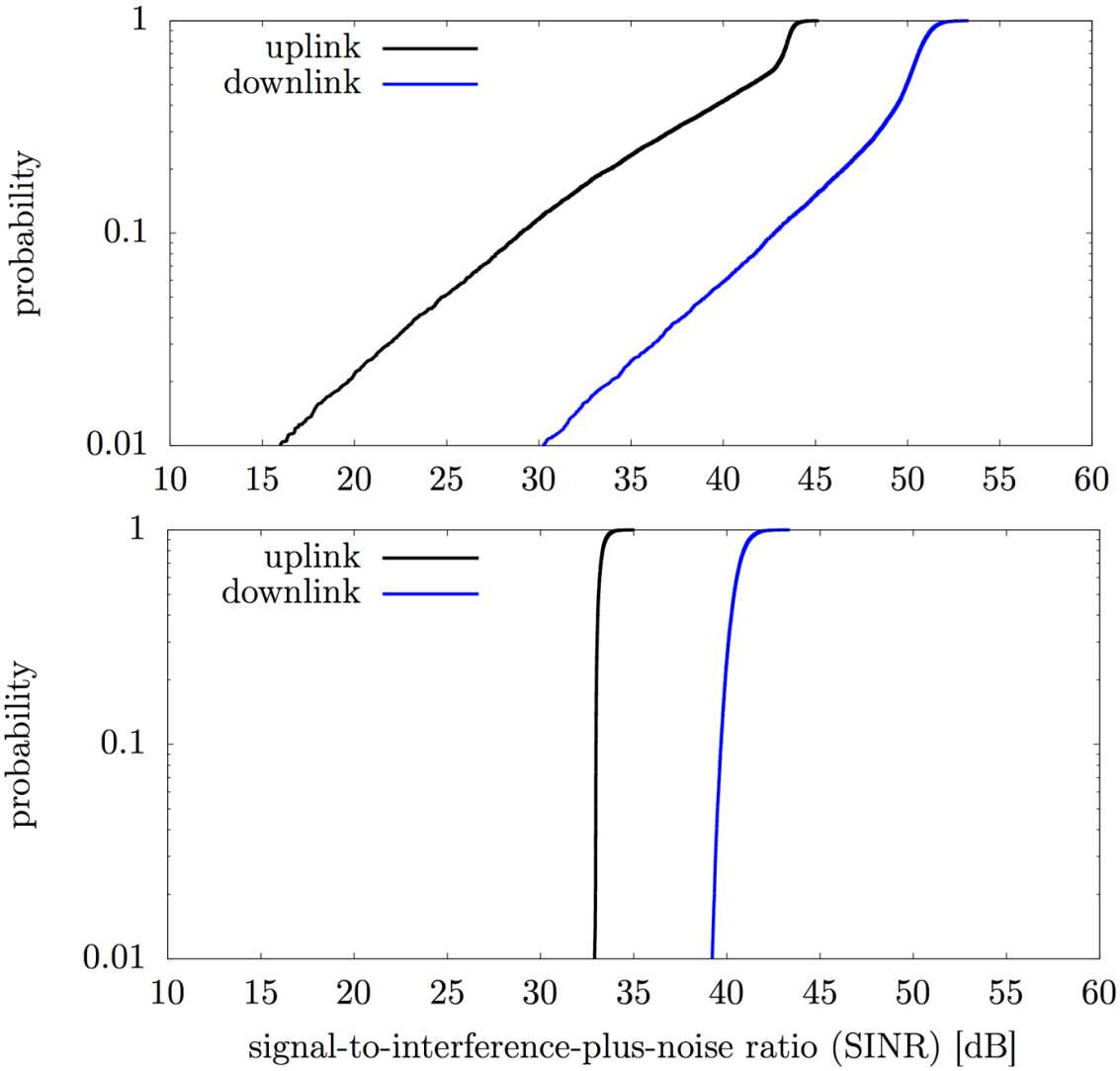


$M = 100$

$$\overline{\mathrm{SINR}} = \frac{\rho}{\sum_{k'=1}^{K} \left[(\boldsymbol{H}^H \boldsymbol{H})^{-1} \right]_{k'k'} / \beta_{k'}}$$

...so much fewer antennas might be needed

128-antenna PCS compares to 10,000-antenna mmWave



PCS
128 antennas
uniform QoS

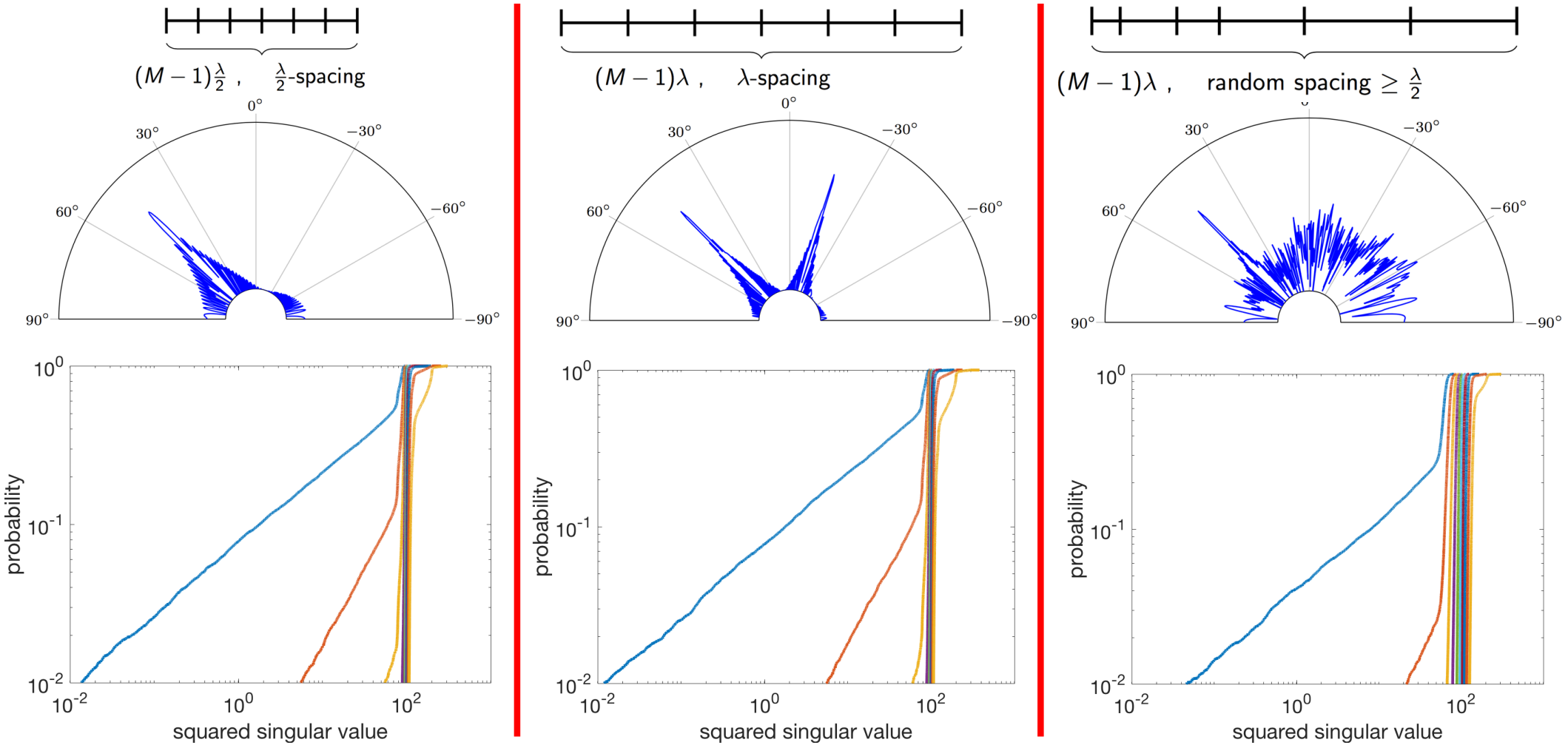
mmWave
10,000 antennas
uniform QoS

arXiv:1702.06111

All arrays are physically rather compact

	Number of antennas		Array diameter (meter)	
95%-likely SINR	PCS	mmWave	PCS	mmWave
10 dB	58	370	1.5	0.29
20 dB	100	853	2.5	0.68
30 dB	177	5100	4.4	4.1

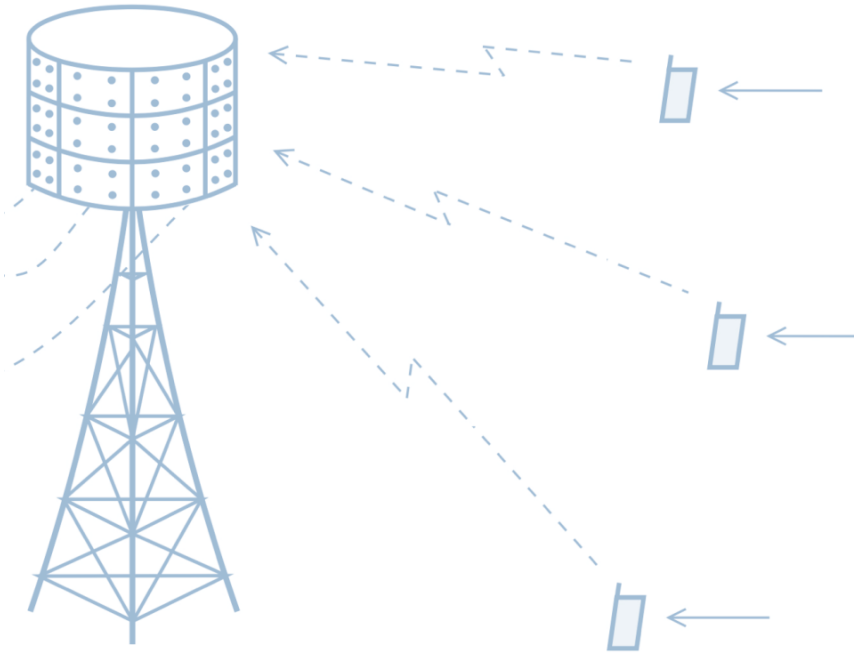
The array geometry does not really matter



Conclusion

10,000-antenna mmWave might compare to 128-antenna PCS,

in static line-of-sight



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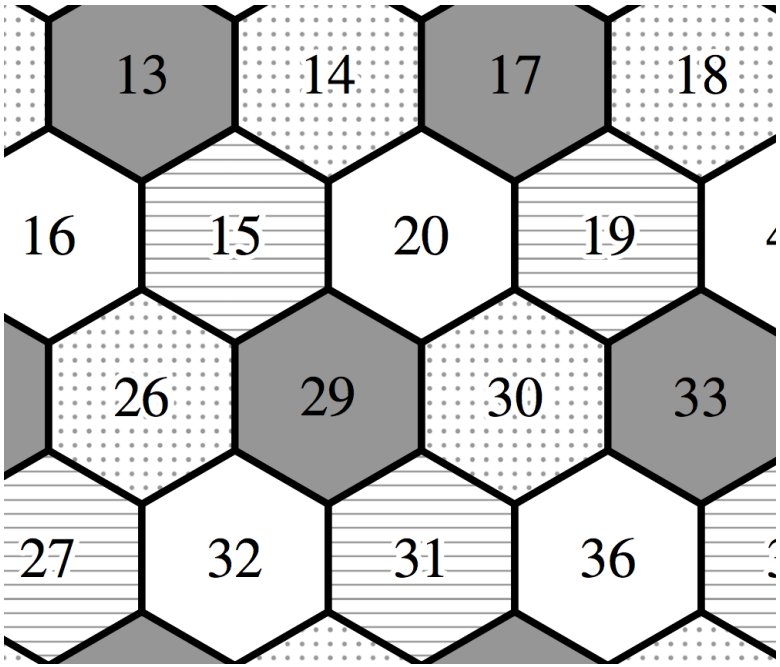
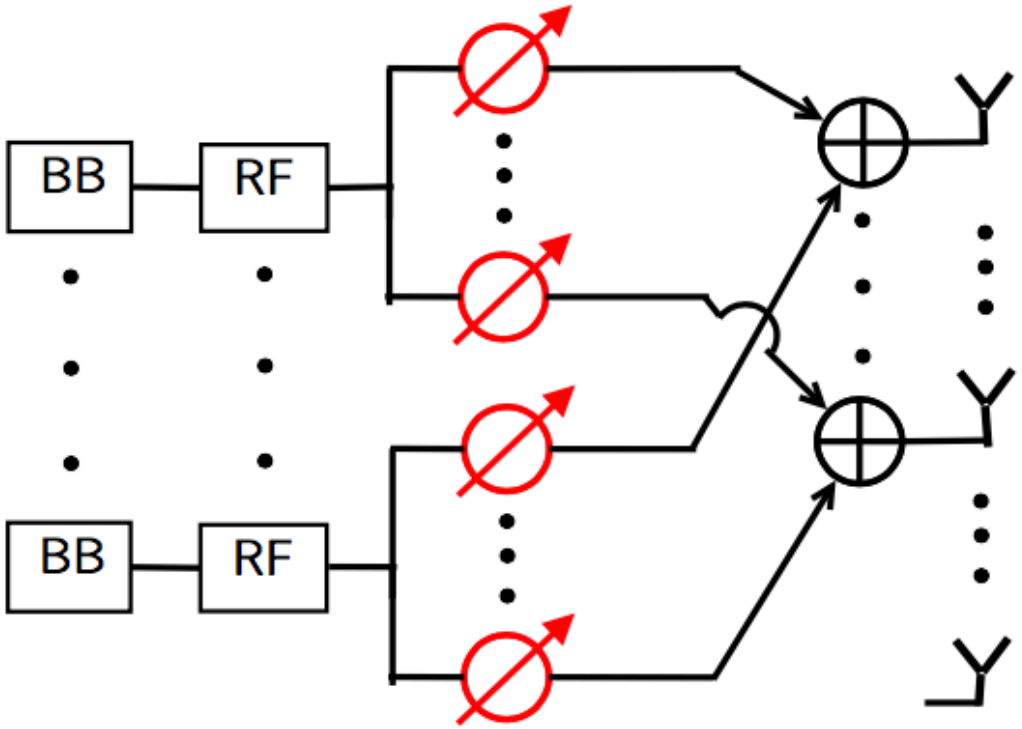
Question: will blocking at mmWave require a sparse frequency reuse?

wood (3 cm):	5-10 dB
human body:	20-35 dB
window (single):	2-3 dB
window (double):	10-15 dB
window (coated):	>40 dB
brick wall:	“∞”



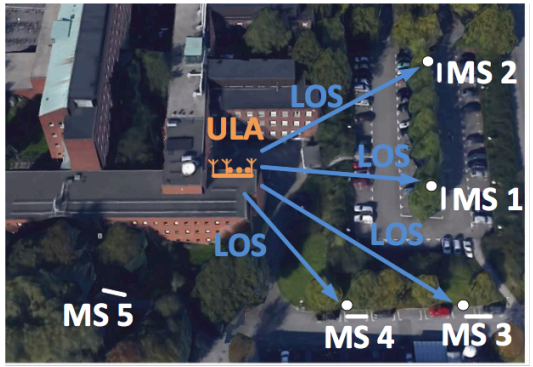
Question: in mmWave bands, can hybrid beamforming help?

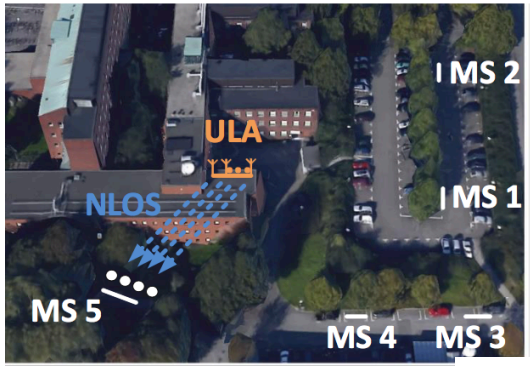


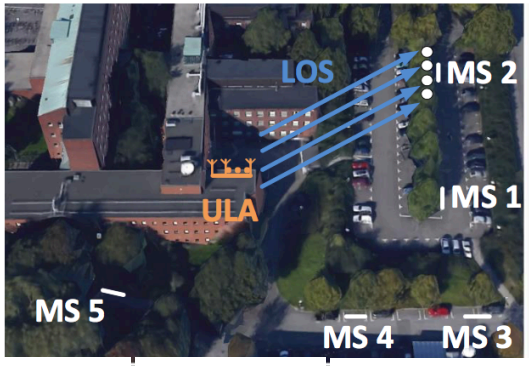
Less electronics?

Even 16-fold reduction yields 10,000 / 16 = 625 !

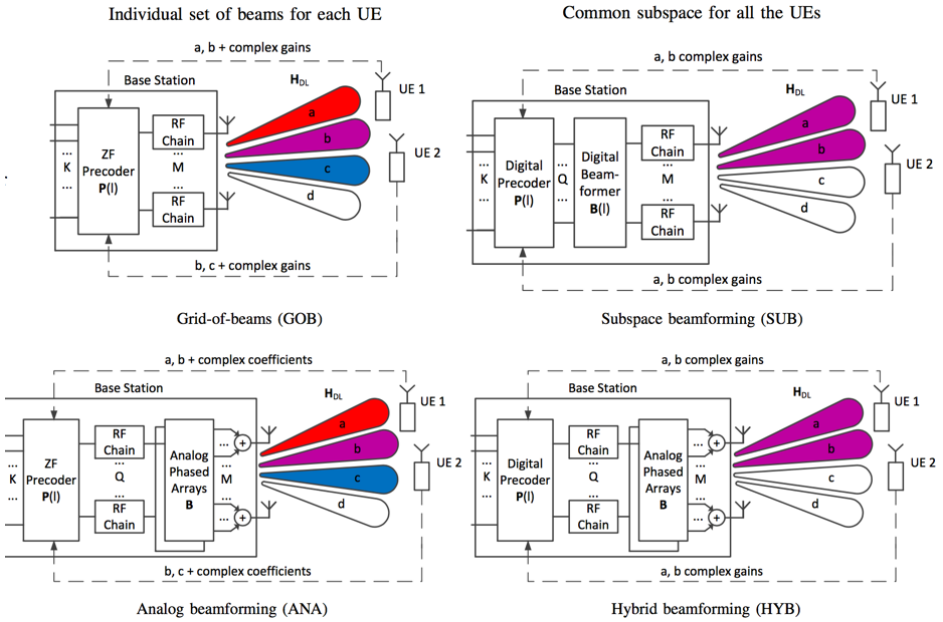
From measurements: in PCS bands, hybrid beamforming is not effective

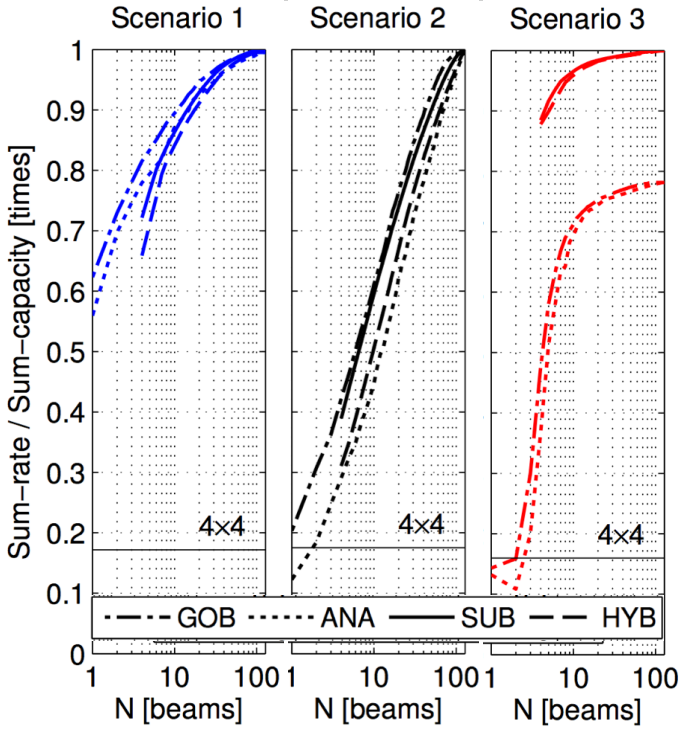




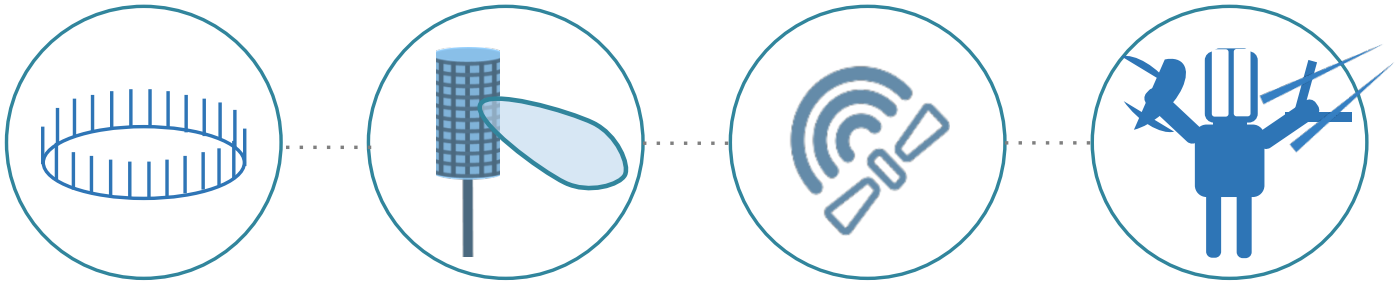


2.6 GHZ
128 ant.
linear array





J. Flordelis, F. Rusek, F. Tufvesson, E.G. Larsson, O. Edfors, arXiv: 1704.00



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