

Google Access

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The Heterogeneous Future

Platforms: satellite • HAPS • balloon • tower • rooftop • street furniture • car • people

Uses: IoT • mobile • fixed • chatting • browsing • streaming • gaming • VR

Technologies: cellular • “5G” • Wi-Fi • P2P • MIMO • mmWave

Regulatory: licensed • shared • lightly licensed • unlicensed



Trends

Heterogeneity

Billions more connected

Exponential data consumption

Incremental spectral efficiency gains

Solutions

Seamlessness

“Densification”

Spectrum





mmWave



Line of sight (ish)

rain • walls • foliage • O2

Need directional antennas

Range?

Spectrum (lots)

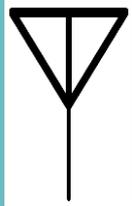
Natural interference control

Well suited to unlicensed and
lightly licensed operation

Range?

Sorry ... Math

The Fris Equation



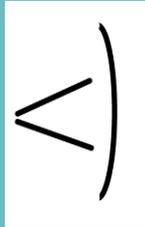
Normal form:

For the same antenna gain, propagation is worse with higher frequency



Alternate form:

For the same antenna size, propagation is better with higher frequency



$$\frac{P_r}{P_t} = G_t G_r \left(\frac{c}{4\pi R F} \right)^2$$

$$\frac{P_r}{P_t} = A_t A_r \left(\frac{F}{R c} \right)^2$$

mmWave Summary

Bountiful spectrum

Will support a broad range of use cases

Very short range • mobile • long range p2p

