Ingegneria delle Telecomunicazioni

Satellite Communications

2. Does it work? Even with smartphones?

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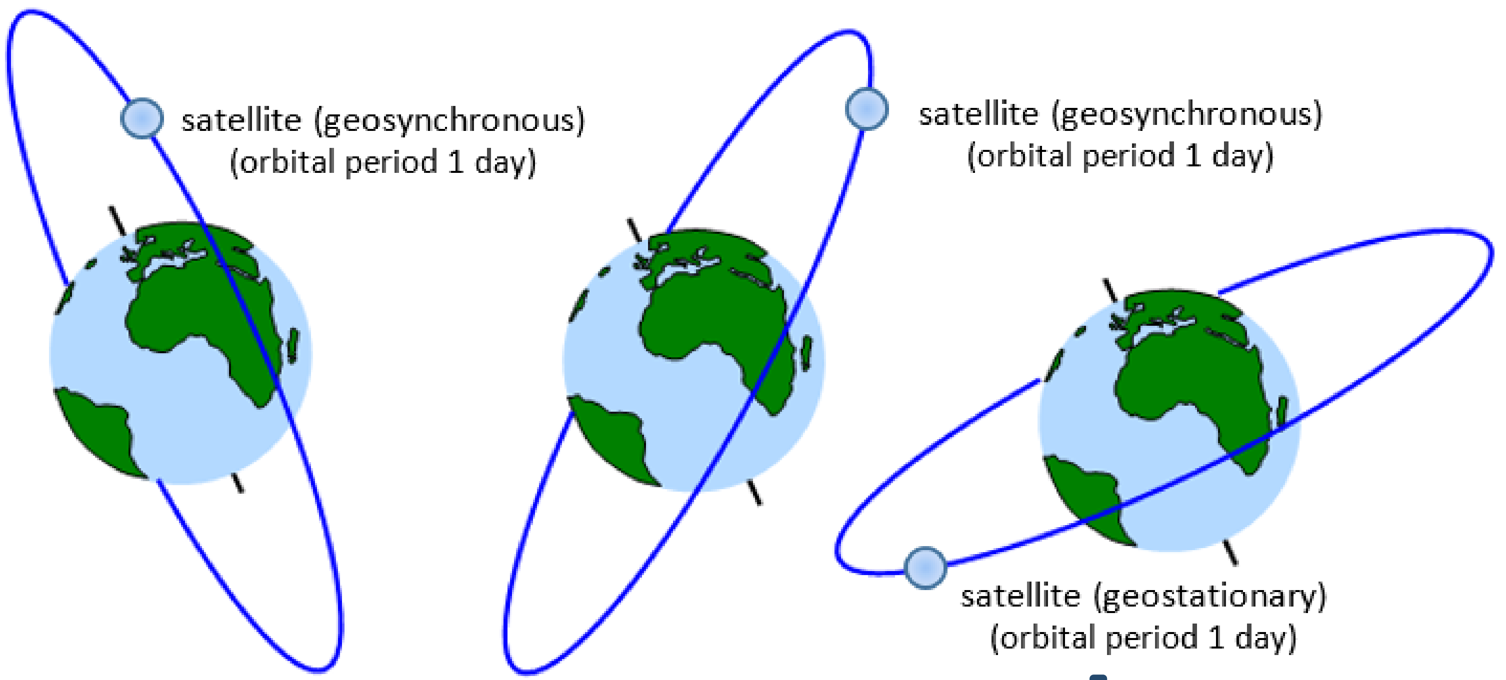
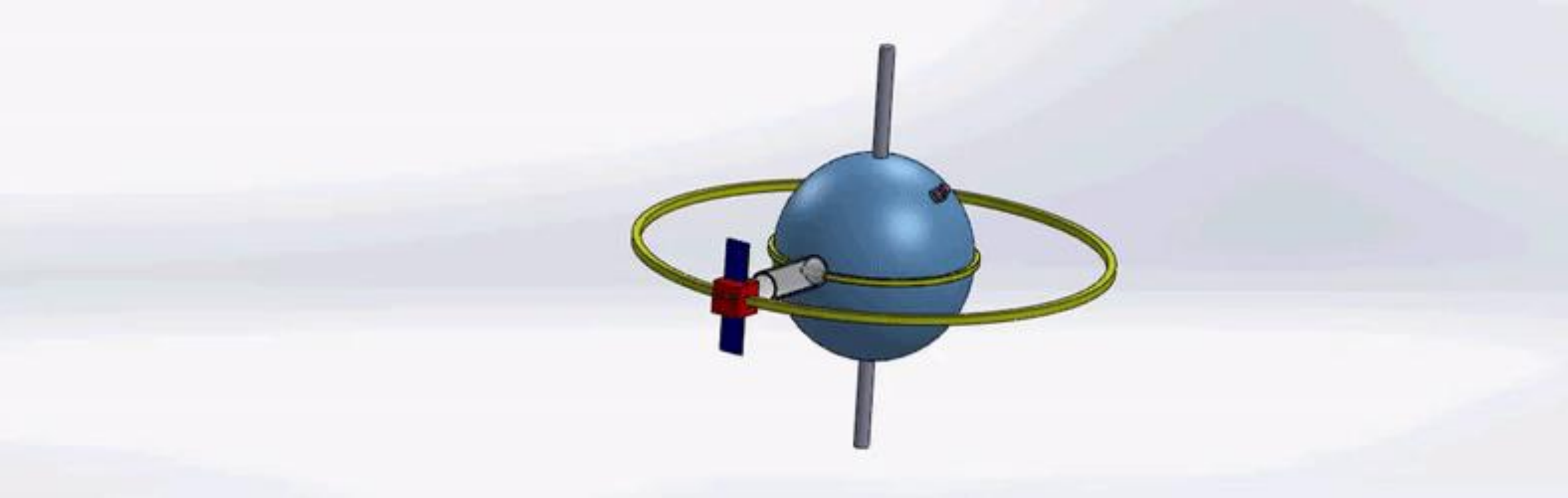
Geosynchronous & Geostationary Orbits



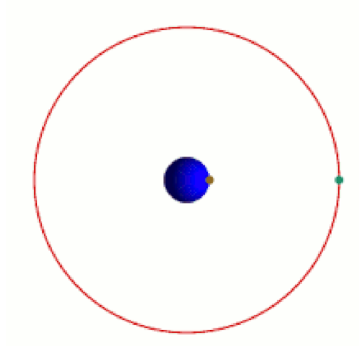
Geostationary Satellite – the MOA Communication Satellites



Computation of GEO Height

Gravity Force=Centrifugal Force

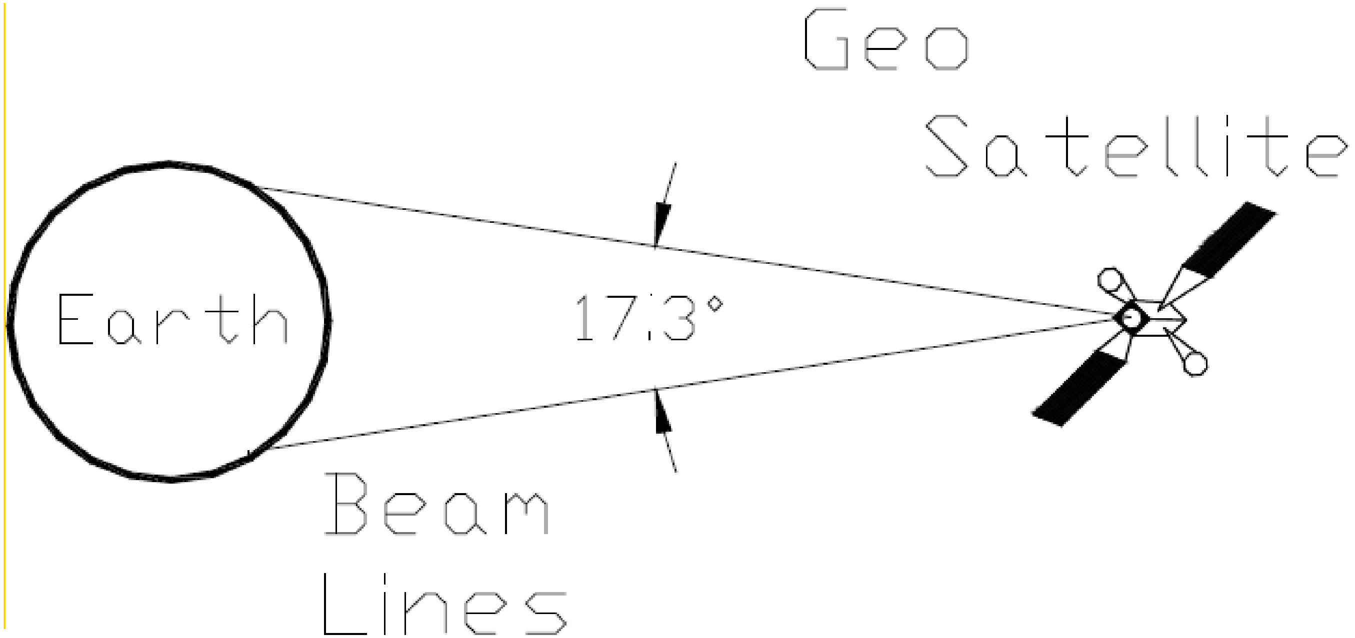
$$G\frac{mM}{r^2} = m\omega^2 r$$



- (Unknown) Satellite Height above ground *h*
- (Equatorial) Earth Radius: *R*=6,378 km
- Distance from the center of the Earth *r*=*R*+*h*
- Universal Gravitational Constant *G*=6.674 x 10^{-11} Nm^2/kg^2
- Geosynchronous angular speed $\omega = 2\pi$ /(24 x 3600) rad/s
- Earth Mass *M*=5.97 x 10^{24} kg
- Standard gravitational parameter μ=GM= 3.99 x 10^{14} m^3s^{-2}

$$h = \sqrt[3]{\frac{GM}{\omega^2}} - R =$$ 42,235-6,378=**35,864 km**

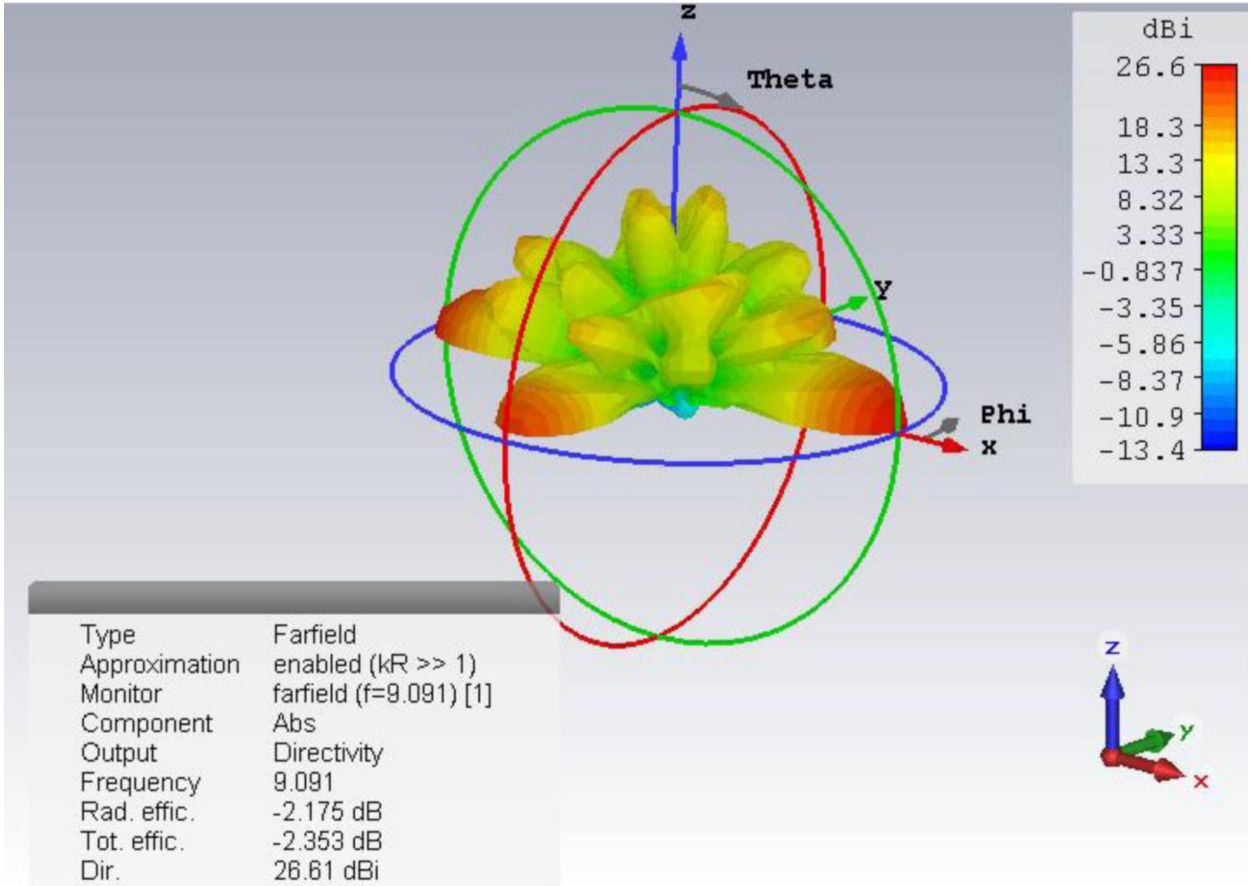
It's very far !



Does the satellite signal get to Earth loud enough (and vice-versa?)

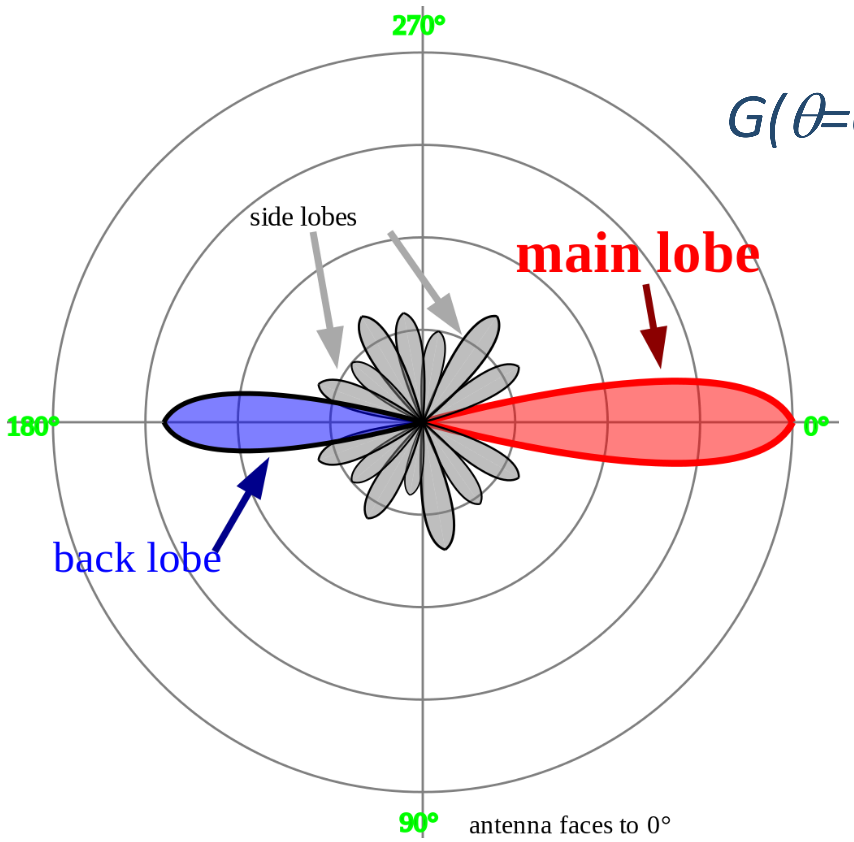
Antenna Radiation Pattern 1/3

$G(\theta,\phi)$ describes the intensity of the far field radiated by the antenna as the angle of view changes: ϕ on the horizontal plane (azimuth), θ on the vertical plane (elevation)



Antenna Radiation Pattern 2/3

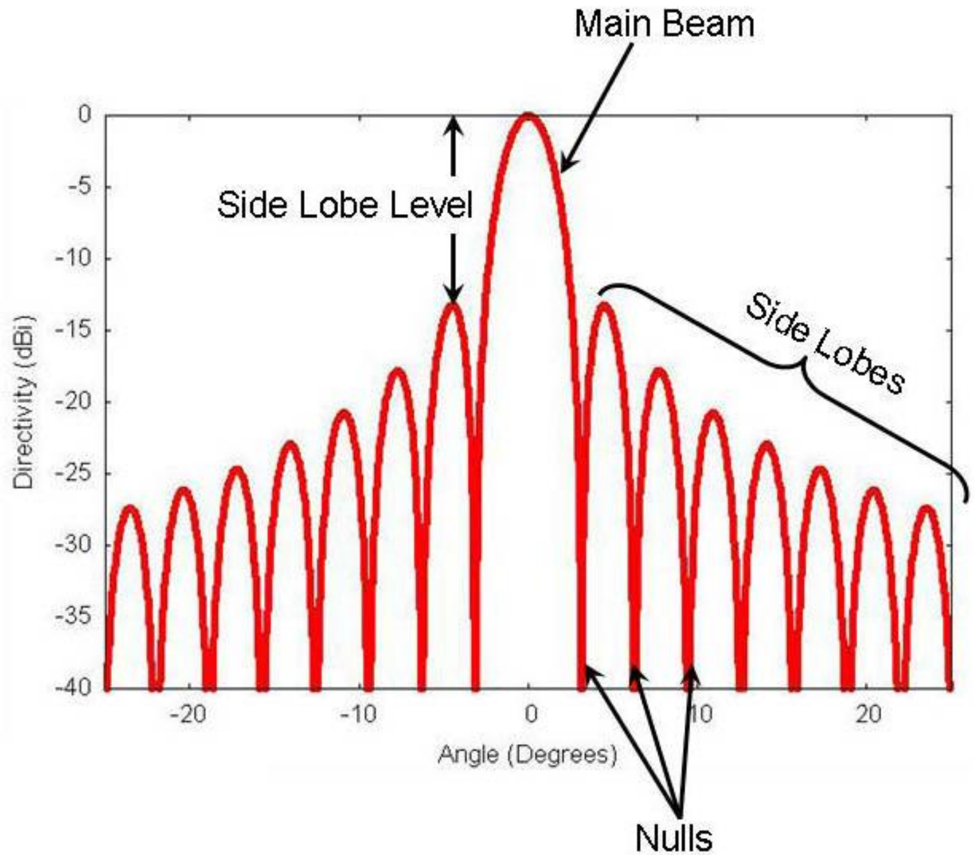
Usually we just use (represent) a cut of the pattern on either the H o the V plan, represented on a polar chart:



$G(\theta=0,\phi)$

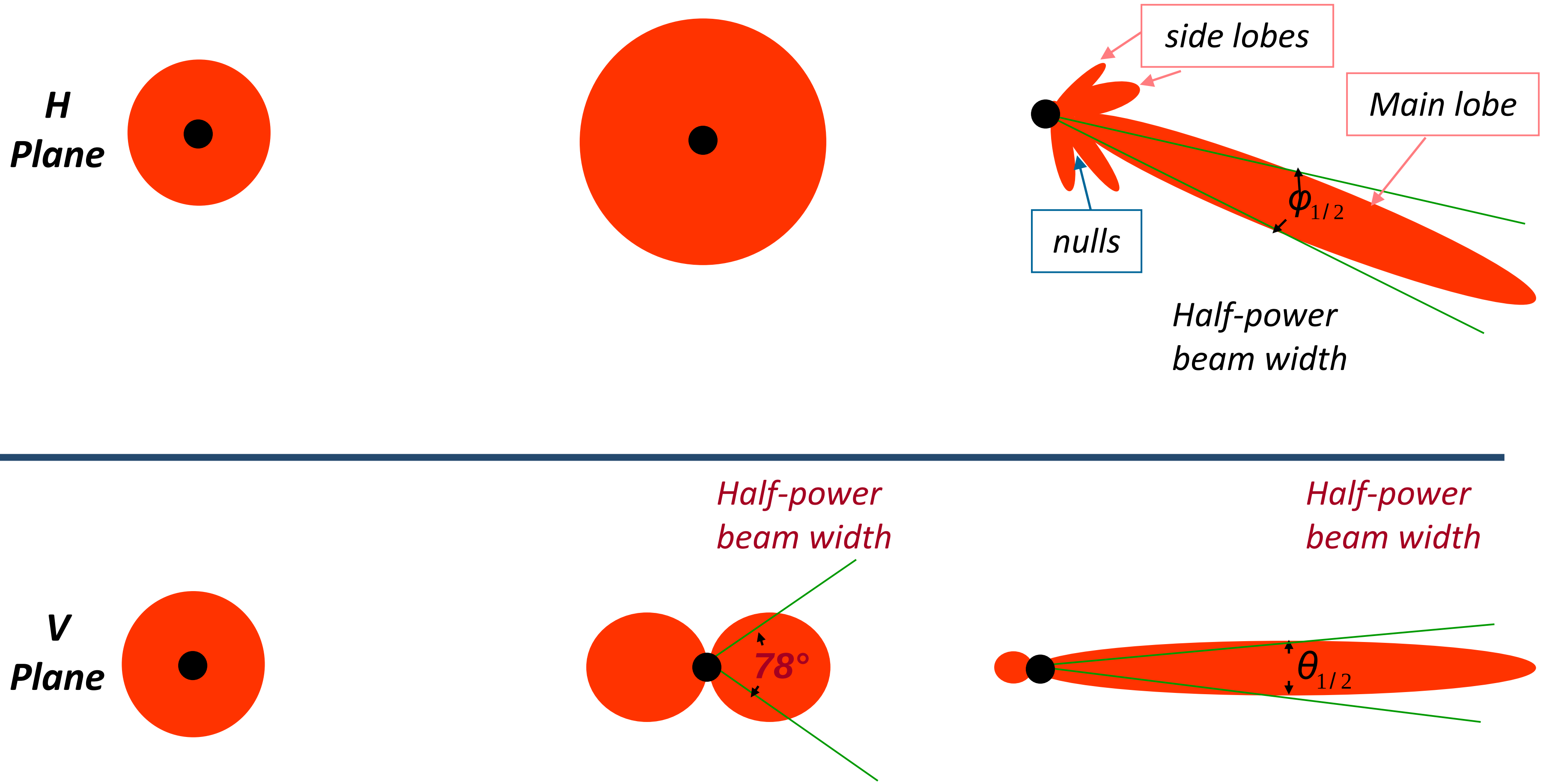
Antenna Radiation Pattern 3/3

- We can also plot the same cut $G(0,\phi)$ as a function of ϕ on a Cartesian rather than polar chart



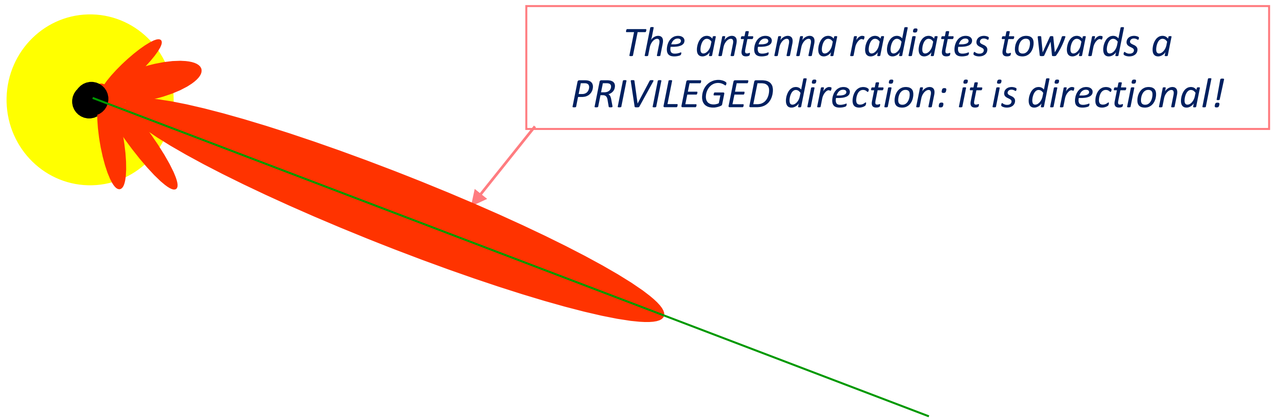
Examples

Ideal Isotropica	λ/2-Dipole	DIRECTIVE Antenna



During *transmission*, the radiation pattern determines the ***gain*** of the antenna in a certain direction of radiation, i.e., the measure of how much in that direction the radiated power at distance *r* (or, the power flux *S* per unit area) is greater than that of an ideal isotropic antenna:

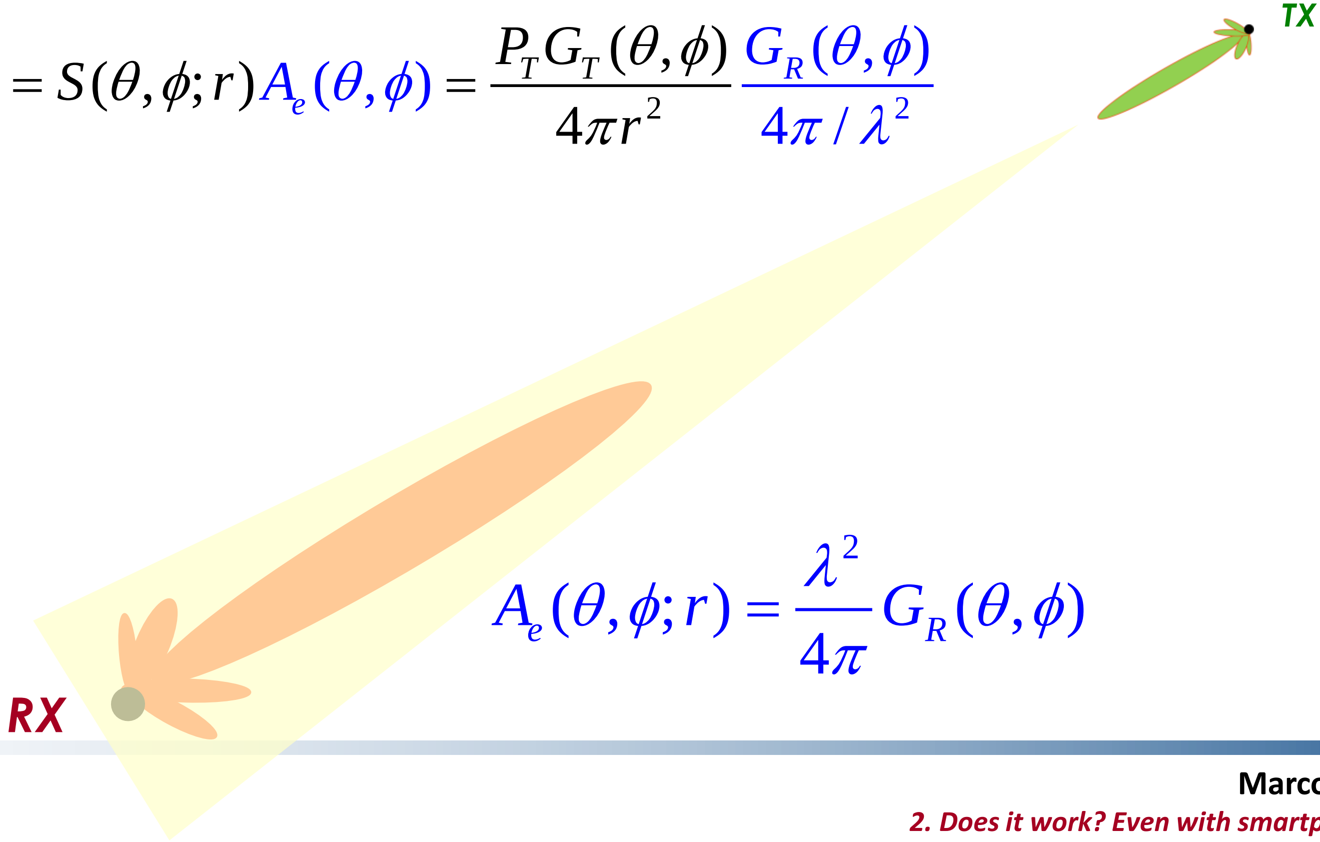
$$S(\theta,\phi;r) = G_T(\theta,\phi)\frac{P_T}{4\pi r^2}$$



Effective Area

Reciprocally, the radiation pattern establishes the directivity of the antenna in *reception* through the concept of ***equivalent area***, i.e., the measurement of how much power the antenna is able to collect in the main direction with respect to that collected by an ideal isotropic antenna:

$$P_R(\theta,\phi;r) = S(\theta,\phi;r)A_e(\theta,\phi) = \frac{P_T G_T(\theta,\phi)}{4\pi r^2}\frac{G_R(\theta,\phi)}{4\pi/\lambda^2}$$



$$A_e(\theta,\phi;r) = \frac{\lambda^2}{4\pi}G_R(\theta,\phi)$$

Example: Parabolic Antenna

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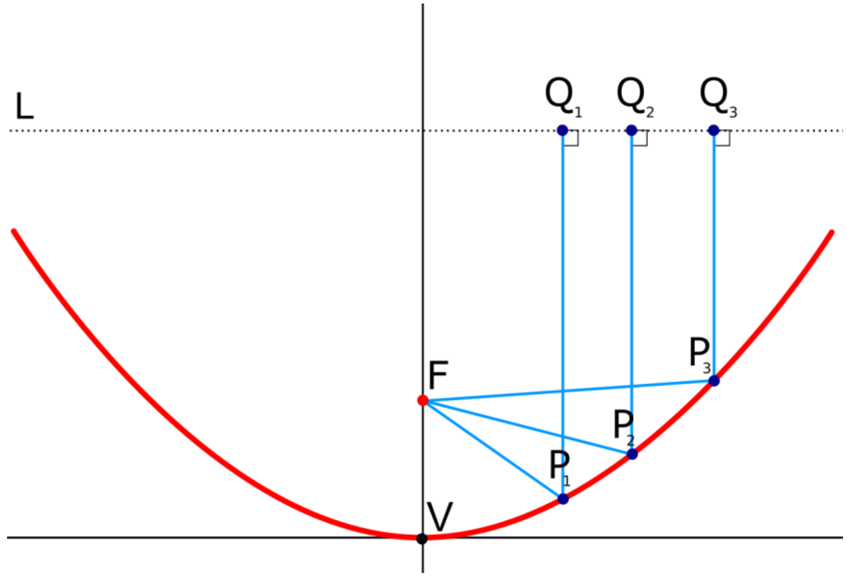
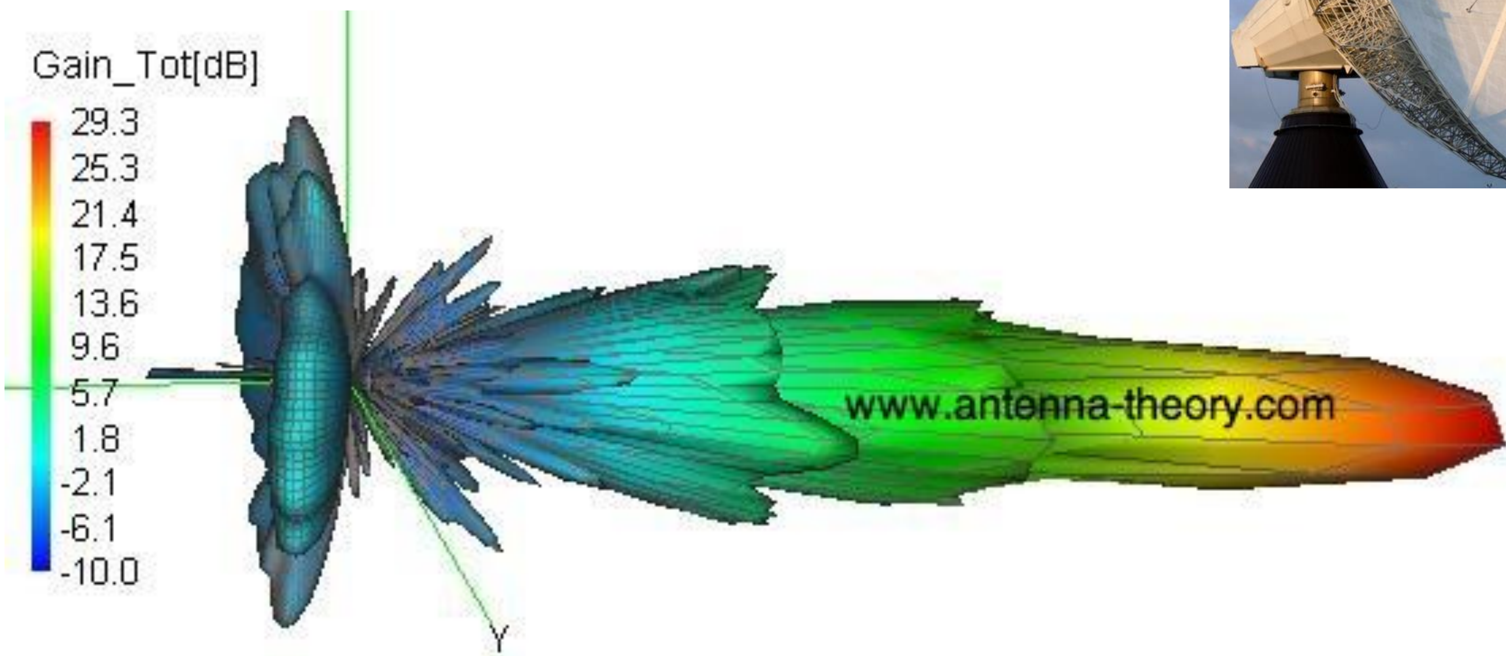
Direzione del lobo principale

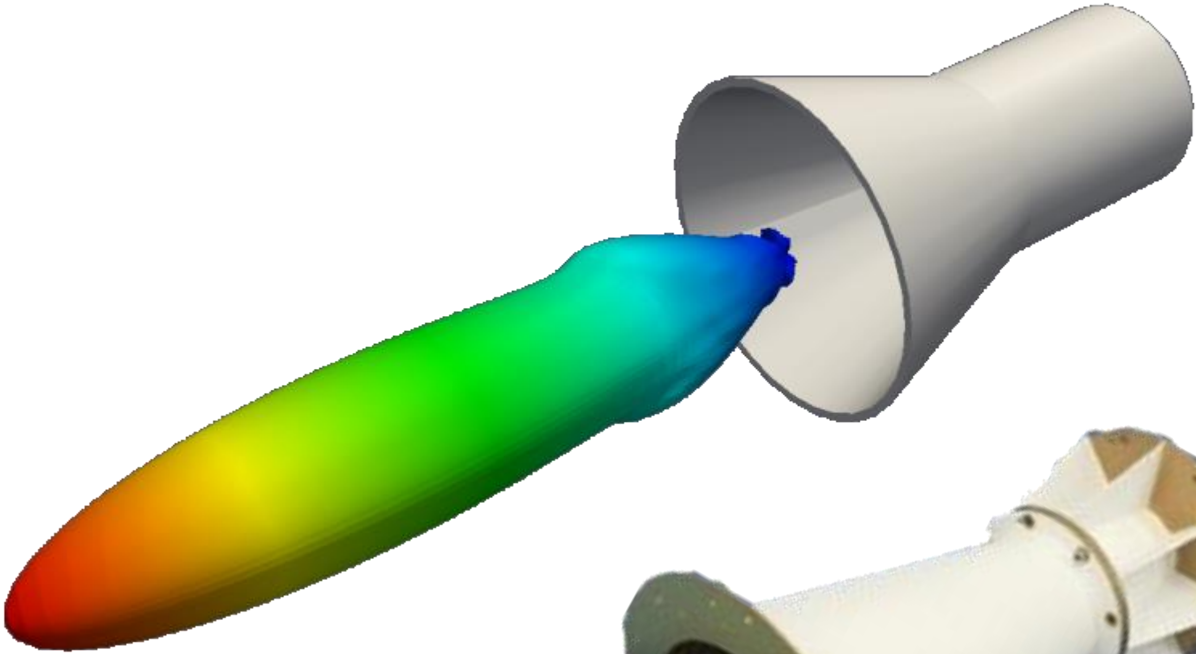


$$A_e = 0.5 \div 0.7 A \quad \leftrightarrow \quad G = 6 \div 9 \frac{A}{\lambda^2}$$

Example: Parabolic Antenna



Horn Antenna



Satellite Communications
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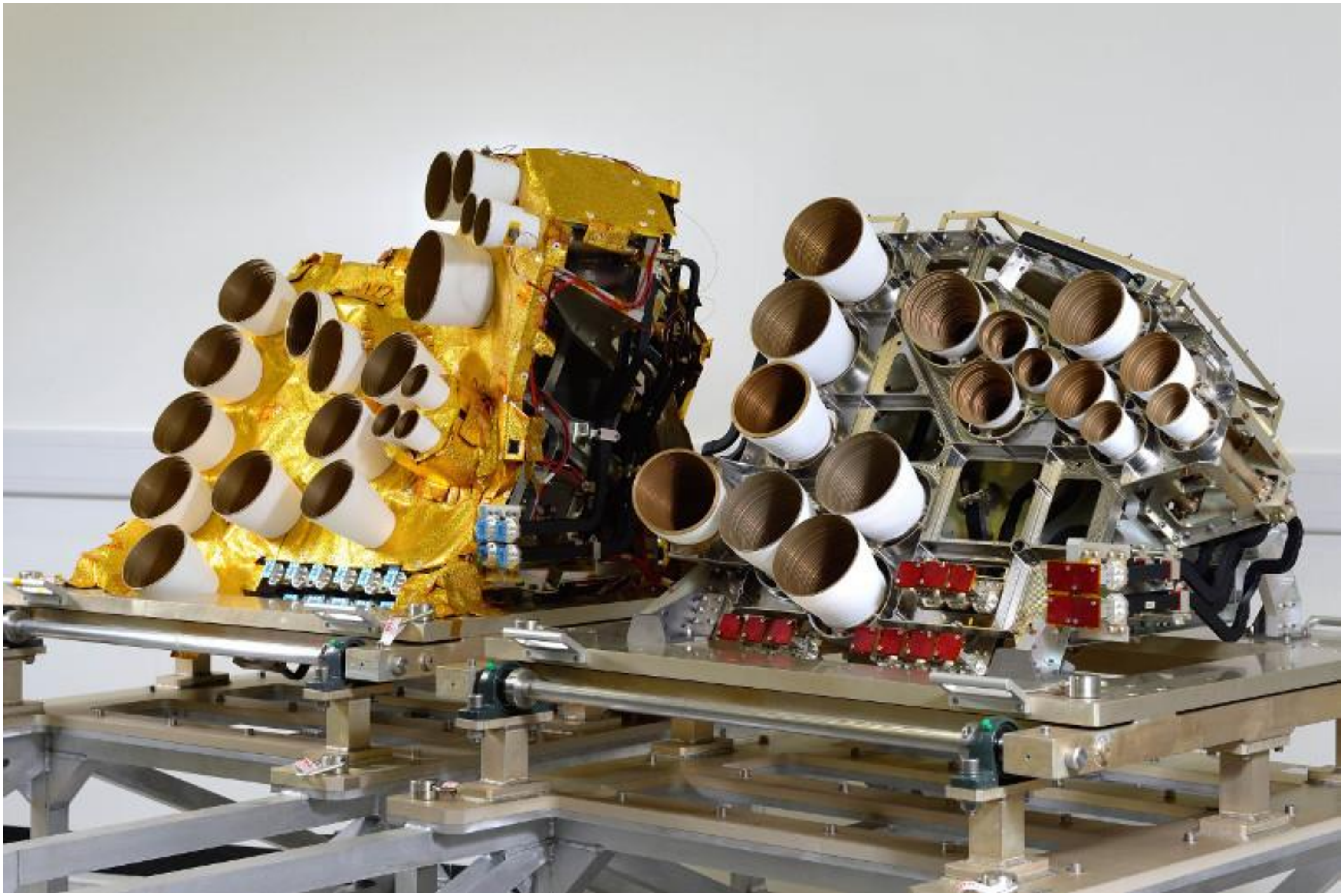
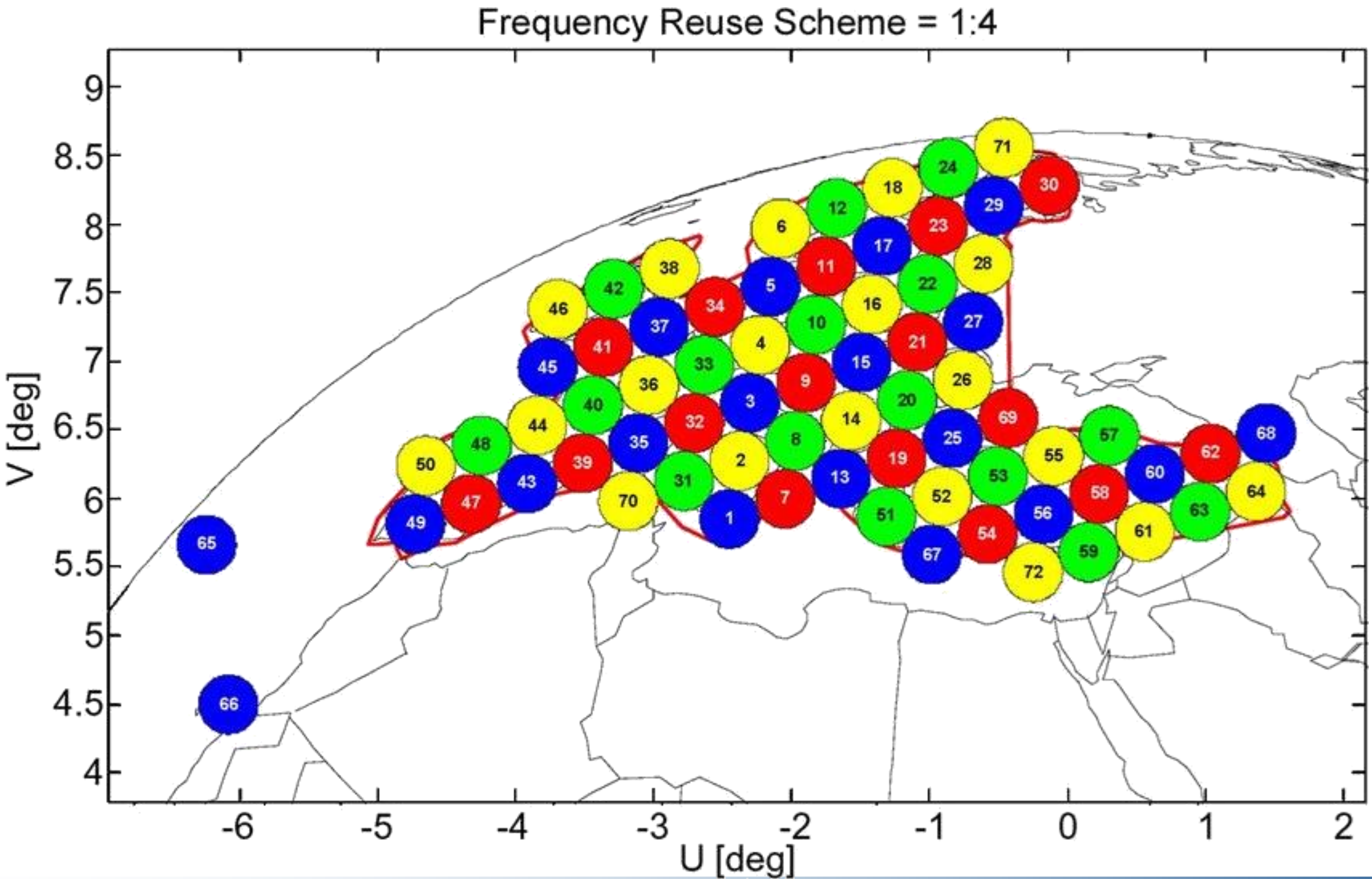
Multibeam Antenna…



…and its footprint



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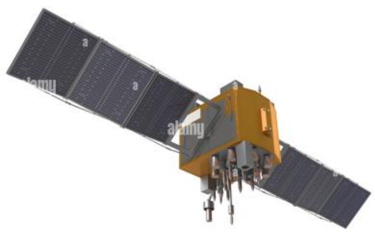
Link Budget 1 – Received power

$$P_R = P_T \frac{G_T G_R}{(4\pi h / \lambda)^2}$$

$$P_R\big|_{dBW} = P_T\big|_{dBW} + G_T\big|_{dB} - L\big|_{dB} + G_R\big|_{dB} = P_T\big|_{dBW} + G_T\big|_{dB} - 20\log\left(\frac{4\pi h}{\lambda}\right) + G_R\big|_{dB}$$



GPS satellite

- Satellite RF power: P_T=25.6 W=14 dBW
- TX Antenna gain (max): G_T= 12 dB (dBi)
- *EIRP* = $P_{T\ (dB)}$ + $G_{T\ (dB)}$ =26 dBW (about 500 W equivalent)
- Satellite altitude: r=20,200 km
- Free-Space Loss @ f_0=1575 MHz: $L=(4\pi h)^2/\lambda^2$ $= (4\pi h f_c)^2 / c^2$= 182 dB
- RX antenna gain (smartphone): G_R =-1 dBi
- Received Power at RX antenna output: $C=EIRP-L+G_R$=-157 dBW=0.2 fW (2. 10^{-4} pW)=0.1 μV in 50 Ω

Link Budget 2 - Noise Computation

- P_R is also called C (carrier power)
- k_B= Boltzmann's constant
- T_n=RX Noise Temperature
- T_b,R_b = bit time, bit rate

$$\frac{E_b}{N_0} = \frac{C\,T_b}{k_B T_n} = \frac{C}{R_b k_B T_n}$$

$$C\,\Big|_{dBW} = EIRP_{dBW} - 20\log\left(\frac{4\pi h}{\lambda}\right) + G_R\Big|_{dB}$$

$$\frac{C}{N_0}\Bigg|_{dBW} = EIRP_{dBW} - 20\log\left(\frac{4\pi h}{\lambda}\right) + G_R\Big|_{dB} - 10\log(k_B T_n)$$

$$\frac{E_b}{N_0}\Bigg|_{dB} = EIRP_{dBW} - 20\log\left(\frac{4\pi h}{\lambda}\right) + \frac{G_R}{T_n}\Bigg|_{dB/K} - 10\log(k_B R_b)$$

TX **Propagation** **RX** **Bit-rate**

Link Budget 3 - E_b/N_0 Computation

- k_B= Boltzmann's constant=1.38 10^{-23} J/K
- T_n=RX Noise Temperature
- T_b,R_b = bit time, bit rate

$$\frac{E_b}{N_0} = \frac{C\,T_b}{k_B T_n} = \frac{C}{R_b k_B T_n}$$

$$\left.\frac{E_b}{N_0}\right|_{dB} = EIRP_{dBW} - 20\log\left(\frac{4\pi h}{\lambda}\right) + \left.\frac{G_R}{T_n}\right|_{dB/K} - 10\log(k_B R_b)$$

- Receiver Noise Temperature: T_n= 290 K (no antenna noise/RX noise figure)
- Resulting Thermal Noise level: $N_0 = k_B T_n$= -204 dBW/Hz
- RX Antenna Gain (handheld): G_R = -1 dB (dBi) , G_R / T_n = -25.6 dB/K
- Receiver C/N_0 ratio: $C/N_0 = C + G_R - N_0$ =47 dB-Hz.
- R_b = 50 bit/s , $10\log(k_B R_b)$=-212 dB/K
- E_b/N_0 ratio: 26-182-26+212 =30 dB (VEEEERY Good)

E_b/N_0 Computation

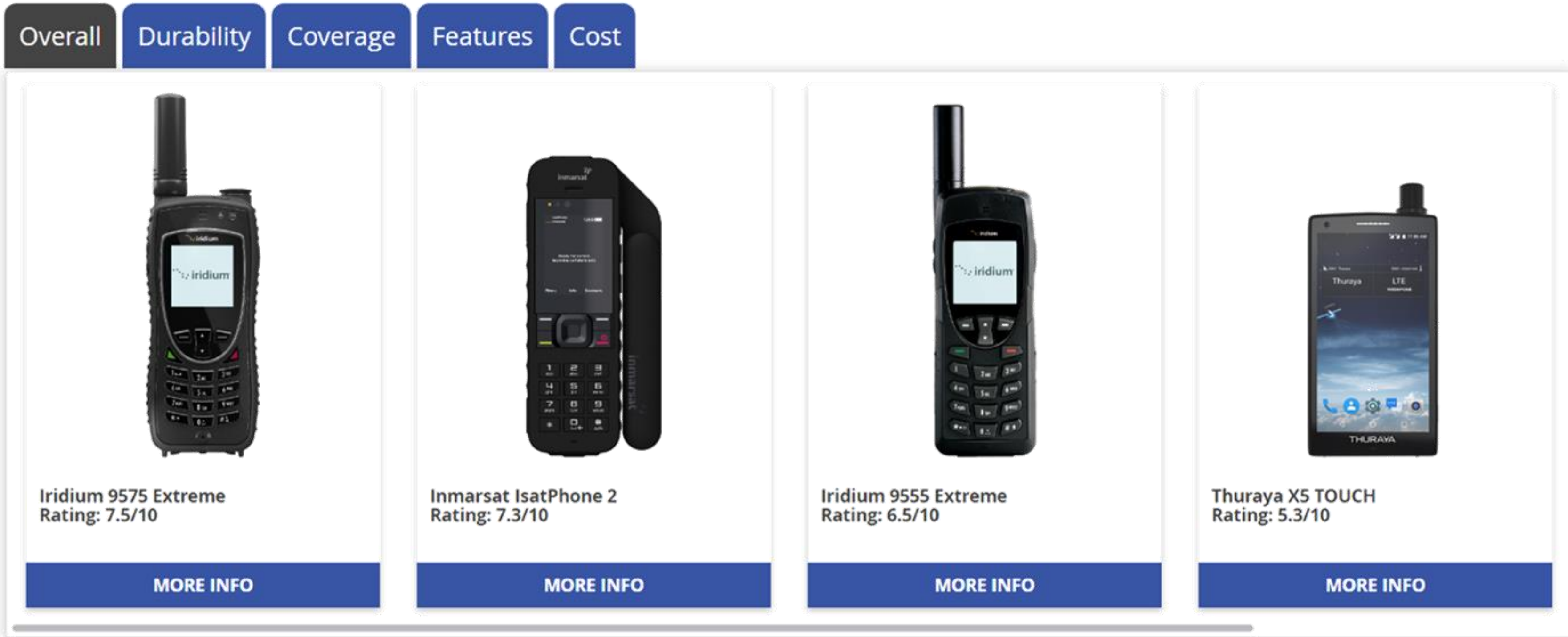
- k_B= Boltzmann's constant=1.38 10^{-23} J/K
- *T*
- *T*

$E_b \quad C\,T_b \quad C$

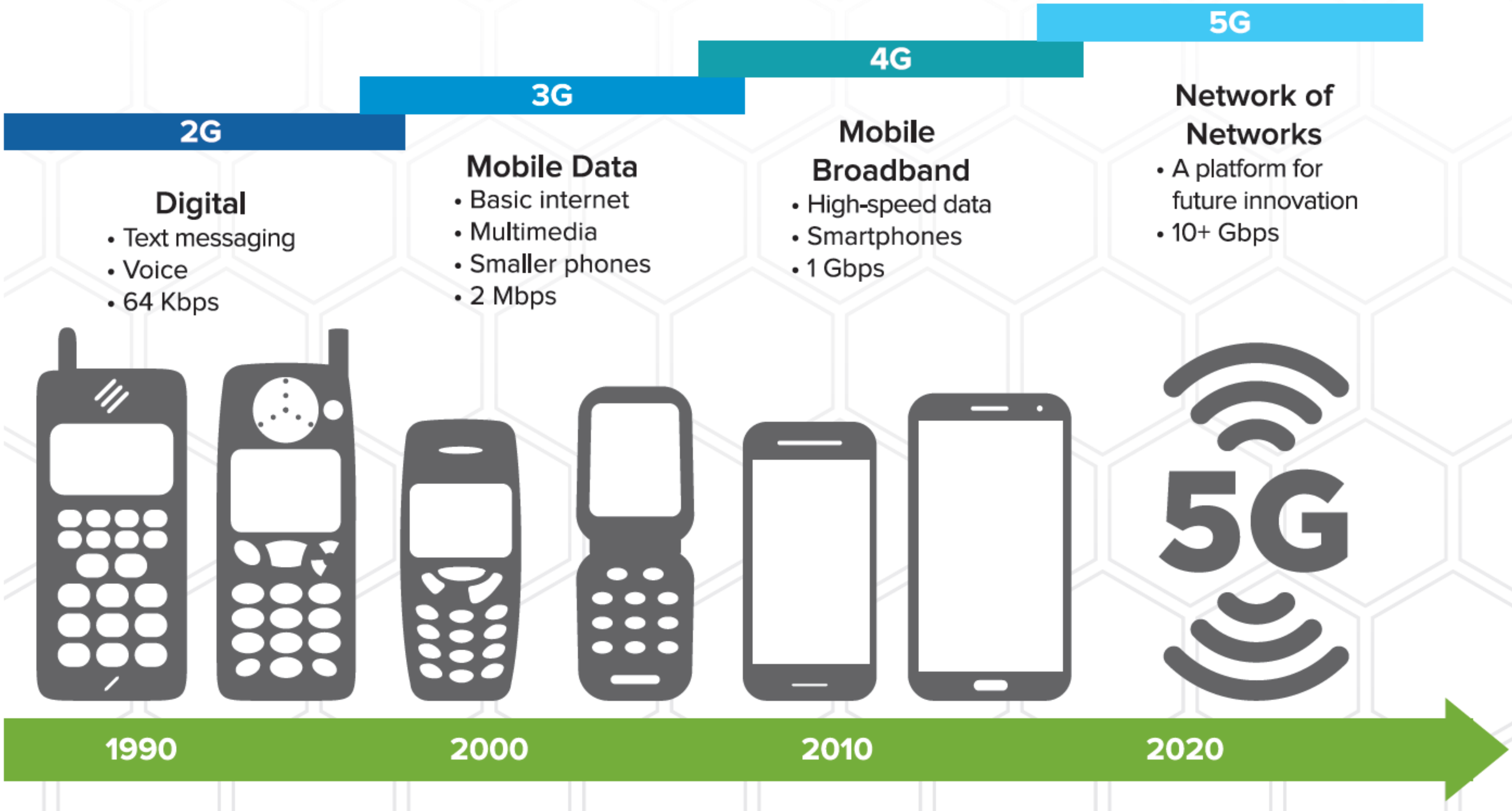
– Receiver C/N_0 ratio: $C/N_0 = C + G_R - N_0$ =47 dB-Hz.

Satellite Handheld User Terminals

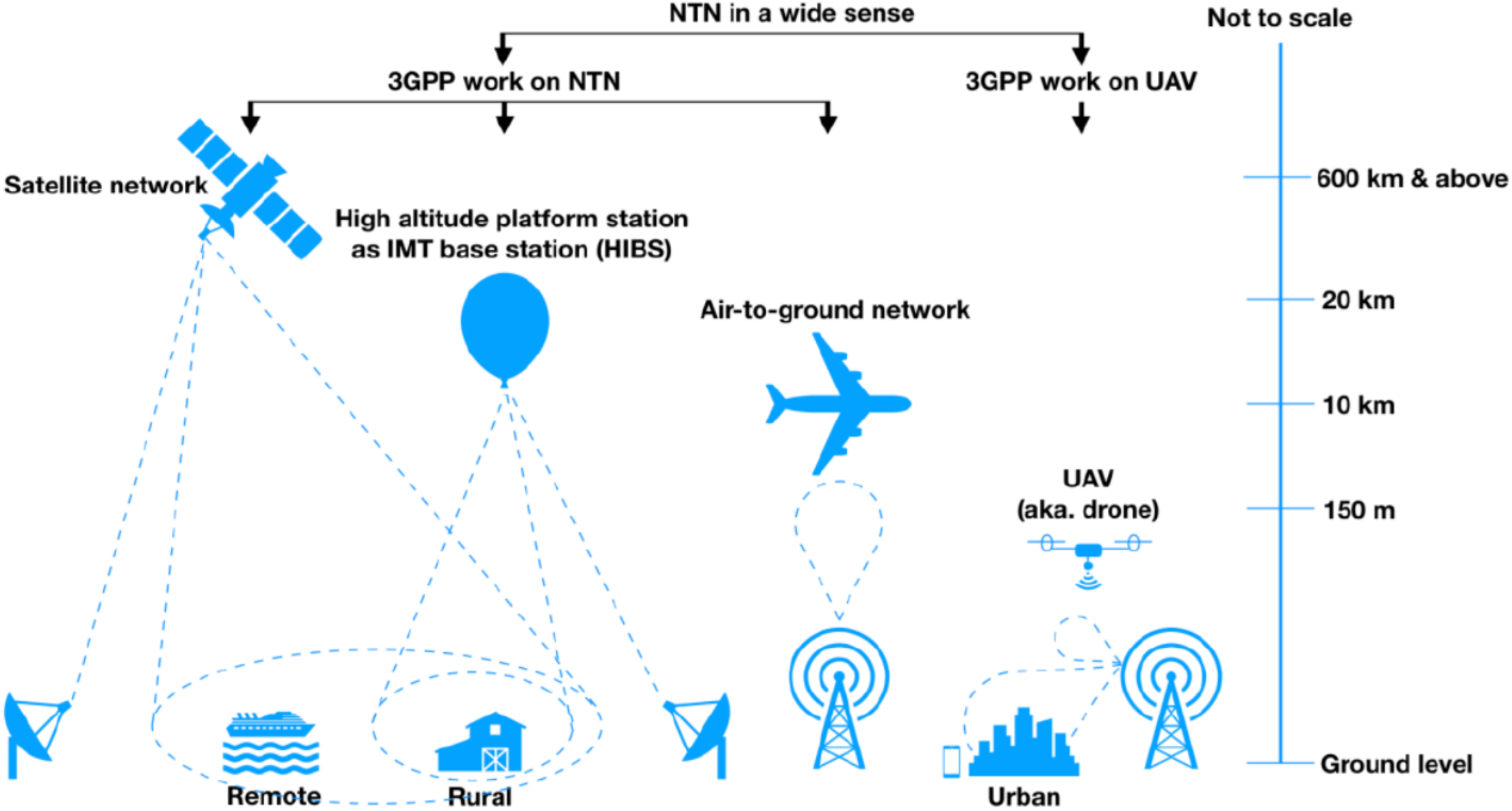
- **Mobile Satellite Communications traditionally require dedicated, expensive terminals and subscriptions**



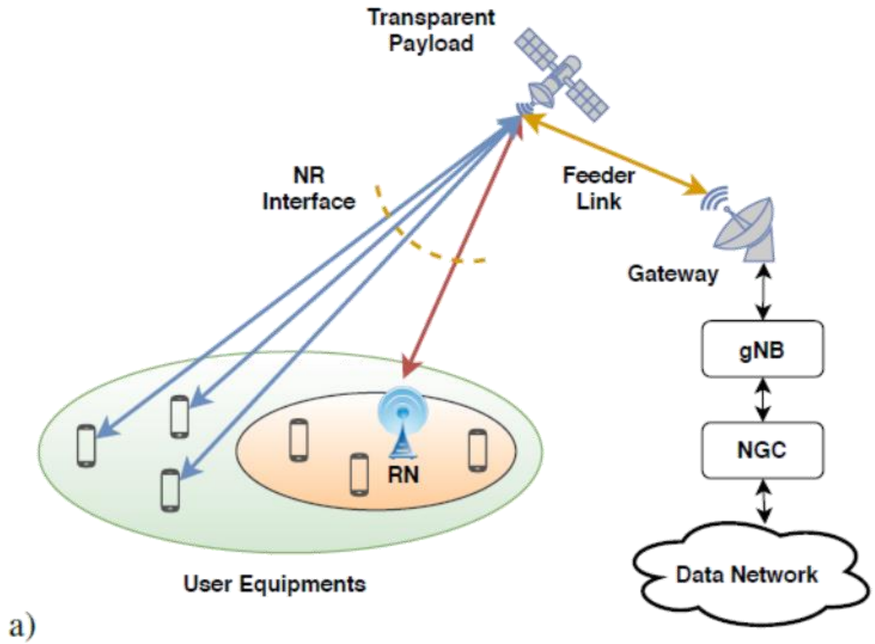
Generations of Cellular Networks



Non-Terrestrial-Networks



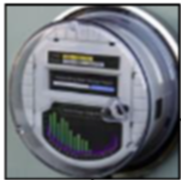
Basic Integrated Architecture



5G Profiles

Enhanced Mobile Broadband (eMBB)

- 10-20 Gbps peak
- 100 Mbps whenever needed
- 10000x more traffic
- Macro and small cells
- Support for high mobility (500 km/h)
- Network energy saving by 100 times



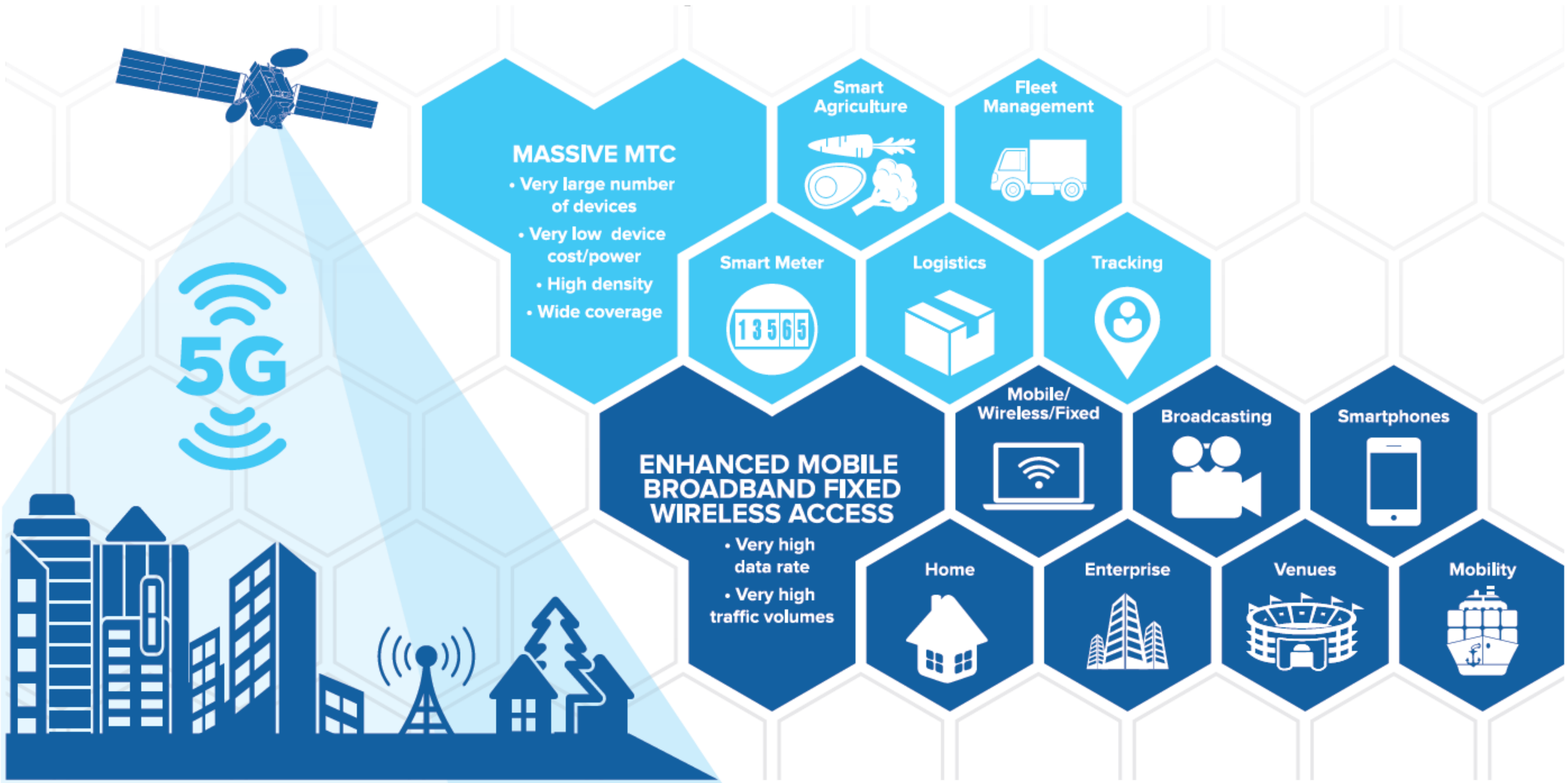
Massive Machine Communication (mMTC)

- High density of devices ($2x10^5$ - $10^6/km^2$)
- Long range
- Low data rate (1 - 100 kbps)
- M2M ultra low cost
- 10 years battery
- Asynchronous access

Ultra Reliability and Low Latency (URLLC)

- Ultra responsive
  - <1 ms air interface latency
  - 5 ms E2E latency
- Ultra reliable and available (99.9999%)
- Low to medium data rates (50 kbps - 10 Mbps)
- High speed mobility

The role of NTNs in 5G



Kepler's Laws

1. The planets move in a plane; the orbits described are ellipses with the sun at one focus (1602).
2. The vector from the sun to the planet sweeps equal areas in equal times (the law of areas, 1605).
3. The ratio of the square of the period T of revolution of a planet around the sun to the cube of the semi-major axis a of the ellipse is the same for all planets (1618).