INTERFERENCE IN SATELLITE COMMUNICATIONS

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INTERFERENCE TYPES

- Adjacent channel
  - Same system, different frequency, same polarization
  - Non ideal performance of filters
- Co-channel
  - Same system, same frequency, same polarization
  - Non ideal (as we would like) performance of antennas
- Cross-channel
  - Same system, same frequency, orthogonal polarization
  - Non ideal polarization isolation
- Adjacent system
  - Different system (even terrestrial) , same frequency, same polarization
  - Non sufficient spatial (angular) separation
- Multicarrier (intermodulation noise, carrier suppression)
  - Strictly speaking not interference, produced in the downlink by power amplifiers operated at or close to saturation

Multibeam Technology ...

Improves

- Spatial selectivity
- Gain

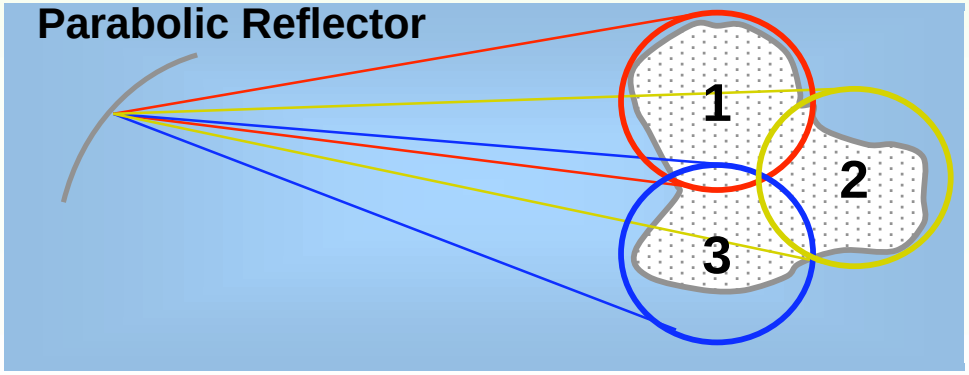
Allows

- Less critical terminal requirements
- Uneven power distribution

Even though ...

Increases

- Complexity
- Costs

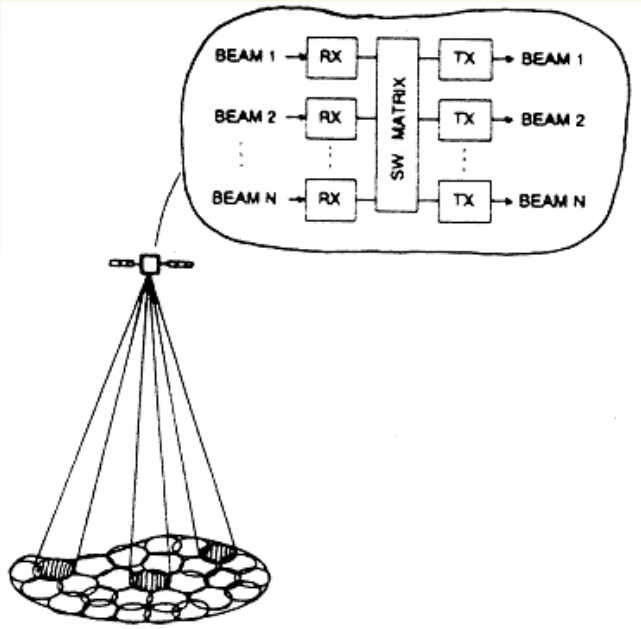


Multiple beam pattern characterisation

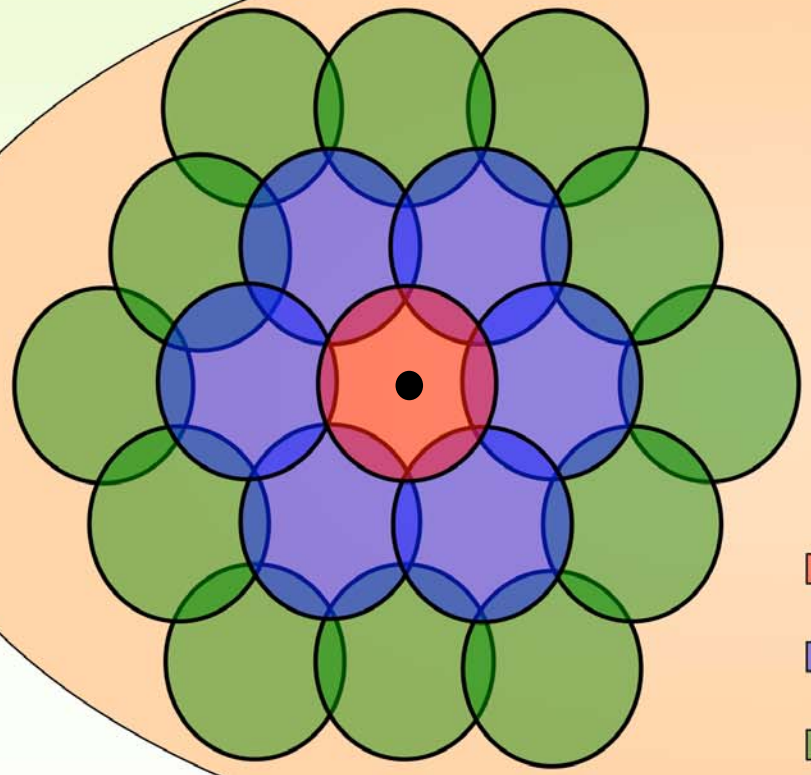
The satellite footprint can be subdivided in N cells

To realise regular coverage

- Circular crowns
- Cluster scheme



Circular crowns



Number of cells

$$N_C = 1 + \sum_{i=1}^{M} 6 \cdot i$$

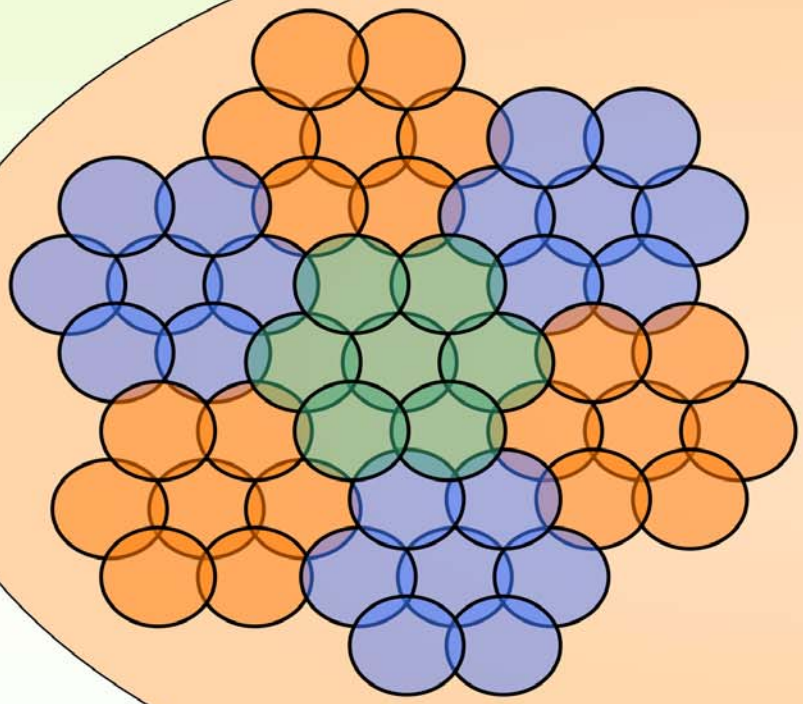
i: crown number

Central beam

Inner crown

Outer crown

Cluster scheme

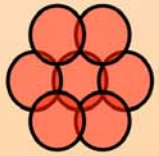


Number of cells

$$N = C \cdot N_C$$

C: cluster dimension

N_C: number of clusters



Cluster

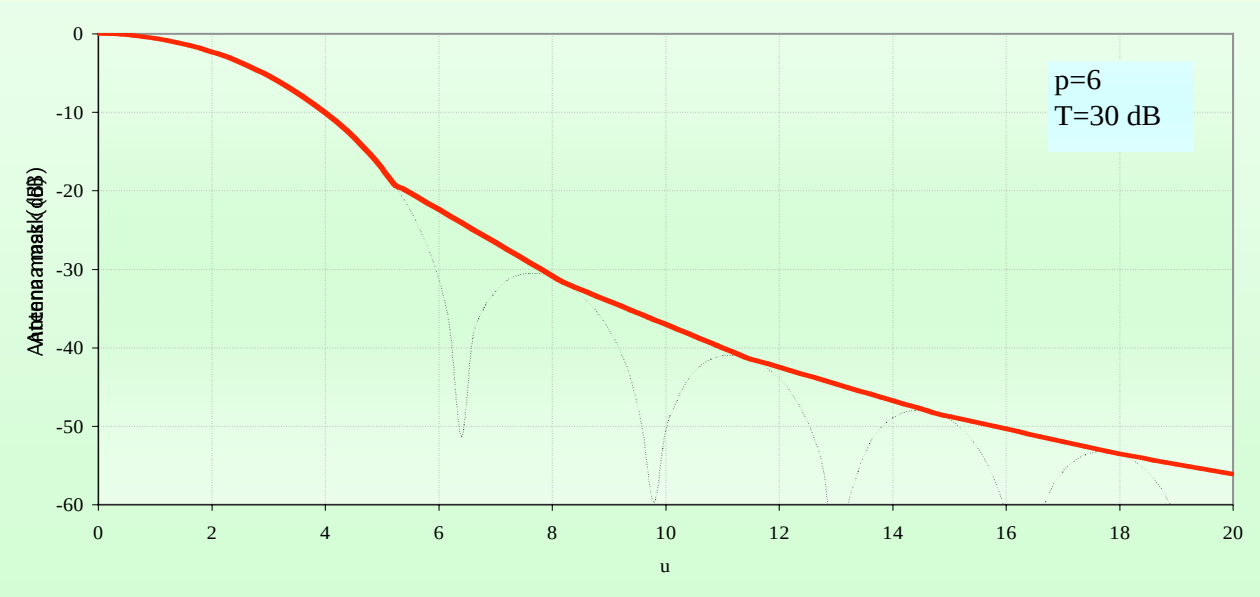
Antenna mask

$$F_j(\theta) = \hat{F}(u_j) = \frac{(p+1)(1-T)}{(p+1)(1-T)+T}\left(\frac{2J_1(u_j)}{u_j} + 2^{p+1}p!\frac{T}{1-T}\frac{J_{p+1}(u_j)}{u_j^{p+1}}\right)$$

$$u_j = \pi\frac{d_a}{\lambda}\sin\theta$$

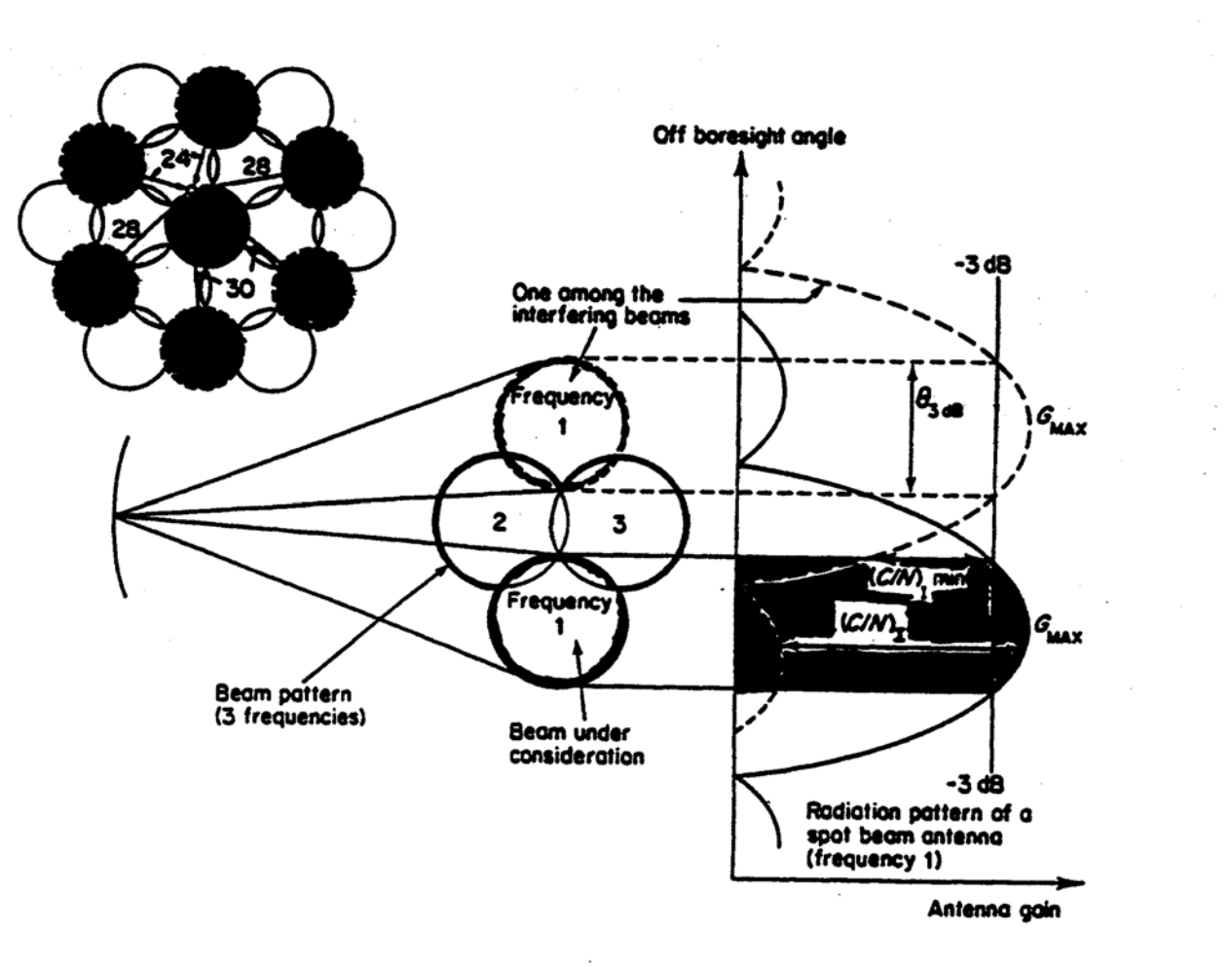
T, p Shape parameters

d_a Aperture diameter

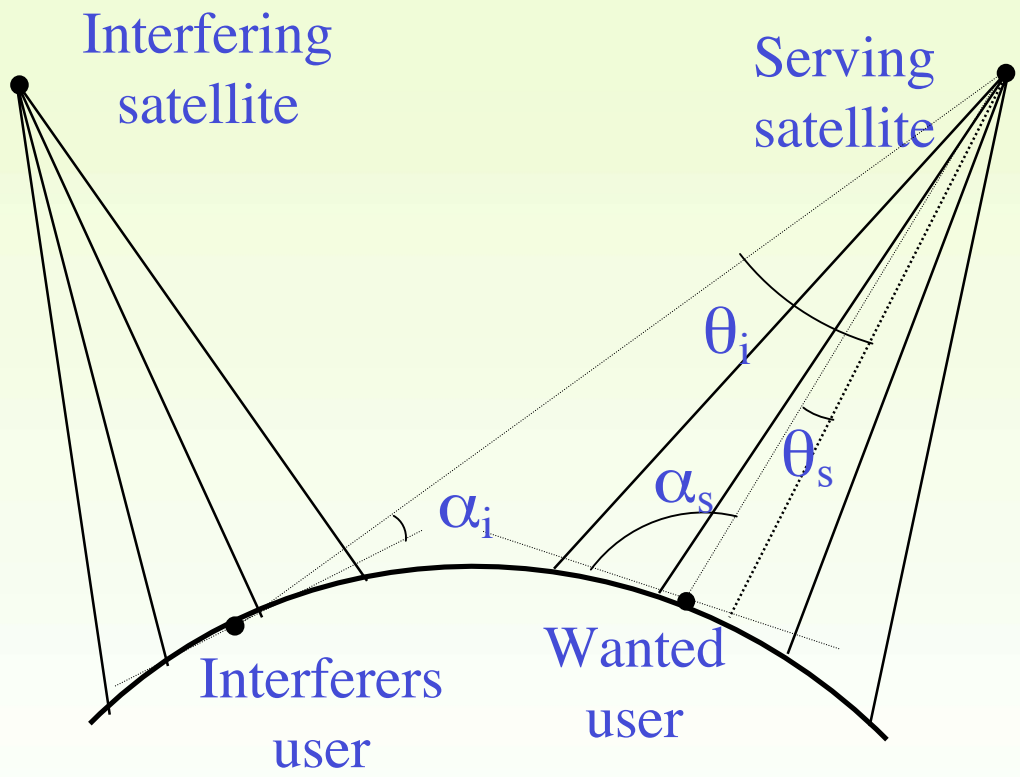


Co-Channel Interference

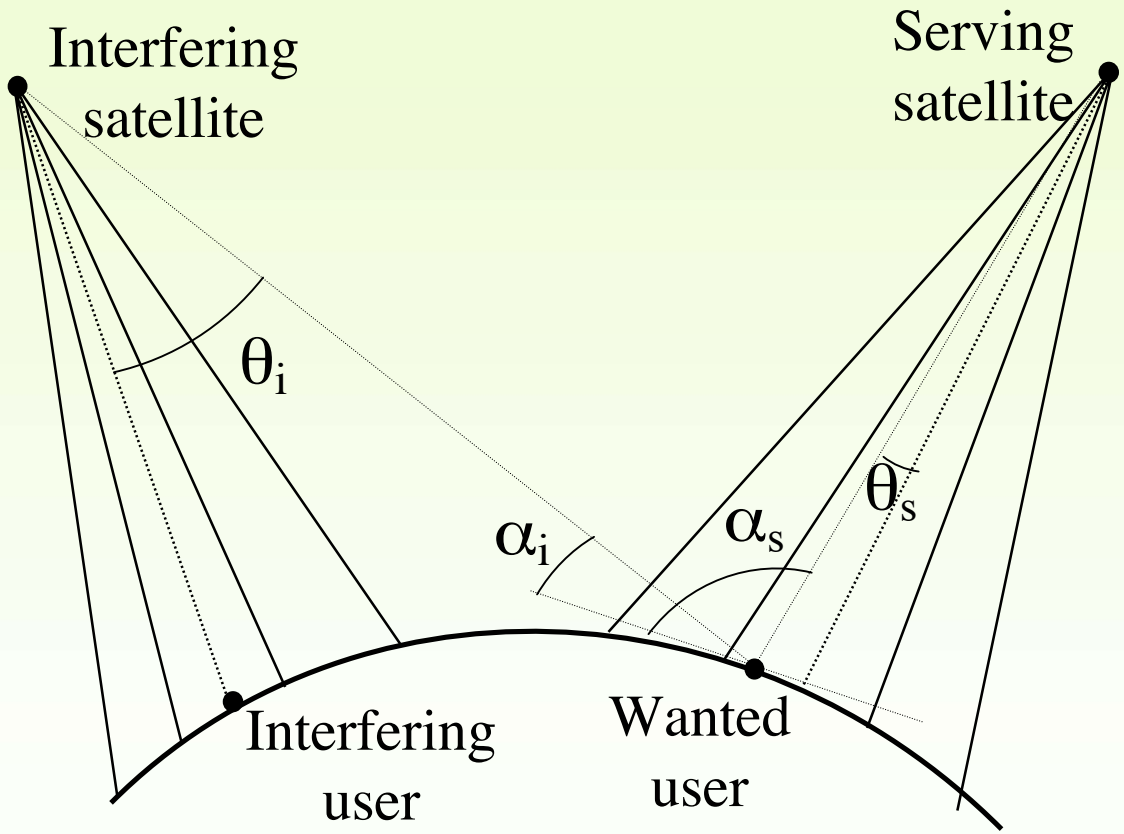
- Construction of interference within a beam lattice with three frequencies



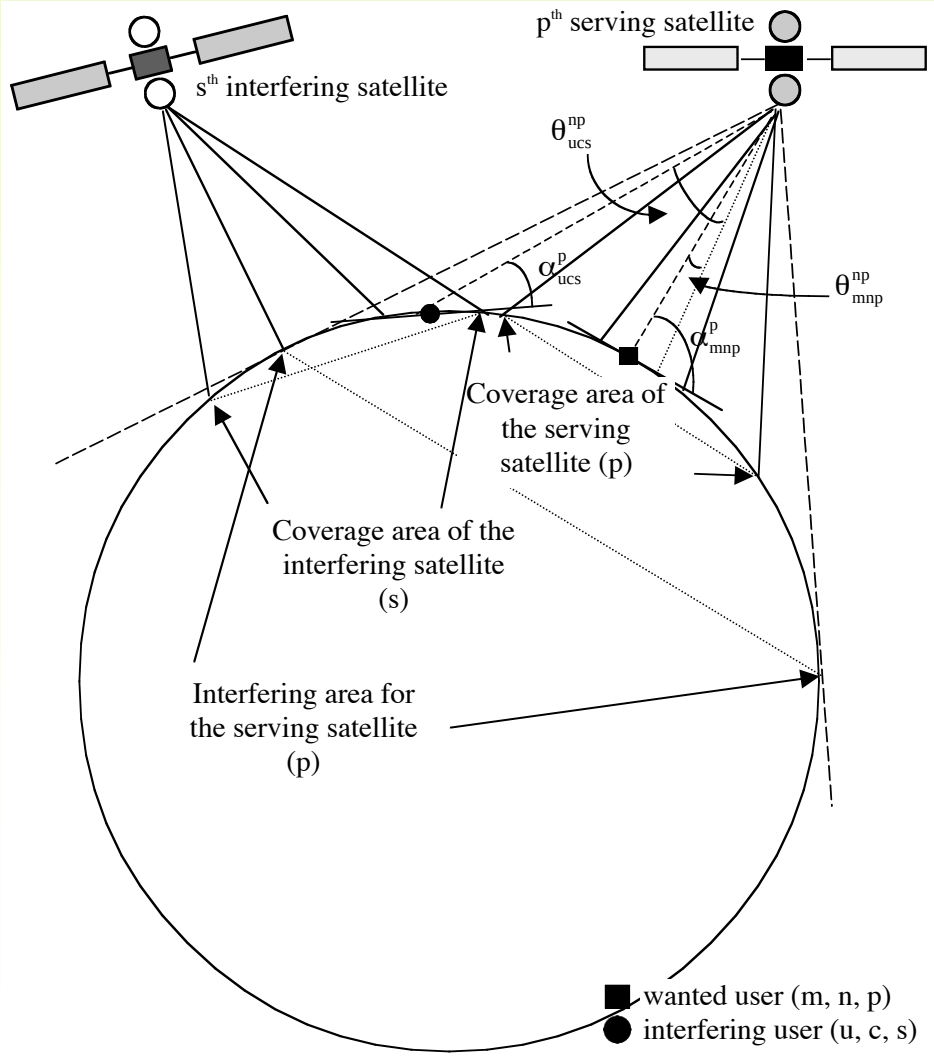
Geometrical structure for the up-link



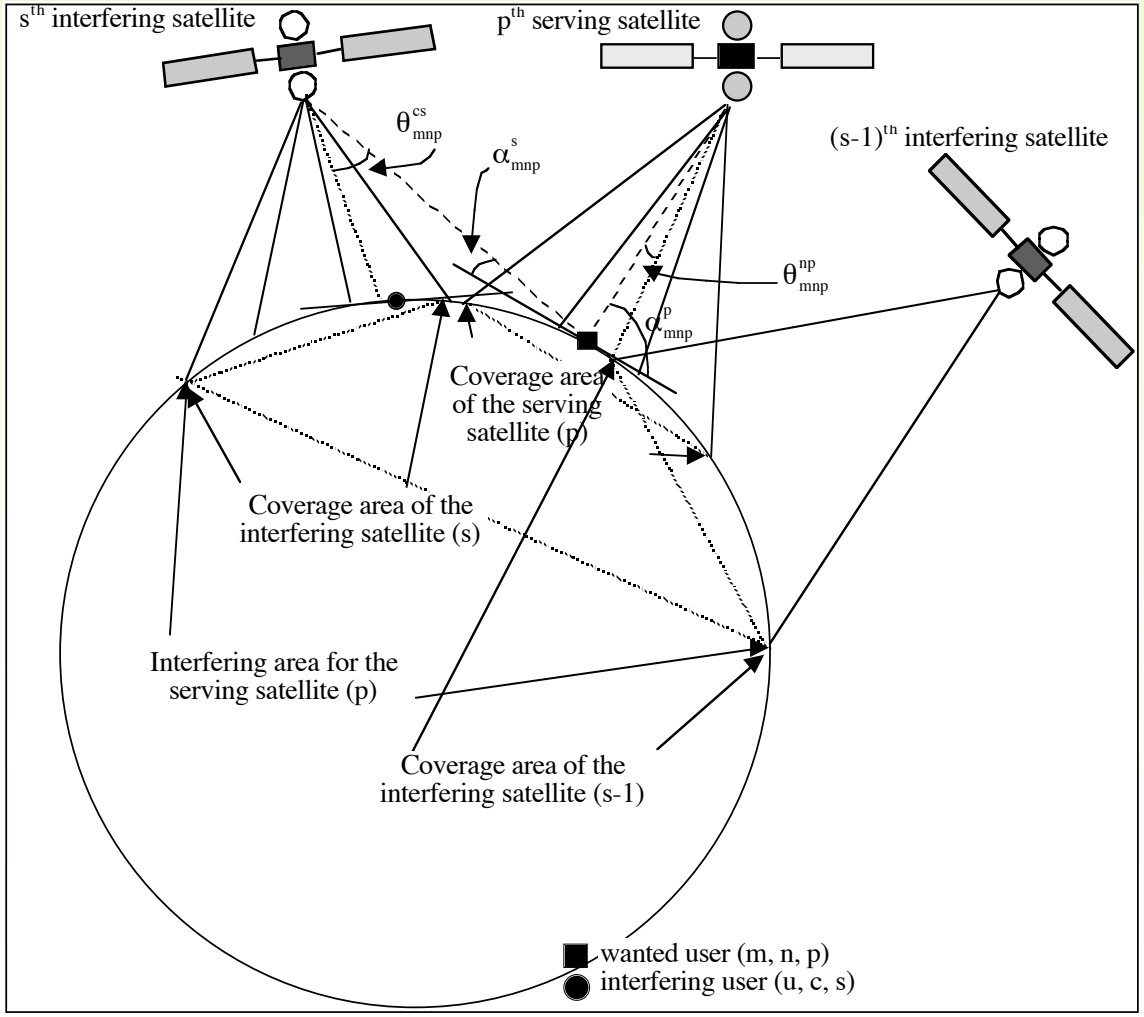
Geometrical structure for the down-link



Multisatellite Multibeam interference scenario (up link)



Multisatellite Multibeam interference scenario (down link)



C/I parameters (1)

Symbol	Parameter
NU_{cs}	number of interfering users in the cell c of satellite s
NC	number of cells in a satellite
NS	number of satellites
NI	number of interfering cells ($1 \leq NS \leq N_{cell}$, where N_{cell} is the number of satellite antenna beam)
ucs	user number u ($1 \leq u \leq NU_{cs}$) of the cell number c ($1 \leq c \leq NS$) of the satellite number s ($1 \leq s \leq NS$)
mnp	wanted user index (m-th user in the n-th cell of the p-th satellite)
CD	cluster dimension
k	number of full cluster in the antenna pattern
q	cluster index ($0 \leq q \leq k-1$)
t	cell number in the cluster ($1 \leq t \leq CD$)
n	cell number in one satellite coverage ($n=CDq_m+t$ in FDMA)
A_{mnp}	Supplementary (e.g. due to atmospheric effects) attenuation experienced by the mnp user

C/I parameters (2)

$\lambda_{[ucs]}$	wave length of the user (u, c, s)
$w_{[ucs]}$	power transmitted by the mobile terminal (u, c, s)
$W_{[cs]}$	power transmitted to cell c by the satellite s
α_{ucs}^{s}	angle between the tangent to the earth in the location of the user (u, c, s) and the line between the satellite s and the user (u, c, s)
$g_{[ucs]}\left(\alpha_{ucs}^{s}\right)$	antenna gain of the mobile terminal (u, c, s) in the direction α_{ucs}^{s}
θ_{ucs}^{cs}	angle between the boresight of the cell c of the satellite s and the line between the satellite s and the user (u, c, s)
$G_{[cs]}\left(\theta_{ucs}^{cs}\right)$	satellite antenna gain in the cell c of the satellite s in the direction of θ_{ucs}^{cs}
d_{ucs}^{s}	slant range for the link from the user (u, c, s) to the satellite s (the one serving the wanted user)
e	type of environment (rural, suburban, urban)
$f_{ucs}\left(e, \alpha_{ucs}^{s}\right)$	mobile channel fading experienced by the user (u, c, s) depending on the environment e and on the angle α_{ucs}^{s}
γ_{ucs}^{mnp}	orthogonality factor between the user (u, c, s) and the user (m, n, p)
μ_{ucs}	activity factor of the user (u, c, s)
ρ_{cs}^{np}	polarization isolation factor between the cell (c, s) and the cell (n, p)
l_{mnp}	Latitude of the user mnp
L_{mnp}	Longitude of the user mnp

C/I evaluation: CDMA case

$$\left(\frac{C}{I}\right)_{uplink} = \frac{C_{up}}{\sum_{i=1}^{3} I_{i-up}}$$

$$\left(\frac{C}{I}\right)_{downlink} = \frac{C_{down}}{\sum_{i=1}^{3} I_{i-down}}$$

$$C_{up} = \frac{w_{[mnp]} g_{[mnp]}\left(\alpha^{p}_{mnp}\right) G_{[np]}\left(\theta^{np}_{mnp}\right)}{\left(\frac{4\pi d^{p}_{mnp}}{\lambda}\right)^{2} f_{mnp}\left(e,\alpha^{p}_{mnp}\right) A_{mnp}\left(\lambda, l_{mnp}, L_{mnp}, \alpha^{p}_{mnp}\right)}$$

$$C_{down} = \frac{W_{np} g_{[mnp]}\left(\alpha^{p}_{mnp}\right) G_{[np]}\left(\theta^{np}_{mnp}\right)}{\left(\frac{4\pi d^{p}_{mnp}}{\lambda}\right)^{2} f_{mnp}\left(e,\alpha^{p}_{mnp}\right) A_{mnp}\left(\lambda, l_{mnp}, L_{mnp}, \alpha^{p}_{mnp}\right)}$$

$$I_{1-up} = \sum_{u\begin{cases}=1\\ \neq m\end{cases}}^{NU_{np}} \frac{\gamma^{mnp}_{unp} \mu_{unp} w_{[unp]} g_{[unp]}\left(\alpha^{p}_{unp}\right) G_{[np]}\left(\theta^{np}_{unp}\right)}{\left(\frac{4\pi d^{p}_{unp}}{\lambda}\right)^{2} f_{unp}\left(e,\alpha^{p}_{unp}\right) A_{unp}\left(\lambda, l_{unp}, L_{unp}, \alpha^{p}_{unp}\right)}$$

$$I_{1-down} = \sum_{u\begin{cases}=1\\ \neq m\end{cases}}^{NU_{np}} \frac{\gamma^{mnp}_{unp} \mu_{unp} W_{[np]} g_{[mnp]}\left(\alpha^{p}_{mnp}\right) G_{[np]}\left(\theta^{np}_{mnp}\right)}{\left(\frac{4\pi d^{p}_{mnp}}{\lambda}\right)^{2} f_{mnp}\left(e,\alpha^{p}_{mnp}\right) A_{mnp}\left(\lambda, l_{mnp}, L_{mnp}, \alpha^{p}_{mnp}\right)}$$

$$I_{2-up} = \sum_{c\begin{cases}=1\\ \neq n\end{cases}}^{NC} \sum_{u=1}^{NU_{cp}} \frac{\gamma^{mnp}_{ucp} \mu_{ucp} w_{[ucp]} g_{[ucp]}\left(\alpha^{p}_{ucp}\right) G_{[np]}\left(\theta^{np}_{ucp}\right) \rho^{np}_{cp}}{\left(\frac{4\pi d^{p}_{ucp}}{\lambda}\right)^{2} f_{ucp}\left(e,\alpha^{p}_{ucp}\right) A_{ucp}\left(\lambda, l_{ucp}, L_{ucp}, \alpha^{p}_{ucp}\right)}$$

$$I_{2-down} = \sum_{c\begin{cases}=1\\ \neq n\end{cases}}^{NC} \sum_{u=1}^{NU_{cp}} \frac{\gamma^{mnp}_{ucp} \mu_{ucp} W_{[cp]} g_{[mnp]}\left(\alpha^{p}_{mnp}\right) G_{[cp]}\left(\theta^{cp}_{mnp}\right) \rho^{cp}_{np}}{\left(\frac{4\pi d^{p}_{mnp}}{\lambda}\right)^{2} f_{mnp}\left(e,\alpha^{p}_{mnp}\right) A_{mnp}\left(\lambda, l_{mnp}, L_{mnp}, \alpha^{p}_{mnp}\right)}$$

$$I_{3-up} = \sum_{s\begin{cases}=1\\ \neq p\end{cases}}^{NS} \sum_{c=1}^{NC} \sum_{u=1}^{NU_{cs}} \frac{\gamma^{mnp}_{ucs} \mu_{ucs} w_{[ucs]} g_{[ucs]}\left(\alpha^{p}_{ucs}\right) G_{[np]}\left(\theta^{np}_{ucs}\right) \rho^{np}_{cs}}{\left(\frac{4\pi d^{p}_{ucs}}{\lambda}\right)^{2} f_{ucs}\left(e,\alpha^{p}_{ucs}\right) A_{ucs}\left(\lambda, l_{ucs}, L_{ucs}, \alpha^{p}_{ucs}\right)}$$

$$I_{3-down} = \sum_{s\begin{cases}=1\\ \neq p\end{cases}}^{NS} \sum_{c=1}^{NC} \sum_{u=1}^{NU_{cs}} \frac{\gamma^{mnp}_{ucs} \mu_{ucs} W_{cs} g_{[mnp]}\left(\alpha^{s}_{mnp}\right) G_{[cs]}\left(\theta^{cs}_{mnp}\right) \rho^{cs}_{np}}{\left(\frac{4\pi d^{s}_{mnp}}{\lambda}\right)^{2} f_{mnp}\left(e,\alpha^{s}_{mnp}\right) A_{mnp}\left(\lambda, l_{mnp}, L_{mnp}, \alpha^{s}_{mnp}\right)}$$

C/I evaluation: FDMA case

$$\left(\frac{C}{I}\right)_{uplink} = \frac{C_{up}}{\sum_{i=2}^{3} I_{i-up}}$$

number of full clusters

'NC' is not a multiple of 'CD

$$k = \left\lceil \frac{NC}{CD} \right\rceil$$

$$NI = \begin{cases} k & \begin{cases} NC = kCD \\ \forall t \le \nu \end{cases} \\ k-1 & \forall t > \nu \end{cases}$$

$$\nu = NC - k \cdot CD$$

$$\left(\frac{C}{I}\right)_{downlink} = \frac{C_{down}}{\sum_{i=2}^{3} I_{i-down}}$$

$$C_{up} = \frac{w_{[mnp]} g_{[mnp]}\left(\alpha^{p}_{mnp}\right) G_{[np]}\left(\theta^{np}_{mnp}\right)}{\left(\frac{4\pi d^{p}_{mnp}}{\lambda_{mnp}}\right)^{2} f_{mnp}\left(e,\alpha^{p}_{mnp}\right) A_{mnp}\left(\lambda, l_{mnp}, L_{mnp}, \alpha^{p}_{mnp}\right)}$$

number of interfering cells

$$C_{down} = \frac{W_{[np]} g_{[mnp]}\left(\alpha^{p}_{mnp}\right) G_{[np]}\left(\theta^{np}_{mnp}\right)}{\left(\frac{4\pi d^{p}_{mnp}}{\lambda_{mnp}}\right)^{2} f_{mnp}\left(e,\alpha^{p}_{mnp}\right) A_{mnp}\left(\lambda, l_{mnp}, L_{mnp}, \alpha^{p}_{mnp}\right)}$$

$$I_{2-up} = \sum_{q\begin{cases}=0\\ \neq q_m\end{cases}}^{NI} \frac{\mu_{m(CDq+t)p} w_{[m(CDq+t)p]} g_{[m(CDq+t)p]}\left(\alpha^{p}_{m(CDq+t)p}\right) G_{[np]}\left(\theta^{np}_{m(CDq+t)p}\right) \rho^{np}_{(CDq+t)p}}{\left(\frac{4\pi d^{p}_{m(CDq+t)p}}{\lambda_{mnp}}\right)^{2} f_{m(CDq+t)p}\left(e,\alpha^{p}_{m(CDq+t)p}\right) A_{m(CDq+t)p}\left(\lambda_{mnp}, l_{m(CDq+t)p}, L_{m(CDq+t)p}, \alpha^{p}_{m(CDq+t)p}\right)}$$

$$I_{2-down} = \sum_{q\begin{cases}=0\\ \neq q_m\end{cases}}^{NI} \frac{\mu_{m(CDq+t)p} W_{[(CDq+t)p]} g_{[mnp]}\left(\alpha^{p}_{mnp}\right) G_{[(CDq+t)p]}\left(\theta^{(CDq+t)p}_{mnp}\right) \rho^{(CDq+t)p}_{np}}{\left(\frac{4\pi d^{p}_{m(CDq+t)p}}{\lambda_{mnp}}\right)^{2} f_{mnp}\left(e,\alpha^{p}_{mnp}\right) A_{mnp}\left(\lambda, l_{mnp}, L_{mnp}, \alpha^{p}_{mnp}\right)}$$

$$I_{3-up} = \sum_{s\begin{cases}=1\\ \neq p\end{cases}}^{NS} \sum_{q=0}^{NI} \frac{\mu_{m(CDq+t)s} w_{[m(CDq+t)s]} g_{[m(CDq+t)s]}\left(\alpha^{p}_{m(CDq+t)s}\right) G_{[np]}\left(\theta^{np}_{m(CDq+t)s}\right) \rho^{np}_{(CDq+t)s}}{\left(\frac{4\pi d^{p}_{m(CDq+t)s}}{\lambda_{mnp}}\right)^{2} f_{m(CDq+t)s}\left(e,\alpha^{p}_{m(CDq+t)s}\right) A_{m(CDq+t)s}\left(\lambda_{mnp}, l_{m(CDq+t)s}, L_{m(CDq+t)s}, \alpha^{p}_{m(CDq+t)s}\right)}$$

$$I_{3-down} = \sum_{s\begin{cases}=1\\ \neq p\end{cases}}^{NS} \sum_{q=0}^{NI} \frac{\mu_{m(CDq+t)s} W_{[(CDq+t)s]} g_{[mnp]}\left(\alpha^{s}_{mnp}\right) G_{[(CDq+t)s]}\left(\theta^{(CDq+t)s}_{mnp}\right) \rho^{(CDq+t)s}_{np}}{\left(\frac{4\pi d^{s}_{mnp}}{\lambda_{mnp}}\right)^{2} f_{mnp}\left(e,\alpha^{s}_{mnp}\right) A_{mnp}\left(\lambda, l_{mnp}, L_{mnp}, \alpha^{s}_{mnp}\right)}$$

Expression of $(C/N_0)_T$ for transparent repeater

Without interference or intermodulation

- $(N_0)_T = (N_0)_D + G(N_0)_U$ (W/Hz)
  - $G = G_{SR}G_TG_R/(L_{FTX}L_DL_{FRX})$ total power gain between the satellite receiver input and the earth station receiver input
    - G_T/L_{FTX} satellite tx antenna gain (including gain fallout and loss from the output of the power amplifier to the tx antenna)
    - G_R/L_{FRX} receiver station composite gain
    - L_D downlink path loss
    - G_{SR} satellite repeater gain
- $(C/N_0)_T^{-1}=(N_0)_T/C_D=[(N_0)_D+G(N_0)_U]/C_D=(N_0)_D/C_D+(N_0)_U/G^{-1}C_D$ (Hz^{-1})
  - $G^{-1}C_D$ = power at the satellite receiver input $\Rightarrow (N_0)_U/G^{-1}C_D = (C/N_0)_U^{-1}$
- $(C/N_0)_T^{-1}= (C/N_0)_U^{-1}+(C/N_0)_D^{-1}$ (Hz^{-1})

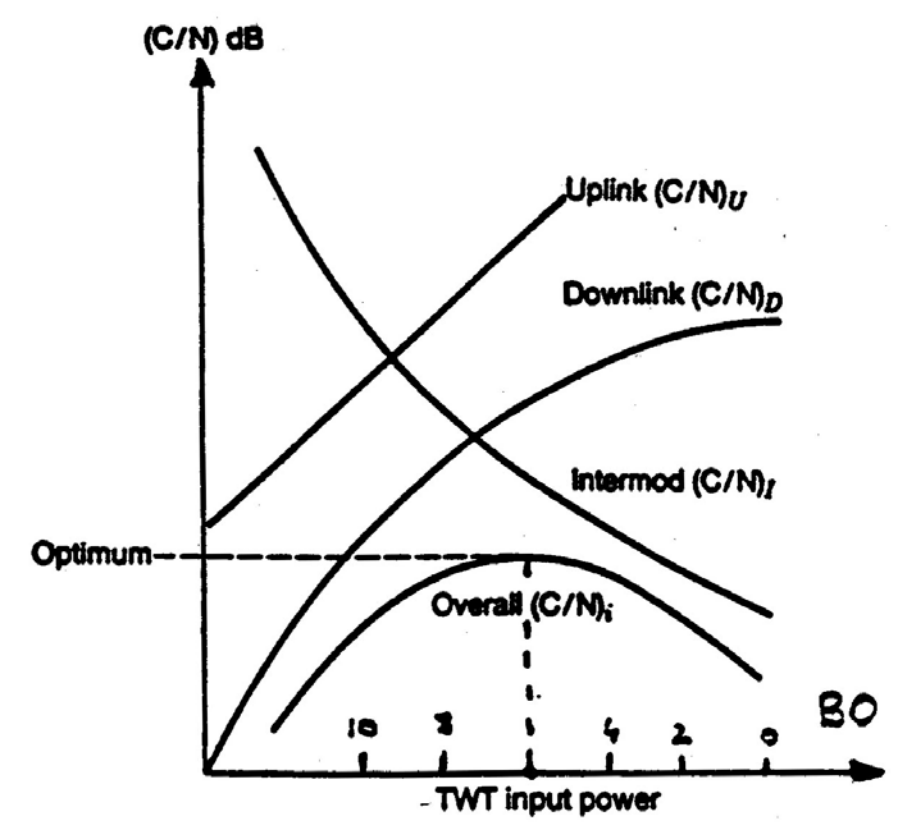
Expression of $(C/N_0)_T$ for transparent repeater (2)

With interference

- $N_0 = (N_0)$ without interference + $(N_0)_I$ (W/Hz)
- $[(N_0)_{wI} + (N_0)_I]/C = (N_0)_{wI}/C + (N_0)_I/C$
- $(C/N_0)_T^{-1} = (C/N_0)_U^{-1} + (C/N_0)_D^{-1} + (C/N_0)_{UI}^{-1} + (C/N_0)_{DI}^{-1}$ (Hz^{-1})

With interference and intermodulation

- $N_0 = (N_0)$ without interference + $(N_0)_I + (N_0)_{IM}$ (W/Hz)
- $(C/N_0)_T^{-1} = (C/N_0)_U^{-1} + (C/N_0)_D^{-1} + (C/N_0)_I^{-1} + (C/N_0)_{IM}^{-1}$ (Hz^{-1})

Back off

- Close to saturation
  - $(C/N_0)_U$ and $(C/N_0)_D$ grow
  - $(C/N_0)_{IM}$ decreases
- $(C/N_0)_{IM}$ shows a maximum
- Back Off