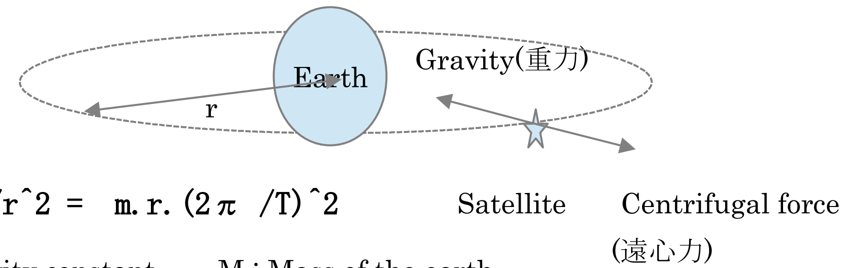
Elements of Satellite Communication

29, March,2013 OsI

1. Space orbits

Centripetal force (求心力) = Gravity of the earth (地球の重力)　$G.M.m / r^2$

Centrifugal force (遠心力)　$= m.v^2 / r = m.r.(2\pi/T)^2$



Balance of force

$$G.M.m/r^2 = m.r.(2\pi/T)^2$$

Where

G ; Gravity constant　M ; Mass of the earth
m; Mass of the satellite　r ; Radius of the satellite from the earth center
T ; Rotation period of the satellite

On the earth; $r = ro = 6{,}366$(km) (Radius of the earth)

$G.M./ro^2 = g = 9.8 (m/s^2)$; gravity acceleration on the earth

Then

$$r^3 / T^2 = g.ro^2 / (2\pi)^2 = 1.0 \times 10^{13}$$

<u>Geosynchronous orbit</u>

(1) Above equator

(2) T = 24(hours) = 86400 (sec)

(3) r = 42,116(km)

(4) Altitude above the equator = h = r − ro = 42,116 − 6,366 = 35,750(km)

(5) Propagation delay

Speed of light = $c = 3 \times 10^8$(m/s)

One hop delay = 2h/c = **0.238(sec)**

<u>Low earth orbit</u>

(1) r = 7,000(km ; 330km above the earth)

(2) T = 5856(sec) = 1 hour 38 min.

<u>The moon</u>

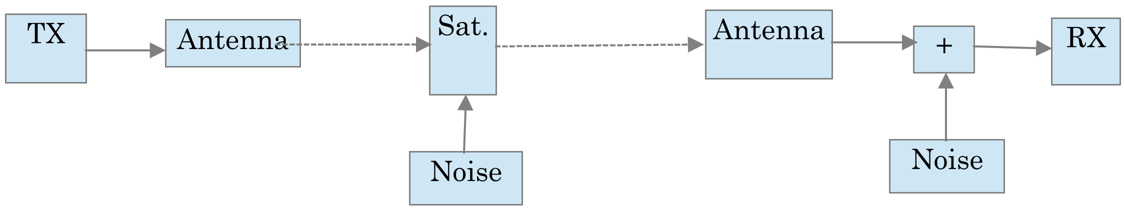
(1) T = 28 (days) = 2,419,200 (sec)

(2) r = 380,649,621 (m)

(3) One hop propagation delay by light ; 2r/c = 2.54(sec)

2. Elements of Antena Technology for Satellite Communications

The satellite communication links are composed as the following figure.



The receive signal quality;

<>Signal power ; **$Pr = Pt \cdot Gt \cdot 1/Lu \cdot Gs \cdot 1/Ld \cdot Gr$**

<>Noise ; $Nr = Nu \cdot 1/Ld \cdot Gr + Nd$

$EIRPt = Pt \cdot Gt$

$EIRPs = Pt \cdot Gt \cdot 1/Lu \cdot Gs$

(EIRP ; Equivalent Isotropic Radiated Power(W))

Pr; Signal power at receiver(W)
Gt; Transmit antenna gain
Pt: Transmit power (W)
Lu; Uplink propagation loss
Gs; Satellite amplifier gain
Ld; Downlink propagaton loss
Gr; Receive antenna gain
Nu; Uplink additive noise (W)
Nd; Downlink and receiver noise

Then the receiver signal power is

$Pr = EIRPs \cdot 1/Ld \cdot Gr$

The EIRP signal spreads in all directions.

At the receiver distant from the satellite by d(m), the signal power density is

$EIRPs / (4\pi \cdot d^2)$ (Watt per m^2) .

The receive antenna collects the signal energy by the area Ae (effective antenna aperture) to get the receive signal power;

$Pr = EIRPs / (4\pi \cdot d^2) \cdot Ae$

Antenna gain and aperture

The antenna theory gives the relation between Ae and the antenna gain Ga;

$Ae = \lambda^2 / 4\pi \cdot Ga$ λ; wavelength of the radio wave (m)

Then the receive signal power is;

$Pr = EIRPs / (4\pi \cdot d^2)$. **$\lambda^2 / 4\pi \cdot Gr = EIRP / Ld \cdot Gr$**

Propagation loss

$Ld = (4\pi \cdot d/\lambda)^2$

For example,

Radio frequency ; f = 12GHz

Distance to the satellite ; d= 40,000(km)

The radio wavelength $\lambda = c / f = 3 \times 10^8 / (12 \times 10^9) = 0.025$(m)

$Ld = (4 \times 3.14 \times 4 \times 10^7 / 0.025)^2 = 4.04 \times 10^{20}$

dB (deciBell)

In communication technology we use dB to treat the losses and gains in the link.

A value x is $X = 10.\log(x)$ in dB. Thus,

$Ld = 4.04 \times 10^{20} \Rightarrow 10 \times \log(4.04 \times 10^{20}) = 206.1$ (dB)

100 = 20dB, 10 = 10dB, 2 = 3dB, 1 = 0dB, 1/2 = -3dB, 1/10 = -10 (dB) 0.01 = -20(dB)

<u>Antenna directivity</u>

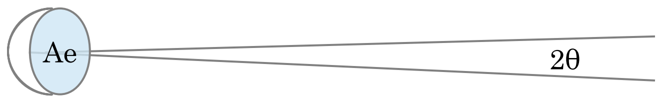
Another aspect of the antenna is its directivity (指向性).

Antenna gain ; **$Ga = 4\pi / \Omega a$**

= [Omni-directional Solid angle]/ [Solid angle of the directive antenna]

Antenna directivity = $1/ \Omega a = Ae / (\lambda^2)$

Example;



Radio frequency ; f = 12GHz,

Parabolic antenna with D=1.2(m) diameter

$Ae = \pi.(D/2)^2 = 3.14 \times 0.6^2 = 1.13$ (m^2)

$\Omega a = (\lambda^2) / Ae = 0.025^2 / 1.13 = 5.53 \times 10^{-4}$ (grad)

The antenna gain is

$Ga = 4\pi / \Omega a = 4 \times 3.14 / (5.53 \times 10^{-4}) = 22720 = 43.5$(dB)

The beam width of the antenna pattern is

$\pi.(r\theta)^2 = r^2. \Omega a$

$\theta = \sqrt{\Omega a/\pi} = \sqrt{5.53 \times 10^{-4} / 3.14} = 1.32 \times 10^{-2}$ (rad) = **0.76 (deg)**

In conclusion

The antenna in the radio transmission link

[1] Amplifies the radio signal in the link.

[2] Limits the direction of radio wave transmission and reception. ==>

[3] The geo-synchronous orbit can be segmented to be used by different systems for satellite communication.

If you divide the orbit in steps of 3 deg, then you have 120 orbit positions.

3 Frequency separations

Different systems can share the same orbit by separation of radio frequencies.

The frequency allocation is important to avoid mutual interferences among systems.

The frequencies alocated to satellite communications in Japan are given in the table.

Applications	Uplink (MHz)	Downlink (MHz)
Mobile satellite communication	1626.5 - 1660.5	1525 - 1559
IMT satellite comm.	2170 - 2200	1980 - 2010

Mobile satellite communication	2655 - 2690	2500-2535
Fixed satellite communication	6725 - 7025	4500-4800
Fixed satellite communication	13.75 -14.5 (GHz)	12.2 - 12.75 (GHz)
Fixed satellite communication	27.5 - 31.0 (GHz)	17.7 - 21.2 (GHz)
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4. Applications of satellite communications

Mobile satellite communications

[1] Inmarsat provides global mobile services for telephony, data and Internet (BGAN)

[2] The BGAN can provide up to 450 kbps data rates.

[3] There are local mobile satellites systems ; Thuraya, ACes, NSTAR, etc.

[4] Very useful for communications in remote areas.

[5] The channel capacity is limited because of small frequency bands, low orbit utilization (small antennae achieve low directivity).

Internet access via satellite

[1] An effective solution of "digital divide" problem.

[2] The satellite system functions as an Internet Service Provider (ISP).

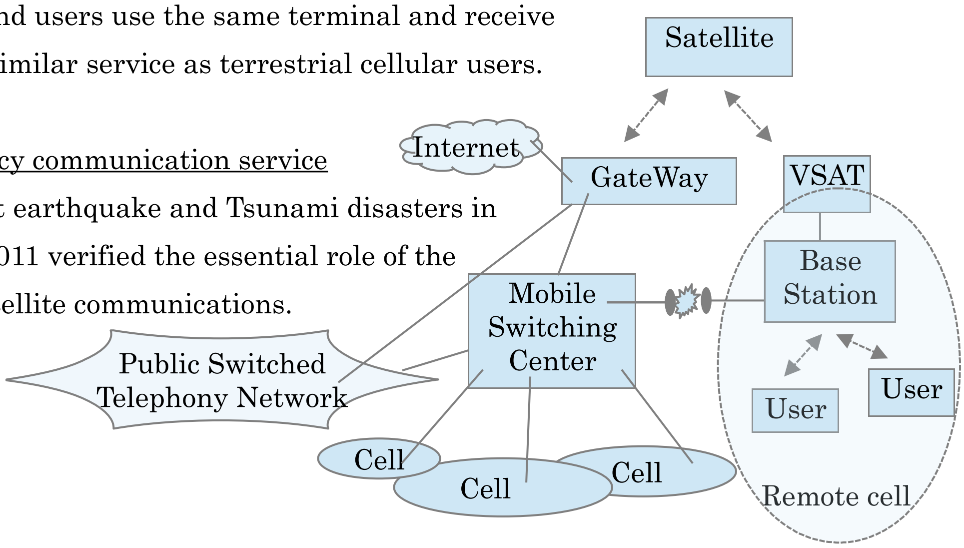
Mobile Trunk service

[1] The satellite coverage provides an additional cell for cellular operators.

[2] The end users use the same terminal and receive very similar service as terrestrial cellular users.

Emergency communication service

The great earthquake and Tsunami disasters in March, 2011 verified the essential role of the above satellite communications.



VSAT ; Very Small Aperture Terminal (Satellite station)