شرکت مهندسین مشاور
شاهین ارتباط تهران

Radio Digital Microwave

شاهین ارتباط تهران

RMW

MICROWAVE LINK DESIGN

Bahman 1386

Contents

شاهین ارتباط تهران

What is Microwave Communication

شاهین ارتباط تهران

A communication system that utilizes the radio frequency band spanning 2 to 60 GHz. As per IEEE, electromagnetic waves between 30 and 300 GHz are called millimeter waves (MMW) instead of microwaves as their wavelengths are about 1 to 10mm.

What is Microwave Communication

شاهین ارتباط تهران

Small capacity systems generally employ the frequencies less than 3 GHz while medium and large capacity systems utilize frequencies ranging from 3 to 15 GHz. Frequencies > 15 GHz are essentially used for short-haul transmission.

Advantages of Microwave Radio

- Less affected by natural calamities
- Less prone to accidental damage
- Links across mountains and rivers are more economically feasible
- Single point installation and maintenance
- Single point security
- They are quickly deployed

Line-of-Sight Considerations

شاهین ارتباط تهران

- Microwave radio communication requires a clear line-of-sight (LOS) condition
- Under normal atmospheric conditions, the radio horizon is around 30 percent beyond the optical horizon
- Radio LOS takes into account the concept of Fresnel ellipsoids and their clearance criteria

Line-of-Sight Considerations

شاهین ارتباط تهران

- Fresnel Zone :

  Areas of constructive and destructive interference created when electromagnetic wave propagation in free space is reflected (multipath) or diffracted as the wave intersects obstacles. Fresnel zones are specified employing ordinal numbers that correspond to the number of half wavelength multiples that represent the difference in radio wave propagation path from the direct path
- The Fresnel Zone must be clear of all obstructions.

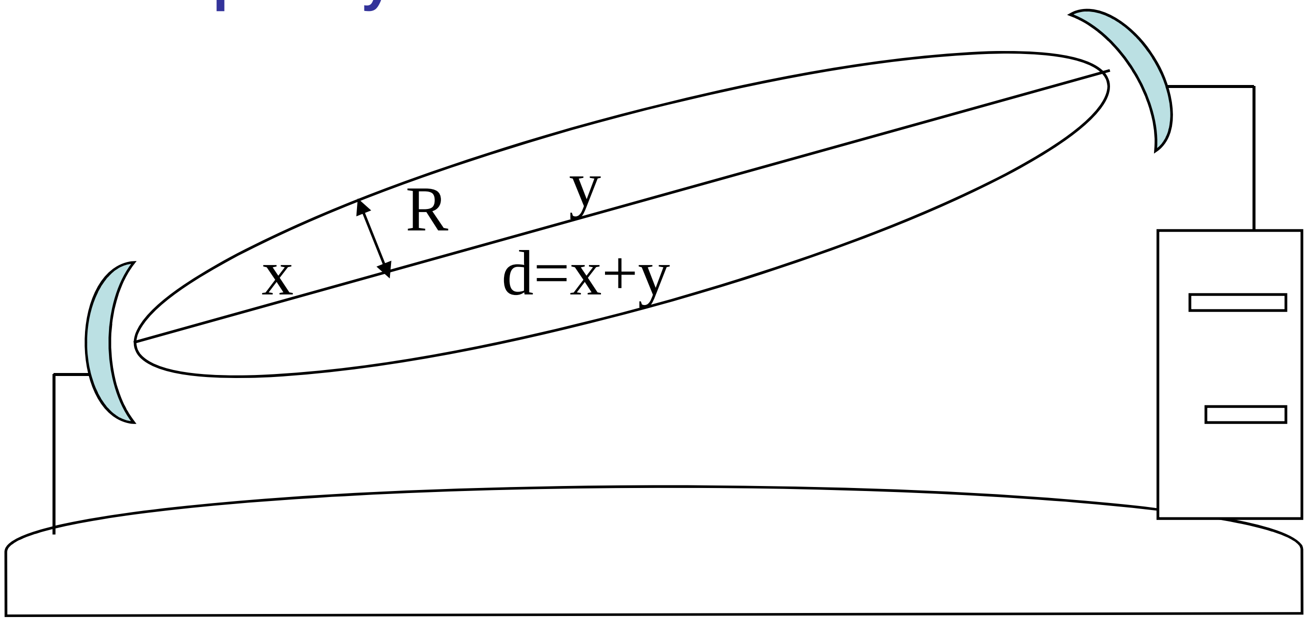
- Radius of the first Fresnel zone

$$R=17.32[x(d-x)/fd]^{1/2}$$

where d = distance between antennas (in Km)

R= first Fresnel zone radius in meters

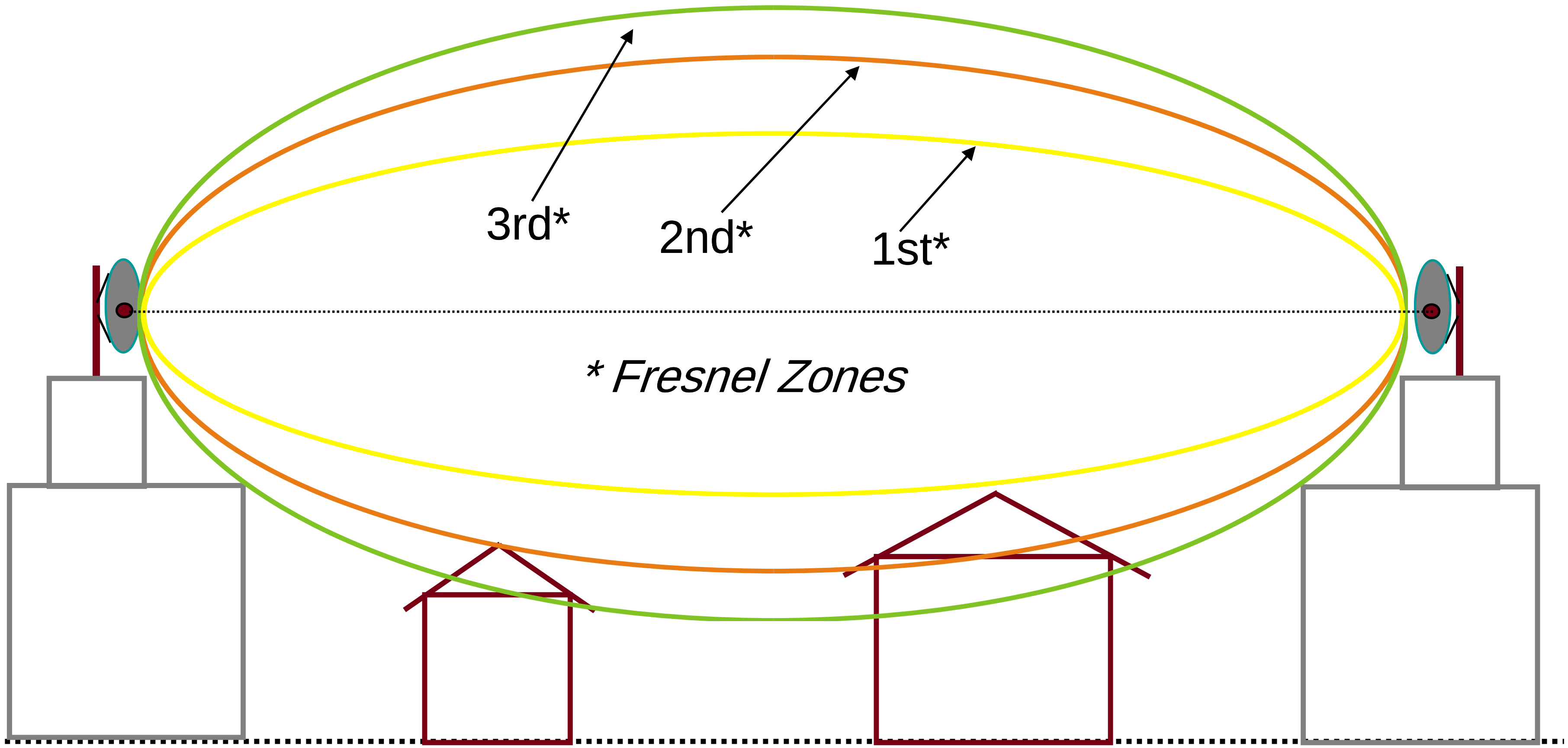
f = frequency in GHz



شاهین ارتباط تهران

شاهین ارتباط تهران

Fresnel Zones

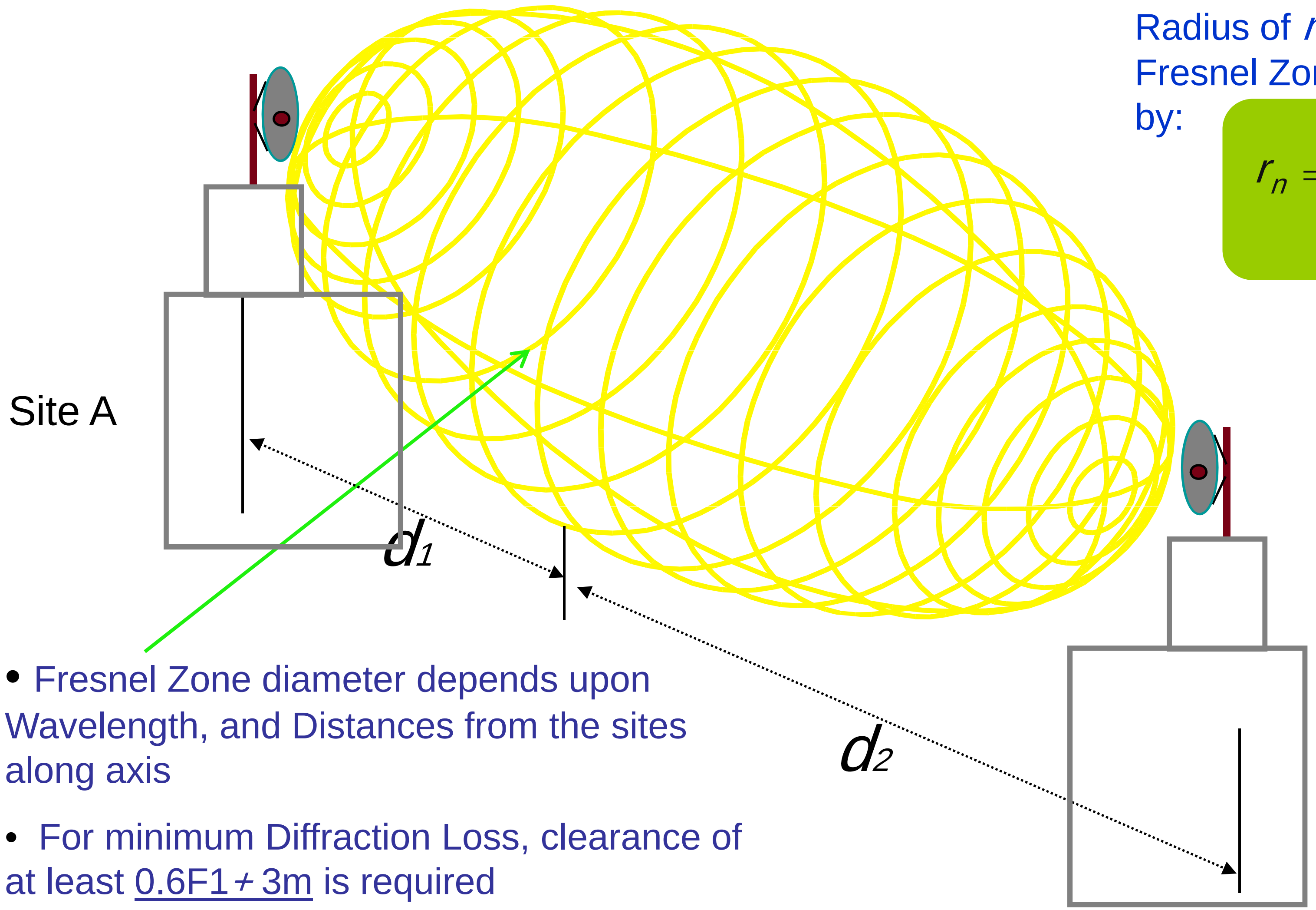


The First Fresnel Zone

شاهین ارتباط تهران

Radius of n^{th} Fresnel Zone given by:

$$r_n = \sqrt{\frac{n \lambda d_1 d_2}{d_1 + d_2}}$$



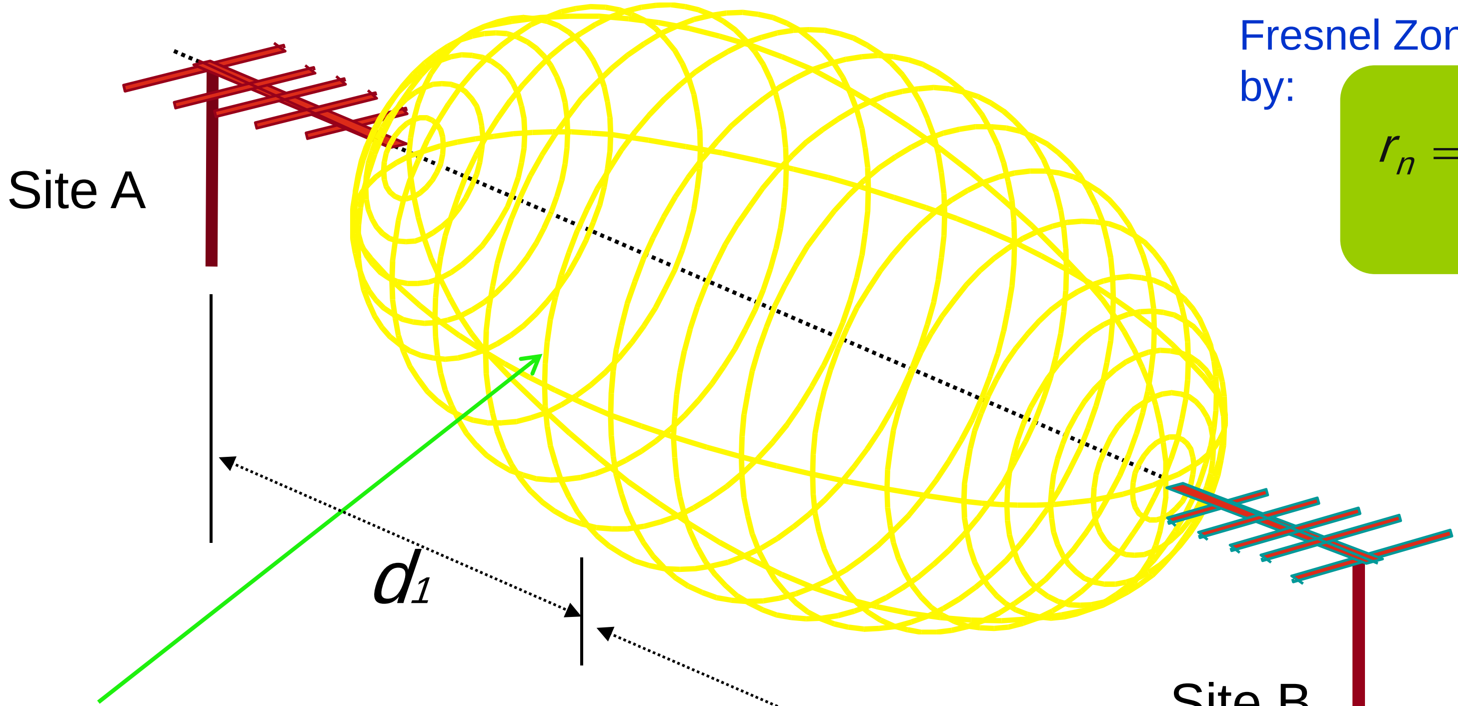
- Fresnel Zone diameter depends upon Wavelength, and Distances from the sites along axis
- For minimum Diffraction Loss, clearance of at least 0.6F1+3m is required

The First Fresnel Zone

شاهین ارتباط تهران

Radius of n^{th} Fresnel Zone given by:

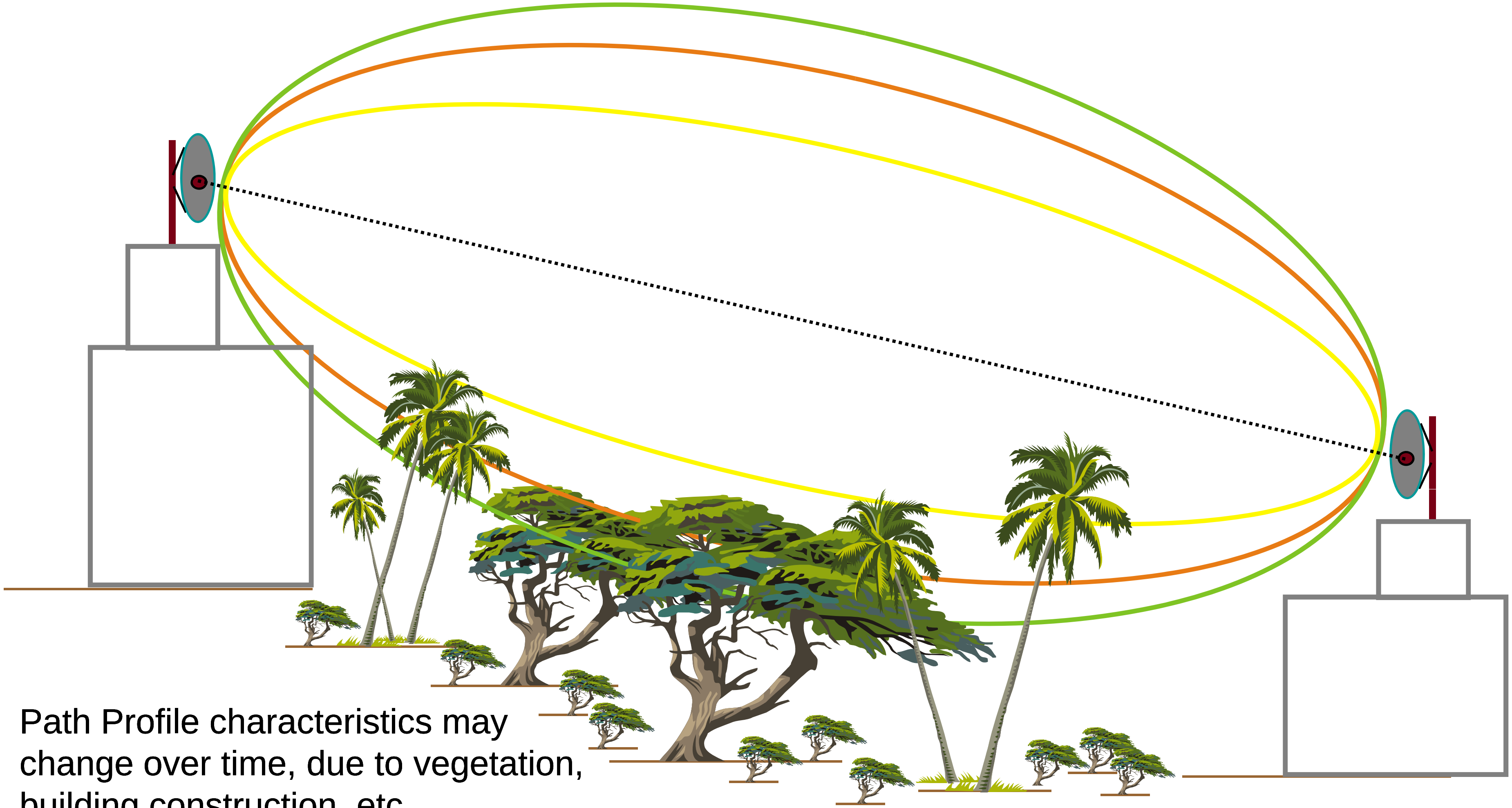
$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$



- Fresnel Zone diameter depends upon Wavelength, and Distances from the sites along axis
- For minimum Diffraction Loss, clearance of at least 0.6F1+3m is required

The Path Profile

شاهین ارتباط تهران



Path Profile characteristics may change over time, due to vegetation, building construction, etc.

Line-of-Sight Considerations

شاهین ارتباط تهران

- Typically the first Fresnel zone (N=1) is used to determine obstruction loss
- The direct path between the transmitter and the receiver needs a clearance above ground of at least 60% of the radius of the first Fresnel zone to achieve free space propagation conditions
- Earth-radius factor k compensates the refraction in the atmosphere
- Clearance is described as any criterion to ensure sufficient antenna heights so that, in the worst case of refraction (for which k is minimum) the receiver antenna is not placed in the diffraction region

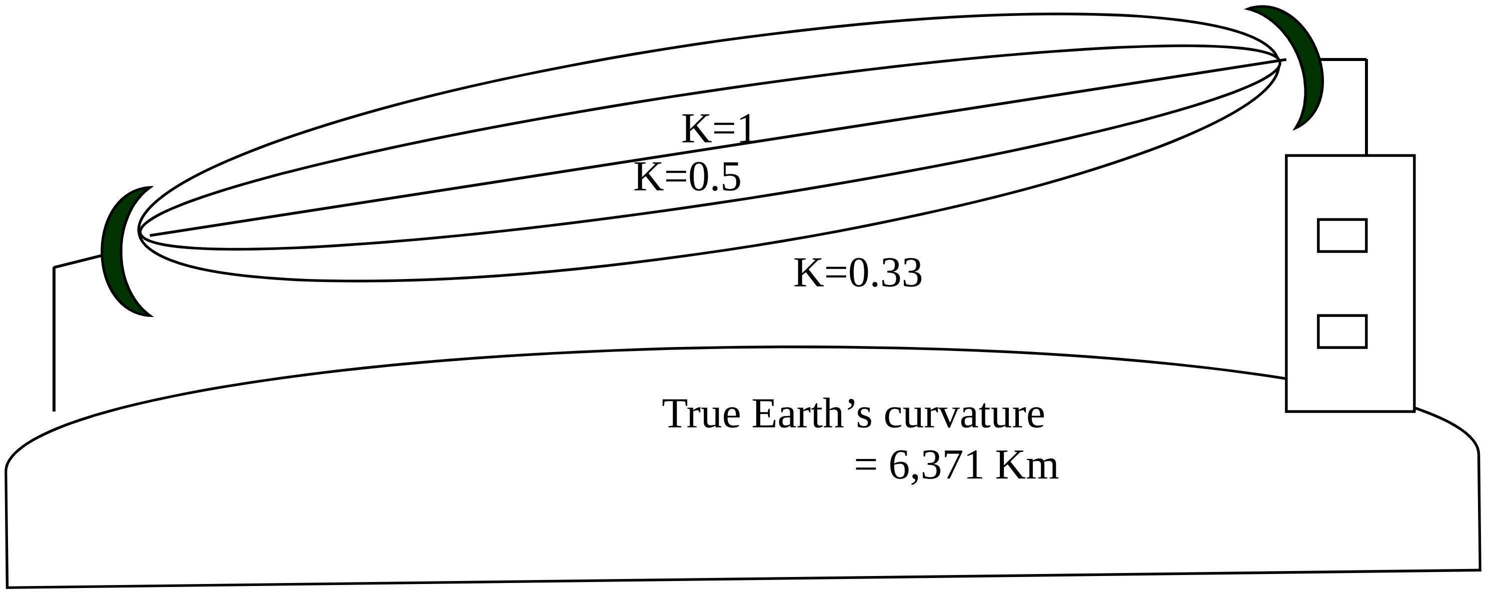
Effective Earth’s Radius = k * True Earth’s Radius

True Earth’s radius= 6371 Km

k=4/3=1.33, standard atmosphere with normally refracted path (this value should be used whenever local value is not provided)

شاهین ارتباط تهران

Variations of the ray curvature as a function of k



Line-of-Sight Considerations

شاهین ارتباط تهران

Clearance criteria to be satisfied under normal propagation conditions

- Clearance of 60% or greater at the minimum k suggested for the certain path
- Clearance of 100% or greater at k=4/3
- In case of space diversity, the antenna can have a 60% clearance at k=4/3 plus allowance for tree growth, buildings (usually 3 meter)

Microwave Link Design

شاهین ارتباط تهران

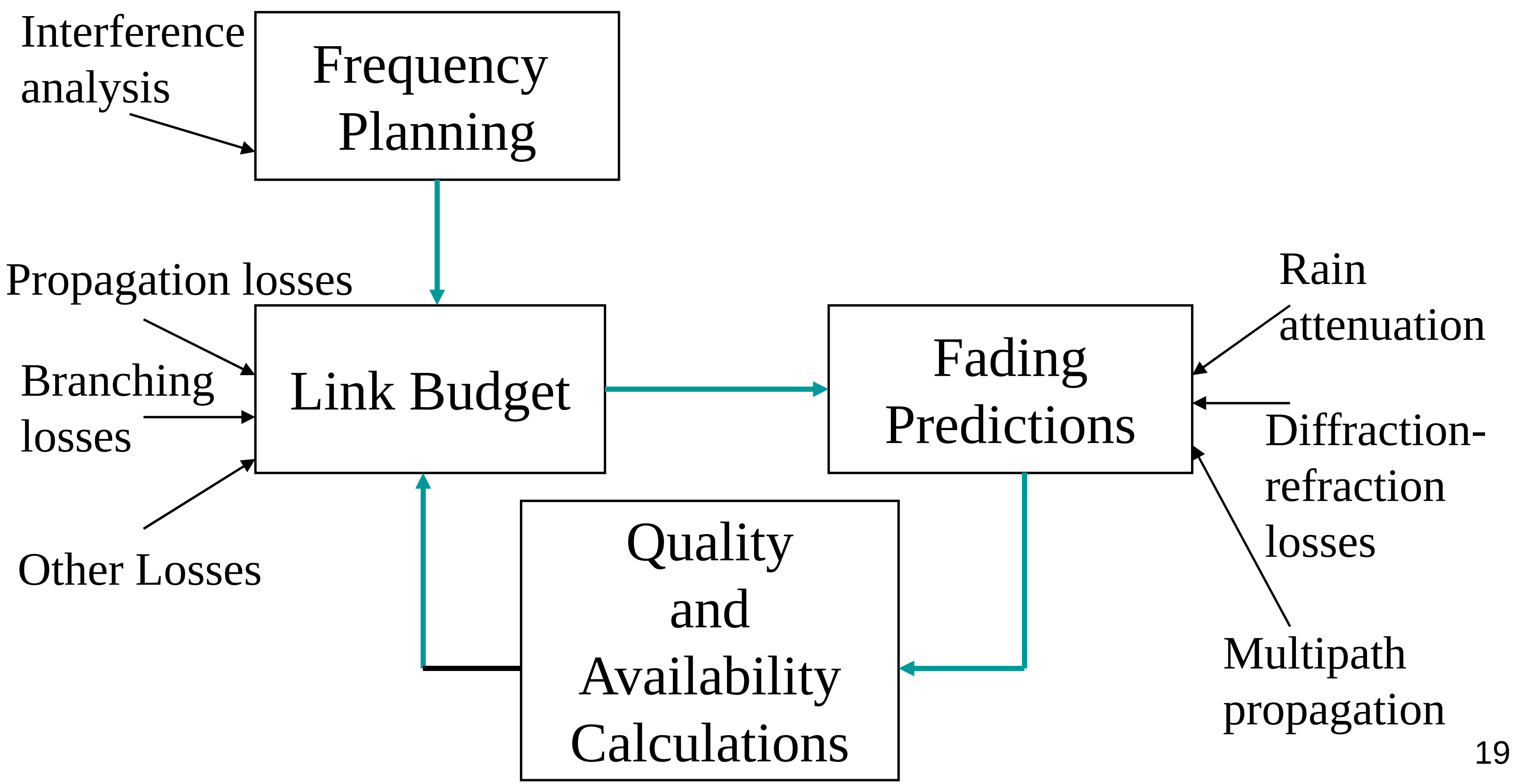
Microwave Link Design is a methodical, systematic and sometimes lengthy process that includes:

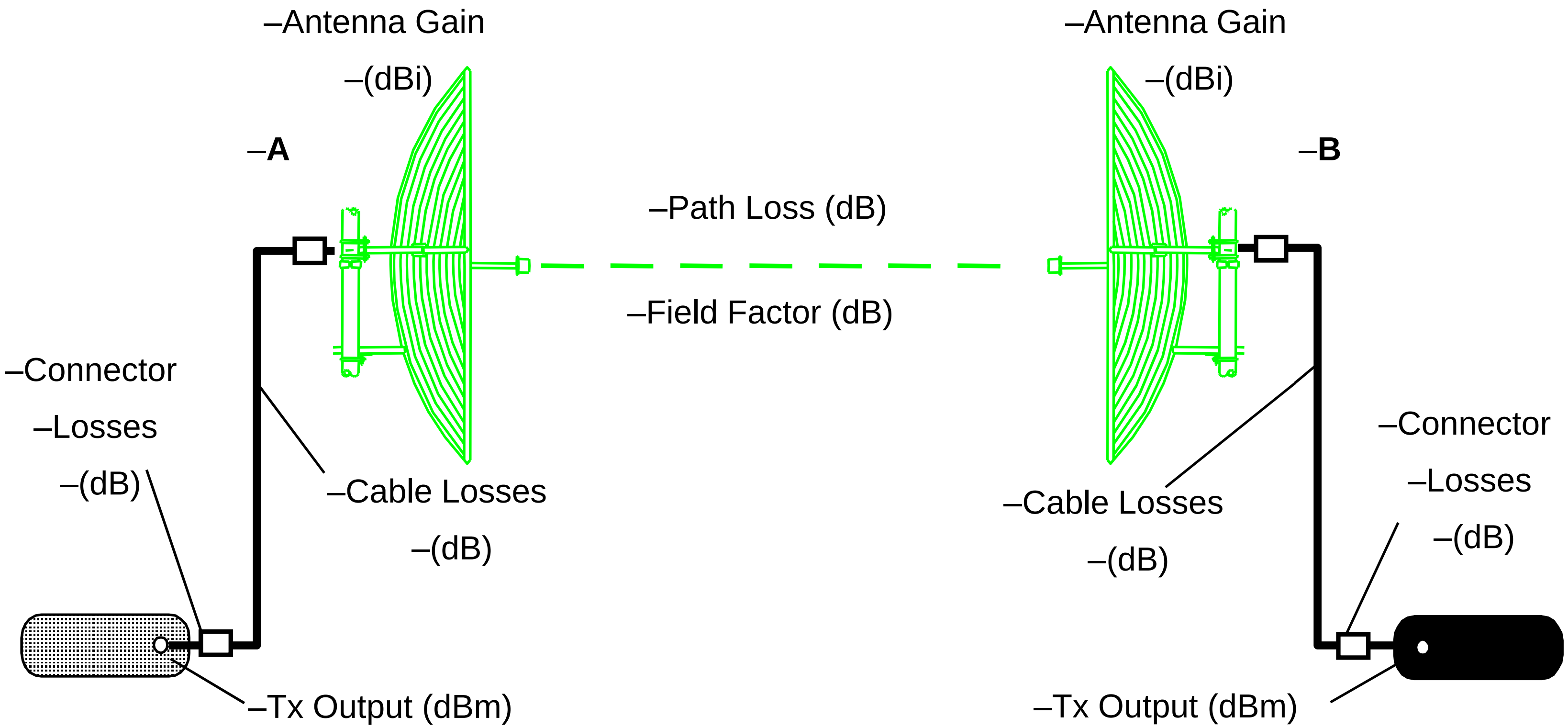
- Loss/attenuation Calculations
- Fading and fade margins calculations
- Frequency planning and interference calculations
- Quality and availability calculations

Microwave Link Design Process

شاهین ارتباط تهران

The whole process is iterative and may go through many redesign phases before the required quality and availability are achieved





–**Received Signal Level** – (dBm) = Tx Output (dBm) - Path

–Loss(dB) - Field Factor (dB) + Total Antenna Gains (dB) - Total

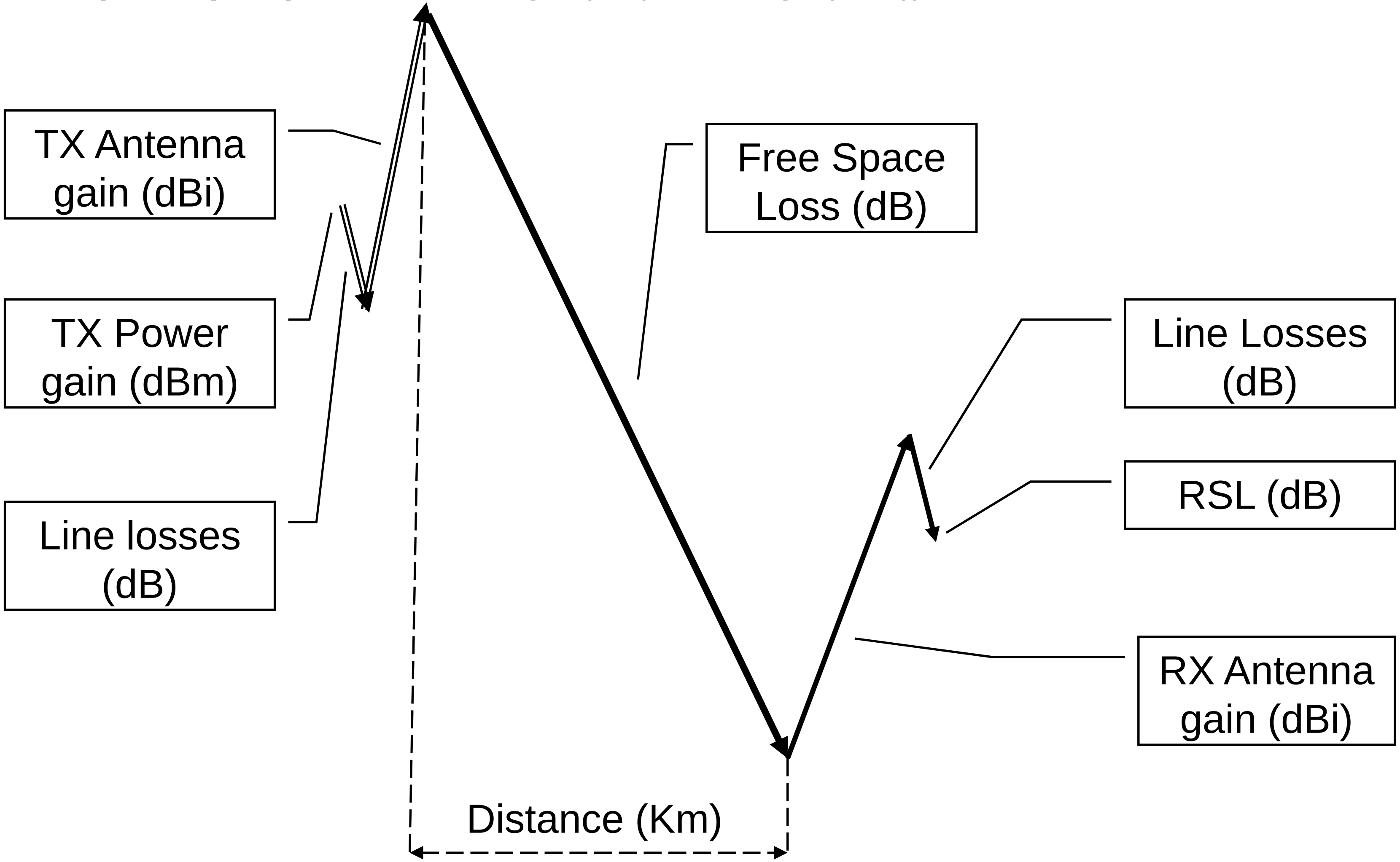
–Cable Losses (dB) - Total Connector Losses (dB)

Path Calculation Diagram & Formula

شاهین ارتباط تهران

RSL= TX power – line TX losses +TX Ant Gain - LFS+ RX Ant Gain - line TX losses

Loss (Free Space) = 92.4 + 20 Log d (Km) + 20 Log f (GHz))



RSL= Receive Level Signal
LFS = loss Free Space

Loss / Attenuation Calculations

شاهین ارتباط تهران

The loss/attenuation calculations are composed of three main contributions

- Propagation losses

  (Due to Earth's atmosphere and terrain)

- Branching losses

  (comes from the hardware used to deliver the transmitter/receiver output to/from the antenna)

Loss / Attenuation Calculations

شاهین ارتباط تهران

– Miscellaneous (other) losses

(unpredictable and sporadic in character like fog, moving objects crossing the path, poor equipment installation and less than perfect antenna alignment etc)

This contribution is not calculated but is considered in the planning process as an additional loss

Propagation Losses

شاهين ارتباط تهران

- Free-space loss - when the transmitter and receiver have a clear, unobstructed line-of-sight

L_{fsl}= 92.45+20log(f)+20log(d)   [dB]

where f = frequency (GHz)

d = LOS range between antennas (km)

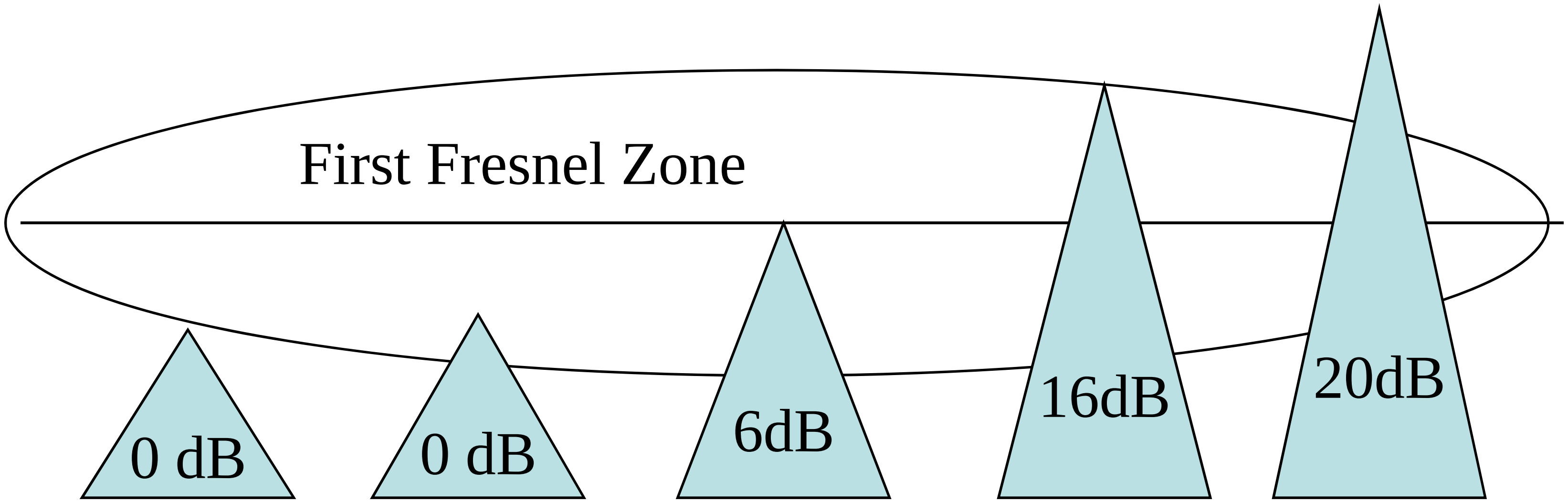
- Vegetation attenuation (provision should be taken for 5 years of vegetation growth)
  $L=0.2f^{0.3}R^{0.6}$(dB)
  f=frequency (MHz)
  R=depth of vegetation in meter's (for $R<400$m)

Propagation Losses

شاهین ارتباط تهران

- **Obstacle Loss –also called Diffraction Loss or Diffraction Attenuation. One method of calculation is based on knife edge approximation.**

  Having an obstacle free 60% of the Fresnel zone gives 0 dB loss



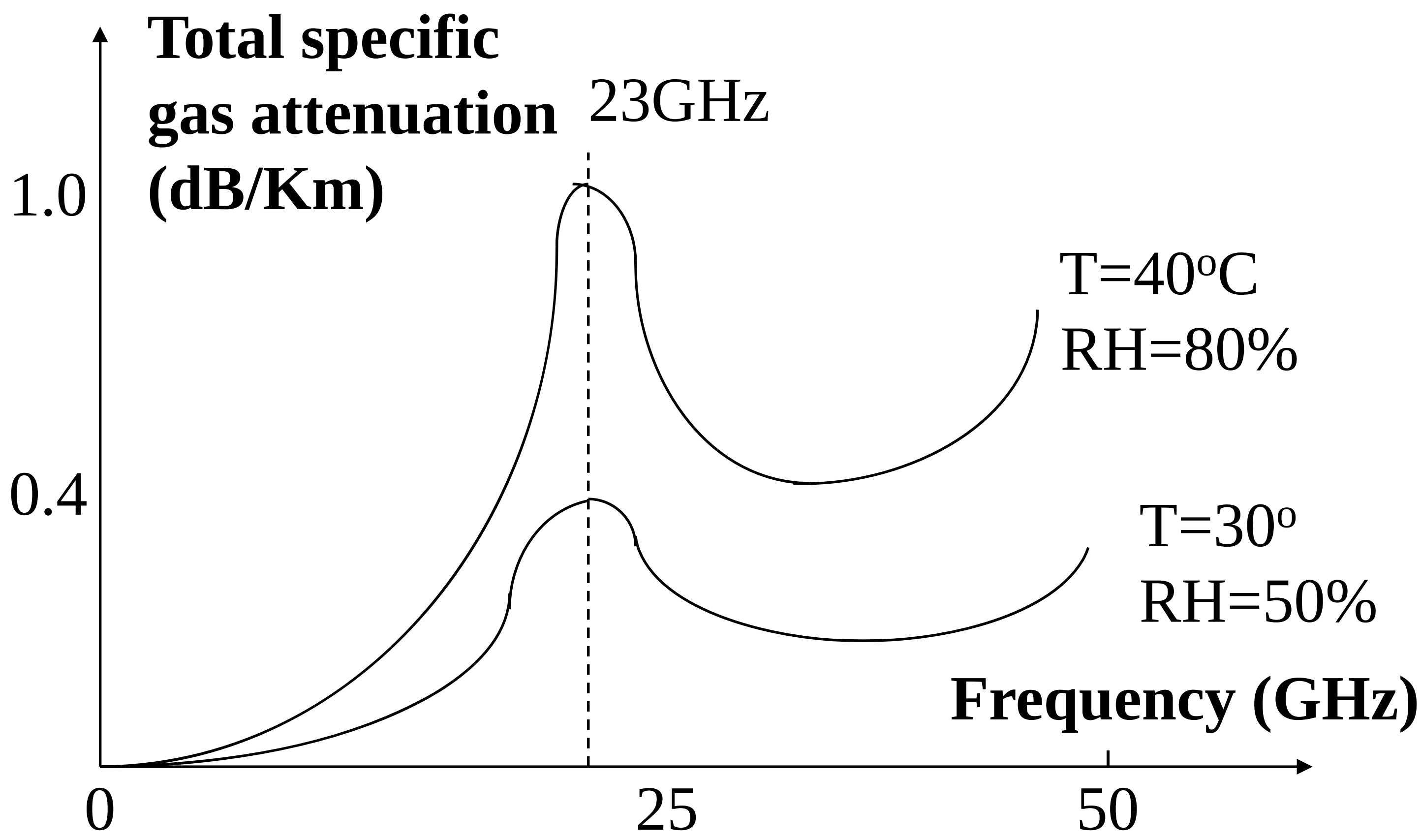
Propagation Losses

شاهین ارتباط تهران

- Gas absorption
  - Primarily due to the water vapor and oxygen in the atmosphere in the radio relay region.The absorption peaks are located around 23GHz for water molecules and 50 to 70 GHz for oxygen molecules.The specific attenuation (dB/Km)is strongly dependent on frequency, temperature and the absolute or relative humidity of the atmosphere.

Gas attenuation versus frequency

شاهین ارتباط تهران



Propagation Losses

شاهین ارتباط تهران

- **Attenuation due to precipitation**
  - **Rain attenuation is the main contributor in the frequency range used by commercial radio links**
  - **Rain attenuation increases exponentially with rain intensity**
  - **The percentage of time for which a given rain intensity is attained or exceeded is available for 15 different rain zones covering the entire earth's surface**

Propagation Losses

شاهين ارتباط تهران

- The specific attenuation of rain is dependent on many parameters such as the form and size of distribution of the raindrops, polarization, rain intensity and frequency
- Horizontal polarization gives more rain attenuation than vertical polarization
- Rain attenuation increases with frequency and becomes a major contributor in the frequency bands above 10 GHz
- The contribution due to rain attenuation is not included in the link budget and is used only in the calculation of rain fading

Ground Reflection

شاهین ارتباط تهران

- Reflection on the Earth’s surface may give rise to multipath propagation
- The direct ray at the receiver may interfered with by the ground-reflected ray and the reflection loss can be significant
- Since the refraction properties of the atmosphere are constantly changing the reflection loss varies.

Ground Reflection

شاهین ارتباط تهران

- The loss due to reflection on the ground is dependent on the total reflection coefficient of the ground and the phase shift
- The highest value of signal strength is obtained for a phase angle of 0^o and the lowest value is for a phase angle of 180^o
- The reflection coefficient is dependent on the frequency, grazing angle (angle between the ray beam and the horizontal plane), polarization and ground properties

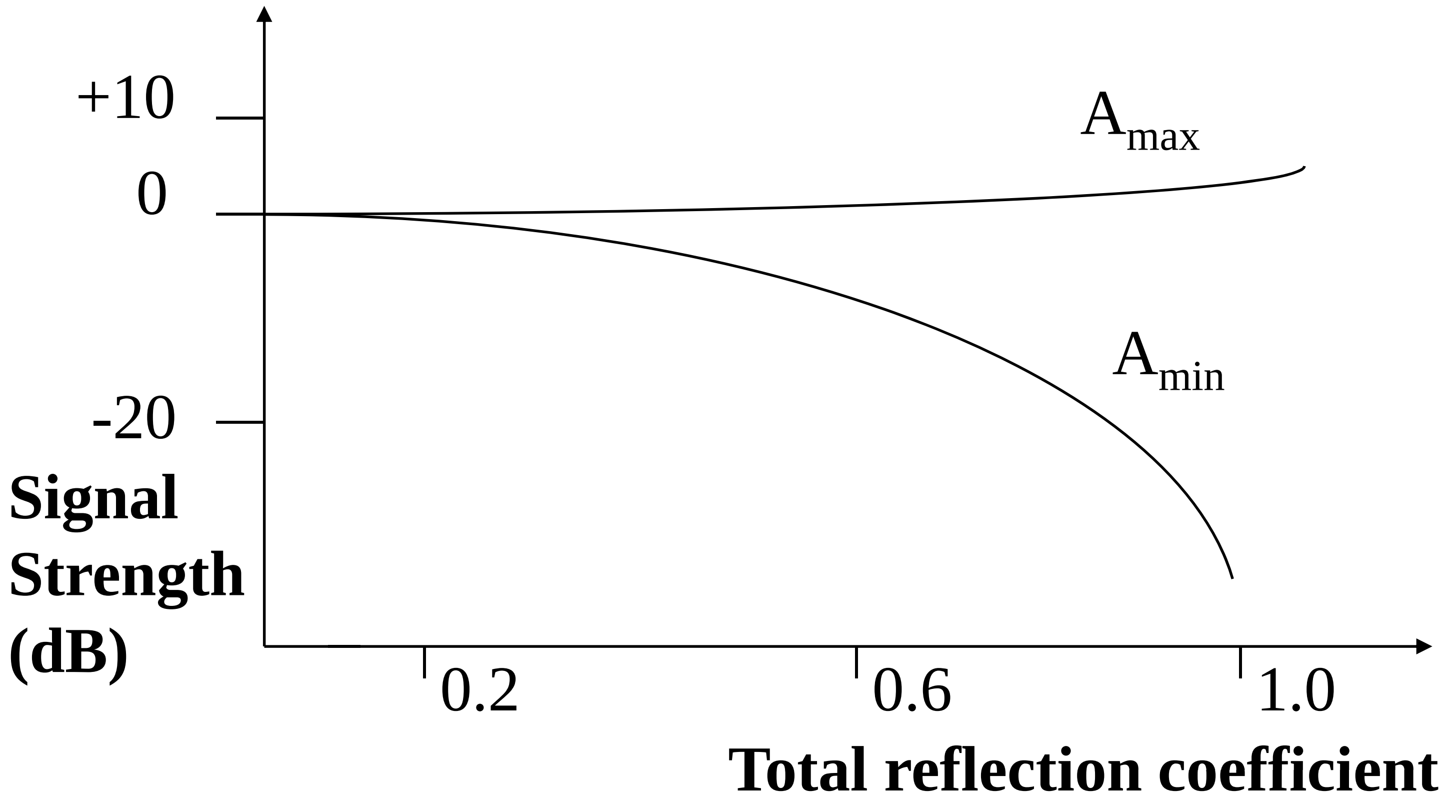
Ground Reflection

شاهین ارتباط تهران

- The grazing angle of radio-relay paths is very small – usually less than 1^{o}
- It is recommended to avoid ground reflection by shielding the path against the indirect ray
- The contribution resulting from reflection loss is not automatically included in the link budget.When reflection cannot be avoided, the fade margin may be adjusted by including this contribution as “additional loss” in the link budget

Signal strength versus reflection coefficient

شاهین ارتباط تهران



Link Budget

شاهین ارتباط تهران

The link budget is a calculation involving the gain and loss factors associated with the antennas, transmitters, transmission lines and propagation environment, to determine the maximum distance at which a transmitter and receiver can successfully operate

Link Budget

شاهین ارتباط تهران

- Receiver sensitivity threshold is the signal level at which the radio runs continuous errors at a specified bit rate

- System gain depends on the modulation used (2PSK, 4PSK, 8PSK, 16QAM, 32QAM, 64QAM,128QAM,256QAM) and on the design of the radio

Link Budget

- The **gains from the antenna** at each end are added to the system gain (larger antennas provide a higher gain).
- The free space loss of the radio signal is subtracted. The longer the link the higher the loss
- These calculations give the fade margin
- In most cases since the same duplex radio setup is applied to both stations the calculation of the received signal level is independent of direction

Link Budget

شاهین ارتباط تهران

Receive Signal Level (RSL)

$$\mathbf{RSL = P_o - L_{ctx} + G_{atx} - L_{crx} + G_{atx} - FSL}$$

Link feasibility formula

RSL ≥ **Rx** (receiver sensitivity threshold)

P_o = output power of the transmitter (dBm)

L_{ctx}, L_{crx} = Loss (cable,connectors, branching unit) between transmitter/receiver and antenna(dB)

G_{atx} = gain of transmitter/receiver antenna (dBi)

FSL = free space loss (dB)

شاهین ارتباط تهران

Link Budget

- The fade margin is calculated with respect to the receiver threshold level for a given bit-error rate (BER).The radio can handle anything that affects the radio signal within the fade margin but if it is exceeded, then the link could go down and therefore become unavailable

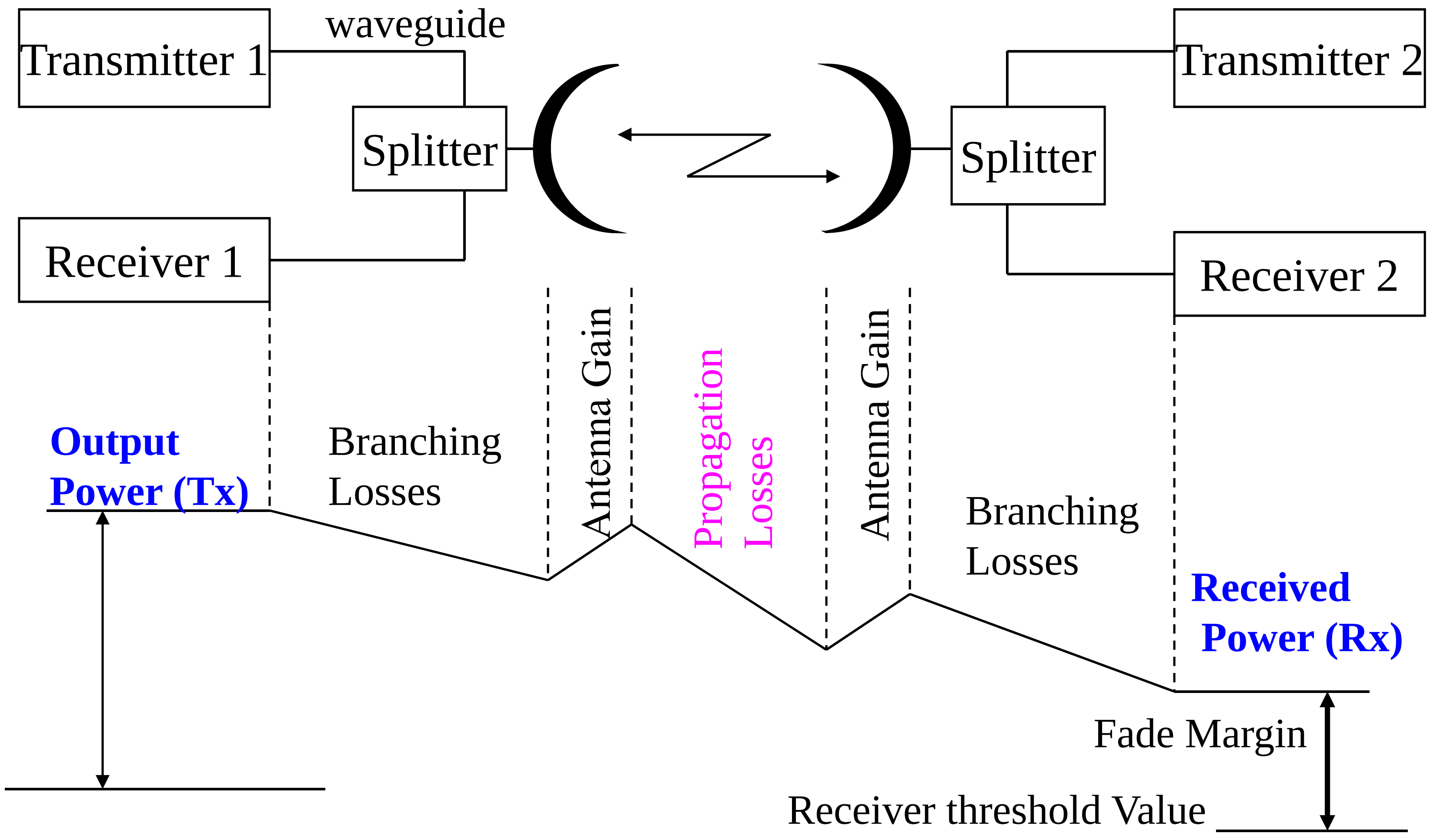
Link Budget

شاهین ارتباط تهران

- The threshold level for BER=10^{-6} for microwave equipment used to be about 3dB higher than for BER=10^{-3}. Consequently the fade margin was 3 dB larger for BER=10^{-6} than BER=10^{-3}. In new generation microwave radios with power forward error correction schemes this difference is 0.5 to 1.5 dB

Radio path link budget

شاهین ارتباط تهران



Fading and Fade margins

Fading is defined as the variation of the strength of a received radio carrier signal due to atmospheric changes and/or ground and water reflections in the propagation path. Four fading types are considered while planning links.They are all dependent on path length and are estimated as the probability of exceeding a given (calculated) fade margin

Fading and Fade margins

- Multipath fading
  - Flat fading
  - Frequency-selective fading
- Rain fading
- Refraction-diffraction fading (k-type fading)

Fading and Fade margins

شاهین ارتباط تهران

- Multipath Fading is the dominant fading mechanism for frequencies lower than 10GHz. A reflected wave causes a multipath, i.e.when a reflected wave reaches the receiver as the direct wave that travels in a straight line from the transmitter
- If the two signals reach in phase then the signal amplifies. This is called upfade

Fading and Fade margins

شاهین ارتباط تهران

- $Upfade_{max}$=10 log d – 0.03d (dB)
  d is path length in Km

- If the two waves reach the receiver out of phase they weaken the overall signal. A location where a signal is canceled out by multipath is called null or downfade
- As a thumb rule, multipath fading, for radio links having bandwidths less than 40MHz and path lengths less than 30Km is described as flat instead of frequency selective

Fading and Fade margins

شاهین ارتباط تهران

Flat fading

- **A fade where all frequencies in the channel are equally affected.There is barely noticeable variation of the amplitude of the signal across the channel bandwidth**
- **If necessary flat fade margin of a link can be improved by using larger antennas, a higher-power microwave transmitter, lower –loss feed line and splitting a longer path into two shorter hops**
- **On water paths at frequencies above 3 GHz, it is advantageous to choose vertical polarization**

Fading and Fade margins

شاهين ارتباط تهران

Frequency-selective fading

- There are amplitude and group delay distortions across the channel bandwidth
- It affects medium and high capacity radio links (>32 Mbps)
- The sensitivity of digital radio equipment to frequency-selective fading can be described by the signature curve of the equipment
- This curve can be used to calculate the Dispersive Fade Margin (DFM)

Fading and Fade margins

شاهین ارتباط تهران

$$DFM = 17.6 - 10\log[2(\Delta f)e^{-B/3.8}/158.4] \text{ dB}$$

Δf = signature width of the equipment

B = notch depth of the equipment

- Modern digital radios are very robust and immune to spectrum- distorting fade activity. Only a major error in path engineering (wrong antenna or misalignment) over the high-clearance path could cause dispersive fading problems

Fading and Fade margins

شاهین ارتباط تهران

- **Rain Fading**
  - **Rain attenuates the signal caused by the scattering and absorption of electromagnetic waves by rain drops**
  - **It is significant for long paths (>10Km)**
  - **It starts increasing at about 10GHz and for frequencies above 15 GHz, rain fading is the dominant fading mechanism**
  - **Rain outage increases dramatically with frequency and then with path length**

Fading and Fade margins

شاهین ارتباط تهران

- Microwave path lengths must be reduced in areas where rain outages are severe
- The available rainfall data is usually in the form of a statistical description of the amount of rain that falls at a given measurement point over a period of time.The total annual rainfall in an area has little relation to the rain attenuation for the area
- Hence a margin is included to compensate for the effects of rain at a given level of availability. Increased fade margin (margins as high as 45 to 60dB) is of some help in rainfall attenuation fading.

Fading and Fade margins

- Reducing the Effects of Rain
  - **Multipath fading is at its minimum during periods of heavy rainfall with well aligned dishes, so entire path fade margin is available to combat the rain attenuation (wet-radome loss effects are minimum with shrouded antennas)**
  - **When permitted, crossband diversity is very effective**
  - **Route diversity with paths separated by more than about 8 Km can be used successfully**

Fading and Fade margins

شاهین ارتباط تهران

ATPC

- **Radios with Automatic Transmitter Power Control have been used in some highly vulnerable links**
- **Vertical polarization is far less susceptible to rainfall attenuation (40 to 60%) than are horizontal polarisation frequencies.**

Fading and Fade Margins

شاهین ارتباط تهران

Refraction – Diffraction Fading

- Also known as k-type fading
- For low k values, the Earth's surface becomes curved and terrain irregularities, man-made structures and other objects may intercept the Fresnel Zone.
- For high k values, the Earth's surface gets close to a plane surface and better LOS(lower antenna height) is obtained
- The probability of refraction-diffraction fading is therefore indirectly connected to obstruction attenuation for a given value of Earth – radius factor
- Since the Earth-radius factor is not constant, the probability of refraction-diffraction fading is calculated based on cumulative distributions of the Earth-radius factor

Frequency planning

شاهین ارتباط تهران

- The objective of frequency planning is to assign frequencies to a network using as few frequencies as possible and in a manner such that the quality and availability of the radio link path is minimally affected by interference. The following aspects are the basic considerations involved in the assignment of radio frequencies

Frequency planning

شاهین ارتباط تهران

- **Determining a frequency band** that is suitable for the specific link (path length, site location, terrain topography and atmospheric effects)
- **Prevention of mutual interference** such as interference among radio frequency channels in the actual path, interference to and from other radio paths, interference to and from satellite communication systems
- Correct selection of a frequency band allows the required transmission capacity while efficiently utilizing the available radio frequency spectrum

Frequency planning

شاهین ارتباط تهران

- Assignment of a radio frequency or radio frequency channel is the authorization given by an administration for a radio station to use a radio frequency or radio frequency channel under specified conditions. It is created in accordance with the Series F recommendations given by the ITU-R. In IRAN the authority is CRA (Communications Regulatory Authority) www.cra.ir

Frequency planning

- Frequency channel arrangements

  The available frequency band is subdivided into two halves, a lower (go) and an upper (return) duplex half. The duplex spacing is always sufficiently large so that the radio equipment can operate interference free under duplex operation. The width of each channel depends on the capacity of the radio link and the type of modulation used

Frequency planning

شاهین ارتباط تهران

- The most important goal of frequency planning is to allocate available channels to the different links in the network without exceeding the quality and availability objectives of the individual links because of radio interference.

Frequency planning

شاهین ارتباط تهران

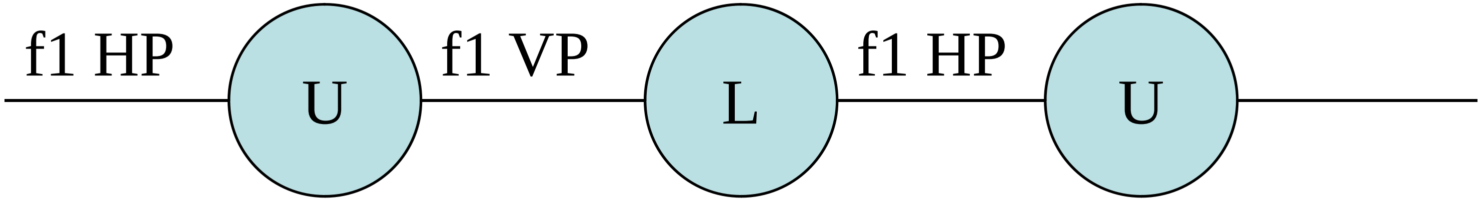
- Frequency planning of a few paths can be carried out manually but, for larger networks, it is highly recommended to employ a software transmission design tool. One such vendor independent tool is Pathloss 4.0. This tool is probably one of the best tools for complex microwave design.

  It includes ITU standards, different diversity schemes, diffraction and reflection (multipath) analysis, rain effects, interference analysis etc.

Frequency planning for different network topologies

شاهین ارتباط تهران

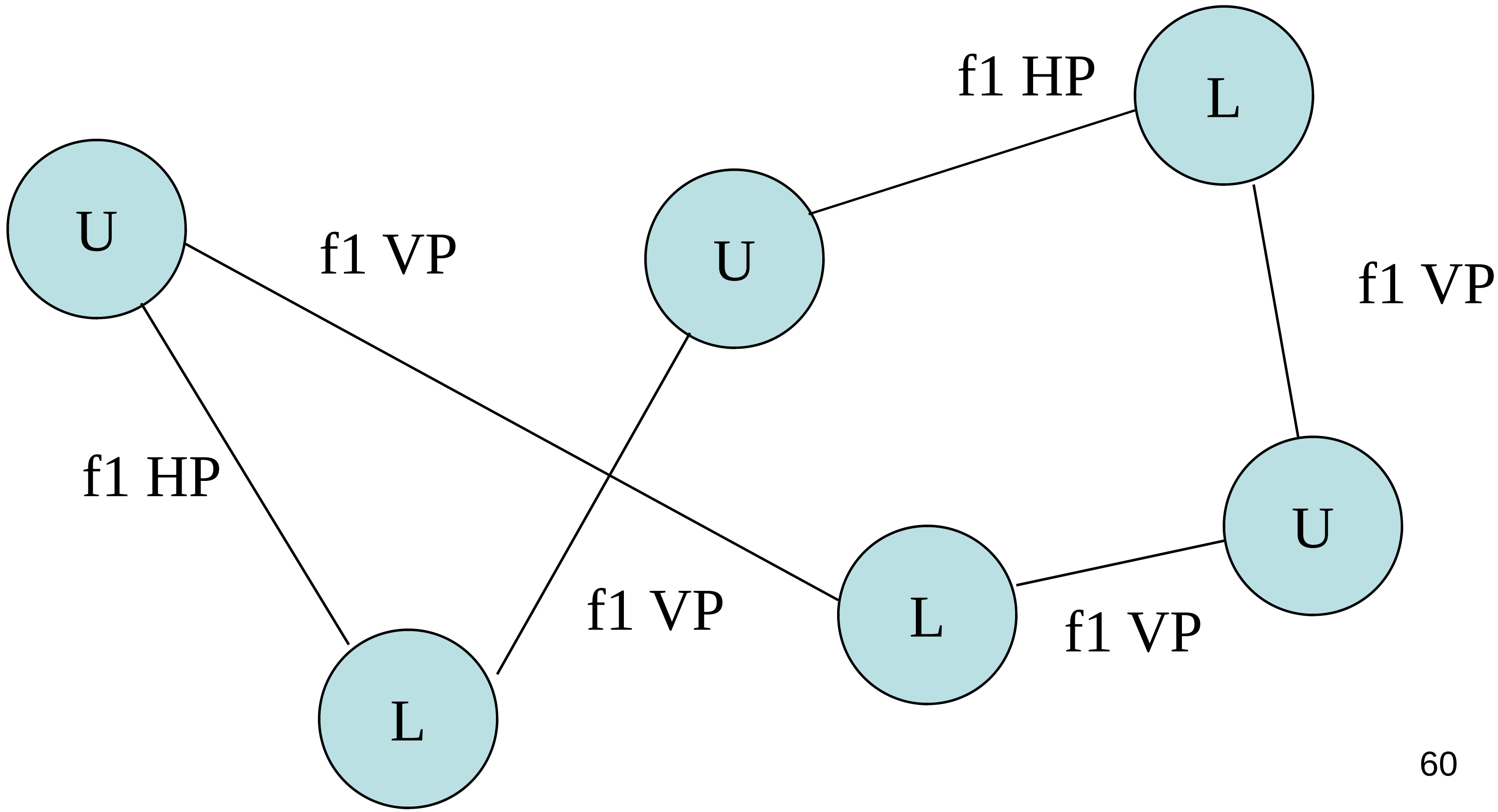
Chain/cascade configuration



Ring configuration

شاهین ارتباط تهران

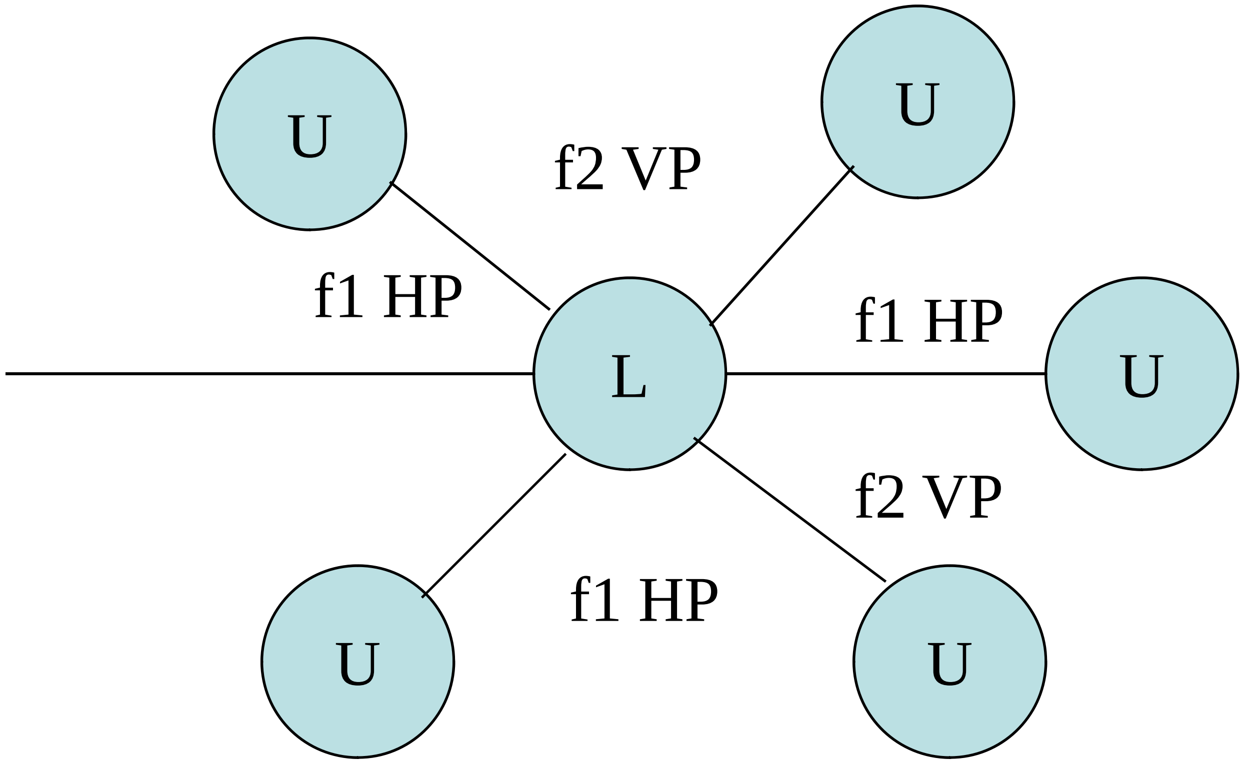
- If the ring consisted of an odd number of sites there would be a conflict of duplex halves and changing the frequency band would be a reliable alternative



Star configuration

شاهین ارتباط تهران

- The link carrying the traffic out of the hub should use a frequency band other than the one employed inside the cluster



Interference fade margin

شاهین ارتباط تهران

To accurately predict the performance of a digital radio path, the effect of interference must be considered.

Interference in microwave systems is caused by the presence of an undesired signal in a receiver.

When this undesired signal exceeds certain limiting values, the quality of the desired received signal is affected. To maintain reliable service, the ratio of the desired received signal to the (undesired) interfering signal should always be larger than the threshold value.

Interference fade margin

شاهين ارتباط تهران

- In normal unfaded conditions the digital signal can tolerate high levels of interference but in deep fades it is critical to control interference.
- **Adjacent-channel interference fade margin (AIFM)** (in decibels) accounts for receiver threshold degradation due to interference from adjacent channel transmitters
- **Interference fade margin (IFM)** is the depth of fade to the point at which RF interference degrades the BER to $1x\ 10^{-3}$. The actual IFM value used in a path calculation depends on the method of frequency coordination being used.

Interference fade margin

شاهین ارتباط تهران

- **There are two widely used methods.**
  - **The C/I (carrier to interference) and The T/I (threshold to interference) methods.**

C/I method is the older method developed to analyse interference cases into analog radios. In the new T/I method, threshold-to-interference (T/I) curves are used to define a curve of maximum interfering power levels for various frequency separations between interfering transmitter and victim receivers as follows

Interference fade margin

شاهین ارتباط تهران

$$I = T - (T/I)$$

where

I = maximum interfering power level (dBm)

T= radio threshold for a 10^{-6} BER (dBm)

T/I = threshold-to-interference value (dB) from the T/I curve for the particular radio

Interference fade margin

شاهین ارتباط تهران

For each interfering transmitter, the receive power level in dBm is compared to the maximum power level to determine whether the interference is acceptable. The T/I curves are based on the actual lab measurements of the radio.

Composite Fade Margin (CFM) is the fade margin applied to multipath fade outage equations for a digital microwave radio

Interference fade margin

شاهین ارتباط تهران

CFM = TFM + DFM + IFM + AIFM

$= -10 \log (10^{-TFM/10} + 10^{-DFM/10} + 10^{-IFM/10} + 10^{-AIFM/10})$

Where:

TFM = Flat fade margin (the difference between the normal (unfaded) RSL and the BER=1 x10^{-3} digital signal loss-of frame point)

DFM = Dispersive fade margin

IFM = Interference fade margin

AIFM =Adjacent-channel interference fade margin

Interference fade margin

شاهین ارتباط تهران

Microwave Link Multipath Outage Models

A major concern for microwave system users is how often and for how long a system might be out of service. An outage in a digital microwave link occurs with a loss of Digital Signal frame sync for more than 10 sec. Digital signal frame loss typically occurs when the BER increases beyond 1×10^{-3}.

Interference fade margin

شاهين ارتباط تهران

Outage (Unavailability) (%) = (SES/t) x 100

where

t = time period (expressed in seconds)

SES = severely errored second

Availability is expressed as a percentage as : -

A = 100 - Outage (Unavailability)

A digital link is unavailable for service or performance prediction/verification after a ten consecutive BER> 1 x 10^{-3} SES outage period.

Quality and Availability

- The main purpose of the quality and availability calculations is to set up reasonable quality and availability objectives for the microwave path.The ITU-T recommendations G.801, G.821 and G.826 define error performance and availability objectives. The objectives of digital links are divided into separate grades: high, medium and local grade. The medium grade has four quality classifications.

Quality and Availability

شاهین ارتباط تهران

The following grades are usually used in wireless networks:-

Medium grade Class 3 for the access network

High grade for the backbone network

Improving the Microwave System

- Hardware Redundancy
  - Hot standby protection
  - Multichannel and multiline protection
- Diversity Improvement
  - Space Diversity
  - Angle Diversity
  - Frequency Diversity
  - Crossband Diversity
  - Route Diversity
  - Hybrid Diversity
  - Media Diversity

Improving the Microwave System

شاهین ارتباط تهران

- Antireflective Systems
- Repeaters
  - Active repeaters
  - Passive repeaters

Basic Recommendations

- Use higher frequency bands for shorter hops and lower frequency bands for longer hops
- Avoid lower frequency bands in urban areas
- Use star and hub configurations for smaller networks and ring configuration for larger networks
- In areas with heavy precipitation , if possible, use frequency bands below 10 GHz.
- Use protected systems (1+1) for all important and/or high-capacity links
- Leave enough spare capacity for future expansion of the system

- Space diversity is a very expensive way of improving the performance of the microwave link and it should be used carefully and as a last resort
- The activities of microwave path planning and frequency planning preferably should be performed in parallel with line of sight activities and other network design activities for best efficiency.
- Use updated maps that are not more than a year old. The terrain itself can change drastically in a very short time period. Make sure everyone on the project is using the same maps, datums and coordinate systems.

- Perform detailed path surveys on ALL microwave hops. Maps are used only for initial planning, as a first approximation.
- Below 10 GHz , multipath outage increases rapidly with path length.It also increases with frequency, climatic factors and average annual temperature. Multipath effect can be reduced with higher fade margin. If the path has excessive path outage the performance can be improved by using one of the diversity methods.

Difficult Areas for Microwave Links

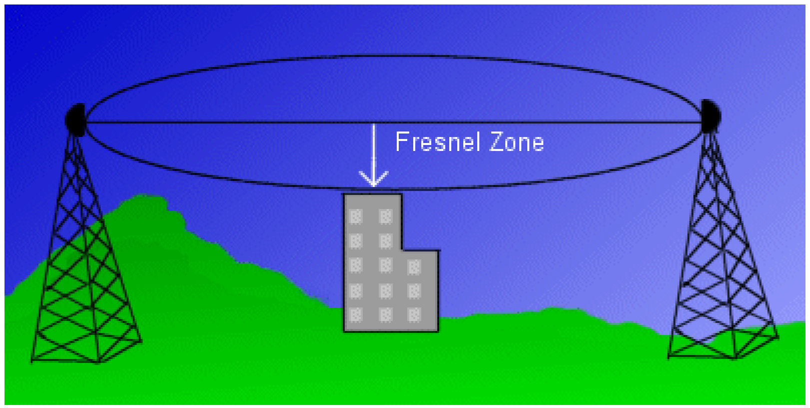
شاهین ارتباط تهران

- In areas with lots of rain, use the lowest frequency band allowed for the project.
- Microwave hops over or in the vicinity of the large water surfaces and flat land areas can cause severe multipath fading. Reflections may be avoided by selecting sites that are shielded from the reflected rays.
- Hot and humid coastal areas

Fresnel Zone – About Height

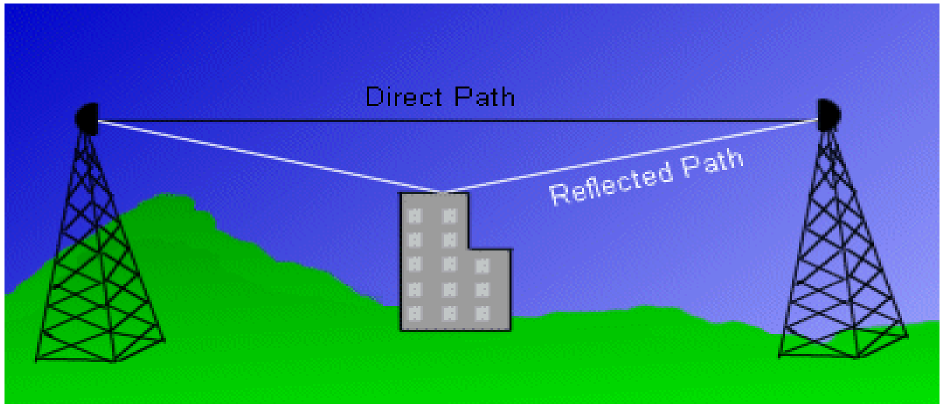
شاهین ارتباط تهران

- The Fresnel effect is one of the most common reasons point to point links do not perform as expected and is often overlooked



Reflections – About Position

- Signals can cancel each other out which leads to signal strength loss.
- The receiver gets confused because it receives two signals



شاهین ارتباط تهران

Thank you !

Reza Moazzami
Shaahin Communication
Telephone: +98 21 2286-7182
E-mail: moazzami@shaahin.com
Bahman 1386