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Negative Role of Atmosphere On Free Space Light Communication

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Abstract— When every a communication system is to be designed whether wireless or wired, the first and the most important issue which is to be considered is about the features possess by the medium through which communication will take place and whether those features will induce a negative role on it or not. In free space light communication technique, it is clear by the name that the atmosphere is being used as a medium for carrying or transferring data using infrared carrier. Various atmospheric phenomena do play a negative role on light communication and what we term them as attenuation phenomenal. This paper deals with such various phenomena and its negative role on free space light communication technique. Also why IR wave is preferred for free space light communication is also explained.

Keywords— Free space light communication (FSLC), Infrared wave (IR), penetration depth (Dp), signal to noise ratio (SNR), bit error rate (BER).

INTRODUCTION

At one time, connecting all of the people at all time around the world was a nice idea but completely impractical. Even communication using light was never imagined that some day it would take a real face. Today's commercially available FSLC systems operate in the near IR spectral windows located around 850 nm and 1550 nm. Even a clean, clear atmosphere is composed of oxygen and nitrogen molecules. The weather can contribute large amounts of water vapor. Other constituents can exist, as well, especially in polluted regions. These particles can scatter or absorb infrared photons propagating in the atmosphere.

ADVANTAGES OF USING LIGHT OVER RADIO WAVE

Free space light communication versus radio communication

Advantage of FSLC over radio communication is its no interference with external fields (magnetic and electric) as well as they do not cause EMI themselves. No problem jamming. Another advantage is that it can carry data over a very long distance than radio waves without using repeaters frequently. Below Fig.1 and Fig.2 shows the difference between them.

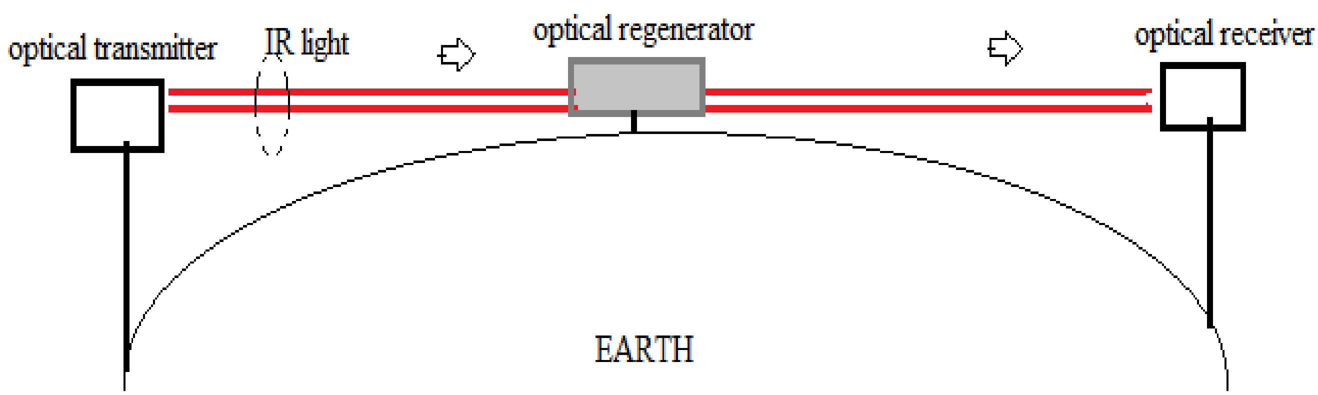

Fig.1: FSLC using IR wave

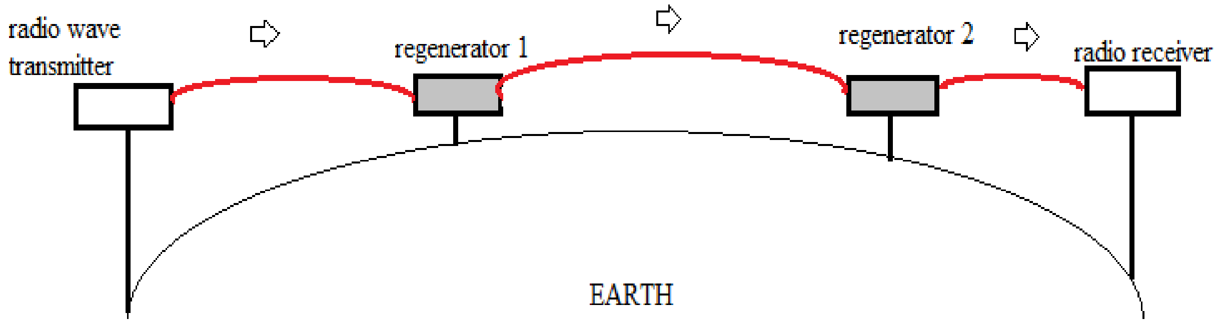

Fig.2: Radio Communication

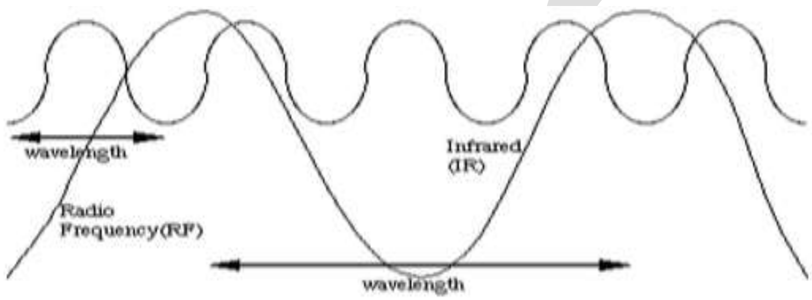

Fig.3. depicts an infrared energy wave and a radio energy wave

PENETRATION POWER OF IR WAVE AND DEPENDENCY OF RECEIVER'S POWER

Penetration power of IR and receiver unit's light capturing strength plays a major role in overcoming various atmospheric attenuation.

Penetration power of IR wave used in FSLC technique

Knowledge about IR penetration depth (Dp) is very important while designing FSLC and separation distance between transmitter and receiver. IR wave has high penetration power than visible light. Hence communication using IR wave is highly preferred. IR can easily penetrate and can pass well when atmospheric condition is not heavily bad. IR suffers from high scattering, distortion, absorption and blocking when atmospheric condition is very bad. We may think that increasing the strength/intensity of transmitted IR will help overcome such penetration loss. This is true up to some level. This means that if the power of IR which is being transmitted is increased by 2 times, do not indicate that the penetration depth is also increased by 2 times. Penetration will only increase by approximately 5%. For example, if 100mW laser penetrates a thickness of 10mm and if same laser is driven at 200mW, then penetration dept will be 10.5mm to 10.9mm approximately. This experiment can be tried using your finger and a laser pointer of power 5mW (legally approved value by FDA and will cause no harm to human finger and tissue). Numerically (Dp) has been illustrated below with figure 4.

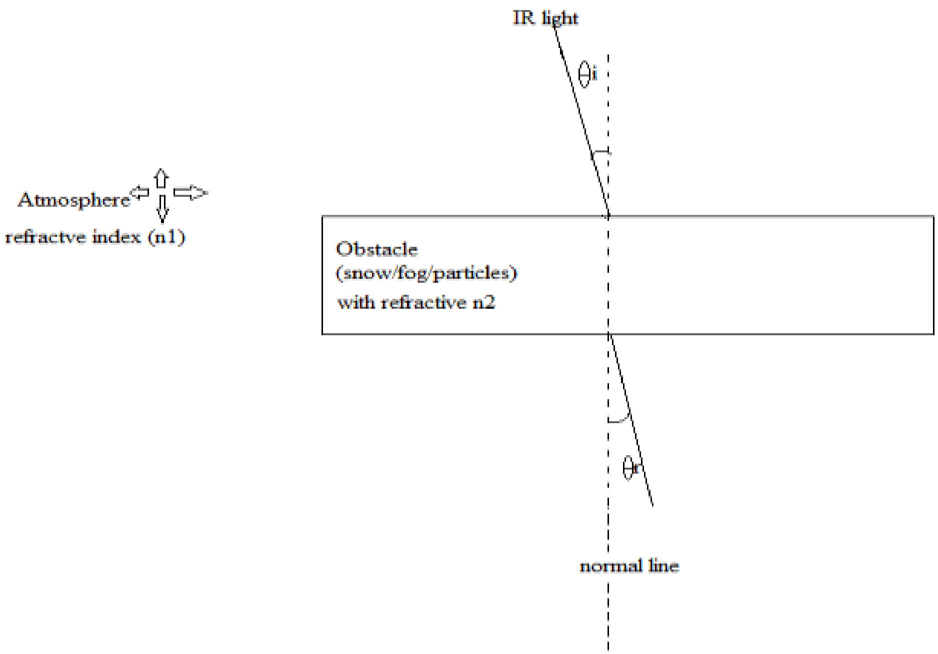

Fig.4: Diagrammatic illustration of penetration depth of IR

$$Dp = \frac{\lambda}{2\pi\sqrt{(n1^2 \sin^2 \theta i - n2^2)}} \qquad (1)$$

Where

λ is wavelength of IR, θ_i is angle of incidence of IR perpendicular to the surface of obstacle, n1 refractive index of incidence medium, n2 refractive index of refractive medium.

Effective penetration (Dp_{eff}) made by IR is given below where ($d\perp$) is depth of perpendicular penetration and ($d_{\parallel}$) depth of parallel penetration.

$$Dp_{eff} = (d\perp + d_{\parallel}) /2 \qquad (2)$$

$$d\perp = \frac{n1^2.n2.cos\theta i}{(n1^2 - n2^2)} \text{ x } \frac{\lambda}{\pi\sqrt{(n1^2 \sin^2 \theta i - n2^2)}} \qquad (3)$$

$$d_{\parallel} = \frac{n1^2.n2.cos\theta i}{(n1^2 - n2^2)} \text{ x } \frac{\lambda}{\pi\sqrt{(n1^2 \sin^2 \theta i - n2^2)}} \text{ x } \frac{2ni^2.sin\theta i^2 - n2^2}{(n1^2 - n2^2).\sin^2 \theta i - n2^2} \qquad (4)$$

Dependency of receiver's power

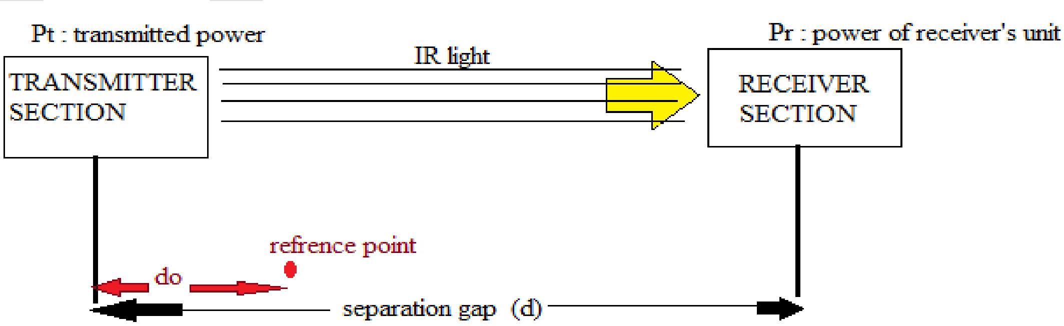

Fig.5: illustration of various factors on which receiver's power depends

In above fig.4, (d_o) represent the distance from the transmitter unit up to the reference point. The reason for measuring (d_o) from transmitter's side is due to the fact that when a signal is transmitted, the strength of the transmitted signal (Pt) is high at this region .Afterward it decreases as it passes through the atmosphere. Dependency of receiver's power (P_r(d)) is given as :

$$P_r(d) \; \alpha \; P_t \; . \left(\frac{do}{d}\right)^2 \tag{5}$$

Typically

d_o = 1 meter ; for indoor communication using IR light.

d_o = >100meters to 10km ; for outdoor.

ATTENUATION AND SCATTERING

Attenuation and scattering are 2 main causes of light power distortion or weakening.

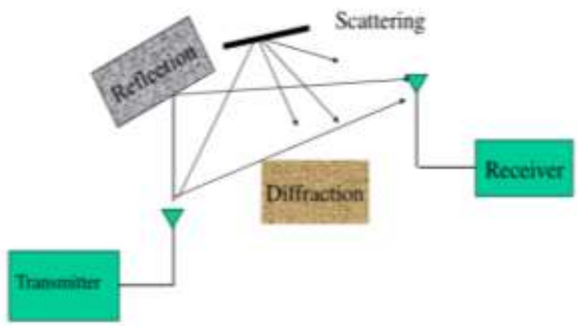

Fig.6: Attenuation and scattering

Attenuation

Attenuation is a phenomenon which contributes in loss of signal strength. It is caused in indoor as well as in outdoor light (IR) communication applications. Attenuation inn outdoor application is based on straight forward calculations. But in contrast, indoor attenuations are very complex as indoor light signals suffers from multiple bounces and penetration through variety of materials causing different levels of attenuations. Below is the table which describes basic objects which causes attenuation and level of attenuation in (dB).

TABLE 1: basic objects causing attenuation and corresponding attenuation level

Objects	***Attenuation level (dB)***
Glass	2
Wall	2
Human body	3
Wood	3
Marble	5
Metal	6
Concrete	10-15
Low fog	25
Heavy fog	120
Rain	24-40

Scattering

Scattering is a phenomenon in which the light's direction is changed or shifted after striking any dust particle of any size. Based on the size of particle, scattering is divided into 3 sub categories (Rayleigh, Mie and Non-selective).

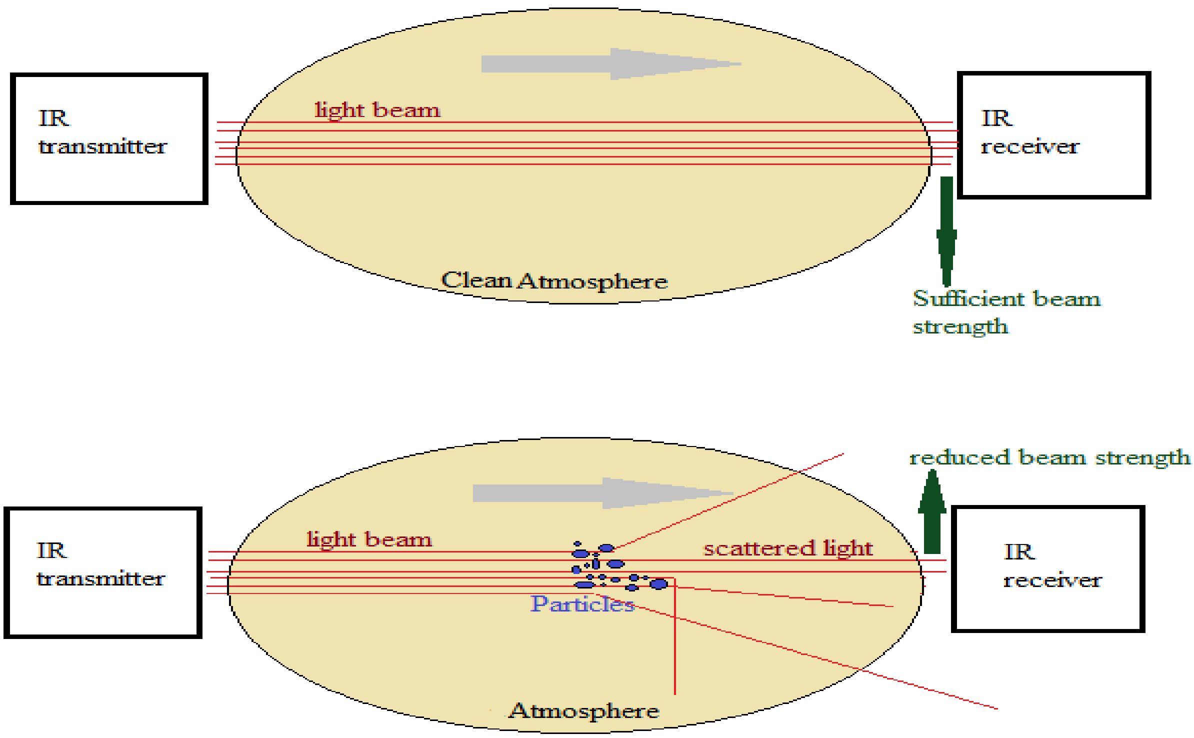

Fig.7: Scattering and its negative effect on receiver

Rayleigh scattering: Caused by those particles whose size is less than wavelength of the scattered light. Example of such particles is air molecule. It occurs at higher atmospheric level. Near IR are scattered more than far IR light.

Mie scattering: Caused by those particles whose size is same as wavelength of the scattered light. Example of such particles is aerosol. It occurs at lower atmospheric level. It influences the complete light spectrum from UV to IR.

Non-selective scattering: Caused by those particles whose size is larger than wavelength of the scattered light. Example of such particles is fog and clouds. It occurs at lowest atmospheric level. Has least effect on IR.

IMPACT OF VARIOUS ATMOSPHERIC ATTENUATIONS ON FSLC COMMUNICATION

Impact of sound on IR light

Sound does affect IR light. Depending on the nature of the medium ie: whether foggy atmosphere or pure atmosphere, sound has less or more significant role on IR light. We know that refractive index of light varies with pressure and a sound wave is nothing more than a pressure wave travelling through the air. Perhaps a picture might explain why the refractive index will change with pressure.

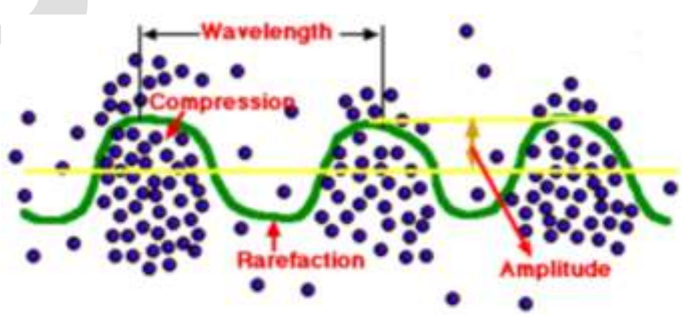

Fig.8: impact of sound on IR light

Impact of fog on IR light

Fog is a visible aggregate of minute water droplets suspended in the atmosphere at or near the surface of the earth. When air is almost saturated with water vapour, this means that the relative humidity is close to 100%, and that fog can form in the presence of a sufficient number of condensation nuclei, which can be smoke or dust particles. There are different types of fog. Advection fog is formed through the mixing of two air masses with different temperatures and/or humidity. Another form is radiative fog. This is formed in a process of radiative cooling of the air at temperatures close to the dew point. Some fogbanks are denser than others because the water droplets have grown bigger through accretion.

In fog conditions droplets can absorb more water and grow considerably in size. There are different ways to classify fog as done in below table 2.

TABLE 2: classification of fog

CATEGORY	***RANGE***
Category I:	visual range 1220 meters
Category II:	visual range 610 meters
Category IIIa:	visual range 305 meters
Category IIIc:	visual range 92 meters

Fog attenuation model:

Attenuation due to fog is a complex function of density, extension, refractive index and wavelength. Normalized fog attenuation (A) concept only deals with the signal wavelength (λ) and temperature of the foggy region (t).

$A = [- 1.347 +0.0372 \lambda + (18/ \lambda) – 0.022t]$ (6)

This is valid only for (3mm < λ < 30cm) and ($-8^0C< t< 25^0C$)

Total fog attenuation (α_{fog}) concept includes the concept of fog density (D) (in g/m^3) and for range (in Km).

$\alpha_{fog = [}$A] X [fog density (in g/m3)] X [fog range (in Km)] (7)

As liquid content decrease, flog density decreases and visibility increases. Thus the IR light receiver can capture or collect much amount of IR light. Visibility is the defined as the distance from an observer at which a minimum contrast ration (c) between black target and bright background is equal to 0.2 (ie: target distinction drops by 2%).

Visibility (v) = $\frac{4.343}{\alpha} \text{In}\frac{1}{c} = \frac{16.99}{\alpha}$ (8)

$V = 0.02D^{-0.6}$ (9)

Relating equations (7) and (8),

α_{fog} = KM (10)

Where K is attenuation coefficient

Impact of atmospheric gases on IR light

Effect of atmospheric gases on long wave IR waves depends on amount of gas by volume, signal's wavelengths. Different gas molecules absorbs different wavelength. Composition of atmosphere includes (N_2, 0_2, H_20, CO_2, CH_4, N_20, 0_3) and chlorofluorocarbon CFCs .Absorption of UV is very high by 0_2 and 0_3 gases. Atmosphere is highly transparent to visible light because its corresponding photon energies are too low for electrons transition. A gas molecule will absorb radiation of specific wavelength only if it can supply energy that can be used to increase internal energy level of the molecule. At this higher state, 3 phenomenal are associated: vibration, rotational and electronic. After absorption of IR light by a molecule if it starts vibrating then its termed as vibration transition and if absorption of IR leads to the generation of free electrons then such transition is termed as electronic.

TABLE 3: transition phenomenon associated with gas molecules after absorption of IR

Electronic transition	Vibration transition	Rotational transition
▪ Transition of electrons to higher electronic state or free state after absorption of IR.	▪ Atoms/molecules vibrate after absorption of IR.	▪ Atoms/molecules start rotating or spinning after absorption of IR.
▪ Generally caused by UV rays	▪ Caused by near IR rays.	▪ Caused by far IR

N_2 and 0_2 are transparent to IR because they have uniform distribution of charges and as a result they do not undergo any of the 3 transition very easily. CO_2 is good absorber of IR because of its easy bending and stretching mechanisms.

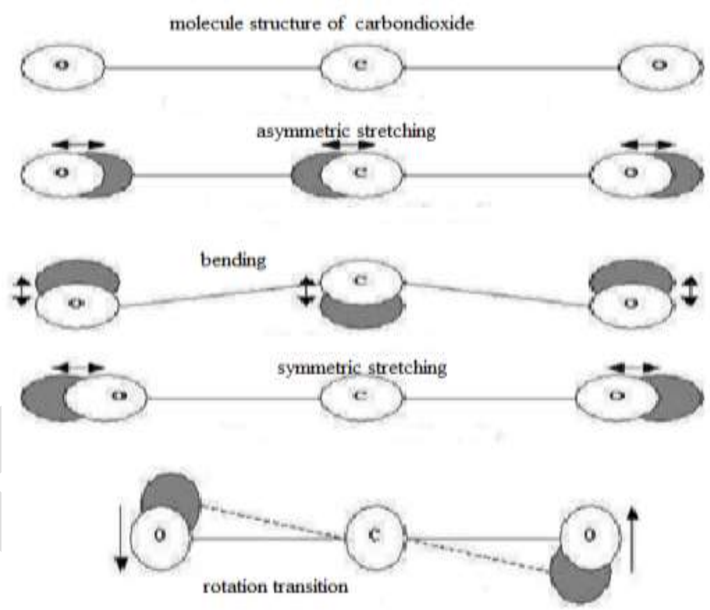

Fig.9: Vibration, rotation, stretching transition associated with carbon dioxide molecule

Water (H_20) is the main absorber of IR. Water content varies about 100 fold between cold and dry desert. Transition happens in various ways in H_20 molecule after absorption of IR. Gaseous phase is associated with vibration and stretching transition. Liquid phase is associated with rotation transition.

Crosstalk between two IR paths

If there is 1 system (ie: transmitter and receiver) and communicating with IR signal then there is no problem of interference. But if 2 systems communicate using IR light then there can arise crosstalk phenomena. Cross talk means cross connection between 2 systems belonging to the same category (in this case both of them are using IR light as data carrier).

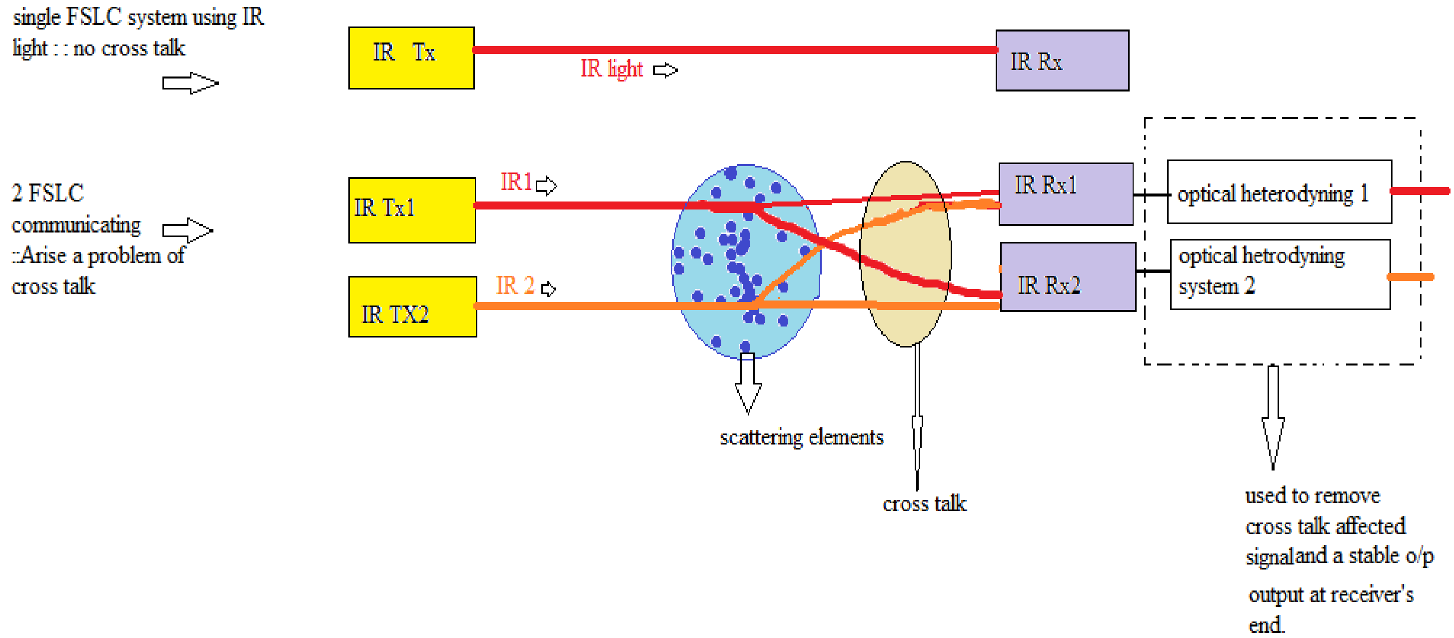

Fig.10: illustration of cross talk

Impact of rain on IR light

Rain reduces visibility. It causes a shift in velocities of light wavelengths. Rain effects signals which are above 10GHz. Higher the frequency of a signal, more power will be absorbed by water droplets. Polarization plays a vital role. Horizontal polarized light gets highly attenuated than vertical polarized light. This is due to the shape of the rain drops.

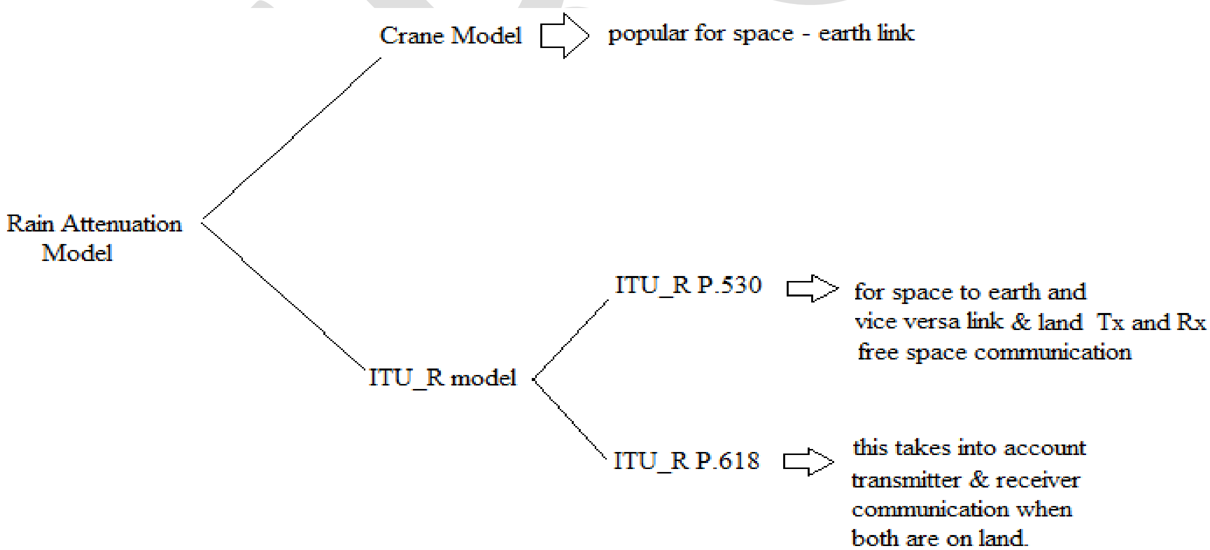

Fig.11: Popular rain attenuation models

Calculation of rain attenuation ($A_{0.01}$) using ITU_R P.530 Model:

Step 1:

The first step is to measure rain rate. This model is used if the rain rate exceeds 0.01% of time. Thus rain rate which is measured in mm/hr is represented as $R_{0.01}$. Rain rate of a particular can be obtained by consulting rain measuring authorities (who monitors weather changes each day and keeps a track of it) of that area.

Step 2:

Compute specific attenuation (γR) in dB/Km. Specific attenuation is the amount of attenuation occurred due to rain per unit length of the signal path.

$\gamma R = K. R_{0.01}$ (11)

where K is frequency attenuation coefficient.
Step 3:
Calculate the effective distance D_{eff} which is defined as the distance over which rain cell(s) is/are located.
$D_{eff} = d*r$ (12)
Where
D = separation distance between receiver and transmitter.
r (path reduction factor) = $1/\left(1+\frac{d}{35*e^{-0.01(R0.01)}}\right)$ (13)
Consider $R_{0.01} = 100$ if $R_{0.01} \geq 100$m/hr .If not, then take values of $R_{0.01}$ provided in the rain rate table.
Step4:
Rain attenuation = $A_{0.01} = \gamma R * D_{eff}$ (dB/Km) (14)

GRAPHICAL REPRESENTATION OF FSLC PERFORMANCE BASED ON ATTENUATION FACTORS

In India, monsoon strikes during June month and continues till the month of September. And we all know rain puts FSLC performance completely down. Thus FSLC face a drastic rise and fall in its performance throughout the complete year.

Fig.12: Performance versus months

During the day time especially during the afternoon time (in India), FSLC communication suffers from stray/ unwanted lights received at the receiver unit. Thus during day time, performance of FSLC goes down.

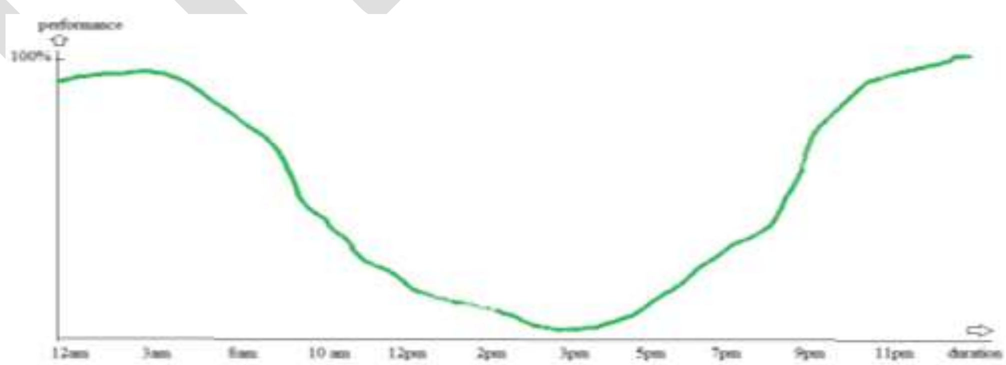

Fig.13: Performance versus day durations

As rain increases, water droplets in the atmosphere increases and thus visibility decreases. Less rain more is the visibility and higher will be the performance of FSLC.

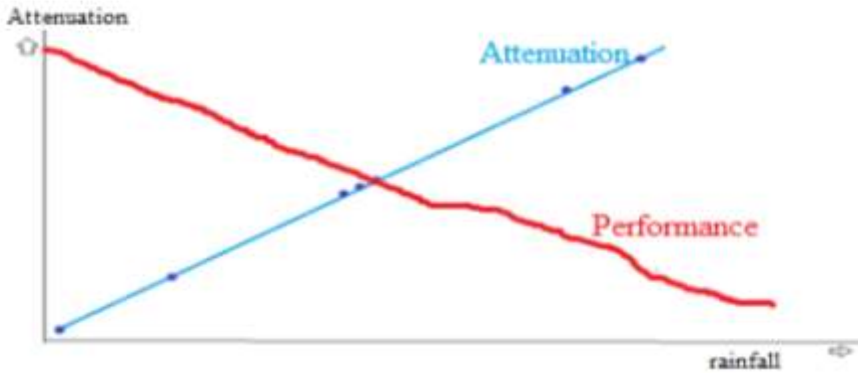

Fig.14: Attenuation versus rainfall

CONCLUSION

Through this paper I have tried to put a clear explanation that why only IR carrier is used in FSLC and its comparison with radio wave. Also various atmospheric attenuations which highly damage the performance of FSLC technology is clearly illustrated.

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