International Journal of Computing and Business Research
ISSN (Online) : 2229-6166
Volume 2 Issue 2 May 2011

UPGRADING EFFICIENCY AND IMPROVEMENT OF THE PERFORMANCE OF BROADBAND WIRELESS OPTICAL ACCESS COMMUNICATION NETWORKS

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***ABSTRACT**: It is commonly agreed that the next generation of wireless optical communication systems, usually referred to as fourth generation systems, will not be based on a single access technique but it will encompass a number of different complementary access technologies. Communication topics such as modulation, multiplexing, and detection are discussed in relation to optical wireless links. Negative channel effects such as dispersion and absorption are investigated with respect to their impact on the channel and the associated bit error rates. The challenges posed by atmospheric disturbances are considered for free space links. As the backbone and the metropolitan area network technologies can increasingly provide unprecedented bandwidth capacities, the focus is being gradually shifted toward broadband access technologies capable of connecting the customer premises to the local exchange. Moreover, power link budgets are prepared for both fiber and wireless optical communication systems to illustrate the optical losses incurred during transmission. This paper proposed new technique for improvement the performance of voice and video signal quality over wireless optical links namely, modified Shannon technique.*

Keywords: *Laser communication; Link budget; Wireless communication systems; Shannon transmission technique; Short Range.*

1. Introduction

A hybrid Wireless optical broadband access network (WOBAN) is an optimal combination of an optical back-end (also called optical backhaul) and a wireless front-end for an efficient access network. At the back-end of the network, optical line terminal (OLT) resides in the central office (CO) and is connected via optical fiber to multiple optical network units (ONU). At the front-end, a set of wireless nodes (routers) forms a wireless mesh network (WMN). End users, both mobile and stationary, connect to the network through these nodes, whose locations are fixed in a WMN. A selected set of these nodes, called gateways, are connected to the optical part of the network. Usually, gateways are attached with one of the ONUs [1]. An end user sends packets to a nearby wireless node of the WOBAN. These packets travel through the wireless mesh, possibly over multiple hops, and reach the OLT via the gateways. As the optical part of a WOBAN has higher capacity compared to the wireless part, capacity enhancement of the wireless nodes is essential to support higher traffic in a WOBAN. For capacity enhancement, wireless nodes need to be equipped with multiple radios which can enable the nodes to carry higher traffic from the end users [2]. Recent years have seen a wide spread adoption of optical technologies [3] in the core and metropolitan area networks. Wavelength Division Multiplexing (WDM) transmission systems can currently support Tbit/sec capacities. Next generation Fiber-to-the-Home (FTTH) access networks are expected to rely on Passive Optical Networks (PONs) in order to deliver reliable, multi-megabit rates to the buildings serviced by the network. Time Division Multiplexing PON (TDM/PON) and Wavelength Division Multiplexing PON (WDM/PON) may constitute a reliable alternative to the Active PON, where routing is done using a large Ethernet switch. However, as optical technologies are starting to migrate towards the access networks the cost factor is a vital issue to the economic prospects of the investments [2, 4]. Unless significant progress is achieved in optical component integration in the near future, in terms of the scale of integration and functionality, the cost of the optoelectronic components is not expected to diminish in view of the tight specifications placed by TDM/PON and WDM/PON. More importantly, if the existing duct availability is limited, one may expect large investment costs due to the enormous fiber roll out required [3, 5]. A decade ago the optical fiber systems of the day were running at gigabit-per-second rates over single-span distances exceeding 100 km. A promising foundation for the development of optical wireless was therefore in place. However, the high performance of optical fiber systems is due in large part to the properties of the fiber itself. Remove the fiber [4], as in a wireless system, and the stable low-loss guided propagation path is no longer available. The underlying technology is less and less satisfying the need and desire of the present communications users who are incessantly demanding more flexibility (mobility, quality of service, any portable unit, etc.) as well as more capacity (bandwidth). Indeed, on the one hand, these consumers are asking for more and more cost-effective communication systems that can support anytime and anywhere any media they want. On the other hand, the users of wireless communications are demanding more capacity and therefore higher frequencies. Unfortunately, these two trends (flexibility and capacity) cannot be simultaneously fulfilled in the scope of wireless communications because of the limits of the radio spectrum. In particular, ad hoc networks offer total mobility. Two main categories of ad hoc networks are distinguished. The first category consists in ad hoc networks that can function as standalone networks meeting direct communication requirements of their users. In addition to existing ad-hoc infrastructure, the second category will be used to extend and enhance the coverage of the first. The second category, which presents a valuable solution to incomplete networks, can be connected via a radio access point to an optical link leading to high-speed fiber-based ad hoc wireless access systems [5].

In the present study, broadband spectrum of optical wireless communication is available, which can fulfill the requirements of high speed wireless communication. This is the basic advantage of optical wireless communication over conventional wireless communication technologies. Wireless optical communication system has received a great deal of attention lately both in the military and civilian information society due to its potentially high capacity, rapid deployment, portability and high security. Therefore we have employed high bit rate capacity technique namely modified Shannon transmission technique over wide range of the affecting parameters for increasing signal to noise ratio (S/N) and decreasing bit error rate (BER) and then to increase the transmission bit rates over wireless optical communication systems.

2. Principles of All Optical Wireless Communication System

It is well known that wireless optical communication systems are sensitive to poor weather conditions, such as rain, fog and scintillation . Thus, the major source of concern of wireless optical communication systems of today is the availability. Much attention has been paid to how performance of wireless optical communication systems can be improved to increase the fade margin in order to realize longer hop lengths. Manufacturers have addressed this using numerous of different technologies, such as multi-beam configurations, microwave back-up, expensive optical amplification by means of Erbium Doped Fiber Amplifiers, Raman amplifiers and semiconductor optical amplifiers. All these technologies have one thing in that are costly [6, 7].

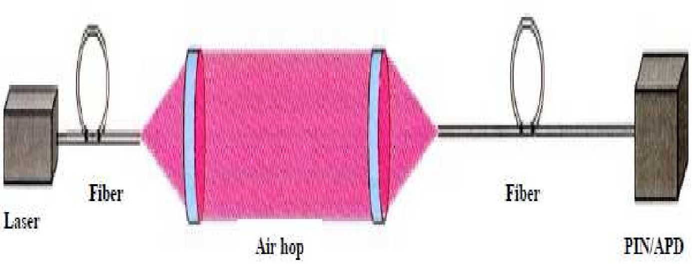


Fig. 1. Wireless optical communication system principle.

The all optical system may be regarded as a “cut in the fiber” as shown in Fig. 1. The optical signal from the laser is guided by an optical fiber to collimating optics. The beam having passed the air hop is then focused directly on the core of an optical fiber by using suitable receiver optics and the optical signal propagates down that fiber to the detector. In this manner, the transmission through the air is achieved without costly electro-optical or additional amplifications stages. The all-optical technology has the following benefits such as a robust low cost technology since no additional electronics for electro-optical conversion is required, and the simplicity and low weight of the system implies easy and fast installations.

3. Modeling Basics and Analysis

A typical wireless optical communication access network has a tree architecture. Other alternatives include multiple point-to-point, ring and mesh architectures. Due to the high bit rates available, wireless optical systems can support many protocols simultaneously such as asynchronous transfer mode (ATM) Ethernet, Fast and Gigabit Ethernet. To share the bandwidth, optical code division multiple access techniques can be applied. WDM can also be used especially in the 1.52 μm to1.6 μm window in order to exploit the available bandwidth with greater efficiency, but this requires more sophisticated components. Atmospheric effects on laser beam propagation can be broken down into two categories: attenuation of the laser power and fluctuation of laser power due to laser beam deformation. Attenuation consists of absorption and scattering of the laser light photons by the different aerosols and gaseous molecules in the atmosphere. Laser beam deformation occurs because of small-scale dynamic changes in the index of refraction of the atmosphere. This causes laser beam wander, laser beam spreading, and distortion of the wavefront or scintillation.

3.1. Atmospheric attenuation

The attenuation of laser power in the atmosphere is described by Beer's law [8]:

$$\tau(R)=\frac{P(R)}{P(0)}=e^{-\alpha R} \quad , \qquad (1)$$

Where τ (*R*) is the transmittance at distance R, P(R) is the laser power at distance R, P(0) is the laser power at the source, and α is the attenuation or total extinction coefficient per unit length. The attenuation coefficient is made up of four parts can be expressed as the following:

$$\alpha=\alpha_m+\alpha_a+\beta_m+\beta_a \, , \qquad (2)$$

Where α_m is the molecular absorption coefficient, α_a is the aerosol absorption coefficient, β_m is the molecular or Rayleigh scattering coefficient, and β_a is the aerosol or Mie scattering coefficient. Molecular or Rayleigh scattering varies as λ^{-4} and is small at these near-IR laser wavelengths. Therefore, aerosol or Mie scattering dominates the total attenuation coefficient [8]. Attenuation due to Mie scattering is a function of the visibility and laser wavelength:

$$\alpha=\beta_a=\frac{3.91}{V}\left(\frac{\lambda}{0.55\ \mu m}\right)^{-q} \quad , \qquad (3)$$

Where V is the visibility in km, λ is the optical wavelength in µm, q is the size distribution of the scattering particles, q=1.6 for high visibility (V 〉 50 km), q= 1.3 for average visibility (6 km 〈 V 〈 50 km), and q=0.585 $V^{0.33}$ for low visibility (V 〈 6 km). The decibel loss per kilometer for different visibility conditions are derived from the attenuation coefficients and calculated using Eq. (3). Laser communication stages due to the attenuation of laser light can be a serious problem during times of heavy fog [9, 10].

3. 2. Wireless optical link design

The main objective of wireless optical link design is to get as much light as possible from one end to the other in order to receive a stronger signal that would result in higher link receive a stronger signal that would result in higher link margin and greater link availability. Link design parameters consists of two parts link design parameters consists of two parts: internal system parameters (system related parameters), and external system parameters (link related parameters). Internal system parameter consists of transmitted power (P_t), transmit beam divergence (θ in mrad), surface Area of receiver aperture (A_R), receiver sensitivity (S_R), and transmitter and Receiver optical losses (η).

These parameters collectively form generalized link margin (GLM) mathematically is given by [10]:

$$GLM = \frac{P_t \, \eta \, A_R}{A_T + (R.\theta)^2} \quad , \qquad (4)$$

Link margin (LM) is a ratio of the available received power on a clear day (at it is a ratio of the available received power on a clear day (at a given range) to the receiver power sensitivity required to meet the bit error rate (BER) specification. Following are various parameters that contribute to the link margin are transmitted Power (P_t), beam width of transmitter, surface area of transmit beam at range R (A_T), optical link range (R), and atmospheric attenuation coefficient (α in dB/km).

$$LM = P_t \frac{A_R}{S_R\left(A_T + (\theta.R)^2\right)} e^{-\alpha R} \qquad (5)$$

3. 3. Transmission bit rate analysis

Assuming the receiver antenna is at the room temperature, and feeds a matched preamplifier with noise figure, F then for a transmitted power P_t the signal to noise ratio at the receiver (S/N) is [11]:

$$S/N = \frac{P_t \, R}{F \, K \, T \, \alpha} \; , \qquad (6)$$

Where P_t is the transmitted signal power in watt, F is the noise figure in dB, K is the Boltzmann's constant, T is the ambient temperature in ºC, and α is the total attenuation coefficient in dB/km. the allowable transmission bandwidth range for audio signal is within the range of 3.4 KHz to 4 KHz, and for video signal is within the range of 6.8 MHz to 8 MHz. Then the Shannon transmission capacity bit rates for audio and video signals are given by [12]:

$$C_{Audio\ signal} = B.W_{Audio\ signal} \log_2(1 + S/N), \quad \text{Gbit/sec} \qquad (7)$$

$$C_{Video\ signal} = B.W_{Video\ signal} \log_2(1 + S/N), \ \text{Tbit/sec} \qquad (8)$$

Where $B.W_{Audio}$ is the bandwidth of the audio signal, $B.W_{video}$ is the bandwidth of the video signal. Where S/N is the signal to noise ratio in absolute value (not in dB). Then the S/N ratio can be expressed in dB as follows:

$$(S/N)_{dB} = 10 \log(S/N), \ \text{dB} \qquad (9)$$

Equations (7, 8) can be expressed in another form as the following formula [13]:

$$C_{Audio\ signal} = 3.3219 \, B.W_{Audio\ signal} \log(1 + S/N), \ \text{Gbit/sec} \qquad (10)$$

$$C_{Video\ signal} = 3.3219 \, B.W_{Video\ signal} \log(1 + S/N), \quad \text{Tbit/sec} \qquad (11)$$

The Shannon bandwidth product can be expressed as a function of transmission bit rate capacity and optical link range as the following expressions:

$$P_{Sh(Audio\ signal)} = C_{Audio\ signal} \cdot R, \quad \text{Gbit.km/sec} \tag{12}$$

$$P_{Sh(Video\ signal)} = C_{Video\ signal} \cdot R, \quad \text{Tbit.km/sec} \tag{13}$$

The BER essentially specifies the average probability of incorrect bit identification. In general. The higher the received SNR, the lower the BER probability will be. For most PIN receivers, the noise is generally thermally limited, which independent of signal current. The BER is related to the signal to noise ratio as follows [14]:

$$BER = \frac{1}{2}\left[1 - erf\left(\frac{\sqrt{S/N}}{2\sqrt{2}}\right)\right], \tag{14}$$

Where erf is the error function, and S/N is the signal to noise ratio in absolute value.

4. Simulation Results and Discussions

We have investigated the high quality and best performance of wireless optical communication networks with using modified Shannon transmission technique to upgrade signal to noise ratio and decreased BER and then to upgrade the transmission bit rates. Based on the modeling equations analysis and the assumed set of the operating system parameters as shown in Table 1, the following facts are assured as shown in the series of Figs. (2-28):

Table 1: Proposed operating parameters for wireless optical link design.

Operating parameter	Value and units
Ambient temperature (T)	25 ºC ≤ T ≤ 65 ºC
Power transmitted (P_t)	100 mWatt
Operating signal wavelength (λ)	0.6 μm ≤ λ ≤ 1.6 μm
Transmitter beam divergence (θ)	5 mrad
Optical link range (R)	5 km ≤ R ≤ 75 km
Receiver Sensitivity (S_R)	- 30 dB/km
Surface area of transmit Beam (A_T)	85 mm^2
Surface Area of receiver aperture (A_R)	85 mm^2

Audio signal bandwidth ($B.W_{audio}$)	3.4 KHz $\leq B.W_{audio} \leq$ 4 KHz
Video signal bandwidth ($B.W_{video}$)	6.8 MHz $\leq B.W_{video} \leq$ 8 MHz
Boltzmann's constant (K)	$1.38 \text{ X } 10^{-23}$
Noise Figure (F)	2 dB ≤ F ≤ 30 dB
Total attenuation coefficient (α)	0.5 dB/km $\leq \alpha \leq$ 5 dB/km

i) As shown in the series of Figs. (2-4) has assured that as the optical link range increases, allowable atmospheric attenuation also increases for low and average, and high visibility. But we have observed for high visibility presents the minimum atmospheric attenuation.

ii) Fig. 5 has proved that as the operating signal wavelength increases, the optical link range decreases. Moreover, we have indicated that for high visibility presents the highest optical link range.

iii) Fig. 6 has demonstrated that as the optical link range increases, the allowable visibility also increases at constant operating wavelength. Also as operating wavelength increases, the allowable visibility also increases at constant optical link range.

iv) As shown in Figs. (7-9) has assured that as optical link range increases, the system link margin also increases for low, average, and high visibility (high visibility>average visibility>low visibility). Moreover we have indicated that the high visibility presents the highest system link margin.

v) Figs. (10, 11) have indicated that as both total attenuation coefficient and ambient temperature increase, the signal to noise ratio decreases at constant optical link range. As optical link range increases, signal to noise ratio also increases at constant both total attenuation coefficient and ambient temperature.

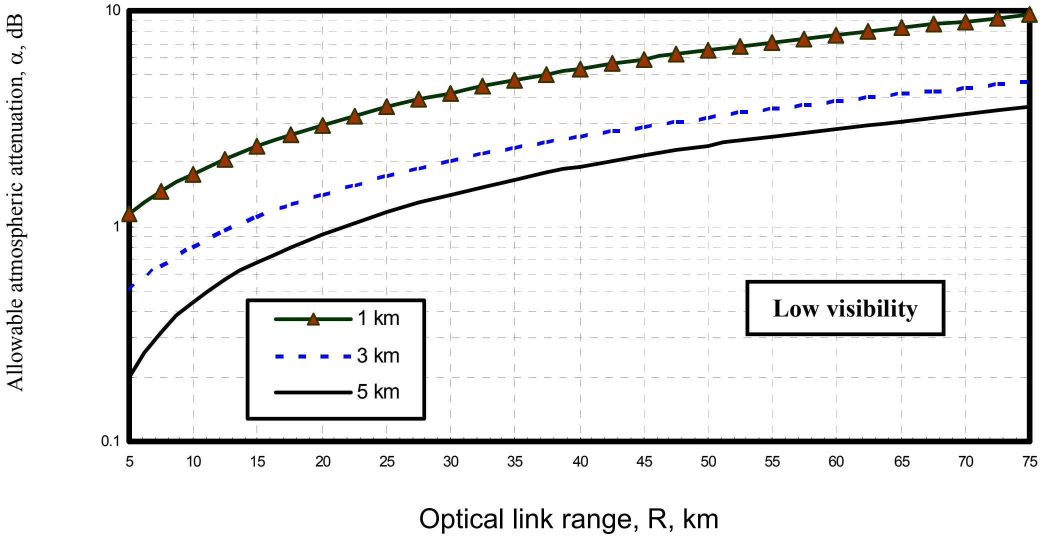


Fig. 2. Variations of the atmospheric attenuation against optical link range at the assumed set of parameters.

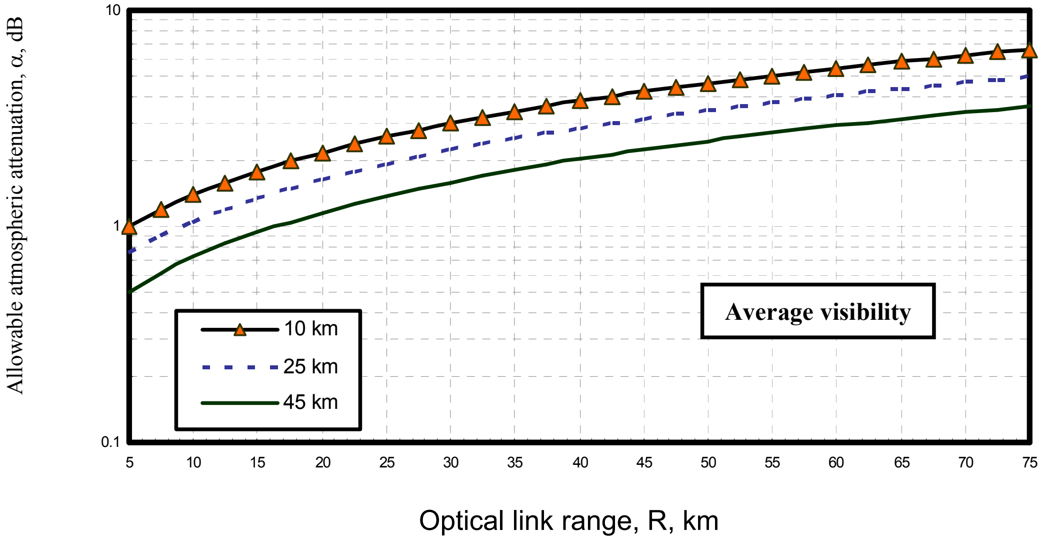


Fig. 3. Variations of the atmospheric attenuation against optical link range at the assumed set of parameters.

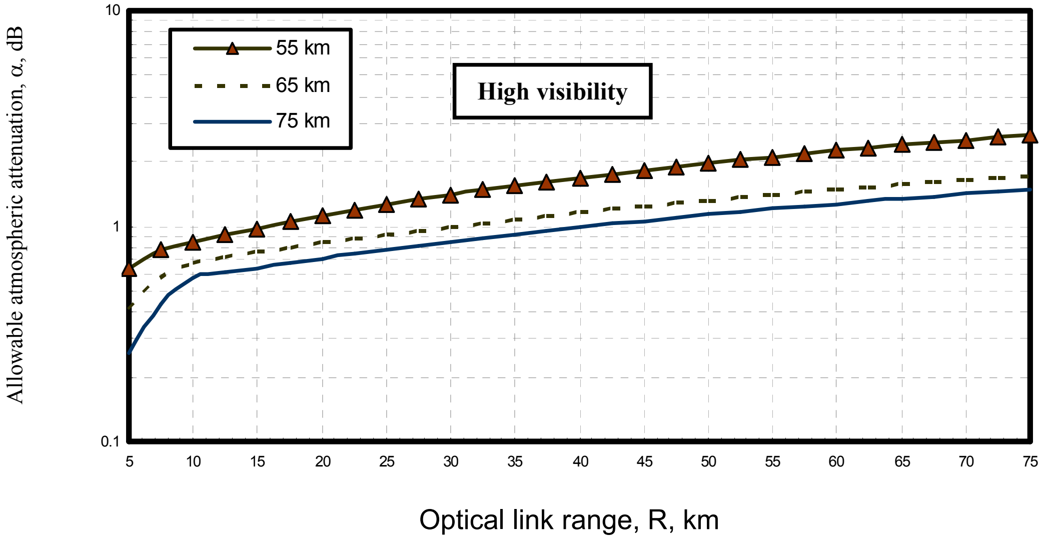


Fig. 4. Variations of the atmospheric attenuation against optical link range at the assumed set of parameters.

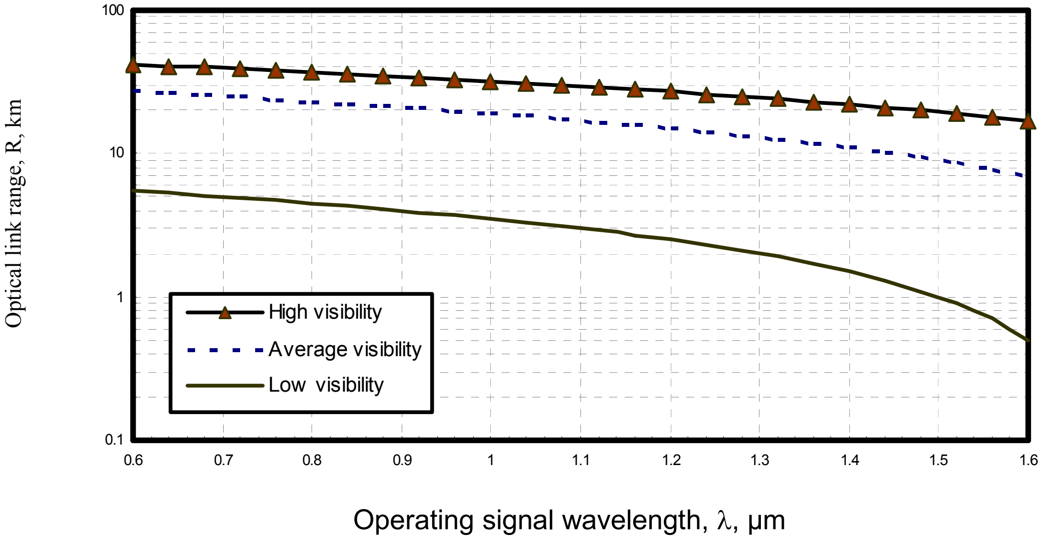


Fig. 5. Variations of the optical link range against operating signal wavelength at the assumed set of parameters.

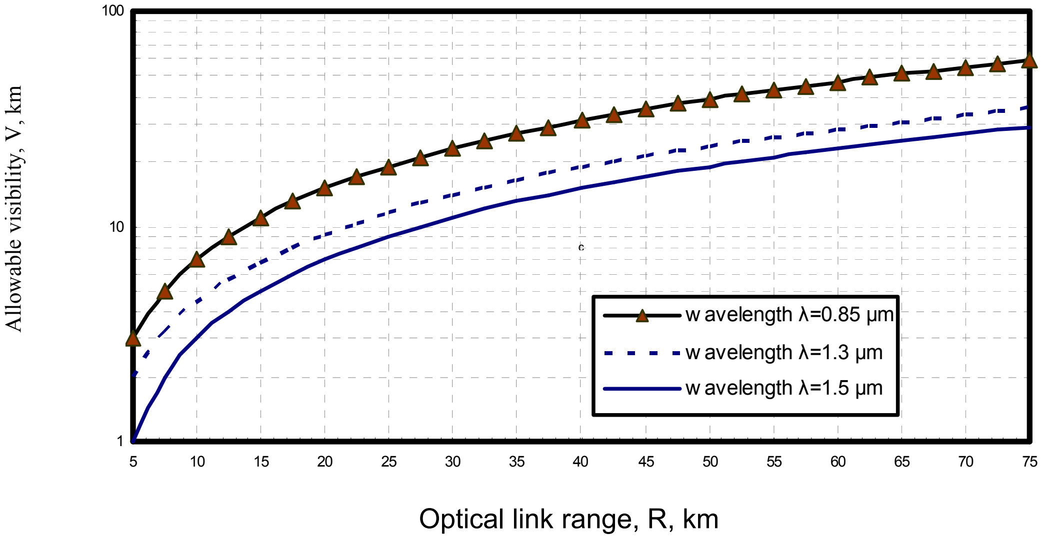


Fig. 6. Variations of the allowable atmospheric attenuation against optical link range at the assumed set of parameters.

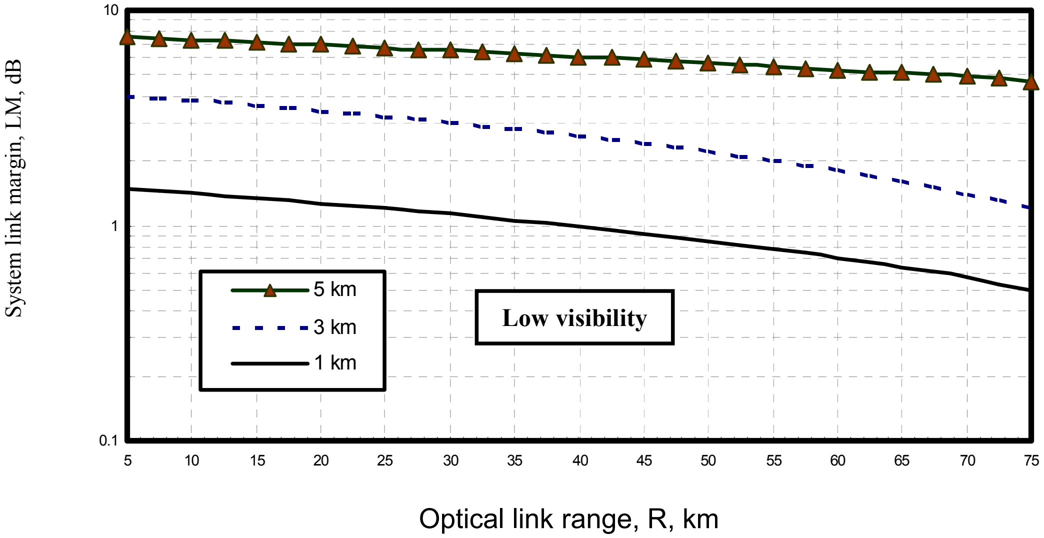


Fig. 7. Variations of the system link margin against optical link range at the assumed set of parameters.

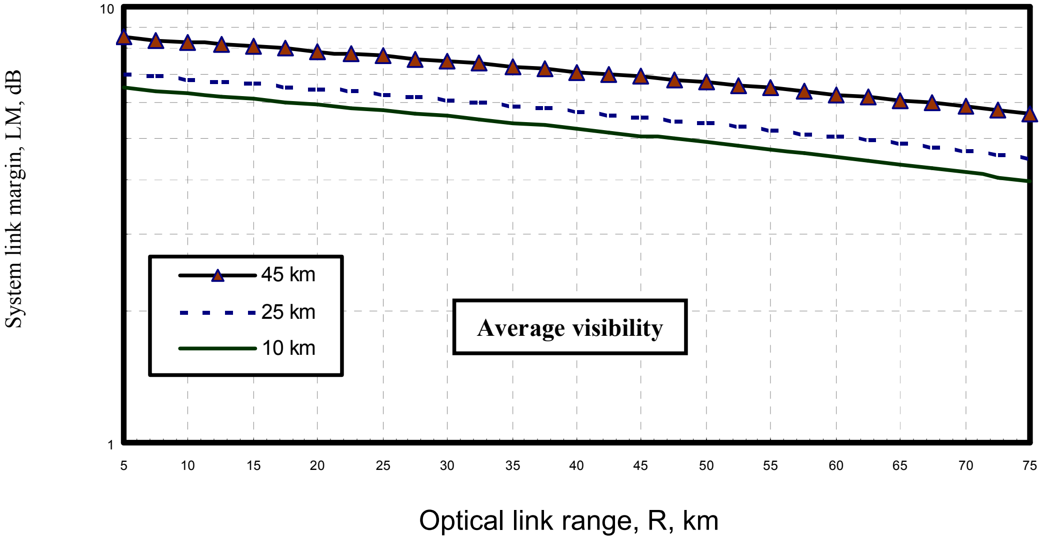


Fig. 8. Variations of the system link margin against optical link range at the assumed set of parameters.

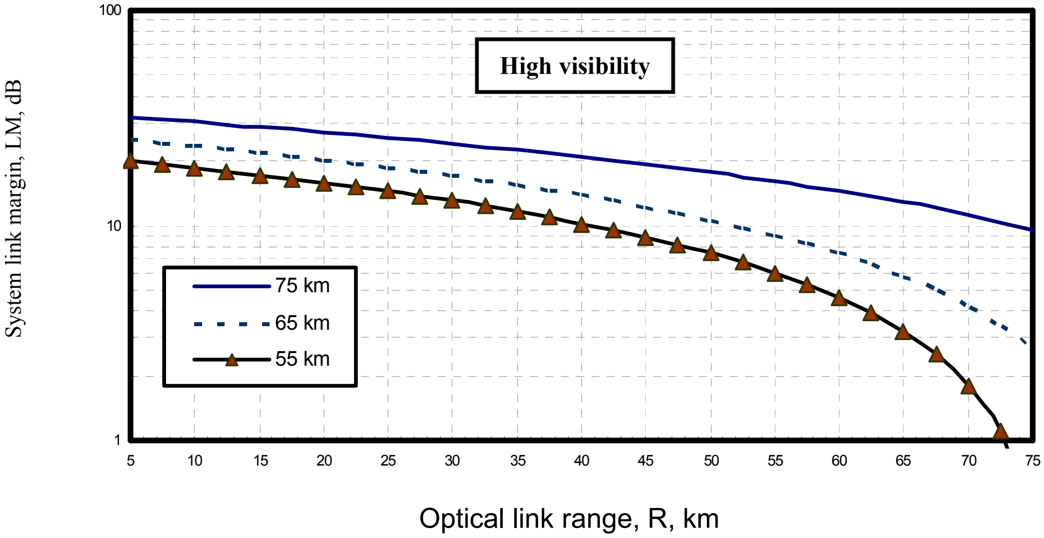


Fig. 9. Variations of the system link margin against optical link range at the assumed set of parameters.

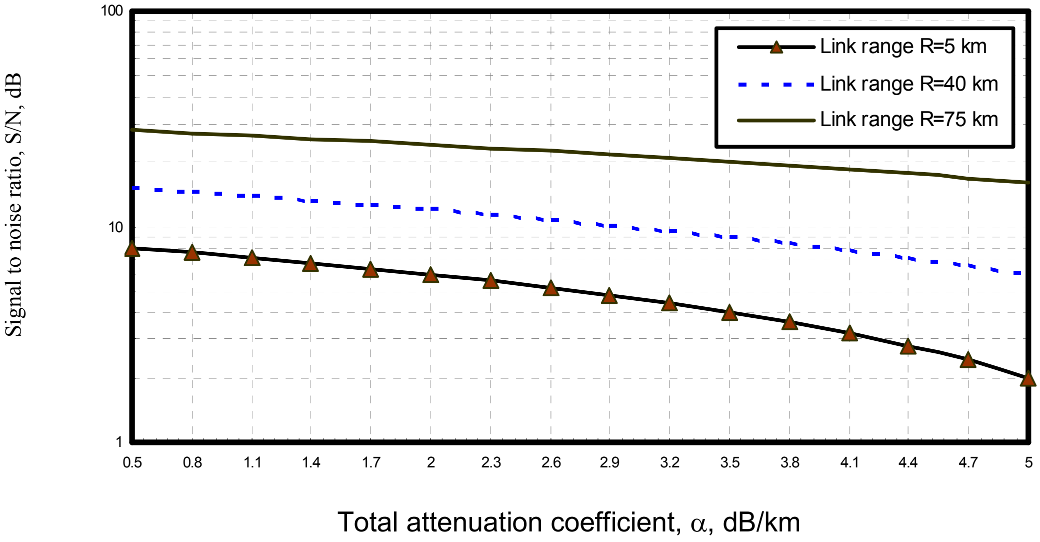


Fig. 10. Variations of signal to noise ratio against total attenuation coefficient at the assumed set of parameters.

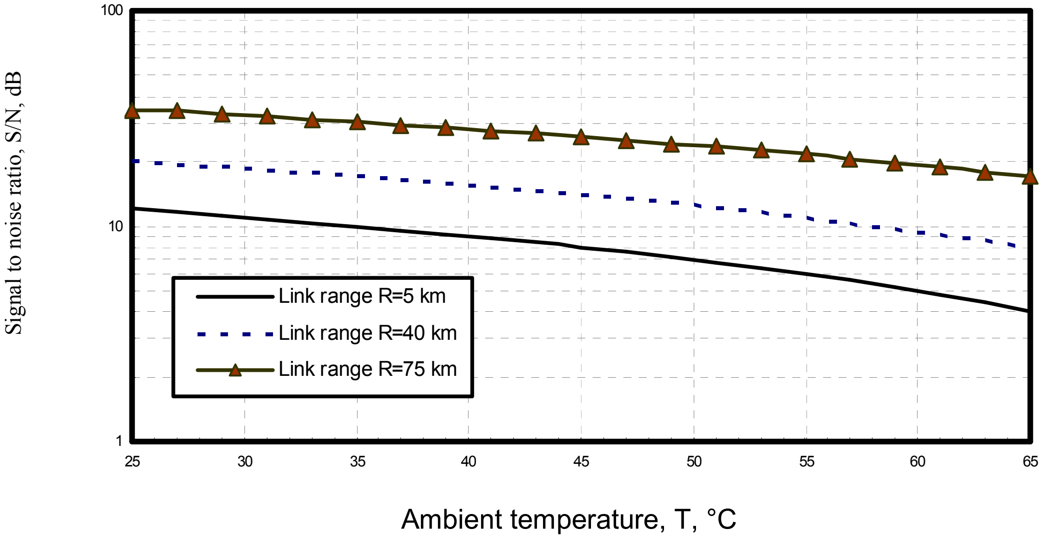


Fig. 11. Variations of signal to noise ratio against ambient temperature at the assumed set of parameters.

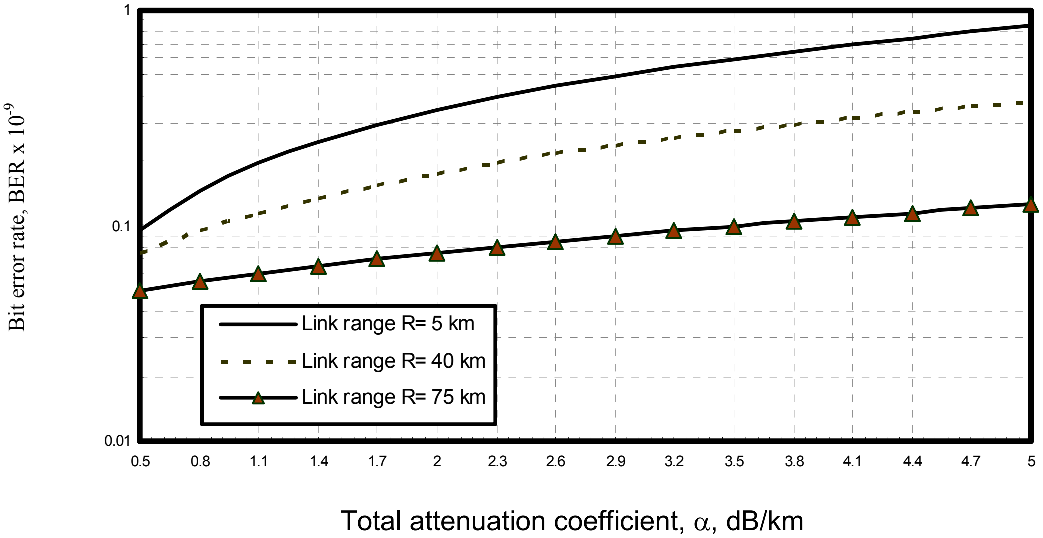


Fig. 12. Variations of signal to noise ratio against total attenuation coefficient at the assumed set of parameters.

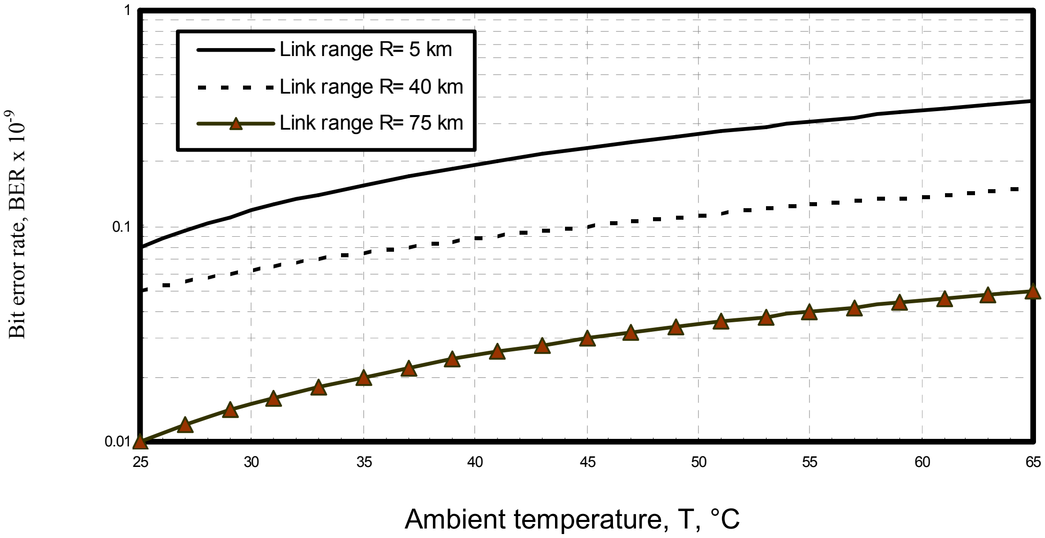


Fig. 13. Variations of signal to noise ratio against ambient temperature at the assumed set of parameters.

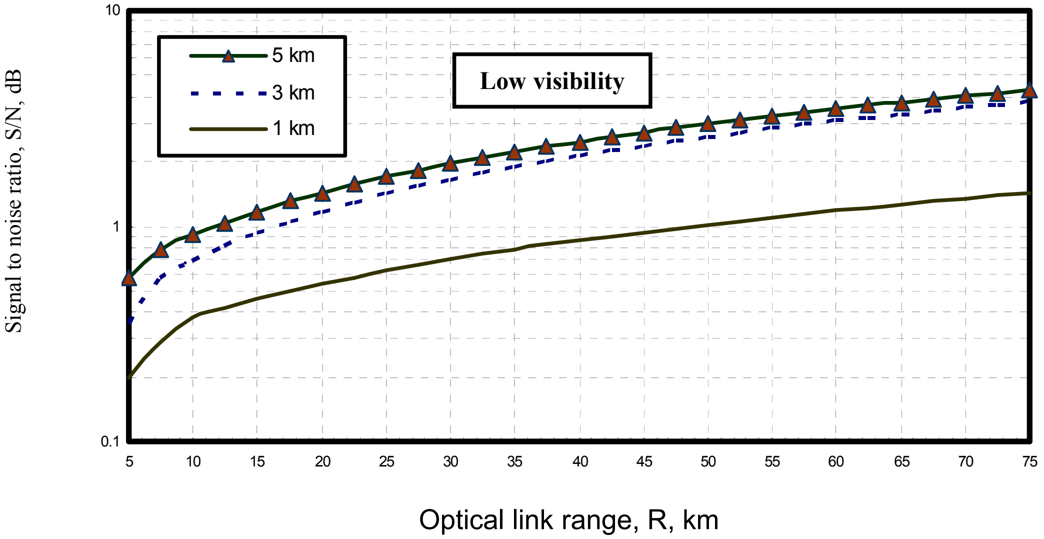


Fig. 14. Variations of signal to noise ratio against optical link range at the assumed set of parameters.

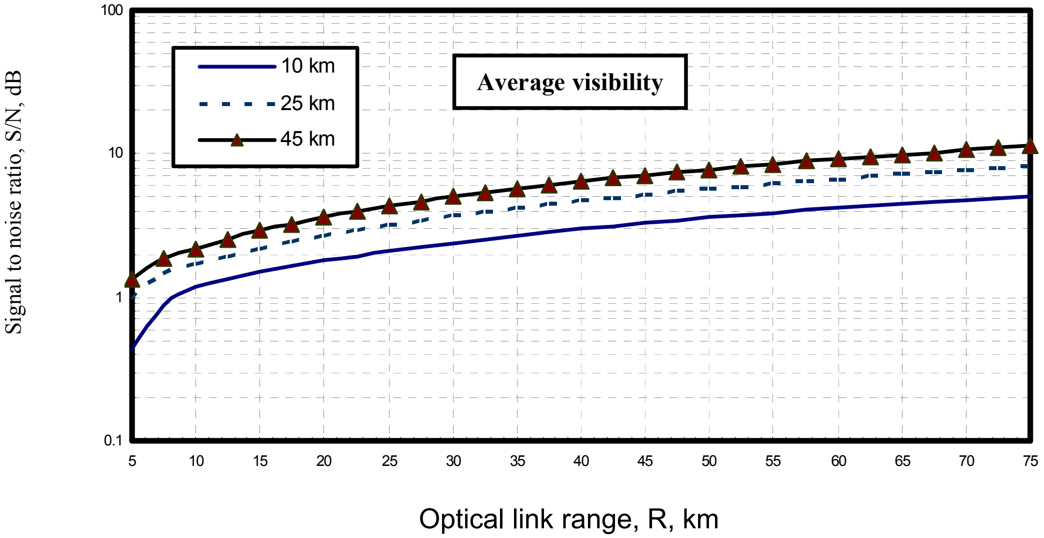


Fig. 15. Variations of signal to noise ratio against optical link range at the assumed set of parameters.

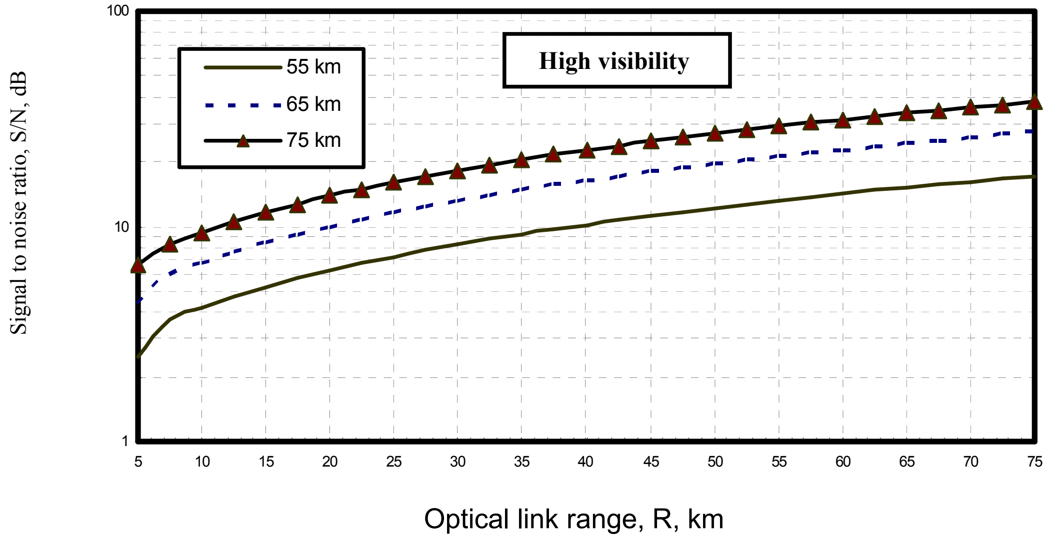


Fig. 16. Variations of signal to noise ratio against optical link range at the assumed set of parameters.

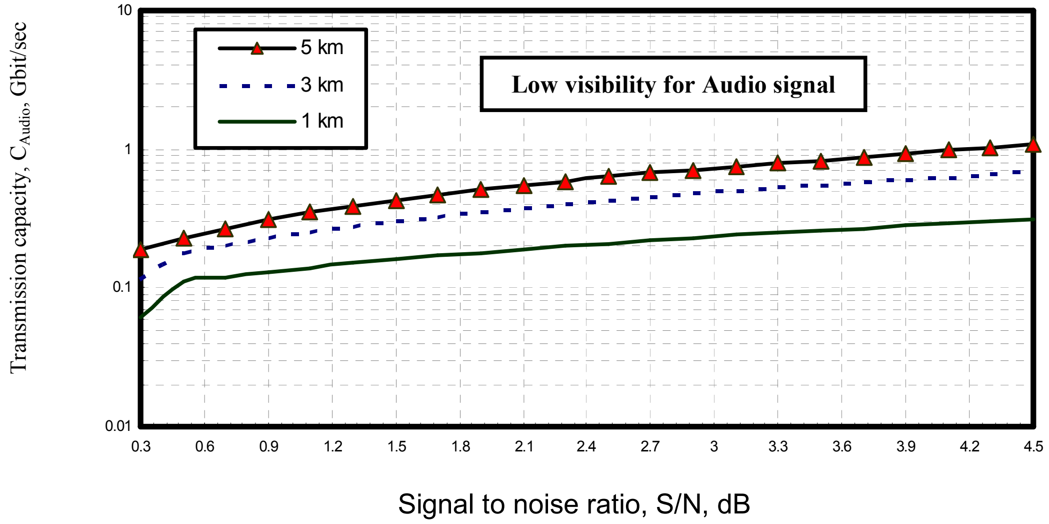


Fig. 17. Variations of transmission bit rate capacity against signal to noise ratio at the assumed set of parameters.

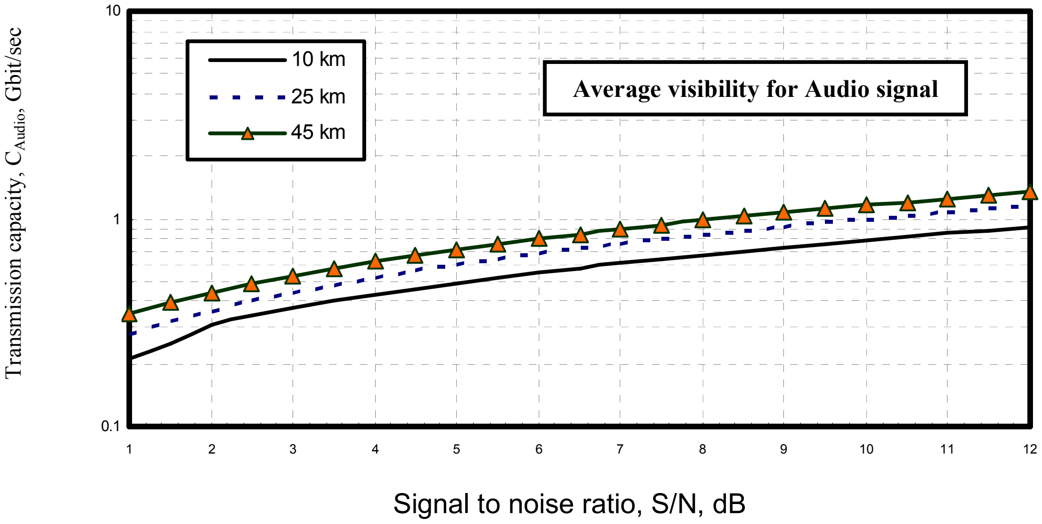


Fig. 18. Variations of transmission bit rate capacity against signal to noise ratio at the assumed set of parameters.

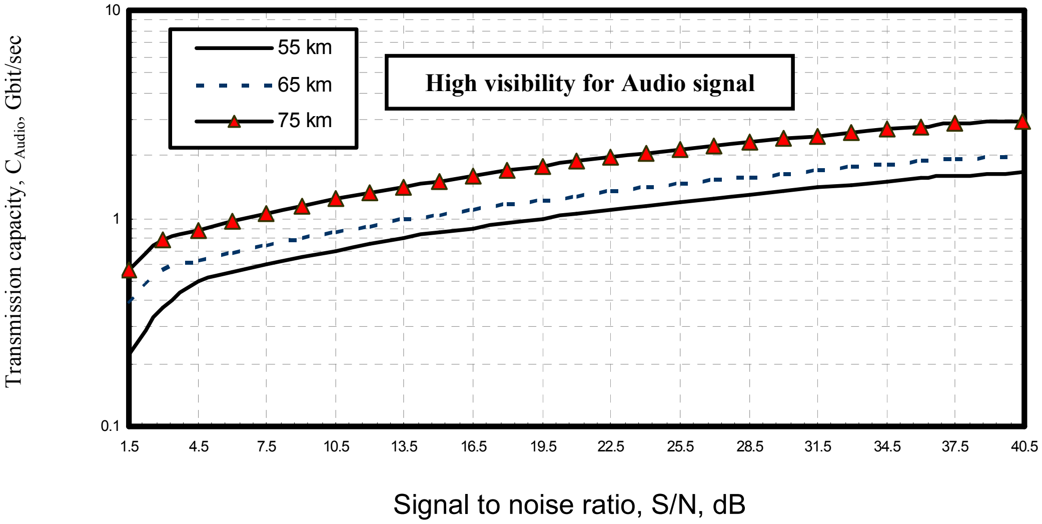


Fig. 19. Variations of transmission bit rate capacity against signal to noise ratio at the assumed set of parameters.

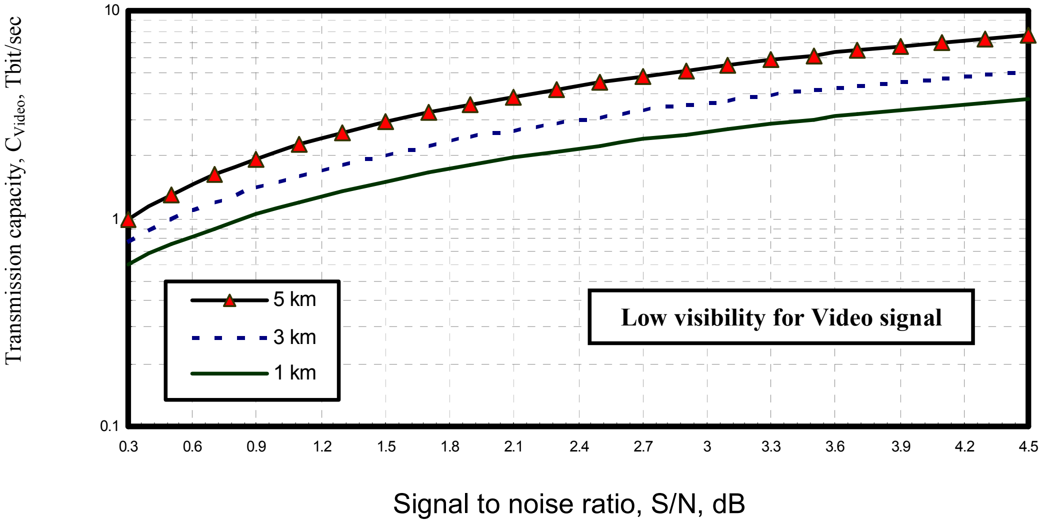


Fig. 20. Variations of transmission bit rate capacity against signal to noise ratio at the assumed set of parameters.

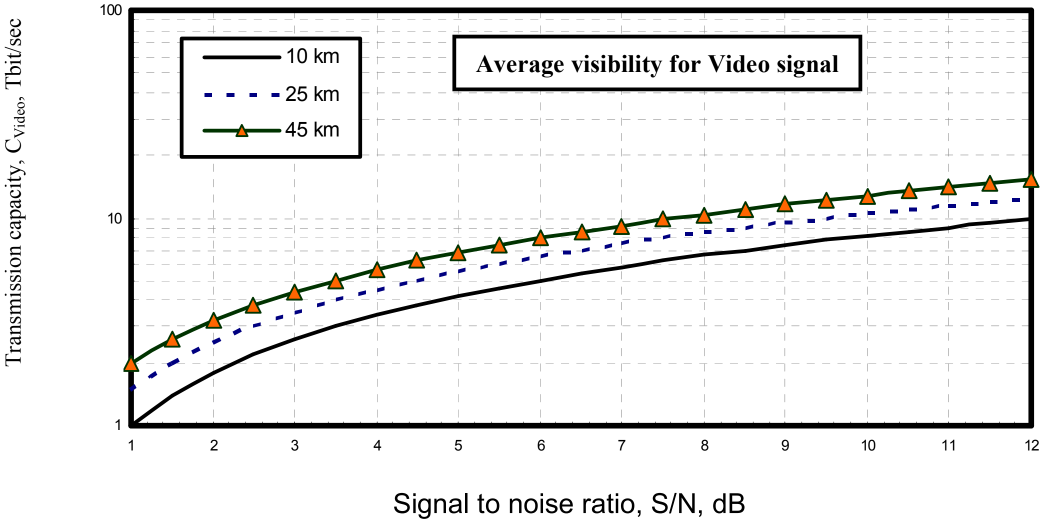


Fig. 21. Variations of transmission bit rate capacity against signal to noise ratio at the assumed set of parameters.

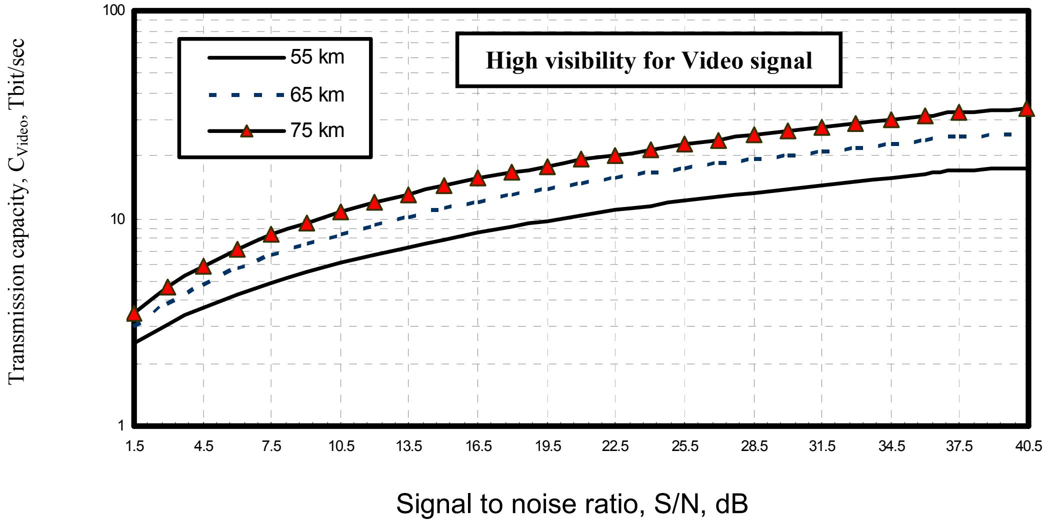


Fig. 22. Variations of transmission bit rate capacity against signal to noise ratio at the assumed set of parameters.

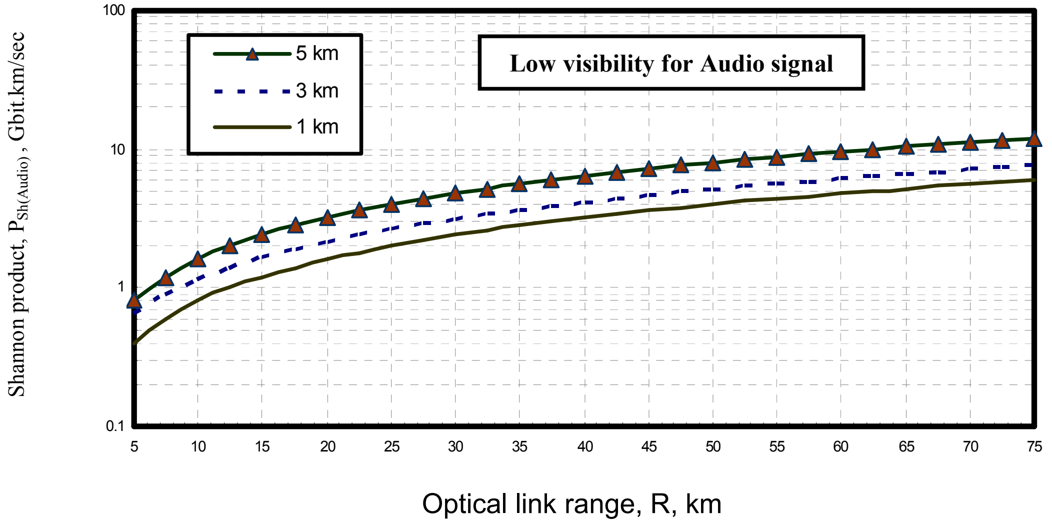


Fig. 23. Variations of Shannon product against optical link range at the assumed set of parameters.

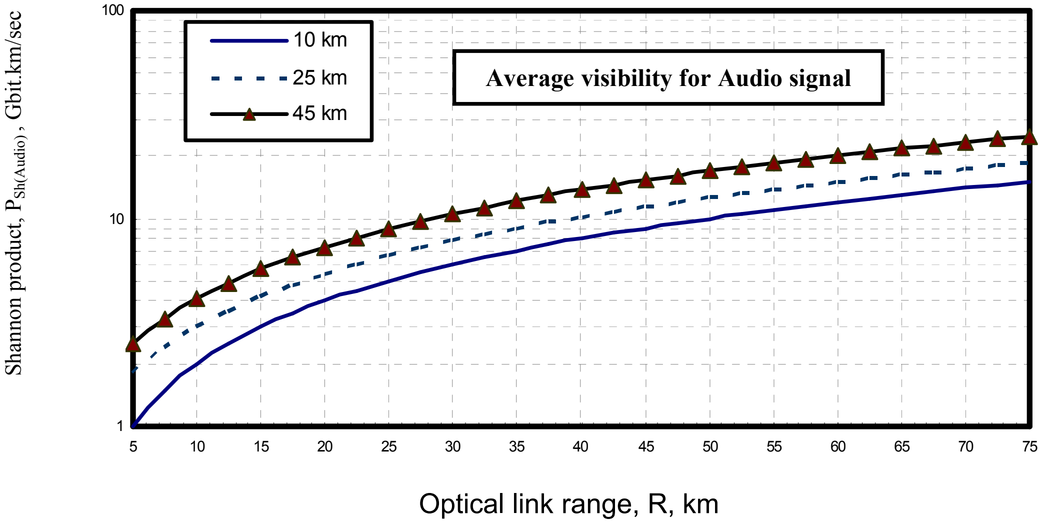


Fig. 24. Variations of Shannon product against optical link range at the assumed set of parameters.

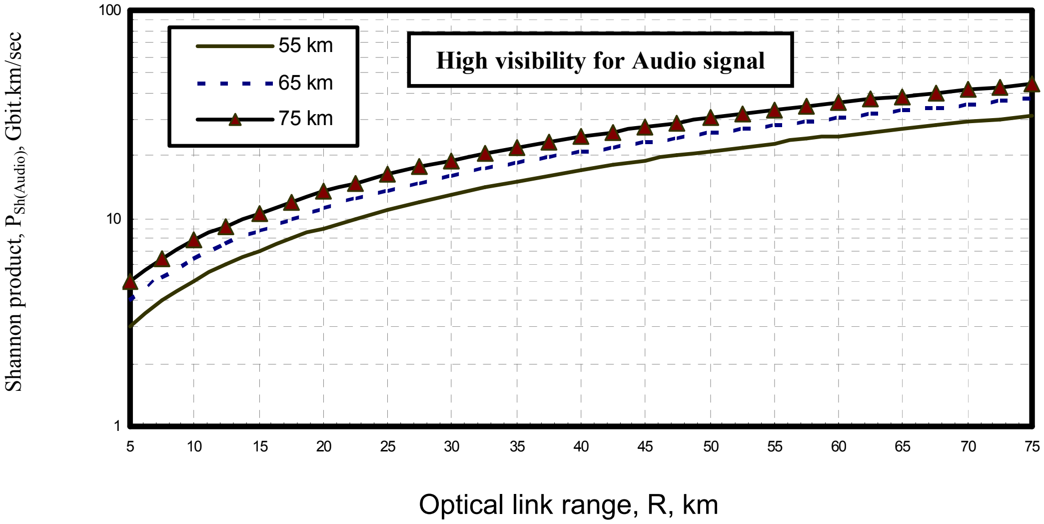


Fig. 25. Variations of Shannon product against optical link range at the assumed set of parameters.

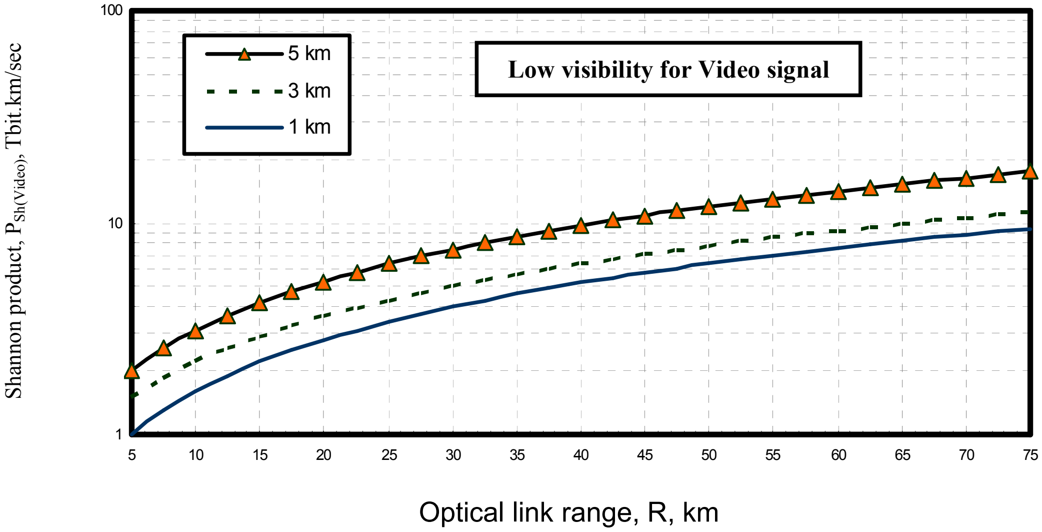


Fig. 26. Variations of Shannon product against optical link range at the assumed set of parameters.

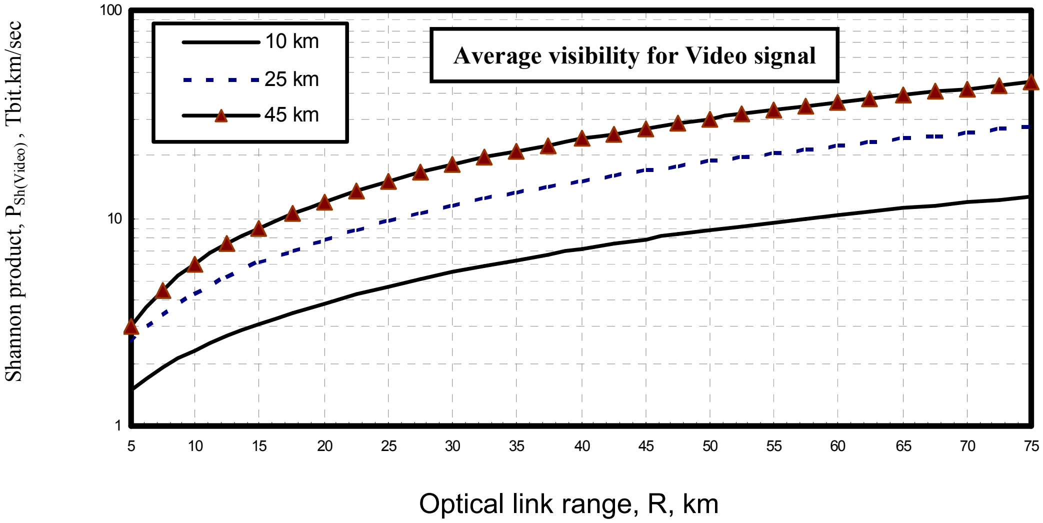
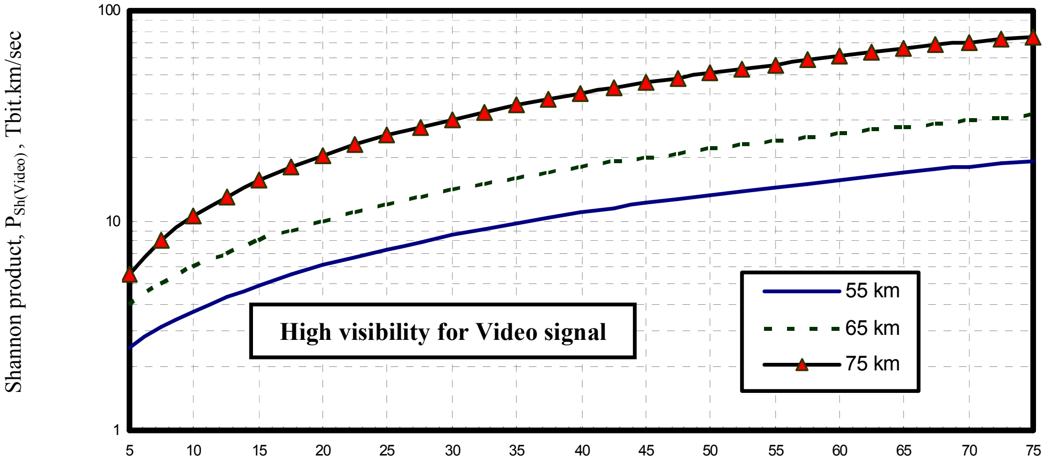


Fig. 27. Variations of Shannon product against optical link range at the assumed set of parameters.



Optical link range, R, km

Fig. 28. Variations of Shannon product against optical link range at the assumed set of parameters.

vi) As shown in Figs. (12, 13) have assured that as both total attenuation coefficient and ambient temperature increase, the BER increases at constant optical link range. As optical link range increases, this leads to BER decreases at constant both total attenuation coefficient and ambient temperature.

vii) As shown in Figs. (14-16) has assured that as optical link range increases, the signal to noise ratio also increases for low, average, and high visibility (high visibility> average visibility> low visibility). We have indicated that the high visibility presents the highest signal to noise ratio.

viii) Figs. (17-22) have proved that as signal to noise ratio increases, the transmission capacity also increases for low, average, and high visibility (high visibility> average visibility> low visibility) for both audio and video signals. We have observed that the high visibility presents the highest transmission capacity for both audio and video signals. Also we have indicated that transmission capacity for video signal is higher than transmission capacity for audio signal.

ix) As shown in Figs. (23-28) have demonstrated that as optical link increases, the Shannon product also increases for low, average, and high visibility (high visibility> average visibility> low visibility)for both audio and video signals. We have observed that the high visibility presents the highest Shannon product for both audio and video signals. Also we have indicated that Shannon product for video signal is higher than Shannon product for audio signal.

5. Conclusions

We have investigated parametrically the improvement of broadband wireless optical access communication networks within modified Shannon transmission technique for audio and video signals. The decreased of both atmospheric attenuation and operating wavelength, the increased optical link range. High visibility presents the minimum atmospheric attenuation, the highest optical link range, the highest transmission capacity for audio, video signals and the highest system link margin. Moreover the decreased of both atmospheric attenuation and ambient temperature, the increased signal to noise ratio and the decreased BER. The increased signal to noise ratio, the highest transmission bit rate capacity for both audio and video signals for different visibility levels. It is evident that the video signal presents higher transmission bit rate capacity and Shannon product than the audio signal. Wireless optical link has poor performance even link failure under adverse weather conditions. Finally, we can say that wireless broadband optical access communication systems and networks are in degradation case under bad weather conditions and upgraded system performance and transmission efficiency under best weather conditions.

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