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Full Length Research Paper

High transmission bit rate of multi giga bit per second for short range optical wireless access communication networks

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In the present paper, the backbone and the broadband wireless access communication network technologies can increasingly provide unprecedented bandwidth capacities, the focus being gradually shifted toward broadband access technologies capable of connecting the customer premises to the local exchange. Optical wireless is increasingly becoming an attractive option for multi giga bit per second within short range (up to 5 km) links where laying optical fiber is too expensive or impractical. For such links, a tracking scheme is essential to maintain proper pointing of the transceivers at each other to establish error-free communication. The optical wireless technology is used mostly in wide bandwidth data transmission applications. Also, we have investigated the maximum transmission distance and data transmission bit rates that can be achieved within broadband wireless optical links for multi giga bit optical network applications. The wireless optical broadband access network architecture has been proposed as a flexible solution to meet the ever-demanding needs in access networks. At the wireless front end multi channel communication, with routers having multiple radio interfaces tuned to non overlapping channels, it can be used to improve network throughput in a cost effective way.

Key words: Optical wireless communications, short range, indoor links, data link, and outdoor links.

INTRODUCTION

Optical wireless communication, also known as free-space optical (FSO), has emerged as a commercially viable alternative to RF and millimeter (Abd El-Naser et al., 2009) wave wireless for reliable and rapid deployment of data and voice networks. RF and millimeter wave technologies allow rapid deployment of wireless networks with data rates from tens of Mb/s (point-to-multipoint) up to several hundred Mb/s (point-to-point). However (Abd El-Naser et al., 2009; Shea and Mitchell, 2009), spectrum licensing issues and interference at unlicensed ISM bands will limit their market penetration. Though emerging license-free bands appear promising, they still have certain bandwidth and range limitations. Optical wireless can augment RF and millimeter wave links with very high (>1 Gbit/s) bandwidth. In fact, it is widely believed that optical wireless is best suited for multi-Gbit/s communication (Shea and Mitchell, 2009; Yong-Yuk Won et al., 2009). Optical and wireless networks were initially developed for different communication scenarios (Ab-Rahman et al., 2009). Optical networks have been mainly used for high-bandwidth and long-distance communications while the wireless technology is used at wireless local networks with flexibility and low bandwidth needs. The present growing demand for bandwidth-intensive services, and the way people now communicate, are accelerating research on efficient and cost-effective access infrastructures whereas optical-wireless combinations are seen as promising approaches. The wireless optical broadband access network architecture has been recently proposed as a flexible solution to meet such ever demanding needs in access networks (Kedar and Arnon, 2006). Wireless optical broadband access network architecture provides a flexible and cost effective solution where fiber is provided as far as possible from the central office (CO) to the end users and then wireless access is provided at the front end. Because of such excellent compromise early versions are being deployed as municipal access

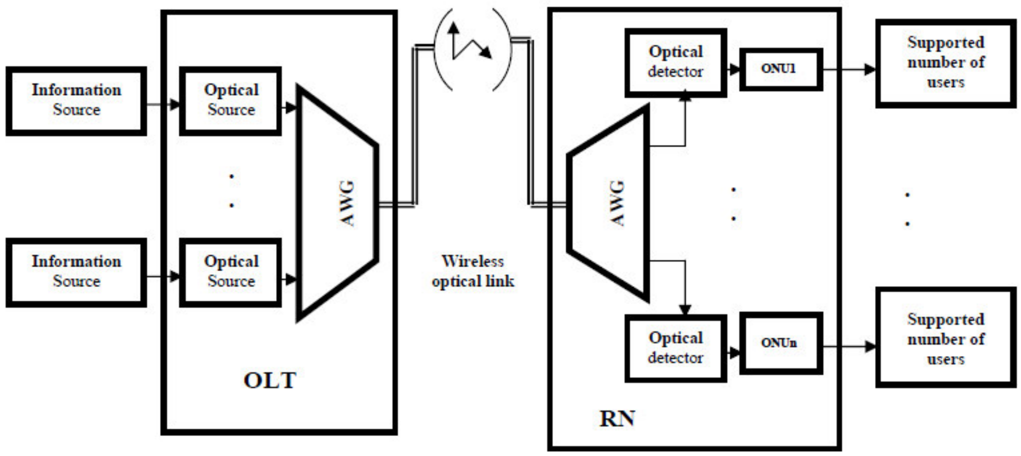

Figure 1. Simplified optical network architecture for wireless links.

solutions to eliminate the need for wired connection to every customer's wireless router thus saving on network deployment cost (Schuster et al., 2005).

Optical wireless communication also known as "lasercom," has become a fact of life over recent years in the sphere of urban wireless networks (Kiasaleh, 2005). There is a growing need for high data-rate transmissions in real time, and optical communications can provide the required bandwidth. Optic fiber backbone has been laid around the globe and reaches most major cities in the world, but the cramping bottleneck still restricts data flow over "the last mile," from the fiber backbone to the end user. Optical wireless communication can bridge the gap by enabling connection with and between offices, business facilities, and other targeted locations without relinquishing the performance parameters offered by optical communications and without the resource expenditure of laying optic fiber. In addition to the capital investment and running costs of fiber, it is not always possible to lay fiber at all, whereas, conversely, the rapid deployment of wireless systems facilitates their application when premises are temporarily or suddenly moved or communication is required in remote areas (Mietzer and Hoeher, 2007). In the present study, we have investigated multi giga bit per second over broadband wireless optical communication networks over wide range of the affecting parameters. Moreover, we have analyzed parametrically and numerically the maximum transmission distance and transmission bit rates and products that can be achieved within wireless optical links for optical networks.

SIMPLIFIED OPTICAL NETWORK ARCHITECTURE FOR WIRELESS LINKS

The architecture model of passive optical network with different optical links is shown in Figure 1. PON consists of many laser diodes as a source of optical signals which converts the electrical signal in the information source to optical signal, arrayed wave grating (AWG) multiplexer in the OLT, different optical fiber links, AWG demultiplexer, optical network unit (ONU) in the remote node (RN), optical detector which converts the optical signal to electrical signal for processing to ONU and connects to the supported number of users. In the transmission direction, the information source (electrical signal) is transmitted from the backbone network to the OLT and according to different users and location, optical source [laser diode or light emitting diode] convert it into optical signal and is transmitted into corresponding wavelength and multiplexed by Mux. When traffic arrives at RN, wavelengths are demultiplexed by Demux and sent to optical detector [Avalanch photodiode or PIN photodiode] convert the optical signal into electrical signal and then sent to ONUs which is distributed to different number of supported users (Abd El-Naser et al., 2009).

MODELING AND EQUATIONS ANALYSIS

In the design of wireless optical link system, it is important to determine the link budget equation. The general link budget equation is given by Ackerman et al. (2008):

$$P_{received} = P_{transmit} \cdot \frac{57.295\, A_{receiver}}{(\theta L)^2} e^{-\alpha L} \quad (1)$$

Where $P_{received}$ is the power at receiver (watt), $P_{transmit}$ is the transmission power (watt), $A_{receiver}$ is the receiver effective area (m^2), θ is the beam divergence (degrees), L is the length of the optical link (m), and α is the atmosphere absorption (dB/Km). The total loss coefficient is determined by:

$$\sigma L = \sigma_{rain} L + \sigma_{fog} L + \sigma_{snow} L + \sigma_{sc\,\mathrm{int}\,illation} \quad (2)$$

where σ_{rain} is the absorption due to rain (Km^{-1}), σ_{fog} is the absorption due to fog (Km^{-1}), σ_{snow} is the absorption due to snow (Km^{-1}), and σ_{scin} is the absorption due to scintillation (Km^{-1}). A variety of models exist for the calculation of these absorption coefficients. In the case of fog, the Kruse model according to Kamalakis et al. (2008):

$$\sigma_{fog}\,(Km^{-1}) = \frac{3.912}{V}\left(\frac{\lambda}{\lambda_0}\right)^{-q} \quad (3)$$

where V is the visibility at ($\lambda=\lambda_0$), Km, λ is the actual wavelength of the beam, µm, λ_0 is the reference wavelength in µm for the calculation of V, and the exponent q is the size distribution of the scattering particles and is equal to 1.3 if 6 Km < V < 50 Km, and equal to 0.585 $V^{1/3}$for low visibility V < 6 Km. Also to calculate the optical losses due to snow, the empirical formula can be used (Suman et al., 2007):

$$\sigma_{snow}(dB/Km) = A\,S^b \quad (4)$$

Where S is the snow fall rate (in mm/hour), A=5.42x10^{-5} λ+ 5.9458, and b= 1.38. In the same way, to calculate the optical losses due to rain, the empirical formula can be used:

$$\sigma_{rain}(dB/Km) = 1.076\,R^{2/3} \quad (5)$$

Where R is the rain fall rate measure (in mm/h). Finally the optical loss due to scintillation is calculated using the following expression:

$$\sigma_{sc}^2 = 4.\left(23.17\left(\frac{2\pi}{\lambda}10^9\right)^{7/6}\right)C_n^2\,L^{11/6} \quad (6)$$

Where C_n^2 is the scintillation strength (in $m^{-2/3}$). It should be noted that the case of wireless optical link system, fog induced absorption is the most impairment and can be significantly affect the performance of the system. A link budget for wireless optical link using one lens in the transmitter and one lens in the receiver is calculated. Different kinds of losses are calculated that may cause power losses during transmission (Jihui et al., 2005). Equation (7) shows that the ray losses of the system depend on the radius of the receiver lens and the beam radius at the receiver unit. A Gaussian beam intensity distribution is assumed (Suman et al., 2008):

$$F_s = 10\log\frac{P_{receiver}}{P_{total}} = 10\log\left(1 - e^{-\frac{2R^2}{w\,(L)}}\right) \quad (7)$$

Where L is the wireless link length in km, F_S is the ray losses, dB, P_{total} is the total beam power at L, watt, R is the lens radius, mm, w (L) is the beam radius, mm. Geometrical losses occur due to the diverence of the optical beam. These losses can be calculated using the following formula [14]:

$$\frac{A_R}{A_T} = \left(\frac{57.295D_R}{D_T + 100.\,d.\theta}\right)^2, \quad (8)$$

where A_R is the effective area of the receiver lens, A_T is the effective area of the transmitter lens, D_R is the diameter of the transmitting lens, D_T is the diameter of the receiving lens, d is the distance between the wireless optical transmitter and receiver, θ is the divergence of the transmitted laser beam in degrees. Based on curve fitting MATLAB program, the fitting equations between optical signal to noise ratio (OSNR), the operating signal wavelength for transmitter and receiver, and the wireless optical link length are (Ramachandran et al., 2006):

$$OSNR = 17.35 - 12.27L + 7.05L^2 - 5.87L^3 \quad , \quad (9)$$

$$OSNR = 3.85 - 10.73\lambda + 2.13\lambda^2 + 9.75\lambda^3 \quad , \quad (10)$$

The radio frequency transmission response provides the relative loss or gain in a wireless communication system links with respect to the signal frequency. Any signal attenuation due to the wireless communication links can be expressed:

$$Transmission(dB) = 10\log\left(\frac{P_{transmitter}}{P_{incident}}\right) \quad , \quad (11)$$

where $P_{transmitter}$ is the radio frequency power calculated at the output of the receiver, and $P_{incident}$ is the radio frequency power calculated at the input to the laser transmitter. Based on curve fitting MATLAB program, the fitting equations between transmission response, operating radio frequency, and amplification range are (Ramachandran et al., 2006):

$$Transmission(dB) = 10.82 - 2.05f + 7.42f^2 - 4.23f^3$$

(without amplification), (12)

$$Transmission(dB) = 3.09 + 13.65f - 2.56f^2 + 1.85f^3$$

(with amplification) (13)

The Shannon capacity theorem to calculate the maximum data transmission bit rate or the maximum channel capacity for the wireless optical links is as follows (Abd El-Naser et al., 2009):

$$C = B.W\log_2(1 + OSNR), \quad Gbits/\sec \quad (14)$$

Then the Shannon bit rate-distance product can be determined by the following expression:

$$P_{Sh} = C\,.\,L \quad , Gbit.km/\sec \quad (15)$$

Where L is the wireless link length in km.

SIMULATION RESULTS AND DISCUSSION

The main objective of the wireless optical link design is to get as much light as possible from one end to the other, in order to 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. As shown in Table 1, the proposed wireless optical link parameters to achieve maximum both tranmission link distance, transmission data rate and transmission bit rate-distance product.

Based on the assumed set of the controlling parameters for wireless optical link design to achieve the best transmission bit rates and transmission distances and the set of Figures 2 to 9, the following facts are assured:

Table 1. Proposed wireless optical link design parameters.

Operating parameter	Value
Power transmitted (P_T)	100 mWatt
Operating wavelength range (λ)	0.85 to1. 55 µm
Transmitter beam divergence (θ)	100 degree
Receiver diameter (D_R)	0.1-0.5 m
Link distance range	0.1 to 10 Km
Receiver sensitivity (S_R)	5 µWatt
Transmitter and receiver losses (η)	50 %

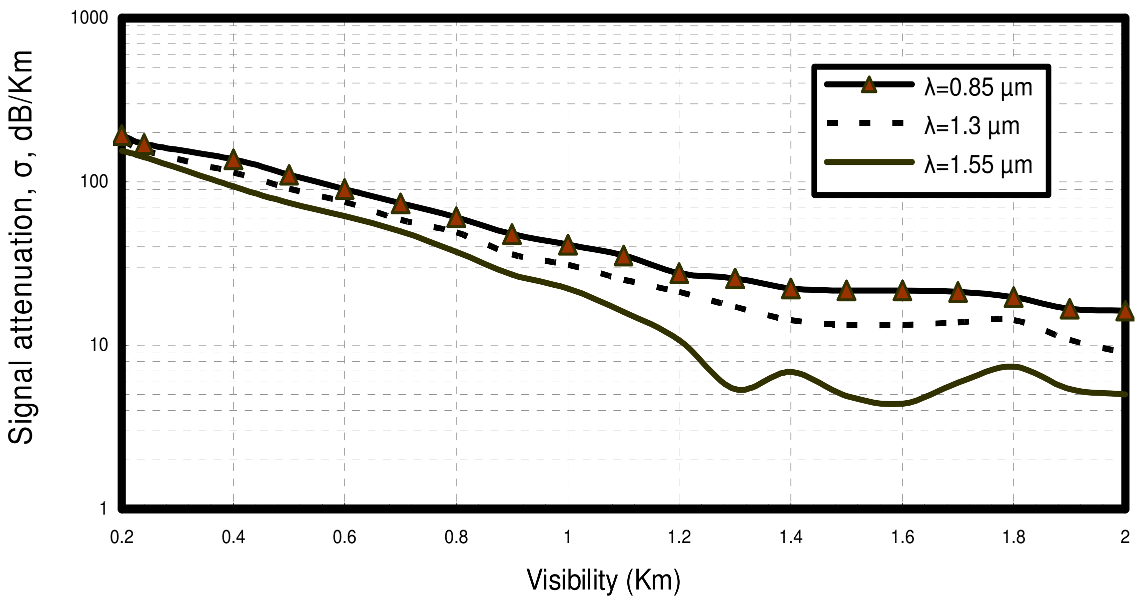

Figure 2. Variations of the signal attenuation with visibility for different laser diode wavelengths at the assumed set of parameters.

(i) Figure 2 has indicated that as the transmission distance (visibility) increases, the signal attenuation decreases at the same optical signal wavelength. While as the optical signal wavelength increases, signal attenuation decreases at the same transmission distance.
(ii) As shown in Figure 3, as the beam diameter at receiver increases, the ray losses also increases at the same lens diameter. While as the lens diameter increases, the ray losses decrease at the same beam diameter at receiver.
(iii) Figure 4 has demonstrated that as wireless optical link distance increases, the optical signal to noise ratio (OSNR) decreases at the same optical signal wavelength. Moreover, as the optical signal wavelength increases, the OSNR also increases at the same wireless optical link distance.
(iv) As shown in Figures 5 and 6, as optical signal to noise ratio increases, this leads to increase in Shannon bit-rate distance product at a constant of both wireless link length and operating signal wavelength. Also, as both the wireless link length and operating signal wavelength increased, this result in increasing Shannon bit-rate distance product at a constant optical signal to noise ratio. Variations of Shannon bit rate-distance product against optical signal to noise ratio at the assumed set of parameters
(v) As shown in Figure 7, as the transmitted radio frequency increases, the signal transmission also increases for both amplification and non amplification techniques. But with amplification technique offered high signal transmission.
(vi) Figures 8 and 9 have indicated that as the transmitted radio frequency increases, the transmission data rate also increasesin both cases of amplification and non amplification techniques at the same wireless link distance. While, as the wireless link distance increases, the transmission data rate decreases at the same transmitted radio frequency. Moreover with amplification

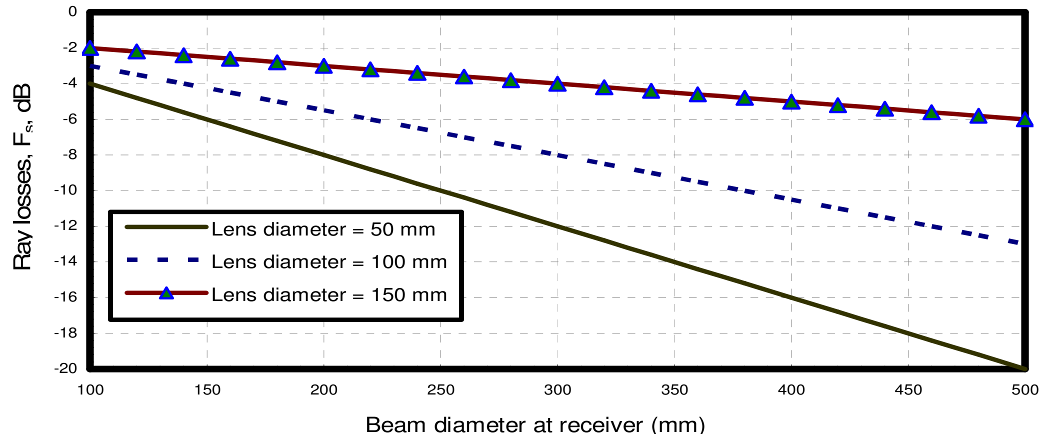

Figure 3. Variations of the ray losses with beam diameter at receiver for different lens diameter at the assumed set of parameters.

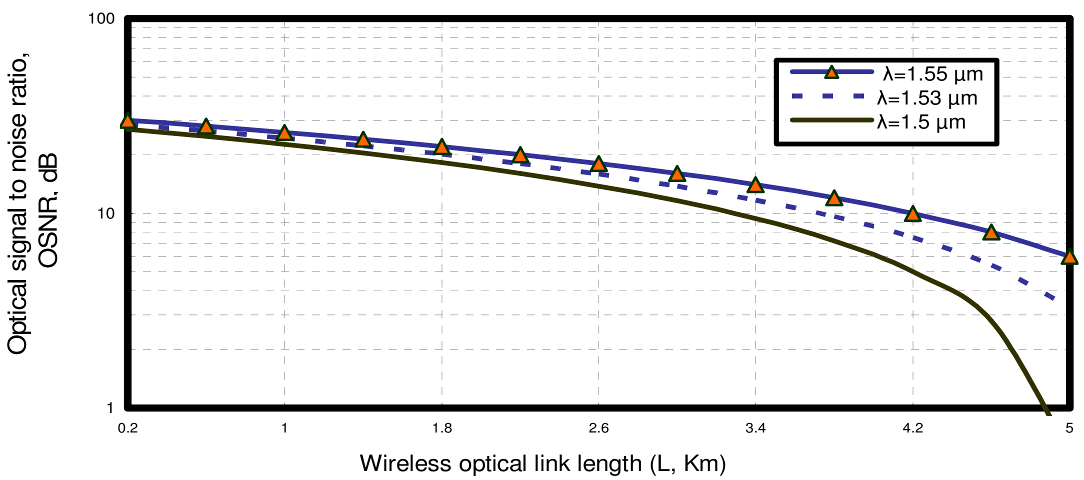

Figure 4. Variations of optical signal to noise ratio with wireless optical link distance at the assumed set of parameters.

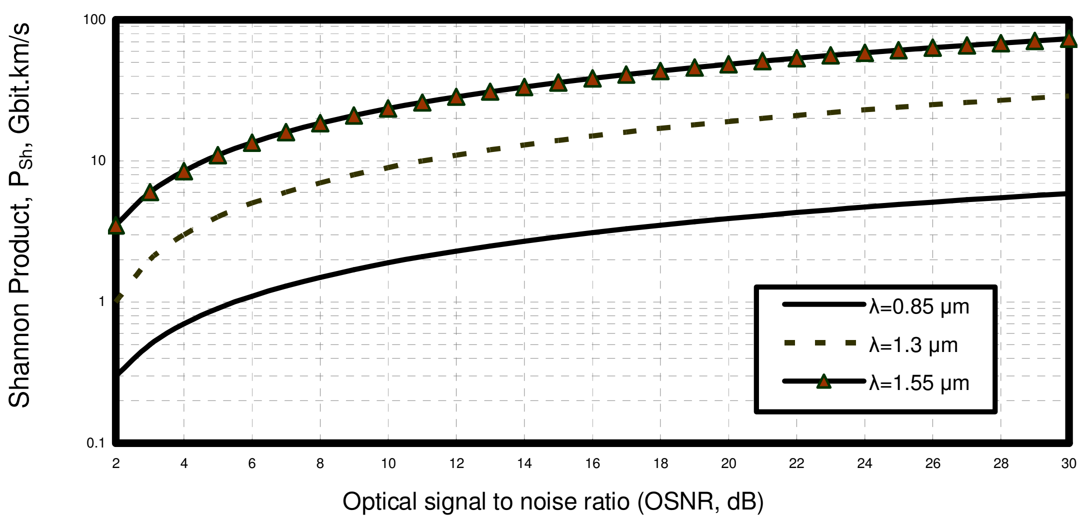

Figure 5. Variations of Shannon bit rate-distance product against optical signal to noise ratio at the assumed set of parameters.

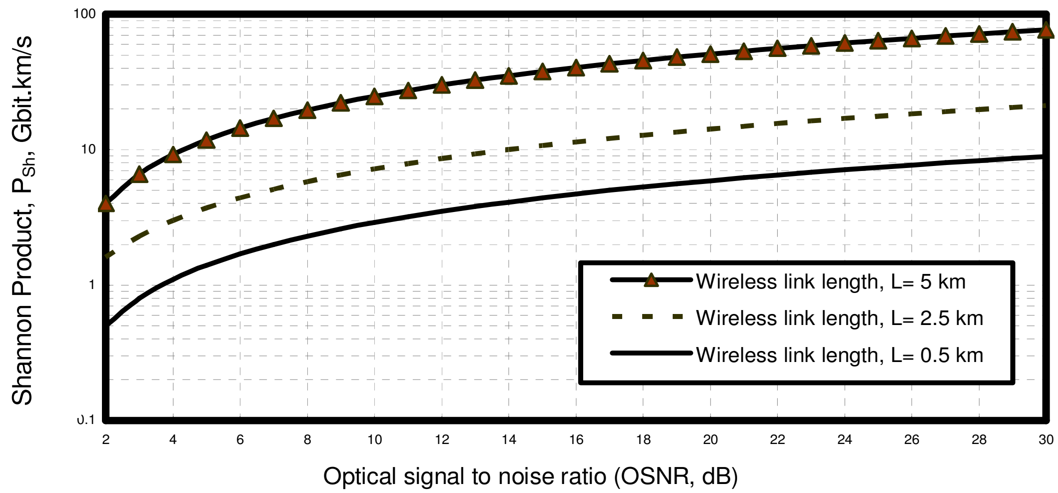

Figure 6. Variations of Shannon bit rate-distance product against optical signal to noise ratio at the assumed set of parameters.

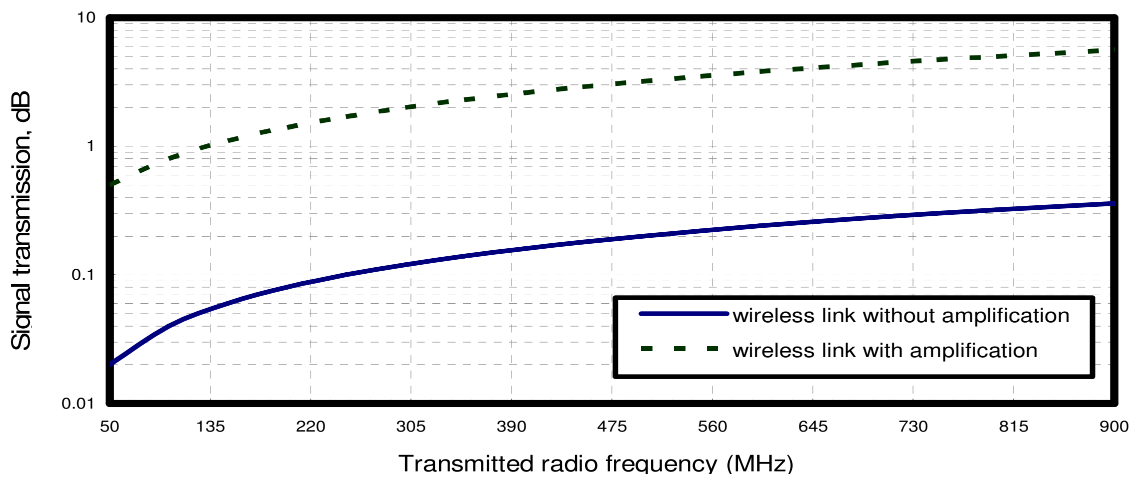

Figure 7. Variations of wireless transmission with transmitted radio frequency at the assumed set of parameters.

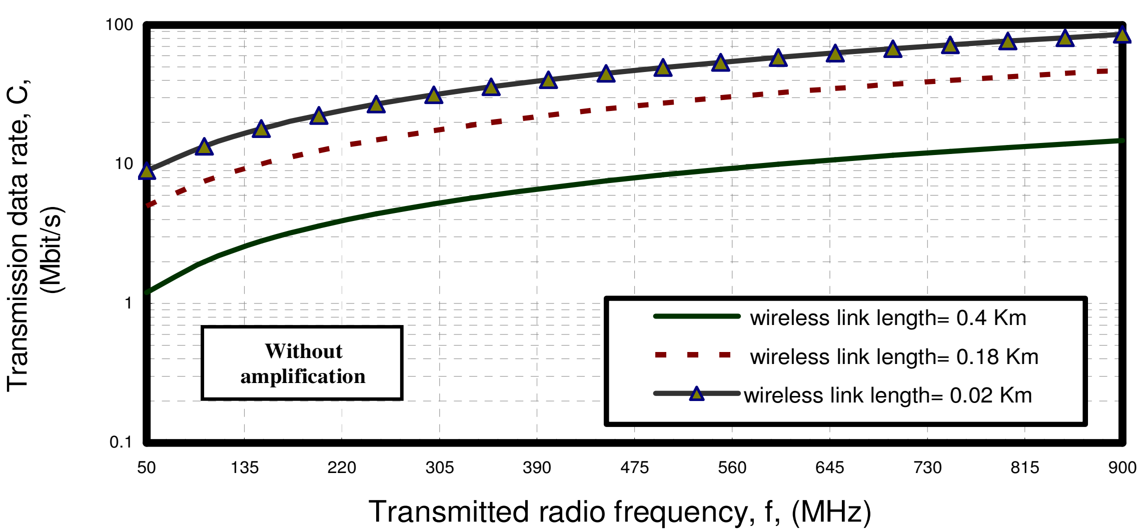

Figure 8. Variations of transmission data rate with transmitted radio frequency at the assumed set of parameters.

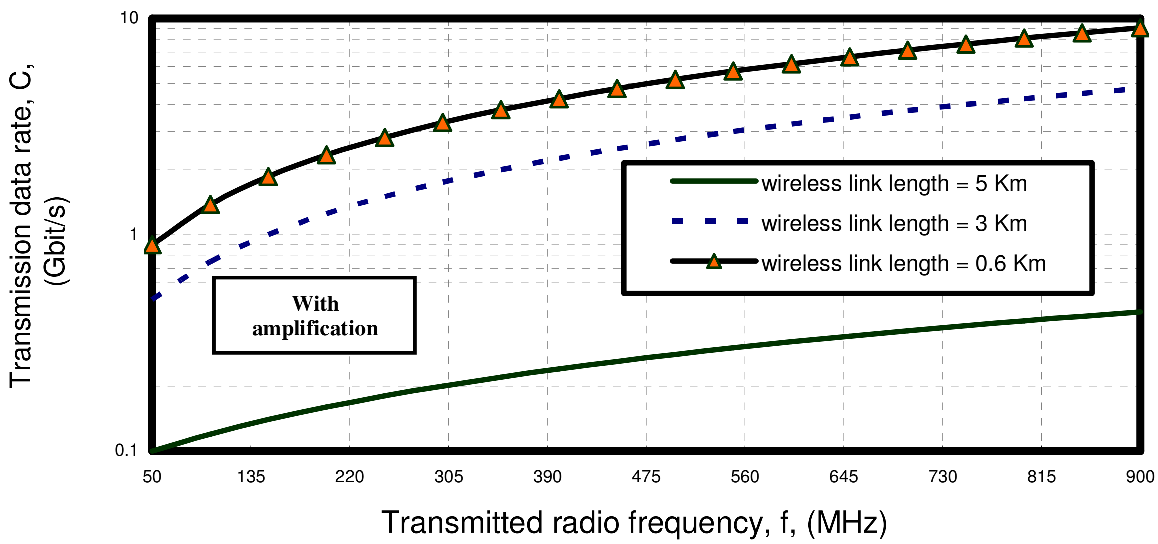

Figure 9. Variations of transmission data rate with transmitted radio frequency at the assumed set of parameters.

techniques offered both high transmission link diatance and transmission data rate.

Conclusions

We have investigated the high transmission bit rate of multi giga bit per second for short range optical wireless access communication networks over wide range of the affecting operating parameters. We have demonstrated that the larger the optical signal wavelength, the higher the transmission distance for both wireless optical links. Moreover, we have demonstrated that with amplification techniques, which added additional costs to the wireless system, the wireless optical link offered both high transmission distances and transmission data rate. It is observed that the increased of optical signal to noise ratio, operating signal wavelength, and wireless link length for short range, the increased Shannon bit rate-distance product.

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