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Operation Performance Evaluation of Intersatellite Optical Wireless Communication Systems in Low Earth Orbits

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Abstract— This paper has presented the intersatellite communication link is modeled and simulated using the optisystem software version 7. As well as we have discussed the intersatellite optical wireless communication system technology for quality enhancement of wavelength and distance between satellites. The operation performance of intersatellite optical communication system is depending on the operating signal wavelength, diameter of antenna and distance between satellites in low earth orbit (LEO). Received power, quality factor, power loss and bit error rate are the main important performance parameters in our study.

Index Terms— *Quality factor; Received Power; Power loss; Inter Satellite Link Intersatellite optical wireless communication; and Bit Error Rate (BER).*

I. INTRODUCTION

The Optical Wireless Communication system (OWC) has a very important role in wireless communications [1, 2]. Optical wireless communication is now able to send data at bit rates up to several Gb/s and at distance of thousands of kilometers [3, 4]. Recently, optical communication system Satellite Links have high speed operation, Quality and reliability [5-7]. The optical wireless communication using satellites can be operated at high transmission bit rates [8].

Optical wireless communication system (OWC) operates at a low frequency range causing many advantages such as: high transmission bit rat and bandwidth, small optical antenna size, power efficiency , narrow laser emit beam and due to light travelling high data speed with minimum loss because the space is considered to be vacuum [9, 11].

II. SIMULATION SETUP OF 64 CHANNEL INTESATELLITE OPTICAL WIRELESS COMMUNICATION MODEL

The optical system of intersatellite link is consisting of transceiver which can be communicated by emitting and receiving optical signals. This model consists of transmitter, OWC channel and receiver. The Optical transmitter includes four subsystems. The first subsystem is user defined bit sequence generator which represents the data that wants to be transmitted. The second subsystem is based on non return to zero (NRZ) pulse generator which can encode the serial data out from user defined bit sequence generator. The third subsystem is the CW laser. Laser can be used instead of light emitting diode for existing system due to its ability to send the date at further distance. The fourth subsystem is Mach Zehnder modulator which varies the intensity of light signal from the laser according to signal out from NRZ pulse generator. The OWC channel between an optical transmitter and optical receiver is the propagating medium for transmitted signal.

The receiver consists of three subsystems which are Avalanche photodiode, low pass filter and 3R regenerator. At the receiver, the process which occurs at transmitter is reversed. APD photodiode receive the optical signal and converted into an electrical signal. Then low pass Bessel filter is used to filter out undesired higher frequency signals. The 3R regenerator uses to rebuild electrical signal of the original bit sequence which can be converted from Avalanche photodiode , and the modulated electrical signal which generated in the transmitter to be used for bit error rate analysis.

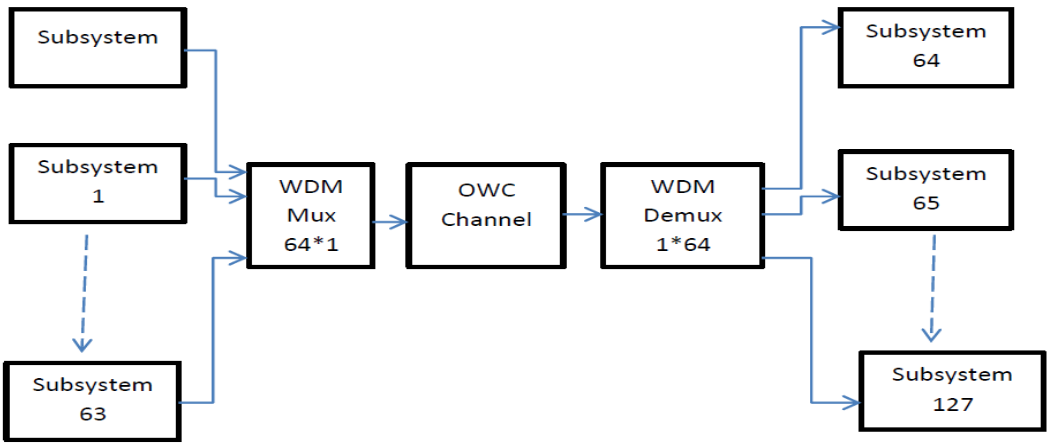

Fig.1. Simulation Model of 64-Channel WDM System for intersatellite optical link.

The system model in Fig.1 consists of 64 subsystem at transmitter. Each subsystem consists of user defined bit sequence generator, non-return to zero pulse generator, CW laser and Mach Zehnder modulator. At receiver, there is 64 subsystem, each of them consists of APD, LPF, 3R generator and BER analyzer.

III. Simulation Results and Discussions.

III.1 The system performance for the relation between quality factor with wavelength

The link performance analysis is obtained using optiwave simulation version. 7 as shown in Fig. 2. Table 1 show the stimulation parameters of ISL system. The propagation distance is taken from 1000 Km to 5000 Km. The operating wavelength is taken to be 860 nm, 1300 nm, 1550 nm. The bit rate is taken to be 3 Gb/s based on Refs [1-3].

Fig. 2 the relation between quality factor and wavelength at distance 1000 km. It is observed that increasing wavelength leads to decreasing in quality factor. When wavelength is 860 nm the quality factor of the system is 21.9 and BER is 4.2 $*10^{-107}$ as shown in Fig. 4. By increasing wavelength to 1300 nm the quality factor decreases to 21.5 and BER is 1.6 $*10^{-102}$ as shown in Fig. 5. At wavelength equal 1550 nm, the quality factor is 21 and BER is $2.6*10^{-98}$ as shown in Fig. 6. The system performance decreases by increasing wavelength.

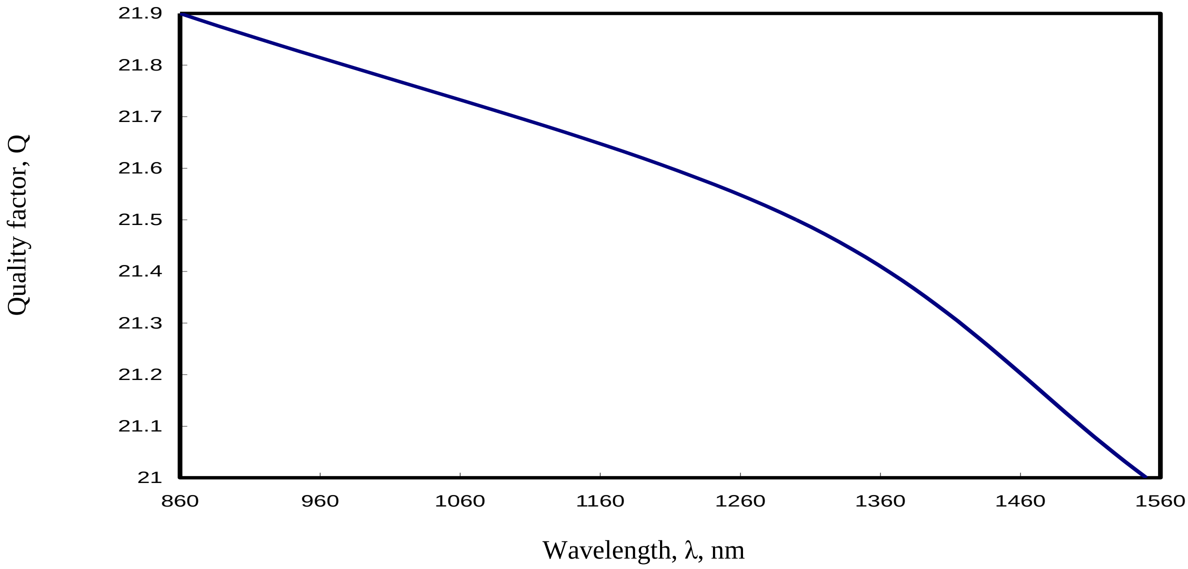

Fig. 2. Relation between quality factor and wavelength .

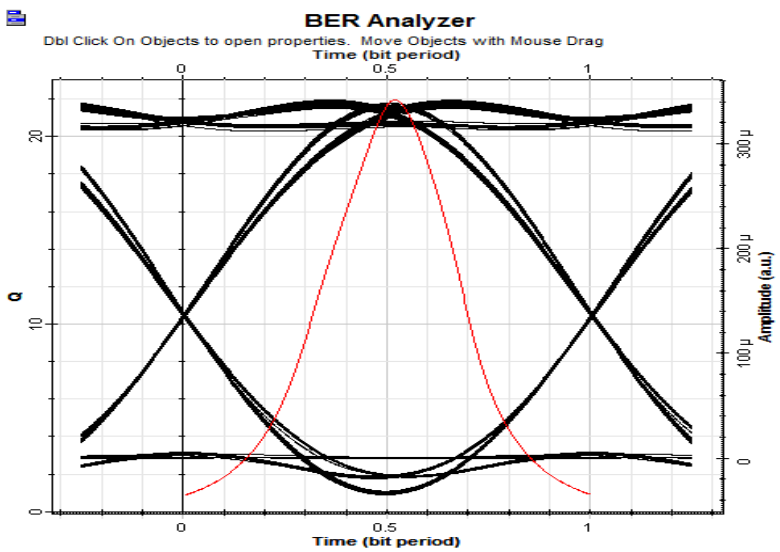

Fig. 3. Eye diagram for Q using wavelength, λ =860 nm at distance=1000 km

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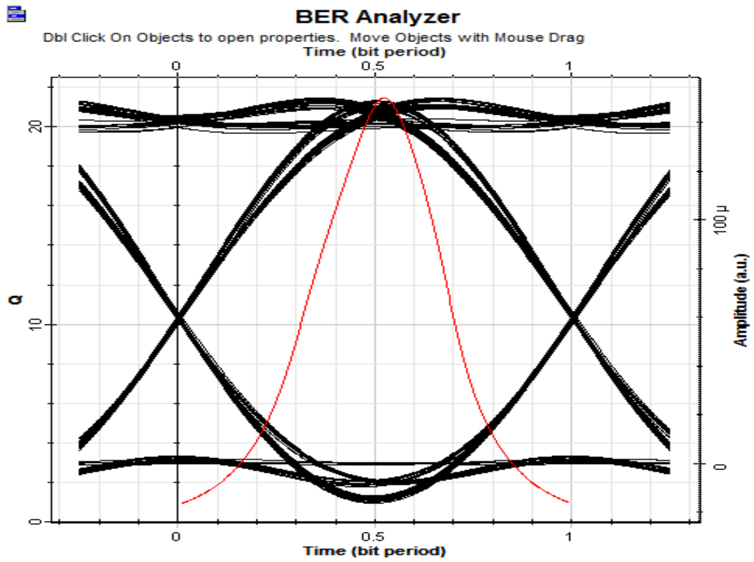

Fig. 4. Eye diagram for Q using wavelength, λ =1300 nm at distance=1000 km

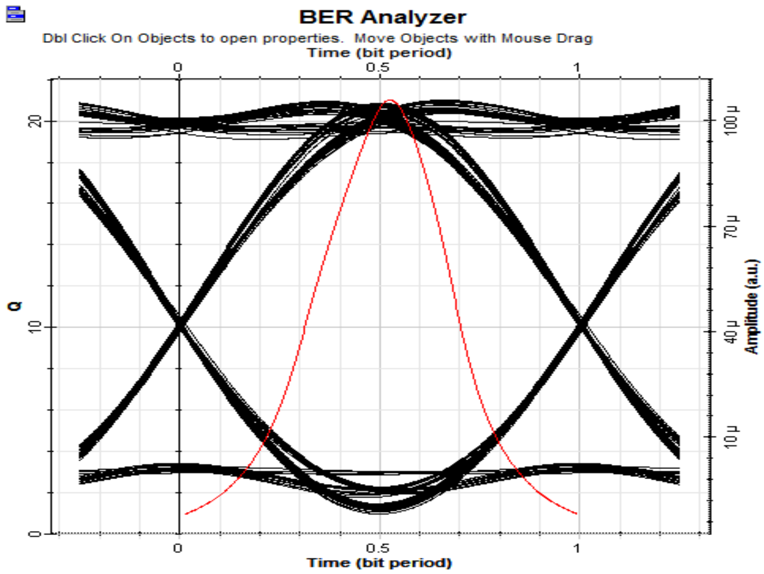

Fig. 5. Eye diagram for Q using wavelength, λ=1550 nm at distance=1000 km

III. 2. Bit Error Rate (BER) eye diagrame at antenna diameter 0.2 m, 0.3 m, 0.4 m at wavelength 1550 nm and distance=1000 km.

By increasing antenna diameters, BER decreases at the same distance. Figs (6-8) shows that, BER at antenna diameter 0.2 m is higher than it at antenna diameter 0.3 m and BER at antenna diameter 0.3 m is higher than it at antenna diameter 0.4 m. The best BER is achieved at antenna diameter equal 0.4 m.

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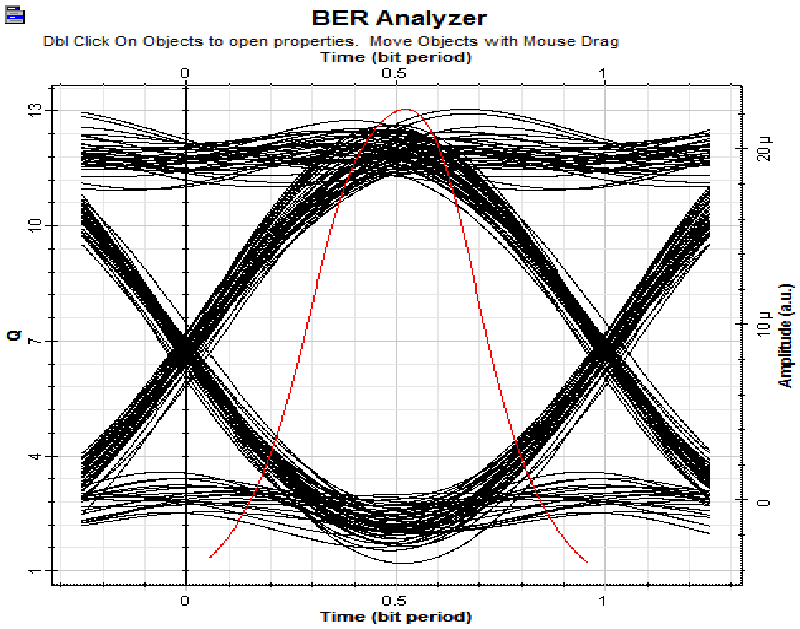

Fig. 6. Eye diagram for BER using antenna diameter = 0.2 m at distance=1000 km.

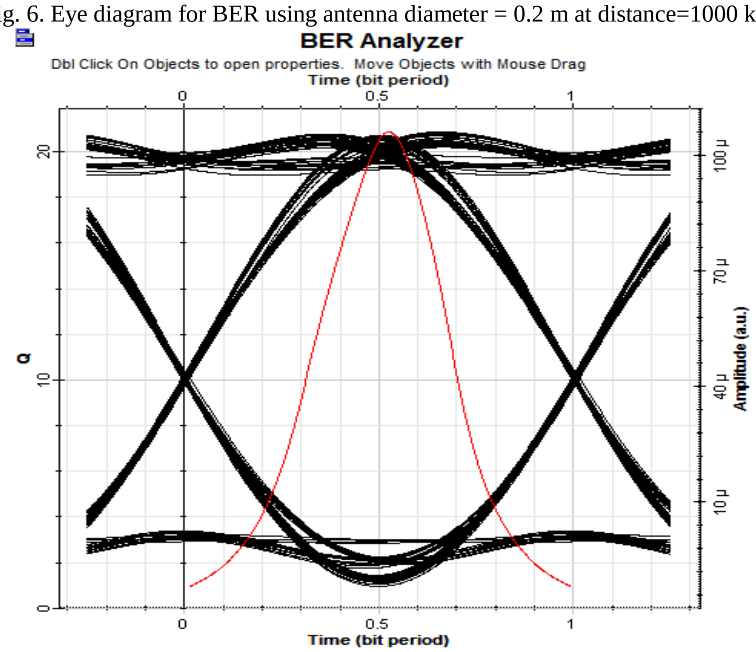

Fig. 7. Eye diagram for BER using antenna diameter = 0.3 m at distance=1000 km.

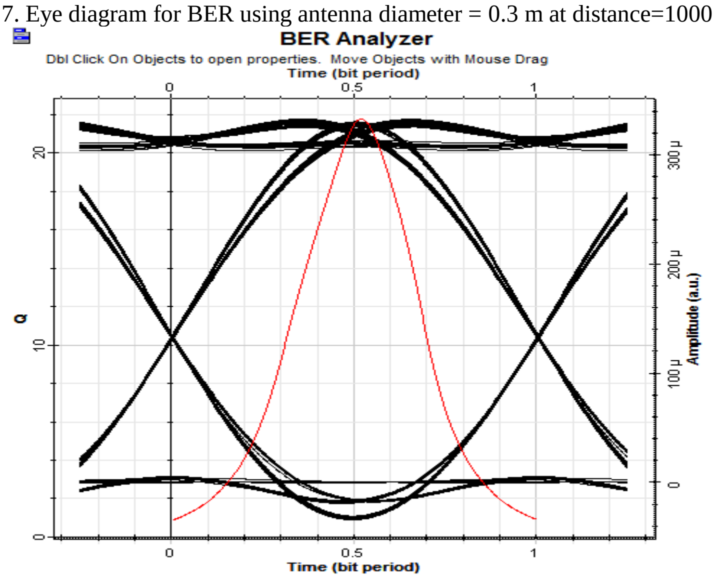

Fig. 8. Eye diagram for BER using antenna diameter = 0.4 m at distance=1000 km.

III. 3. Relation between Quality Factor and Distance at Different Wavelengths

By increasing distance, quality factor decreases at the same wavelength as shown in Fig [7]. So, quality factor is inversely proportional to distances. In Fig.7, the quality factor at wavelength equal 860 nm is better than quality factor at wavelength equal 1300 nm and the quality factor at wavelength equal 1300 nm is better than quality factor at wavelength equal 1550 nm.

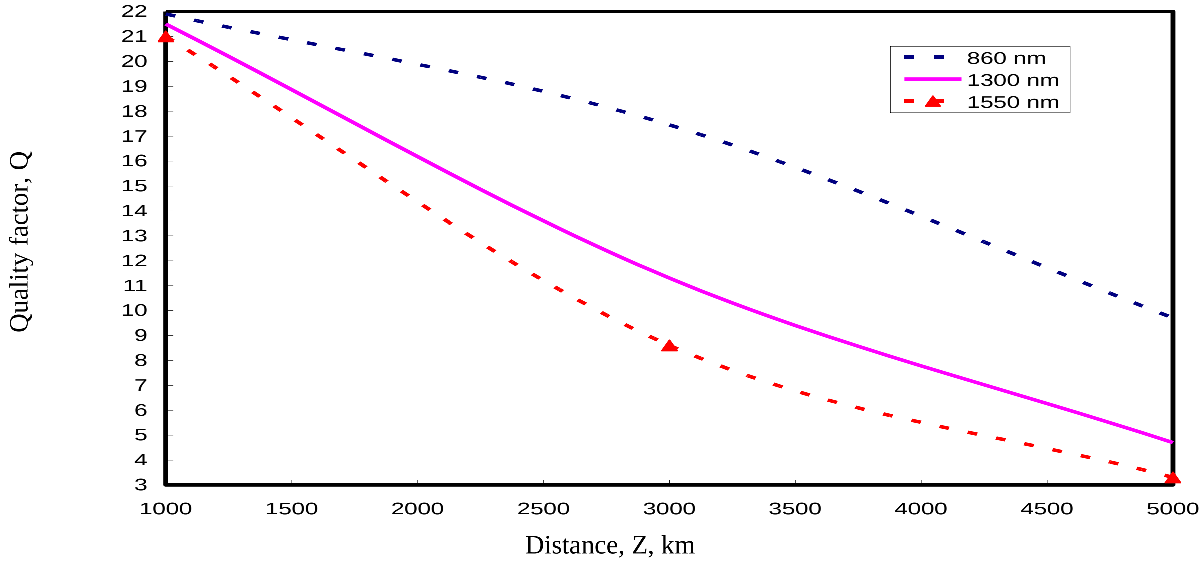

Fig. 9. Relation between quality factor and distance for different values of wavelengths

III. 4. Relation between Received Power and Distance at Different Values of Antenna Diameter.

In the OptiSystem software, the transmitter and receiver gains are zero dB. Optical wireless channel is modeled by:

$$P_R = P_T\, \eta_T\, \eta_R\, (\lambda/ 4\pi * Z\ )\, G_T\, G_{RL} L_T\, L_R \qquad (1)$$

Where P_R is optical transmitted power; η_T is the transmitter optical efficiency; η_R is the optical efficiency of the receiver; Z is the distance between the transmitter and the receiver; λ is the wavelength; G_T is the transmitter antenna gain; G_R is the receiver antenna gain; and L_T is transmitter pointing loss factor, L_R is the receiver pointing loss factor. In this research, it is assumed that diameter of transmitter antenna D_T is equal to diameter of receiver antenna D_R. So G_T is equal G_R, the gain of antenna can be calculated by the following equation:

$$G=(\pi D/\lambda)^2 \qquad (2)$$

Where $G= G_T= G_R$, and D is diameter of antenna , $D=D_T=D_R$. The received power from equation (1) can be calculated as the following:-

$$P_R=P_T\eta_T\eta_R(\pi^3 D^4/4Z\lambda^3)L_T L_R \qquad (3)$$

Equation (3) show that the received power is proportional to D^4, so by increasing diameter of antenna, the received power increases for the same distance as shown in Fig.10. Antenna diameter is choosen to be 0.2 m, 0.3 m and 0.4 m and wavelength is chosen to be 1550 nm. It is also observed that the maximum received power is achieved at antenna diameter equal 0.4 m and distance equal 1000 km. the least received power is achieved at antenna diameter equal 0.2 m and distance equal 5000 km.

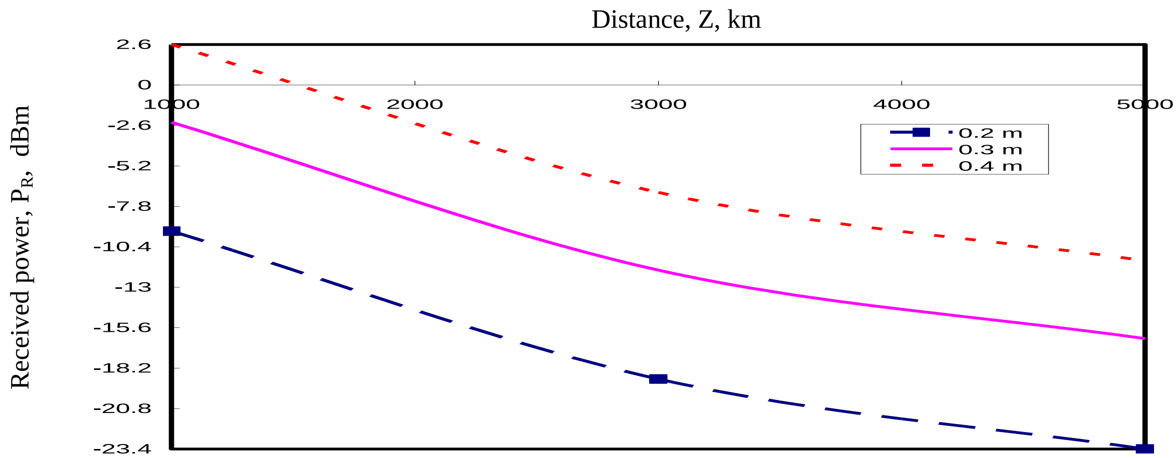

Fig .10. Relation between received power and distance at different antenna diameters.

III. 5. Relation between power loss and distance at different values antenna diameter .

Power loss is proportional to the distance. The power loss is inversely proportional to received power. By increasing antenna diameter, power loss decreases as shown in Fig. 11. In Fig. 11 antenna diameter is chosen to be 0.2 m, 0.3 m and 0.4 m and wavelength is chosen to be 1550 nm. Power loss is calculated from the following relation:

$$P_{loss} = (P_{in} - P_R)/P_{in} \quad \% \qquad (5)$$

Where P_{loss} is the power loss , P_{in} is the input power and P_R is the received power.

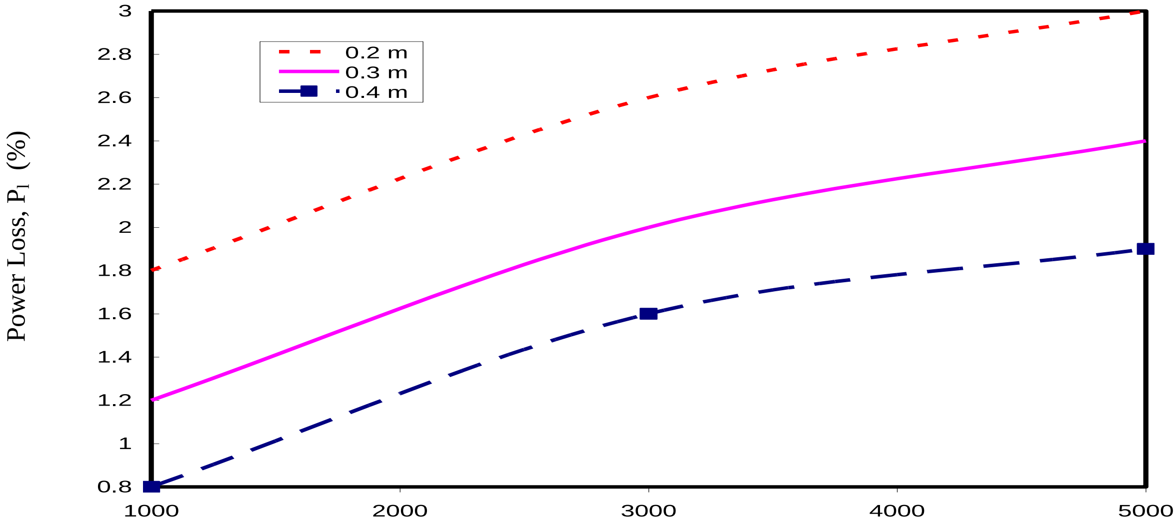

Fig. 11. Relation between power loss and distance at different antenna diameters.

IV. Conclusion

By increasing wavelength, the quality factor decreases and BER increases at the same bit rate, as shown in Table.1. Quality factor is inversely proportional to BER. BER decreases by increasing antenna diameters. When distance increases, quality factor decreases at the same wavelength as shown in Table. 2. Quality factor is inversely proportional to distance. With increasing the distance, the received power decreases and power loss increases as shown in Table. 3. At low wavelengths and small distances the performance of the system is high because the quality factor is high. By increasing antenna diameter, the received power increases and loss power decreases at the same distance as shown in Tables (3,4).

Table. 1. Relation between quality factor and wavelength.

Wavelength (nm)	Q factor	BER
860	21.9	$4.2 * 10^{-107}$
1300	21.5	$1.6 * 10^{-102}$
1550	21	$2.6 * 10^{-98}$

Table. 2. Relation between quality factor and distance at different wavelengths.

Distance (km)	Q factor		
	860 nm	1300 nm	1550 nm
1000	21.9	21.5	21
3000	17.5	11.3	8.6
5000	9.7	4.7	3.3

Table. 3. Relation between received power and distance at different antenna diameters.

Distance (km)	Received Power (dBm)		
	0.2 m	0.3 m cm	0.4 m
1000	-9.4	-2.4	2.6
3000	-18.9	-11.9	-6.9
5000	-23.4	-16.3	-11.3

Table. 4. Relation between power loss and distance at different antenna diameters.

Distance (km)	Power loss (%)		
	0.2 m	0.3 m	0.4 m
1000	1.8	1.2	0.8
3000	2.6	2	1.6
5000	3	2.4	1.9

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