FSO communication system to improve the resilience to natural disasters: Mexico Challenges

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***Abstract*— A free space optical communication system using fixed terrestrial stations and unmanned vehicles in the principal regional and national security locations after a natural disaster in order to increase the capacity of the resilience activities is proposed. A general scenario of the communication links for resilience in different areas is considered, being these areas the most affected by tropical cyclones. Also, some experimental setups designed and implemented in Mexico are shown.**

Keywords—free space optics, natural disasters, unmanned vehicles, hydro-meteorological phenomena

I. INTRODUCTION

Based on information from the National Center for Disaster Prevention (CENAPRED), Mexico has an average of 23 tropical cyclones between May and November and it is known that in the states of Baja California Sur, Michoacán, Sinaloa, Sonora and Tamaulipas the cyclones have the highest occurrence of penetration (2-4 years). Also, due to the existence of important concentration of population settled along the shores, it has been estimated that there are approximately 4 million people exposed to this phenomenon (40% of the total population of these states, located in 31 seaside municipalities). In other states, the cyclonic penetration recurrence range goes from 5 to 7 years; it is estimated that in these states, approximately 2 million people are at risk. This group is comprised by the states of Baja California Sur, Campeche, Colima, Jalisco and Quintana Roo and 19 seaside municipalities in which 26.3% of its total population is at risk. Finally, a group integrated by the states of Nayarit, Guerrero, Tabasco, Tamaulipas, Oaxaca, Veracruz, Chiapas and Yucatan, has a period of recurrence or penetration of cyclones is 8-26 years. This group is characterized by a greater dispersion of the seaside population: it is estimated that four million people (23.9% of total) in 176 municipalities, are exposed to this risk. In this way, we are referring to about 10 million people are at risk from tropical cyclones without considering other hydro-meteorological phenomena. The states with a higher probability of a tropical cyclone in a year are: Baja California Sur (34%), Quintana Roo (22%), Jalisco (30%) and Colima (32%) (Fig.1). In such way it is determined that, the states of Baja California Sur, Colima, Jalisco and Quintana Roo are the areas with higher risk. Based on the latest, it is concluded that it is a national problem, and is necessary to know the needs produced by natural disasters in this regions as well as the existent of a resilience program for disasters considering optimal communication systems [1-3]. On the other hand, among the many problems caused by natural disasters (tropical cyclones) are the partial or total destruction and / or intolerability of communication networks, which causes a lack of information concerning to the social concerns and collective effervescence in relation to criminal acts, needs of the victims, actual damages, etc. Therefore, it is necessary to have an emergency communication system in order to help and support the existing radio frequency communication systems between all government levels, and at the same time, to the society in general. Nowadays, it is true that there are agreements between governments and private telecommunications companies to assist in natural disaster, however, this still has some common challenges related to human resources and technological performance, among which are the coordination and identification of contacts, technical and operational challenges [4-8].

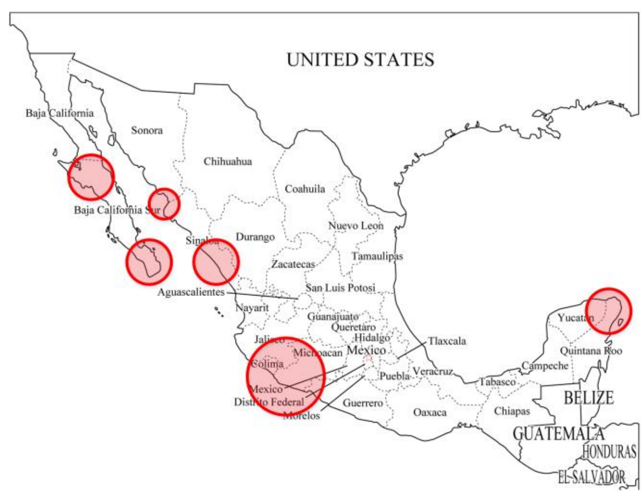

Fig. 1. Map of Mexico with high-risk areas of impact of tropical cyclones

This paper presents a Free Space Optical (FSO) communication system proposal in order to improve the resilience activities for natural disasters. The work is divided into the following sections: technical and scientist background of free space optical links, some experiments, potential impacts of the design in accordance with government and private

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institutions, manufacturing and implementation of the required systems considering various government departments at different levels.

II. Scientific And Technical Background

This section shows general information about the FSO links, components and performance. In addition, the principal challenges about the performance of FSO systems are presents in order to clarify the research and innovation trends.

a) General aspects

Currently, the free space optical links are an important alternative to transmit information between nearby and remote locations (e.g. metropolitan areas and global satellite networks). Such systems have many advantages over radio frequency systems; the most significant advantage is the high transmission rate (which leads to a larger amount of data concerning to the resilience) and reduced beam divergence using optical signals; therefore, the communication area sectorization (according to the damages and others aspects) is possible in a relatively simple way. Among the optical communication schemes used, there are those which due to their simplicity are frequently used, called IM/DD system, which requires a system of Intensity Modulation (IM) of the optical signal and a receiver system using Direct Detection (DD). These schemes, although widely used, have some disadvantages in comparison with the systems that use coherent reception; mainly, the relatively short transmission distance. Besides, the systems that use coherent detection, the transmitter system can modulate any variable of the optical signal (intensity, phase, frequency and polarization) to send information through a communication channel (free space), which is detected by a system with coherent reception. It also requires an optical local oscillator to produce a mixture of the optical data signal with the local oscillator, in order to obtain the electrical data in a baseband or an intermediate frequency. In addition, the coherent detection system presents some advantages over IM/DD systems, where the principal advantage is the resistance to some environmental phenomena such as turbulence [9, 10].

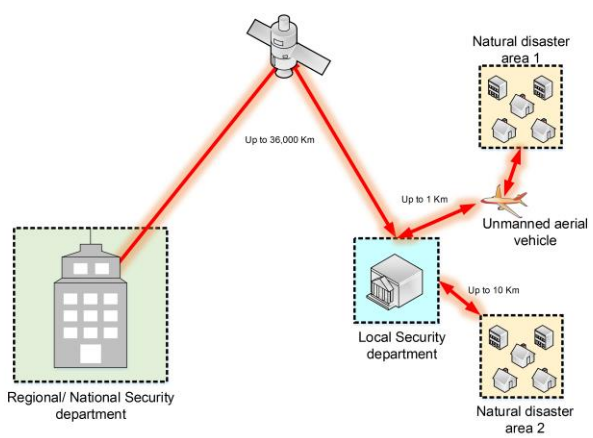

Fig. 2. General scheme of the optical network using spacecraft and fixed terrestrial links.

Furthermore, in order to determine the optimal set-up of a free space communication system, both transmission-reception schemes (IM/DD and coherent detection) have to be analyzed in order to determine the relevance of the aforementioned systems, i.e., each application imposes particular technical requirements and trade-offs for the development of the design, analysis and subsequently the prototype manufacturing [11, 12].Thus, the design of a communication network for resilience considering the diverse detection techniques is necessary. Fig. 2 shows the general scheme of an optical communication network to improve resilience activities. The proposed communication system considers that in different natural disaster areas exist permanent optical transmission systems which are easy to implement; these systems send the relevant and exclusive information in order to improve the resilience activities. Depending on the network configuration, different local areas can communicate with direct optical links to local security departments located within 10 Km or to an aircraft / spacecraft with a specific mission. Among the specific applications of the spacecraft is the collection of high quality data (videos and pictures) in order to obtain accurate information in real time (also off-line or recorded video) from the damage caused by the natural disaster, among others. At the same time, the ideal application imposes that the local security departments should have systems for free-space optical communication (vertical or horizontal links), in order to provide the necessary bandwidth for the transmission of information considering quantity and quality of service with other local/regional security departments. However, the establishment of vertical links with a specific local security department based on the technical and economical trade-offs is possible. In addition, an optical receiver-transmitter system (horizontal link) should be established in order to provide communication with the regional or national security departments according to the case [13-14]. Regarding the technical aspects, various commercial systems use transmission rates from 125 to 155 Mbps in SDH (Synchronous Digital Hierarchy) and some even up to 1Gbps, although with less transmission distance (from 300-5400 meters) depending of the environmental conditions (especially rainfall). Another advantage of these systems is that it can be powered in different ways; the most common is to using an AC source (100-240 VAC), it is also possible to use a direct voltage source (-48 VDC). The latter makes possible the use of portable batteries (or solar energy systems) to be used in areas of natural disaster without using the conventional electrical distribution network [15].

b) Technological and research trends

Although the FSO links has an enormous advantage in comparison with the traditional RF links, it is true that these links also have important challenges. In general, these challenge are regarding the next issues: atmospheric channel randomness, dynamical performance of the TAP systems (tracking, acquisition and pointing), optical fading, network robustness and congestion, among others. Thus, currently, diverse viable solutions have been proposed such as Statistical channel modeling with various fading factors, autonomous TAP system, advanced components, autonomous topology reconfiguration and high performance protocols, respectively [16]. Based on the last, there are exists diverse open research issues.

III. Experimentals Set-Up And Simulations

a) Horizontal FSO link

Our team work has diverse experimental set-ups in laboratory and real environmental conditions. In addition, diverse important simulation activities are performed as fundamental design method for the overall FSO systems.

Fig. 3. User calibrating the telescope in the receiver side.

Fig. 3 shows the calibrating of the receiver system of a FSO horizontal link implemented in Ensenada city, Mexico. This receiver system consists of a telescope with broad aperture in order to collect the maximum optical power from the transmitter system after that the signal traveled through the atmospheric channel. Fig. 4 shows the spot of the laser beam of the transmitter side (bottom of the figure) and the receiver side (front of the figure or behind of the telescope).

Fig. 4. Alignment process between the transmitter (bottom) and receiver (front) side using a green laser.

This particular atmospheric link has a specific atmospheric condition, dynamical and dense fog, therefore, the condition affects the transmission performance. In addition, the TAP system was neglected due to the short distance link and high performance stability of the mechanical components used

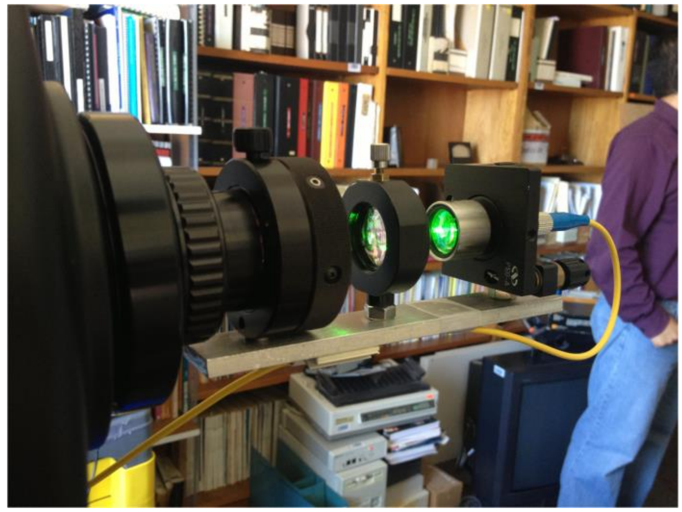

Fig. 5. Collimating set-up in the receiver side

Due to that the receiver system uses fiber optics in the internal subsystems for the photo detection and processing (the telescope is used only to collect the optical power), the collimating of the laser beam in a fiber is necessary. Therefore, Fig. 5 shows the collimating set-up with the optical discrete devices needed. On the other hand, both vertical and horizontal links require an accurate alignment using auxiliary Finder systems as Fig. 6 shows.

Fig. 6. Using Finder in order to improve the alignment process between two locations.

b) Unmanned Aircraft System (UAS) testing.

Another project that our group has been working on regarding the design, implementation and performance measurements of optical communication systems; using an Unmanned Aircraft System (UAS) based on, radiofrequency measurements. Fig. 7 shows the UAS used in the measurements.

Fig. 7. Unmanned Aircraft System used for the characterization of the optical communication system.

Nowadays, the UAS allows us to obtain performance measurements regarding the control and telemetry subsystem using a radio frequency link in order to improve and support the national research, development and innovation about the issue focused on this paper. In addition, each possible scenario has to be simulated using a high level software, in our case, System Tool Kit (STK). In particular, Fig. 8 shows the visual simulation of a horizontal communication link considering a ground station and a water station. On the other hand, Fig. 9 shows a vertical communication link using a conceptual satellite and a ground station.

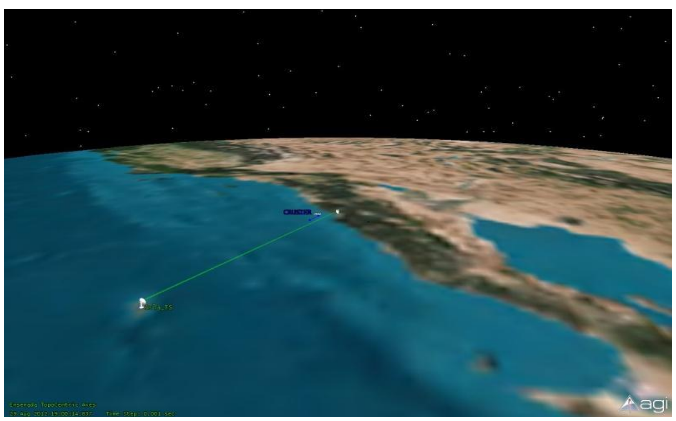

Fig.8. Horizontal communication link using STK.

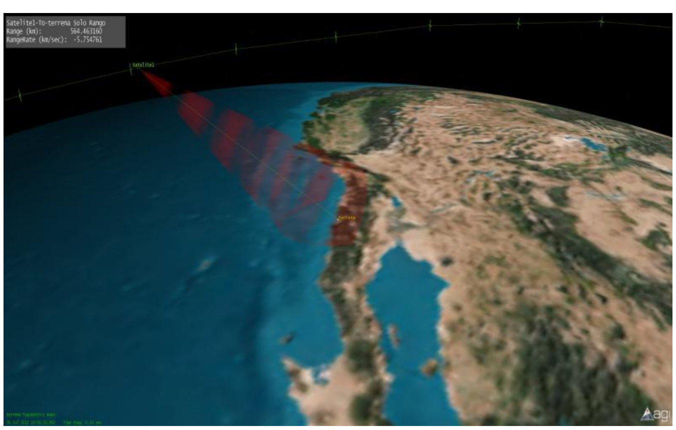

Fig. 9. Vertical communication link using STK.

IV. Commercial Options for FSO Network

There are exist several commercial options systems for implement FSO networks from short to long distances links or coverage. However, all the commercial systems are based on OOK (On-Off Keying) modulation scheme yet. The more important companies that provide FSO systems are Fsona and Lightpointe. Basically, the maximum transmission rate is 2.5 Gbps for short distance links (i.e. 1,000 and 1,900 meters according the weather conditions). In addition, it is possible establish FSO link at 1.25 Gbps for distance link of 4,800 meters. In fact, the FSO system that have high performance are based on high power transmission levels at 1550 nm.

Table 1. FSO Models Characteristics

Model	**Transmission rates at full duplex**	**Operational range (meters)**		**Some Tech spec**
		clear air (3 dB/km)	*extreme rain (10 dB/km)*	
FSONA				
155-E	155 Mbps	50-3,200	50-1,600	320 mW (2 x 160mW), 1550 nm
155-M		300-5,400	300-2,400	640 mW (4 x 160 mW), 1550 nm
1250-E	1.25 Gbps	50-2,700	50-1,400	320 mW(2 x 160 mW), 1550 nm
1250-Z		50-500	50-350	160 mW, 1550 nm
1250-M		400-4,800	400-2,200	640 mW(4 x 160 mW), 1550 nm
2500-E	2.5 Gbps	50-1,900	50-1,000	320 mW(2 x 160 mW), 1550 nm
2500-Z		50-500	50-350	160 mW, 1550 nm
LIGHTPOINTE				
Airebridge SX (hybrid laser-radio)	1 Gbps	1,100	750	1 Tx / 1 Rx, 850 nm
Airebridge LX (hybrid laser-radio)	1 Gbps	2,500	1,500	4 Tx / 4 Rx, 850 nm,
Aire X-Stream	1.25 Gbps	2,800	1,600	4 Tx / 4 Rx, 850 nm,

Based on the information showed in Table I, the real implementation of a FSO Networks is suitable using multiple Tx/Rx systems. For example, a coverage of 50 Km is theoretically possible considering the model 1250-M

V. Mexico Challenges For Reach Potential Impacts

The implementing of a regional optical fixed communications network (or mobile) in free space (horizontal link) and a national satellite network (vertical link) in specific military areas (or in other areas after a feasibility analysis) is a very interesting proposal with important potential impacts. This network will help to determine in a relatively short time the level of damage caused by natural phenomenon, and this should accelerate the response time of the resilience activities of the competent authorities. In addition, the establishment of the backup optical communication network at a regional level would improve the management of public security operation centers in nearby areas. Specifically, the impact of the overall project is: to reduce the number of deaths, injuries and economic losses caused by emergencies resulting from natural disasters, such as lack of security, social health issues, lack of information between competent authorities which causes slow development of resilience activities, scarce or null communication with civil society outside the damaged area, which increases uncertainty and reduces the institutional trust, etc. Generally, in order to accelerate the development of FSO systems for resilience activities it is necessary a direct contact with the federal government entities, private companies and universities to give details of the prototype system and technical requirement. Such mentioned entities are: The Secretariat of National Defense (SEDENA), the Secretariat of Public Security (SSP), the Secretariat of Communications and Transportation as well as the Mexican Space Agency (AEM), among others.

VI. CONCLUSION

Experimental setups designed and implemented in Mexico about FSO links in order to improve the resilience activities are shown in this paper. In summary, this paper proposes to use the most innovative tools of optical communication combined with technologies in manned and unmanned vehicles (aircrafts and spacecraft) in order to establish early warning systems when facing a natural disaster and being able to reduce response times of government entities, civil society and Non-governmental organizations (NGOs). The communication between the mentioned organizations allows shorter recovery promotion of affected areas and reduce the immediate needs in the population of an affected area that can be seen submerged. In addition, this project aims to be a nationally and internationally watershed as a model for resilience in natural disasters of all kinds and at same way, breaking the barrier of wired communication proposing optical wireless systems to achieve the better results. We firmly believe that in Mexico there are the human resources, institutional strength of different government agencies and universities to carry out such projects to a successful completion and become an international benchmark in this area. Finally, owning a communication system as mentioned in this document is considered as an indicator of community resilience according to [17,18], where the resilience emanating from the government as an institution must possess the following indicators: emergency service plans, emergency response plans, continuity plans and operations, and this paper was focused on the plans for emergency communication systems [19-22].

Nowadays, many universities and research center have been working in the complete design of FSO systems that allow enhance the traditional communication network. In addition, these institutions working in systems resilience engineering in order to support to the governmental, private and public sector.

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REFERENCES

[1] "Diagnóstico de Peligros e Identificación de Riesgos de Desastres en México", CENAPRED. 2001.

[2] M. Jiménez, L. Matías Ramírez, Ó. and Fuentes Mariles. "Ciclones Tropicales". CENAPRED 2003. Available http://www.cenapred.unam.mx/es/

[3] "Desarrollo de la resiliencia frente a desastres naturales y tecnológicos. Pronunciamiento de las academias". G-Science 2012, Available: www.comunicacion.amc.edu.mx/.../docs/amc-150612-g8resiliencia.pdf.

[4] X. Miao and X. Chen. "Natural Disasters Prevention of Power Communications System", International Conference on Power System Technology (POWERCON), Hangzhou, pp. 1-6, October 2010

[5] S. Neumayer, G. Zussman, R. Cohen and E. Modiano, "Assessing the Vulnerability of the Fiber Infrastructure to Disasters", *IEEE/ACM Transactions on Networking*, vol. 19, No. 6, pp.1610-1623, 2011

[6] P. Smith, D. Hutchison, J. P.G. Sterbenz, M. Schöller, A. Fessi, M. Karaliopoulos, C. Lac and B. Plattner. "Network resilience: a systematic approach". *IEEE Communications Magazine*, vol.49, No.7, pp.88-97, 2011

[7] S.L. Cutter, L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate and J. Webb, "A place-based model for understanding community resilience to natural disasters", *Global Environmental Change*, vol. 18. No. 4, pp. 598–606, 2008

[8] A.R.A Dahlan and H.M. Dahan, "The government information sharing (GIS) in natural disaster management and risk reduction", 5th International Conference on Information and Communication Technology for the Muslim World (ICT4M), Rabat, pp.1-7, 2013

[9] N.T. Dang and H.T. Pham, "Average BER analysis of multihop FSO systems over strong turbulence and misalignment fading channels". IEEE/CIC International Conference on Communications in China (ICCC), Xi'an, pp. 153-157, 2013

[10] S. Rajbhandari, Z. Ghassemlooy, P.A. Haigh, T. Kanesan and T. Xuan. "Experimental Error Performance of Modulation Schemes Under a Controlled Laboratory Turbulence FSO Channel". *Journal of Lightwave Technology*, vol. 33, No.1, pp. 244-250, 2015

[11] S. Kartalopoulos, *Free Space Optical Networks for Ultra-Broad Band Services*, Wiley-IEEE Press, New Jersey,2011.

[12] O. Bouchet, H. Sizun, C. Boisrobert, F. de Fornel and P.N Favennec. *Free-Space Optics: Propagation and Communication*. Wiley-ISTE. 2010.

[13] C. Schmidt, J. Horwath, A. Shrestha, F. Moll, M. Brechtelsbauer and C. Fuchs. "High-speed, high-volume optical communication for aircraft", *SPIE Newsroom, Optoelectronics & Communications*, 2013.

[14] UN-Habitat and UNDP, "The Impact of Decentralization and Urban Governance on Building Inclusive and Resilient Cities", Asia-Pacific Urbanization and Climate Change Issue Brief Series. 2. 2014.

[15] H. Willebrand and B. Ghuman, Free Space Optics: Enabling Optical Connectivity in Today's Networks 1st Ed. SAMS, 2001

[16] I. Keun Sonb and S. Maoa, "A survey of free space optical networks", *Digital Communications and Networks*, vol.3, pp.66-7-77, 2017

[17] M. Kristen. "Community Resilience: An Indicator of Social Sustainability"., Society and Natural Resources, pp.401-416, 2010

[18] International Federation of Red Cross and Red Crescent Societies. "IFRC Framework for Community Resilience". 2014.

[19] Y-L. Chen, Z-K. Kao, P-S. Wang, C-W. Huang, Y-C. Chen and Y-T. Wu, "Resilience of functional networks: A potential indicator for classifying bipolar disorder and schizophrenia", International Automatic Control Conference, Pingtung, pp. 1 – 5, 2017.

[20] P. Eder-Neuhauser, T. Zseby and J. Fabini "Resilience and Security: A Qualitative Survey of Urban Smart Grid Architectures", *Access*, vol. 4, pp. 839-848, 2016.

[21] C. Yu and Z. Hao, “Resilience Degree----A New Indicator of Sustainable Development to Water Resources System”, International Conference on Bioinformatics and Biomedical, Shanghai, pp. 3499 – 3502, 2008.
[22] Committee on Measures of Community Resilience, “Developing a Framework for Measuring Community Resilience”, Washington, 2015.