Using Multiple Input Multiple Output as Hybrid Free Space Optics/Radio Frequency Links

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***Abstract*—This paper describes overview and definitions about Multiple Input Multiple Output (MIMO) formats which can be used in hybrid Free Space Optics/Radio Frequency (FSO/RF) links. Free space optical links allow obtain high speed data transmission without optical fibers. This type of communication is dependent on weather properties and line of sight is needed. This fact has negative influence on infrared beams which are being use for transmission. Radio frequency links have different restrictions in compare with FSO links. Both links can complement each other. Availability can increase with using hybrid FSO/RF links as MIMO systems.**

Keywords—free space optics; hybrid FSO/RF links; radio frequency links; MIMO systems

I. INTRODUCTION

Free Space Optics (FSO) technology offers full duplex connectivity that can be installed license free worldwide and can be installed in less than one day. It requires line of sight between two transceivers. Air is medium transmission and FSO uses infrared beam, which is for human eyes invisible. It light to provide optical bandwidth connections [1,2].

Radio Frequency (RF) link uses for communication radio signal at a given frequency, typically in range from 9 kHz to 300 GHz [3]. Transmission medium is air too, but at different frequency the weather conditions create different attenuations.

Weather and various phenomena in atmosphere have negative impact on these two wireless communication methods. Each of method has its own advantages and disadvantages, but when we join them together to one wireless system, they will be complementary.

II. DIFFERENT MIMO FORMATS

The shortcut MIMO includes another three configurations or formats that can be used. These are called SISO, SIMO and MISO. These different formats offer different advantages and disadvantages which can provide the optimum solution for any given application. Each of MIMO format requires different numbers of antennas [4].

A. SISO (Single Input Single Output)

The simplest form of radio link can be defined as SISO. It is a standard radio channel with one antenna on both sides (Fig.1). There is no diversity and no additional processing required. The main advantage of SISO system is its simplicity. The SISO channel is limited. Its performance and channel bandwidth is limited by Shannon´s law. Interference and fading have higher impact on the system than a MIMO system which is using some form of diversity [4].

Fig. 1. Single Input Single Output model.

B. SIMO (Single Input Multiple Output)

The SIMO occurs when the transmitter has a single antenna and the receiver has multiple antennas (Fig.2). This is also known as receiving diversity. Receiver system receives signals from a number of independent sources to combat effects of fading. SIMO is relatively easy to implement but in the receiver additional processing is needed.

Fig. 2. Single Input Multiple Output model.

C. MISO (Multiple Input Single Output)

The MISO is also known as transmitting diversity channel. In this case the same data is transmitted redundantly from several transmitter antennas (Fig.3). The receiver is able to receive the optimum signal with required data. The advantage of using MISO is that it can use the multiple antennas and the redundancy coding. This can be a significant advantage in terms of space for the antennas and reducing the level of processing required in the receiver for the redundancy coding. This has a positive impact on size, cost and battery life. The lower level of processing requires less battery consumption [4].

Fig. 3. Multiple Input Single Output model.

D. MIMO (Multiple Input Multiple Output)

The MIMO uses more than one antenna on transmitter and receiver side (Fig.4). This requires coding on the channels to separate the data from the different paths. It provides additional channel robustness and data throughput capacity. MIMO is able to provide significant improvement of performance, but cost for MIMO is higher than for other three systems. MIMO needs number of antennas and additional processing. It is necessary to find a balance of performance against costs, size and processing [4].

Fig. 4. Multiple Input Multiple Output model.

III. HYBRID FSO/RF LINKS

The hybrid FSO/RF links we can define as MIMO systems, because they contain two transmitters and two receivers. Primary link is based on FSO system and RF system is backup link of primary link. Availability and reliability of FSO/RF is better than for separate links. Important part of hybrid link is switch or router which makes switching between FSO and RF link.

The FSO communication link is able to define as a telecommunication technology which uses infrared optical beam to transmit information between two static points. It is a broadband communication technology which needs direct visibility between transmitter and receiver, called Line of Sight (LOS). The distance between transmitting and receiving points can be from several meters up to a few kilometers. Data rates are from hundred of Mbps up to 5 Gbps [5]. This technology uses optical modulated pulses for fibreless optical data transfer [3]. Typical wavelengths for the FSO are 850 nm, 1300 nm and 1550 nm. Each of them belongs to the three atmospheric windows in which attenuation of air is the lowest [6]. In the FSO, light pulses are transmitted via atmosphere. It causes number of drawbacks because transmitted medium is unstable and unpredictable. The main causes of disruptions are fog, absorption, scattering and scintillation. Secondary negative influences on FSO link are caused by physical obstructions, buildings sway, rain and snow.

Installation of FSO link is very easy and fast, there are no expensive fibre optic cables, no expensive rooftop installations and no spectrum license are required.

In RF communication link, the data is transmitted through the air too, but by the digital radio signals. The LOS is no needed. In combination with FSO systems, RF systems are using 60 GHz antennas. The beam width for antenna´s diameter 30,48 cm is 4,7 ° (Fig.5). This 60 GHz antenna allows using high speed bit rate and radio connection has high resistance to interferences, high security and multiple use of frequency [7]. The factors which have negative effects on FSO are negligible for RF systems. This is a main reason, why are RF links used as backup links. For FSO systems fog and with fog join visibility is critical factor for availability and reliability of them. On the other hand, RF links show almost negligible fog attenuation, while they usually suffer from other precipitation types like rain or wet snow. Combination of these two technologies to FSO/RF hybrid network may increase overall availability, guaranteeing quality of service and broadband connectivity regardless of atmospheric conditions [8].

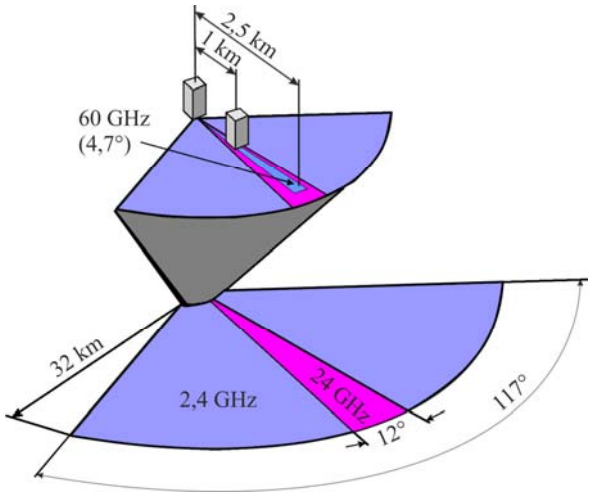

Fig. 5. Negative influences on FSO.

IV. AVAILABILITY OF HYBRID LINK

Availability of FSO link strongly depends on fog and its influence on communication link. In this case fog is represented by visibility. For FSO communication link, there are two possibilities how to obtain information about overall availability. First, we can capture information about fades and then percentual evaluate data during whole year. Another way how to determine availability of FSO link is capture information about visibility in place, where the link will operate. For second way, the fog sensor is a good device for measuring visibility. In this paper, two FSO systems will be used for calculating availability in campus of Technical University in Košice (TUKE). First FSO system is Lightpointe, Flightstrata 155E, second system is FSONA, Sonabeam 155E. Edge values of visibility for 1 km FSO link is calculated by software package FSO SystSim, which was created at TUKE. This software calculates availability for specific systems by mathematic models and energy balance of FSO connections. After entering inputs parameters of individuals systems, edge values of visibility was calculated. Edge visibility for 1 km long FSO link is 515 m for Lighpointe 155E and 620 m for Sonabeam 155E. From this distances is known, that Sonabeam will have worst availability than Lightpointe.

On the other hand, the main drawback of RF link is caused by rain. If we want to determine availability of RF link for 1 km, we need to know how often per year are rainy days. Measuring about fallen precipitations is performed worldwide. With these results of measurement, models of world rainy zones have been proposed (Fig.6). International Telecommunication Union has classified these rainy zones in different regions around the world. From Fig. 6 we can see that Slovakia belongs to rainy zone letter H [10].

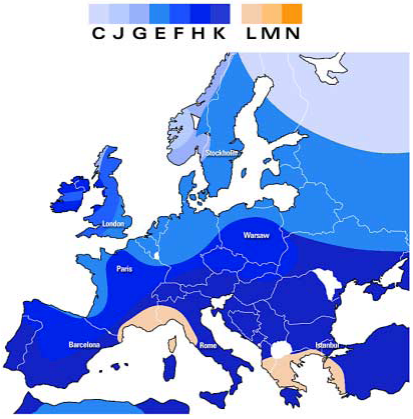

Fig. 6. Rainy zones of Europe.

For 60 GHz RF link 33 cm antenna is used from HXI Company. From TAB I. we can see an availability of 60 GHz link for 1 km. It is 99,9 %.

TABLE I. AVAILABILITY OF 60 GHZ ANTENNA FOR 1 KM

Availability of systems	Volume of precipitation (Region H, mm/h)	Maximum distance for BER=10^{-7}
99	0,7	1240 m
99,9	5,2	1050 m
99,99	23	950 m
99,999	66	730 m

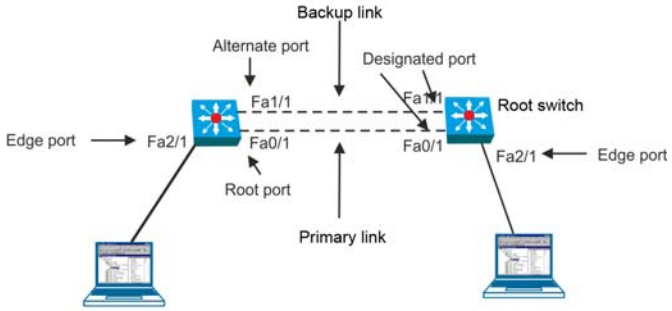

Fig. 7. Hybrid FSO/RF link.

In these days communication system is reliably when its availability is 99,999 % (only 318 seconds per year can be link down). When we join these two communication systems together to hybrid FSO/RF link it is possible to obtain five 9´s availability. These two links are switching by CISCO switch with RSTP protocol Fig. 7. It is important to connect primary link to lower ports on both switches. Time required to switch between links is 6 seconds.

A. *Functions of ports*

- Root port- It is a port from which leads the best route with the lowest metric. In our case it is the FSO link toward the root switch.
- Designated port- It is a port, from which leads a best path towards the root port. Designated port is on one side of the link and the root port is on the opposite side of the same line.
- Alternate port- It provides a redundant connection. In case of failure of the primary path can become a root port.
- Backup port- It creates a back up connection.
- Edge port- It is a port that is directly connected to the end station.
- Root switch- In every network there can be only one root switch, which is selected according to the best identifier (Switch-ID). The identifier can be set manually by users or in the case of equal priority will be selected root switch with the lowest MAC address [9].

B. *Configuration of RSTP protocol*

When we turn the switch on, we are in unprivileged user mode. With typing “enable” we get to privileged user mode.

- Switch> enable
- Switch#

Furthermore with command “configure terminal” we get into the configuration mode.

- Switch# configure terminal
- Switch (config)#

Command “spanning-tree mode rapid-PVST” sets RSTP on the switch.

- Switch (config)# spanning-tree mode rapid-PVST

We move into interface configuration mode by command “interface (interface type) (number of interfaces).”

- Switch (config)# interface (interface type) (number of interfaces)
- Switch (config- if)#

Interface that is connected to the terminal edge port we can configure by the command “spanning-tree PortFast” in the interface configuration mode.

- Switch (config- if)# spanning-tree PortFast

After entering the interface we set point-to-point connection.

- Switch (config- if)# spanning-tree link-type point to point

Now, you can check the settings by the next two commands. We can save the configuration by the command "write" or "copy running-config startup-config."

- Switch# show spanning tree summary
- Switch# show spanning tree interface (interface type) (number of interfaces)
- Switch# write
- Switch# copy running-config startup- config

The sample calculation of availability of hybrid link is shown below for year 2012:

$$D_{FSO} = \left(1 - \frac{time\,of\ \ fades}{total\,time}\right)\cdot 100\,\%\,, \tag{1}$$

$$D_{FSO} = \left(1 - \frac{306}{2.8760}\right)\cdot 100 = 98{,}2534\,\%\,, \tag{2}$$

where D_{FSO} is availability of FSO Flighstrata 155E. *Total time* is given like two multiply hours per year due to half an hour measuring interval [7].

$$D_{RF} = \left(1 - \frac{time\,of\ \ fades}{total\,time}\right)\cdot 100\%\,, \tag{3}$$

$$D_{RF} = \left(1 - \frac{306{,}08466}{8760}\right)\cdot 100 = 96{,}5058\,\%\,, \tag{4}$$

where D_{RF} is availability of RF link. *Total time* is given like hours per year. *Time of fades* is given by [7]:

$$time\,of\ \ fades = NS\cdot TS + TF_{FSO}\,, \tag{5}$$

where *NS* is number of switching RF link, *TS* is total time, TF_{FSO} is time of fades of FSO.

$$time\,of\ \ fades = 51\cdot 0{,}00166 + 306\,. \tag{6}$$

Other calculated values for FSO systems and for RF system are entered in the next two tables:

TABLE II. AVAILABILITY OF FSO LINKS

FSO system	Year	Availability
Flightstrata155E	2007	98,1621
Sonabeam 155-E		97,1095
Flightstrata155E	2008	98,3904
Sonabeam 155-E		98,1963
Flightstrata155E	2009	98,5308
Sonabeam 155-E		98,3288
Flightstrata155E	2010	98,1566
Sonabeam 155-E		97,1345
Flightstrata155E	2011	98,2368
Sonabeam 155-E		98,1287
Flightstrata155E	2007	98,1621
Flightstrata 155E	2012	98,2534
Sonabeam 155-E		97,9019

Overall availability of hybrid FSO/RF link using FSO Flightstrata 155E is:

$$D_{FSO/RF} = \left[1 - \left(1 - D_{FSO}\right)\cdot\left(1 - D_{RF}\right)\right]\cdot 100 = \\ = 99{,}9389\,\%. \tag{7}$$

TABLE III. NUMBERS OF SWITCHING RF LINKS

Year	Flightstrata 155E	Sonabeam 155-E
2007	48 times	62 times
2008	44 times	46 times
2009	48 times	49 times
2010	53 times	58 times
2011	49 times	53 times
2012	51 times	54 times

Overall availability of hybrid FSO/RF link using FSO Sonabeam 155E is 99,99809 %.

V. CONCLUSION

Special type of MIMO system is hybrid FSO/RF link using both links strength to overcome their weaknesses. By combining these two systems will the hybrid FSO/RF link be able to achieve higher availability of transmission links as an independent FSO or RF link. Because of the RF hybrid FSO/RF can reduce the impact of heavy fog and FSO can reduce the impact of the rainfall. Advantages of using FSO link in case of lost connection may not be lost due to using a 60 GHz RF system as back-line which has similar properties than FSO link. Average availability of hybrid FSO/RF system in Košice is 99,998205 %.

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REFERENCES

[1] Z. Kolka, O. Wilfert, V. Biolkova "Reliability of Digital FSO links in Europe," Int. J. Electronics, Communications, and Computer Engineering, vol. 1, no. 4, pp. 236–239, 2007.

[2] H. Willebrand, B. S.Ghuman,"Free Space Optics: Enabling Optical Connectivity in Today´s Networks," Indiana, USA, pp 278, December 2001.

[3] M. Ahmad, A. Fuqaha, O. Awwad, B. Khan, "Synergies of Radio Frequency and Free Space Optics Communication: New Hybrid Solutions for Next Generation Wireless Mesh Networks", International Journal of Computer Networks (IJCN), Vol. 4, 2012.

[4] G. Tsoulos, "MIMO System Technology for Wireless Communications," CRC Press, Taylor & Francis Group, 2006.

[5] S. S. Muhammad, M. S. Awan, A. Rehman. „PDF Estimation and Liquid Water Content Based Attenuation Modeling for Fog in Terrestrial FSO Links". Radioengineering, Vol. 19, No. 2, June 2010.

[6] R. Kvicala, V. Kvicera, M. Grabner, O. Fiser, "BER and Availability Measured on FSO Link." Radioengineering, Vol. 16, No. 3, 2007.

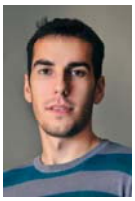
[7] R. Luna, D. K. Borah, H. Tapse, „Behavior of hybrid optical/RF channels.", Proc. IEEE GLOBECOM, Honolulu, HA, November-December 2009.

[8] D. M. Forin, G. Incerti, G. M. Tosi Beleffi, B. Geiger, E. Leitgeb, F. Nadeem, „Free Space Optical Technologies", Trends in Telecommunications Technologies, March 2010.

[9] W. Vojdak, "Rapid Spanning Tree Protocol: A new solution from an old technology," in Compact PCI Systems, March, 2008.

[10] M. Tatarko, Ľ. Ovseník, J.Turán "Properties of Hybrid FSORF Link with 60 GHz RF backup link," Mipro 2013, 36th international convention , Opatija, Croatia, May 20-24, 2013, pp. 595-597, ISBN 978-953-233-074-8.

BIOGRAPHIES



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