High attitude platform free space optics system using various filtering operations for fifth generation system

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Abstract
This paper presents high attitude platform Free space optics (HAP-FSO) channels using various filtering operations for fifth generation (5G) system. Performance analysis is done utilizing different types of optical filters such as Bessel, Trapezoidal, Gaussian and Rectangular. A comparison is carried out between our proposed scheme and reported counterpart. HAP-FSO performances have been investigated to be taken into account the effects of different factors such as transmission distance, transmitting aperture diameter, beam divergence, transmitter aperture diameter, and receiver diameter. Simulation analysis is performed in highly recognized software tool called Optisystem™ to validate the implementation and performance of the proposed system. It is found that the most extreme quality calculation can be accomplished via utilizing Gaussian optical channel in comparison with distinctive optical channels. In particular, with increasing data rate up to 5G coverage range application, minimum BER value is increased for all type of filters. But the trapezoidal filter achieved better results compared with other types of filters.

Keywords HAP · FSO · 5G · Optical filters · BER

1 Introduction
It is expected that the high attitude platform free space optics (HAP-FSO) could be a modern innovation in photonics industries. This innovation makes it conceivable to collect the received optical channels via the FSO link under ultra-high throughput transmission rate. This method decreases the trouble while deploying optical filaments (Roy and Babu 2015; Noor et al. 2012; Jyoti et al. 2014). The HAP-FSO system offers wide unique properties in...
terms of free range, straightforward establishment, and transmission security. Lasers and (Light Emitting Diodes) LEDs are utilized as sources; both are broadly utilized for long-haul and short-haul communication individually. Low earth orbit and small satellites orbit are their practical applications.

The method identifies application where a temporary channel is a fundamental for a communication network especially for the case of a drop in a standing communication (Sushank 2014; Bouchet 2006; Chaudhary and Amphawan 2014). The present portable clients need more reliable multi-services and faster data speeds. The 5G promises to convey that, and much more. One of the proposed solutions for achieving ultra-high data rate can be implemented by using FSO system. Meanwhile, more number of active users producing demanded for high data rates, 5G must handle maximum throughput at much higher speeds up to 50 Gbps than the today’s traditional cellular networks.

Based on the previously published articles (Chaudhary and Amphawan 2014; Singh and Malhotra 2020a,b, 2021; Singh 2016), the researcher studies various types of optical communication system such us, Radio over Fiber based FSO Transmission, Inter-aircraft optical wireless communication system using optical Amplifier, Radio over Free Space optics transmission System based on Mode Division Multiplexing, and spectral-efficient 2-D orthogonal modulation scheme. None of these studies has offered any investigation to integrate the FSO in 5G network based on different sources of optical filters. An FSO beam divergence is one of the significant factors which can adjust the signal-to-noise ratio (SNR) for cellular base stations that identifies the most efficient data-delivery route to a particular user (Dhasarathan and Singh 2020; Gupta and Jha 2015). Also, it helps to reduce the interference for nearby active users by sending individual data packets in many different directions. Modulation schemes have been analyzed to investigate the impact of different modulation scheme such us M-QAM, and DQPSK in a 2 × 20 Gbps under 40 GHz hybrid MDM–OFDM-based radio over FSO transmission system (Singh and Kumar 2013; Singh and Malhotra 2019). Moreover, the ultra-high-speed of 3.84 Tbps hybrid WDM–PDM based inter-satellite optical wireless communication system using orthogonal modulation scheme also been analyzed without considering 5G cell environments (Sumathi et al. 2020). In our analysis, we have proposed several ways to implement the FSO in 5G networks. Depending on the application and the system performance, one of the key 5G enabling components, optical filters, which plays as a component that mitigates noise power less than (∼45 dBm) as much as possible to allow only the desired data with a limited bandwidth to pass from transmitter to receiver, the filter provides both system quality of service and reliability. Other parameters are the FSO antennas aperture with differential feeding, which maintains a high gain and wide bandwidth compared with conventional RF aperture antennas. In the previously published articles, many applications have been investigated such as visible light communication, infrared data acquisitions, and inter-satellite communication (Singh and Malhotra 2019; Sumathi et al. 2020). Today’s, 5G network is proposed using the radio-over-fiber channel which has been employed in various methods such as cellular architecture 5G, millimeter wave 5G communications, and 5G backhaul wireless network (Dhasarathan and Singh 2020; Gupta and Jha 2015; Singh and Kumar 2013). As data capacity and processing resources transfer into the cloud, this issue required data centers for storage and data transfer capacity. Key elements driving higher limit server farm interconnect data transfer capacity include Broad bandpass filters to transmit the entire O-band, C-band or L-band. Optical filters are the premier solution for HAP-FSO application to ensure faultless signal transmission, dependable results, cost-effectiveness and exceptional service quality for optical communication systems. Filters have the ability to block all unwanted ambient wavelengths and pass only the necessary wavelength output
while increasing transmit power and resolution. Optical filters can help to achieve a more stable, accurate system. Many types of optical filters are available such as Rectangular, Trapezoidal, Gaussian and Bessel filters. In order to select the best filter, we have investigated various types of optical filters needed to overcome the main drawback we had currently having in terms of transmission distance, bit-error rate (BER) and received power. One of the most common filters used for enhancing proposed systems is a bandpass filter. For discovering the best bandpass filter according to the proposed HAP-FSO application, we have used an array of laser light source and a bandpass optical filter to highlight various wavelengths to be collected at the receiver side. In this work, the HAP-FSO using various 5G frequency bands is designed and investigated. Moreover, its framework exhibitions with different affecting factors such as transmission distance, receiver diameter, transmitter aperture diameter, and beam divergence have been analyzed. Further analysis is investigated for various filtering signal processing with the help of numerical equations of the transfer function of various filters. The rest of this paper is organized as follows. Section 2 describes the 5G system design with and without optical filter process. Section 3 presents the findings of proposed system. Section 4 introduces feasibility of FSO-5G system. Finally, the conclusions are drawn in Sect. 5.

2 5G system design

2.1 Without and with optical filter process

The essential diagram based on HAP-FSO system is shown in Fig. 1, which presents the transmitter, HAP-FSO link, and the receiver part, indicated by detection and Low-pass filter (LPF). The Semiconductor Optical Amplifier (SOA) is mainly employed under long-haul transmission distance. Table 1 shows the system parameters adopted in our analysis, to design the optical receiver, four various types of optical filters have been

![Fig. 1 HAP-FSO block diagram without optical filter](image-url)
The proposed platform is considered as a standard with respect to 5G optical network, to prove the effectiveness in the new 5G network which employing under the same optical parameter (Dhasarathan and Singh 2020; Gupta and Jha 2015).

For mobile wireless communications an OFDMA modulator considered the most dominate modulator because of their unique features and advantages that is being used in 4G LET and 5G as well. Moreover, the main limitation of using the OFDMA system in our application is that the peak to average power ration (PAPR) will be increased as the transmit optical power exceed 16 dBm. Since the proposed application is related to HAP-FSO system integrated with 5G system. Thus, the modulation technique used is mainly based on Phase Shift Keying (PSK), increasing the highest order modulation format will increase the system complexity and produces nonlinearities effects (Bouchet 2006). In order to overcome these limitations, 4-PSK format is used in our proposed system. This will provide the highest data throughput and it will also provide the most robust link; and as such it can be used when the received signal power levels are low or to suppress the phase intensity induced noise in free space optic channel.

Similarly, Fig. 2 shows the modified system designed with the optical filters. The signal is transmitted via the optical-HAP link and it first amplified using the SOA. The light source used is Continuous wave laser with various power levels according to environment condition which has been simulated under clear weather condition. Then the optical filter is used to reconstruct the signal according to filter shape. Different optical filters can be utilized, namely Gaussian optical filter, Bessel optical filter, Trapezoidal optical filter, and Rectangular optical filter. The filtered signal is detected using the photo-detector and filtered before transferring to the optical spectrum analyzer (OSA) to analyze the optical spectrum which displays an eye diagram and threshold. The transfer function \( H(f) \) of each filters used have been presented in Table 2 (Bouchet 2006). There are many types of optical amplifiers; we have utilized SOA as their properties are more suitable to HAP application. Moreover, it can be made in a compact size and its lower running costs compared to an EDFA mean it more economically efficient. Also, the range of wavelengths (1310, 1400, 1550, 1610 nm) can be integrated with various range of 5G application (wavelength selectable). That is, the SOA output power is higher than EDFA and the electrical pumped, which is often less expensive than EDFA. Additionally, SOA can be run with a low power laser (Singh and Malhotra 2020).

| Parameter                         | Value            |
|----------------------------------|------------------|
| Data rate                        | 50 Gbps          |
| HAP altitude (H)                 | 50 km            |
| Ground Tx altitude (h_o)         | 100 m            |
| Wind velocity (w)                | 0–20 m/s         |
| Refractive parameter index (A_0) | \(1.75 \times 10^{-14} \) m^{-2/3} |
| Light source                     | Continuous wave lasers |
| Wavelength (\(\lambda\))        | 1550 nm          |
| Zenith angle (\(\xi\))          | 0–\(\pi/2\)      |
| Transmit aperture diameter (T_AD)| 10–17 cm         |
| Optical bandwidth of the receiver| 10 nm            |
| Receive aperture diameter (R_AD) | 15–22 cm         |
where \( H(f) \) is the filter transfer function, \( \alpha \) is the insertion loss, \( f_0 \) is the filter center frequency, \( B \) is the filter bandwidth, \( B_{0\text{dB}} \) is the zero dB bandwidth, and \((d_o, A, R)\) are filter constant for Bessel filter, trapezoidal, and Rectangular filters, respectively (Bouchet 2006).

### 2.2 Proposed simulation model

Figure 3 shows the optical transmitter section in the proposed design consists of Pseudo Random Binary Sequence (PRBS) generator comprises of the first subsystem. The PRBS generator generates a stream of binary digits in random sequence which is considered the input data for 5G system. The output from PRBS generator is then directed towards phase shift keying (PSK) pulse generator. The quadrature modulator converts the binary signal at its input terminal from PRBS generator to corresponding electrical signals in 4-PSK modulation format. In 4-PSK modulation format, two different phase shift are represented by a particular binary condition (00, 11) and another two phase shift are represented by another binary condition (10, 01). The last subsystem in the proposed transmitter design consists of Continuous Wave (CW) laser operating at 1550 nm central wavelength and with a maximum output power of 20 dBm. The light signal from the CW Laser is directed toward

| Optical filter type | Transfer function \( H(f) \) |
|---------------------|--------------------------------|
| Gaussian filter     | \( \propto e^{-\ln(\sqrt{2/\pi}} \frac{(f-f_0)^2}{B}} \) |
| Bessel filter       | \( \propto \frac{d_o}{B_{0\text{dB}}} (s) \) |
| Trapezoidal filter  | \( \propto 10^{\ln\left(\frac{(f-f_0)}{B_{0\text{dB}}}}\right)} \) |
| Rectangular filter  | \( \propto \left(\frac{1-R}{1-Re^{2\pi(f-f_0)/B}}\right)^4 \) |

**Fig. 2** HAP-FSO block diagram with optical filter
Mach-Zender (MZ) pulse modulator which modulates the electrical signal from PSK pulse generator with continuous wave output from the laser. In our proposed FSO link, the transmission channel is simulated under clear weather condition medium. The OWC (Optical Wireless channel) used to carry the signal transmitted from the optical transmitter to reach the optical receiver, the detailed OWC link parameter are listed in Table 1. The optical receiver section consists of an optical filter (Four different types of optical filters have been simulated under same simulation environments) that allow the transmission of a specific wavelength of 1550 nm and to limit the signal bandwidth according to 5G frequency bands given in Table 3. Avalanche photodiode (APD) with APD dark current of 1 µA and efficiency of 0.8 which converts the optical information signal to the corresponding electrical signal. An electrical Bessel Low-pass filter (LPF) removes any high-frequency noise present in the received electrical signal. The received signal is then further analyzed by WDM and BER analyzer.

### 3 Results and discussion

In our analysis, four (4) optical filters can be used, namely Bessel optical filter, Trapezoidal optical filter, Gaussian optical filter, and Rectangular optical filter. For each case of utilized filter, the next filter can be replaced with the other three optical filters too. Figure 2

| Filter type   | Filter bandwidth (GHz) | 5G frequency band | Max. throughput (Gbps) |
|---------------|------------------------|-------------------|------------------------|
| Rectangular   | 60–125                 | 400 MHz–1 GHz     | (2.45–10.52)           |
|               |                        | 1–30 GHz          | (10.52–34.87)          |
|               |                        | 30–60 GHz         | (34.87–58.65)          |
| Gaussian      | 60–125                 | 400 MHz–1 GHz     | (2.65–11.81)           |
|               |                        | 1–30 GHz          | (11.81–35.75)          |
|               |                        | 30–60 GHz         | (35.75–64.2)           |
| Trapezoidal   | 60–125                 | 400 MHz–1 GHz     | (2.43–9.52)            |
|               |                        | 1–30 GHz          | (9.52–33.63)           |
|               |                        | 30–60 GHz         | (33.63–56.50)          |
| Bessel        | 60–125                 | 400 MHz–1 GHz     | (2.54–10.52)           |
|               |                        | 1–30 GHz          | (11.52–34.87)          |
|               |                        | 30–60 GHz         | (34.95–60.85)          |
shows the proposed system that has been designed with the integration of optical filters, the received signal is first amplified using the optical amplifier, and then the amplified signal is filtered. At the receiver part, the filtered signal is detected via the photo-detector and filtered before giving to the Bit Error Rate (BER) analyzer. Meanwhile, the optical spectrum analyzers can be used to analyze the optical spectrum of each filter type in terms of optical signal-to-noise ratio (OSNR). The received optical signal has been measured via power meter represents the power received in dBm. The BER analyzer automatically calculates the BER value, displays an opening window of eye diagram including the threshold level. The channel used for transmitting the optical signal has been configured via FSO medium, the clear weather has been assumed throughout the study. The HAP-FSO system investigated in Fig. 2 has a significant impact on the whole system performance specially the BER value. Figures 4, 5, 6, 7, 8 and 9 show the simulated results that have been analyzed the BER value as a function of transmission distance, aperture diameter, and beam divergence.

The simulated results with respect to the input laser power present the comparative system performances of different optical filters as a function BER, data rate, and link range. Figures 5 and 6 depict the relation between minimum BER and aperture diameter at the transmitter and receiver part. It is seen that with the expanding aperture diameter, the minimum BER value is diminished for various optical filters. The Gaussian filter has accomplished better outcomes than the other filter types.

Figure 7 presents that the relationship of minimum BER as a function of beam divergence. It is seen that with the expanding beam divergence, minimum BER value is increased for all type of filters. But the rectangular filter achieved better results compared with other types of filters.

![Fig. 4 Minimum BER value versus transmission distance (km) for HAP range applications using various optical filters](image-url)
Fig. 5  Minimum BER value versus transmitting aperture diameter for HAP-FSO system

Fig. 6  Minimum BER value versus receiver aperture diameter for HAP-FSO system
Fig. 7 Minimum BER value versus beam divergence for HAP range applications using different optical filters

Fig. 8 Minimum BER value versus data rate for 5G range applications using previous model (without optical filter)
Figure 8 simulates the minimum value of BER as a function of data rate using trapezoidal filter optical filter, it has been seen that among the worst case of all optical filters, the trapezoidal filter optical filter has a significant impact compared with the previous modal (without optical filter).

Table 3 shows the relationship of 5G frequency band based various optical filters. The 5G frequency band is divided into low-band (400 MHz–1 GHz), medium band (1–30 GHz), and high band (30–60 GHz). It can be seen that as the frequency band increases the maximum throughput data is increased as well for all band levels. Higher data rate can be achieved when employing a Gaussian filter over other types of filters.

Figures 9, 10, 11 and 12 show the optical data waveforms as a function of received power for the four types of optical filters via OSA. It is seen that the received power in all filter types are almost the same which is -20 dBm whereas the OSNR is 37.91 dB, 33.90 dB, 34.04 and 33.95 dB for Rectangular, Trapezoidal, Gaussian and Bessel filters, respectively. Also, noise power has been measured as −60 dB, −56 dB, −56.34 dB, and −56.26 dB for rectangular, Trapezoidal, Gaussian and Bessel filters, respectively.

4 Feasibility of FSO-5G system

Past decade have witnessed a multi-fold increase in the requirement of bandwidth due to the proliferation of data communicating devices. Now every person in a household, education institute, or office carries multiple devices including smart phones, smart
watches, laptops, and tablets etc. All these devices are connected to the Internet and consumes data through numerous applications. Furthermore, introduction of Internet of Things (IoTs) have evolved the mode of communication such that Internet is no longer used to connect humans but is also facilitating communication between machines and devices (Kulshreshtha and Garg 2020; Esmail et al. 2019; Zhang et al. 2016; Feng et al. 2017; Li et al. 2020; Guan et al. 2021).

All these factors have not only multiplied the demand for bandwidth, but also created a very dense network of interconnected devices that requires a very large and dense Access network connecting these devices to the core or backhaul network. The existing 3G and 4G networks, rely on base stations and large cells that cover a few kilometers of distance to provide connectivity. However, the current solution might soon exhaust owing to the exponential growth of devices and bandwidth requirement. In the said reference, the deployment of communication networks have shifted towards small cells that are deployed everywhere and connect devices to the core network. 5G systems, employing such a large density network, are expected to provide broadband high speed connections of upto 20 Gbps (Kulshreshtha and Garg 2020). 5G networks are designed to provide set of application that differs from the existing communication networks including, but not limited to, mobile broadband connectivity, mission critical application, massive IoTs applications, smart grids, etc. Furthermore, 5G networks are likely to give rise to a new class of applications that do not exist today but can take advantage of the underlying network features including latency, bandwidth and coverage (Esmail et al. 2019; Zhang et al. 2016; Feng et al. 2017).

**Fig. 10** Trapezoidal optical filter received power versus wavelength
However, provision of small scale interconnections, ubiquitous computing, and high speed connectivity will require more cell towers to be installed. 5G cell planning is expected to be ultra-dense with 40–50 towers per Kilometer square (Zhang et al. 2016). Consequently, a major shift in network architecture is necessary that encompasses the use of centralized Radio Access Networks (CRANs). Figure 12 describes schematic diagram about potential application of FSO link in 5G networks. The CRANs utilizes cloud based network architecture that facilitates the separation of Remote Radio Heads (RRH) from the Baseband units (BBU) and provides centralized BBUs. The connectivity between the BBU and the RRH is referred to as front haul networks (Esmail et al. 2019; Li et al. 2020).

The massive deployment of RRH in order to provide the services promised by 5G networks makes the front hauling complex (Esmail et al. 2019; Feng et al. 2017). Furthermore, deployment of such a large number of RRHs will increase the utilization of optical fiber media by 10-folds that entail heavy civil work and massive capital expenditure (CAPEX) (Feng et al. 2017; Failed 2019). Moreover, deployment of optical fiber media in densely populated localities is second to impossible. Traditional microwave and RF links cannot be employed in such scenarios owing to high data rate requirements of 5G network. Consequently, free space optical (FSO) communication is a suitable candidate to provide the required high speed connectivity with relative less complexity. Since 5G technology uses new frequency bands that are well above those traditionally used for 4G LTE, and above the range, a new mechanism should be adopted in terms of filtering process to support higher frequencies required by mm Wave (Fig. 13).

Fig. 11  Gaussian optical filter received power versus wavelength
Fig. 12  Bessel optical filter received power versus wavelength

Fig. 13  Application of FSO link in 5G networks
Figure 14 shows the relation between minimum BER and data rate. It is observed that with increasing data rate up to 5G coverage range application, minimum BER value is increased for all type of filters. But the trapezoidal filter achieved better results compared with other types of filters.

5 Conclusion

A practical way to achieve 5G network standard requirement under FSO backbone is to select an efficient filtering processing. Such filters are evolving to support higher frequencies and increased bandwidth with ever increasing performance. In particular, the proposed system was analyzed for various filtering signal processing: Bessel, Trapezoidal, Gaussian and Rectangular. The HAP-FSO based 5G system communication is studied in which its system performances under various factors such as transmission distance, transmitting aperture diameter, beam divergence, transmitter aperture diameter, receiver diameter have been investigated. It is observed that with increasing data rate up to 5G coverage range application, minimum BER value is increased for all type of filters. But the trapezoidal filter achieved better results compared with other types of filters.

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