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OUTDOOR WDM-BASED OPTICAL WIRELESS COMMUNICATION

[1]ALI SHAHIDINEJAD, [2]SAEED SOLTANMOHAMMADI, [3]TONI ANWAR

[1]PhD Student, Faculty of Computer Science & Information Systems (FCSIS), Universiti Teknologi Malaysia (UTM), 81300 Johor Bahru, Malaysia.

[2]Master Student, Faculty of Computer Science & Information Systems (FCSIS), Universiti Teknologi Malaysia (UTM), 81300 Johor Bahru, Malaysia.

[3]Assoc. Prof., Faculty of Computer Science & Information Systems (FCSIS), Universiti Teknologi Malaysia (UTM), 81300 Johor Bahru, Malaysia.

E-mail: [1]a.shahidinejad@gmail.com , [2]soltanmohammadi.s@gmail.com , [3] tonianwar@utm.my

ABSTRACT

In the past two decades, wireless communications has attracted vast popularity in which Radio Frequency (RF) and Optical Wireless (OW) have been applied for transferring data. OW has the potential to be an alternative to RF and fiber optic communication systems. WDM technique can be easily integrated with outdoor OWC systems and it can significantly increase the bitrate in OWC systems. This paper describes reviews of the current state of the art WDM-based OWC systems. Then, challenges of WDM-based OWC are clustered. This paper proposes solitonic WDM-based OWC using microring resonators to compensate the WDM-based OWC problems.

Keywords: *Optical wireless communication (OWC), Microring resonator (MRR), wavelength division multiplexing (WDM), Soliton.*

1. INTRODUCTION

The demand for high speed wired and wireless access is continuingly increasing due to the rising interests in services such as multimedia, voice over internet protocol (VoIP), high definition video streaming and [1-3]. Comparing to wired access, wireless access offers some advantages like easiness of deploying and mobility. Various technologies for example Wi-Fi and Wi-Max have been broadly used. However, all of them have a limited bandwidth up to 400 Megabit per second [4]. This is caused by using radio bandwidth of 40 MHz or less.

To provide higher bitrates, millimeter wave (10 to 1 mm) systems were introduced to provide wireless communication for a limited range [5]. However, the wave in 60 GHz is not proper for long distance communications as a result of increased attenuation by oxygen and also Mm waves do not penetrate walls and obstacles so their coverage is suitable for single room deployment. To solve the coverage problem of these systems, radio over fiber (ROF) technology was proposed as a potential solution [6-8]. Although, ROF technology is expensive because it needs fiber optic cabling, high speed modulator and photo diodes and its performance is limited by chromatic dispersion. Digitized radio over fiber has recently been recommended as a potential cost effective solution. However, in Mm wave technology frequencies are given in 54.25 to 59 GHz licensed band and 59.0 to 66 GHz unlicensed band therefore just about 7 GHz license-free bandwidth is accessible.

OW has the potential to be an alternative to RF (including microwave and millimetre wave) and fiber optic communication systems, because of license-free operation (in contrast with RF communication), immunity to electromagnetic interference, ease of deployment, low power consumption, high security caused by the high directionality and narrowness of the beam [9-11]. WDM technique can be easily integrated with outdoor OWC systems and it can significantly increase the bitrate in OWC systems. WDM-based OWC systems have been classified to indoor and outdoor systems. Outdoor systems can be used for outdoor environments which are mostly applied for bridging two different networks. While, indoor systems can be used to provide access in a limited area.

This paper describes reviews of the current state of art about WDM-based OWC systems. Then,

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challenges of WDM-based OWC are clustered. Finally, this paper proposes solitonic WDM-based OWC using microring resonators to compensate the WDM-based OWC problems.

2. OUTDOOR WDM-BASED OWC

Outdoor systems were first demonstrated by [12]. They demonstrated 40 Gb/s optical wireless channel transmission over 1.2 km distance using WDM-based OWC [12]. Four different wavelengths from 1555.7 nm to 1558.1 nm with 100 GHz spacing were applied and then each wavelength light was modulated using a LiNbO3 intensity modulator. They utilized non-return-to-zero coding scheme in which each binary “1” has a rectangular pulse shape. Reference [13] proposed 80 Gb/s terrestrial optical wireless transmission over 3.4 km using an optical repeater at 1.7 km. Eight different wavelengths from 1551.9 nm to 1557.5 n were applied. Modulation technique and channel spacing are same the previous work. Compared to the previous work they could increase the bitrate by using more wavelengths. Reference [14] introduced 80 Gb/s WDM-based OWC system between an aerostat and a ground terminal (1.2 km). They proposed two systems with applying two different numbers of wavelengths; 2x40 Gb/s and 4x10 Gb/s where each carrier was modulated using electro optic (EO) and electro absorption (EA) modulator. They used non-return-to-zero coding system with rectangular pulse shape. Reference [15] proposed a 160 Gb/s optical wireless transmission over 2.16 km. They showed that in the normal weather condition, the bit error rate can reach around 10-8. They applied 16 different wavelengths and then these carriers modulated by Mach-Zehnder interferometer.

However, introduced systems [12-15] showed an average BER higher than 10-8, low availability (usually less than a minute), low capacity (compared to fiber optic capacity) and also all these systems suffer from power fluctuation.

Reference [16] proposed a novel full optical wireless communication (FOWC) system which works by directly transmitting an optical wave from a fiber optic termination point through free space using a FOWC transceiver. At the receiver part the related transceiver directly couples the free space propagated optical waves into a fiber optic port. They explained the scheme concept and they experimentally combined FOWC with WDM and reached multi Gb/s bitrate. After that [17] continued this research by developing the concept of advanced WDM radio over free space (RoFSO) system. They have been developing RoFSO link equipment for transferring multiple wireless services with WDM technique over the free space. In [18] they evaluated the performance of heterogeneous optical wireless waves after being propagated over 1 km free space by measuring BER and optical power of received optical signal.

Reference [19] achieved the capacity of 320 Gbit/s over a free-space optical link of 210 m using WDM-based OWC. Eight wavelengths from 1545.93 nm to 1557.36 with 200 GHz spacing were used and then each wavelength light was modulated using a LiNbO3 intensity modulator. They utilized non-return-to-zero coding scheme with rectangular pulse shape. They proposed a novel FSO terminal which is able to transparently connect to a single-mode fiber optic which leads to achieve higher bitrate. Reference [20] continued the previous project and they demonstrated that this system was able to support even higher transmission capacity of 1.28 Terabit/s over a free space link, which represented a four times increase compared to the previously reported highest value by [19]. The FSO terminals have some features that allow higher link reliability and improved capacity. The only difference, compared to the previous work, is that they used 32 wavelengths from 1535.7 nm to 1560.5 nm with 100 GHz spacing. The system was completely tested more than six hours with no error burst. These results indicated that FSO has potential to achieve higher reliability and capacity. Thus, OWC could become a promising technology for a much broader range of outdoor applications than previously projected.

In all practical usages, OWC would be an extension of optical fiber therefore it is highly better if the OWC terminal is directly connected to optical fiber. Many WDM-based OWC systems [12-16, 18] applied equipment that needs optical to electrical and optical to electrical conversions at the transceiver terminals, which significantly decreases the cost effectiveness and the flexibility of the system. However, the proposed WDM-based OWC systems by [19, 20] applied such a terminal that is able to transparently connect to a single-mode fibre optic.

Moreover the most important limitation of OWC technology is its lack of reliability. Many proposed WDM-based OWC systems [12-16, 18] presented error bursts in long time operation and they showed very frequent performance and had a BER higher than 10-8, available over less than a minute. But in [19, 20] due to using transparent OWC terminals,

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the system availability and reliability is by far better than other works.

3. CHALLENGES OF WDM-BASED OWC

According to literature review of outdoor DWM-based OWC systems, two types of problems categorized; reliability, capacity. The most important limitation of OWC technology is its lack of reliability. Reliability problems are caused by some factors like distance, modulation format (especially pulse shape), alignment difficulties, dispersion, attenuation, low availability (achievability), high BER and power fluctuation. OWC has gained significantly lower capacity than optical fiber. Therefore, some measures needed to increase the capacity of WDM-based OWC. Capacity problems are caused by modulation format, using low number of wavelengths. However, capacity and reliability problems are strongly related together. Table 1 shows the problem clustering of the literature review on outdoor WDM-based OWC.

As can be seen from Table 1, two main problems that need to be addressed in future outdoor WDM-based OWC are the lack of reliability and capacity.

4. SOLITONIC WDM-BASED OWC USING MICRORING RESONATORS

OWC systems have applied different techniques to compensate the mentioned problems in the previous section for instance, using receivers with large receive apertures, using different modulation techniques [21], MIMO [22], applying new transceivers which have special fine tracking optics and they can be directly connected to single-mode optical fiber [19, 20] and the use of different pulse shapes for transmission [23, 24]. Following the last technique, different Gaussian pulse shapes with reduced duty cycle are proposed to improve the performance of traditional systems which use rectangular pulses [23, 24]. Reference [24] proposed a rate adaptive communication technique for indoor OWC based on applying adaptable silence periods and on-off keying formats with memory. Reference [23] proposed solitonic pulse shape for OWC for the first time and they mathematically analyzed solitonic pulse shape for OWC. They mathematically prove that solitonic pulse shape has lower bit error rate and better peak to average optical power ratio compared to rectangular and Gaussian pulse shapes. Their results confirm the significant superiority of the proposed pulse shape for atmospheric OWC links. However they stated that solitonic pulse generation is more complicated than generating other pulses and new modulation techniques are needed and how to generate Solitonic pulse shape appropriate for OWC systems should be addressed in future. All the introduced WDM-based OWC systems were used RZ or NRZ coding system with rectangular pulse shape. Therefore all of these systems could have better performance by using enhanced pulse shapes like Gaussian or solitonic pulse shape.

The most interesting features of a solitonic pulse shape are self-phase modulation (SPM) and cross phase modulation (CPM). Moreover, the key advantage of soliton pulse is its non-dispersion behavior. Therefore, it can be utilized in long distance communication, where the long distance communication can be achieved without repeaters. Soliton pulses can be generated by microring resonator (MRR).

Recently some OFRR systems, which are able to generate solitonic pulse shapes and WDM channels, are proposed. Some OFRR are proposed which have different applications in which specific full width at half maximum (FWHM), free spectral range (FSR), and intensity are needed [25-34]. Reference [30] shown that the capacity of optical communication can be improved by the multi-soliton communication, where more wavelengths can be generated by using the OFRR system. They achieved channel spacing of 300 pm and FWHM of 10 pm. Reference [34] presented a novel OFRR systems that increase the channel capacity in Mobile Ad Hoc Network where high capacity channel achieved by decreasing FSR and FWHM. Reference [33] proposed an OFRR design for security camera system in which broad output light spectra is generated. Reference [32] offered a new DWDM system using the OFRR system that provides noticeable WDM wavelength enhancement for closed circuit television and large population monitoring.

Outdoor WDM-based OWC systems could have a better performance by using enhanced pulse shapes like solitonic pulse shape because, soliton shape pulse is able to decrease power attenuation of the received signal and also it can travel longer distance due to its innate features like self-phase modulation. Therefore, more reliability and distance can be achieved using solitonic pulse shape.

Moreover, in WDM-based OWC studies one of the most important issues is to achieve a higher capacity with specific FSR, FWHM and intensity.

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In all previous studies [12-16, 18-20] on outdoor WDM-based OWC, the generated wavelengths are not exactly separated and there are power fluctuations between different wavelength. However these deviations decrease the reliability and are not desired. But this research proposes high capacity WDM-based OWC with exact and appropriate FSR, FWHM and intensity.

5. CONCLUSION

This research reviewed current outdoor WDM-based OWC systems and then identified and clustered the challenges of these systems. Possible solutions to these problems were investigated and solitonic WDM-based OWC proposed to compensate the lack of reliability and capacity. MRR systems have the ability to generate solitonic pulse shape needed in WDM-based OWC. Moreover, MRR systems can be used to achieve higher capacity. However, more researches are needed to generate the proper soliton pulses and wavelength for WDM-based OWC systems.

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Table 1: Problem clustering of the literature review on outdoor WDM-based OWC

Ref.	Literature Review Issues/Problems	Problem Type	
		Reliability	Capacity
[20]	212 meters distance	✔	
[18]	Alignment difficulties	✔	
	High dispersion and attenuation which leads to misalignment	✔	
[17]	High dispersion	✔	
	High signal attenuation and loss	✔	
[16]	Alignment difficulties	✔	
	Attenuation and dispersion problems	✔	
[19]	Low capacity		✔
	212 meters distance	✔	
[15]	BER higher than 10^{-8}	✔	
	Low availability (less than one minute)	✔	
	Power fluctuation	✔	
[14]	BER higher than 10^{-6}	✔	
	Low availability (less than one minute)	✔	
	Low capacity		✔
[13]	BER higher than 10^{-8}	✔	
	Low availability (less than one minute)	✔	
	Low capacity		✔
	Power fluctuation	✔	
[12]	BER higher than 10^{-8}	✔	
	Low availability (less than one minute)	✔	
	Low capacity		✔
	Power fluctuation	✔	