A Novel Optical Wireless Data Center Network Architecture Based on Passive Diffractive Optics and Fast Tunable Lasers

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Compared to wired Data Center Networks (DCNs), optical wireless DCNs can be a promising solution to fast reconfiguration and high throughput. A novel optical wireless DCN architecture based on passive diffractive optics and fast tunable lasers is currently being explored. Reconfigurability is achieved by fast tuning the laser wavelength which alters the exit angle of light from a diffractive grating. Our architecture can provide around 0.7nm channel bandwidth per link for connecting more than 32×32 Top of the Racks (TORs). Maximum 10.75dB power loss of the links due to the grating has been measured within the pair of TORs.

1. Introduction

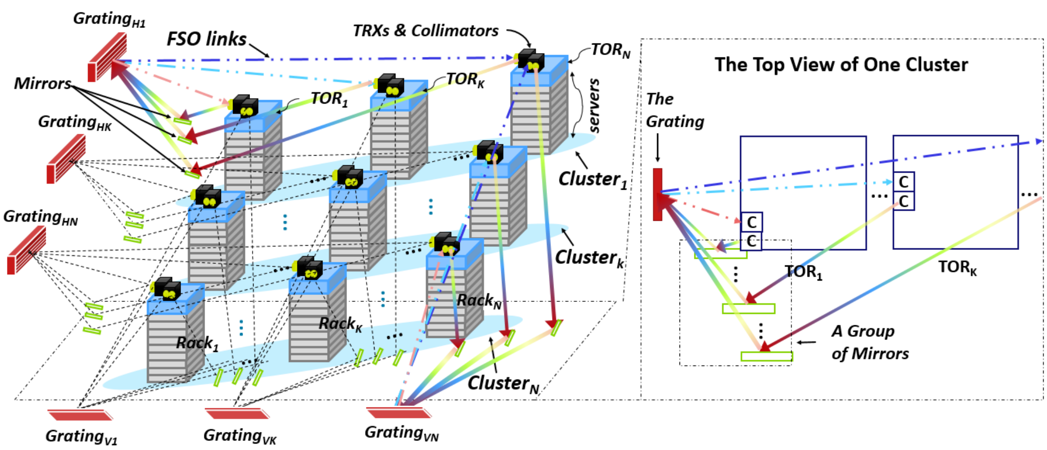
As the revolution created by cloud computing, internet of things, and big data applications such as Google, YouTube, Facebook and Twitter, the traffic is massively increasing in Data Center [1].This puts a stringent requirement on the switching functions in DCN to provide high throughput, fast reconfigurable, low latency, high scalability, low cabling complexity interconnections [2, 3]. Wired DCNs, which require large number of copper and optical fiber cables to support the large scale and high bandwidth, have been studied extensively. This wired architecture results in design and development problems such as the infrastructure of wire ducting and power consumption. Furthermore, the cables show high dispersion at high data rate which limits the network throughput. Meanwhile, they restrict the possible topologies, connectivity and scalability [4]. Moreover, facing the complex traffic, DCNs must dynamically adapt to fast reconfigurations and bursty traffic patterns [5]. To address these problems, the incorporation of wireless communication technology into DCNs is seen as a promising solution to next-generation DCNs [4].

There are two candidates of wireless technology, one is radio frequency (RF) and the other is optical wireless communication (OWC), also known as free space optics (FSO) [6]. As for the RF technology, 60GHz technology has been investigated in [7]. Although promising, it is limited by the low useable bandwidth and suffers from high propagation losses, high electromagnetic interference and low antenna gain which lead to high power consumption and high complexity of routing and network management [8]. On the other side, the free space optics offers a more promising alternative. It can not only offer a very attractive wide license optical spectrum [9], but also can increase the speed by 1.5 times than the optical fiber communication, hence lower propagation latency. Besides, the limited dispersion and attenuation of free space optics yields an excellent performance at higher data rate. Moreover, it provides fast reconfiguration and has the potential to realize on-demand links to adapt to the changing traffic patterns in DCNs. The light waves cannot penetrate walls, metals or racks while keeping good capacity in physical layers security, and the absence of electromagnetic interferences makes it safely usable within DCNs [10].

In this work, we propose a novel optical wireless DCN architecture based on passive diffractive optics and fast tunable lasers that exploit optical wireless interconnection within the DCN. The scalability of this DCN will be investigated considering the physical layout of a real DC hall and various rack/cluster configurations. We demonstrate the feasibility of using a passive grating as the interconnection medium for the optical wireless DCN. Therefore, the performance of the free space interconnection links have been simulated, and the feasibility regarding the power loss of this system has been experimentally tested. Simulation results show that the proposed DCN architecture could provide around 0.7nm wavelength bandwidth connecting for a 32×32 TORs, and therefore > 40,000 servers. Experimental results confirm that the power loss of these free space links is at most 10.75 dB, which is sufficient to operate the link within the pair of TORs.

2. Optical wireless DCNs architecture

The proposed optical wireless DCN architecture is shown in Fig.1 (a). The main concept of the optical wireless network in this DCN is that it translates the wavelength tuning of the tunable laser to the angle tuning by the optics grating. The DCN consists N clusters and each cluster group N racks. Each Rack contains K servers interconnected via TOR switch. The free space links, which based on fast tunable lasers, collimators, mirrors and a group of gratings, have been used for the interconnection of the TOR switches. The links based on grating H1 to grating HN are used for the intra-cluster communication, while the links based on grating V1 to grating VN are used for the inter-cluster communication, respectively.



(a) (b)

Fig.1: (a) The optical wireless DCN architecture based on passive diffractive optics and fast tunable lasers; (b) The top view of one cluster of the optical wireless DCN; C: Collimator

The top view of this architecture for one cluster is shown in Fig. 1(b). The transmitter with a fast Tunable Laser (TL) is used for tuning the wavelength of the output optical signal. The output optical signals will be reflected by mirrors, and then diffracted by the diffraction grating, and eventually received by the receiver collimator on top of each rack.

3. Numerical investigation of the optical wireless DCN

We performed numerical simulations to investigate the performance of the proposed DCN architecture. We use TL with full C-band tuning range, collimator with 10mm aperture and 15mm outer dimension (based on the parameter of the used collimator (TC18FC-1550) from Thorlab), and an echelle grating of 31.6 grooves/mm with a blazed angle of 63 degree for the simulation. The simulation results show that this grating can provide around 0.7nm wavelength bandwidth for the connection of higher than 32 TORs with a c-band TL as one cluster, and therefore > 40,000 servers (if each TORs groups 40 servers) can be inter-connected as one DCN, as shown in Fig. 2. Moreover, by properly designing the passive diffraction grating, the collimators and fast TL, a better wavelength assignment strategy can be achieved and a scalable DCN architecture can be built.

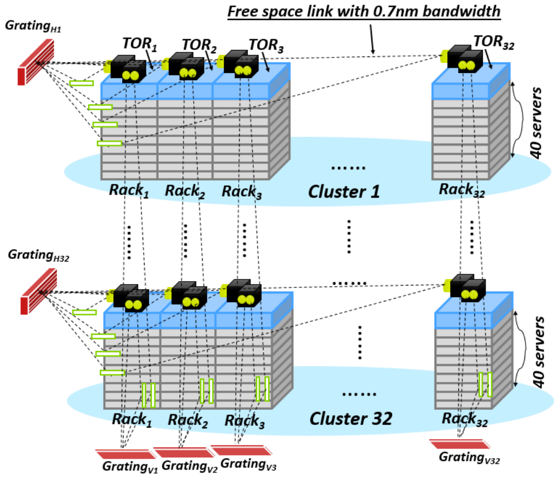


Fig.2: The optical wireless DCN architecture with 32*32 racks interconnected

4. Experimental setup and results

This optical wireless DCN system based on passive diffractive optics and fast tunable lasers should be implemented as the line of sight system, which requires a precise alignment with highly directional power efficiency beams. Therefore, we build a compact testbed as shown in Fig. 3 with a free-space distance around 24cm to check the feasibility regarding the optical power loss of the selected echelle grating (Thorlabs GE2550-0363). A triplet fiber collimator (TC18FC-1550) from Thorlab has been employed in the system. These collimators, which are ideal for free-space transmissions, have been experimentally studied in [9, 10].

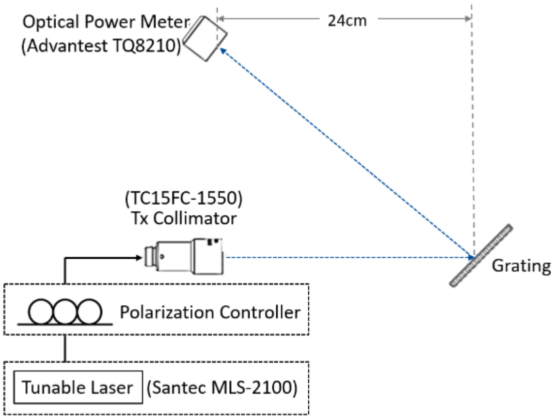


Fig.2: Experimental setup for power loss measurement

The optical power loss is characterized at far field over a wavelength range from 1530nm to 1565nm. The swept interval is 5nm. The optical power loss is measured as the difference between the optical power of the transmitted signal and the received power after the grating. Since the grating is a highly polarization dependent component, a polarization controller is connected directly to the transmission collimator and adjusted for each wavelength to maximize the received power. The optical power loss ranges from 6.75dB to 10.75dB for a wavelength range between 1530nm to 1565nm, as reported in table. 1. It can be seen that the optical power loss of the diffraction grating at different wavelengths provides enough power budget for the receiving of a normal photo detector.

Table.1: Measured optical power loss at each wavelength for grating (Thorlabs GE2550-0363)

Wavelength (nm)	1530	1535	1540	1545	1550	1555	1560	1565
Optical power loss (dB)	10.75	10.42	10.04	9.7	9.29	8.78	8.27	6.75

5. Conclusion

A novel scalable optical wireless DCN architecture based on passive diffractive optics and fast tunable lasers is proposed. The performance is assessed with a practical/off-the-shelf grating, collimator and a C-band tunable laser. It is verified that a bandwidth of up-to 0.7nm can be achieved and over 40,000 servers can be interconnected for the optical wireless DCNs. Moreover, the feasibility of the free space interconnection has been proved, since the optical power loss of the link is around 6.75dB to 10.75dB. This amount of power loss assures that the system has enough power budget for the free space link within one pair of TORs. To sum up, the proposed optical wireless DCN architecture provide a promising solution to meet the requirements on good scalability, fast reconfiguration, less power consumption and lower cost of next-generation DCNs.

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