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# WIRELESS COMMUNICATION IN DATA PROCESS

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**ABSTRACT:**

**Data centers (DCs) is becoming increasingly an inte- gral part of the computing infrastructures of most enterprises. Therefore, the concept of DC networks (DCNs) is receiving an increased attention in the network research community. Most DCNs deployed today can be classified as wired DCNs as copper and optical fiber cables are used for intra- and inter-rack con- nections in the network. Despite recent advances, wired DCNs face two inevitable problems; cabling complexity and hotspots. To address these problems, recent research works suggest the incorporation of wireless communication technology into DCNs. Wireless links can be used to either augment conventional wired DCNs, or to realize a pure wireless DCN. As the design spectrum of DCs broadens, so does the need for a clear classification to dif- ferentiate various design options. In this paper, we analyze the free space optical (FSO) communication and the 60 GHz radio fre- quency (RF), the two key candidate technologies for implementing wireless links in DCNs. We present a generic classification scheme that can be used to classify current and future DCNs based on the communication technology used in the network. The proposed classification is then used to review and summarize major research in this area. We also discuss open questions and future research directions in the area of wireless DCs.**

**Index Terms—Wireless data centers, 60 GHz, free space optical (FSO), optical wireless communication (OWC), data centers, data center network.**

## INTRODUCTION:

IG DATA is a term used to describe high volume, high velocity, and/or high variety data sets [1]. Big Data applications can be found in disciplines like, social media, bioinformatics, Internet-of-Things (IoT), nanoin formatics, and real-time research analytic services. For example, it is expected that the Large Synoptic Survey Telescope (LSST), which will be deployed in Chile in 2016, will acquire around 10 Gbps for ten years resulting in a final disk storage and database size of 0.4 Exabytes and 15 Petabytes, respectively [2]. According to the International Data Corporation (IDC), the IoT market is expected to grow from 9.1 billion devices and objects con- nected to the Internet in 2013 to 28.1 billion by 2020 [3].

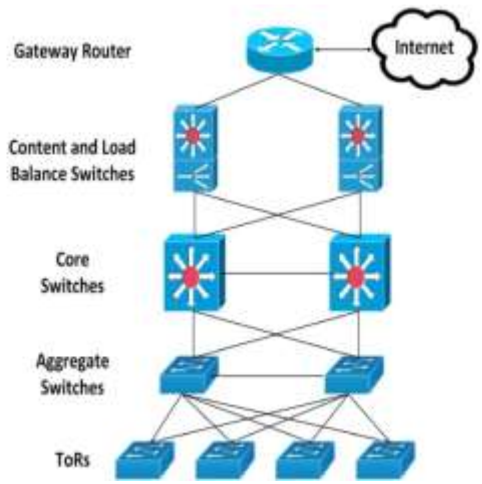



**Fig. 1. Conventional hierarchical tree-based DCN architecture.**

Certain nodes in a DCN may contain data blocks that are required by many jobs. Such nodes are referred to as hotspots [12], [13], [17]–[19]. It is difficult for tree-based DCNs to adapt to unpredictable traffic patterns resulting from hotspots due to the fixed hier 8577 rchival topology and link over subscrip- tion. Inadequate network capacity and oversubscribed links can lead to flow congestions. This in turn can cause increased pro- gramming effort and reduction in concurrency of execution of applications, and thus overall network performance degradation [13]. In addition to the oversubscription problem and inability to adapt to hotspots, conventional tree-based DCNs may suffer from limited scalability, high cost, high energy consumption, and low cross-section bandwidth [20].

## A. MOTIVATION AND SCOPE:

Most existing DCNs can be classified as wired DCNs in which copper and fiber cables are used for networking. Wired DCNs received an increasing attention in the DCN research community evident by the increasing number of papers and sur- veys that discuss, analyze, and motivate new developments in wired DCNs (see for example [20], [60]–[62]).

As discussed earlier, the need for developing adaptive DCNs has motivated the research community to investigate the fea- sibility of incorporating wireless technologies in DCNs. As a result, several research papers on wireless DCNs have been published.

A few recent survey papers on wired DCNs only briefly dis- cuss the deployment of 60 GHz RF technology in DCNs [20], [60], [62]. On the other hand, a recent survey paper that exclu- sively focuses on the topic of wireless DCNs was published early 2015 [63]. Similar to the survey papers on wired DCNs [20], [60], [62], Baccour et al. [63] focus their discussion only on deploying the 60 GHz RF technology in DCNs. In [64], we focus our discussion on DCNs using FSO. We analyze exist- ing indoor FSO standards and the challenges that may face the DCN designers. We also identify standardization needs and opportunities to help accelerate the development of FSO links for DCNs.

From the above discussion, we make the following observations:

1) DCN design space is reshaping as new technologies for networking are deployed, and there is a current need to rethink the design philosophy of DCNs. Therefore, a clas- sification scheme that can formally express the changes in the DCN design space is required to help identify new DCN designs.

2) Deploying 60 GHz and FSO technologies in DCNs encounter different design requirements and challenges. However, as we will show in Section II, there are many similarities between the two wireless technologies.

Therefore, we believe that the development of DCNs using one of the technologies can significantly benefit from the other.

In the absence of a systematic description of the DCN design space evolution, it can be difficult for researchers to fully explore the DCN design space and identify potential designs. This motivates us to develop a new survey to collate and present current advances in wireless DCNs in a systematic fashion to facilitate the sharing of knowledge among researchers using different wireless technologies to develop wireless DCNs. We propose a classification that can be used to classify existing and emerging wired and wireless DCNs. Based on this classifica- tion, we survey current state of the art of wireless DCNs. We review the requirements, challenges, and trends using 60 GHz RF and FSO technologies. The proposed classification leads to a nearly complete picture of the design space for DCNs. This help us to identify potential unexplored solutions for next-generation DCNs.

## B. NOTATIONS:

Lasercom, OW, or FSO are three names used to refer to fiber-less optics technology in the literature. However, fiber-less optics and lasercom are rarely used nowadays. Even though it is not a rule of thumb, it has been noticed that OWC is used to refer to indoor fiber-less optic systems, whereas, many publica- tions use FSO to refer to outdoor point-to-point fiber-less optic systems. Since both names (i.e., FSO and OWC) refer to the fiber-less communication systems disregard the environment in which the link is established, and taking into consideration the fact that both terms have been widely used in the literature, we use both terms interchangeably in this survey paper.

## C. PAPER ORGANIZATION:

The remainder of this paper is organized as follows. In Section II., we discuss the basics of wireless communication and candidate wireless technologies in DCNs. We dedicate Section III to discuss the proposed DCN classification. In Section IV, DCNs employing RF technology are discussed followed by a discussion on DCNs using FSO in Section V. Challenges and potential solutions of wireless DCNs are ana- lyzed in Section.

**ACRONYMS AND ABBREVIATIONS TABLE**

| Acronym | Description |
|---|---|
| 5G | $5^{th}$ Generation of Wireless Communication Systems |
| BER | Bit Error Rate |
| CATV | Cable Television |
| CG | Cayley Graph |
| DC | Data Center |
| DCN | Data Center Network |
| DD | Direct Detection |
| ECS | Electrical Circuit Switching |
| EPS | Electrical Packet Switching |
| FCC | Federal Communications Commission |
| FOV | Field of View |
| FSO | Free Space Optical |
| GA | Genetic Algorithm |
| IM | Intensity Modulation |
| IR | Infrared |
| ISM | Industrial, Scientific and Medical |
| LD | Laser Diode |
| LED | Light Emitting Diode |
| LOS | Line of Sight |
| MAC | Medium Access Control |
| NLOS | Non-Line of Sight |
| OOK | On-Off Keying |
| OW | Optical Wireless |
| OBS | Optical Burst Switching |
| OCS | Optical Circuit Switching |
| OPS | Optical Packet Switching |
| PD | Photodetector |
| PSD | Power Spectral Density |
| RF | Radio Frequency |
| SAS | Shortlex Automatic Structure |
| SNR | Signal to Noise Ratio |
| ToR | Top-of-Rack |
| UTP | Unshielded Twisted Pair |
| UWB | Ultra-wideband |
| WO | Wireless Optical |
| WTU | Wireless Transmission Unit |

**POTENTIAL WIRELESS TECHNOLOGIES IN DCNS:**

In this section, we discuss two candidate wireless technologies, 60 GHz RF and FSO, that can be used in wireless DCNs. We compare their attributes, advantages, and disadvantages. We also compare FSO and optical fiber since they both are optical technologies. For the sake of completeness, we first give a brief introduction on wireless communication systems.

**BASICS OF WIRELESS COMMUNICATION:**

Wireless communication is one of the active areas of research in the communication field today. In wireless communication, information is transferred from the transmitter to the receiver without the need for a confined medium (e.g., cable). Figure 2 depicts part of the electromagnetic (EM) spectrum. The wave- length of a signal decreases as the frequency increases and different frequencies across the EM spectrum have different propagation properties. According to Friis law, the effective area of an antenna decreases as frequency squared.

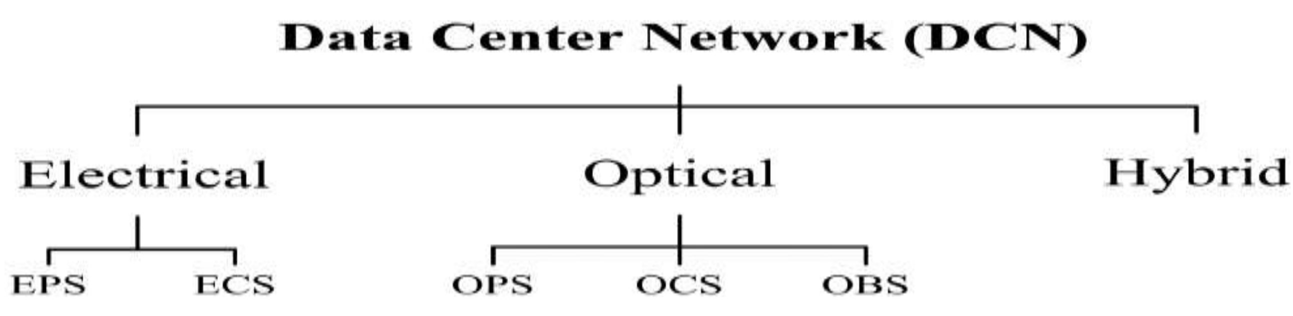
Audio frequencies extend from 3 kHz to 20 kHz in the very low frequency (VLF) band, whereas radio frequency (RF) occupies a very wide range of spectrum (20 kHz – 3 THz). Depending on the nature and requirements of the application, a suitable carrier RF frequency is selected. For example, radio waves have limited propagation capability in electrical conductors such as salt water due to absorption, and thus very long wavelengths (i.e., very low frequency and very large antenna) is required. Therefore, ground-to-submarine communications utilize audio waves, or RF in the VLF band which can pen- etrate only up to 20 meters below sea surface. On the other hand, IEEE 802.11b/g/n (WiFi) wireless local area networks require worldwide compatibility and moderate capability of penetrating windows, walls, and ceils. Therefore, the unlicensed 2.4 GHz UHF and 5 GHz SHF industrial, scientific, and medical (ISM) radio bands are utilized to realize short and medium range links in homes and offices.

**PROPOSED CLASSIFICATION OF DCN ARCHITECTURES:**

DCN architectures are broadly classified into switch-centric [21], [22], [100] and server-centric [25], [27], [28], [101] architectures. In switch-centric DCNs, servers operate only as computing nodes and switches are used for data routing. In server-centric DCNs, servers perform both, computation and data routing.

Wired DCNs are commonly classified based on switching schemes into three classes (see Figure 3); namely, electrical (circuit or packet switching), optical (packet, circuit, or burst switching), and hybrid [20], [38], [62], [102].

Wireless communication is a promising flexible approach that can help addressing the nondeterministic unbalanced traffic distribution of DCN applications and help alleviate congested hot spots [6], [17]. Wireless communication technologies can be used in DCNs by either augmenting already existing wired infrastructure with additional inter-rack wireless links, or by




**Classification of conventional wired DCNs.**

Completely replacing the wired infrastructure by a pure wireless network. In the latter, wireless communication links are used to perform intra and inter-rack communications.

Augmenting wired DCNs with wireless links can solve the problem of hotspots; however, the wiring complexity problem remains unsolved. On the other hand, realizing a pure wireless DCN is expected to solve the hot spot and wiring complexity problems.

As wireless communication is finding its place in DCNs, we believe that a new classification is needed in order to include the emerging new DCN models. We identify four types of communication technologies that can be used in DCNs, wired (electrical cables and optical fiber) and wireless (RF and FSO). We classify DCNs based on the used communication technologies. Figure 4 depicts the proposed classification with all pos- sible DCN design schemes based on the four communication technologies.

DCNs can be broadly classified as Pure or Hybrid. Several DCN designs can fall under the broad hybrid class. In the following we formally define different types of DCN designs:

Pure Wired/Wireless DCN: refers to a DCN in which a single (wired or wireless) communication technology is used for intra and inter-rack communication. This can result in a pure electrical/optical/RF/FSO DCN.

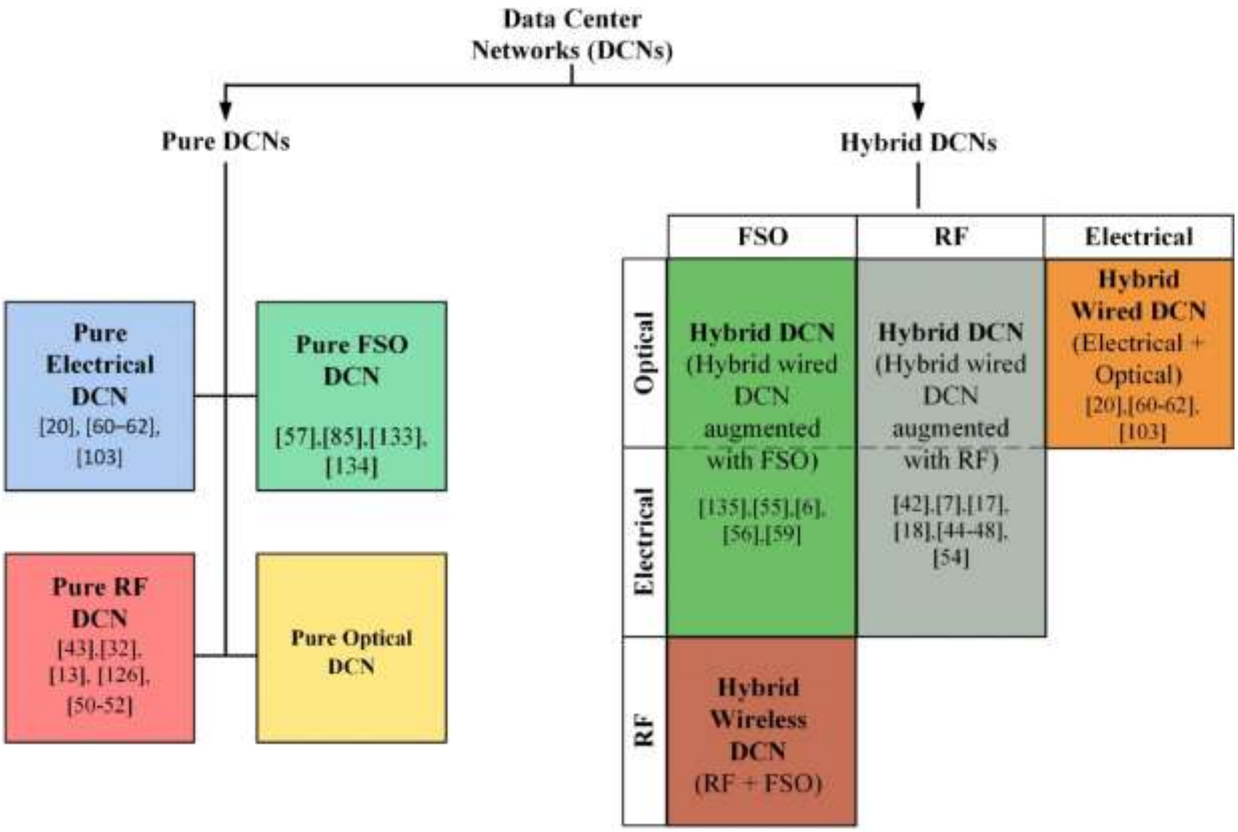
**HYBRID DCN: REFERS TO A DCN THAT UTILIZES TWO OR MORE TECHNOLOGIES.**

Hybrid Wired DCN: is a DCN that deploys two or more wired technologies. This refers to a DCN in which electrical cables and optical fibers are used.

Hybrid Wireless DCN: a DCN that uses two or more wireless technologies. A hybrid wireless DCN refers to a DCN in which RF and FSO are used for communication. Hybrid (wired + wireless) DCN: Refers to a DCN that deploys at least one wired technology and augmented with at least one wireless technology. This can lead to six types of hybrid DCNs:

1) Pure Electrical + RF
2) Pure Optical + RF
3) Hybrid wired + RF
4) Pure Electrical + FSO
5) Pure Optical + FSO
6) Hybrid wired + FSO

In for the sake of brevity, we only show Hybrid wired augmented with RF and Hybrid wired augmented with FSO DCNs. Dashed line indicates that we can further break it down to more categories as discussed above.




**Proposed data center network (DCN) classification.**

**SUMMARY:**

DCs have become a critical part of today's computing and enterprise infrastructures. Currently deployed wired DCs suffer from increasing cabling complexity and hotspots problems. This has motivated the researchers to investigate the possibility of incorporating wireless technologies into DCs. Existing surveys and classifications on DCs chiefly focus on wired DCs. In this paper, we present a detailed survey on wireless DCs.

We start by comparing the two potential candidate technologies for wireless communication in DCs, namely; 60 GHz and FSO. Comparison shows that both technologies are unlicensed and have link length suitable for the confined environment of DCs. Moreover, 60 GHz and FSO technologies depend on LOS links, but 60 GHz technology has lower practical bandwidth and can be affected by interference. On the other hand, FSO links require careful alignment to maintain the LOS.

We propose a classification that can be used to classify any DC, including existing wired and emerging wireless DCs. Our classification is based on the communication technologies used to realize the DCN. According to the proposed classification, wired DCs can be classified as pure electrical/optical wired DC, or hybrid wired DC. On the other hand, wireless technology can be used either to augment wired DCs resulting in hybrid DCs, or to realize pure RF/FSO DC. We discuss differ- ent wireless-based DC designs and collate the major work in the field to jump-start researchers to tap into the growing research on wireless DCs.

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