Wireless Communications: Principle and Applications, Fall 2014 Final Report

Wireless Technologies in DataCenter Networks

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Abstract

Cabling complexity in data centers is reaching unmanageable proportions, leading to maintenance challenges, inefficient cooling, and substantial operational costs (about 7-8% of the total infrastructure cost according to a recent study). To reduce this complexity, this report envisions replacing some or all of the wires in the data centers with wireless interconnects operating in the 60 GHz range. I will describe several features that 60 GHz radios offer, and discuss their suitability in meeting the stringent capacity, reliability and security requirements in data centers.

1 Introduction

The datacenter network is the key component of cloud computing. The datacenter network is consisted of thousands of thousands of work stations and switches. Datacenter applications that cause unbalanced traffic distributions suffer from inadequate network capacity. Based on the traffic statistics obtained from a real-world data center, typical applications usually generate a traffic demand with only a few nodes being hot, that is, these nodes need to transmit a high volume of traffic. The non-deterministic distribution of hot nodes makes it impossible to set up additional wired links for certain nodes to alleviate their congestions. To tackle this problem, a good way is to utilize wireless transmissions in datacenter networks. Currently, the 60 GHz wireless technology that is now emerging has the potential to provide dense and extremely fast connectivity at low cost. This report I will talk about why we choose the wireless technology in datacenter networks and how the 60 GHz wireless technology is meeting the requirement for datacenter networks.

2 The Case for 60 GHz Wireless

Over the last decade, *data centers* have become a critical part of enterprise infrastructure [1], and a fundamental need inside these data centers is that of reliable, high-speed connectivity between nodes such as servers, switches, routers, etc. While state-of-the-art cabling techniques use CAT6 or fiber optic cables along with industry “best practices” such as *structured cabling* [14] and *managed density* [15], cabling complexity is still a major issue that needs further consideration.

Cabling complexity exists in multiple networking domains, such as homes and offices. However, data centers take this problem to a whole new level by increasing the number of interconnected components by at least two orders of magnitude (For example, less than 10 nodes in a home vs. tens of thousands of nodes at each site of a data center [1]). Further, the ever increasing processing requirements for the ever evolving services (such as web 2.0, etc.) and space constraints [1] have led to increased density of servers per unit volume.

This has subsequently led to denser cabling networks (see Figures 1(a) and 1(b)).

(a) Unstructured cabling [2]: A definite problem for maintenance and cooling

(b) Structured cabling [3]: These cable bundles incur significant initial effort and cost to setup, and still may cause airflow blockages and inefficient cooling.

Figure 1: Unstructured and structured cabling.

Cabling networks within data centers should be replaced by wireless interconnects. This would reduce cabling complexity in data centers and the associated costs (7-8% of initial infrastructure costs [4]) and has the potential to inherently avoid the problems created by wired cables outlined earlier.

2.1 Data Center Requirements

To replace wires, wireless connectivity in data centers should exhibit the following properties:

1. **High inter-node link capacity:** To deliver adequate runtime performance, many online infrastructure services need high link and network capacity. Examples include: (a) distributed file systems (e.g. GFS [6]) that use bandwidth-demanding operations and (b) services involving distributed processing of large amounts of data (e.g. MapReduce [6]).

2. **Reliability:** Provisioning of network resources to meet the requirements of hosted data center services assumes predictable performance of links over time.

3. **Security Isolation:** Data exchanged between services hosted on multiple nodes

in a data center must be isolated from other unintended services for security and confidentiality.

4. **Scalability:** Networking infrastructure inside data centers interconnects tens of thousands of servers. Link connectivity should scale to support these large numbers of machines and also allow for the incremental addition of new machines to the network.

5. **Small form factor of networking components:** Higher processing requirements, floor space constraints, and reduced energy consumption [1], necessitate that all machine components, including network interfaces, have small form factors.

2.2 Suitability of 60 GHz radios

Intuitively, wireless interconnects are an obvious alternative to cables to avoid their drawbacks. While several spectral ranges and standardized technologies (see Table 1 for a summary) such as 802.11n and UWB exist, Radios in the license-free 60 GHz range have several unique characteristics that make them more suitable for adoption in data centers:

1. **Spectrum availability:** The available 7 GHz of spectrum in the license-free range of 57-64 GHz enables the creation of multiple links of Gbps speeds per unit volume. Further, as spectral efficiencies keep improving due to better modulation and coding techniques, even greater number of links of the same capacity can be placed in the same volume. For example, with a spectral efficiency of 10 (that is common in today's technologies such as 802.11n), creation of a 1Gbps link requires a channel bandwidth of 100MHz. In the 60 GHz spectrum, with 7 GHz of total bandwidth, this will amount to about 70 orthogonal channels.

2. **Improved interference mitigation and security:** Because Oxygen absorption in the 60 GHz range [7, 8] is seen as a concern in other contexts, but this loss (15dB/km) is negligible for the typical distances within data centers (few 10s of meters), 60 GHz radios provide increased immunity to wireless interference and reduced opportunities for over-hearing wireless transmissions. First, since path loss attenuation of wireless signals is directly proportional to the square of the frequency, signals at 60 GHz have reduced range relative to signals at lower frequencies (e.g. 2.4 GHz or 5GHz, where 802.11 interfaces operate) [1].Second, since wavelengths at 60 GHz are relatively small (approx. 5mm), it facilitates the use of phase array antennas with a large number of elements. Since phase-array antenna dimensions are dictated by signal wavelength, entire arrays of antennas can be accommodated in a single chip package [9, 10], or on a board of the size of a PCMCIA card. For instance, a circular phased array (such as Phocus Array [11]) with 40 antenna elements operating in the 60 GHz range can easily fit on a

5cm x 5cm board. Note that increased number of antenna elements in a phased array helps achieve highly directional beams with small footprints, thereby increasing the number of simultaneous transmissions in a network of nodes using such antennas. For example, with 40 elements, the phased array can generate beamwidths of lower than 10 degrees.

To illustrate the capacity improvements of using highly directional beams, we borrow the results from recent work by Yi et. al [12] in the context of ad hoc networks. They demonstrate that in a random network of ten thousand nodes, with beamforming on both senders and receivers, network capacity approaches close to the capacity of a corresponding hypothetical wired network with the same per-link capacity (i.e. most of the sender, receiver pairs communicate simultaneously) when the beamwidth used by the senders and receiver is less than 15 degrees. Such low beamwidths are readily achievable in the 60 GHz range. Further, *adaptive beamforming* can be used to deal with temporary obstructions in the line-of-sight (LOS) path [10] and non-LOS (NLOS) locations.

3. **Scalability:** The combination of a large amount of spectrum and a large number of independently operating directional links possible in the 60 GHz range, promises to scale data center connectivity in a small volume to tens of thousands of links of Gbps capacity.

4. **Small form-factors:** Small wavelengths at 60 GHz enable the design of sophisticated interfaces with very small form factors, as also discussed earlier (see Figure 2) [9, 10]. In contrast, 3.1 to 10.6GHz (such as UWB) requires 30cm x 30cm form factor.

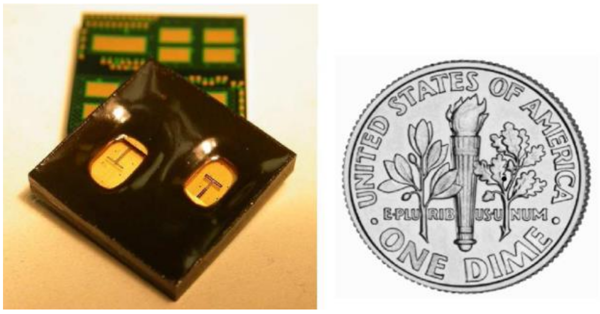

Figure 2: IBM's dime-sized 60 GHz chipset package (for illustrative purposes only): small wavelengths at high frequencies enable the design of small form-factor interfaces.

5. **Universal operation:** From a deployment perspective, the band between 57-64GHz is license-free in a large number of countries making it possible to launch products world-wide.

Spectrum	Spectral bandwidth	Form-Factor for N=40 antenna elements	Free Space Path LOSS(10 meters)	Relative susceptibility to obstacles
2.4/5 GHz (e.g. 802.11n)	83.5/575 MHz	60cm x 60cm	60 to 65 dB	low
3.1-10.6 GHz (e.g. UWB)	7 GHz	30cm x 30cm	70 dB	low
mmWave 60 GHz	7 GHz	5cm x 5cm	88 dB	high

Table 1: A comparison of available spectra

2.3 Propagation Challenges

Despite the benefits outlined in the previous section, radio signal propagation characteristics at 60 GHz pose some challenges that need to be addressed well to create high bandwidth reliable links. Signal propagation at 60 GHz is very different from that at lower frequencies (e.g. the 2.4 and 5 GHz used in 802.11a/b/g WiFi networks) [13]. Mainly, transmissions at these frequencies

- travel shorter distances (e.g., free space propagation loss at 60 GHz, for a given transmitter-receiver distance, is 20 dB more than what it would be at 5 GHz).
- suffer significant attenuation from obstacles (cannot diffract around them) due to smaller wavelengths.

The above two characteristics lead to **a)** lower bandwidth in practice than what is theoretically achievable, and **b)** lower reliability due to high propagation loss and attenuation. One way to recover some of these losses is to use high transmit powers; however, this is inefficient since it may adversely impact network throughput and more importantly, increase energy consumption.

Along with propagation challenges, several system level challenges have to be addressed, which I will do in the future work.

3 Related Work

Prior work can be categorized into solutions for reducing cabling complexity for data centers and network design for 60 GHz radios.

Cabling complexity: This problem is primarily dealt with using standardized techniques for cabling(i.e. *structured cabling* [14]) and balancing the maximization of server density with the increase in cable density (i.e. *managed density* [15]).

60 GHz Network Design: The majority of existing literature on 60 GHz radios focusses on physical layer issues [16, 17, 18, 19] and hardware challenges [20, 21, 22]. Network design efforts closest to ours come from the standards bodies [23, 24] and recent work [13] focusing on wireless personal area networks (WPANs). However, these efforts are targeting environments with different requirements that do not have to deal with the stringent demands of data centers.

4 Conclusions

This report envisions replacing some or all of the wires in the data centers with wireless interconnects operating in the 60 GHz range. I describe several features that radios in the 60 GHz range of the wireless spectrum offer, and discuss their suitability in meeting the stringent capacity, reliability, and security requirements in data centers.

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