Fi-Wi Network for Future Cloud

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ABSTRACT

This article explores the potential role of Fi-Wi (Fiber-Wireless) networks in supporting the future Cloud computing model. As Fi-Wi could be the next wave of advancements in networking and communications infrastructure considering the current trends, the article analyzes various facets of the issue from theoretical and practical perspectives. This is basically a tutorial article written for the wide range of general readers. Alongside clarifying various facets, we also analyze the pros and cons of the technology.

Keywords:

Cloud, Fiber, Fi-Wi, Platform, Computing.

1. UNDERSTANDING THE TERMINOLOGIES: FI-WI AND THE CLOUD

The term, "*Fi-Wi*" confuses many, including many academics and researchers. Hearing the term, often people want to correct it saying, "*I guess you mean Wi-Fi?*". This is because of the lack of proper exposure of this term in the current literature and research fields. Fi-Wi stands for "*Fiber-Wireless*" [1], which is significantly different than the Wi-Fi (Wireless Fidelity) technology. Fi-Wi technology is also called Optical Wireless technology which is basically a combination of "*optical*" (optical fiber) and "*wireless*" (radio frequency) communications technologies to provide telecommunications facility to clusters of end points which are geographically distant. A typical Fi-Wi network is the combination of Passive Optical Networks (PONs) and Wireless Mesh Networks (WMNs). Wi-Fi technology is basically considered under the WMN part of Fi-Wi.

In such an infrastructure, optical networks are designed to provide long distance, high-bandwidth communications with the help of wireless networks to provide ubiquitous, flexible communications in community areas. The high capacity optical fiber is used to span the longest distances, and lower cost wireless links carry the signals for the last mile to nearby users. On the other hand, a WMN (included in a Fi-Wi infrastructure) consists of multiple gateways to the Internet and a group of wireless mesh routers with multiple wireless mesh clients. PON subnetwork in Fi-Wi network can provide up to 1.25 Gbps EPON (Ethernet PON) and GPON (Gigabit PON) supporting 2.488 Gbps rate in the downstream and 1.244 Gbps rate in the upstream [2], which are very high bandwidth facilities. However, the network still may face the impact of interferences in wireless communications which may lead to limiting the network throughput in wireless subnetworks, which is a topic of further investigation. In practice, Fi-Wi network can support various types of communications such as upstream, downstream, and peer-to-peer (P2P) communications.

Hence, given the notion of this technology, it could well-support a fast-service providing Cloud computing scenario over a long distance or within a community area.

Cloud computing is also a relatively recently coined term when distributed processing is seen from the perspective of providing '*computing service*'. The basic concept of Cloud computing is to pay based on the resource usages and the ICT (Information and Communication Technology) resources that do not exist on the user's side. This strategy makes the users capable of doing tasks with their resource-constrained computing devices that they could not have done before. To support such types of communications and computing, there are many research issues (e.g., load balancing, fair scheduling, speed of delivery, security, economic efficiency) to consider so that the resources could be managed efficiently and securely. However, by this time, the service dynamism, elasticity, and choices offered by this highly scalable technology have attracted various enterprises. Many big and renowned companies like Amazon, Verizon, Citrix, Bluelock, Microsoft, VMware, and so on [3] have already started harnessing the benefit of this technology either using it for various computing services or by providing Cloud services to others.

The concept of "*Cloud*" tells that the users are able to access ICT capabilities from the Internet without knowledge of and control over the technology infrastructure that supports them – hence, the term "*Cloud*", in which the exact solution providers and underlying infrastructure are not precisely enumerated. To understand the concept in the easiest way – users or clients in a Cloud service scenario can submit a task, such as image processing or some heavy computation tasks, to the service provider without actually possessing the required software or hardware. The client's computer may contain very little software or data (perhaps, a minimal operating system and web browser only), serving as little more than a display terminal connected to the Internet. As the Cloud is the underlying delivery mechanism of the client's task requests and solution provider's response, Cloud-based applications and services may support many types of software applications or services in use today. The basic characteristics of Cloud computing are [4]:

- On-demand self-service that enables users to consume computing capabilities when required.
- Resource pooling that allows combining computing resources to serve multiple consumers/clients - such resources being dynamically assigned.
- Rapid elasticity and scalability that allow functionalities and resources to be rapidly and automatically provisioned and scaled.
- Measured provision to optimize resource allocation and to provide a metering capability to determine usage for billing purposes, extension to existing hardware and application resources; thus, reducing the cost of additional resource provisioning.

2. LAYERS IN CLOUD COMPUTING

Different practitioners would look at Cloud computing in different ways. In fact, too many concepts, definitions, and models are available today. Even the definition of Cloud could be stated in various ways from various sources. It could be categorized as Public Cloud, Community Cloud, Hybrid Cloud, Private Cloud, or other. Whatever the notion or model is, without going into that debate, in this article we would learn about Fi-Wi network's possible involvement in any type of Cloud scenario. Let us first know about the service layers that any form of Cloud may have. As this technology is still advancing and gaining more inputs from various quarters, a universally accepted model is yet to be finalized. So, just like OSI (Open Systems Interconnection) reference model layers in which each layer exists conceptually on the foundation of the previous layers, we can have the following layers for Cloud computing (some of which are as defined by ITU (International Telecommunication Union) Focus Group on Cloud Computing [5]):

2.1 The Hardware Layer

This layer is sometimes called the server layer. It represents the physical hardware resources that provide actual usable devices and resources that make up the Cloud.

2.2 The Virtualization Layer

The virtualization layer is the result of various operating systems being installed as virtual machines. This is sometimes named as infrastructure layer. The scalability and flexibility of Cloud computing are realized by the inherent ability of virtual machines to be created and deleted at will.

2.3 Software-as-a-Service (SaaS)

A category (or, layer) of Cloud services, where the capability provided to the Cloud service user is to use the Cloud service provider's applications running on a Cloud infrastructure. Such applications can be email, customer relationship management, and other office productivity applications. Enterprise services can be billed monthly or by usage while some software-as-service is offered directly to consumers, often free of any charge (for instance, email).

2.4 Communications-as-a-Service (CaaS)

A category (or, layer) of Cloud services, where the capability provided to the Cloud service user is to use real-time communication and collaboration services, which include Voice over IP (VoIP), instant messaging, and video conferencing, for different user devices.

2.5 Infrastructure-as-a-Service (IaaS)

A category (or, layer) of Cloud services where the capability provided by the Cloud service provider to the Cloud service user is to provision processing, storage, intra-cloud network connectivity services (e.g., VLAN (Virtual Local Area Networks), firewall, load balancer, and application acceleration), and other fundamental computing resources of the Cloud infrastructure where the user is able to deploy and run arbitrary application. The user does not manage or control the resources of the underlying Cloud infrastructure but has control over operating systems, deployed applications, and possibly limited control of selected networking components like for instance, host firewalls.

2.6 Platform-as-a-Service (PaaS)

A category (or, layer) of Cloud services where the capability provided to the Cloud service user is to deploy user-created or acquired applications onto the Cloud infrastructure using platform tools supported by the Cloud service provider. Platform tools may include programming languages and tools for application development, interface development, database development, storage and testing. The platform layer rests on the infrastructure layer's virtual machines.

2.7 Network-as-a-Service (NaaS)

A category (or, layer) of Cloud services where the capability provided to the Cloud service user is to use transport connectivity services and/or inter-cloud network connectivity services. NaaS services include flexible and extended VPN (Virtual Private Network), bandwidth on demand, etc.

2.8 The Client Layer

While this layer is not a Cloud computing service, it is an essential part of the entire concept. The client layer acts as the user interface to which Cloud computing services are delivered. Client layer hardware can include personal computers, web browsers, mobile devices, and even telephones.

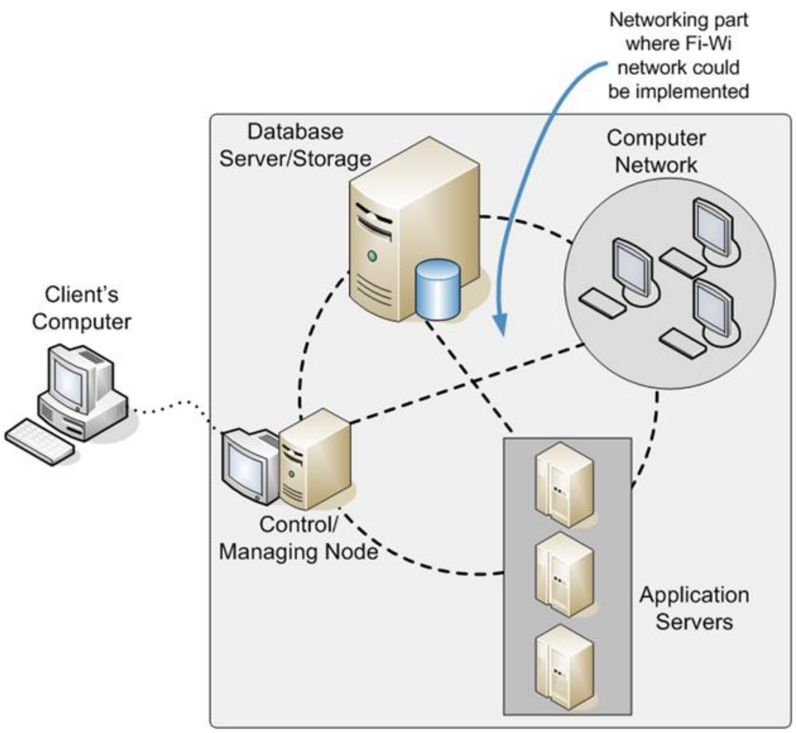

Figure 1. A sample Cloud computing scenario.

If Cloud computing is seen as mentioned above, there are five different service layers that are used to specify what is being provisioned: SaaS, CaaS, IaaS, PaaS, and NaaS. Three remaining layers are not provided as user services. The Hardware Layer and the Virtualization Layer are owned and operated by the Cloud service providers while the Client Layer is owned/supplied by the end users.

Among all these various facets of Cloud concept, Fi-Wi networks would be relevant in CaaS layer, IaaS layer, and especially in NaaS layer. In “Network-as-a-service (NaaS)” paradigm, the network supports user-oriented capabilities with the best utilization of the network. This is where the Fi-Wi technology could fit in properly as shown in the Cloud scenario depicted in Figure 1. In fact, Cloud computing would require dynamic, complex service set-up and tear down with strict requirements (for example, content streaming with adequate bandwidth, delay and jitter and performance of streaming server, etc.). Inclusion of Fi-Wi could allow faster Cloud service delivery and service for users on the move. To understand the issue further, let us know more about the architecture, performance, maintenance, and other aspects of Fi-Wi technology.

3. FI-WI BASICS

The integration of optical and wireless technologies in Fi-Wi can be addressed for low cost of deployment, high bandwidth provision, and scalable extension of communication coverage. Such *wireless-optical-wireless* communication mode introduced by Fi-Wi networks can sustain the interference in wireless subnetwork because packets of different flows are sent through multiple paths in wireless network and then these packets are sent to OLT (Optical Line Terminal) through different ONUs (Optical Network Units) in the optical subnetwork. Figure 2 shows a typical architecture of a Fi-Wi network. As depicted in the figure, in Fi-Wi network, Passive Optical Network (PON) [10] consists of an Optical Line Termination (OLT) at the communication company's office and a number of Optical Network Units (ONUs) near end users. Several ONUs can be connected to an OLT through Remote Note (RN). An ONU is connected to the mesh clients through wireless mesh routers. Communication can be performed in various ways, through the WMN part or through the PON part, even a peer-to-peer (P2P) communication can be carried through the wireless-optical-wireless mode in which the traffic is sent from the source wireless client to its nearest ONU, which is then sent to the closest ONU of the destination wireless client through the PON subnetwork and then traffic is delivered to the destination wireless client. For the traffic route to the Internet, the traffic is sent from mesh client to nearest ONU through the closest wireless mesh router, then sent to OLT, and afterwards the traffic is sent to Internet from OLT.

Such structure would be useful for Cloud computing scenario, where the client may just place a request for fast delivery of solution and the network would do the rest of the activities. To understand how the network could be utilized in the best interest of the mobile or fixed user, the underlying technologies and operational methods should be understood. Let us investigate in a bit more detail.

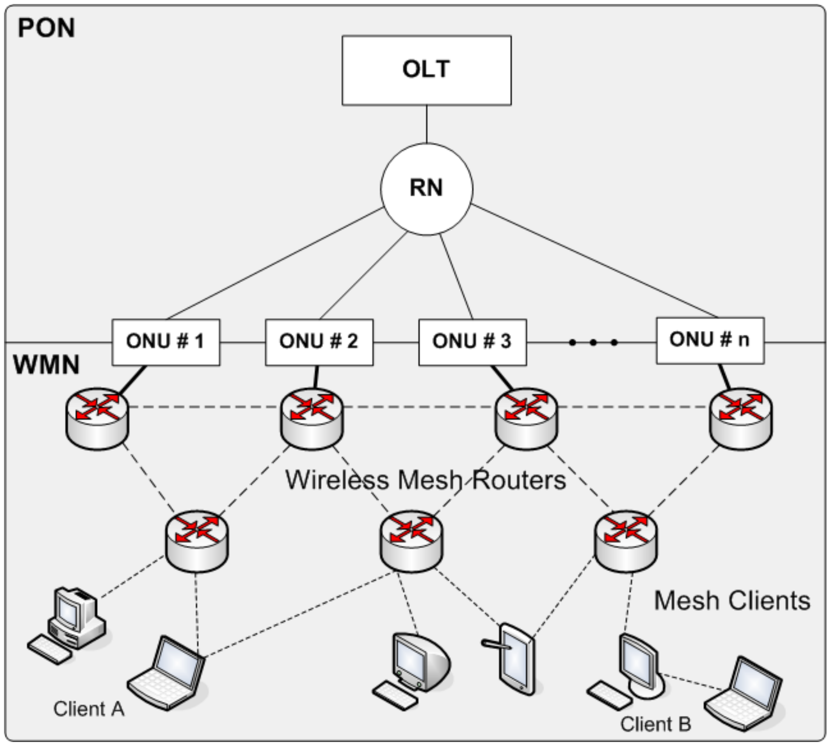

Figure 2. Typical architecture of a Fi-Wi Network.

3.1 RoF vs R&F Network Technologies

As basic underlying communications technologies in Fi-Wi networks, both RoF (Radio-over-Fiber) and R&F (Radio and Fiber) technologies are used.

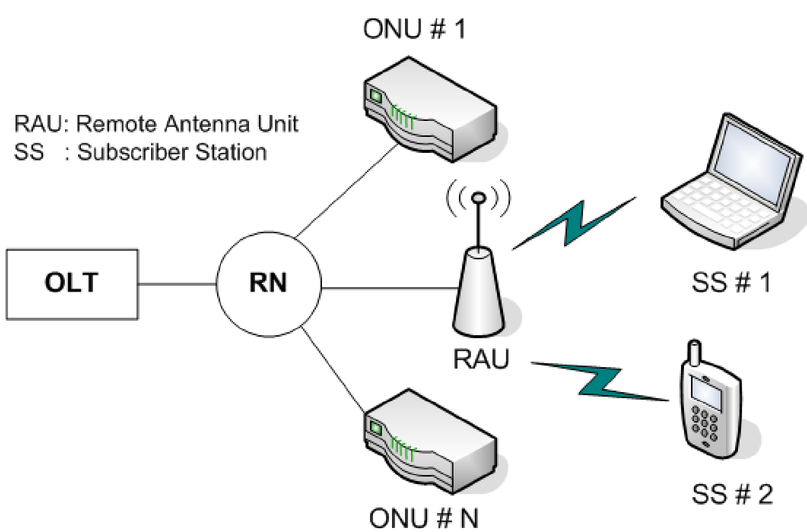

Figure 3. RoF Wi-Fi access network architecture: PON and its wireless extension RAU.

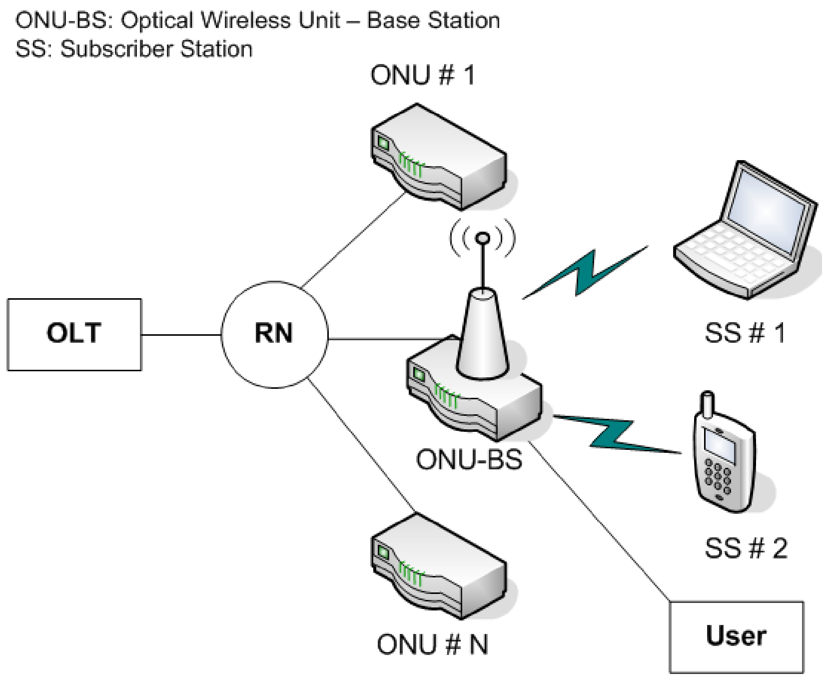

Figure 4. R&F Wi-Fi access network architecture: PON and its Wireless Extension ONU-BS.

In RoF Wi-Fi networks, radiofrequencies (RFs) are carried over optical fiber links between a Central Office (CO) and multiple low-cost remote antenna units (RAUs) to support variety of wireless applications. RoF networks provide transparency against modulation techniques and are able to support various digital formats and wireless standards in a cost effective manner. These networks use optical fiber as an analogue transmission medium between a central control office and one or more RAUs (Radio Antenna Units). The CO is in charge of controlling access to both optical and wireless media. Figure 3 shows a sample RoF Wi-Fi access network architecture that can be used within a Fi-Wi network.

R&F Wi-Fi networks use two different MAC (Medium Access Control) protocols separately for the optical and wireless media to access PON and WMN. Protocol translation must be done at the interface of optical and wireless segments by an appropriate *optical-wireless* device, such as Optical Network Unit – Base Station (ONU-BS). In this case, wireless MAC frames do not have to travel along the optical fiber to be processed at the central control office, but simply traverse their associated access point and remain in the wireless mesh network. In WLAN-based (Wireless Local Area Network-based) R&F networks, access control is done locally inside the wireless subnetwork without involving any central control office so that it can avoid the negative impact of fiber propagation delay on the network throughput and it can also reduce the interferences in wireless subnetwork. R&F networks are most suited architecture to build WLAN-based Fi-Wi networks of extended coverage. Figure 4 shows a sample R&F Wi-Fi access network architecture that can be applied in a Fi-Wi network infrastructure.

3.2 How to Access Optical Network?

Now, let us see how an optical network could be accessed, which would also illustrate why PON is combined with WMN in Fi-Wi architecture and what types of equipments are needed. A typical optical access network can be deployed in various ways and there is no fixed structure to follow. Figure 5 shows a sample architecture. In a typical point-to-point (PtP) architecture, all subscribers are connected to an access node (e.g., CO - Central Office) via dedicated fibers. Today's PtP deployments are mainly based on Ethernet technology using Ethernet switches in the access node with a high port density. The media converters (like, 100Base-TX, 100Base-BX) or mini-switches terminate the network at the subscriber site. Usually, a PtP architecture with its dedicated fiber connections requires large number of fibers in the whole access network. This, in fact, causes high costs for fiber rollout and handling. In addition, each connection requires two interfaces, which causes high footprint and power consumption. In order to reduce the number of fibers in the access network, point-to-multipoint (PtMP) architectures can be used which offer one or more additional aggregation layers between the subscriber location and CO. In general, two PtMP architectures can be distinguished: the Active Optical Network (AON) and Passive Optical Network (PON), as mentioned earlier.

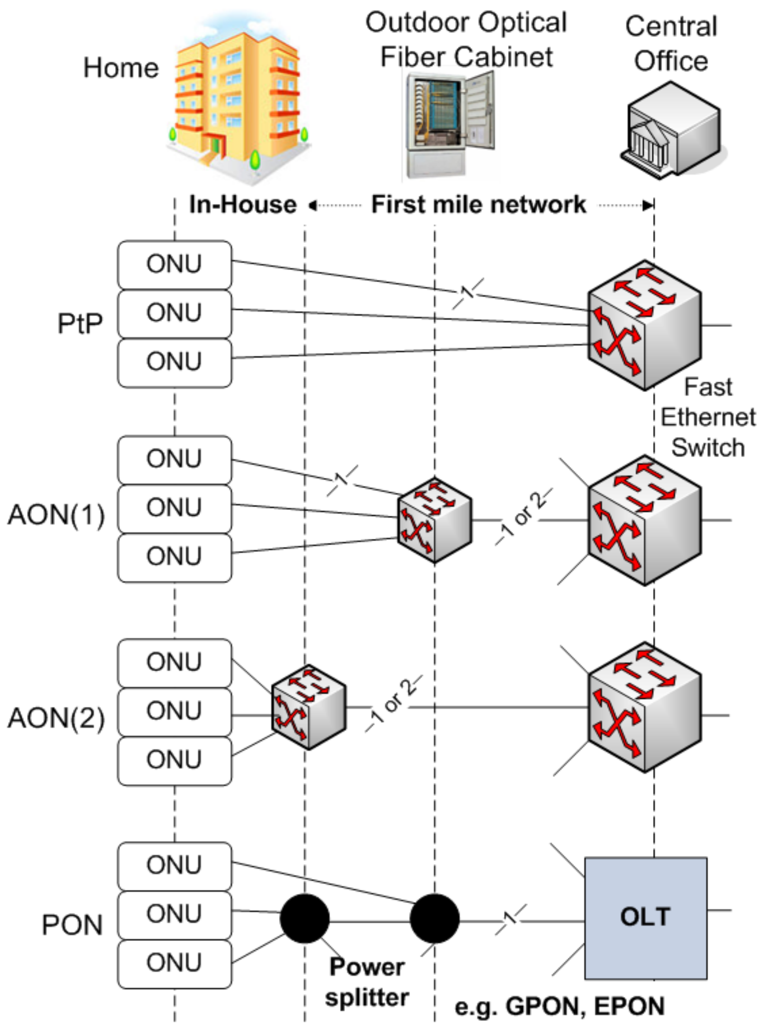

Figure 5. A sample architecture of Optical Access Network.

Active aggregation elements like Ethernet switch is placed within first mile to support AON (see Figure 5). In an AON concept, an Ethernet switch is located at the street cabinet while a second Ethernet switch is used at the building location. Though AON allows a reduction of the number of fibers in the access network compared to a PtP solution, it is not able to decrease the number of required interfaces, so it is virtually impossible to reduce the footprint and power consumption. In contrast to an AON, PON aggregation is based on passive components such as optical power splitters or WDM (Wavelength-Division Multiplexing) (de)multiplexers. Typically 32-64 ONUs could be connected to one PON port at the OLT. This means that PON architecture enables fiber count reduction as well as optimization of the footprint and power consumption compared to PtP architecture, which would be beneficial to balance various objectives [6].

3.3 Optical Fiber's Role in Data Centers

As Cloud computing would require involvement of data centers, in this section, we will investigate how today's data centers could make use of the fibers to get the speed of communications, thus attain timely delivery of outputs to meet Service Level Agreement (SLA). Today's fiber can carry Terabits – that is one trillion bits per second. This huge amount of information could pass through a human hair-like strand of fiber at the speed of light. Eventually, it gives us the idea that we are running for the speed of communications both within the local network and the wide area network.

A data center is a facility used to station computer systems and associated components, such as telecommunications and storage systems. It generally includes redundant or backup power supplies, redundant data communications connections, environmental controls (e.g., air conditioning, fire suppression) and security devices. Data centers of the past were mainly copper-based with multiple Digital Signal 1 (DS1, with approximate transmission rate of 1.54 million bits per second) and Digital Signal 3 (DS3, approximate transmission rate of 45 Mbits/sec) lines handling the load of servers to an Optical Carrier 3 (OC3) with a transmission rate of 155 Mbits/sec [7]. This OC3 would connect the servers to the network Cloud or outside world. In the recent past, mainly copper-wire dominated in a data center environment and the only fiber would be installed was the single line connecting the servers to the network Cloud. All DS1 and DS3 connections were on copper panels, possibly with a digital access and cross-connect system (DACS).

Today the situation has changed greatly. Data centers are offering rates at DS1, DS3, 5 Mbits/sec, 10 Mbits/sec, 20 Mbits/sec and up to an OC3, all connecting to the outside world via 10-Gbit Ethernet or 100-Gbit Ethernet connections from multiple providers. Today, fiber is heavily deployed, placing a large concentration of revenue-generating traffic in a small place. To reduce risk, the data center architecture is evolving away from the previous copper DS1 and DS3 panels, to fiber panels with multiple connections to the client and to the Cloud for redundancy [7]. Hence, it is possible now to provide various services like; delivering huge amount of videos (iTunes, Netflix, Hulu and others) at high speed, Cloud computing/hosted servers, backup and storage facilities, Microsoft CRM (Customer relationship management), hosted private branch exchanges (PBXs), web analysis tools and web hosting, and so on.

While previously two standards were maintained when it comes to dealing with fiber; one by the data centers and other by the telecommunications service providers, today the difference is not much. In fact, same level of sophistication, maintenance, and management policies are employed in many cases for both scenarios. The increasing role of data centers in Cloud computing makes it an imperative to keep the internal lines well-managed to ensure reliable, undeterred service to the clients.

4. THE BENEFITS, CHALLENGES, AND PROSPECTS OF FI-WI BASED CLOUD

Having gained knowledge on various underlying technologies in a Fi-Wi architecture, let us now analyze the prospects of Fi-Wi based Cloud from practical perspectives.

4.1 Cost Effectiveness

Using fiber optics in data centers and networking does not need huge cost. Though there would be slight increase of expenditure at the initial stage to set up the network, the benefits in the long run would be manyfold. Choosing a fiber-management architecture that delivers reliability, modularity and scalability, without giving up density, could actually reduce the cost of fiber deployment. A modular fiber panel ensures future fiber connection expansion based on demand, which would prove to be cost-effective in the long run (i.e., lowering the ongoing cost per port).

4.2 Supporting Mobile Users and Services

Mobile users sitting in a moving vehicle or within a university campus or in a place with Wi-Fi connectivity could use Fi-Wi Cloud to get fast response and solution from anywhere, anytime. This is one of the greatest benefits of Fi-Wi Cloud. The wireless mesh or Wi-Fi would simply carry the user requests to the network and if the user chooses to get fast service, the PON subnetwork would be used. Today's existing Cloud computing scenarios are yet to ensure such time-guaranteed speedy service to the Cloud clients/users.

4.3 Performance of Optical Network

As optical network is involved in the architecture, ensuring minimal insertion loss is very crucial to the performance of the network. Insertion loss is defined as the loss of signal power resulting from the insertion of a device in a transmission line or optical fiber and is usually expressed in decibels (dB). If the power transmitted to the load before insertion is P_T and the power received by the load after insertion is P_R, then the insertion loss in dB, (if denoted by θ_{dB}) is calculated by,

$$\theta_{dB} = 10 \log_{10} \frac{P_T}{P_R}$$

In recent years, Telcordia has established that the standard for loss should be no more than 0.4 dB. When Telcordia re-set the standard to 0.4 dB of loss, most patch cord vendors claimed their performance "*typical*" of the Telcordia standard. However, the reality is that only a few patch cord vendors were guaranteeing the 0.4-dB loss, as it required extensive quality-control measures in their production process and very tight tolerances in their test metrics [7]. Many of the vendors found the strict performance specifications as expensive and cost-prohibitive. As the required guarantee was not ensured, network designers needed to allow variations in patch cord performance. As a result, their network designs did not fully benefit from the reported performance enhancements. Just to clarify here, a patch cable or patch cord is an electrical or optical cable used to connect ("patch-in") one electronic or optical device to another for signal routing.

As is understood, the practical scenario often could be different than the mere claims or theories. However, as now-a-days the networking technologies have become more dynamic, we realize that it is critical to ensure the user's expectations and the promises of Cloud computing. For this, not only guaranteed (rather than typical) performance of fiber networks is required but also 0.4 dB should not be good enough in today's demanding connected globe. Vendors that have built their data centers for optimal performance are now delivering guaranteed 0.2-dB loss.

4.4 Maintenance of Fiber and WMN

The fiber-connected optical segment should be carefully maintained. Proper handling techniques like cleaning the fiber are very important. Some connected copper wires could be simply wiped clean, but, cleaning fiber cables is a bit tricky. A dirty fiber connection can cause a completely blocked signal or introduce attenuation, thus limiting the distance traveled by the signal. Equipment such as a fiber microscope is used to look at a fiber to see how clean the connection is (a fiber that is already connected to a system should not be looked into). Cleaning the fiber can be performed with specialty products available in the market, used in adherence to industry cleaning standards. Some specifications are [8]:

IEC 61300-3-35, Fiber Optic Interconnecting Devices and Passive Components – Basic Test and Measurement Procedures
IPC 8497-1, Cleaning Methods and Contamination Assessment for Optical Assembly
IEC 62627 (DTR), Fiber Optic Interconnecting Devices and Passive Components – Fiber Optic Connector Cleaning Methods

In practice, standards or specifications do not provide any details and/or guidance on troubleshooting installation issues. Hence, testing and troubleshooting often require knowledge and prior experience, which can save significant amount of time and money. The leading cause of failure of fiber-optic systems today is dirty connector endfaces [9]. Though several new cleaning products and video-inspection systems have been marketed that enable the installer to see images of the connectors under test or during the installation, maintenance still remains as an expert's task. Like any other system, people specialized in the domain should be employed to ensure proper maintenance of the whole network that includes fiber optic cables. The WMN part or any wireless segment on the other hand, could be easily maintained as there are numerous network solution providers with many experts and the maintenance of wireless products and tools is relatively easier than optical networking items.

4.5 Environmental Aspects

Large data centers mean industrial scale operations that use as much electricity as a small town and sometimes are a significant source of air pollution in the form of diesel exhaust. In fact, various items like the number of fibers, optical networking devices, air conditioners, lights, etc. add to the carbon footprint by consuming electricity and generating heat. The wireless part could have relatively smaller amount of electricity usage as some devices would use batteries and would not need constant electricity connections. As we are moving towards Green Computing era, all infrastructures supporting Clouds should also consider zero carbon policy and zero carbon Internet. For instance, more computers could become handheld and solar powered. In fact, energy harvesting from various sources for various types of devices is an open field of research. New technologies may pave the way to reduce the environmental impact of Fi-Wi Cloud data centers. Other than this, applications and services could be hosted on the Cloud that is based on zero carbon infrastructure. Various types of businesses could move services and applications to zero carbon data centers using Clouds. Innovative technologies could be devised to reduce carbon emission from high-speed optical networks.

4.6 Working from Home and its Benefit

Many users could simply work from home via Fi-Wi based Cloud reducing the electricity usage by air conditioners, lights, or other electrical devices in the offices. This in fact could greatly contribute to the notion of Green Computing by achieving minimal footprints and acting conscious of global warming. This translates to significant savings and reductions in Greenhouse gas emission. If everyone worked at home just one day a month, it is possible to reduce gasoline usage by a good extent, lower road expenditures, and save commute hours!

5. CONCLUSION

Imagine the coming days that a student is capturing the full lecture of a professor and streaming the video live to his friends outside, or storing the entire lecture somewhere in the Cloud for later use, or someone moving around a large gas field or building complex is getting his heavy computing tasks performed within a short period of time via simply a low-resource handheld device which is not equipped with powerful processor. Fi-Wi based Cloud infrastructure could make such high-speed Cloud service a reality. Of course, the payment for the speedy network service may deter some users like the student in the example, but there would still be many entrepreneurs and business personnel who would find such speedy computation service availability rightly suited to their interest.

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