Chapter 7
Teaching from Home: Computer and Communication Network Perspectives

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7.1 Introduction

Starting from early 2020, CoViD-19 has fundamentally changed how teaching and learning are done from K-12 schools to colleges and universities around the world [1]. Many education institutions had to move their in-person teaching online without advance notice [2]. Although there are many online conferencing, lecturing, and meeting (CLM) platforms such as Blackboard Collaborate Ultra, WebEx, Zoom, etc., this sudden and massive move still created a lot of new challenges for teachers and students [3]. Online teaching or distance education is not entirely new, but often supported by professional information technology (IT) staff in education institutions [4]. Teaching from home, on the other hand, is totally new for most instructors who have to deliver their lectures, tutorials, and even labs online. Many teachers and students have noticed considerable degradation of their teaching and learning experience.

Due to the lack of dedicated IT support staff, teaching from home encountered technical challenges in addition to pedagogical ones. Many instructors were caught off guard, even though most of them do have Internet access at home. However, their work-from-home computers and Internet access are not intended for teaching activities, especially synchronous lecturing and online discussion (e.g., office hours). Although Blackboard, WebEx, and Zoom all increased their network and data center capacity and improved their software on short notice, teachers and students still observed unacceptable audio/video quality degradation during prearranged sessions. Upon close examination, many of the issues happened at their home and from it to the Internet, as most home Internet access has been designed and optimized for

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Email, Web browsing, and video streaming-like applications, i.e., the massive data stream is mainly going from the Internet to the home user.

Online teaching and learning, as its name implies, is a two-way, synchronous and interactive communication process, where one or a few teaching staff interact with a potentially large population of students possibly scattered around the world. Online CLM platforms dealt with this challenge by deploying their cloud meeting platforms all around the world in dedicated data centers, often interconnected by private network links with high quality of service (QoS) guarantees, such as sufficient link bandwidth, limited delay variation, and negligible communication loss. Home Internet access, on the other hand, is likely arranged by individual consumers, constrained by available service providers and plans in certain regions, which usually advertise download data rates much higher than upload ones and can easily become the bottleneck for two-way communications to the Internet. If the lecturer's audio, video, or screen-sharing streams were delayed or lost, it will affect all students regardless of their own locations or network provisioning.

Therefore, the uplink capacity and reliability become the bottleneck of "teaching from home" and are the main focus of this book chapter. Based on the experience since Spring 2020 when we switched to online teaching in the middle of the semester, and the input from professional IT support staff, this book chapter first presents the challenges brought by this new teaching and learning paradigm. Next, it examines the possible technologies and alternatives in home networks and Internet access, leveraging the decades-long advance of computer networking research and education. Further, it proposes a few new approaches and solutions to improving the capability and reliability of wireless fidelity (WiFi) home networks and digital subscriber line (DSL) and cable modem (CM) Internet access, which are commonly used by many instructors at home. The purpose of this book chapter is to create the much needed discussion on these technical issues that have been impeding the successful delivery of online teaching during the pandemic, and it can offer further insights into the future online and distance education paradigm, where "lifetime teaching and learning anywhere" is the ultimate goal, regardless of whether there is another "stay at home" order due to pandemic or other reasons, as well as for home, small- and medium-sized business (SMB) without dedicated IT infrastructure and support staff.

The rest of the book chapter is organized as follows. Section 7.2 scans the literature on related work, and Sect. 7.3 summarizes and compares the existing networking technologies for teaching from home. Section 7.4 proposes feasible approaches to addressing the WiFi interference problem and Internet access reliability problem and makes some recommendations. Further discussion is offered in Sect. 7.5, and Sect. 7.6 concludes the book chapter with future work and directions.

7.2 Related Work

Both home network and Internet access have been well studied and developed in academia and industry, and there is a rich body of the literature on distance education (e.g., pedagogy) and IT technical support in not-for-profit institutions and for-profit organizations [4]. Mature online lecturing, meeting, and conferencing (CLM) tools are readily available at affordable cost, many of which offer free or extended free services during the pandemic, and some have been integrated at least partially with mainstream learning management systems (LMS) [3]. Thus we refer interested readers to each branch of the related work for the status quo and the state-of-the-art.

However, study on “teaching from home” is quite rare and was considered unrealistic pedagogically and technically. Here, “home” refers to the places not where traditional classroom education happens, regardless at K-12, college, or university levels [4]. There have been some attempts on “learning from home” and online learning with various degrees of success and acceptance. Nevertheless, classroom teaching and learning are still the mainstream in normal days, and many hi-tech equipments such as computers, video/data projectors, smart boards, etc., become more and more commonplace. Flipped classroom also happens, where students conduct some, if not all, learning activities in their own time, probably at home, but come to classroom for face-to-face interaction and discussion with instructors and other classmates, supported by many newer LMS systems [5]. Regardless, none of them have gone that far to totally “home,” which was set precedent by this pandemic worldwide. SMB such as YouTube broadcasters may encounter similar problems.

With the “stay at home” orders in various forms, teachers and students have to continue their teaching and learning missions entirely online, and for teachers, most likely to instruct from their own home. This is a brand new adventure for many instructors. There are lots of pedagogical challenges, but the focus of this book chapter is on technical ones. Of course, pedagogy is more important, and we try to achieve the same pedagogical goals as classroom teaching, with the assistance of existing technologies, to the maximum possibility first [4–6]. A lot of teachers, students, and some literature have pointed out the long preparation and low efficiency of online teaching and learning, contributed by many factors beyond the scope of this book chapter. Here, we differentiate teaching from home vs. the usual teaching from classroom or office and learning from home and have identified the bottleneck at the instructor’s first hop to the Internet, i.e., home networks and Internet access.

The majority of the existing home network and Internet access technologies is designed, engineered, and optimized to deliver massive data from the Internet to home users for Email, Web browsing, and video streaming-like applications. For example, DSL and CM both have more bandwidth allocated to downlink (from the Internet to home) than uplink (vice versa). Even the WiFi access points (AP) in our home and cellular base stations (BS) on the street are engineered to give more opportunities to downlink traffic. These asymmetric links work well until we have the need for broadcasting from home, for teaching or other purposes. There are symmetrically allocated links such as Ethernet, leased circuits, and fiber optics, but they are mostly available in business and backbone settings nowadays, even though the networking research communities and standardization bodies have recognized the need for symmetric links, driven by the previous ups and downs of consumer peer-to-peer (P2P) applications, where the uplink was also a bottleneck. However, with synchronous teaching, meeting, and discussion from home, the bottleneck is severer as the audio and video sources come from ordinary houses. Most CLM platforms allow audio streams to “call in” through telephone systems or bridges, which is very cumbersome and incurs additional cost for education entities.

In this book chapter, we are motivated to make the best out of the existing technologies, to improve the capability and reliability of home network and Internet access. It seems to be a short-term solution but can also shed light into the future of online teaching and learning, for lifetime anywhere, and family Skype video calls.

7.3 Network Technologies Involved

In this section, we first examine the network technologies involved in supporting teaching from home, by host computers, home networks, and Internet access, from the computer and communication network support viewpoint, as illustrated in Fig. 7.1 with recommendations proposed in Sect. 7.4.

7.3.1 Host Computers

Most online CLM tools can run as a standalone application (normally requires download and installation on Windows, Mac OS, and Linux desktop or laptop computers), or an app (lightweight application on portable devices such as iOS and Android tablet computers or smart phones), or even in a Web browser (without additional download and installation and thus operating systems, OS, independent).

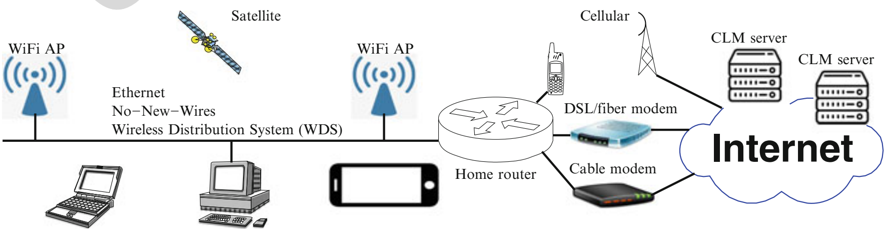

Fig. 7.1 Teaching from home: computer and communication network support

Besides user preferences, here we are concerned about their impact on the computer and communication network support for online teaching.

7.3.1.1 Desktop, Laptop, or Tablet?

The choice of desktop, laptop, or tablet computers for online teaching is mainly device availability and user preferences. Different educational institutions may have different policies to bring institutional equipment home for work or teaching, and some educators have to use their personal devices. Most desktop computers come with Ethernet network interface controller (NIC), for wired network connectivity most common in workplace. At home, Ethernet wall socket may not be available, so alternate wires (see Sect. 7.3.2.2) or wireless (Sect. 7.3.2.3) interfaces and adapters are needed. For laptop computers, most of them come with WiFi interfaces for mobility, but WiFi coverage may vary at home and have high interference from neighbors (see Sect. 7.3.2.3). Some old laptops may have Ethernet NIC embedded, and for newer ones, external Ethernet or additional WiFi adapters via PCMCIA or USB ports are also feasible. Tablet computers are very convenient for annotation during online lecturing, and most of them only have embedded WiFi and some may have cellular Internet capabilities (e.g., through 4G or the emerging 5G mobile communication systems). For tablets and smartphones, external Ethernet interface may be possible through dedicated adapters with micro-USB, Lightning, or USB-C connectors. The form factor further affects the sensitivity of internal antennas, as well as human body (hand and grip gestures) shadowing effect on WiFi signals.

7.3.1.2 Windows, Mac OS, or Linux?

Windows, Mac OS, and Linux, and their tablet and smartphone counterparts, such as iOS and Android, all have the capability of being connected to the Internet through the standard TCP/IP protocol stack. Again, the choice for teaching is mainly personal preferences but dependent on the device availability. From the viewpoint of network support, all these mainstream operating systems come with some network diagnosis tools, such as `ping` for end-host reachability and `traceroute` (or `tracert` on Windows) to discover the routing path. More advanced tools (e.g., `tcpdump` to capture packets and observe protocol interactions) with better user interface (`wireshark`) are also available with additional packages or installation, e.g., Windows or Mac OS `Network` or `Wireless Diagnostics`. Popular network performance testing websites, e.g., `speedtest.net`, further allow users to check their achievable download and upload throughput and ping time to one of the available test servers (often auto-selected by testing websites according to the user location and server availability and load) through any web browser, thus OS independent and convenient. These tools are useful for teachers at home too.

7.3.1.3 Other Necessary Peripherals

Besides host computers running online CLM tools, instructors may choose to use wireless camera (for multi-view), headset (microphone with in or on-ear buds), and in-hand presenters to enrich their presentation. Many of these devices use either Bluetooth, WiFi, or proprietary radio technologies, but often in the same license-free channels as WiFi, which may cause some extra noise and interference. Also many of these devices are powered by batteries and use power-saving techniques extensively to reduce the need of frequent recharging, at the cost of additional delay for audio and video, increasing the mouth-to-ear latency and variation (e.g., voice cutoff or skipping at the beginning of a talk spurt). Whenever possible, wired connectivity (e.g., by USB) of such peripherals to host computer is preferred, especially when the host computer relies on WiFi for Internet access.

7.3.2 Home Networks

As the "last-meter" technology, home network is responsible to interconnect home computers and connect them to the Internet.

7.3.2.1 Ethernet Structured Wiring

Ethernet is the most preferred way of constructing local-area computer networks (LAN) and universally adopted in workplace such as office and commercial buildings. It also becomes common in newly built houses and apartment buildings. Wherever Ethernet is available, it is highly recommended to host computers for reliability and consistency. Even if the host computer does not have an Ethernet interface, various Ethernet adapters are available for different desktop, laptop, and tablet computers and smart phones. However, for most existing houses, Ethernet wiring is not available, and it is very expensive and cumbersome to retrofit for Ethernet structured wiring. Thus, the following options can be considered and are in fact more widely used at home.

7.3.2.2 No-New-Wires Home Backbone

Most existing houses have telephone and television cables wired and sockets installed in some if not all rooms on different floors. Regardless, almost all rooms have power line and outlets for electricity. IP television (IPTV) at the beginning of this century has witnessed the booming of the so-called no-new-wires (NNW) technologies, to transport Ethernet frames over telephone, television, and electricity wires, through an extra adapter connected to computers by wired or wireless Ethernet or USB. Older adapters and technologies only allow networking over a given type of wires, e.g., HPNA for telephone wires, MoCA for coaxial cables and HPPA (HomePlug) for power lines, and the connectivity is limited, so is the capacity, as each kind of these wires shares their capacity, sometimes even with neighbors. The newer adapters following the G.hn standards can run over different wires, and some even multiple (different kinds of) wires, greatly improving availability and capacity. However, when compared with the switched `Ethernet`, `MoCA` is still the second choice due to the high noise, interference, and collision in the house as shown in Fig. 7.2.

7.3.2.3 Wireless Home Network

WiFi probably is the most common home network technology preferred by many users, especially due to the support for portability and mobility. However, running in 2.4 GHz license-free industrial, scientific, and medical (ISM) and 5 GHz unlicensed wireless channels also means WiFi has to compete with other WiFi and household devices such as cordless phones, microwave ovens, and baby monitors. Particularly, the high-power microwave ovens running in 2.4 GHz frequency bands can easily kill any ongoing WiFi or Bluetooth sessions, as shown in Fig. 7.2 around `ping` #30 for `WiFi 2.4 GHz`, despite various techniques to avoid so. For office buildings, WiFi access points (AP) and channel allocation have been carefully surveyed and arranged, so the interference between nearby APs is minimized. However, in a home environment, WiFi AP is collocated with Internet service provider (ISP)'s modem, depending on the location of point of entry to a house. A single WiFi AP often cannot have an adequate coverage for the entire house, especially when the AP is located at a corner of a house where the modem is located. Even worse, users can easily find many WiFi APs around their house by a simple channel scan, as shown in Fig. 7.4, some even stronger than their own (e.g., `Cable` and `DSL-2.4 GHz` and `5 GHz`). Certain coordination with neighbors is possible but not always feasible. Compared with `Ethernet`, 1-hop `WiFi` has much higher delay (in 64-byte round-trip time by `ping`) and more variation as shown in Fig. 7.2, even for 5 GHz due to heavier propagation loss. We will focus on how to address this problem in Sect. 7.4.1, which is one of the two main technical contributions of this book chapter.

7.3.3 Internet Access

The "last-mile" ISPs are responsible to provide Internet connectivity to end users. Based on the communication infrastructure that ISPs use, common consumer-market Internet access technologies are summarized below and further compared for the purpose of online teaching.

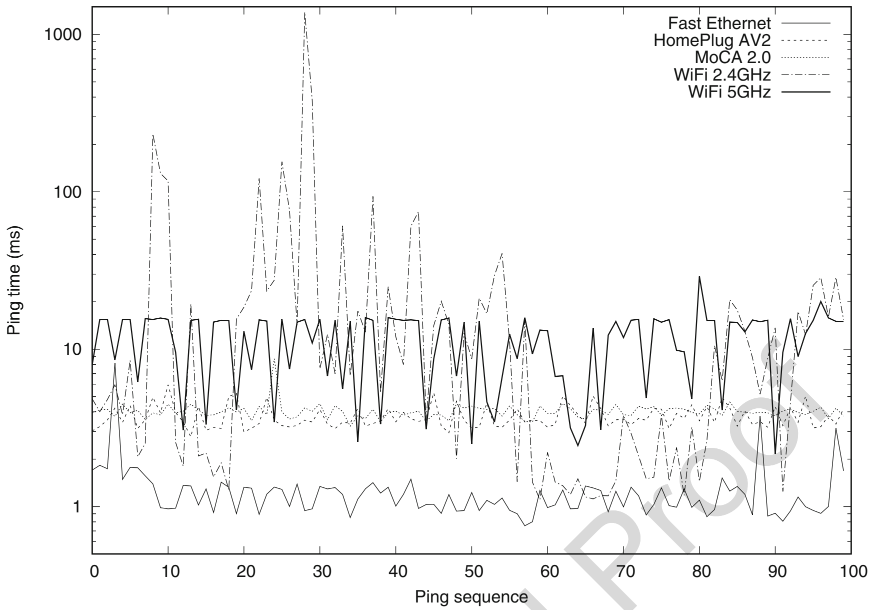

Fig. 7.2 Ping time from the host to home gateway through Ethernet vs. HPPA vs. MoCA vs. WiFi

7.3.3.1 Fiber, Cellular, or Satellite?

Fiber optics are the most common communication medium used by the Internet backbone and commercial Internet access networks commonly found in business organizations, education institutions, and government agencies, mainly due to its high capacity and cost, often associated with the need to lay down the fiber optical cable. Fiber to the node, curb, building, and home (FTTN/C/B/H, or FTTx) starts to appear on the consumer market, especially in some countries with emerging economy and highly concentrated population. However, it is still not readily and widely available in many places around the world at consumer level, other than some pilot projects such as Google Fiber. Cellular coverage is almost ubiquitous in urban and suburban areas, but the high cost of data plans in many countries still limits it to an emergency replacement or backup only for home Internet access. Similar concerns are for satellite-based Internet access.

7.3.3.2 Telephone Service Providers

DSL through telephone service providers is one of the two most common home Internet access technologies. Initially designed to carry voice traffic with limited bandwidth and data rate, unshielded twisted pairs (UTP) are the most common wires from telephone companies to customer premises in local loop. Dial-up modem was the first widely adopted Internet access technology, followed by DSL where larger bandwidth is freed over shorter distance through the same UTP wires with limited capacity and susceptible to electromagnetic noise and interference. However, due to the wide availability of dedicated telephone wires to most houses, DSL is still very popular, although some telephone companies are now motivated to bring fiber optics to consumers in selected markets. DSL is less likely affected by neighbors.

7.3.3.3 Television Service Providers

Coaxial cables due to its shield construction and thus much wider bandwidth and better electromagnetic properties were initially used for cable TV broadcasting. With the booming of the Internet, television service providers also upgraded their infrastructure with bidirectional power amplifiers and hybrid fiber-cable (HFC) networks to provide Internet services. Due to the large link bandwidth, cable modem (CM) often can provide higher data rates than their DSL competitors. On the other hand, neighbors do share the same drop cable, and thus the bandwidth and achievable throughput can vary significantly.

As shown in Fig. 7.3, `DSL` has smaller delay and less variation than `Cable` modem, as the latter is indeed affected by neighbors, and `Fiber` has the smallest delay, while `LTE` the highest. Compared with Fig. 7.2, the "last-mile" delay around 10 ms is actually smaller and more stable than the "last-meter" in-home WiFi.

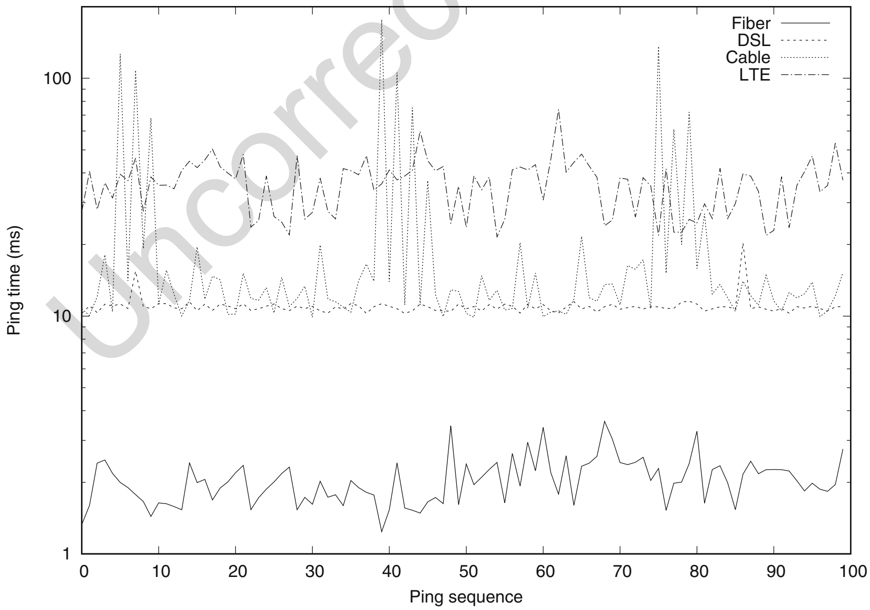

Fig. 7.3 Ping time from the home gateway to first ISP router by Fiber vs. DSL vs. Cable vs. LTE

7.4 Improvement for Online Teaching

Based on the summary and comparison of the existing technologies above, in this section we focus on how to improve WiFi home networks and leverage both DSL and CM ISPs for reliability.

7.4.1 WiFi Interference Avoidance

Many home Internet access issues are actually the problem caused by WiFi networks at home. Service providers often advise their customers to troubleshoot their Internet access problems with a wired Ethernet cable to their so-called modem, AP, or router. A `ping` and `traceroute` can easily identify the additional delay caused by home WiFi networks, due to the poor coverage and severe interference. The following approaches can address these issues with the technologies already existing in most homes.

7.4.1.1 A Better (Al)located WiFi AP

As analyzed above, WiFi home networks have two major issues: coverage and interference. Most DSL or cable modems come with an IEEE 802.11a/b/g/n/ac WiFi AP running in 2.4 GHz and 5 GHz, with 20, 40, or 80 MHz-wide channels. Normally speaking, the higher the operation frequency, more and wider channels available, and shorter the transmission range at the same transmission power due to more signal attenuation (path loss), as shown in Fig. 7.4 with received power in dBm as a quality (Q) indicator, so higher Q for `2.4 GHz` channels (`1` to `14`) than `5 GHz` ones (`36` to `165`). Thus, the choice of operation frequency and communication channel depends on the location of WiFi AP and host computer for online teaching, as well as the nearby appliances (particularly microwave ovens) and neighbor APs. Many

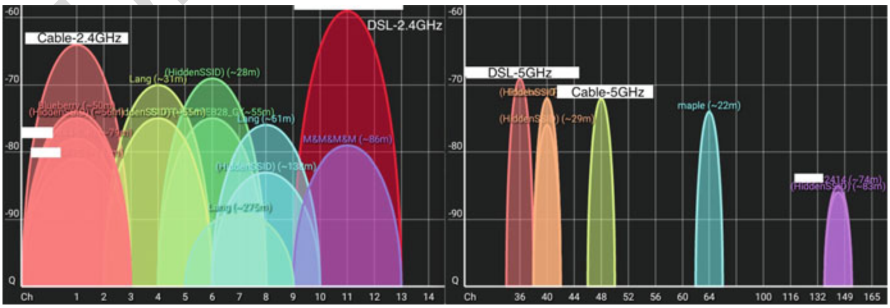

Fig. 7.4 Home WiFi signals in 2.4 GHz and 5 GHz channels

newer APs allow them to "automatically" select a channel based on observation, and some third parties (e.g., `WiFi Analyzer`) offer tools to survey and visualize wireless channels to help consumers choose a less congested channel with stronger signals, e.g., the purposely spaced out 5 GHz channels in Fig. 7.4. Nevertheless, a single WiFi AP, as the default setting for many users (channel 1, 11, 40 and 140), still suffers the whole-house coverage and interference problems.

7.4.1.2 Wired Interconnected WiFi APs

For some houses, a single WiFi AP is not sufficient to cover the entire house well, especially when the DSL or cable modem is at one corner of the house. To improve the coverage, multiple WiFi APs at different locations can be deployed and interconnected by Ethernet cables if available through the LAN ports of these APs, which is very similar to the setting in workplace. If Ethernet is not available, NNW in Sect. 7.3.2.2 can be used, as shown in Fig. 7.1. With multiple WiFi APs, certain coordination is needed to designate one as the Internet gateway to the outside world with DSL or cable modem, and other APs running in access point mode only, with coordinated addressing and routing if multiple subnets exist. On the other hand, these WiFi APs can run in different channels to minimize the interference among themselves. Instructors can choose the best operation frequency and channel for their host computer. This is often the best home network configuration. Unfortunately, Ethernet is not always available, and NNW can introduce delay variation and security concerns.

7.4.1.3 Wireless Interconnected WiFi APs

On the other hand, when neither Ethernet nor NNW links are available, WiFi APs can be interconnected without wires through wireless distribution system (WDS) [7], which is equivalent to a wired home network backbone. Such approach is often used in cellular systems to interconnect BSs in their wireless backhaul network. Not all DSL or cable modems with integrated AP support WDS in their stock firmware, but many off-the-shelf consumer WiFi APs, especially those powered by `OpenWRT` and `DD-WRT`, can be easily configured to support WDS and have more advanced and flexible configuration. Due to the wireless interconnection, further attention on channel selection is needed to avoid the interference between the home backbone and access networks. By associating to nearby APs, WDS offers a smooth roaming experience, similar to a wired backbone.

7.4.2 *WAN Reliability Augmentation*

Both consumer-grade DSL and cable Internet access services suffer reliability issues, far below what fiber optics can offer in commercial workplace. For instructors to lose connection to the Internet, even briefly or intermittently, is unacceptable for a potentially large group of students during lectures. In the following, we examine and compare DSL- and CM-based Internet access and the possibility to leverage both ISPs when feasible to improve reliability.

7.4.2.1 DSL vs. Cable Modem

As discussed in Sects. 7.3.3.2 and 7.3.3.3, DSL and cable both have their pros and cons. DSL is not affected by neighbors but has limited bandwidth and is more susceptible to noise and interference. CM has more bandwidth but has to share the capacity with neighbors, especially for the uplink. For example, an advertised 25/5 Mbps (for downlink and uplink, respectively) DSL plan only achieves a 3 Mbps uplink, but the ping time from the DSL modem to the first DSL ISP router is lower and more stable due to the dedicated uplink. An advertised 50/5 Mbps CM plan can achieve a 59 Mbps downlink during off-peak hours, but its ping time to the first CM ISP router is a bit higher and highly variable due to the shared capacity, as shown in Fig. 7.3. According to the most CLM platforms, a 500 kbps uplink is sufficient for a standard-definition video stream, which is well accommodated by most DSL and CM links, but delay and loss affect the live video streaming much more.

However, from the DSL and CM ISP networks to CLM data centers, depending on how and where CLM providers deploy their services, the varying bandwidth and delay can cause additional QoS fluctuation, as illustrated in Table 7.1 with `traceroute` to a public enhanced DNS server. In terms of reliability, both DSL and CM can vary by providers and regions, the cable plant, and supporting infrastructures. Consumer-grade ISPs and plans also have routine maintenance and unexpected outage without guaranteed backup and recovery as allowed by their service agreement. Thus, relying on one DSL or CM service provider is often not sufficient for high reliability. Paying higher cost for a business service plan is an option, but in the following we explore other more flexible alternatives.

Table 7.1 Traceroute from the home gateway to 1.1.1.1: Cable vs. DSL ISP

Hop	Cable modem	DSL (router IP, RTT)
1	XX.66.224.1, 10.153 ms	10.31.254.1, 6.553 ms
2	YY.59.161.241, 13.243 ms	* * *
3	YY.163.72.22, 11.705 ms	AAA.11.12.198, 11.644 ms
4	YY.163.68.18, 13.340 ms	BBB.41.104.52, 10.739 ms
5	ZZ.81.81.10, 13.713 ms	**1.1.1.1**, 10.973 ms
6	**1.1.1.1**, 14.765 ms	

Bold indicates the destination (1.1.1.1) reached

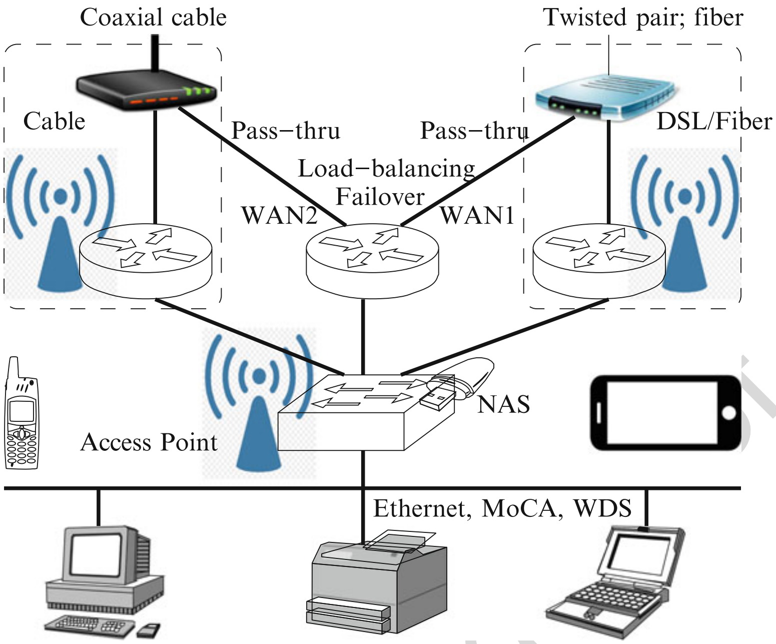

Fig. 7.5 Home network improvement for teaching from home

7.4.2.2 Primary vs. Backup

As shown in Fig. 7.5, we subscribed to two ISPs, one DSL and one CM, which are often available in and competing for the same market. Note that some DSL and CM ISPs wholesale from other major ISPs and then resale to consumers, but here we know these two ISPs are actually independent in terms of their wiring infrastructures and maintenance schedules, to improve reliability. Depending on the service quality and cost of these two ISPs, one can be designated as the primary upstream ISP (e.g., the one offers a flat monthly fee or without data cap) and the other backup (the one charges by the data amount transferred, including cellular or satellite ISPs). To facilitate the automatic switch between the primary and backup upstream ISP, the WiFi AP (or an interconnected group of them) with routing functionalities and connected to both DSL and cable modems shall check the liveliness of the primary ISP, e.g., by `pinging` a known IP address periodically, and then set the default route to the backup ISP when the primary one fails. Depending on the user-defined policy, the home gateway can keep checking the primary ISP periodically and switch back when the primary one becomes available. In this case, there is only one active ISP at any time by default routing. It improves the reliability, unless both fail at the same time, without additional capacity.

Most modern Web-era applications, including Blackboard, WebEx, and Zoom, can sustain the switch of ISPs, and thus the change of the publicly assigned IP address, during an active audio and video session, as these applications keep their session states and recognize mobile users in the application layer (e.g., by HTTP cookies), instead of by IP addresses and TCP or UDP port numbers. When one connection fails, others are automatically created to continue the session, similar to multi-path TCP (MPTCP) [8]. This is also used by many smart phones to switch between WiFi and cellular connections automatically. For old, single-connection applications such as `ssh`, however, users have to reconnect manually.

7.4.2.3 Load Balancing

Beyond primary and backup ISPs, it is also possible to *bond* both DSL and CM ISPs at the same time, through a technique known as load balancing, i.e., some connections use one ISP and others use another, either equally or proportionally to a predefined or self-learned weight, as shown in Fig. 7.5. The advantage is obvious: user can utilize both links if paid already, and each can back up the other for reliability. However, it requires more sophisticated configuration at the home gateway, where two upstream default routes have to be maintained at the same time, one for each group of flows. Open-source routers such as those powered by `OpenWRT` and `DD-WRT` have user-contributed scripts to automatically create virtual LAN (VLAN) for different upstream ISPs, define rules to split traffic, check network connectivity periodically, and fail over to the other link when necessary, under the so-called Dual WAN capability [9]. Most full-blown Linux systems, e.g., Ubuntu, have multi-homing capability, and some low-cost SMB routers, such as TP-Link R470T+, offer multi-WAN capability with very simple and intuitive graphic user interface (GUI)-based configuration. Table 7.2 lists the delay and throughput to `speedtest` servers hosted by Cable and DSL ISP, through Cable and DSL individually, and jointly as bonded. It shows the great advantage of bonding.

However, there are still some subtle issues with load balancing in terms of the "bonding" granularity, i.e., whether the packets from the same session can be distributed over different upstream ISPs. If so, a single application can fully benefit from both ISPs, in terms of both reliability and capacity, but this capability depends on specific applications and whether they or the transport-layer protocol they use can deal with out-of-order packet arrivals through different paths. For most CLM tools, even free but not open source, we cannot guarantee their behavior. Nevertheless, they seem to be able to handle when video and audio streams are carried by different ISPs, similar in concept but different in technology as the call-in feature in most

Table 7.2 Individual and bonded speed test: Cable vs. DSL ISP

Thru	To Cable hosted server	DSL (ping, down/upload)
Cable	13 ms, 59.18/5.28 Mbps	13 ms, 57.43/5.32 Mbps
DSL	11 ms, 24.55/2.84 Mbps	10 ms, 24.25/2.81 Mbps
Bonded	11 ms, 80.99/8.15 Mbps	10 ms, 83.03/8.14 Mbps

Table 7.3 CLM interruption: host vs. Internet link down vs. up

CLM	Ethernet	WiFi	Cable (t: timer)	DSL (down/up)
App	0/0 sec	1/0 sec	t/0 sec	t/t sec
Web	40/0 sec	40/0 sec	3t/0 sec	2t/3t sec

commercial CLM tools. Table 7.3 compares the interruption due to host interface and Internet access down and up events for `App` and `Web`-based CLM platforms. With bonding, load balancing, and liveliness checking, CLM only suffers in the order of the detection timer, which can be as low as 1 sec and much lower than the down-to-up time of DSL (40 sec) and CM (few minutes).

7.4.3 Recommendations on Teaching from Home

Based on the above summary, comparison, and proposal, and the experience in 2020 and 2021, in this section, we make some recommendations on online teaching in 2021 and beyond. First, use a computer with Ethernet connection to home router whenever possible, and choose an ISP with reasonable data rates, especially the uplink one, but more importantly with less delay and variation and fewer packet losses and service outages. When wired Ethernet is not available, consider NNW or improved WiFi with wired or wireless interconnection if needed. When feasible and affordable, consider to have two independent ISPs to guarantee the reliability for teaching from home, especially when large-scale synchronous lecturing is anticipated. If there are other active users at home at the same time, consider allocating them to use a low-priority WiFi channel and ISP when possible to avoid link congestion.

7.5 Further Discussion

Currently, most colleges and universities planned to have online teaching for undergrad or large classes, and possibly in-person teaching for grad or small classes. Teachers may or may not have to teach from home. However, CoViD-19 spikes may return again later 2021 or early 2022 in north hemisphere when another flu season starts, and instructors may have to teach from home again, if a vaccine or proven medicine is not widely available or accepted. Looking beyond the pandemic and Fall 2021, some further thoughts deserve more discussion:

- **Online or offline?** Regardless another pandemic looming in the next few years, the mixed online and offline teaching is likely to stay with us. Online teaching can help us reach more population to further the education mission.

- **Synchronous or asynchronous?** This book chapter mainly addresses the challenges due to synchronous lecturing from home. Another option is asynchronous lecturing where instructors record video lectures in advance. To compensate the lack of interaction during lectures, additional Q&A sessions can be held, where synchronous communication is needed. We believe that both synchronous and asynchronous communications will be a part of our teaching regardless during or after another pandemic or other events.
- **The future of teaching and learning**. Unarguably, CoViD-19 has fundamentally changed the way how education, as well as other sectors of the societies around the world, conducts their business, once forever. It is unlikely we fully go back to the traditional classroom teaching—it is not all necessary, nor sufficient. However, there are still many other pedagogical challenges due to online teaching and learning, e.g., how to conduct labs and evaluate students against expected learning outcomes meaningfully and truthfully.

7.6 Conclusions

In this book chapter, based on our experience in 2020 and 2021 during the CoViD-19 pandemic and the input from professional IT support, we examined the challenges brought by the sudden massive move to online teaching, particularly teaching from home. By comparing existing technologies and alternatives, we proposed and validated some approaches to improving the capability and reliability of home networks and Internet access, specifically for synchronous lecturing from home to a large student population. The purpose of this book chapter is to create some much needed discussion on this topic, even after the first few waves of CoViD-19. Insights obtained can also be applied to other scenarios such as SMB and "broadcast yourself" from home or even family video calls. After addressing these technical issues, we hope the community can be better equipped to focus on other more challenging issues in pedagogy for enriched teaching and learning experience.

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