A Year in Lockdown:
How the Waves of COVID-19 Impact Internet Traffic

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ABSTRACT

In March 2020, the World Health Organization declared the COVID-19 outbreak a global pandemic. As a result, billions of people were either encouraged or forced by their governments to stay home to reduce the spread of the virus. This caused many to turn to the Internet for work, education, social interaction, and entertainment. With the Internet demand rising at an unprecedented rate, the question of whether the Internet could sustain this additional load emerged. To answer this question, this paper will review the the impact of the first year of the COVID-19 pandemic on Internet traffic in order to analyze its performance. In order to keep our study broad, we collect and analyze Internet traffic data from multiple locations at the core and edge of the Internet. From this, we characterize how traffic and application demands change, to describe the "new normal", and explain how the Internet reacted during these unprecedented times.

1 INTRODUCTION

The worldwide pandemic caused by the Corona Virus 2019 (COVID-19) is a once-in-a-generation global phenomenon that changed the lives of billions of people and destabilized the interconnected world economy. What started as a local health emergency in Asia at the end of 2019, turned into a global event at the beginning of 2020 when the first cases appeared on other continents. By March 2020, the World Health Organization (WHO) declared COVID-19 as a pandemic, causing many governments around the globe to impose strict lockdowns of economic and social activities to reduce the spread of COVID-19. These measures changed the habits of a large fraction of the global population, who now depend on residential Internet connectivity for work, education, social interaction, and entertainment.

Changes in Internet user behavior are common, but they normally occur gradually and over long periods of time. Notable examples of such changes are the increase in demand for peer-to-peer applications that happened in the early 2000s; the increase of traffic served by content delivery networks – including an increase in streaming – that took place in the 2010s; and, more recently, the elevated demand for mobile applications. In all of these cases, the telecommunications industry and network operator community reacted by increasing the investment on network infrastructure. However, the changes in Internet user behavior during the pandemic has been unique because the shifts took place within weeks, leaving hardly any time to react. This raised questions of whether user behavior changes yield to changes in Internet traffic and, more importantly, concerns if the Internet is able to sustain this additional load.

In this paper, we investigate the impact of the COVID-19 pandemic on the Internet traffic by analyzing more than two years of Internet traffic data including the first year of the pandemic. More specifically, we characterize the overall traffic shifts and the changes in demand for particular applications that became very popular in a short amount of

time. During the process, we try to understand if there is a "new normal" in Internet traffic and to see how the Internet reacted in these unprecedented times. We summarize our observations for the spring 2020 wave (February 2020 to June 2020)[1] and then extend our study for the fall[2] 2020 wave (September 2020 to February 2021). To that end, we collect and analyze network traffic data from multiple vantage points, including a large Internet Service Provider (ISP) in Europe, three Internet Exchange Points (IXPs) in Europe and the US, as well as a mobile operator and a metropolitan academic network in Europe (REDIMadrid).

Our main observations can be summarized as follows:

- Changes in traffic volume follow demand changes, causing a traffic surge of 15-20% during the spring 2020 lockdown for the ISP/IXPs in our study. In summer 2020, after the reopening of the economy, an increase of about 20% at one IXP, but only 6% at the Tier-1 ISP, are still visible. The fall 2020 wave also had an impact, with the annual traffic increase in 2020 being higher than in a typical year.
- The observed traffic increase mostly takes place during non-traditional peak hours. Daily traffic patterns are moving to weekend-like patterns, especially during the spring 2020 lockdown.
- Traffic related to remote working applications, such as VPN connectivity applications and video-conferencing applications, surge by more than 200%. VPN traffic seems to remain at elevated levels even during the fall 2020 wave.
- Traffic changes across networks differ. For example, in the REDIMadrid campus network, there was a significant drop (by up to 55%) in traffic volume on workdays after the spring 2020 lockdown as most people were not on campus, but an increase during the fall 2020 lockdown. Traffic at the IXP and the ISP also varies depending on the mandated lockdown policy and due to the different customer profiles.

2 DATASETS

The Internet is formed by a network of networks. Depending on their size and position, networks may act as large traffic hubs forwarding network traffic between up to hundreds or even thousands of other networks (backbone/core). In other cases, they are interconnected weakly and closer to the consumer at the edge of the topology.

To obtain a broad perspective on the impact of the pandemic on the Internet, we observe the Internet from multiple and diverse vantage points. They are located at the backbone and peering points of a major Tier-1 Internet Service

Provider (ISP), at the core of the Internet—namely, three Internet Exchange Points (IXPs) around the globe—, and at the edge (a metropolitan university network and a mobile operator).

ISP: A large Central European ISP that provides service to more than 15 million fixed line subscribers and also operates a transit network (Tier-1).

IXPs: An IXP is an interconnection facility where networks become members to exchange traffic with other members across the IXP's infrastructure. In our study we consider three major IXPs. The largest IXP, namely IXP-CE, is located in Central Europe. It has more than 900 members and a peak traffic of more than 9 Tbps. The second IXP, namely IXP-SE, is located in Southern Europe and has more than 170 members. The third IXP, namely IXP-US, is located at the US East Coast and has more than 250 members.

REDIMadrid university network: We collect and analyze data from the REDIMadrid academic network, which interconnects 16 independent universities and research centers in the region of Madrid. It serves nearly 290,000 users including students, faculty, researchers, student halls, WiFi networks (including Eduroam), and administrative and support staff.

Mobile operator: A European mobile provider with more than 40 million customers.

At each vantage point, we collect and analyze traffic flows before and during the pandemic. This allows us to reason about the impact of the COVID-19 pandemic on Internet traffic and discuss related traffic shifts. In order to guarantee user privacy, we only analyze anonymized or aggregated datasets. For additional details on our measurement methodology, we refer to [9].

3 NETWORK TRAFFIC SHIFTS

To understand traffic changes during the COVID-19 pandemic, we first look for overall changes in well-established traffic patterns before, during, and after the strictest lockdown periods for both the spring and fall 2020 waves. Since all data sources exhibit very different traffic characteristics and volumes, we normalize the data to make it comparable. In Figure 1 we show the normalized aggregated traffic of the ISP, the IXPs, and mobile operator vantage points from January 2019 until the end of February 2021. We normalize this by using the traffic of the first week of January 2020 for each corresponding vantage point.

3.1 Macroscopic Observations

In Figure 1, we annotate the week of the initial lockdowns in the countries that host the ISP and IXPs in Central and Southern Europe, and the mobile operator. Although the exact dates of when the lockdown was imposed differs across Europe, these dates are very close to each other and followed

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[1]An earlier version of this paper was published in the Proceedings of the 20th ACM Internet Measurement Conference (IMC'20) [9].

[2]We use "spring" and "fall" from the viewpoint of the Northern hemisphere, where our vantage points are located. Exchange both terms for the Southern hemisphere.
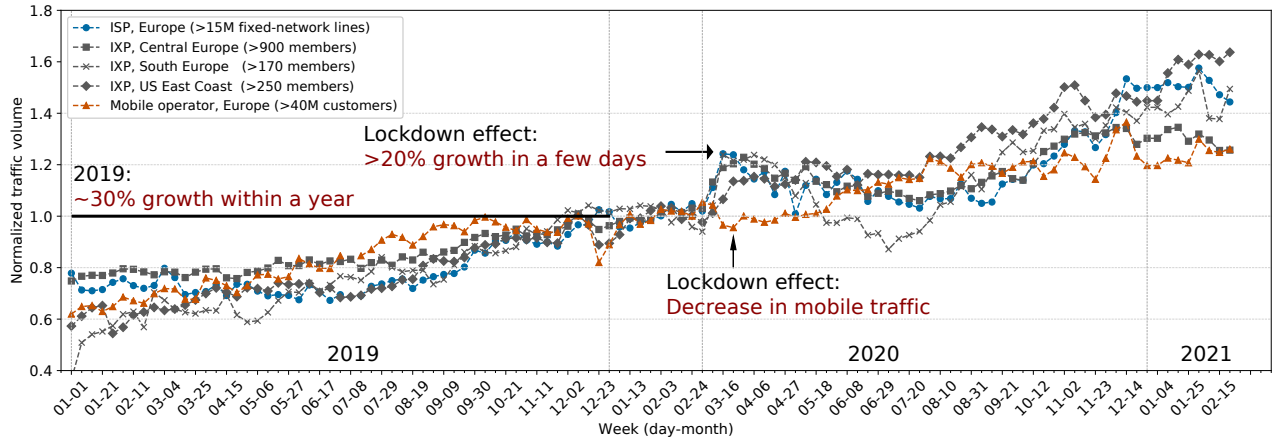
Figure 1: Traffic changes during the COVID-19 pandemic's spring and fall waves at our Internet vantage points.

the declaration of COVID-19 as a pandemic by the WHO. A first observation is that the ISP and IXPs in Central and Southern Europe show a more than 20% traffic increase within a week after the official announcement of the lockdown. This could be perceived as a "moderate" surge in traffic. However, in Internet-reality, this is a substantial increase in traffic in only a short period of time. To put it into perspective, the figure shows that the annual increase of 2019 was around 30%, which is similar to the annual increase in previous years. This means that the expected traffic increase in one year happened only within a couple of weeks in March 2020 following the spring 2020 lockdown. Well-provisioned networks, like the ones we measured for our study, could cope with this surge. However, networks that "ran hot" may have faced problems as this increase is significant and takes place in a relatively short period of time. In sharp contrast, the traffic of the European mobile operator decreased as users switched to WiFi and reduced their commute and traveling. This aligns with reports in other studies [15]. It is worth noting, that, during the same period, the traffic at the IXP at the US East Coast surged only by 2% as there was no announcement of strict lockdowns in the US at that time.

The impact of the spring wave was significant as the traffic levels remain at same elevated level during the lockdown. The traffic of the IXP at the US East Coast increased significantly when lockdown measures took place by the state authorities. However, when the economy opened again after June 2020, we observe a slight decrease of ISP and IXPs traffic as well as an increase of the mobile operator's traffic.

The impact of the fall wave is clearly visible in traffic patterns beginning in September 2020. The traffic at the ISP and all IXPs surged again, while the traffic of the mobile operator declined, except for the holiday period at the end of 2020. Although the lockdowns in the fall of 2020 differ
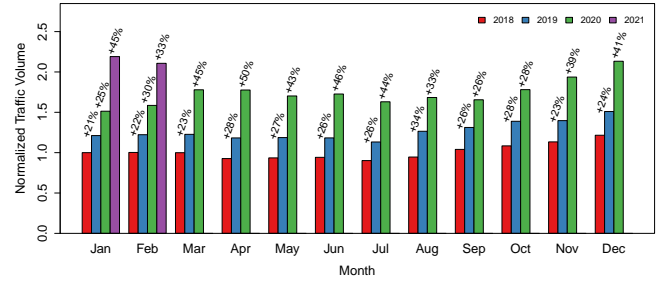

Figure 2: ISP monthly normalized downstream traffic change during the COVID-19 pandemic with percentage increase compared to the previous year.

significantly from country to country, and in some cases there were lockdowns with on-off periods, the impact of the fall wave was significant. The 2020 annual increase for the ISP and the IXPs varied between 35%–50%, i.e., higher than the expected annual increase. The mobile operator showed an annual increase of around 20%, which is lower than expected. As the fall wave of COVID-19 continues into 2021, we observe similar trends until February 2021. It is also worth noting that in some countries, the fall wave was a superposition of multiple waves of COVID-19 and its mutations, which were faced with harder lockdown restrictions. Additionally, the severe weather conditions in Southern Europe with historic snow volumes in January and February 2021 may have also played an additional role in keeping people at home and the corresponding increase of Internet traffic at the ISP and IXPs.

Figure 2 focuses on the ISP, where we show the normalized aggregated traffic for each month for the years 2018–2021. Although during the years 2018–2019 the traffic increase was around 30% compared to the same month in the previous year,
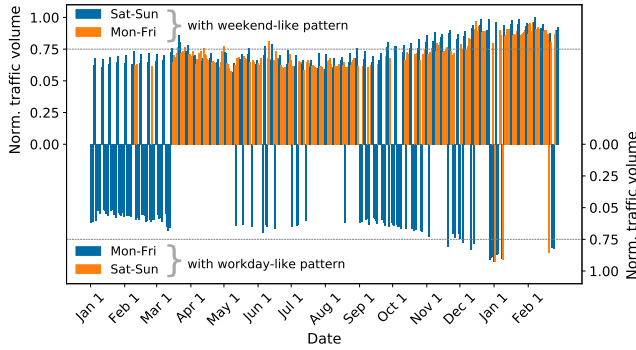
(a) ISP-CE: Weekend-like (top) vs. workday-like (bottom).
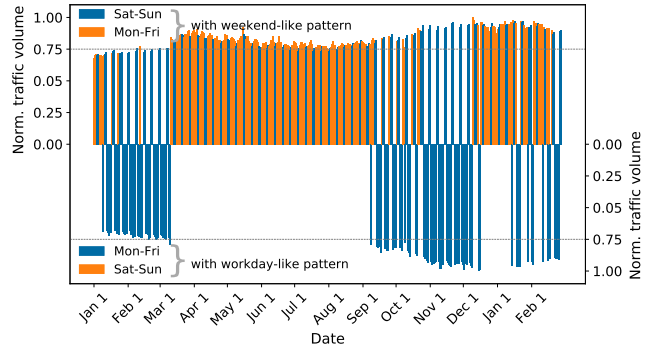
(b) IXP-CE: Weekend-like (top) vs. Workday-like (bottom).

Figure 3: Drastic shifts in Internet usage patterns during the COVID-19 pandemic. Classification of weekends- and workdays-like pattern.

there is a dramatic change after March 2020. To understand this, we annotate the increase between a given month and the one in the previous year for 2019, 2020 until February 2021 above the bars in the figure. During the spring 2020 wave, the traffic in each month increased by around 45% compared to the traffic in 2019; the peak was in April 2020 with about 50%. Between August and October 2020 the traffic increase was similar to previous years. This aligns well with good weather conditions and the relaxation of lockdown policies. However, this period was followed by stronger lockdown policies, and there is again a surge that continues until the end of our observation period, i.e., February 2021.

The traffic increases we have seen across vantage points can arise unexpectedly and may create a need for capacity increases by network operators. We observed capacity increases in the order of 1,500 Gbps (3%) across many IXP members at the IXP-CE alone. Beyond our datasets, some networks publicly reported that traffic shifts due to the pandemic resulted in partial connectivity issues and required new interconnections [8, 20]. The vantage points in this paper range from extremely large to moderate sizes with sufficient resources and a lot of experience in network provisioning and resilience. In general, smaller networks with limited resources may not be able to plan with sufficient spare capacities and fast enough reaction times to compensate for such sudden changes in demand. In fact, performance degradation issues have been reported in less developed regions [1], that also highlights the digital divide.

3.2 Drastic Shifts in Internet Usage Patterns

Beyond the macroscopic observations, our analysis sheds light on the shifts in Internet usage patterns that are also relevant to network operation and management. The Internet's

regular workday traffic patterns are significantly different from weekend patterns [13]. On workdays, traffic peaks are concentrated in the evenings, typically between 18:00 and midnight, also referred to as "peak hours". During the weekend, the activity is more distributed also in the non-peak hours as more people are at home and using the Internet.

With the pandemic lockdown in March, this workday traffic pattern shifts towards a continuous weekend-like pattern. More specifically, we call a traffic pattern a workday pattern if the traffic spikes in the evening hours and a weekend pattern if its main activity gains significant momentum from approximately 9:00 to 10:00 am. Figures 3a and 3b show the normalized traffic for days classified as weekend-like on the top and for workday-like on the bottom. If the classification is in line with the actual day (workday or weekend) the bars are colored in blue, otherwise they are colored in orange. We find that up to mid-March, most days are classified correctly. The only exception is the holiday period at the beginning of the year in Figure 3b. This pattern changes drastically once the lockdown measures are implemented. Indeed, almost all days are classified as weekend-like. This change persists in Figure 3b until the end of August due to the vacation period, which is consistent with the behavior observed in 2019 (not shown). In contrast, Figure 3a shows that the shift towards a weekend-like pattern becomes less dominant as countermeasures were relaxed in mid-May, but in August the pattern resembles again the weekend-pattern due to the vacation period.

During the period of August to December 2020 the patterns both at the ISP and the IXP are back to the usual weekday and weekend pattern. When the first lockdowns of the fall COVID-19 wave are imposed in December 2020, this pattern is disrupted, more noticeably at the IXP. In the first two months of 2021, there is a mixed pattern for both the ISP
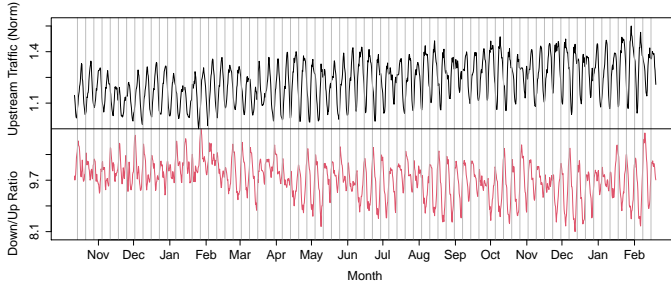
Figure 4: ISP aggregated over 8 hours traffic during October 2019 - February 2021: upstream traffic normalized growth (top), and downstream vs. upstream traffic ratio (bottom).

and the IXP. We conclude that we still observe a transient behavior in 2021 and it is unclear whether the changes of daily usage patterns are here to stay.

3.3 Effect on the Traffic Asymmetry

As we discussed in the previous sections, residential traffic surged both during the spring and fall COVID-19 waves. In this section we take a closer look on the directionality of the traffic and comment on new patterns in upstream and downstream traffic. Recall that residential traffic is asymmetric in nature, i.e., downstream traffic is typically many times higher than the upstream one. This is to be expected as users send less traffic than they receive when using applications like video streaming and browsing. In Figure 4 (top) we show the aggregated upstream traffic from October 2019 to end of February 2021. There is a slight increase in upstream traffic after the first lockdown in mid March 2020. This trend manifests itself in the following months: The minimum, but more noticeably the maximum upstream level increase across the rest of the observation period.

As a result of the general elevated traffic levels, the downstream traffic also increases during this period. To assess if there is a change in the established ratio between upstream and downstream traffic, in Figure 4 (bottom) we plot the ratio of upstream vs. downstream traffic. Before the COVID-19 pandemic, typical values of this ratio were around 9.8 with some noticeable variation. After the initial lockdown in the beginning of March 2020 and until the end of February 2021, this pattern changes. Indeed, the ratio of upstream vs. downstream traffic decreases significantly, with typical values around 9 and very high variation. During the weekdays, this ratio is as low as 8.1. This shows that the relative increase of the upstream traffic is up to 18% higher than that of the increase of the downstream traffic. An independent study that analyzes traffic data from US ISPs reported even higher upstream vs. downstream traffic ratios during the

pandemic [2]. We attribute this to the increase in remote working and teleconferencing applications that utilize user upstream bandwidth much more than other popular user applications, e.g., video streaming and browsing. This is an important observation as ISPs in general allocate way less upstream than downstream capacity to end users. If we see a persistent change in demand from end users to push more traffic towards the Internet, ISPs may need to adapt their handling of subscriber lines. This is a notable result, because last mile capacity is notoriously expensive for ISPs and hard to replace with new technology.

4 APPLICATION TRAFFIC SHIFTS

We now turn our attention towards the traffic shifts for different application classes that were expected to be affected by the COVID-19 pandemic, namely, Web conferencing applications, Video-on-Demand streaming, online gaming, and traffic that originates from university service networks. We refer to [9] for technical details on how we classified traffic in any of these categories.

4.1 Application Classes' Traffic Shift

In Figure 5, we visualize two weeks in the Spring and Fall waves, namely, the second week in March 2020, June 2020, December 2020, and January 2021, as the difference of the respective week. We compare them to a base week before the initial lockdowns began, i.e., February 20–26, 2020. As the traffic classes we are considering show growth way beyond the expected natural increase over one year we do not factor out that increase. Each column represents one hour of a day. This approach enables quick visual identification of increased/decreased application class usage compared to pre-COVID-19 times. We focus on the observations gathered at the ISP and the IXP in Central Europe (IXP-CE) vantage points.

Web conferencing: Web conferencing applications have seen a dramatic surge during the lockdown periods. In this category the ISP and IXP-CE experience a large traffic growth in March – right after the first lockdown began – spanning across all hours of the day, especially during weekdays. This trend accelerates in June and culminates in December and January with an increase exceeding 300% compared to the base week at both vantage points. Notably, in December and January, the extreme growth also persists at weekends. This indicates that not only work life has moved online but private social activities did as well.

Video-on-Demand: video streaming applications' usage shows high growth both in the Spring and the Fall wave. Interestingly, the ISP only sees a moderate growth during the lockdown in the first half of March followed by a reduction of volume in the second half of March below the pre-COVID-19
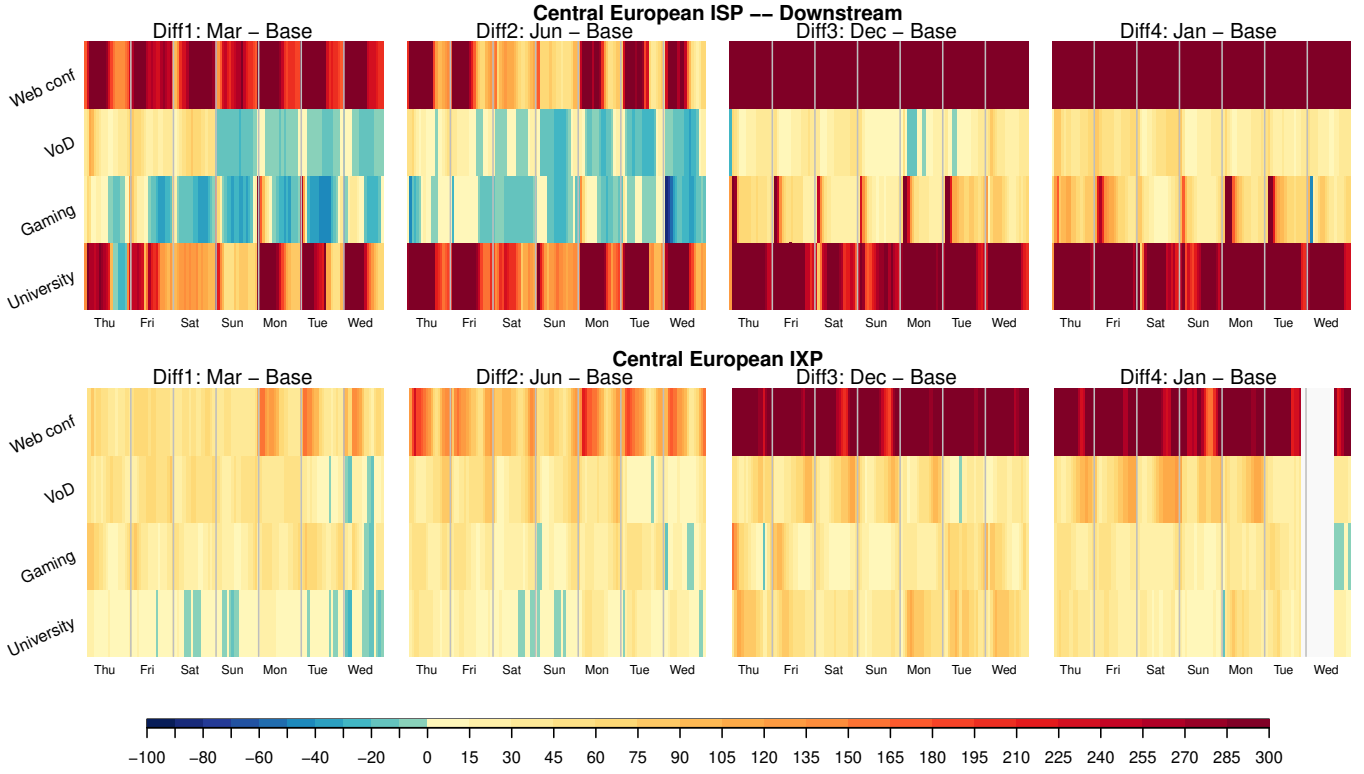
Figure 5: ISP (top), IXP-CE (bottom) heatmaps of application classes' traffic at the ISP and IXPs during COVID-19 pandemic: spring and fall waves. Each subplot shows the change in the aggregated traffic volume per hour for the respective class compared to the base week in February 2020. White areas mark missing data.

reference time frame. We attribute this to major streaming companies reducing their streaming resolution in Europe by mid-March for 30 days [18]. In the case of the IXP a similar but not that much pronounced trend can be observed in March. However, there is a significant increase of the traffic related to Video-on-Demand in June, December and January, that exceeds 200% (IXP) and 100% (ISP) for some days, especially on weekends indicating that more people stayed at home during leisure time instead of going outside.

Gaming: The strong growth of gaming applications is more coherent at the IXP vantage point, especially during the day. While the ISP shows a significant increase during morning hours, it generally leans towards declining in the Spring wave. Note, that this effect is mainly caused by unusually high traffic levels in this category during our baseline week in February 2020. The initial download of a game nowadays supersedes the amount of data transferred although playing these high levels may relate to new releases or updates of popular games. Gaming applications, typically used in the evening or at weekends, are now used at any time. The trend starts to flatten in June—this may in relation with people going on vacation or spending more time outside. The ISP

sees an increase up to 300% in gaming related traffic during the fall wave across all weekdays, but with emphasis to the first half of the day. A similar pattern unfolds at the IXP, but with smaller increases. One explanation for the strong increase at both vantage points in the morning hours is that schools were closed during the fall wave.

University networks: Traffic that originates from such networks behaves similar at both vantage points with the ISP showing a more pronounced trend. Both vantage points see a high increase in traffic especially during the fall wave with a growth of 100% and more. This growth could be attributed to some European educational networks providing video conferencing solutions, which are now being used by customers of the ISP/IXP. In December 2020 and January 2021 most academic collaboration and teaching activities moved to an online setting. This is in line with the smaller surge of activity at weekends.

4.2 VPN Traffic Shift

Working from home leads to a higher demand for Virtual Private Network (VPN) solutions as employees need to access
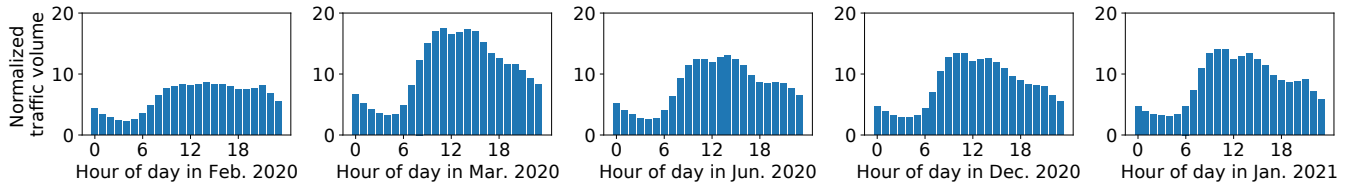
Figure 6: VPN traffic evolution during the COVID-19 pandemic.

firewall-protected resources hosted in internal company networks. We identify VPN traffic using a novel technique based on transport port data as well as DNS data [9]. In Figure 6 we show the changes in VPN traffic during the spring and fall COVID-19 waves in 2020. We use five weeks of data from the IXP in Central Europe from February 2020 to January 2021, each in different months, to highlight the differences. February 2020 serves as a baseline, i.e., to show the state of VPN traffic before COVID-19 restrictions were enforced.

In March 2020—after the first lockdown restrictions were authorized in Europe—we notice a large increase in VPN traffic during working hours. This growth partially recedes in June 2020 as lockdown restrictions are relaxed again and employees could return to their workplaces. Nevertheless, VPN traffic volume is still over the February 2020 baseline levels. In the Fall wave, VPN traffic increases again but not as high as in March 2020.

We also investigate the *share* of VPN traffic among the total volume across waves. We find that the VPN traffic share remains stable from February to March 2020. This suggests that overall traffic volumes increase, regardless of the application. However, in June 2020, VPN traffic share increases whereas overall traffic volume decreases. Towards December 2020 and January 2021 we see a slight decrease in the VPN traffic share as the overall traffic gains traction again after the summer holiday.

In summary, we see that VPN traffic increases during working hours since the first lockdown measures were implemented. The increase is higher in the spring wave than in the fall one. This finding aligns with reports indicating that more people in Central Europe were working from home in the Spring wave compared to the fall wave [23].

4.3 A View from REDIMadrid

In addition to investigating changes at ISPs, IXPs, and mobile networks, we analyze changes at a special type of network: REDIMadrid, a large European academic network. As a large portion of traffic is generated by students and staff being physically on the campus, we expect to see quite drastic changes after lockdown measures are imposed. As a response to the COVID-19 pandemic, the regional government of Madrid announced the closure of the educational system

from March 11, 2020 onward for the 2019-2020 academic year. By the end of April, most universities had fully transitioned towards an online-lecturing model. The 2020-2021 academic year followed a semi-presence model, allowing for some lectures to take place on campus.

Traffic volume. Figure 7 shows the normalized traffic volume for six different weeks ranging from February 2020 (one week before announcing that the academic system would be closed down) to January 2021. We observe a significant drop in the traffic volume on working days right after the lockdown, with a maximum decrease of up to 55% on Tuesday and Wednesday. This is expected since users no longer use the network from within the campus. Traffic on weekends sees increments of up to 14% on Saturday. Similar to what we see at the IXP-CE and the ISP (cf. Section 3.1), traffic patterns on working days and weekends become more similar in terms of total volume. The traffic volume observed in September and December 2020 reveals an increase with respect to the Spring regime, though the pre-COVID-19 levels are not reached. We observe how traffic on weekends continues to increase, and the difference with work days vanishes even further. We note that the week from January 14 to 21, 2021 constitutes an interesting anomaly caused by the Filomena snow storm that brought heavy snow to Madrid for over a week. The effects caused severe mobility limitations for more than two weeks, during which campuses were inaccessible and all lectures were canceled. The effect is noticeable as minimum traffic levels across all categories since the lockdown measures were implemented in February 2020.

Traffic in/out ratio. In the days before the lockdown, incoming traffic was up to 15× the volume of outgoing traffic during workdays. This ratio dropped to around 2× or 3× during lockdown, where traditional weekend vs. work-day patterns also disappeared. This change of traffic asymmetry might be explained by the nature of remote lecturing and remote working: students and research staff connect to the services hosted at the universities to access teaching resources, hence the increase in outgoing traffic. On the other end, as students and staff no longer access the Internet from the universities, incoming traffic decreases. The semi-presence teaching model implemented for the 2020-2021 academic year has resulted in a new intermediary scenario
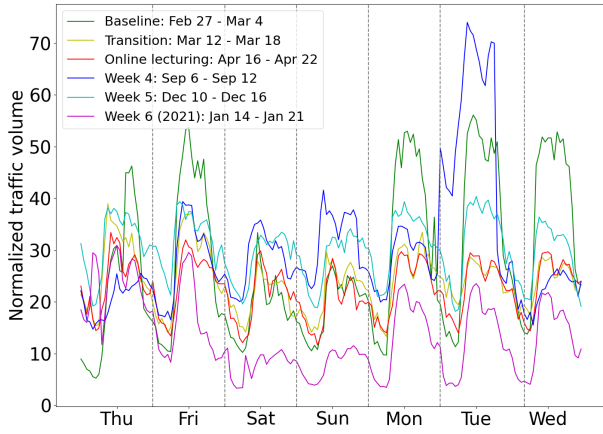
Figure 7: Volume shifts at the REDIMadrid network for selected weeks.

compared to the first COVID-19 wave and the pre-COVID-19 regime. This observation is corroborated at the connection level. Incoming VPN, email, and Web traffic connections remain at high levels compared to February 27th 2020 (5×, 2.3×, 2.4× growth on average, respectively) due to online-lecturing and remote working. Outgoing web traffic and push notification traffic—tightly related to mobile devices—have doubled compared to April 2020 in 2020-2021. However, their overall values are still considerably lower compared to the pre-COVID-19 regime.

5   DISCUSSION

Internet operation during the pandemic: a success story.
The COVID-19 pandemic "underscored humanity's growing reliance on digital networks for business continuity, employment, education, commerce, banking, healthcare, and a whole host of other essential services" [10]. At the beginning of the pandemic and the first lockdown measures to control its spread, sudden changes in user demand for online services raised concerns for network operators. In fact, the pandemic increased the demand for applications supporting remote teaching and working to guarantee social distancing which manifests itself in our analysis across all vantage points. The Internet could handle this increased load thanks to its original design concept to find efficient routes [22], the flexibility and elasticity that cloud services offer, and the increasing connectivity of cloud providers [3, 4, 12, 21, 24]. Our results confirm that most of the applications with the highest absolute and relative increases are cloud-based.

Taming the traffic increase. In this paper, we report a traffic increase of more than 20% a week after the lockdown began. This is in line with reports of ISPs and CDNs [6, 11, 16, 17] as well as IXPs [19]. Typically, ISPs and CDNs are prepared for a traffic increase of 30% in a single year period [3, 5, 14]. While networks perform yearly plannings,

the pandemic has created substantial shifts within only a few days. As a result, ISPs either needed to benefit from over-provisioned capacity—e.g., to handle unexpected traffic spikes such as attacks or flash-crowd events—or add capacity very quickly. The latter was possible due to the adoption of best practices on designing, operating, and provisioning networks which contributed to the smooth transition to the new normal. Due to the advances in network automation and deployment, e.g., automated configuration management and robots installing cross connects at IXPs without human involvement, it was possible to cope with the increased demand. For example, DE-CIX Dubai managed to quickly enable new ports within a week for Microsoft which was selected as the country's remote teaching solution for high schools [7].

6   CONCLUSION

Despite the disruption due to COVID-19, life continued thanks to the increased digitization and resilience of our society, with the Internet playing a critical support role for businesses, education, entertainment, purchases, and social interactions. In this paper, we analyze Internet flow data from multiple vantage points in several developed countries. Together, they allow us to gain a good understanding of the impact that the COVID-19 waves and the lockdown measures caused on Internet traffic. One year after the first lockdown measures were enforced, the aggregated traffic volume increased by around 40%, well above the typical expected annual growth. Additionally, workday traffic patterns have rapidly changed and the relative difference to weekend patterns has almost disappeared during lockdowns. Applications for remote working and education, including VPN and video conferencing, experienced traffic increases beyond 200%.

Our study reveals the importance of covering different lenses to gain a complete picture of these phenomena. Additionally, our observations highlight the importance of approaching traffic engineering with a focus that looks beyond Hypergiant traffic and popular traffic classes to consider "essential" applications for remote working. In fact, our study demonstrates that over-provisioning, proactive network management, and automation are key to provide resilient networks that can sustain drastic and unexpected shifts in demand such as those experienced during the COVID-19 pandemic. Yet, as the pandemic is still on-going, it is critical to continue studying the traffic activity to understand usage shifts during these unprecedented times.

Acknowledgements

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